Architectural Integration of Transpired Solar Thermal Technology in Building Envelopes and Associated Technological Innovation Analysis

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A Thesis

Submitted in Fulfilment of the Requirements for the

PhD in Architecture

Welsh School of Architecture, Cardiff University

May 2014

ABSTRACT

This thesis addresses the architectural integration of transpired solar collectors (TSC), as a building envelope technology patented in 1980s to pre-heat ambient air that would be used for space heating. It explores the reasons for low take up of the technology. It further explores the preferences, perceptions and recommendations of architectural integration quality of TSC in buildings. The research analyses the associated technological innovation development at entrepreneurial level in the UK and North America in a variety of terms including knowledge diffusion and research and development.

Building-integrated renewable energy is an important response to concerns about climate change and energy poverty. As space heating accounts for 61% of total domestic energy consumption in countries with long cold seasons, the transpired solar collector (TSC) is a promising technology. However, TSC suffers from low take up despite its apparent technical competitiveness.

A large-scale questionnaire, an experimental prototype and technological innovation system analysis were used to provide insight into architecturally integrating and developing TSC technology in buildings, and clarifying its potential contribution to pre-heating ambient air. The research outcomes inferred multi-dimensional reasons behind limited adoption of the technology.

Respondents were generally aware of TSC technology; however, few were satisfied with available technology. Various preferences determining selection of TSCs were investigated, including: ‘invisible’ integration, planning guidelines for traditional buildings, stage of integration and sustainable factors. Respondents indicated that the ultimate feature considered when sourcing TSC technology was its reliability followed by capital cost.

The solar irradiation only needed to exceed 60W/m^2 for TSC to generate an output temperature greater than the ambient temperature. A significant temperature increase was observed when solar irradiation exceeded

400W/m^2. Output temperature increased to 16ºC above ambient temperature in autumn and 12ºC in winter in the TSC prototype.

A comparison of relevant actors, institutions and networks of TSC in the United Kingdom (UK) with North America, found both to be cautious about communication to protect intellectual property: this hampers knowledge exchange and development. Despite TSC take up in North America being restricted by cheap gas prices, end-user feedback reflects a level of satisfaction versus fewer such examples in the UK.

Identified barriers included immaturity of technology, reluctance to implement new technology, lack of supply chain and low institutional support. A framework of potential enablers and architectural design guidelines were proposed to breakthrough take up of TSC.

DEDICATION

I dedicate this work:

To my wonderful great parents, and my beloved wife, children and whoever wishes me success and prosperity,

My heart pleasure for your love, sacrifice and patience

To the soul of my grandmother,

I wish you were here to witness this moment.

ACKNOWLEDGEMENT

First and foremost, all praises be to Allah, the most Gracious the most Merciful for his non-endless blessings and bestowments. I pray to him in humility that this work serves beneficial development for this world.

My greatest gratitude is to my parents for their uninterrupted love and sacrifices for me to pursue success and distinction. Their financial and passionate support for my study was always driving me to challenge and improvement. I owe them my success and accomplishment all over my life.

I express my thanks and appreciation to my supervisor Dr. Vicki Stevenson for her uninterrupted guidance, assistant and support throughout my PhD journey. Her continuous encouragement and enthusiasm in the research was effective endorsement for me to accomplish improved work. My special thanks to Professor Phil Jones who supervised and mentored this thesis, particularly during the early days. I remember his assistance to finalise the topic of this thesis.

I thank the participants in the survey and interviews, including the pilot studies collaborators for their participation, time, efforts, and information. I also would not forget to dedicate acknowledgement to anyone who helped in guiding this study to success, including Katrina Lewis. I appreciate the time and efforts of Dylan Dixon and the SBED team for helping building and collecting data for the prototype units. I further thank the Graduate Centre for the very helpful training sessions and the facilities provided.

I wish success for all students I met in Cardiff University especially those who elected me as a postgraduate support officer in the student's Union (2011-2012). I also wish success to all the people who came into my life leaving respectable personal or social impact.

I express my everlasting gratitude to my wife, my daughter, Malak, and my son, Jamil, who have borne the full burden with my studies and travels throughout the PhD journey.

LIST OF PUBLICATIONS

Alfarra, H., Stevenson, V. and Jones, P. J. 2013. The architectural perception of incorporating innovative solar energy technologies in the built environment. In: *SB13, 8-10 December 2013.* Dubai.

Alfarra, H., Stevenson, V. and Jones, P. J. 2013. Architectural integration of transpired solar thermal for space heating in domestic and non-domestic building envelopes. In: *CISBAT 2013, September 4-6, 2013.* Lausanne, Switzerland. pp. 631-636.

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NOMENCLATURE

NOMENCLATURE	DESCRIPTION
η	Efficiency
°C	Degree Celsius
ϵ_{HX}	Heat Exchange Effectiveness of the absorber
A	Amplitude of Corrugations (m)
A_c	Collector area (m2)
A_{cs}	Cross sectional area of the duct/pipe (m2)
α_c	Collector absorptance
C	Wavelength of Corrugations (m)
c_p	Specific heat at constant pressure (J/ kg °C)
E	The expected data
$IR_{surf-grndc}$	Infrared radiation between TSC surface and ground
$IR_{surf-sky}$	Infrared radiation between TSC surface and sky
I_c	Solar insolation incident on the collector (W/m^2)
i	The rows in the contingency table
j	The columns in the contingency table
$\dot{m}$	Mass flow rate of air (kg/s)
O	The observed data
Q_{conv}	Collector convective heat loss (W)
Q_{rad}	Collector radiant heat loss (W)
p	Effect size (significance) - Statistics
ρ	Density (kg/m^3) – Air density for efficiency
T_{O1}	Temperature of air as it enters a hole
T_{O2}	temperature of air as it leaves a hole
T_{amb} T_a T_∞	Ambient air temperature
T_{coll} T_P	Collector surface temperature
T_i	Temperature of heated air in the hole
T_{out}	TSC output temperature
T_{sup}	Supply temperature into the room
U_∞	Free stream velocity (m/s)
$V_{0_{min}}$	Minimum average suction velocity (m/s)
v_o V_S	Suction Velocity (m/s)
z_{obs}	Coefficient of determination
χ^2	Pearson’s Chi-square statistical test
v (OR) V_h	Kinetic Viscosity of Air (m^2/s)

NOMENCLATURE	DESCRIPTION
AIA	American Institute of Architects
AIA-CES	American Institution of Architects on the continuing education system.
ARB	UK Architects Registration Board
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc.
a-Si	Amorphous silicon
BC GBR	British Columbia Green Building Roundtable
BiPV	Building Integrated Photovoltaics
BIST	Building Integrated Solar Thermal
BRE	The Building Research Establishment
BRECSU	Building Research Energy Conservation Support Unit
Btu	British Thermal Unit
CanSIA	Canadian Solar Industries Association
CAQDAS	Computer assisted qualitative data analysis software
CFD	Computational Fluid Dynamics
CIBSE	Chartered Institution of Building Services Engineers
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
COP	Conference of the Parties
CPD	Continuous Professional Development
Cramer's V	Statistical coefficient, commonly indicates effect size for larger than 2x2 tables
Cronbach's α	Cronbach's Alpha Reliability Statistics
CSA	Canadian Standard Association
D	Hole Diameter
DECC	Department of Energy and Climate Change
df	degree of freedom
DHW	Domestic Hot Water
EIA	Energy Information Administration
FIT	Feed-in-tariff
GBCI	Green Building Certification Institute
GHG	Greenhouse Gas
GHP	Ground source heating pump
$GtCO_2$	Gigatonne Carbon Dioxide
HVAC	Heat, Ventilation, and Air-Conditioning
IBM	International Business Machines Corporation
ICT	Information and Communications Technology
IDP	Integrated Design Process
IEA	International Energy Agency
IEA SHC	International Energy Agency Solar Heating and Cooling
IIS	International Innovation System
IP	Internet Protocol
IPCC	Intergovernmental Panel on Climate Change
IPP	intellectual property protection
LCRI	Low Carbon Research Institute
LEED	Association of Leadership in Energy and Environmental Design
M&E	Mechanical and Electrical (engineers)
m/s	Meter per Second

NOMENCLATURE	DESCRIPTION
m^3/s	Cubic Meter per Second
micro-CHP	Micro combined heat and power
mm	Millimetre
n	Number (of participants)
NIS	National Innovation Systems
NRC	Department of Natural Resources Canada
NRCan	Natural Resources of Canada
NREL	National Renewable Energy Laboratory
NSTF	National Solar Test Facility
NVivo 10	Qualitative Data Analysis Software (version 10)
OSTHI	Ontario solar thermal heating initiative
P	Pitch
PV	Photovoltaic
PV/TSC	Hybrid Photovoaltaic / Transpired Solar Collectors
PVC	Polyvinyl Chloride
QDA	Qualitative Data Analysis
R&D	Research and Design
REN21	Renewable Energy Policy Network for the 21st Century
RETs	Renewable Energy Technologies
rho	Spearman's correlation Coefficient
RIAC	Royal Architectural Institute of Canada
RIBA	UK Royal Institute of British Architects
RIS	Regional Innovation Systems
ROI	Return On Investment
SAHWIA	Solar Air Heating World Industry Association
SBEC	Sustainable Building Envelope Centre
SBED	Sustainable Building Envelope Demonstration
SBET	Sustainable Building Estimation Tool
SESCI	Solar and Sustainable Energy Society of Canada
SIS	Sectoral Innovation Systems
SPSS	Statistical Product and Service Solutions
TIS	Technological Innovative System/Studies
TRNSYS	Transient System Simulation Software
TSC	Transpired Solar Collector
Turn	Turner Fenton School, Canada
TWh	Tera Watt hour
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
US DOE	United Stated Department of Energy
USA	United States of America
W/m°C	Watt per meter Celsius
W/m^2	Watt per Square Meter
WEST	Welsh Energy Sector Training
WSA	Welsh School of Architecture
phi	phi coefficient, indicates effect size for 2x2 tables

CHAPTER 1 ||

INTRODUCTION

1.1 OVERVIEW

This thesis addresses the architectural integration of transpired solar collectors (TSC), as a building envelope technology patented to pre-heat ambient air that would be used for space heating. It explores the reasons for low take up of the technology. It further explores the preferences, perceptions and recommendations of architectural integration quality of TSC in buildings. The research analyses the associated technological innovation development at entrepreneurial level in the UK and North America in a variety of terms including knowledge diffusion and research and development.

This chapter comprises a preface of the thesis (section 1.2) in order to present the merits of the research being adopted. It indicates the current situation relating to anthropogenic climate change and demand for lowering carbon emissions from buildings (section 1.3). Space heating is found to consume approximately two-thirds of buildings' operational energy and be responsible for almost one-quarter of its carbon dioxide emissions (section 1.3.4). Therefore, transpired solar collector technology is introduced as a building-integrated renewable energy technique for space air heating. Furthermore, this chapter presents the aim, objectives and structure of the thesis in addition to a brief description of the methodology and highlights the contribution of this study to research.

1.2 RESEARCH PREFACE

This research represents a first empirical study into architectural integration issues specific to Transpired Solar Collectors. The research rationale was derived from the increasing climate change impacts on the built environment (section 1.3.1), the continuous efforts to diminish the effect of climate change (section 1.3.2), and the increasing demand for energy (section 1.3.3) which increases energy poverty. Energy sources in the built environment could be fossil fuels, renewables or deployable (section 2.1). For future prosperity, it is necessary to ensure a secure, equitable, affordable and sustainable supply of energy. The demand for clean energy is likely to rise due to population growth and economic expansion in the world generally and UK specifically. Improved standards of living also play a role in increasing future energy demand. Therefore, low-carbon and clean energy are likely to be in great demand for future energy scenarios.

Renewable energy sources deemed capable to supply clean energy for the built environment include solar water heating, photovoltaic, wind, geothermal and solar thermal technologies (section 2.2.2). There is apparent increasing utilisation of solar and wind energy in recent years as shown in Figure 2-2 (REN21 2010). Wind energy remains relatively immature (European Wind Energy Association 2012) especially when integrated in buildings.

Space heating consumes about two-third of the total domestic energy consumption (section 1.3.4) that would be supplied through solar energy source. Solar energy in buildings could be passive design techniques, active solar thermal (water and air) or active solar photovoltaic (section 2.3.3). Passive design techniques (section 2.3.1) are long studied (Hamdy and Fikry 1998; Chiras 2002; Alter 2009; Christensen 2009; Chan et al. 2010) and remain to be supported by active source of energy. Solar water heating (section 2.3.2i) is deemed a well-established technology (Saving Energy 2007; Chow et al. 2009; Hawkey 2012). Photovoltaic technologies (section 2.3.3) were further well researched in terms of building integration (Nelson 2003; Cheng et al. 2005; Henson 2005; Paul et al. 2010; Jun Huang 2011;

Tabriz et al. 2011; Yoon et al. 2011; Petter Jelle et al. 2012) and market deployment (Negro et al. 2012b; Smith et al. 2013; Vasseur et al. 2013).

The Transpired Solar Collector (TSC) technology is a recently developed technology for using solar energy to preheat air before it enters the building. It was developed in Canada and many of the projects used to assess its performance have been based in North America. It has recently been introduced to the UK; however, its market penetration has remained low. Furthermore, many of the current solar thermal installations, generally, in buildings have been assessed as having poor architectural quality which discourages the potential development of integration regimes (Probst and Roecker 2007). Solar collectors are commonly mounted onto buildings' roofs as pure technical elements. There is an increasing demand for attractive architectural integration which solves energy problems and mitigates climate change. This architectural integration of a technology in buildings should occur through integrated design process (IDP) which intensifies comprehensive involvement of all building stakeholders in the design process from concept until hand-over (Hestnes 1999; Prowler and Vierra 2008) (section 3.2.2). It should moreover satisfy architectural integration quality that was defined as the interaction of solar thermal collectors in the building envelope in a controlled and coherent manner as reported by Krippner and Herzog (2000) and Probst and Roecker (2011). This interaction should simultaneously satisfy three principal pillars: the functional, the constructive, and the aesthetic aspects of architectural design (section 3.2.3). The consideration of integrating the technology differs according to the buildings type, location, function and status; for example new and existing buildings. For both new and refurbished buildings, the consideration of TSC could take place at the very early stage that equivalent to RIBA stage 0 'Strategic definition' (RIBA 2013) which defines the appropriate procurement route for the integration. For new buildings, the TSC can be incorporated within the concept design stage whereas this prevailage is not available for refurbished buildings or even late integrations where the concept has been developed and likely constructed. Therefore, the integration of TSC in existing buildings would take place at the 'revised' technical design stage (RIBA stage 4) in a way that to complement the original concept design (section 7.4.3).

The null hypothesis therefore deemed that there is a low awareness or acceptance of the technology among design team members (e.g. architects, building owners, and investors) which may be hindering the adoption and development of the technology; therefore, those groups were targeted in this study. This research accordingly explores the reasons for the low take up of TSC technology, particularly in the UK. It further explores the preferences, perceptions and recommendations of architectural integration quality of TSC in buildings. Actors in the future development of renewable energy technologies for buildings are considered to be architects, building owners and investors. However, the role of the architect is seen as particularly key where they are principally deemed to be design facilitators. In this context, the views of architects have been thoroughly explored within this work. Although the focus of this research is Wales, UK, views were sought from countries across the world with climates appropriate for the deployment of TSC technology. The countries considered represent a variety of social, cultural and legislative contexts, which are considered in the analysis where significant. This analysis has been considered in the context of potential contribution of TSC technology to pre-heating ambient air in Wales (section 5.10) and socio-technical innovation development (chapter 6).

The research aim (section 1.4) was therefore designed to investigate the hypothesis; the reasons for low take up of TSC in the UK and the potentially recommended improvements of the technology in terms of architectural integration in building envelopes, knowledge diffusion, research and development. Research objectives were drawn accordingly as steps to achieve the research aim. Combined research methodology was therefore designed to serve the inter-disciplinary research aim and the multi-dimensional objectives as briefed in section 1.5. This was followed by structuring the research into chapters (section 1.6). Following completion of the relevant literature review and completion of the identified methodologies, the results were divided into two chapters (5 and 6) followed by a chapter of discussion that provided summative discussion of the main findings. Chapter

5 was tailored to analyse the responses to the architectural integration survey described in section 4.4. It includes the analyses of experimental prototype described in section 4.5. Chapter 6 was tailored to analyse the interviews and other secondary data related to TSC TIS development described in section 4.6.

1.3 CONTEXT

The built environment is generally powered by conventional energy sources which have impacts on climate change through greenhouse gas (GHG) emissions. The buildings sector was responsible for 44.6% of total GHG emissions in 2010 in the United States for example (Conti et al. 2011, cited in Mazria 2013). Barker et al. (2007) stated that the residential and commercial sectors were responsible for 33% of GHG worldwide emissions in 2004. The buildings sector in the United Kingdom (UK) emitted more than 45% of the country's total GHG in 2009 versus 21.7% for transport and 8.8% for agriculture. The buildings sector here comprises: residential; commercial; industrial and public. Carbon dioxide (CO_2) emissions make up 96% of emissions from this sector (DECC 2011c).

Certain techniques including energy efficiency, demand management, and controlling suitable insulation level are appropriate approaches to reduce GHG emissions from the built environment. This can be achieved through proper design of buildings with contributions from building-integrated low-carbon energy generation. This will also contribute towards sustainability, cost efficiency and energy security.

1.3.1 CLIMATE CHANGE

The Earth's climate is a complex interactive system comprising of the atmosphere, land surface, snow and ice, oceans, water reserves, and living things. The climate system is affected by internal dynamics (e.g. volcanic eruptions and changes to the atmospheric composition) and external forcing factors (e.g. solar variations). As stated in the Intergovernmental Panel on Climate Change's (IPCC) fourth report, solar radiation powers the compound climatic system; therefore, changing the natural atmospheric concentration fundamentally changes the radiation balance on the Earth (Rogner et al. 2007).

Climate change has negative effects on the built environment. These effects include escalating temperature levels of ambient air and oceans which in turn lead to melting of long term snow and ice and rising the sea levels. Bates et al. (2008) indicated that the further progress of climate change will submerge massive areas of land due to rising sea levels. The inhabitants will be forced to migrate to safe land or become extinct. Climate change will lead to fluctuating heating demand and energy consumption in households (Sælthun et al. 1998, cited in Lisø et al. 2003). Health is susceptible to climate change. Heat and cold-related illnesses and death due to thermal extremes as well as psychological disorders could ensue. The maintenance cost of the built environment might also increase due to precipitation, wind and weather related issues like floods and landslides (Lisø et al. 2003).

It was during the ninetheenth century that the atmospheric greenhouse effect was initially recognised; Joseph Fourier described this phenomenon in the 1820s (Weart 2014). The global atmospheric concentration of CO_2 has increased from nearly 280ppm (parts per million) in the pre-industrial era to 399ppm as of August 2014 (Fig. 1-1).

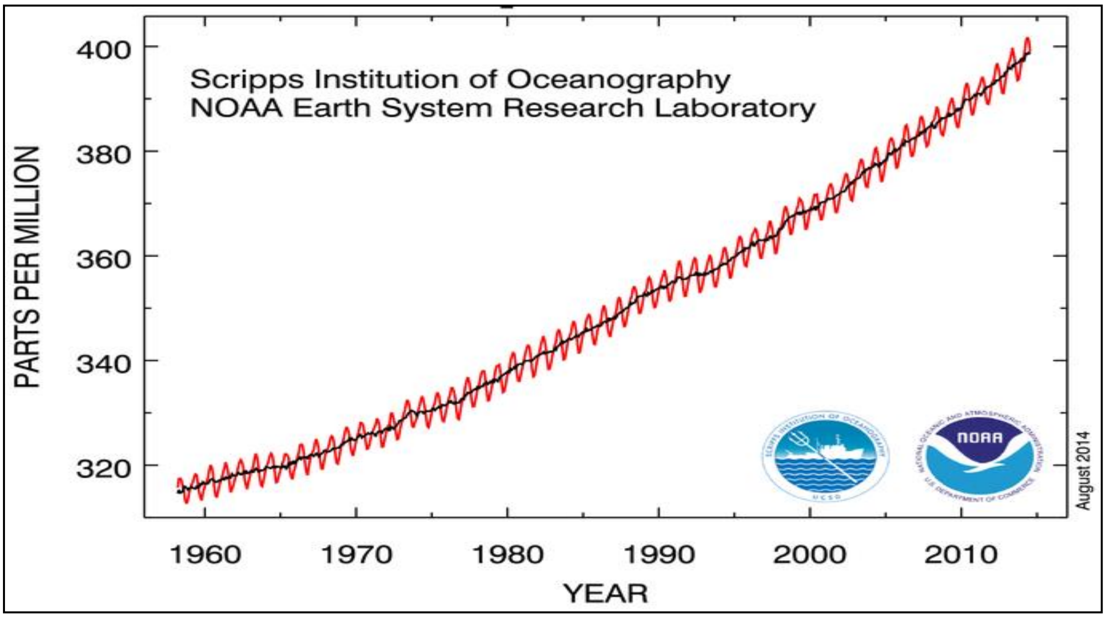


Figure 1-1: Recent atmospheric CO_2 levels, black line is the average (Tans and Keeling 2014)

The current CO_2 level in the atmosphere exceeds the natural fluctuation of 180 to 300ppm over the past 650,000 years based on reliable data from ice cores (Sims et al. 2007; US EPA 2012; Tans and Keeling 2014).

Fossil fuel combustion is the main source of the steady increase in CO_2 atmospheric concentration since the pre-industrial era. Carbon dioxide emissions from fossil fuel increased from about 23.5 $GtCO_2$ (gigatonne carbon dioxide) per annum in the 1990s to around 26.4 $GtCO_2$ per annum in 2005. An annual projection of 37.2 to 53.6 $GtCO_2$ from energy use is expected in 2030 (Rogner et al. 2007; Sims et al. 2007).

The net GHG emissions from the UK in 2009 was 566Mt CO_2e – equivalent (DECC 2011c). The per capita emission has, nonetheless, decreased from 9.60 tons per person a year to 7.54CO_2e ton/capita/year a 21.4% reduction (IEA 2011).

1.3.2 INTERNATIONAL AGREEMENT ON CLIMATE CHANGE

The Kyoto Protocol international agreement came into effect on 16th February 2005 following formal adoption in 1997 and targeted Annex I countries to limit or reduce GHG emissions. Annex I, however, is a reflection of 37 industrialized countries and the European community who mostly exceeded or approached the threshold of CO_2 emmision unlike the non-annex 1 countries who were accepted to resume with a certain level of increase in emissions to reach stabilization in 2060s. The agreed amount of GHG reductions related to their 1990 levels applied over the five year period 2008-2012. However, a few Annex I countries were allowed to exceed their 1990 levels such as the 1% increment for Norway (Tjernshaugen 2002), 8% for Australia and 10% for Iceland (UNFCCC 1998). Few countries recorded good achievements on their targeted levels of reduction; these countries include for example Italy, France, Norway, Slovenia and UK (UNFCCC 2013).

By 2050, the share of energy sources is expected to change drastically (Kainuma 2013) towards low-carbon sources of energy. Hence, governments are encouraged to focus on progress towards low-carbon societies. United Nations Climate Change summits continued following the Kyoto Protocol which was amended in the Conference of the Parties (COP19) in Doha to accommodate a second commitment period towards reducing CO_2 emissions. The new commitment period of the extended Kyoto Protocol spans from 2013 to 2020, however, this amendment is expected to enter into force by 2014 (Harrabin 2012).

1.3.3 ENERGY CONSUMPTION AND SECURITY

Energy is a principal factor for a nation’s economic development. There are abundant supplies of renewable energy on Earth. Renewable energy sources backed-up by an energy saving regime, especially from existing architecture, is a practical approach to reduce fossil fuel use.

The world’s energy consumption has increased more than ten times from 1900 to 2000 versus a four times increase in the world’s population from 1.6 billion to 6.1 billion. The consumption of global primary energy was around 225.6 quadrillion (10^{15}) Btu (British Thermal Unit) in 1972 to rise to almost 439.8 quadrillion Btu in 2004 (Sims et al. 2007). This became almost 524 quadrillion Btu in 2010 with a projected rise to 820 quadrillion Btu in 2040 (EIA 2013). The energy demand is expected to increase significantly in the future due to steady economic and population growth.

The UK power sector is threatened by increasing demand and fossil fuel dependency. The UK exported energy until 2003 but thereafter became a net energy importer. In 2010, fossil fuel dependency had increased to 89.8% due to rising gas consumption and falling nuclear electricity generation, the total electricity demand was 384 TWh, i.e. a 1.3% increase on 2010 (DECC 2011d).

1.3.4 SPACE HEATING IN UK

Space heating in the UK counts for 61% of the total domestic energy consumption (see Fig. 1-2) (DECC 2011b). Furthermore, it is responsible for 25% of the UK's total CO_2 emissions and more than 40% of the energy costs in households (Liao et al. 2005). Therefore, significant energy savings in buildings could be achievable through space heating. Despite this, there has actually been a slight increase in the energy required for space heating during the last three decades (DECC 2011b).

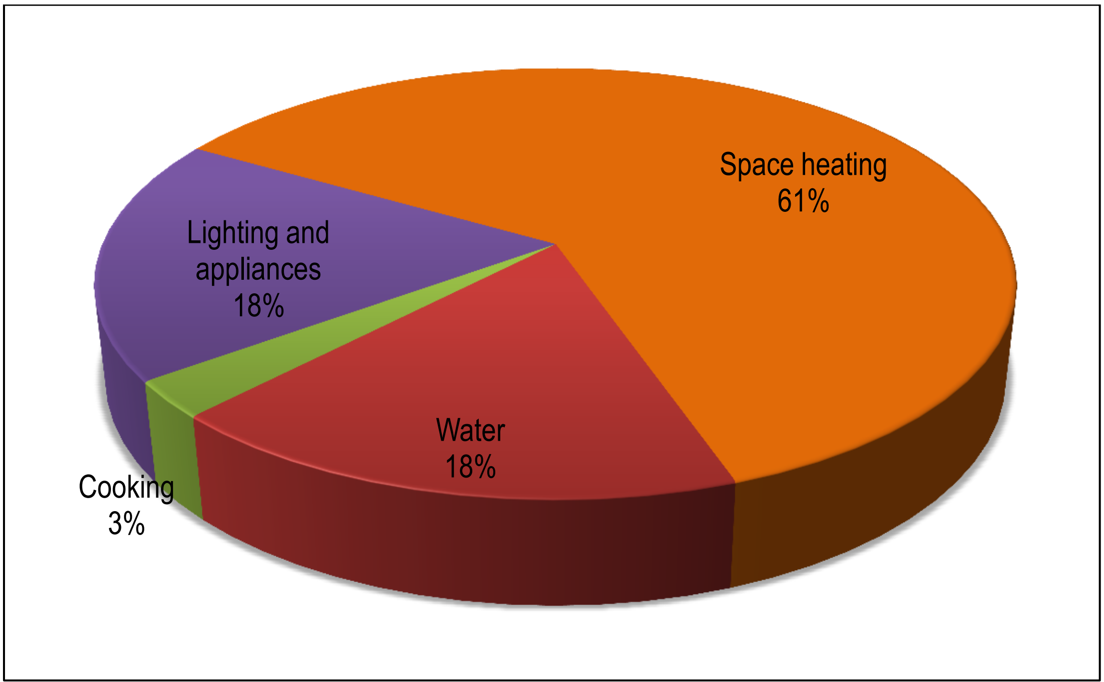


Figure 1-2: UK domestic energy consumption in 2009 (DECC 2011b)

Figure 1-3 indicates the space heating energy fluctuations which can be attributed to increases in the number of buildings and living standards as well as buildings being refurbished to be more energy efficient under stricter building regulations. However, there is still scope to improve the energy efficiency of space heating in the UK (Liao et al. 2005).

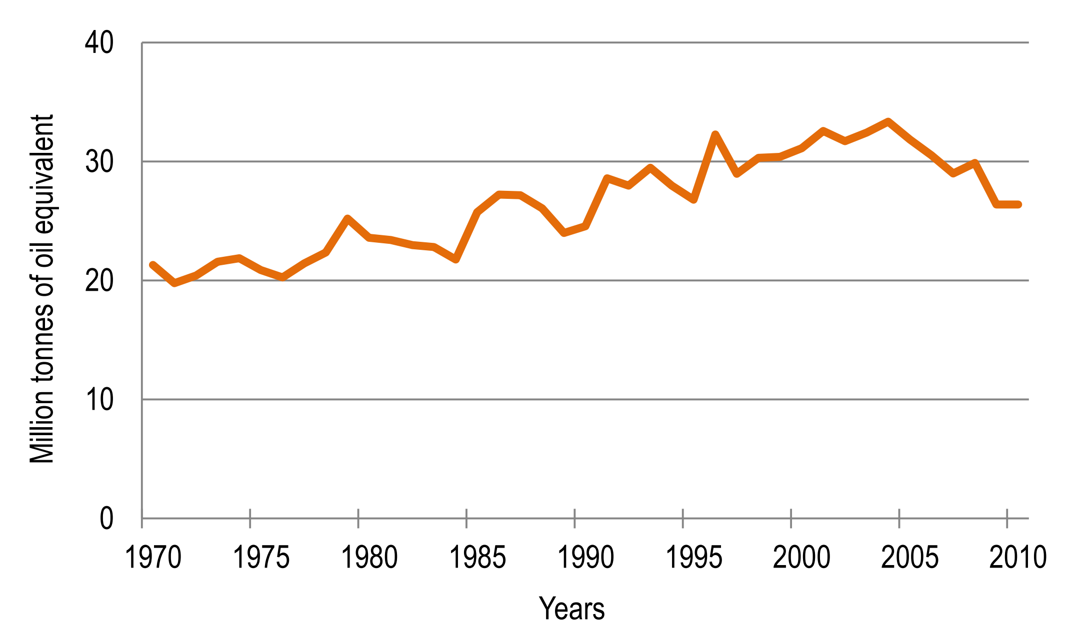


Figure 1-3: Space heating trend in UK from 1970-2009 (DECC 2011b)

Although a significant improvement in space heating energy efficiency could be made by improving the control of heating systems (BRECSU 2002), there is also scope for introducing novel efficient systems in the UK market, particularly if they could be designed to be aesthetically pleasing and sustainable.

1.4 AIM AND OBJECTIVES

The aim of this work is to provide insight into architecturally integrating transpired solar thermal technologies in buildings for space heating in temperate regions, and clarify its potential contribution to pre-heating ambient air in Wales.

This includes:

- An investigation of the limited adoption of integrating and deploying TSC in building envelopes despite its apparent technical competitiveness.

- The socio-economic concerns of technological innovative development are explored at entrepreneurial level in the UK and North America.

In order to achieve the aim, the following objectives were set according to the interrelated research directions explained in the brief methodology (section 1.5):

Architectural Integration of TSC:

i) Examine the existing awareness of the TSC and verify the role of the architect as a principal decision maker who facilitates integrating the technology in design. This includes verifying the decision making actors and elucidating the integrated design process (IDP) which produces more consolidated architectural outputs.

ii) Investigate different functional and aesthetic integration preferences of TSC and hybrid PV/TSC, and find out the preferable optimum architectural integration scheme for architects and end-users.

iii) Understand the architects' perceptions and recommendations of building-integrated transpired solar thermal technologies.

iv) Identify the needs of architects, engineers, and building professionals for improved architectural integration quality and flexibility of solar thermal energy, in a form of design prerequisites.

v) Gain insight into the constructability and integration practise of the TSC through design, planning and building a prototype project. The protoype project to be furthermore practically tested to clarify the potential usefulness of TSC technology for space heating in Wales.

Technological Innovation Development (TIS) of TSC:

vi) Evaluate the technological innovative development of TSC in the UK at the entrepreneurship level and compare it to the North American case using interviews as the main source of data and other secondary data sources.

vii) Identify the barriers of integrating the TSC, and highlight potential enablers to integrating and deploying TSC technology for researchers, entrepreneurs and policy-makers to consider for further improvement and technological development.

viii) Investigate the contribution of the technological innovation system to the development, diffusion and utilisation of transpired solar collectors.

Objective 1.4vii overlaps between architectural integration and technological innovation development.

1.5 BRIEF METHODOLOGY

The research method is divided into two interrelated directions: 'architectural integration' and 'technological development'. The former focuses on the architects' perceptions, preferences and challenges of integrating TSC technology in buildings, whereas the latter interrelated term focuses on the potential systematic development of TSC. Figure 1-4 in section 1.6 shows the research methodology.

This study is being conducted using combined methodology to satisfy the inter-disciplinary research aim and the multi-dimensions contained within the objectives:

- Mixed-methodology (qualitative and quantitative) analysis of a questionnaire mainly serves the first research objectives; architectural integration (objectives 1.4i to 1.4v in addition to 1.4vii).
- Design and construction of an experimental prototype was a secondary method within the architectural integration direction to gain 'hands-on experience' (objective 1.4v).
- Qualitative analysis of interviews and other secondary data for the purpose of technological innovation development analysis of TSC in the United Kingdom and North America (objectives 1.4vi to 1.4viii in addition to 1.4i).

1.6 THESIS STRUCTURE

The thesis is divided into eight chapters as described in this section. Figure 1-4 shows the chapters below:

Chapter 1: Introduction of thesis that gives context to the research. The chapter highlights the issues of climate change and CO_2 emissions attributable to the UK's built environment. It proposes that investigation into architectural integration and technological innovation systems of TSC could contribute to a solution. It also includes the aim and objectives of the research and a brief highlight of the methodology with a statement of the contribution of the PhD thesis to the existing research.

Chapter 2: Solar Energy: it highlights a background of solar energy (history, types and development). It focuses on the transpired solar thermal technology and highlights its working principles, literature, and state-of-the-art development and research.

Chapter 3: Integration and Innovation: the integration section reviews previous studies and literature relevant to architectural integration of solar technologies in building envelopes. Similarly, the innovation section reviews previous studies that include the development of innovation systems, and the components and functions of the technological innovation system in addition to the interaction between these functions.

Chapter 4: Methodology: this defines the research parameters and indicates the reasons for choosing the research methods. The research methodology implementation is explained.

Chapter 5: Architectural Integration: quantitatively and qualitatively analyses and reports the questionnaire results in order to explore the actors' perception towards integrating TSC in buildings. The chapter furthermore reports the findings gathered from designing and constructing a TSC prototype (experimental prototype) in order to gain hands-on experience of the difficulties which might face the constructability and integration of TSC through design, planning and operation.

Chapter 6: Technological Innovation Development: reports the findings from interviews, questionnaire and other collected secondary data in order to analyse the socio-economic aspects facing the deployment of TSC in the marketplace and to draw lessons from a comparison of the formative stage of UK development with the mature North American TSC deployment.

Chapter 7: Discussion: brings together the findings from the two strands and combined methodologies to form a coherent response to the aims and objectives set in the introduction.

Chapter 8: Conclusion of the research and recommendations for relevant future works.

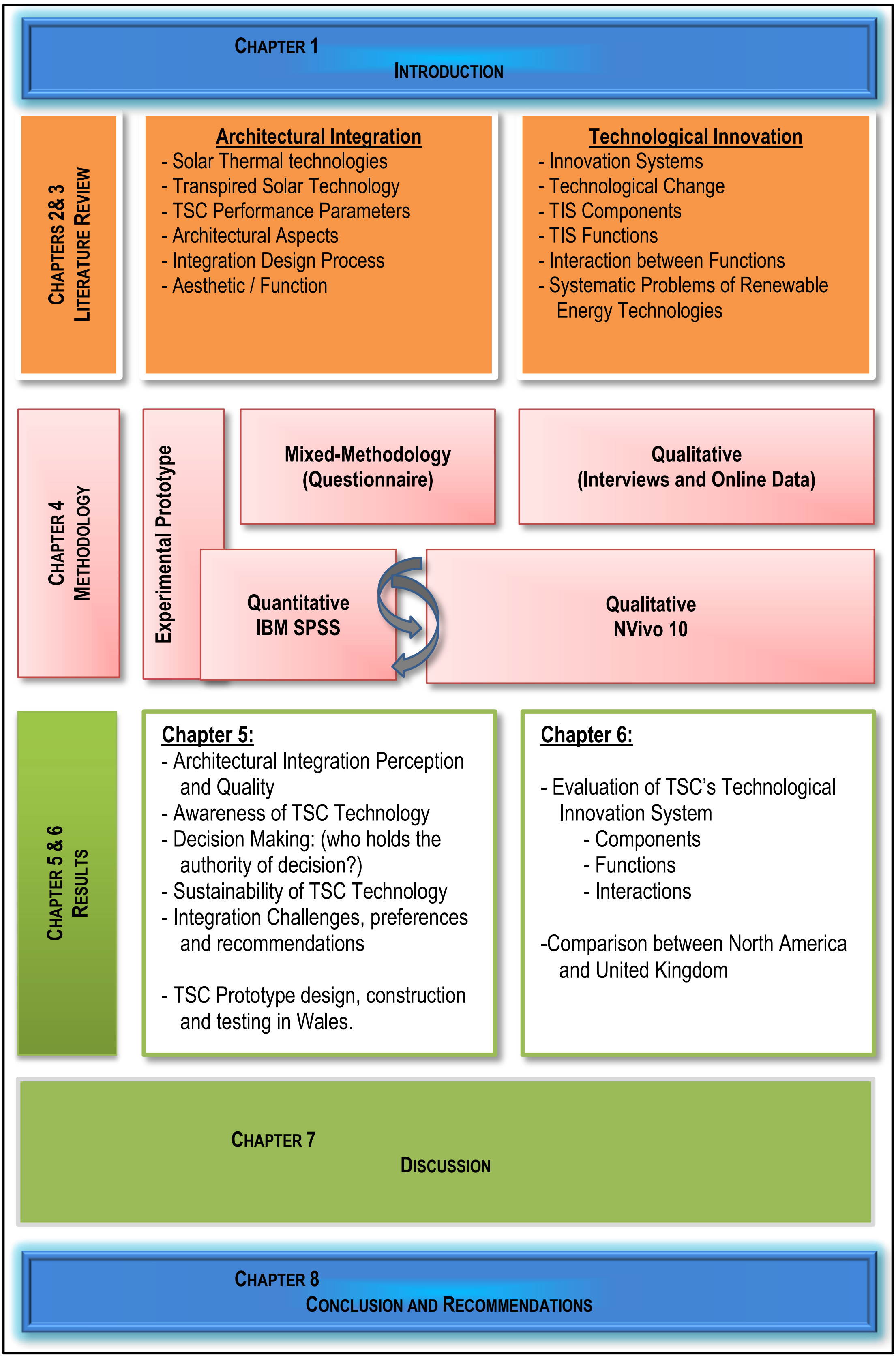


Figure 1-4: Research matrix illustrates the research ideology. It shows the development of research process along with thesis structure (section 1.6)

1.7 CONTRIBUTIONS OF THE RESEARCH

Contributions to the existing knowledge were made at various phases in this PhD research. These include selection of the topic, methodology, research findings and discussions as follow:

i) RESEARCH TOPIC:

This research, to the author's knowledge, is the first empirical piece of work that provides insight into architectural integration issues related specifically to TSC. Building on the proposition of Probst and Roecker (2011) surveying architects and engineers in relation to integrating solar thermal systems, human dimension towards the research and building integration of TSC was explored. The focus on a specific technological system was recommended by (Hekkert et al. 2007) and confirmed later by Negro et al. (2012a) to produce precisely directed identification and measures. The TSC prototype is deemed the first experimental model in Wales, which has allowed 'hands-on experience' in constructing and testing the TSC. The collated results of these methodologies allow multi-directional insights into the research aim being targeted.

ii) STATISTICAL ANALYSIS OF QUANTITATIVE DATA:

Although quantitative analysis of previous surveys related to this topic have been reported (Horvat et al. 2011), a key criticism has been the lack of statistical analysis. This work brings the rigour of statistical analysis to reinforce confidence in the results.

iii) PARTICIPATION IN THE SURVEY:

The total returned responses on the questionnaire (1,734) was considerably higher than previous related studies targeting architects and professionals such as Probst and Roecker (2011) and Horvat et al. (2011) as explained in section 5.2. This adds an accreditation and confidence to the validity and reliability of the data being analysed. It would further infer a generalisation about the group types being targeted (Field 2009).

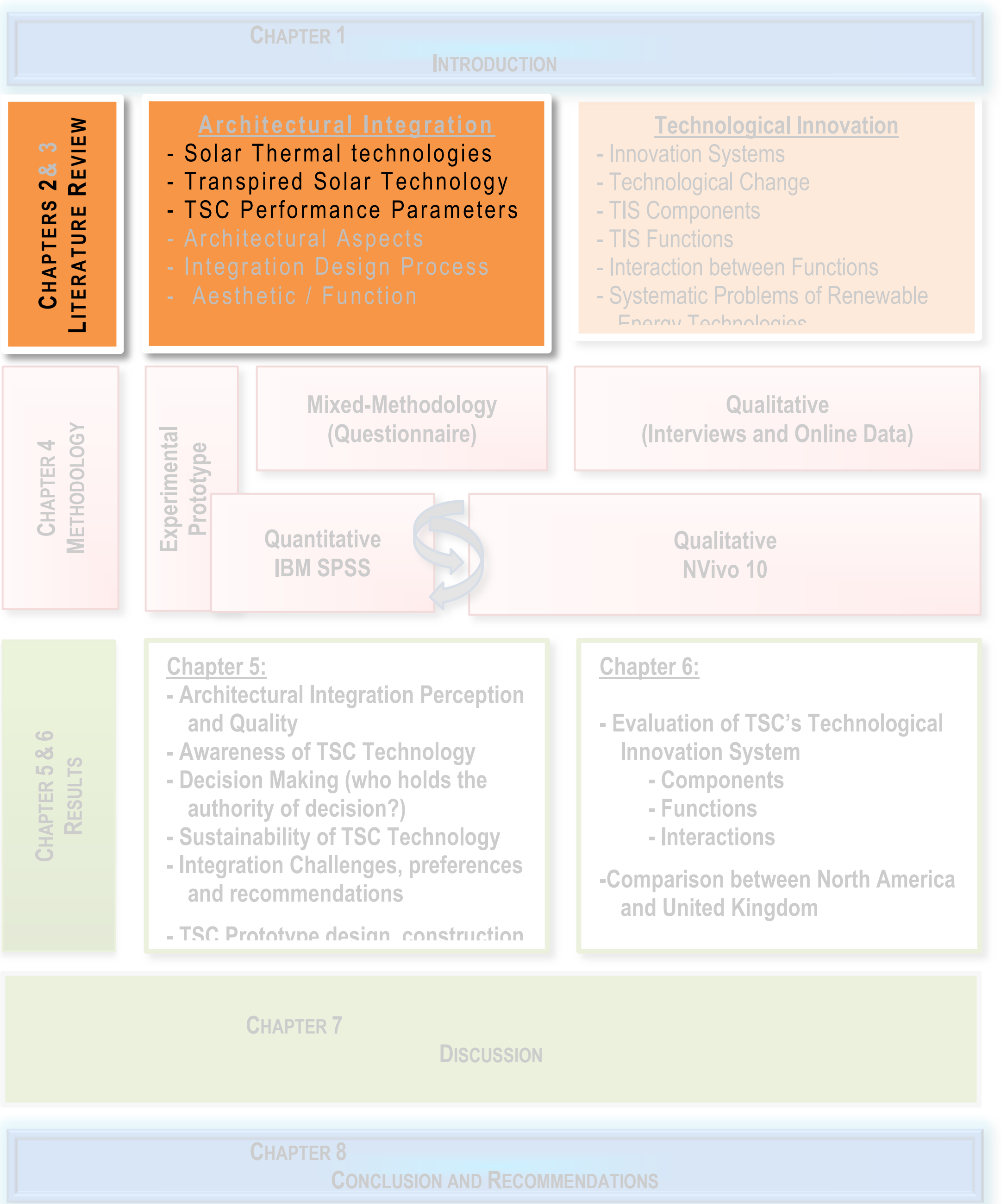
iv) SETS OF BARRIERS, ENABLERS AND DESIGN GUIDELINES:

Derived with the aim of providing insight into the low take up in TSC integration and deployment, a set of barriers, either in research or in design, was identified hindering the potential breakthrough of the technology. A few previous studies analysed barriers for renewable energy such as Painuly (2001) and Philibert (2006). Nevertheless, this study is the only up-to-date and empirical research identifying specific barriers for TSC technology, to the author's knowledge.

In order to overcome barriers, a set of potential enablers and architectural design guidelines were proposed as strategic solutions. These sets are proposed as a framework to provide a breakthrough in the research, design, policy-making decisions, development and deployment of TSC in the UK. Nonetheless, this framework would likely be applicable to other countries and other solar thermal technologies as discussed in sections 7.6 and 7.7.

CHAPTER 2 ||

BUILDING-INTEGRATED SOLAR ENERGY



2.1 INTRODUCTION

There are three major types of energy sources; fossil fuels (i.e. coal, oil and natural gas), renewables (i.e. wind, solar, geothermal, biomass, and ocean energy) and deployable (i.e. nuclear energy). This chapter presents current energy use in the built environment and indicates methods that will allow more renewable energy to be used. This will focus on the utilisation of the Transpired Solar Collector (TSC) for space heating energy.

2.2 ENERGY IN THE BUILT ENVIRONMENT

Measures to reduce CO_2 emissions from buildings while maintaining environmental and sustainable requirements fall into the following categories:

- Reduction of operational and embodied energy in buildings.
- Switching to low-carbon energy sources.
- Capture of carbon dioxide emissions (Levine et al. 2007).

Switching to low-carbon energy is deemed the practical approach, especially in existing architecture. Low-carbon energy can be supplied to buildings from the grid or be generated on-site by an integrated technology (Levine et al. 2007).

2.2.1 NON-RENEWABLE ENERGY SOURCES

Non-renewable energy sources include coal, oil and gas. As well as being finite resources, these also emit greenhouse gases that impact on the greenhouse gas emissions of electricity generated from these fuels.

Figure 2-1 shows a comparison of full life cycle CO_2 emissions for electricity generation from a variety of sources around the world. It is evident that electricity generated from lignite, coal and gas has much higher emissions than electricity generated from solar photovoltaics (PV), wind, nuclear and hydro energy sources (WNA 2011).

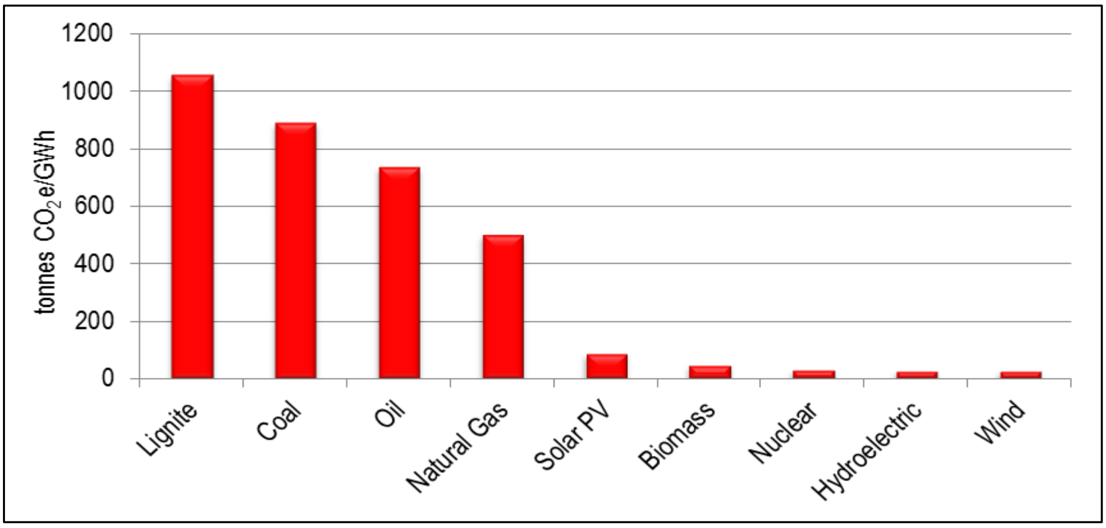


Figure 2-1: Lifecycle of GHG emissions from electricity generation sources (WNA 2011)

2.2.2 RENEWABLE ENERGY SOURCES

Contemporary renewable energy technologies have been developing since the late 1970s. In some countries, such as the UK, this progress has been encouraged by government sponsored incentives (Edquist 1998; Foxon and Pearson 2007). Continuous and rapid growth capacity was reported by the status report of the Renewable Energy Policy Network (REN21 2010). In particular, an increased growth capacity of 41% was reported for solar thermal power in 2009 (Fig. 2-2). Hence, increasing utilisation of solar and wind energy has been apparent in recent years.

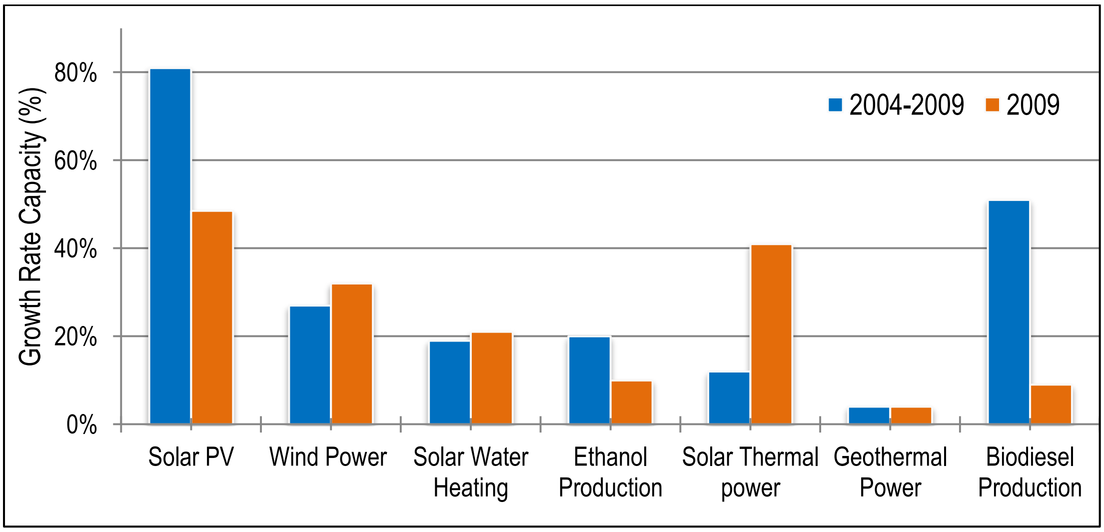


Figure 2-2: Average annual growth rate of renewable energy capacity, 2004–2009. 2009 figures present the year's growth in relation to the previous five years (REN21 2010)

2.3 SOLAR ENERGY IN BUILDINGS

The sun has been known as a source of light and warmth since the beginning of creation. In 1767, Horace de Saussure built the world's first solar thermal collector. Thereafter, the first commercial solar water heater was patented by Clarence Kemp in 1891. The following 50-60 years witnessed further development where Albert Einstein won the Nobel Prize in physics for his theories in the photoelectric effect. Following the Gulf War in the 1990s, solar power gained further popularity due to concerns about future oil availability (US DOE 2002; History of Solar Power n.d.) and concerns about anthropogenic climate change. Future buildings, therefore, are expected to incorporate renewable energy and energy-efficient design techniques.

The solar energy technologies associated with buildings are divided into three main categories. Firstly, 'passive solar energy' focuses on orientation, window design sunshades, and thermal insulation (discussed in 2.3.1); secondly, 'active solar thermal energy' could be integrated into buildings to capture solar energy for water and space heating (discussed in 2.3.2); and thirdly; 'active solar photovoltaic' could generate electricity (discussed in 2.3.3). Further, buildings might incorporate passive and active solar technologies to be a 'solar building'. This type of building constitutes an area of interest to architects and energy specialists to jointly design such buildings (Hestnes 1999).

2.3.1 PASSIVE SOLAR THERMAL

In the mid twentieth century, passive solar design themed as a technique in buildings' architecture. Guidelines for solar heating in domestic architecture were presented by George Nelson and Henry Wright in the 1945 but were not named as passive techniques. Passive solar heating was first applied in house design in the 1932 as published by the Royal Institute of British Architects (RIBA) (Nelson and Wright 1945). The first commercial office building with passive design and solar water heating techniques was designed in the mid-1950s by an American Architect, Frank Bridgers (US DOE 2002; History of Solar Power n.d.). Passive solar techniques refer to heating or cooling inhabited spaces using the sun's energy. It is a natural process relying on the characteristics of materials and air under exposure to direct sunlight. Passive solar design is conceptually simple; it is a balance of building components which work as a system. There are no electrical or mechanical interventions required for the system to function, which reduces maintenance and costs. Specific attention by architects was usually given to certain principles of passive design that include building location and orientation, thermal mass of building components, sun path, appropriate ventilation, and size and placement of openings.

Solar passive design principles can be utilised to reduce energy consumption and therefore CO_2 emissions while maintaining indoor comfort. However, a house with passive design features should not be confused with 'Passivhaus' that is a design philosophy which has been certified as meeting the required design and construction standard (Alter 2009; Kuang 2009) (Table B-1, Appendix B).

As Christensen (2009) and Chiras (2002) mentioned, passive solar heating has three configurations: direct solar gain, indirect solar gain (i.e. Trombe walls/thermal storage wall systems), and isolated solar gain (i.e. sunrooms) (Fig. B-2, Appendix B).

The deliberate use of sunlight in buildings has steadily increased as windows design has improved. This has allowed larger glazing areas to admit solar energy without causing too much heat loss when the sun is not shining (Hastings 2007). Once admitted, solar energy can be stored for heating later on when necessary, or alternatively used for air ventilation (Chan et al. (2010). Passive solar cooling is achieved through operable windows and ventilation such as wing walls and solar chimneys.

2.3.2 ACTIVE SOLAR THERMAL

Active solar thermal systems usually require solar collectors and heat distribution methods using water or air. Active solar thermal is divided into low and high temperature applications. High temperature applications are not included in buildings and are therefore beyond the scope of this study. Typical building related applications include domestic hot water (DHW), space heating (Fig. 2-3) and cooling. Although these technologies, particularly domestic water heating, have been widely used for a long time, improvements in integration and performance remain essential for solar energy to substitute conventional sources of energy.

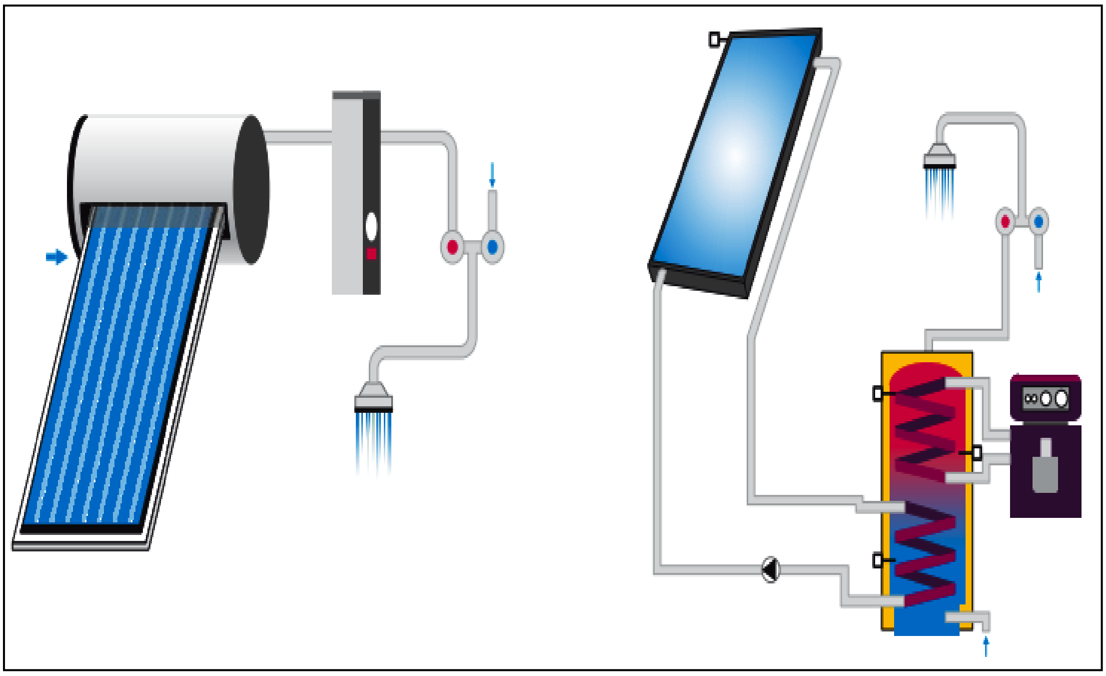


Figure 2-3: Schematic of a typical solar thermal system, it can be used to provide hot water for domestic use (DHW) and space heating (IEA 2012)

Integrating solar thermal systems in building envelopes differs according to the solar collector type, design, function and economic feasibility. According to Zhai et al. (2008), the integration of solar thermal technologies in buildings to supply hot water, space heating and cooling, is under rapid development. However, solar collectors are usually key components of active solar heating systems whereas this study focuses particularly on heating type. A description of the common types of solar heating collectors follows according to their functional category in delivering energy (Fig. 2-4 shows a schematic diagram for all active solar energy classifications).

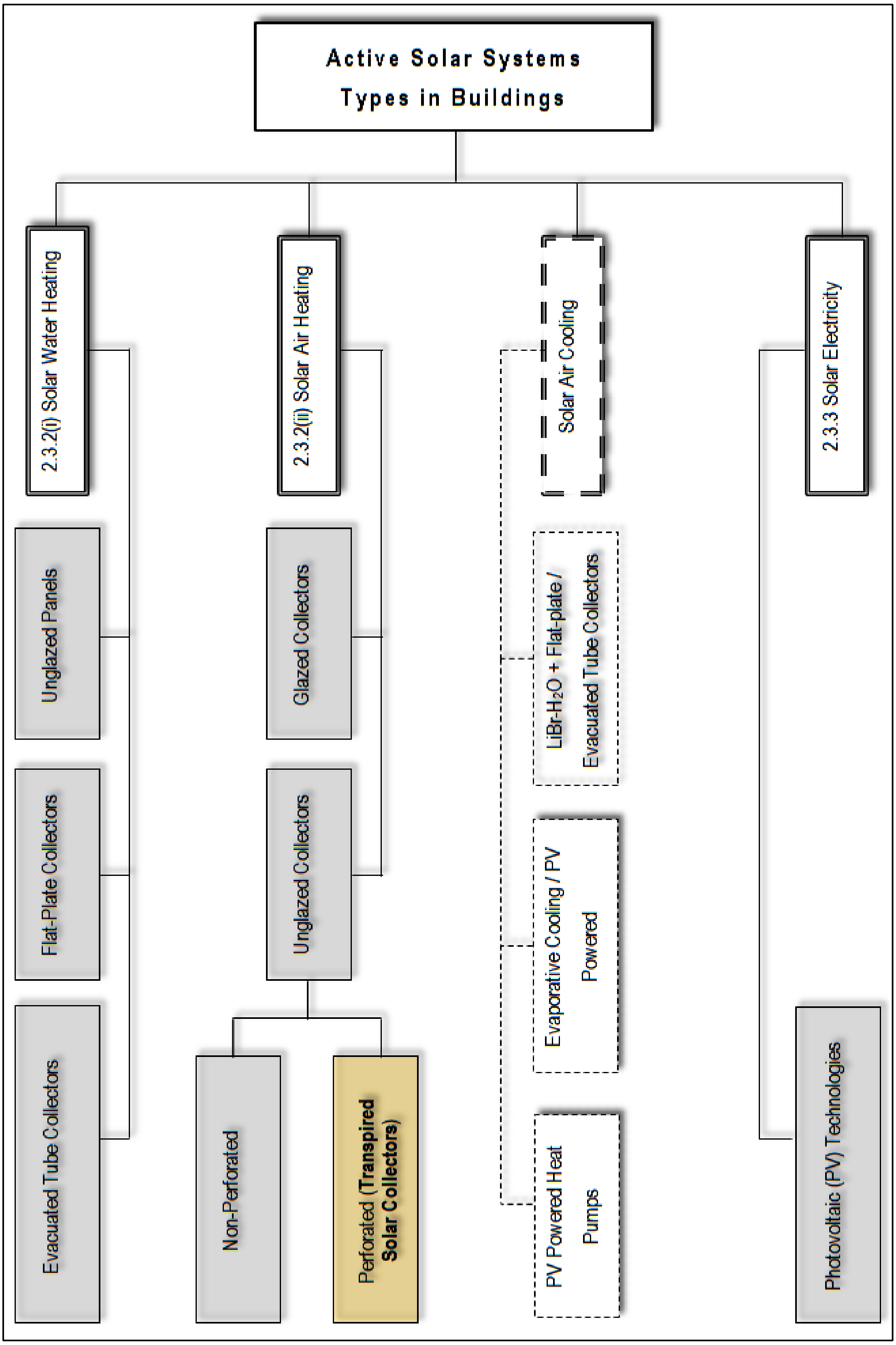


Figure 2-4: Schematic diagram of solar energy types in buildings, author (solar air cooling types are not discussed in this research)

i) SOLAR WATER HEATING

UNGLAZED PANELS: This type is suitable when only a few degrees of heating are needed. It is suitable for swimming pool heating and in tropical or subtropical regions where heat loss is minor (Clarkson 2010).

FLAT-PLATE WATER COLLECTORS: The most widely used solar collectors are flat-plate water collectors, especially, those developed in the 1950s by Hottel and Whillier. They usually consist of an insulated, weatherproof box enclosing a highly absorptive dark metal plate to absorb almost 90% of the incident radiation. They are covered with one or more transparent or translucent layers (i.e. glass or plastic) (see Fig. 2-5). Heat conducting fluid runs in pipes beneath the absorber plate for heat exchange (Sakhrieh and Al-Ghandoor 2013; Apricus n.d.).

New polymer flat-plate collectors were recently introduced as an alternative to metal collectors. These do not need antifreeze fluid in the pipes, allowing water to be directly pumped into the water tanks at higher efficiency than using heat exchangers. The average life expectancy of flat-plate collectors exceeds 25 years (Mahjouri 2004).

Figure 2-5: Flat-plate thermal system for water heating deployed on a flat roof (Qwiki 2011)

EVACUATED TUBE COLLECTORS: An evacuated tube collector, or 'vacuum tube collector', consists of a number of vertical tubes. Each tube comprises two Borosilicate glass tubes. The outer tube is translucent allowing light to pass through with minimal reflection while the inner tube is coated with a special heat absorbent material (Fig. 2-6). A vacuum is created between the tubes to minimise convection and conduction heat loss. The evacuated tube collectors have a much higher efficiency than flat-plate collectors, especially in colder conditions (Duffie and Beckman 1980; Hitemp 2006).

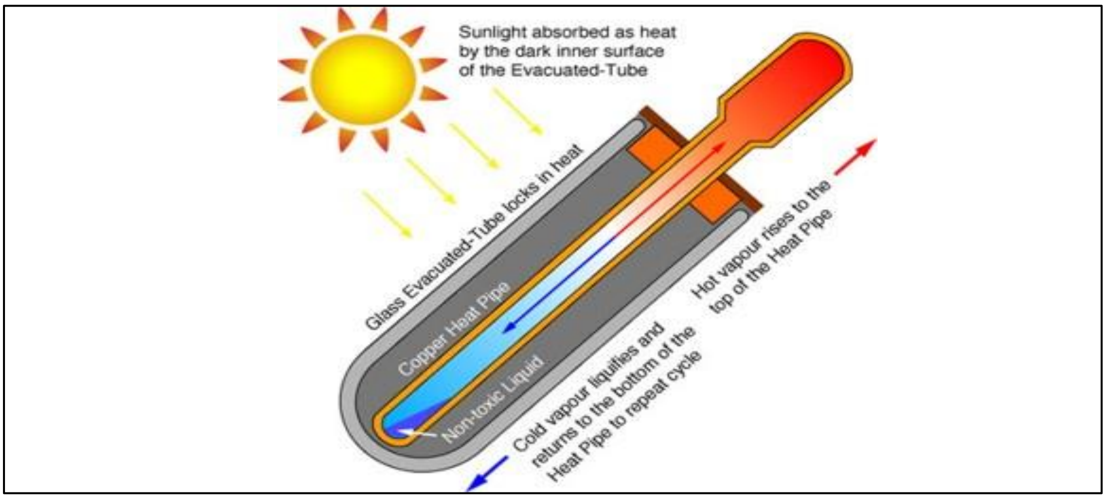


Figure 2-6: Glass-glass evacuated tube (cross section) (Hitemp 2006)

ii) SOLAR AIR HEATING

Solar air heaters are less common than solar water heaters. One reason for this is that the available air heaters only satisfy space heating (Papadopoulos 2003; Solar Air Heating n.d.). The flat-plate solar air collector is considered to be efficient, dependable, and economically viable. Air collectors can be classified into two main types, either glazed or unglazed as follows:

GLAZED SOLAR AIR COLLECTORS consist of a glazing layer and an absorbing layer. Solar energy is transmitted through the glazing layer and causes the absorbing layer to get hotter. When air is circulated through the duct formed by the two layers it absorbs heat from the absorbing layer. Figure 2-7 illustrates one specific type of glazed solar collector (Solar Air Heating n.d.). Payback for glazed solar air heating panels ranges from 9–15 years (Duffie and Beckman 1980).

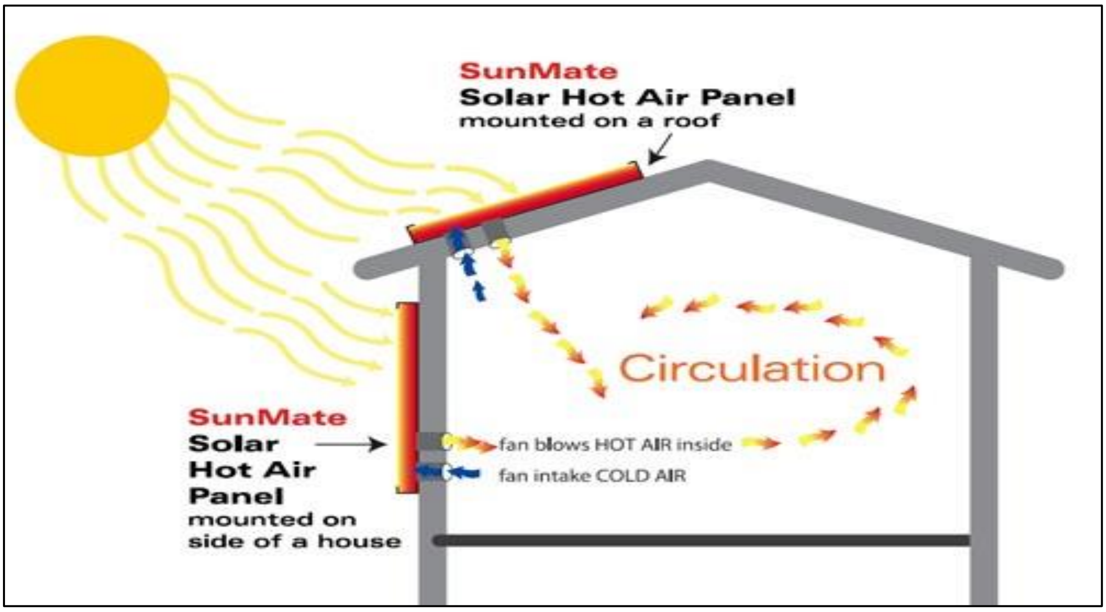


Figure 2-7: Glazed solar air collectors (SunMate n.d.)

U̲NGLAZED SOLAR AIR COLLECTORS have an absorber layer exposed to the sun without glass or glazing on the top. Generally the heated air is transferred into the building through a fan inlet. They are primarily used to heat the ambient air for space heating rather than recirculating interior air. A non-contaminated air flow is achieved therefore which satisfies human health and indoor comfort (Qwiki 2011; Solar Air Heating n.d.). Most glazing reflects about 15% of incident radiation which decreases its efficiency. However, glazed collectors reduce the heat loss from the absorber layer. Unglazed collectors are less expensive as they eliminate the glass (US DOE 1998; Resouce Smart Business 2007). Therefore, payback for unglazed solar air heating panels ranges from 2-7 years. Unglazed panels can be classified into either perforated or non-perforated solar collectors as follows:

a. NON-PERFORATED SOLAR COLLECTORS

A solid non-perforated collector designed in the 1980s is known as the backpass unglazed collector. The system uses solar energy to preheat the ambient outdoor air. It comprises solid metal collector plates, either flat or corrugated, attached to module of vertical and horizontal grit channels on the the external creating about 15 centimetre of a cavity. A fan is fixed in a penetration through the building's exterior wall and feeds heated air into the interior space or duct work. The backpass system is similar in construction and function to the transpired solar collectors (sections 2.3.2iib and 2.4). The difference, the backpass has no perforation in the collector plate therefore the air enters the system from the bottom of the system (Fig. 2-8).

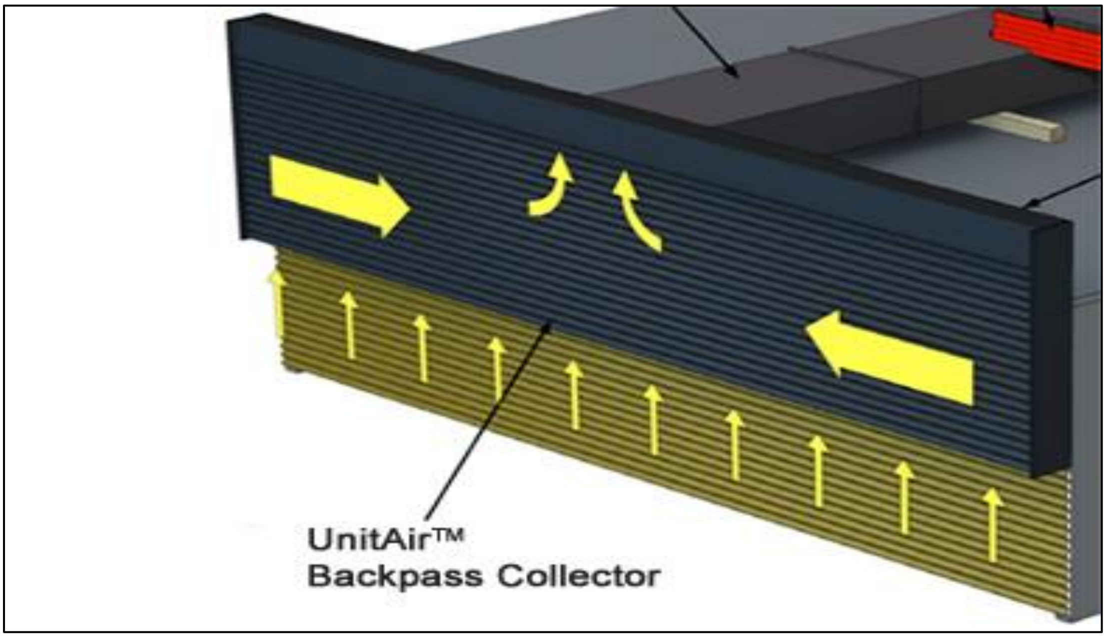


Figure 2-8: Typical backpass collector draws air from the bottom (Solar Air Heating n.d.)

The collector's solidity prevents about 50% of the solar heat being captured by the system as the heated air on the outside surface remains static at the ambient. Field experience has shown that wider cavity depth is necessary when larger air volumes are needed for heating. Nonetheless, increasing the depth reduces the air friction against the absorber surface which reduces the heat transfer rate and subsequently lowers the solar efficiency. However, narrower cavities increase the pressure drop and require more fan power. The recorded solar efficiency of a backpass panel for a typical industrial wall was less than 30% (Ekechukwu and Norton 1999; MatrixAir n.d.; Solar Air Heating n.d.).

b. PERFORATED SOLAR COLLECTORS

This solar air heating system features a perforated absorber. This type of unglazed perforated collector is often known as the transpired solar collector (TSC) (Fig. 2-9). According to Solar Air Heating (n.d.) and Qwiki

(2011), the TSC is most favoured in North America due to its low comparative cost, satisfactory performance, integration scheme, and operational simplicity. TSC technology is the main focus in this study and is therefore reviewed and detailed hereafter in sections 2.4 and 2.5.

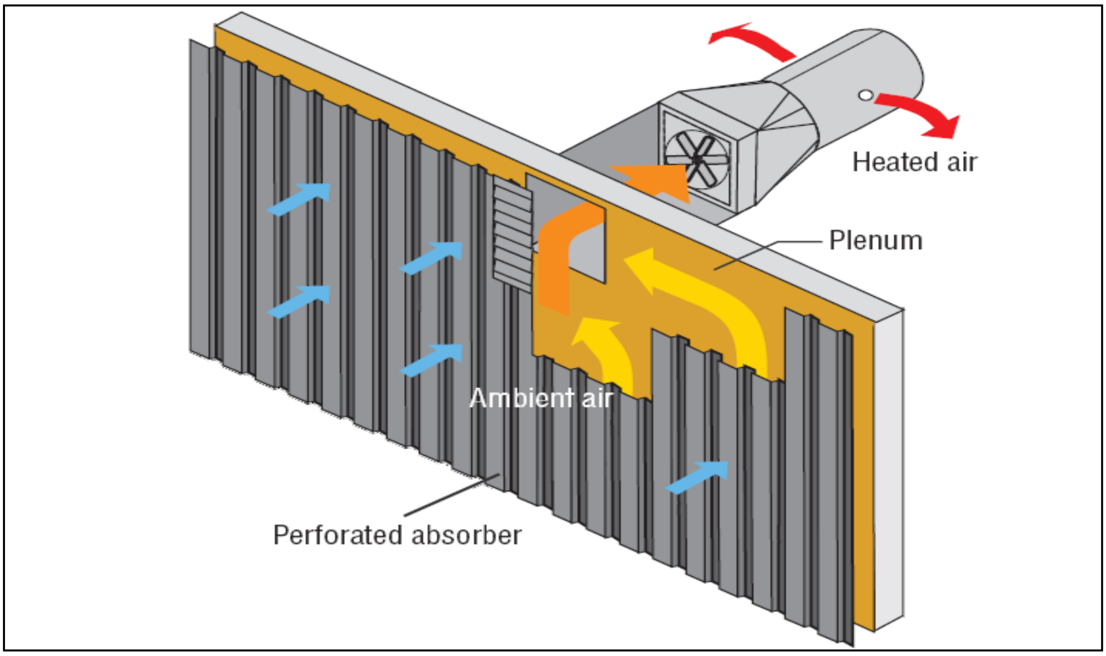


Figure 2-9: Unglazed, 'transpired', solar air collector (Qwiki 2011)

2.3.3 ACTIVE SOLAR PHOTOVOLTAIC

Photovoltaic (PV) was the fastest growing energy technology in the world from 2000–2009 (Rüther et al. 2008; Kok 2009). Solar electricity from PVs was the most costly energy generation (Kok 2009). The cost of solar electricity from PVs continues to plummet to reasonable and affordable levels that beat electricity from some fossil fuel sources (Bhavnagri 2014; Parkinson 2014). However, in a survey completed in June 2014 in the UK for example, almost half of households were reported unaware unaware that solar generated electricity is cheaper than grid sources one (Woods 2014).

Photovoltaics can be installed on roofs or façades taking account of design considerations like location, azimuth, PV type and orientation. PV efficiency depends on several factors, primarily PV type (Table B-4 and Fig. B-3, Appendix B). The term building-integrated photovoltaics (BiPV) has become common in architecture and energy generation. It satisfies the option of the multi-functional façade, which combines energy generation and construction (Bazilian et al. 2001). The PV integration can be in a façade, parapet, shading device, porch or roof. Thin-film technology based on amorphous silicon (a-Si) has a range of attractive features for BiPVs such as thin panels, light weight, and sturdy material. BiPV elements may combine various functions, namely electricity generation, lighting, thermal insulation, shading, and aspects of architectural aesthetics and design (Benemann et al. 2001; Maurus et al. 2004) (explained in section 3.1).

Semi-transparent modules became available within thin-film technology by removing opaque layers from the substrate via laser techniques. This allows almost colour-neutral transmissions and hence provides a *"see-through"* effect (see Fig 2-10). Although the semi-transparent modules have slightly lower comparative efficiency, they serve functional lighting and temperature management in buildings as well as electricity generation (Maurus et al. 2004, pp. 24-25).

Figure 2-10: SmartSolarFab®, façade of a production facility in Alzenau (Maurus et al. 2004)

The TSCs satisfy an alternative energy source for space heating which is in a mainstream demand as highlighted in section 1.3.4. Therefore, the TSC has been focused in the literature and further investigated in this study to satisfy the research aim and objectives (section 1.4).

2.4 TRANSPIRED SOLAR COLLECTORS

TSC technology is a solar space heating technology as presented under section 2.3.2iib. It is usually classified as an active solar energy, although

Chan et al. (2010) classified it as a passive solar air heating technology due to the buoyancy mechanism and similarity to the Trombe wall and solar chimney except for the fan. According to McLaren et al. (1998) and Hall et al. (2011), TSC technology is well proven and readily available. The technology uses solar energy to preheat the ambient outdoor air as it is drawn into a building. The TSC is presented as an ideal application for buildings with moderate heating requirements over long heating seasons. According to the US Department of Energy (US DOE), TSCs deserve attention as the technology was a highly reliable, best-performing, and comparatively inexpensive form of solar heating for buildings amongst the commercially available energy sources of the time (US DOE 1998, cited in Riegger 2011).

2.4.1 BRIEF HISTORY

TSCs were patented by John Hollick in the mid-1980s (Hollick 1985) to preheat buildings' ventilation air using solar radiation. Further patent was developed by John Hollick and Rolf Peter in the 1990s (Hollick and Peter 1997). The product was piloted initially on the North American continent, predominantly the Canadian market, as SolarWall by Conserval Engineering Incorporation in the 1990s. CEI worked closely with the National Renewable Energy Laboratory (NREL) under US DOE, and with the Department of Natural Resources Canada (NRC) on the entrepreneurial development of the technology (Hollick 1994; McLaren et al. 1998).

The first TSC commercial installation in the 1990s was at Ford Motor Company assembly plant in Ontario, Canada. Since then, a few hundred TSCs have been installed in more than 30 countries worldwide. These installations were predominantly in commercial, industrial, agricultural and process application projects (Hall et al. 2011). Several examples have proven that the TSC technology is cost effective (McLaren et al. 1998; Resouce Smart Business 2007). A number of installations are currently in operation around the UK since the first installation in 2005 (Table 2-1).

Table 2-1: UK commercial installations of TSC, (Brewster 2010; Hall et al. 2011; Brown et al. 2013)

N	Project	Location	Year	TSC area: m^2	Predicted Energy savings: kWh/year
1	CA Group Mill Building A (Renovation)	Evenwood, County Durham	2005	410	N/A
2	CA Group Mill Building B (New Build)	Evenwood, County Durham	2006	1,211	299,000
3	Sainsbury's Distribution Centre	Pineham Park, Northampton	2006	947	256,093
4	Beaconsfield Motorway Services	Beaconsfield, Buckinghamshire	2008	255	99,235
5	Jaguar Land Rover Material Planning & Logistics Centre	Leamington Spa, Warwickshire	2009	268	80,530
6	Premier Park 33	Winsford, Cheshire	2009	580	130,000
7	Royal Mail	Swan Valley, Northampton	2009	800	233,396
8	Willmott Dixon Healthcare Campus (Full Scale Showcase)	BRE Innovation Park, Watford	2009	24	N/A
9	Firth Park Community Arts College	Sheffield, South Yorkshire	2010	218	N/A
10	RCT Homes Dwelling	Cwmbach, Aberdare	2010	9	
11	Chartek International Paints	Felling, Gateshead	2010	100	31,169
12	Sustainable Building Envelope Centre (SBEC)	Deeside, Flintshire	2011	262	N/A
13	Deeside Leisure Centre	West Queensferry, Deeside	2011	260	N/A
14	Jaguar Land Rover Deck 92	Solihull, West Midlands	2011	565	N/A
15	Royal Mail	Strood, Kent	2011	700	N/A
16	TWI Technology Centre	Port Talbot, Neath Port Talbot	2012	486	N/A
17	Armstrong Point Business Park	Wigan, Greater Manchester	2012	390	N/A
18	SSE	Treforest, Rhondda Cynon Taf	2012	210	N/A
19	Marks & Spencer	Castle Donington, Leicestershire	2012	4,334	N/A
20	Royal Mail	Chorley, Lancashire	2013	495	N/A

2.4.2 DESIGN CONCEPT AND MECHANISM

The technology of the TSC is remarkably simple. It consists of a corrugated perforated solar absorbing sheet placed approximately fifteen centimetres from the building's external wall creating a plenum of air. The corrugation is provided to stiffen the structure of the TSC and increase the exposure area to the sunlight (Gawlik and Kutscher 2002). The perforated pane usually has dark colours to maximise the absorption of solar radiation which can be converted to heat. The supporting framing consists of vertical and then horizontal grids which receive the perforated pane (Fig. 2-11) but technical details for each manufacturer are different. A fan is fixed in a cut-out through the building's exterior wall and connected to the duct work connection or Heat, Ventilation, and Air-Conditioning (HVAC) system. The fan creates negative pressure in the plenum which draws fresh air through the perforations. The air collects heat from the perforated layer and from the rear surface of the layer while passing through. The solar heated air is then transported via the outlet into the duct or HVAC system. In the case of duct work, the solar heated air is directly distributed into the interior space, where the air in the HVAC system can be heated further if required (Fig. 2-12) (McLaren et al. 1998; Resouce Smart Business 2007; Brown 2009; Hall et al. 2011).

Figure 2-11: Before, supporting framing, and after installation of TSC (Rowley 2007, cited in Brown 2009)

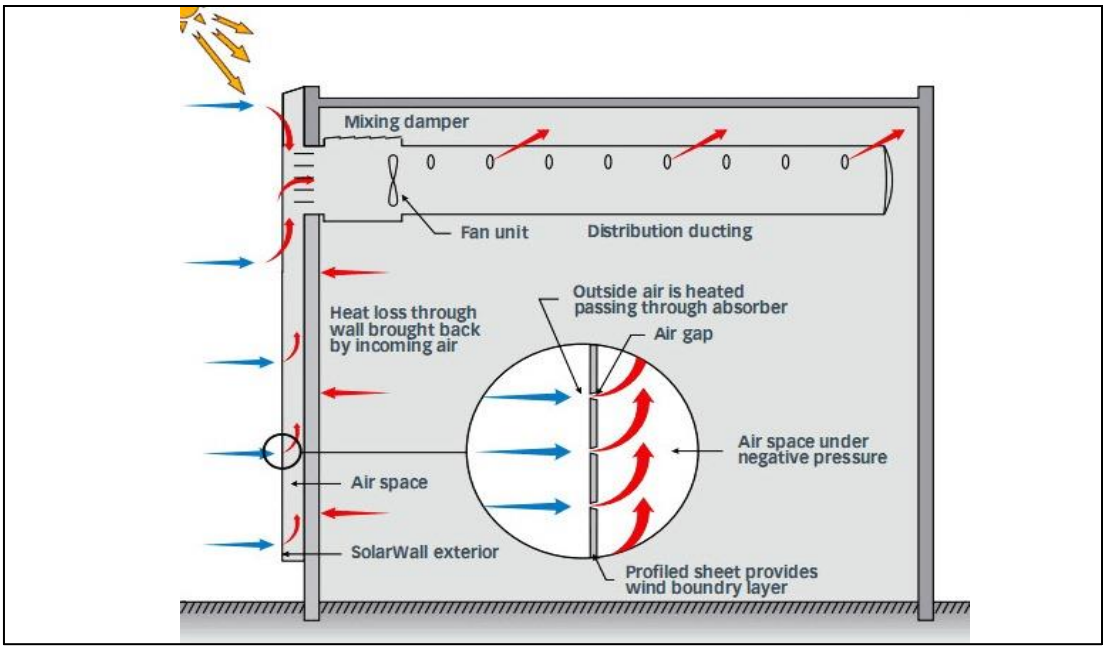


Figure 2-12: Typical TSC mechanism with rooftop HVAC unit (SolarWall n.d.)

TSCs have a bypass opening for when heated air is not required, especially in summer, so heated air from the plenum is avoided (McLaren et al. 1998; Resouce Smart Business 2007; Brown 2009; Hall et al. 2011). The TSC can form part or whole of a south-facing building's envelope, so as to receive the optimum exposure to direct sunlight during heating seasons (McLaren et al. 1998). Nevertheless, orientations other than north are still possible but at reduced efficiency. Openings such as windows within the TSC system also reduce the efficiency (Resouce Smart Business 2007). The size of the system is based on variables such as heating loads, airflow, climate, available solar irradiation and south-wall area (McLaren et al. 1998). Due to their sensitivity to such variables and solar fluctuations, TSCs are commonly linked to a conventional space heating system (air based or radiant) to satisfy thermal comfort. It is therefore recommended that the technology is combined with a thermal storage system to extend its heating capacity (Resouce Smart Business 2007).

This technology of preheating outdoor air with solar energy substitutes a substantial load from a building's conventional space heating system, saving energy and money (Hall et al. 2011). The instantaneous thermal efficiencies of the TSC exceeded 70% with low capital costs. Those two factors constitute the basic potential of simple economic payback of almost two years for large installations (Christensen et al. 1990; Brunger et al. 1999; Brewster 2010; Hall et al. 2011). However, as McLaren et al. (1998) mentioned, the saving scheme in energy and money by TSCs depends on a number of factors. These factors include: type of the displaced conventional fuel; pattern of use; building design; and the availability of solar energy during heating seasons.

2.4.3 TSC FORMS OF INTEGRATION

The TSC could be integrated into building envelopes in three basic forms: wall mounted; rooftop mounted; and stand-alone (Hall et al. 2011). Each of these can form a hybrid system by incorporating PV.

i) WALL MOUNTED

Most of the installed TSCs are commonly wall mounted (Fig 2-13), predominantly on the south-facing façade. The ideal orientation is within 20° of south which gets 96-100% of available solar gain. Orientation within east and west is possible (Fig. 2-14) but at lower solar gain efficiency (as low as 60% of the total available solar radiation) (CA Group 2011).

Figure 2-13: Northern Arizona University - USA (SolarWall n.d.)

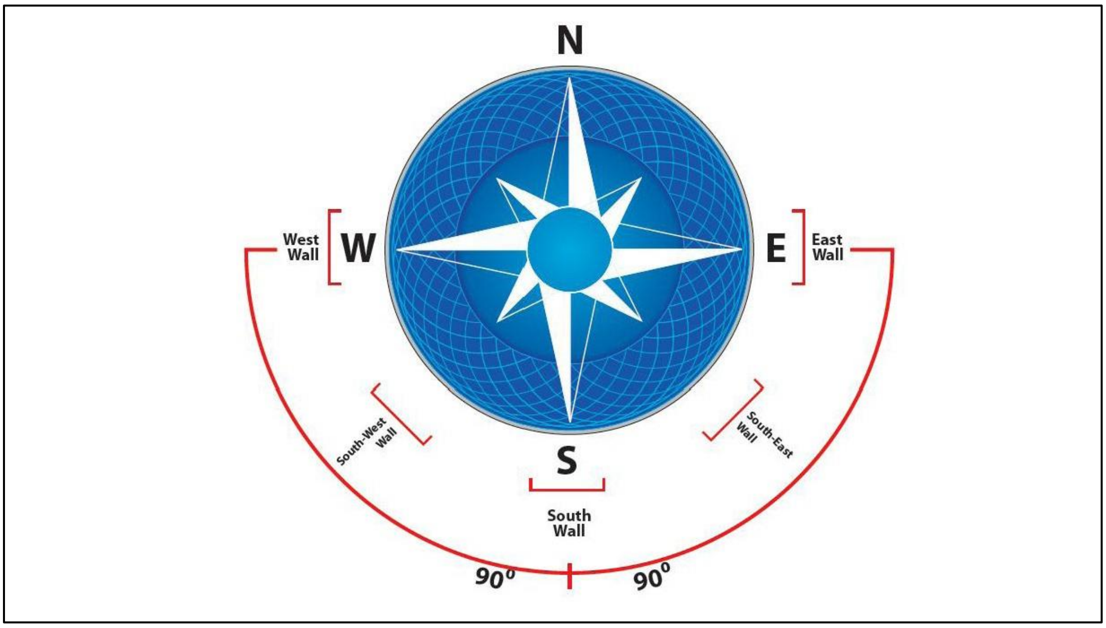


Figure 2-14: Ideal orientation for TSC (CA Group 2011)

ii) ROOF MOUNTED

Roof mounted TSC technology is mostly known as solar duct or modular. This has the same design concept and mechanism as the wall mounted TSC (Fig. 2-15). It is suitable when adequate roof area is available but there is no feasible south-facing wall area (SolarWall n.d.). According to Kozubal et al. (2008), the modular type has potentially achieved higher energy yields than wall mounted due to tilt optimisation which receives further solar radiation. However, a roof installed TSC does not necessarily satisfy a multi-functional option and may therefore entail a higher cost especially when occupying a space on the roof that could be used for another function (i.e. roof garden).

Figure 2-15: Renault dealership, Spain (SolarWall n.d.)

iii) STAND-ALONE

In the stand-alone system, the system's back plate is made of a non-perforated sheet which is usually exposed to the ambient environment (Fig. 2-16). The TSC unit is independent (Hall et al. 2011) which is suitable for under-construction sites and temporary processes. Kozubal et al. (2008) evaluated the performance of a prototype modular unit, which is similar to the stand-alone type, versus a south-facing façade mounted system. The stand-alone type provided slightly better performance over the wall mounted one due to the tilted angle which collected more solar irradiation. However, it is still subject to installation cost, availability of space, and architectural acceptance.

Figure 2-16: A prototype TSC under test (Kozubal et al. 2008)

iv) HYBRID PV/TSC

TSCs, either wall mounted or solar duct, can be used in combination with PVs as in a hybrid system (Fig. 2-17) to produce both space heating and electricity (Charalambous et al. 2007, cited in Hall et al. 2011). SolarWall claimed that the hybrid system provides four times the total energy from the same surface area. Furthermore, the hybridisation significantly helps to reduce the ROI (return on investment) timeframe (equation 2-1), on a PV system which offers more financial accessibility to building owners and investors (Solar Air Heating n.d.).

Figure 2-17: Ste Marguerite Bourgeoys school, Ontario (SolarWall n.d.)

$$ROI = \frac{(Gain\ from\ Investment - Cost\ of\ Investment)}{Cost\ of\ Investment}$$ (Schmidt 2009) (2-1)

One advantage of a hybrid PV/TSC system is the removal of heat from the back of the PV module which supplements the heating system while increasing the PV efficiency (Naveed et al. 2006; Delisle 2008). However, the PV cells reduce the TSC exposed area to solar radiation. The ideal electric conversion efficiency of an ordinary PV module is about 16-18% of the incident solar radiation they receive (Athienitis et al. 2011). This heat increases the PVs' operating temperature which decreases their overall performance despite those PV collectors absorbing almost 80% of the incident solar radiation (van Helden et al. 2004). The total solar energy conversion of hybrid PV/TSC increases to more than 50%, compared to the typical conversion for PV modules alone (10-15%) as tested at Canada's National Solar Test Facility (NSTF) and International Energy Agency Solar Heating and Cooling (IEA SHC) (Solar Air Heating n.d.). There are a variety of other options in which PV and solar thermal can be integrated in buildings. These include: passive air circulation behind the PVs; water heating; and bi-fluid which combine both water and air techniques (Krauter et al. 2000; Assoa et al. 2007; Tonui and Tripanagnostopoulos 2008; Anderson et al. 2009).

2.4.4 TSC COMMERCIAL AVAILABILITY

Conserval Engineering Inc. pioneered SolarWall® in Canada: www.solarwall.com. Two further products in the Canadian market are MatrixAir TR from Matrix Energy: www.matrixenergy.ca and Lubi™ system from Enerconcept Technologies: www.enerconcept.com. The MatrixAir has the air drawn from the bottom of the plenum unlike SolarWall. The installation is slightly angled whenever possible for more solar absorbing efficiency. Matrix Energy claims that these technical features increase the efficiency of the system, although the Canadian Standards Association (CSA) certifies this system at a lower performance factor than SolarWall. The second product, Lubi, uses polycarbonate panels rather than metal and allows light transmission through to the building wall. The manufacturer claims that the technology is the most efficient due to reduced heat loss and sensitivity to windy conditions. The reports from the CSA confirm that the Lubi system has a higher performance factor than MatrixAir or SolarWall. (Ehrlich 2011). Another TSC product in the Canadian market is ventilated thermal panels of Murox system from CANAM: www.canam-construction.com.

InSpire™ wall is commercially available in the American market: www.atas.com. Whereas, in the UK, the TSC technology is available under the trade name of SolarWall® from the CA group: www.cagroupltd.co.uk that is the same product of the Conserval Engineering Inc. A local entrepreneur in the UK is TATA Steel that has TSC products known as Colorcoat Renew SC®: http://www.colorcoat-online.com.

2.4.5 STRENGTHS AND LIMITATIONS

The following factors constitute a general view of the features and challenges towards building-integration of TSC technology; however, these can vary depending on time, location and design:

i) STRENGTHS

- The long life span of the absorber which exceeds 40 years subject to coating quality (Hall et al. 2011). However, the CA group provides a 25 year warranty on UK installations (CA Group 2011).

- Suitability for new and existing building as the TSC can be an additional component to building envelopes (Hall et al. 2011).

- A short payback period, usually 2–12 years subject to the nature of construction and design (McLaren et al. 1998; SolarWall n.d.).

- TSC technology has high performance and efficiency up to 75% as tested for SolarWall by NREL and NRC (SolarWall n.d.).

- The TSC helps mitigate CO_2 emissions from the built environment, and improves indoor air quality and thermal comfort (Shah et al. 2009; SolarWall n.d.). This occurs by replacing a considerable proportion of fossil fuel-derived heating.

- The TSC can be an aesthetic feature, especially when supported with a wide range of colours (Probst and Roecker 2007).

ii) LIMITATIONS

- Shading and large architectural openings limit the use of TSCs.

- Unsuitable for use with an existing heat recovery system (Resouce Smart Business 2007) and for non-ventilated structures like long-term storage warehouses (McLaren et al. 1998).

- If the required TSC area is larger than the south façade, then the integration could affect the architectural aesthetic characteristics of the building envelope (Probst and Roecker 2007) which leaves no choice to the architect but to eliminate using a TSC.

2.5 PARAMETERS AFFECTING TSC OPERATION

Published research of TSCs can be traced back to the late 1980s and mainly focused on heat transfer, effectiveness and efficiency. The explored characteristics affecting TSC technology include perforations geometry and arrangement, absorber layer conductivity, wind speed, and solar radiation exposure. This section reviews studies relating to each parameter: geometry, conductivity, solar irradiation, wind effect, heat transfer theory, effectiveness, efficiency and performance (Fig. 2-18). The indicators of these parameters are usually the TSC effectiveness (2.5.6) and efficiency (2.5.7) that are defined and discussed at the end of this section.

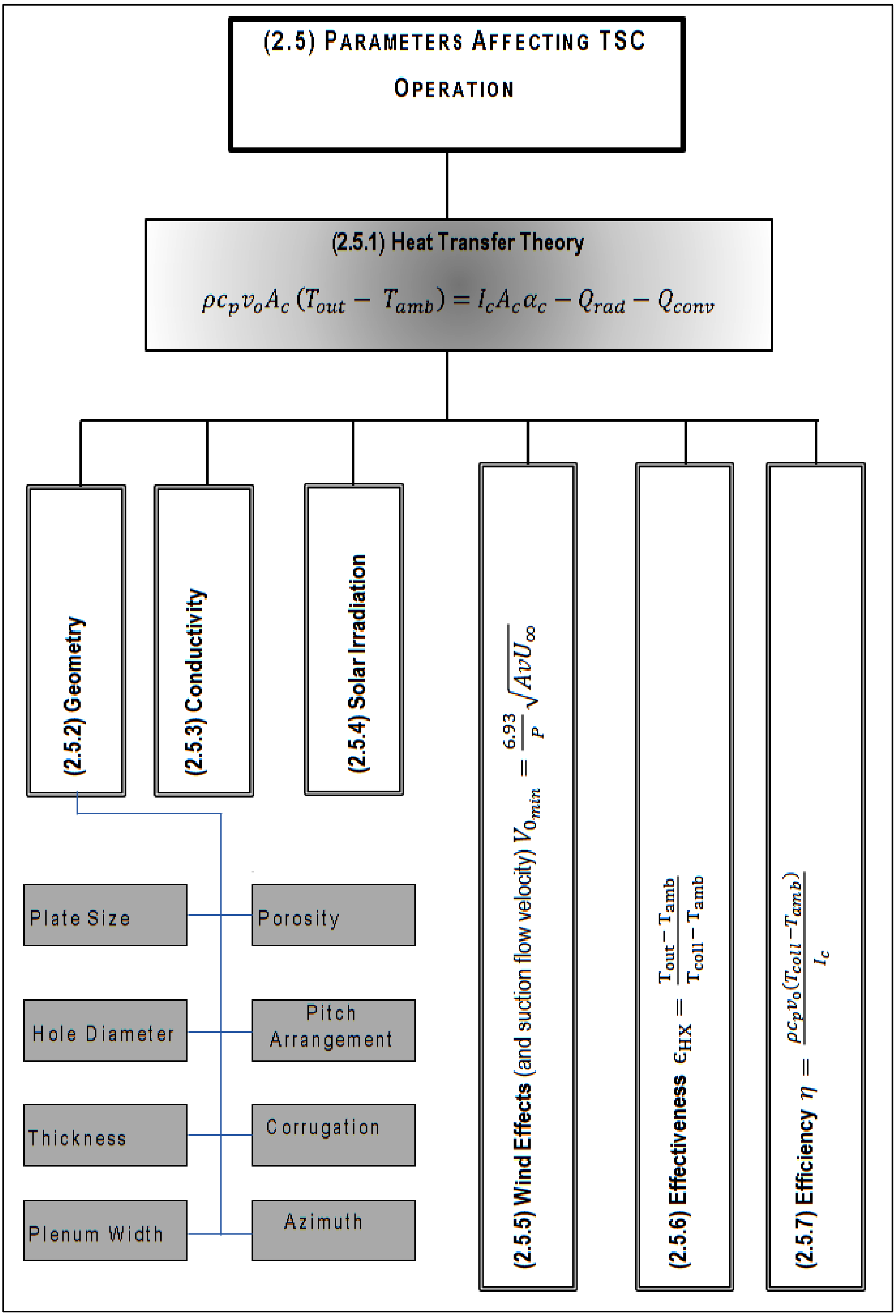


Figure 2-18: Parameters affecting the operation of TSC, author

2.5.1 HEAT TRANSFER THEORY

Sparrow and Ortiz (1982) conducted an early study of heat transfer through transpired plate with oncoming fluid flow feature. They determined the heat transfer coefficients with the ambient air. The perforations were at equilateral triangular centres. This pattern forms a hexagonal region surrounding each hole with identical characteristics of heat transfer and fluid flow. The researchers correlated two variables – the pitch-to-diameter ratio and the per-hole number, for normal flow under no-wind conditions. The correlation was, however, not appropriate to TSC since the porosities were higher (14-22%) than that typically used in TSC (0.1-0.5%) (Sparrow and Ortiz 1982, cited in Delisle 2008).

Following Sparrow and Ortiz (1982), the first fundamental research on TSCs was started by Kutscher et al. (1993) in regards of heat loss theory for a flat-plate collector with homogeneous air flow suction. Their study included: an equation representing TSC overall heat balance (equation 2-2), and estimation of radiative and convective heat loss into a simple model to predict thermal performance. They thoroughly reviewed the effects of suction flow and heat transfer for natural and forced laminar convection, and forced turbulent convection.

$$\rho c_p v_o A_c (T_{out} - T_{amb}) = I_c A_c \alpha_c - Q_{rad} - Q_{conv} \qquad (2\text{-}2)$$

Where ρ is air density, c_p is specific heat, v_o is the air suction velocity on the panel, A_c is the collector area, T_{out} is the collector output temperature, and T_{amb} is the ambient temperature (which represents the useful energy collected). The I_c reflects the total solar radiation striking the absorber (solar irradiation), and α_c is the collector absorptance along with A_c. The two remaining terms are the losses from the collector to the environment via radiation Q_{rad} and convection Q_{conv}. Special attention was given to convection in their theory due to concern over heat loss due to wind.

Kutscher et al. (1993) concluded in their basic theory that the TSC has negligible heat loss due to natural convection, especially for a large scale

TSC (the largest studied was 3m x 3m). Heat transfer is significantly influenced by TSC geometry (2.5.2), suction velocity and crosswind speed (2.5.5) (Kutscher 1994). Both of these studies (Kutscher et al. 1993; Kutscher 1994) constituted the bedrock in the field of TSCs.

2.5.2 GEOMETRY

The perforation geometry constitutes a primary issue in all the preceding research. The pitch arrangement was presented in either triangular or rectangular arrangement of circular holes. However, geometry of the TSC includes plate size, pitch arrangement, perforation diameter, corrugation, plate thickness, porosity (ratio of perforations volume in the total absorber plate) and plenum width (Fig. 2-19) in addition to azimuth. All of them have an effect on the performance and efficiency of the system.

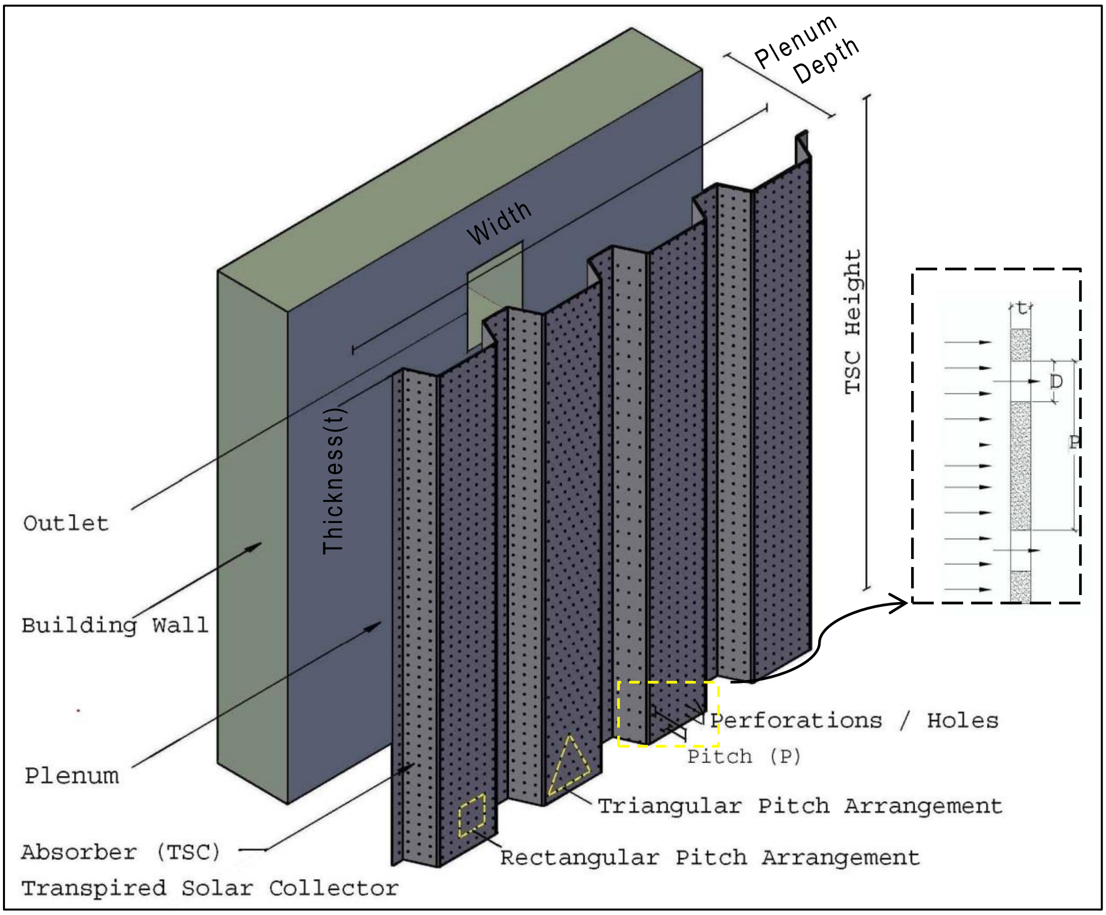


Figure 2-19: Schematic diagram illustrates geometry of components; D: hole diameter, author

McLaren et al. (1998) stated that the typical TSC plate is a 0.8mm (millimetre) thick corrugated metal, either aluminium or galvanized steel. The perforation diameter is 1.6mm arranged at regular intervals. However, these were just primary guidelines for understanding the TSC in the late 1990s. Van Decker et al. (2001) proposed a study for some geometric variables: perforation diameter, pitch, and plate thickness. Nine study plates were investigated with either square or triangular perforation layout of circular holes (Table B-5, Appendix B). The researchers found that plate thickness has a direct correlation with heat transfer in the perforation. Furthermore, triangular pitch arrangement was found to have a 0.05 higher effectiveness than the rectangular one over the experimental study. Larger perforation pitch (24 mm) has smaller heat transfer effectiveness (0.32).

Wang et al. (2006) investigated two parametric models of plenum width in their study; 200mm and 50mm, while porosity was kept constant at 1.12%. The plenum width of 50mm was found to provide 0.72 effectiveness value versus 0.7 for the 200mm plenum indicating a minimal effect on the TSC effectiveness.

Leon and Kumar (2007) investigated a range of geometric considerations (Table B-6, Appendix B). The pitch in the research was triangular that varied from 12 to 24mm as advised in preceding studies of Kutscher (1994), Arulanandam et al. (1999) and Van Decker et al. (2001). The perforation diameter varied from 0.8 to 1.55mm at 120mm constant plenum width. The researchers found that transpiration diameter and pitch have strong effects on the TSC performance, particularly at low air flow rates and high solar irradiation. Increasing pitch from 12 to 24mm along with increasing diameter from 0.8 to 1.55mm drops the temperature rise by 5.5 °C. The highest value of temperature rise was obtained at the smallest combination of pitch and diameter. In terms of effectiveness and efficiency, porosity showed slight effects on the effectiveness and slighter on efficiency at inverse correlation (Figs. B-4 and B-5, Appendix B). The perforation diameter alone has moderate effects on heat exchange effectiveness and efficiency. However, higher pitch-diameter combination has lower heat change effectiveness and efficiency, but the pitch has more effect than the diameter. Increasing pitch from 12 to 24mm drops the effectiveness by 11.5%, whereas, increasing the diameter from 1.25 to 1.55mm at 18mm pitch drops the effectiveness by just 1.4% (Fig. B-6, Appendix B).

Motahar and Alemrajabi (2010) conducted a research procedure to find the optimum design of perforation diameter and pitch to maximise the exergy efficiency (maximum performance from the system). The researchers focussed on the perforation diameter and pitch as the significant design parameters influencing the heat transfer performance and pressure drop within the TSC. The range of triangular pitch varied from 12 to 24mm and diameter from 0.8 to 1.55mm. They found that the optimum design dimensions were perforation diameter 0.9mm and pitch 12mm within the parameters of their work (Table B-7, Appendix B). However, there is some ambiguity to these results as they are taken from a chart of exergy efficiency contours (Fig. B-7, Appendix B). It should be noted that this work assumed the temperature rise in the plenum and collectors was uniform, according to Van Decker et al. (2001) and Chan et al. (2011) such an assumption gives rise to inaccuracies.

Commercial TSC producers often provide technical data sheets that include all the above information for each TSC type. An example of this is Enerconcept Technologies: www.enerconcept.com (Table B-8, Appendix B). Solar wall is available in different system profiles (i.e. SW 150 and SW 400). The SW 450, for example, has a thickness of 0.7mm for TSC wall and 1.2mm for solar duct whereas the porosity varies according to air volume requirements.

CONCLUSION:

The geometry comprises all the features of the surface plate and the TSC system (i.e. absorber thickness, perforation diameter, plenum width, and pitch arrangement). Each feature has a different effect on TSC performance and operation. All the TSC surface plates are corrugated (i.e. ribbed); however, the most researched type is the sinusoidal one. Although, the typical thickness in the late 1990s was 0.8mm, the bulk of the researched plate thickness ranged from 0.8–1.55mm. The perforation pitch distance has a research range between 12–24mm. The plenum width varied in the research from 50–200mm. Most of the studies used triangular pitch arrangement due to its higher effectiveness than the rectangular pitch type. The plate thickness has a direct correlation with heat transfer and efficiency.

The plenum width has minimal effect on effectiveness (almost 0.7 at 200mm versus 0.72 at 50mm). Porosity has slight effect on the effectiveness and a slighter effect on efficiency at inverse correlation. Perforation diameter has moderate effects on effectiveness and efficiency versus stronger effects of the pitch, however, diameter-pitch combination has strong inverse correlation with effectiveness and efficiency. Many researchers such as Van Decker et al. (2001), Leon and Kumar (2007) and Motahar and Alemrajabi (2010) tried to find an optimum geometric configuration; these configuration remain dependent on external parameters such as solar radiation, wind flow and TSC location and orientation.

2.5.3 CONDUCTIVITY

The types of commercially available and researched TSC materials are commonly: aluminium with the highest conductivity of 186 to 216W/m°C (Watt per meter Celsius); stainless steel of 15.12W/m°C; styrene of 0.16W/m°C; and PVC with the lowest conductivity of 0.149W/m°C. However, stainless steel of 18W/m°C is not presented in the surveyed literature papers. The lower conductive material resulted in slight reduction in the efficiency according to Arulanandam et al. (1999).

In contrast, Gawlik et al. (2005) found that higher conductivity materials have slightly higher efficiency. This difference seems due to the different equation used for measurement where Kutscher et al. (1993) and Arulanandam et al. (1999) used heat exchange effectiveness and Gawlik et al. (2005) used the temperature rise in the plenum which is more appropriate for non-isothermal plates. However, conductivity proved to have a very minimal effect on the TSC thermal performance. Therefore, other factors such as cost savings and corrosion resistance could play possible roles in selecting low conductive material for TSC plates.

2.5.4 SOLAR IRRADIATION

Solar radiation, the amount of available electromagnetic waves emitted by the sun (Kaplanian and Kaplanis 2012), is the principle concept behind TSC technology. However, solar irradiation is a particular term which refers to the 'total solar radiation striking the absorber' (Dymond and Kutscher 1997) whether it is absorbed, transmitted or reflected. Figure 2-20 shows components of solar irradiation of the TSC surface: solar beams on the TSC surface (I_c); infrared radiation between TSC surface and ground ($IR_{surf-grndc}$), and between TSC surface and sky ($IR_{surf-sky}$). The term *'solar radiation intensity'* is used similarly as referring to *"direct solar radiation intensity on the plane which is perpendicular to the direction of the Sun's rays"* (Hu and Yang 2000, p. 588).

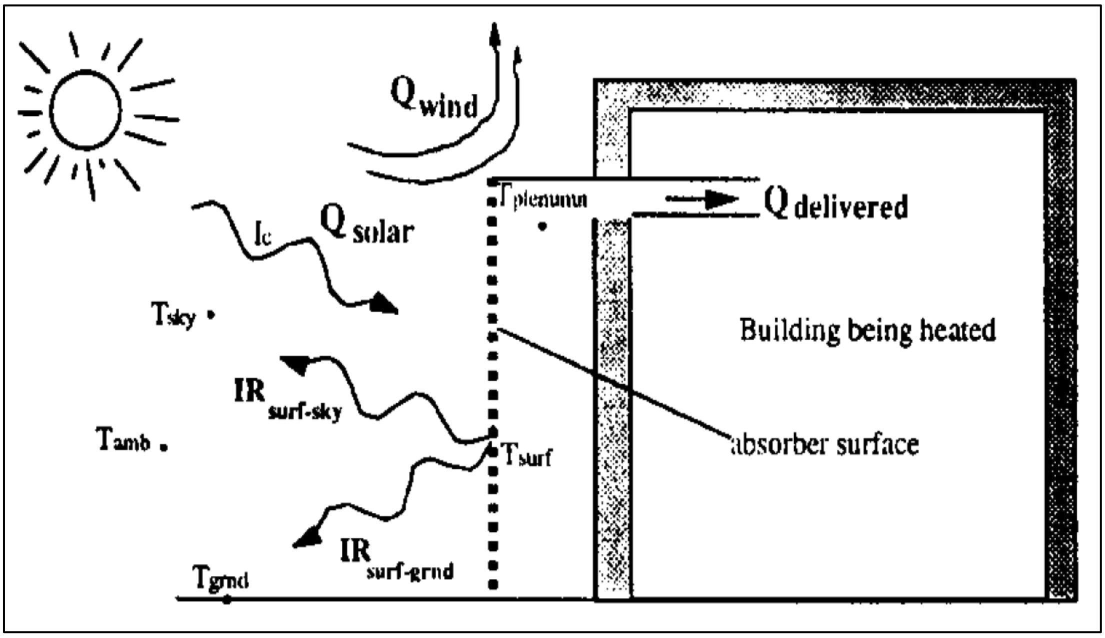


Figure 2-20: Schematic diagram of energy balance on TSC surface (Dymond and Kutscher 1997)

Gunnewiek et al. (1996) considered solar irradiation within the range of 400 and 900W/m^2. Ben-Amara et al. (2005) studied the solar irradiation as one of the parameters affecting TSC efficiency for a desalination process. The solar irradiation ranged between 600 and 1000W/m^2. The researchers found that the increase in solar irradiation intensity increased the outlet temperature steadily (Fig. B-16, Appendix B).

Wang et al. (2006) investigated the system effectiveness at solar irradiation of 400, 600, 800, and 1000W/m^2. They found that the increase of solar irradiation steadily increases the temperature rise. However, solar irradiation has an inverse effect on effectiveness. It was noticed that effectiveness decreased when solar irradiation increased (Fig. 2-21).

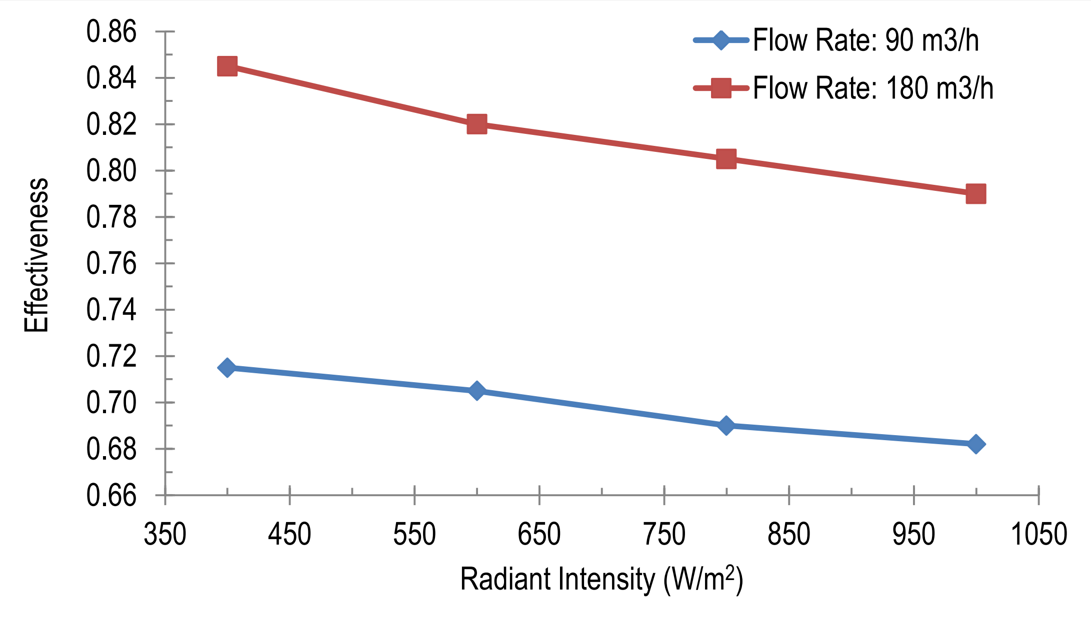


Figure 2-21: CFD results in the form of effectiveness versus radiant intensity (solar irradiation) (Wang et al. 2006)

Leon and Kumar (2007) examined the solar irradiation effect for drying fruit and vegetables in a tropical climate which is abundant in solar energy. They ran the simulation under solar irradiation incident on a TSC surface range of 400-900W/m^2 as practically available in tropical climates. The results confirmed the direct correlation between solar irradiation on the TSC surface and outlet temperature. The researchers presented the relation of outlet temperature and solar irradiation incident on the TSC surface, under five different air flow rate conditions (Fig. 2-22).

The simulated results of the rise in temperature in Leon and Kumar (2007) are slightly higher than SolarWall records. This could be due to the tropical climate rather than a cold climate. The linear direct correlation between incident solar radiation and temperature rise as well as efficiency is also confirmed by Motahar and Alemrajabi (2010) who investigated a solar irradiation range between zero and 1000W/m^2.

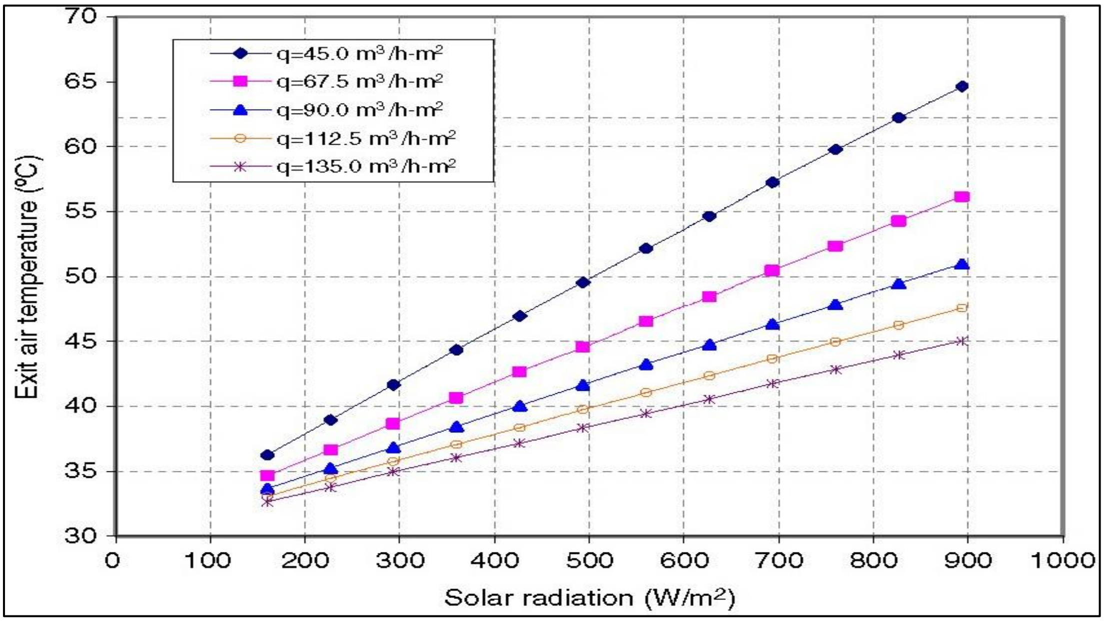


Figure 2-22: Outlet air temperature as a function of solar radiation 'incident on the TSC surface' and (q) airflow rate, ambient temperature: 30 °C, pitch: 20 mm, hole diameter: 1.25 mm (Leon and Kumar 2007)

Solar irradiation parameters in Chan et al. (2011) vary from 300 to 800W/m^2 (Table B-10, Appendix B). They assumed a homogeneous solar absorption by the collector plate. The researchers found that solar irradiation increases the temperature rise as presented in section (2.5.6). They proved that solar irradiation constitutes a significant factor in thermal performance of the TSC (Figs. B-9 and B-10, Appendix B).

CONCLUSION:

Solar radiation is a general term while solar irradiation specifically refers to the incident solar beam and diffused irradiations on the TSC surface. The term 'solar radiation intensity' was used similarly. However, few researchers confused the use of the 'solar irradiation' such as Leon and Kumar (2007, p. 63) who described the term in their study as 'solar radiation incident on the collector'. The solar irradiation in the aforementioned studies has a parametric range between zero and 1,000W/m^2, however, the focal range was between 400 and 900W/m^2. Solar irradiation has a strong direct correlation with the temperature rise in the plenum and therefore the outlet temperature.

2.5.5 WIND EFFECT AND SUCTION VELOCITY

Kutscher et al. (1993) conducted a study under a set of assumptions including a 10 m/s (meter per second) maximum wind speed. The wind speed increases the efficiency as the suction velocity decreases, particularly for a low emissivity absorber (Fig. B-11, Appendix B). Wind direction was acknowledged by the researchers as important although it was not included in the study. The suction velocity refers to the local velocity of flow at the surface of the TSC. The amount of heat loss due to natural convection was found negligible. Moreover, heat loss due to wind was found to be small for a large TSC (the larger collector studied was 3m x 3m) at a typical suction velocity of about 0.5 m/s (Fig. 2-23).

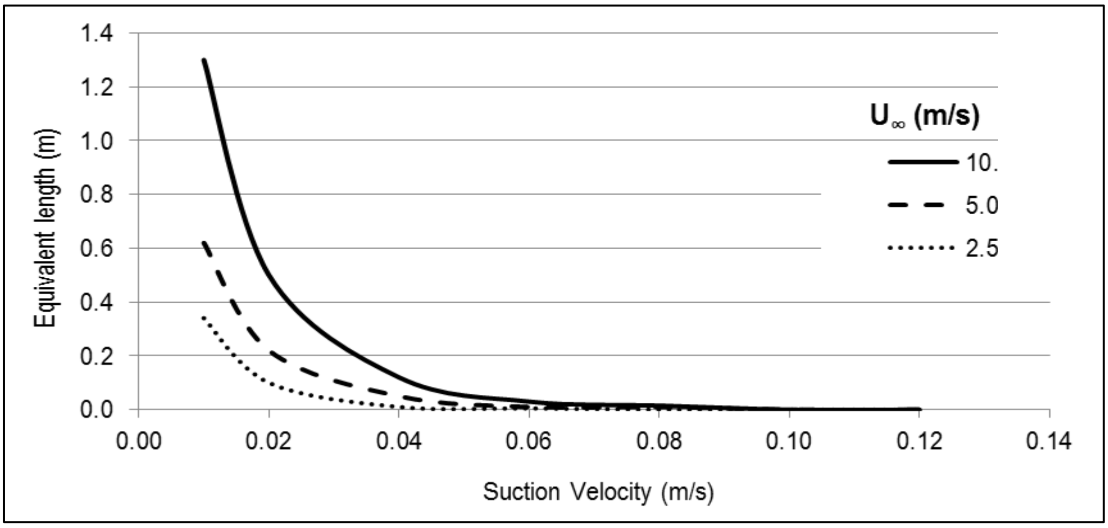


Figure 2-23: Equivalent convection heat loss length versus suction velocity at various wind speeds (Kutscher et al. 1993)

Gunnewiek et al. (2002) extended their earlier study, Gunnewiek et al. (1996), to include the effect of building shape and TSC orientation for the collector's height (3.0m ≤Height≤6.0m) and solar irradiation (400–900W/m^2). Wind was found to have significant effects on the distribution of suction velocity. They found that a higher suction velocity of 0.017 m/s was required to avoid reversed flow for long frontal-face buildings with collectors facing into the wind. For cubic buildings, Gunnewiek et al. (2002) recommended minimum suction velocity of 0.026 m/s when facing into the wind. Whereas for wind at 45° to the collector, the minimum suction velocity to avoid reversed flow should be 0.039 m/s. These minimums are under the condition of average wind speed of 5m/s at the highest point of the collector, which is quite practical for most locations.

Fleck et al. (2002) addressed the wind effects on the performance of TSCs via a field study in Canada. They included in the monitoring: wind speed; direction; and fluctuation intensity (Fig. B-12, Appendix B). The average wind speed during the monitoring phase was 5.4 m/s. It has been observed that the boundary layer of air adjacent to the TSC absorber plate is usually turbulent. This turbulence increases as TSC size increases (Fig. 2-24). Greater turbulent intensity was found to negatively affect the efficiency. Therefore, wind direction constitutes a dominant factor on flow pattern and TSC performance.

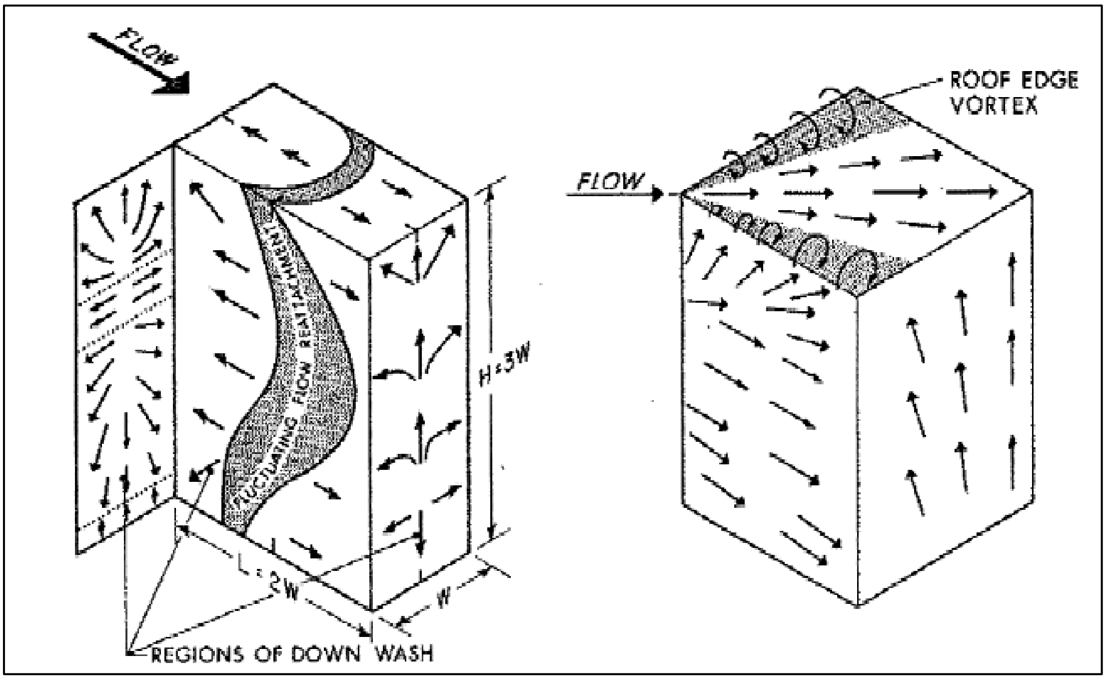


Figure 2-24: Detailed schematic showing zones of fluctuating, reverse and parallel flow on a tall building for incident wind normal and diagonal to one wall (Fleck et al. 2002)

The wind speed and direction were investigated by Cordeau and Barrington (2011) in their research on performance of TSCs for broiler chicken barns. They found that every increase of wind speed by 1 m/s drops heat recovery efficiency by 5.7%. In spite of bypass opening during summer, the output temperature of the incoming fresh air increased 1-2°C with higher ventilation rates than those used in winter. The rate of ventilation in the study ranged between 0.86 and 1.17m^3/s with three operational fans. The surface air velocity was either 0.012 or 0.016 m/s which respects the minimum recommended levels of Gunnewiek et al. (2002) for long buildings. Cordeau and Barrington (2011) concluded that wind speed is the main factor, besides solar radiation, which affects the energy recovery efficiency of TSCs. An average wind speed of 2m/s encourages 65% recovery efficiency versus 25% for wind speed above 7m/s.

CONCLUSION:

The parameters for higher TSC efficiency in relation to wind effects are: low average suction velocity (0.02–0.05m/s) and relatively wide plenum (200mm). Wind effect on the TSC performance has an inverse correlation with suction velocity. However, the suction velocity must be maintained at a level which avoids flow reversal. The minimum suction velocity possible while avoiding flow reversal differs according to the building shape and TSC orientation. Suction velocity is recommended to exceed 0.017m/s for long frontal-face buildings and 0.026m/s for cubic buildings with collectors assuming they face into the wind. Whereas for incident wind at 45° to the collector, the minimum recommended suction velocity is 0.039m/s. The wind turbulence intensity negatively affects the TSC efficiency.

2.5.6 HEAT TRANSFER EFFECTIVENESS

The heat transfer effectiveness is defined as *"the ratio of the actual temperature rise of air as it passes through the absorber plate to the maximum possible temperature rise"* (Leon and Kumar 2007, p. 67). Previous research has been conducted on heat transfer effectiveness or TSC effectiveness; however, both terms refer to the effectiveness of the TSC system. It depends on the overall heat transfer coefficient for the air passing through the TSC. Kutscher et al. (1993) provided an equation to estimate the heat exchange effectiveness of the absorber ϵ_{HX} as follows:

$$\epsilon_{HX} = \frac{T_{out} - T_{amb}}{T_{coll} - T_{amb}} \qquad (2\text{-}3)$$

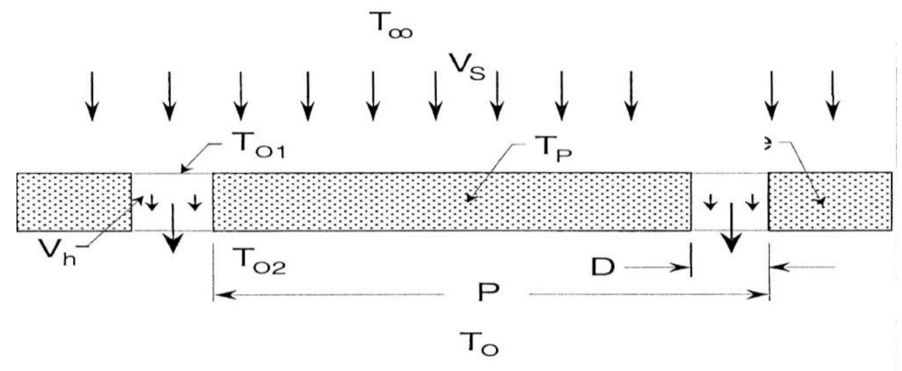
Where T_{coll} represents the collector's surface temperature, and the other terms are defined in equation (2-2).

Kutscher (1994) investigated convective heat transfer effectiveness for low-speed air velocity, 0 to 4m/s, through perforated plates on the upstream face. The study aim is to optimise design porosity. The researchers concluded that heat transfer effectiveness has a direct correlation with wind speed versus an inverse correlation with suction flow rate, and pitch and diameter of the hole.

Arulanandam et al. (1999) determined the TSC effectiveness in their analysis of heat transfer. They used a model of circular holes on a square pitch under no-wind conditions. Unlike Kutscher (1994), the researchers modelled the back side of the absorber as an adiabatic surface in terms of heat transfer. The effectiveness depends on certain factors: wind speed; suction velocity; and geometry of the plate. Arulanandam et al. (1999) found an inverse correlation between effectiveness and conductivity which is reviewed under section 2.5.3. The results presented were in agreement with Kutscher (1994) published data.

Van Decker et al. (2001) investigated effectiveness in relation to heat transfer at each of the plate parts: frontal surface; the hole; and the plenum (Fig. 2-25). The research aimed to estimate the effectiveness in the asymptotic region under wind conditions including zero wind speed. Normally about 62% of the air temperature rise might occur at the outer surface of the plate, 28% in the hole, and 10% on the back side of the plate (Van Decker et al. 2001).

The effectiveness levels from 0.32 to 0.91 were achieved for the range of studied parameters: suction velocity; wind speed; pitch and diameter of the hole; plate thickness; and plate thermal conductivity. The researchers found that effectiveness has an inverse correlation with suction velocity, and pitch and diameter of the perforation versus direct correlation with wind speed and plate thickness. Suction velocity and plate thickness have the strongest impact on effectiveness. The results are consistent with Kutscher (1994) (Fig. B-13, Appendix B) except for conductivity and thickness which were new factors in the study of Van Decker et al. (2001).



T_∞: ambient air temperature, T_{O1}: temperature of air as it enters a hole, T_{O2}: temperature of air as it leaves a hole, T_O: bulk mean temperature of air in the plenum, T_P: plate temperature, V_S: suction velocity (m/s), V_h: air velocity in the hole (m/s), P: Pitch, D: Diameter of the hole

Figure 2-25: Schematic diagram shows the heat transfer components (Van Decker et al. 2001)

Wang et al. (2006) compared the effectiveness of TSCs with other types of solar air collectors which are the flat-plate collector and unglazed un-transpired collector (Table B-12, Appendix B). The effectiveness is presented as a function of two quantities of heat; provided and received by the TSC. They found that effectiveness is minimally affected by plenum width as the significant part of heat exchange process occurs at the absorber surface. However, TSCs have the highest effectiveness of more than 0.7 when compared to other solar air collectors (i.e. non-perforated collectors and flat- plate collectors). Effectiveness has direct correlation with flow rate to a top effectiveness value of 0.8 when the impact diminishes significantly (Fig. 2-26).

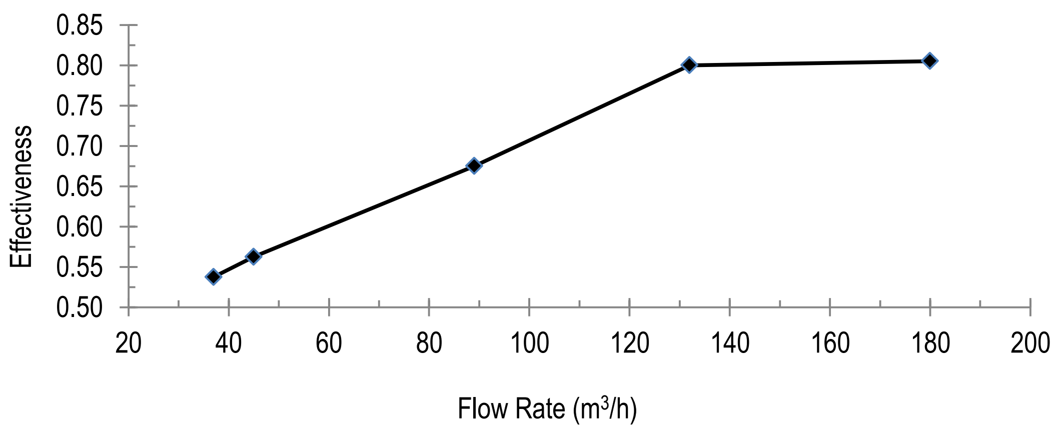


Figure 2-26: Effectiveness versus flow rate (Wang et al. 2006)

On the other hand, effectiveness had a minimal inverse correlation with solar irradiation (Fig. B-15, Appendix B), although, the exit temperature of the heated air is increased (Wang et al. 2006).

Leon and Kumar (2007) carried out a parametric study of TSCs to predict thermal performance in relation to: porosity; air flow; solar radiation; solar absorptivity and thermal emissivity (Table B-6, Appendix B). The assumptions included a uniform temperature along the plenum and plate's surface, homogeneous air flow through the perforations, and negligible convective losses Q_{conv}. The researchers found that heat exchange effectiveness improved from 0.6 to 0.8 for smaller pitch (12mm) and hole diameter (0.8mm) (Fig. B-4, Appendix B). Furthermore, effectiveness is slightly influenced by porosity at an inverse correlation. They concluded that the heat exchange effectiveness is strongly influenced by solar absorptivity, pitch, and airflow rate against moderate effects of thermal emissivity.

Chan et al. (2011) conducted an experimental performance of TSCs which involved temperature rise in the plenum. They pointed-out that TSC is an appropriate technology for solar heating and also reduction of convection heat loss from the original building wall. Heat transfer of the TSC occurs at three components: front-of-plate surface; the hole; and the plenum. The key factors of heat transfer coefficient are: the geometry (pitch and diameter) of the hole and suction velocity of air flow. The researchers acknowledged that heat transfer in the plenum has been ignored in a number of preceding studies. Therefore, they decided to investigate the temperature rise along the vertical air flow at the back of the plate. (Experimental parameters are shown in Table B-10 in Appendix B).

The overall air temperature rise by the system is divided into three parts: outlet temperature from the system (T_{out}); temperature of heated air in the hole (T_i); and the ambient air temperature (T_a). The overall temperature rise decreases with the airflow rate. In the study of Chan et al. (2011) it dropped by almost 3ºC as a result of increasing the rate of mass flow by 0.02kg/sm^2 (Fig. B-9, Appendix B). The total temperature rise has a direct correlation with solar irradiation (Fig. B-10, Appendix B). The researchers found that the vertical air flow temperature rise $(T_{out} - T_i)$ accounts for about 39-49% of the overall TSC temperature rise $(T_{out} - T_a)$. Thus, ignoring the temperature rise in the plenum affects the accuracy of research outcomes (Chan et al. 2011).

CONCLUSION:

Heat transfer of the TSC occurs at three components: frontal surface; the hole; and the plenum. Although heat transfer in the plenum is ignored in some studies, a significant amount of heat transfer occurs there (Fig. 2-25).

The key factors of the heat transfer coefficient are: the geometry of the hole and suction velocity of air flow. The heat transfer effectiveness depends on a group of parameters: heat transfer coefficient; wind speed; solar absorptivity; and thermal emissivity. Effectiveness has a direct correlation with wind speed, plate thickness, and solar absorptivity. However, the effects of flow rate stops when effectiveness reaches 0.8. Effectiveness has an inverse correlation with suction flow rate, pitch and diameter of the hole, conductivity, plenum width, porosity, solar irradiation. This inverse correlation is minimal for solar irradiation and porosity.

2.5.7 EFFICIENCY (THERMAL PERFORMANCE)

The efficiency of TSC is defined as *"the ratio of the useful heat delivered by the solar collector to the total solar energy input on the collector surface"* (Leon and Kumar 2007, p. 67). The collector efficiency is computed as a function of mas flow rate, specific heat of air, output and ambient temperature, solar radiation and collector's area according to the following equation.

$$\eta = \frac{\dot{m} C_p (T_{out} - T_{amb})}{I_c A_c} \tag{2-4}$$

Where $\dot{m}$ is mass flow rate of air (kg/s) and the other parameters were defined in equation (2-2). The mass flow rate is substituted from the following equation (Hall et al. 2011):

$$\dot{m} = p v_o A_{cs} \tag{2-5}$$

The A_{cs} is the cross sectional area of the pipe (Badache et al. 2013). The other parameters were defined in equation (2-2) above. The TSC efficiency is influenced by the direct radiation losses to the ambient air Q_{rad} that was substituted in equation (2-2). The natural convective heat losses Q_{conv} were noted negligible although it remains considered in the above equation. Conductive heat loss was not reported by the researchers. The efficiency is almost constant when suction velocity is above 0.05m/s independent of wind speed. The temperature rise in the collector increases with decreasing air flow; however, this adversely affects the overall efficiency and increases the importance of wind effects. Based on this model, an error of 10-20% in predicting effectiveness leads to 5-10% error in calculating efficiency; therefore, a better prediction model is required (Van Decker et al. 2001).

McLaren et al. (1998) stated that the TSC is classified among the most efficient solar thermal systems available commercially as it absorbs 60-75% of the total available solar radiation. This includes absorbing diffuse solar radiation which comprises around 25% of the annual surface radiation on the Earth. The efficiency was found to marginally decrease with increasing plate conductivity (Arulanandam et al. 1999; Van Decker et al. 2001).

In a field study on a 63m^2 TSC that was installed in early 1999, Fleck et al. (2002) defined the efficiency as the proportion of incident solar heating that preheats the transpired air. The efficiency of the TSC was estimated by comparing the overall temperature rise with the change in energy of preheated air in the plenum. Fleck et al. (2002) found an inverse correlation between efficiency and solar irradiation (Fig. B-14, Appendix B). This can be interpreted using the concept of 'diminishing return'. Higher solar intensities will cause higher plate surface temperatures which encourage higher radiative and convective losses. The efficiency was also found to have an inverse correlation with wind speed (Fig. B-15, Appendix B). The peak efficiency occurs at wind speed from 1-2 m/s. The efficiency was found, moreover, to be in inverse correlation with the turbulence intensities. TSC efficiency is therefore influenced by wind speed, direction, and turbulence in addition to solar irradiation.

Gawlik et al. (2005) have presented results indicating that efficiency varies between 63-84% (Table B-11, Appendix B). The maximum efficiency was reported for a 1.6mm aluminium absorber with 1.6mm perforation diameter, 27mm pitch, 0.3% porosity and at 0.006 kg/m^2.s mass flux. The range in efficiency depends on mass flux (mass flow rate of the suction air per collector's unit area), plate geometry, temperature rise, and conductivity.

Leon and Kumar (2007) found minimal impact on efficiency by pitch. Increasing pitch from 12 to 24mm decreased efficiency by 3%. Moreover, efficiency is minimally influenced by porosity as a 42% increase in porosity drops the efficiency by just 2% (Fig. B-6, Appendix B). Efficiency furthermore has a direct correlation with air flow rate (Fig. 2-27), solar absorptivity, and thermal emissivity. However, the highest recorded efficiency in the study exceeded 80%. This highest recorded efficiency was under the condition of 0.95 solar absorptivity of the collector.

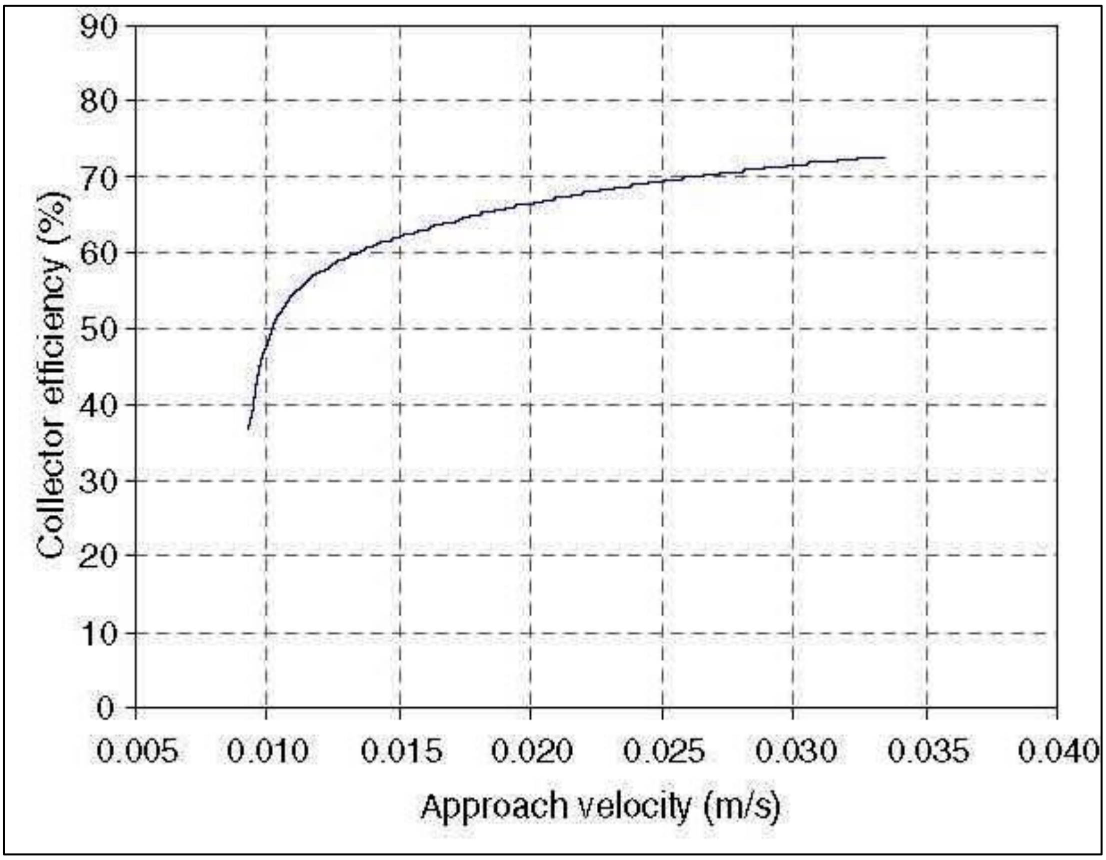


Figure 2-27: Effectiveness versus flow rate (approach velocity) (Leon and Kumar 2007)

Kozubal et al. (2008) mentioned that TSC theory indicates efficiency can exceed 70% of incident solar radiation and this is backed up with performance testing. Higher efficiency can possibly be achieved by applying a low emissivity coating with good solar absorptivity to the collector surface.

CONCLUSION:

The TSC efficiency can exceed 80% of the total received heating energy. Parameters which support high efficiency are: mass flux (i.e. 0.006 kg/m^2.s), low suction velocity (section 2.5.5), high solar absorptivity collectors (0.95), plate geometry, and heat transfer. Parameters which adversely affect efficiency are: wind speed above 2m/s, and turbulent intensities. Fleck et al. (2002) noted that efficiency has a slight inverse correlation with solar irradiation. This was considered due to higher radiative and convective losses due to higher plate temperature that was confirmed by Leon and Kumar (2007). Efficiency is considered to be independent of suction velocity above 0.05m/s.

2.6 SUMMARY

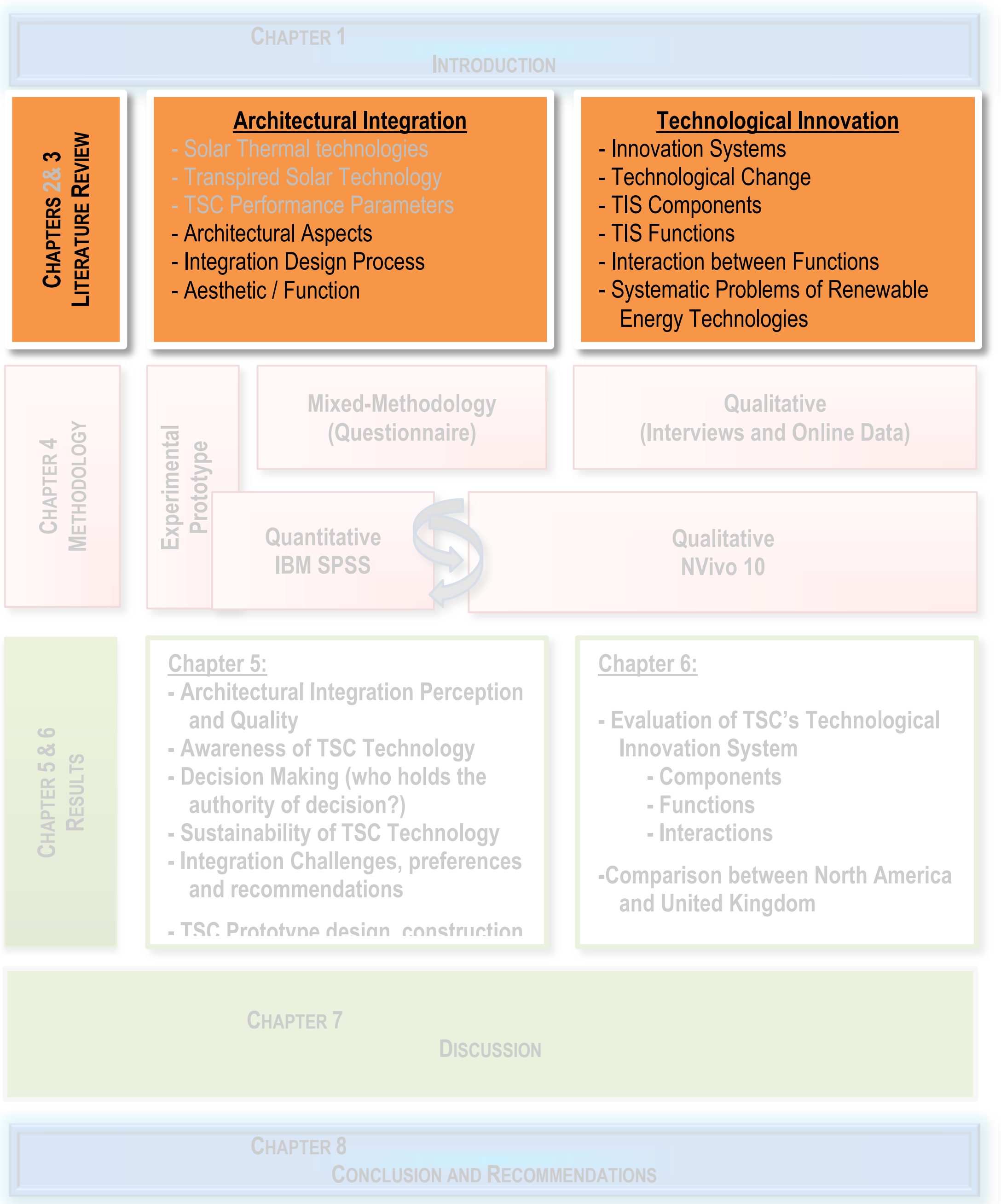
Energy types used in the built environment were introduced and classified according to their source: fossil fuel, renewables, and deployable sources. Touching on renewable energy sources and focusing on buildings, potential building-integrated passive and active solar energy technologies were classified and described. Following a brief consideration of active solar energy, transpired solar collector technology (TSC) was introduced in detail and analysed in terms of its forms of integrations in building envelopes (wall mounted, roof mounted, and stand-alone) in addition to the possibility of combining it with PV for a hybrid system. Parameters affecting the operation of TSCs were analysed from the available literature. These parameters include the geometry of the TSC unit, conductivity of the collector, solar irradiation, wind effect, heat transfer effectiveness and efficiency of the TSC system (Table 2-2).

Table 2-2: Comparison between the effectiveness and efficiency of TSC under the influence of other parameters

Influential Parameter	Determinant Parameters, influence on:	
	Effectiveness	Efficiency
Geometry		
- pitch distance (12 – 24mm) - diameter (0.8 – 1.6mm)	Moderate effects for diameter. Higher pitch-diameter combination has lower effectiveness.	Moderate effects for diameter. Higher pitch-diameter combination has lower efficiency.
- plenum width (50 – 200mm)	Minimal effect (almost 0.7 at 200mm versus 0.72 at 50mm)	-Data N/A
- pitch arrangement	Triangular arrangement has 0.05 higher effectiveness than the rectangular pitch	- Data N/A
- Porosity	Slight effect at inverse correlation	Slighter effect than effectiveness at inverse correlation
- Plate thickness	Direct correlation	Direct correlation
Conductivity	Minimal effect (inverse correlation)	Direct effect
Solar Irradiation	A small inverse correlation	A small inverse correlation
Wind and suction velocity	Direct correlation with wind speed versus an inverse correlation with suction flow rate	Inverse correlation with wind speed above 2m/s. Independent of suction velocity above 0.05m/s

CHAPTER 3 ||

ARCHITECTURAL INTEGRATION AND TECHNOLOGICAL INNOVATION



3.1 INTRODUCTION

This chapter discusses two interrelated terms associated with solar technologies that are needed to develop and improve the appropriate usage of solar thermal technologies in buildings. The first term is 'architectural integration' and the second is 'technological innovation'.

The architectural integration of solar technologies in buildings and transpired solar technology in particular, aims to place the appropriate technology configuration in a well-designed context for the whole building as a unified system (section 3.2.2); this applies to both new build and existing renovation projects. Appropriate integration is increasingly demanded due to the need for attractive architectural integrative quality (section 3.2.3); to cohere and control the interaction of the TSC in the building envelopes' functions and aesthetics. The architectural integrated design process (IDP) involves a core team which is part of the technological innovation system (TIS).

The TIS was developed as a mechanism to understand the factors involved in developing, improving and diffusing technological knowledge. This particularly applies to new technologies (section 3.3.3ii) which face resistance by existing technologies supporters (section 3.3.6). TIS analysis of the TSC technology will be valuable, since the technology is at an early stage of development, particularly in the UK. The innovation system maps development in a socio-technical framework and has been robustly applied for energy technologies (section 3.3.1). The TIS combines structural components (section 3.3.3) with mediation innovative functions (section 3.3.4) and analyses the interaction between these functions (section 3.3.5) in order to analyse the development of new technologies. Furthermore, innovation systems have been used to analyse problems in many renewable energy technologies in a systematic manner (section 3.3.6) in order for entrepreneurs, researchers and policy makers to propose the appropriate policy or decision at the most opportune time.

3.2 ARCHITECTURAL INTEGRATION

Design concepts are essentially contributing to increasing public acceptance of the architecture through visual emphasis of integrated elements in the building envelopes. Solar technologies must be regarded as architectural elements rather than just technological systems producing heat or power. The solar technologies should enhance, accentuate and distinguish the architecture from the mass (Hermannsdörfer and Rüb 2005, cited in Basnet 2012). The architectural integration approach delivers compatible buildings with important integrated components, solar energy technologies in particular.

The building-integrated solar thermal (BIST), according to Archibald (1999), was patented in the 1940s by Bjorn Christenson. The patent indicated a *"...system adapted to control the temperature of air and water for domestic and industrial use…whereby the condition control is accomplished by solar radiation*" (Christenson 1949, p. 1). This integration approach was reinforced, according to Hestnes (1996) in Task 13 'Advanced solar low energy buildings' of the International Energy Agency's Solar Heating and Cooling Programme. The Task was initiated in 1989 in Norway and was completed in 1996. Lessons learned from Task 13 include: *"It is necessary to consider the building as a system, where the different technologies used are integral parts of the whole"* and "*Designing new, innovative building concepts requires a multidisciplinary design team*". At this point it was established that *"Active solar space heating is technically feasible but not cost effective"* (Hestnes 1996, pp. 12-13). This statement was concluded based on one active solar system installed on the German house building in Berlin in a combination with a seasonal storage system. Increasing insulation level was deemed sufficient to decrease heating demand and therefore decrease the size of solar heating system and seasonal storage as a successful step towards cost effectiveness (Hestnes 1996). The level of insulation remains essential as a passive technique, however, this level has to be carefully considered and estimated as additional insulation will cause overheating in summer which would increase cooling loads and demand.

This study focuses on the architectural integration of active solar technologies, particularly solar air heating, and to some extent its hybrid combination with electricity generation from photovoltaics. However, passive design techniques have a special necessity in architecture as stated in Task 13 *"Passive solar gains can make a major contribution to space heating ...."* (Hestnes 1996, p. 12). Passive solar technology has been thoroughly researched (Hestnes 1999; Knight and Rudkin 2000; Yudelson 2009; Clesle 2010) unlike the yet fertile research area of building-integrated solar air heating in architecture. Therefore, this research focuses on further investigating the architectural integration of solar energy for space heating.

3.2.1 ARCHITECTURAL BUILDING ENVELOPES

Successful architecture has to satisfy three pillars: commodity, firmness and delight as identified by Watton (1624) in an English translation to the original work of the Roman architect Vitrivius (1914) who first outlined these conditions. Architectural systems are *"comprehension of the ordered and disordered relationships among a building's elements and systems, and responding to the meanings they evoke"* (Ching 2007, p. xi). It comprises: function, form, space, and technics (Fig. 3-1).

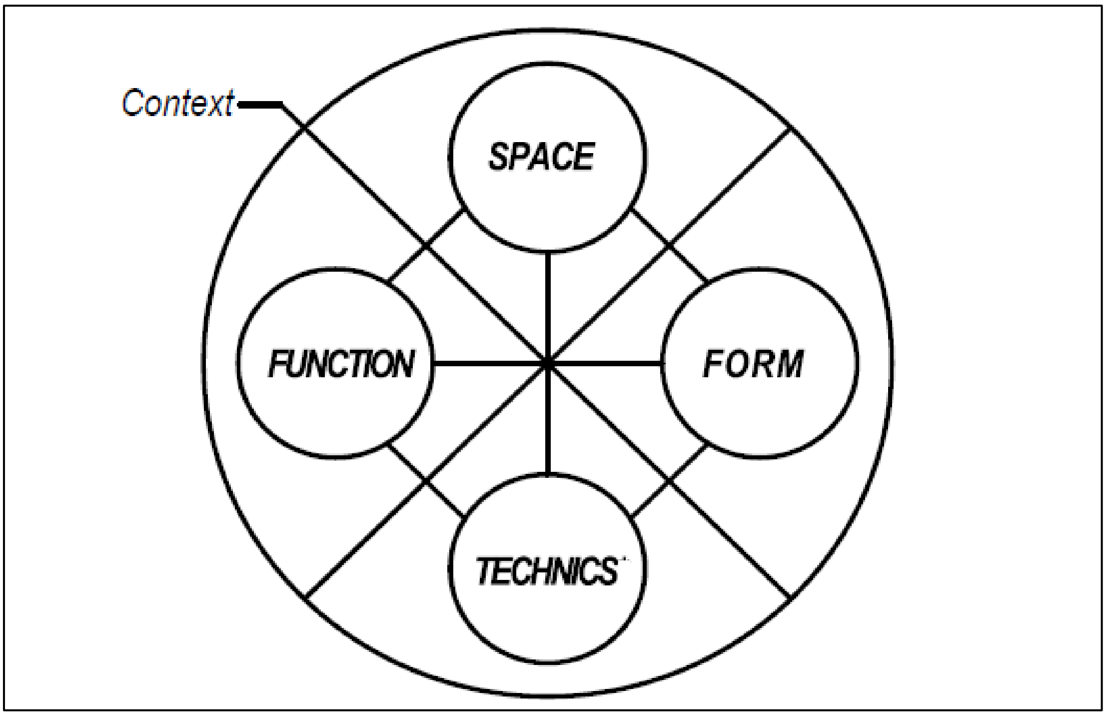


Figure 3-1: Conceptual contexts of architecture (Ching 2007)

The architectural mantra *“form follows function”* was dictated by the American architect Louis Sullivan in 1896 (Sullivan 1918, pp. 403-409, cited in Guimerá and Sales-Pardo 2006, p. 1). The function refers to the satisfaction of the intended purpose of design (section 3.2.3i) whereas technics refers to the theory, principles, or study of process.

Form and space refer to physical status which reflects the solids and voids; and the exterior and interior. In 1974, Edmund Bacon stated that *“Architectural form is the point of contact between mass and space…”* (Ching 2007, p. 33). The form is, however, an inclusive term which also refers to building envelope and integration aesthetics within the envelope. The building envelope constitutes the external part of the form which comprises the external walls, roof, openings and shading devices, and construction materials. The space is enclosed by the envelope, which often encompasses the human being (Ching 2007). People spend a large proportion of their lives in enclosed spaces; therefore, the spaces deserve attention to provide comfortable and healthy environments for occupants.

The relation between the indoor heated or cooled space (volume) and the surface of the envelope (area) affects the thermal performance of the building. Compact architectural form is ideal for cold climates versus open form for hot, dry regions (Nudds and Oswald 2007). The building envelope has to satisfy a wide range of the following targeted protection and regulation functions (Probst and Roecker 2011; Basarir et al. 2012):

- Satisfy provision of air tightness, water sealant properties, and sound proofing.
- Protect from other intrusions, odours, and pollution.
- Insulate the space from winter and night cold, and summer heat.
- Achieve comfort of the occupants while minimising the use of conventional energy sources for heating, cooling and power.
- Regulate visual connection throughout and allow natural ventilation, day light, and passive solar gain.

- Enclose the indoor space activities and life while satisfying design privacy.
- Determine the architectural identity of the building.

In order to satisfy a sustainable design approach, the optimum design guides of these parameters should include balanced orientation for appropriate solar gain and natural light, and use construction material with low embodied energy. According to Bolin (2009), efficient integrated building envelopes help reduce energy demand and therefore, reduce the size and cost of the heating system.

3.2.2 INTEGRATED DESIGN PROCESS (IDP)

Integrated design intensifies comprehensive involvement of all building stakeholders in the design process from concept until hand-over. Among those stakeholders, designers form multi-disciplinary teams with professional knowledge and capability to integrate the vital parts of the whole design (Hestnes 1999; Prowler and Vierra 2008). The whole building design, also known as 'Integrated Design Process' (IDP) or 'integrative design' (Rossi et al. 2009), draws a road map for designers and stakeholders. IDP aims to achieve a successful holistic design by following eight objectives. As shown in figure 3-2, these objectives are accessibility, aesthetics, cost-effectiveness, function, historic preservation, productivity, security and sustainability (Prowler and Vierra 2008).

Larsson (2002, p. 4) described the IDP as

> *...a method for realizing high performance buildings that contribute to sustainable communities. It is a collaborative process that focuses on the design, construction, operation and occupancy of a building over its complete life-cycle ....* [allowing the design team to] *develop and realize clearly defined and challenging functional, environmental and economic goals and objectives.*

Figure 3-2: Design objectives of the whole building design (Prowler and Vierra 2008)

A further important term within the IDP is the integrated process team (Fig. 3-3). The coherent interactions of expert teams promote successful high performance outputs. All stakeholders together are hence involved in the seven IDP phases including: planning, design, construction, and operation (Prowler and Vierra 2008) (Table B-14, Appendix B for selective core team members). The core team includes the client as the ultimate decision maker, with the facilitator and the project manager. The next level includes the consulting teams whereas the outer level includes specific technical teams (Cole 2008).

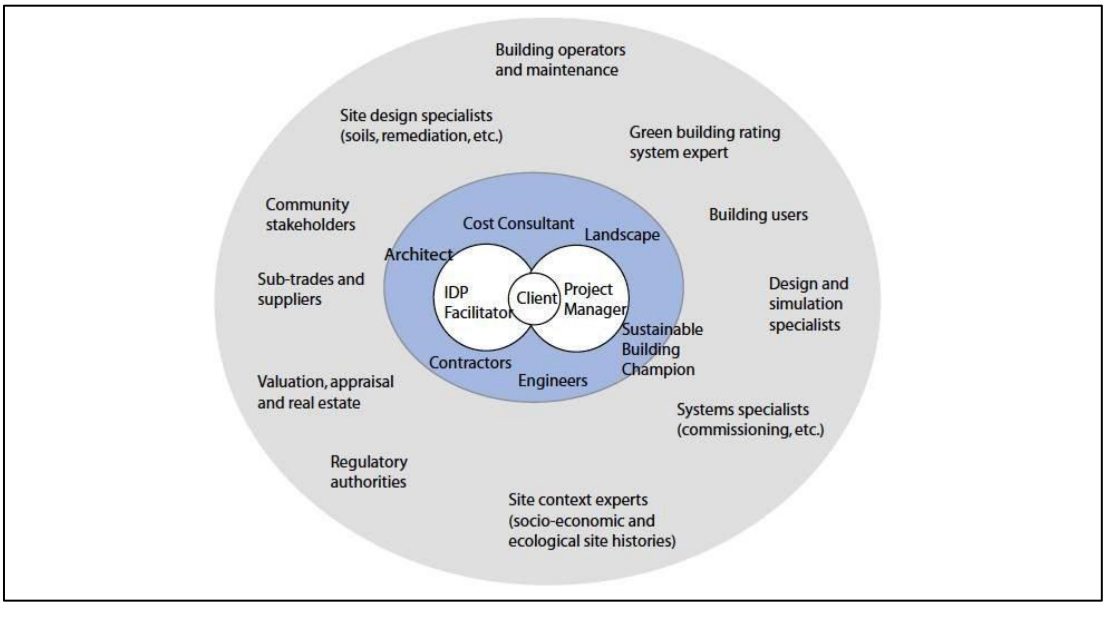


Figure 3-3: Integration process team organisation chart (Cole 2008)

There are various IDP approaches and methods to match individual teams' coherence and project nature. These differences are minimal and remain within a unified IDP loop unlike the conventional design process which has significant application variations (BC GBR 2007). The foremost differences between IDP and conventional design process are presented in Table 3-1.

Table 3-1: Differences between integrated design process and conventional design process (BC GBR 2007)

Integrated Design Process	Conventional Design Process
Inclusive from the outset	Involves team members only when essential
Front-loaded - time and energy invested early	Less time, energy, and collaboration exhibited in early stages
Decisions influenced by broad team	More decisions made by fewer people
Iterative process	Linear process
Whole-systems thinking	Systems often considered in isolation
Allows for full optimisation	Limited to constrained optimisation
Seeks synergies	Diminished opportunity for synergies
Life cycle costing	Emphasis on up-front costs
Process continues through post-occupancy	Typically finished when construction is complete

Yudelson (2009) mentioned that IDP is becoming more common than the conventional design process. It strategizes energy efficiency and cost competitiveness through the best design practice and comprehensive team collaboration. This process is a core concept of sustainable (or green) building. Successful sustainable projects, however, are only produced via the IDP process where the right information is available to the right stakeholders at the right time.

The IDP technique for solar technologies was reinforced, according to Larsson et al. (2002) and Hestnes (1999), by Task 23 'Optimization of solar energy use in large buildings' of the International Energy Agency's Solar Heating and Cooling Programme. The Task provides necessary optimisation exercises to ease the integration processes by architects and designers. These can ensure that the proper integration schemes of solar thermal technologies are perfectly merged into building design and construction. A set of design tools is made accessible by Task 23 to promote sustainable development. These tools are categorised into criteria and sub-criteria (Table 3-2). However, not all principles have the same level of importance to stakeholders. Furthermore, not all team members value the criterions at similar levels which differ according to each discipline speciality. Therefore, Task 23 proposed an evaluation facility which is called a 'star-diagram' that is shown in the example in figure 3-4. Building with *"a smaller score, and therefore a smaller ''footprint'', indicates better performance"* (Hestnes 1999, p. 182).

Table 3-2: The criteria and sub-criteria used in IEA Task 23 (Hestnes 1999)

Criteria	Sub-Criteria	
Architectural Quality	· Identity · Scale / Proportion	· Integrity / Coherence · Integration in Urban Context
Indoor Quality	· Air Quality · Lighting Quality	· Thermal Quality · Acoustic Quality
Environmental Loading	· CO_2 Emissions from Construction · Annual Operational CO_2 Emissions · SO_2 Emissions from Construction · NO_x Emissions from Construction · Annual Operational NO_x Emissions	
Functionality	· Functionality · Flexibility	· Maintainability · Public Relations Value
Resource Use	· Annual Electricity · Annual Fuel · Annual Water	· Construction Material · Land
Life Cycle Cost	· Construction Cost · Annual Operation Cost	· Annual Maintenance Cost

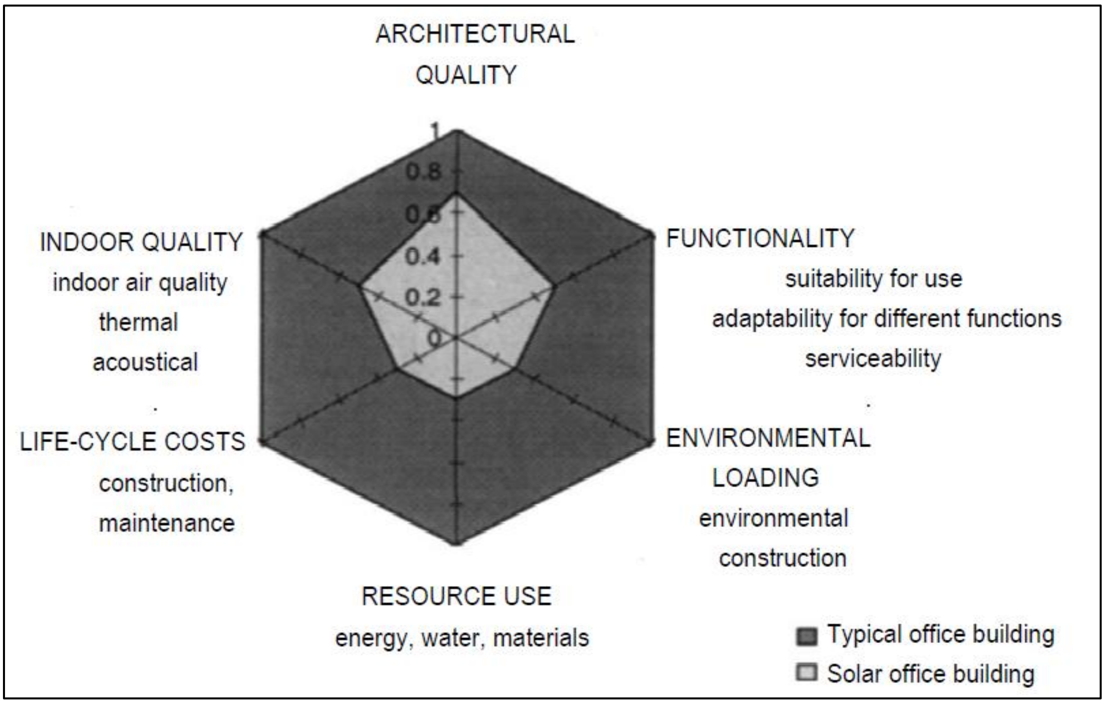


Figure 3-4: Example of a 'footprint' of a solar office building versus a typical office building (Hestnes 1999)

i) THE ROLE OF THE ARCHITECT

In considering the role of the architect in integrating solar technologies in building envelopes, the realm of the architect extends beyond adding technological elements to include public acceptance, social influence and environmental context (Clesle 2010). In the conventional design process, the architect (or designer) follows the client organisationally and leads the entire team. In an agreement with the client, the architect in the conventional design process is entirely responsible for the design concept through to completion of the project (BC GBR 2007). Although the IDP team (Fig. 3-3 above) can vary, the architect usually occupies the facilitator position who often initiates, coordinates, and leads the IDP team (Larsson et al. 2002; BC GBR 2007). In a survey about digital tools used for solar design which was targeted at architects in various countries, Horvat et al. (2011) found that 53% of the respondents indicated the architect alone undertook decisions at the conceptual phase in small projects. Although participants indicated involving specialists at the conceptual phase for large projects, 32% of the respondents stated the architect's sole responsibility of decision making at the conceptual design phase. The other specialists were often involved in the later design phases. The architect is furthermore seen by Krippner and Herzog (2000, p. 1) as one who *"designs and constructs buildings* [whereas, the engineer] *develops components for construction".*

Architects therefore, would have a significant influence contributing to the success of integrating solar technologies in building envelopes in order to meet environmental and climatic needs (section 1.3). This influence includes integrating solar energy technologies in new and existing buildings. The architect's role is the key to successful integration schemes as they are mostly the decision makers at the early design phase that determines the nature, orientation, shape and potential size and characters of technologies targeted for integration. This phase is often the key determinant of any project (Potvin 2005; Horvat and Dubois 2012). Although BIST has been recognised since the 1940s (Archibald 1999), some architects, according to Otis (2011), remain fearful of taking the decision to incorporate solar energy technologies in the design. However, it is often the client who was found not to be interested in financing solar technologies rather than a lack of interest by architects (Farkas and Horvat 2012).

ii) PHASE OF INTEGRATION

The incorporation of solar technologies in building envelopes could be either superimposed or integrated. The superimposed applications are deemed to lack architectural quality (Basnet 2012) as explained earlier (introduction of section 3.2). The integration of solar technologies in buildings is gaining increasing interest by designers. The integration of solar elements however, must be considered in the early design stages, rather than adding them after the architectural design or construction is completed (Hestnes 1999; Horvat et al. 2011; Farkas and Horvat 2012). This early consideration is necessary to achieve a well-facilitated design (Yudelson 2009) as the decisions taken and verified in the early design phase were found to lead to opimum advantages of integration and energy use (Larsson 2002).

iii) COMPATIBILITY VERSUS INVISIBILITY

'Integration' is often used synonymously with 'invisibility' where it is deemed desirable to hide the solar elements or to match them with other building envelope elements. By contrast, a preference for 'compatibility' by architects and/or clients sees solar elements designed to contribute to the overall aesthetic appeal. The LRE building in Switzerland (Fig. 3-5) presented an example where solar elements were designed similar to other building elements. The original metal cladding panels below the first floor windows were replaced by solar panels (Sick and Erge 1996, cited in Hestnes 1999). This is an example that existing buildings can receive supplementary integration of solar energy technologies, while retaining an elegant aesthetic appeal. Therefore, it was aesthetic compatability of solar elements as design features rather than invisibility which was the goal of the architectural design of the LRE building modification.

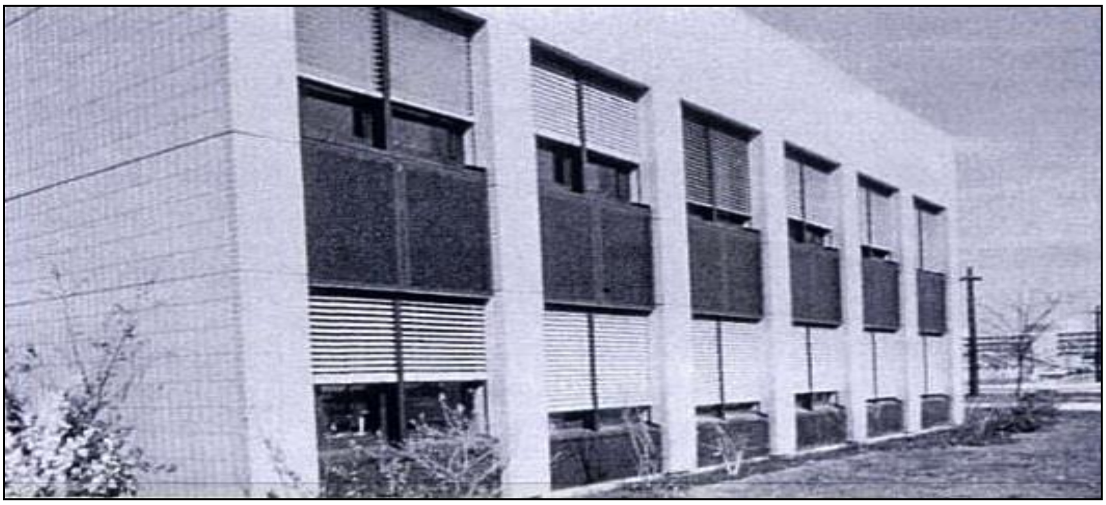


Figure 3-5: The LRE building at EPFL (École Polytechnique Fédérale de Lausanne) in Lausanne, Switzerland (Sick and Erge 1996)

3.2.3 ARCHITECTURAL INTEGRATION QUALITY

The architecture comprises planning, design, and construction reflecting functional, cultural, social, technical, environmental and aesthetical considerations (RIBA 2013). The perception of architecture therefore is built on a contextual compromise of elements including cultural, social and technological factors. This compromise is built experientially through sequential development by time; that reflects the individual's objective and subjective stimuli of understanding (Oostendorp and Berlyne 1978; Ching 2007). This concept constitutes an integral part of this study which is concerned with a careful consideration of the architectural perception of TSC technology.

As reported by Krippner and Herzog (2000) and Probst and Roecker (2011), the quality of architectural integrated solar thermal was defined as the interaction of solar thermal collectors in the building envelope in a controlled and coherent manner. This interaction should simultaneously satisfy the functional, constructive, and aesthetic aspects of architectural design.

When technology integration is involved, the three pillars for successful architecture that introduces in section 3.2.1 would be equivalent in the modern language to the following (d'Aquin and Gangem 2011):

- Durability that to satisfy a robust integration
- Utility that technology should fit-for-purpose
- Beauty that aesthetically pleasing

The term 'Solar Architecture' combines selective features of passive solar thermal design (section 2.3.1), day lighting, natural ventilation and active solar thermal technologies (section 2.3.2). According to Probst and Roecker (2011), functional and constructive elements to facilitate integrating solar thermal technologies into façades are well-matured. However, the aesthetics and the acceptable perception of solar thermal remain massively underestimated. The reasons behind this limitation include: i) the absence of relevant studies and investigations; ii) the architect has almost no influence in the development of solar thermal; and iii) the aesthetics in the technical development of solar thermal systems is usually perceived as an indefinite and subjective matter.

However, many of the current solar thermal installations in buildings have been assessed as having poor architectural quality which discourages the potential development of integration regimes (Probst and Roecker 2007). Offsite solar installations for example are a possible option but not sustainable due to occupying land, energy waste in the pipe lines and extra cost, therefore, building installations are to be targeted to achieve a competitive, sustainable and affordable source of energy into buildings.

Solar collectors in buildings are commonly mounted onto buildings' roofs as pure technical elements. Roofs are usually out of sight, especially in multi-story buildings, and by placing the solar collectors there designers tried to hide them to avoid negative impacts on the aesthetic of buildings. There is an increasing demand for attractive architectural integration which solves energy problems and mitigates climate change. For a solar thermal scheme, this integration should combine passive design techniques as a basic requisite. In the meantime, the integration of solar thermal technologies has to supply the demanded energy for both new build and existing projects (NREL 2011).

i) FUNCTIONAL ASPECTS

The function of integrating solar thermal in architectural envelopes has several advantages that exceed economic feasibility to act as multi-functional integral elements. These multi-functions combine architectural design needs (i.e. cladding, roof tile, glazing, and shading devices) and technical energy purposes (i.e. heating, cooling, and power) (Hestnes 1999; Probst and Roecker 2011). Eliminating the need for new land and additional support structure provides a further advantage of cost saving (Basnet 2012). According to Archibald (1999), the TSC for instance, resists wind and provides external façade cladding in addition to existing façade insulation. BiPV and other solar technologies could satisfy: cladding elements, day lighting, sun shading, noise reduction, electricity production (Benemann et al. 2001), and heat insulation (Montoro 2008).

Hence, solar systems contribute to reducing the total costs and improve the integration design process. Solar systems in the integrated design approach would be a fundamental element of solar architecture. The functions of solar technologies have been discussed in sections 2.3 and 2.4.

Architectural form follows function (section 3.2.1); Probst and Roecker (2011) claimed that the multi-functional feature of a solar collector leads to easier aesthetic integration. This feature gives architects the option to deploy fewer elements to achieve the designed function. Furthermore, the multi-functionality contributes to the constructive aspects (section 3.2.3ii) through eliminating construction time, planning, and effort. Therefore, the multi-functionality is an effective feature to architectural quality.

Figure 3-6 shows an example of evacuated tubes used as sun shading and daylight control in addition to water heating. Evacuated tubes could also be used as a balcony fence.

Figure 3-6: Multi-functional evacuated collector (sun shading and day lighting control). Schott-Rohrglas company and Stuttgart University (Probst and Roecker 2011)

ii) CONSTRUCTIVE ASPECTS

Construction characteristics have fundamental considerations in the integration process. The technical specification of the integrated solar technology must comply with the related building codes and standards. These standards include loadbearing of walls and roof, air cavity ventilation and thermal bridging, and type of hosting material (Krippner and Herzog 2000; Probst and Roecker 2011) in terms of rigidity, reliability, life cycle, soundproofing, fire resistance, and thermal transmitting specifications.

Further attention is given to the solar technology specificities in the integration, which focus on the specification of solar collectors. The technology has to be safely and accessibly positioned within the building envelope to avoid possible water leakage that leads to fabric damage. Moreover, hosting and adjacent envelope material to solar collectors should tolerate the collector's temperature, and heat transfer differences for PV and TSC technologies. Hence, the development of system fixing and jointing to allow for suitable expansion details which comply with the construction engineering. The possibility of vandalism and access to hot surfaces by children, especially for unglazed collectors, should be evaluated appropriately. Furthermore, the integration of solar technology should satisfy adequate vapour transfer and avoid condensation on both the collector and the adjacent envelope parts (Probst and Roecker 2011). Brown (2009) further addressed number of factors to be considered in the construction of transpired solar technologies in buildings. These factors should include architectural style, noise of the fan, design configuration and performance of the technology.

iii) AESTHETICS

Façade is originally a French word from the Italian facciata from the seventeenth century and defined as the *"the front of a building* [or] *any face of a building given special architectural treatment"* (Merriam-Webster n.d.). Façade is also considered to be the public appearance or illusion of architecture. The integration of solar technologies and different architectural elements is necessary to fulfil the function and construction standards in the building envelope. This integration is furthermore crucial to present coherent and controlled aesthetic configuration of these elements (Nikolaus et al. 1981, cited in Probst and Roecker 2011) in harmony with the overall design concept (Krippner and Herzog 2000; Kovács et al. 2003). The aesthetics of solar integrations generally leave room for enhancing the architectural appearance of buildings (Basnet 2012).

Probst and Roecker (2011) conducted a questionnaire to investigate the quality of architectural integration of building-integrated solar thermal systems (BIST) in Europe using ten examples of solar technology applications in building envelopes. The researchers had European architects and engineers rate the architectural quality of these examples. Façade integration quality of glazed collectors into a balcony (Fig. 3-7) was rated as the best out of the ten examples (+76% average architects rating). TSC at an industrial facility (Fig. 3-8) was rated the second best example of integration quality (+54%). A case of TSC integration on a gymnasium at a Canadian school was rated as just acceptable (+29%), its dark blue colour was perceived as a drawback (Fig. 3-9) and the integration in this building was deemed as 'superimposed' on the upper part of the elevations.

Figure 3-7: Glazed collector at Upperstage centre in Germany (Probst and Roecker 2007) as arrowed

Figure 3-8: TSC industrial Canadair facility in Canada (SolarWall 1996)

Figure 3-9: Gymnasium building, Canada (Probst and Roecker 2007)

The blue colour of the collectors was found to be either bad or just acceptable in the survey (Probst and Roecker 2011). Although well rated cases have black colour modules, 85% of architects in an Austrian study preferred coloured collectors even at slightly lower efficiency (Bergmann 2002, cited in Probst and Roecker 2007).

3.2.4 DESIGN GUIDELINES

The following recommended general guidelines when integrating solar technology were found from the literature. All of these would be applicable to TSC, however, there are case-to-case variations according to geographic location, cultural differences, and style of architectural design that affect size, orientation and requirements of the TSC system design:

- Shading to be avoided on the solar collector (Lisell et al. 2009) as this reduces efficiency.
- Possible noise from the operating fan has to be considered in evaluating the occupants' comfort. Therefore, sound silencers could

be installed along with high quality fans. Reliability and cost efficiency must be considered when selecting fans (Brown 2009).

- Air quality near an air heating solar collector is extremely sensitive. Adjacent car parking, for example, would allow exhaust fumes into the indoor environment (Brown 2009). Therefore a different arrangement is necessary.
- For warehouse and industrial buildings, it is advisable to avoid allocating large openings and doors on the south façade (Brown 2009).
- An automatic ON/OFF switch is recommended to control the heating quantity and quality (Brown 2009). However, automatic shutdown should be mandatory in the case of fire.
- Auxiliary heating technology is expected to co-exist with the TSC. In the absence of such heating, either some form of thermal storage should be installed, or periods of thermal discomfort are possible (Hall et al. 2011).

Having studied the architectural integration of TSC technology, there is a need for well-designed integration schemes of solar technologies in buildings that would need a systematic design process. The IDP facilitates appropriate integration of solar technology as it intensifies the comprehensive involvement of all building stakeholders. This is of considerable importance in the absence of a comprehensive set of design guidelines specific to TSC; IDP would better manage cost and resources during the design process by considering technology integration options at an early stage of design (section 3.2.2ii). Solar technologies are being taken up in a way which utilises their full potential to contribute to low-carbon energy in buildings. It has been predicted that a change is needed to approach technical development. For this reason an analysis of the innovation system around this technology seems appropriate.

3.3 INNOVATION STUDIES IN THE CONTEXT OF SOCIO-TECHNICAL CHANGE

Innovation studies gained importance for addressing energy challenges such as: energy security, energy poverty, air and water pollution, and global climate change (Gallagher et al. 2012). This section introduces the innovation system studies that address technical change in a social context, and contribute to developing, diffusing and utilising new products. The structure of this section is derived from a scheme of analysis proposed by Bergek et al. (2008) as a guideline for researchers to analyse innovation systems for a technology. It explains the development of innovation systems (i.e. linear, national, sectoral, and technological) preceded by a brief highlight of socio-technical change.

Given the emerging nature of TSC in the UK, this research focuses on the technological innovation system (TIS) as deemed the most appropriate to analyse technologies in the formative stage. This section therefore highlights the TIS definition, components dynamics, functions, interaction between functions and systematic problems.

SOCIO-TECHNICAL CHANGE

The development and improvement process of invention, innovation, and diffusion of technology throughout industry or society is known as ‘technological change’. Technological change involves procedures, adopters, and governances who are profoundly affected by market structure, regulation, industrial networks, cultural setting, and political institutions (Jaffe et al. 2002; Hekkert et al. 2007; Bergek et al. 2008). The terms ‘technological change’ and ‘socio-technical change’ were used interchangeably by Hekkert and Negro (2009, p. 584); they noted that *”Technological change always co-evolves with changes in the social system”*. This is traceable back to an early work on the rate of adoption in innovation diffusion by Rogers (1962) which is the *“relative speed with which an innovation is adopted by members of a social system”* (Rogers 1962, p. 206). The key variables determining this rate of adoption are social system, time, innovation and communication (Rogers 1962). These variables were however addressed in the developed innovation systems that being discussed in the following sections. The concept of technology combines two interrelated terms: first, the artefact (hardware such as a product and software such as process or code) and second, technical knowledge (Bergek et al. 2008).

Innovation studies have increasingly focused on the emergence of sustainable energy technologies into the market (Coenen and Díaz López 2010). In recent studies such as Geels (2002), Smith et al. (2005) and Kemp et al. (2007), the economic re-structure of sustainable energy has been referred to as the process of sustainable socio-technical change, industrial transformation and socio-technological transitions (Hekkert and Negro 2009). Socio-technical framework has been robustly applied in previous studies (Jacobsson and Bergek 2011; Wilson and Grubler 2011; Hawkey 2012; Lai et al. 2012; Negro et al. 2012a; Smith et al. 2013) with a consistent emphasis on applying the concept of change and transition management. The term transition involves the system-wide interaction and co-evolution of new technologies, changes in markets, user practices, policy and cultural discourses, and governing institutions (Geels et al. 2008; Coenen and Díaz López 2010). The socio-technical change, hence, refers to a dynamic interactive development of technology within a system. This development is not an autonomous process; therefore, there is a necessity for a strategic management of technological change.

3.3.1 THE DEVELOPMENT OF INNOVATION SYSTEMS

The notion of innovative studies was pioneered as a systematic concept in the 1980s. Following work on the nature of innovation by Schumpeter (1934), Freeman (1974) and Gibbons and Johnston (1974), scholars have developed a substantial literature on the process of innovation in techno-economic, engineering and related fields (Dodgson and Hinze 2000; Carlsson 2006). These studies addressed the societal structure of change in technology and economic growth within nations, regions, sectors and technological boundaries.

Innovation refers to improved product, tangible processes or services which are technologically novel (Edquist 2005, cited in Coenen and Díaz López 2010). This differs from 'invention' which is the creation or 'breakthrough' idea. According to Schumpeter (1934), inventions could become an innovation only when a carrier, usually an 'entrepreneur', commercialises that invention (Wang 2011). Innovation is rather an activity that occurs in a context of a wider system which is recognised as the 'innovation system' (Vasseur et al. 2013). Innovation systems have different definitions; almost all of them share a common concept that derived from one of the early definitions: *"...systems of innovation are networks of institutions, public or private, whose activities and interactions initiate, import, modify, and diffuse new technologies"* (Freeman 1987, cited in Hekkert and Negro 2009, p. 585).

The innovation system has a primary goal that contributes to the improvement, knowledge development and diffusion (Hekkert and Negro 2009) of a product, process or service. Therefore, there is an increasing emphasis amongst scholars on the innovation system as a learning process rather than a material development (Schumpeter 1934, cited in Suurs 2009; Lundvall 2010).

For the purpose of study and analysis, Edquist (2005) recommended that boundaries should be drawn around innovations to simplify the analysis process. These boundaries could be: i) geographic areas such as international, national, or regional; ii) technological fields; iii) product sectoral area; or iv) type of activities. Each prospective innovation system is to be studied in association to its indigenous environment and context (Coenen and Díaz López 2010).

Various concepts and theories have formed the development of the innovation system approach since the 1980s (Hekkert et al. 2007). This development is represented in figure 3-10.

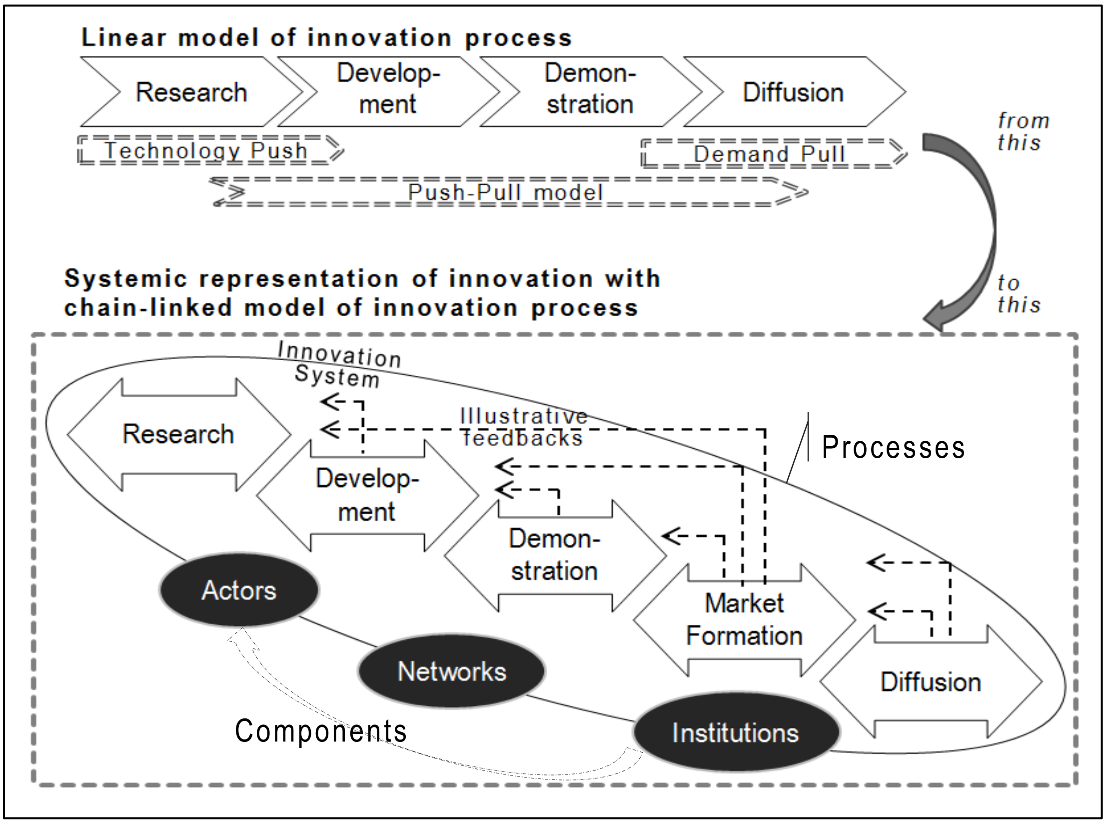


Figure 3-10: The development of innovation processes and system, adapted from Gallagher et al. (2012) and Leete et al. (2013)

i) LINEAR INNOVATION PROCESS

Before the consideration of innovation systems in the 1980s, innovation was considered as a simple linear sequential process with emphasis on research and development leading to commercial development. This was proposed based on the traditional theoretical understanding of the interaction between science, technology and economy (Godin 2008; Lai et al. 2012). The first generation was called 'technology push', where the market has been considered as a receptacle for new technology. This was followed by 'demand-pull', where the need was the drive for innovation. The third generation was called the 'push-pull model'. They were followed by the integrated model and thereafter the networking model; which added new factors into the innovation processes such as including joint ventures, collaborative research, and collaborative marketing arrangements (Rothwell 1994, cited in Dodgson and Hinze 2000).

ii) STRUCTURAL INNOVATION SYSTEMS

The linear model has been found insufficient when addressing the mechanism of innovation development in recent decades (Lai et al. 2012). Therefore, a systemic process started forming an innovation system (Fig. 3-10 above). This system included a dynamic network within its processes and components.

There are four common frameworks of innovation systems as briefed hereafter: National (NIS), Regional (RIS), Sectoral (SIS) and Technological (TIS) Innovation Systems (Carlsson 2006; Wang 2011). Other concepts of innovations systems such as international (Carlsson 2006) and socio-technological (Coenen and Díaz López 2010) appeared in few literature sources that however could be analysed as dimensions within any of the four common innovation systems. Evaluation of the international dimension within TIS, for instance, was studied by Gallagher et al. (2012) and Vasseur et al. (2013).

a. NATIONAL INNOVATION SYSTEM (NIS):

This system was defined as *"a set of institutions whose interactions determine the innovative performance ... of national firms"*. The system however has no presumption of a conscious or coherent dynamic between the involved actors (Nelson 1993, p. 349). The NIS has been derived from the economic importance of knowledge. This framework sets geographical boundaries to the knowledge flow and innovation development.

b. REGIONAL INNOVATION SYSTEM (RIS)

The NIS has not provided adequate support for rural regions and for small and medium-sized firms in particular. The national policy of central governments encountered difficulties in addressing the regional differentiation. Therefore RIS came to address these differences in innovation development (Hassink 1992, cited in Wang 2011). The RIS has the same characteristics as NIS but over a smaller geographic area.

c. SECTORAL INNOVATION SYSTEM (SIS)

The most comprehensive description of SIS is:

> *...composed of a set of new and established products for specific uses, and a set of agents carrying out activities and market and non-market interactions for the creation, production and sale of those products* (Malerba 2004, p. 16).

The framework of SIS, traditionally, has been used to evaluate the interaction of existing industries with a little empirical application on emerging innovation systems. These activities were unified to a certain group of linked products or processes (Malerba 2004; Coenen and Díaz López 2010; Vidican et al. 2012).

d. TECHNOLOGICAL INNOVATION SYSTEM (BRIEF INTRODUCTION)

The TIS is not associated with geographic borders, although the national level of innovation remains important since it influences the creation of international technological development. The TIS however could be studied at national, regional and international level. The TIS acknowledges that there are socio-industrial differences, economic competence and institutional differences among areas and sectors. (Carlsson 2006; Coenen and Díaz López 2010; Wang 2011). The TIS is further detailed in a separate section (3.3.2) due to its individuality and significant relevance to the innovative development of TSC technology that is the core focus of this research. Figure 3-11 shows a schematic relation between TIS and other systems of innovation.

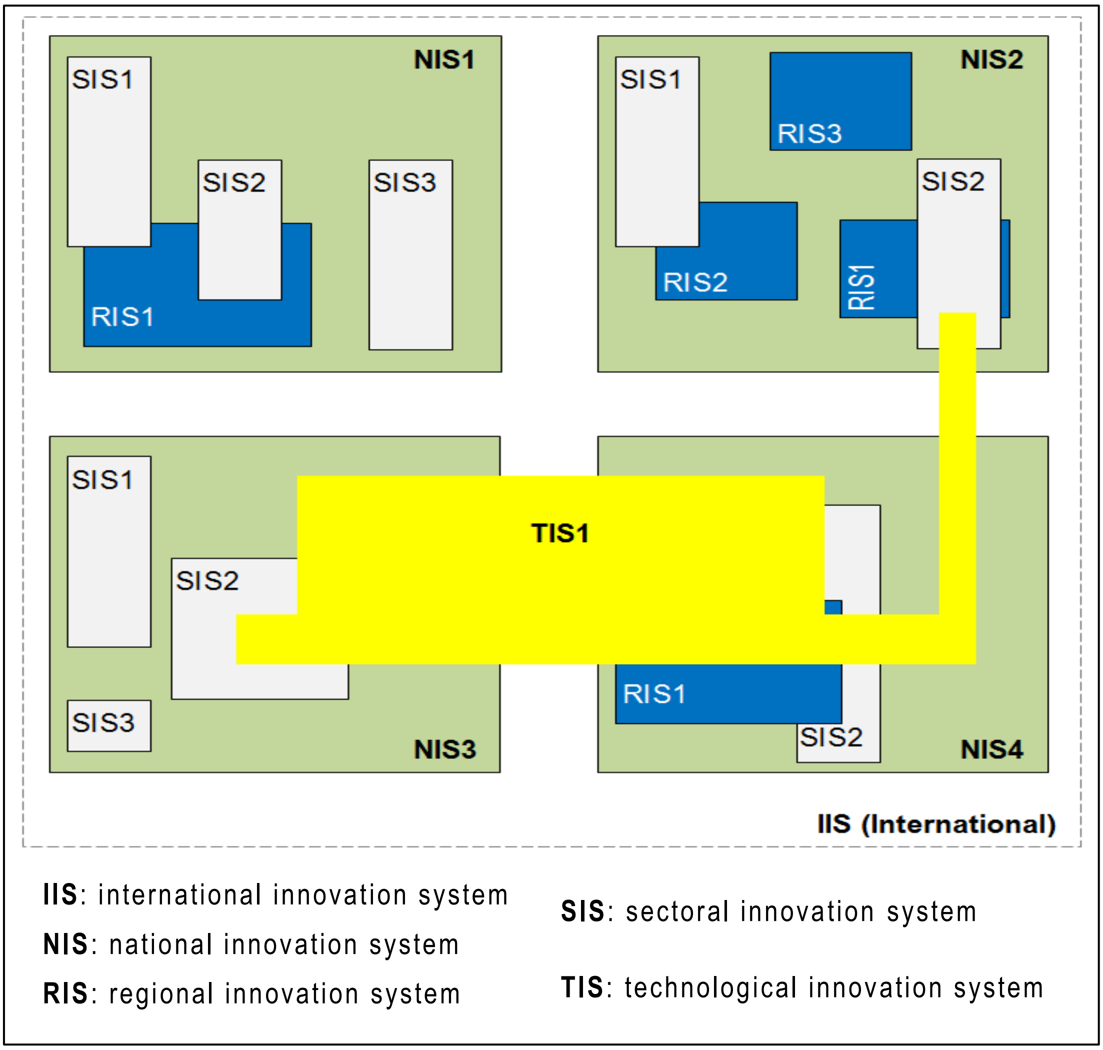


Figure 3-11: Schematic relations between Technological and Geographical Innovation Systems, developed from Hekkert et al. (2007)

iii) MULTI-LEVEL INNOVATION SYSTEM

Smits et al. (2010) distinguished between two terms in innovation processes: first, 'strategic innovation policy' which deals with structural change in innovation systems and second, 'operational innovation policy' which focuses on gradual improvement of innovation systems in steady state situations. Building on this terminology, Weber and Rohracher (2012) introduced a term of 'multi-level innovation system' which builds on a notion of 'transformation-oriented innovation policy'. They have argued that this concept complements structural innovation systems and focuses on the strategic transformation of the entire innovation system along with the production and consumption operations.

The structural innovation systems (NIS, RIS, SIS, and TIS) were seen by Weber and Rohracher (2012) as emphasising the firms' role as key actors in the economic growth and innovation development contexts (i.e. knowledge infrastructure, financial capacity, research and development, patent legislation and government incentives). The systems were moreover criticised by Alkemade et al. (2011) and Tukker et al. (2008) as focusing on the optimisation of institutional policies, and ignoring the transformation of the entire system of production and consumption.

Although the TIS has not addressed broader transformation-oriented innovation policies, the TIS analysis remains reliable to provide the foundation for technology-specific policies. Weber and Rohracher (2012) have nonetheless acknowledged that TIS has gained increased attention over other structural innovation systems, as adapting to the transformations of the techno-economic environment. The researchers furthermore acknowledged that TIS analyses the challenges of transformative change to some extent, for instance in fields such as renewable energy technologies. The TIS moreover was seen as contributing to improving technology-specific development and diffusion which supports the socio-technical configuration of change (Weber and Rohracher 2012). The innovation systems, including the multi-level approach, are however, complementary in their focus (Weber and Rohracher 2012) and the difference between them remains a matter of boundaries; either geographic or socio-technical (Suurs 2009).

3.3.2 TECHNOLOGICAL INNOVATION SYSTEM (TIS) - DETAIL

In the early 1990s, researchers noticed that economic growth is determined by the development potential of a country. Technological systems are deemed to be the core function of this development where a variety of economic agents participate. This was an outcome of a five-year research framework 'Sweden's Technological Systems and Future Development Potential' (Coenen and Díaz López 2010; Wang 2011). In this framework, the technological innovation system was developed and defined as a dynamic *"... network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilisation of technology"* (Carlsson and Stankiewicz 1991, p. 111). Different to other innovation systems, the TIS explains the knowledge diffusion and creation in more depth and focuses on the dynamics of interaction (Wang 2011; Lai et al. 2012).

The dynamics were discarded by many researchers in NIS, RIS, and SIS innovation systems as they are usually difficult to map due to the large number of actors, relations, and institutions those systems comprise (Galia and Legros 2004; Klein Woolthuis et al. 2013). A comprehensive insight into the dynamics of TIS is therefore possible due to the smaller number of actors, networks, and institutions related to a specific new technology (Hekkert et al. 2007; Hekkert and Negro 2009).

The TIS has been presented as an effective tool for entrepreneurs and policy makers to facilitate the emergence of new technologies and to enhance the functioning of mature technologies rather than to rectify individual market failures (Negro et al. 2012a). The TIS is often analysed in terms of its system components (section 3.3.3), functions (section 3.3.4) and its interactive dynamics (section 3.3.5). Figure 3-12 illustrates a schematic organising these contexts of TIS as explained in the following sections:

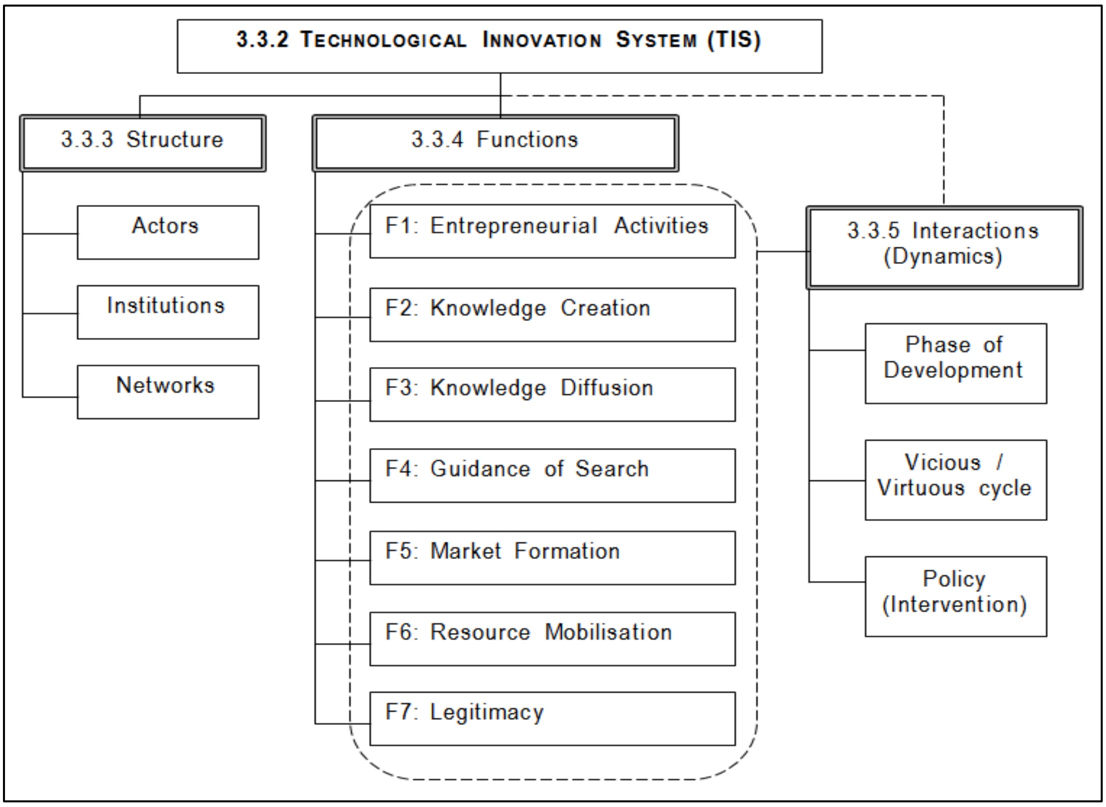


Figure 3-12: Schematic diagram of TIS context, derived from Vidican et al. (2012) and Bergek et al. (2008)

3.3.3 STRUCTURAL COMPONENTS

The innovation systems consist of three structural components: actors (3.3.4i), institutions (3.3.4ii), and networks (3.3.4iii). These components are applicable to all structural innovation systems; however, they have been considered extensively by TIS researchers (i.e. Vidican et al. 2012; Vasseur et al. 2013).

i) ACTORS

The term 'actors' usually refers to firms, organisations, authorities, and individuals involved in the innovation development of an emerging technology. Malerba (2005, p. 390) stated that *"firms are the key actors in the generation, adoption, and use of new technologies"* that lead the systematic socio-technical change. These primary actors are responsible for building and adapting broader institutional structures that develop the emergence of new technology (Coenen and Díaz López 2010; Musiolik et al. 2012; Vidican et al. 2012). Secondary actors (i.e. universities, research institutes, financial organisations, public facilities, and local authorities) also play a significant complementary role in the process of innovation development. The encouraging interrelations between actors as an interconnected chain are necessary to start investment in innovation development.

ii) INSTITUTIONS

The concept of institutions as rules and regulations, was used by Smith (2000) whereas Carlsson and Jacobsson (1997) referred to organisations as institutions. This particular example adds a terminological confusion in the TIS as acknowledged by many researchers (Klein Woolthuis et al. 2005). Innovation researchers, particularly economists, used the term 'institutions' to specifically correspond to rules; whereas 'organisations' within TIS studies refer to innovation 'actors' (3.3.3i). These terminologies however, are used in this thesis as defined under the preceding sections and as adopted by most of the researchers in the field.

Institutions were defined as *"sets of common habits, routines, established practices, rules, or laws that regulate the relations and interactions between individuals, groups and organizations"* (Edquist and Johnson 1997, p. 46, cited in Vidican et al. 2012, p. 180). The definition combined both legal institutions (i.e. regulations, laws and intellectual property protection (IPP)) and customary institutions (i.e. culture, morals and habits). Those combined parts form the 'rules of the game' or 'the codes of conduct' which is necessary to reduce uncertainty in innovation development and in the economic system (Klein Woolthuis et al. 2005). Institutions were considered as the prominent factors that shape innovation processes (Coenen and Díaz López 2010), and emphasise interconnection between the actors. Institutions provide a guiding balance of the actors' behaviour towards the innovative development process.

The actors however, compete in manipulating the institutional contexts and the marketplace in order to gain legitimate access to resources for collective survival (Vasseur et al. 2013). The institutions hence imply a contextual rather than structural influence on innovation systems (Coenen and Díaz López 2010).

iii) NETWORKS

Networks often constitute the modes for transferring tacit and explicit knowledge (Metcalfe 1992). Actors collaborate in networks to form a strategic supportive system such as technology specific R&D programmes. This collaboration is needed to influence the future shape of innovative development by maintaining successful diffusion and implementation of the new technology through engaging a wider number of actors (Vidican et al. 2012; Vasseur et al. 2013).

Networks can be divided into two strands. First: 'learning networks' that are orchestrated which connect field specific actors such as standardisation networks, public–private partnerships, supplier groups, technology platform consortia, competitors or researchers. Second: 'advocacy coalition' which evolves in a less orchestrated fashion such as buyer-seller relationships and university-industry links. Similar to institutions, the concept of networks usually has a contextual rather than structural influence on innovation systems (Bergek et al. 2008; Vidican et al. 2012; Vasseur et al. 2013).

3.3.4 TECHNOLOGICAL INNOVATION FUNCTIONS

The focus on the structural components of innovation systems (actors, institutions, and networks) was widely critiqued for delivering static, snap-shot analysis (Carlsson et al. 2002). Consequently, Hekkert et al. (2007) and Bergek et al. (2008) investigated the dynamics of innovation system (Coenen and Díaz López 2010). The dynamics link the structural components and comprise different innovation activities. Many other activities occur beyond these dynamics; however, mapping the relevant activities was the only feasible task. The relevant activities are those which influence the goal of the TIS; that is to develop, implement and diffuse new technological knowledge. Those activities are the so-called 'functions of innovation systems' (Hekkert et al. 2007) that were listed in figure 3-10. The functions are therefore related to the interaction between the structural components of a specific TIS (Hekkert and Negro 2009).

TIS has been empirically validated by researchers in the field of renewable energy, such as Hekkert and Negro (2009), Vidican et al. (2012), Lai et al. (2012) and Vasseur et al. (2013). The functional analysis of a new technology helps identify 'system failure' or weakness in the dynamic activities. Therefore, policy makers or entrepreneurs should adopt the suitable action or policy intervention to improve the innovative technological development (Bergek et al. 2008).

There are seven functions which are defined below.

i) FUNCTION 1: ENTREPRENEURIAL ACTIVITIES

As entrepreneurs are often the principal actors in an innovation system, the entrepreneurial activities are the principal function in TIS. The innovation system would not start without entrepreneurship. The entrepreneur's role is to *"turn the potential of new knowledge development,* *networks and markets into concrete action to generate and take advantage of business opportunities"* (Hekkert and Negro 2009, p. 586).

Entrepreneurial activities could be: a) new entrants with a vision of business opportunities in new or existing markets; b) diversifying incumbent firms that compete for new developments (Hekkert et al. 2007; Bergek et al. 2008) or; c) various technological applications or demonstrations. The function of entrepreneurial activities is a prime indicator of the TIS's performance. It is the function that connects the rest of the innovation functions. The function of knowledge creation (Function 2) has often been noticed following entrepreneurial activities (Function 1) as observed by Hekkert and Negro (2009), it is also a good indicator of the progress of technological diffusion.

ii) FUNCTION 2: KNOWLEDGE CREATION

The function of developing or creating new knowledge (Function 2) has been seen as an influential driver of innovation. This is particularly true in the early stages of emergence of complex technologies when there is high uncertainty about technological performance (Hekkert and Negro 2009; Gallagher et al. 2012). It has been noted by researchers that knowledge creation often co-evolves or precedes entrepreneurial activities. Knowledge creation therefore comprises a much broader context than knowledge about the technological performance (Hekkert and Negro 2009).

According to Lundvall (2010, p. 329), *"the most fundamental resource in the modern economy is knowledge and, accordingly, the most important process is learning"*. Therefore, knowledge creation and learning is a fundamental function within the TIS. The learning in this function encompasses both learning by doing and learning by searching (Hekkert and Negro 2009). Emphasis was placed on social learning with innovation development; this refers to the transformation of tacit knowledge and exchange of experience (Coenen and Díaz López 2010). Bergek et al. (2008) defined different types and sources of knowledge creation. The types of knowledge creation could be scientific, technological, marketing, logistics and design knowledge; whereas the sources of knowledge creation could be

R&D, learning from doing, learning from searching and imitation. Accordingly, this function could mainly be mapped by a few typical indicators: a) number and variety of R&D activities, b) patents, c) investments in R&D and, d) the (mis)match between the created technical knowledge from universities and the demand by industry (Hekkert et al. 2007).

iii) FUNCTION 3: KNOWLEDGE DIFFUSION

In spite of the attention given to codifying social and technological knowledge, abundant knowledge remains tacit at individual or institutional level particularly for new energy technologies. Therefore the accumulation of experience and exchange of information to diffuse knowledge through networks, is important for innovation system development (Gallagher et al. 2012). The importance of knowledge diffusion exceeds the strict R&D settings to a heterogeneous context of R&D where policy makers and competitor entrepreneurs are involved. Therefore, this function is regarded as ‘learning by interacting’ where the networks are regarded as a prerequisite to the fulfilment of knowledge diffusion function (Hekkert and Negro 2009).

The knowledge diffusion seems quite difficult to map, however, it could be analysed by measuring relevant aspects that include: a) the number of technology specific events such as conferences, workshops, and platforms; b) network size and intensity (Hekkert et al. 2007; Hekkert and Negro 2009), c) amount and type of collaboration between innovation actors, and d) the kind of knowledge that is shared within innovation components.

iv) FUNCTION 4: GUIDANCE OF THE SEARCH

Guidance of the search relates to the activities within the innovation system that impact the visibility and clarity of specific goals, targets and expectations of the desired technological future. For example, the government announcement of incentives for certain renewable energy leads to a certain degree of developing sustainable energy technologies and mobilises resources for this development (Hekkert and Negro 2009).

Guidance of the search (Function 4) is important to align the innovative visions of various actors, reduces uncertainties and stimulates attention within TIS (Vasseur et al. 2013). There are various actors involved in this function, such as government, entrepreneurs, and consumers; however, it has neither controlled nor organised formation. The power of this function is influenced by numerous factors as proposed by Bergek et al. (2008) that include: a) technological visions and expectations, b) beliefs in growth potential, c) TIS growth in other countries, regions or technologies, d) the perception and knowledge type and source of actors, e) regulations and policy, f) articulation of demand from leading customers and, g) present crises in business and environment.

v) FUNCTION 5: MARKET FORMATION

Incumbent technologies are normally well established and easily win the competition over new technology emerging into the marketplace, particularly for sustainable technologies. According to Rosenberg (1976), most inventions are quite incompetent in their early stage. These inventions might be susceptible to slow diffusion, technological imperfections, high cost, and various uncertainties over the incumbent industries. Therefore, it is necessary to form a protected space for new technologies to have a chance in the market (Hekkert and Negro 2009; Vasseur et al. 2013). The investment in market formation (Function 5) involves public and private sectors for a new technology (Gallagher et al. 2012). This investment could occur through governmental formation of a specific niche market for new technology or through institutional changes such as tax regimes or minimal consumption quotas. The mapping of market formation could measure factors such as: a) the phase and the potential of the market, b) the fulfilment of the market demand and, c) actions towards uncertainties (Bergek et al. 2008; Hekkert and Negro 2009).

vi) FUNCTION 6: RESOURCE MOBILISATION

The resources that need to be mobilised under this function could refer to financial, human and physical resources that are basic inputs for all the activities within TIS (Hekkert and Negro 2009; Vasseur et al. 2013). Following from market formation; resource mobilisation (Function 6) involves the resources of public and private investment. The allocation of sufficient resources is often necessary for a specific technology to start the knowledge creation process (Function 2).

The fulfilment of this function could be analysed quantitatively by investigating the actors' perception of access to sufficient resources. Nonetheless, there are various determinant factors that could be measured, that include: a) volume and quality of human capital such as training and university degrees, b) rising financial capital such as government funding, c) increasing satisfaction with resources, and d) changes in complementary assets (Bergek et al. 2008).

vii) FUNCTION 7: LEGITIMACY

This function refers to the creation of legitimacy which is the social acceptance and compliance with relevant innovation institutions. The emergence of a new technology has to be rationally advocated; in order for this technology to acquire political strength and legitimacy acceptance. Additionally, this function of legitimacy (Function 7) includes 'counteracts resistance to change'. Actors from incumbent regimes often resist the creative emergence of new technologies and in such a case, an advocatory coalition could act as a catalyst to legitimise a new technology and counteract resistance. The absence of this function hence indicates poor alignment between the institutions and the actors' needs, and therefore a poorly functioning innovation system (Bergek et al. 2008; Hekkert and Negro 2009).

The functional dynamics that could be analysed for mapping the legitimacy function (Function 7) in the vision of different actors include: a) public perception towards the technology, b) the relation between legitimacy and demand, legislation and firm behaviour, c) the role of the media and, d) the availability and strength of lobbying groups (Bergek et al. 2008).

3.3.5 INTERACTION BETWEEN FUNCTIONS

Since the introduction of innovation systems, scholars have increasingly focused on the dynamics between system components and functions. The system functions influence each other; therefore, the individual fulfilment of a certain function impacts on the fulfilment of other functions. Interaction between functions or structural components is often unplanned and unintentional. The notion of 'functional fulfilment' or 'overall function' therefore does not imply the progressive interaction of all actors in a particular system or function. The successful fulfilment of these functions however leads to a better performance of the TIS which implies a successful development, diffusion and implementation of new technologies. The ineffective fulfilment of the system functions would thus hamper the development of the TIS (Hekkert et al. 2007; Bergek et al. 2008; Vasseur et al. 2013).

Until 2009, there was an ambiguity in the method of analysing the interaction between system functions. Hekkert and Negro (2009) induced a conceptual benefit from analysing this interaction by focusing on the implication of the innovation system dynamics and the sort of interaction patterns that could be identified. Similar studies that analysed the function fulfilment and interaction pattern were thereafter conducted by Vidican et al. (2012), Lai et al. (2012) and Vasseur et al. (2013). In light of this introduction, the following sections highlight key analytical terms of interaction dynamics and patterns:

i) PHASE OF DEVELOPMENT AND TECHNOLOGICAL CHARACTERISTICS

Although the TIS has been set up to analyse technological development, it is useful for the analyst to distinguish between the phases of this development; these are either the 'formative' or 'growth' phase. The assessment of the system functions of each phase is different due to the time dimensions of technological emergence. **The formative phase**, which is often the emerging stage of a new technology, could be indicated by:

a) large uncertainties in diffusion and implementation,

b) immature development of price and performance of the technology,

c) absence of powerful self-reinforcing features,

d) low rate of demand (Bergek et al. 2008),

e) low number of new entrants and entrepreneurial activities, and

f) knowledge creation (Hekkert and Negro 2009).

The growth phase of mature technologies on the other hand could be indicated by:

a) knowledge diffusion,

b) new entrants, and

c) growing size and density of networks (Hekkert and Negro 2009).

Therefore, the phase of development and the development of a TIS is a typical example of co-evolution relationship; they mutually influence each other. Analysts mad a common error by using the same criteria to judge both the formative and growth phase of TIS development as argued by Bergek et al. (2008). The growth phase, for instance, could have a rapid rate of diffusion or market activities that is unlike the technologies in the formative phase which might have a small number of activities and more research and development efforts. The knowledge diffusion (Function 3) and guidance on search (Function 4) are, for instance, more important than market formation (Function 5) at the formative phase of development, in spite of their small number of activities (Bergek et al. 2008; Hekkert and Negro 2009).

ii) VIRTUOUS AND VICIOUS CYCLES

As highlighted in the introduction of this section, system functions influence each other in the interaction and functional fulfilment. This leads to creating virtuous or vicious cycles within TIS. The virtuous cycles occur as a result of positive interaction between the functions. These cycles have been claimed as accelerating the development of the innovation system as they reinforce the dynamics within TIS. These cycles could encourage policymaking decisions and entrepreneurial activities that lead to knowledge diffusion and legitimacy lobbying. The virtuous cycle is characterised by a positive loop moving in the same direction, whereas, the vicious cycles could slow down or stop the innovative development of technologies. These cycles occur as a result of negative fulfilment to one or more functions that reduces the activities in the other system functions (Hekkert and Negro 2009; Suurs 2009).

iii) POLICY (INTERVENTION)

The policy intervention was rationalised by Edquist (2005) in the satisfaction of two conditions: 1) a problem must exist, and 2) of government agencies must have the desire and ability to solve such a problem. The intervention policies for innovative development often target entrepreneurs, however, this is likely to be extended to involve universities, research activities and social movements (Coenen and Díaz López 2010). Therefore, policy intervention was arguably justified by market failure in order to address certain challenges in the structure of innovation system such as learning, research, knowledge, networking and resources (Weber and Rohracher 2012). Furthermore, effective policy intervention would encourage the hesitant entrepreneurs to peruse research and development actions of new technologies. For example, feed-in-tariff (FIT) proved effective in achieving deployment of renewable energy technologies as was favoured by entrepreneurs in Denmark, Germany and the USA (Leete et al. 2013). The studies of systematic problems (section 3.3.6) have gradually received attention as a tool for policy intervention (Coenen and Díaz López 2010).

3.3.6 SYSTEMATIC PROBLEMS OF RENEWABLE ENERGY TECHNOLOGIES

Innovation studies were found useful in analysing the system failure or systematic problems that hamper technological innovation development and diffusion. Various researchers in the field of innovation system failure, such as Jacobsson and Johnson (2000), Klein Woolthuis et al. (2005), Foxon and Pearson (2007), Negro et al. (2012a) and Weber and Rohracher (2012), focused on the perceived weakness in the structural components. They provided categories and listings of possible systematic failures and problems. Further researchers such as Philibert (2006) and Painuly (2001) however tackled the innovation development problems in the form of barriers to technological development rather than in a systematic context. Foxon et al. (2005) analysed the barriers of new renewable technologies in the UK. The innovative barriers, for the purpose of this study, were seen fitting within the systematic problem analysis as a shell context that helps map policy intervention options.

The systematic problems framework, as a tool for analysis, helps policy makers to identify the following according to Klein Woolthuis et al. (2005):

- The position where failure occurs (i.e. lack of entrepreneurial spirit hinders innovation).
- The actors or interactions that should be addressed to make change possible (i.e. provide venture capital).
- The effectiveness of policy for each individual systematic problem.

The system problems should be addressed in a context rather than independently, as derived from a multi-level innovation system (3.3.3iv), due to the involvement of various actors, institutions and complex mixture of causes and effects. The use of a framework for system problems helps prioritise the most significant problems; this leads to implementing the most appropriate innovation policy. It also creates a clear-cut categorisation of systematic problems that serve as a rationale for government intervention. This framework was often used to evaluate an already implemented policy programme (Klein Woolthuis et al. 2005). In order for the categorised problems to lead to policy intervention, Negro et al. (2012a) suggested mapping a clear link between the empirically observed problems and the conceptually possible categories. The categories of system problems (Fig. 3-13) are explained hereafter along with the connection to empirical observations of renewable energy technologies (RETs) wherever available by the researchers:

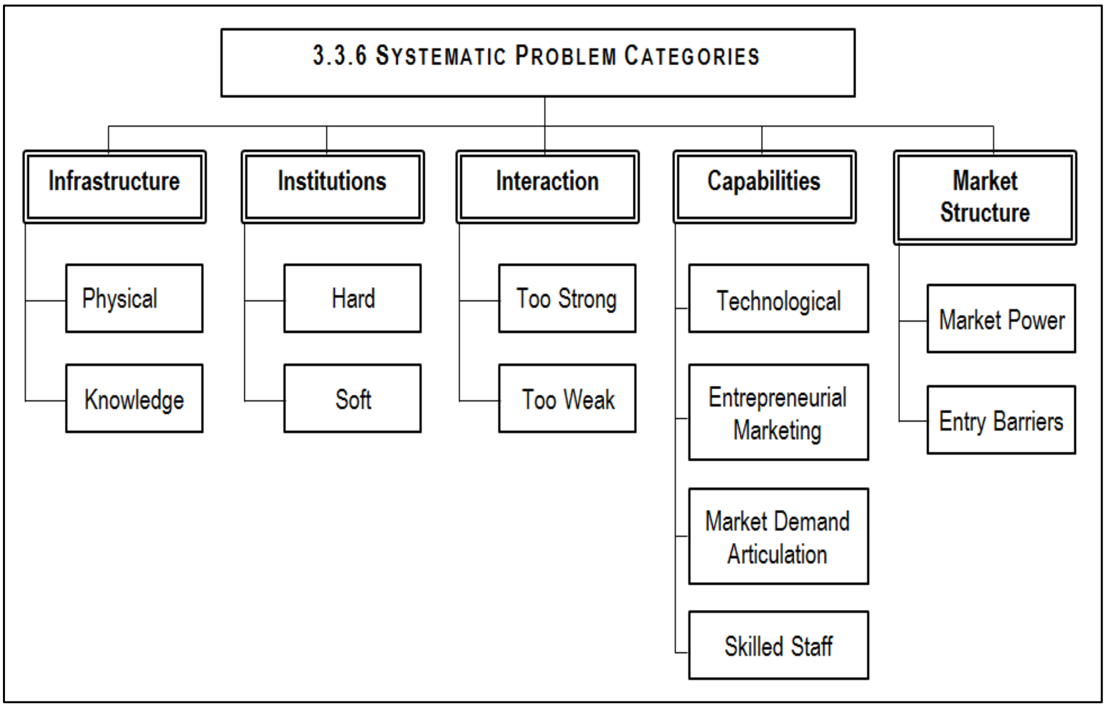


Figure 3-13: Analytical framework for market and system failure, adapted from Klein Woolthuis (2010)

i) INFRASTRUCTURE PROBLEMS (PHYSICAL AND KNOWLEDGE)

Infrastructure refers to the physical and knowledge structures (i.e. roads, railways and telecom networks) (Klein Woolthuis 2010):

a. PHYSICAL INFRASTRUCTURES

Reliable physical infrastructure is essential for technological diffusion and development. The absence of the appropriate infrastructures would hinder innovative development as well as the economic growth in general (Klein Woolthuis 2010).

The needed infrastructure for RETs however is different from the current conventional grid power systems (Negro et al. 2012a). Klein Woolthuis (2010) reported in his infrastructures study of the Dutch construction industry, that the current infrastructures are often based on the paradigm of a central power grid as a producer and individual receivers who are the consumers. On the contrary, the new paradigm opens the doors for the consumers to produce energy and feed in to the central grid. The Dutch entrepreneurs found difficulties in implementing this switch even though an electricity switchboard entrepreneur had developed a product that allowed households to feed electricity to the central grid while the infrastructure allowed households to individually act as receivers in the current system.

b. KNOWLEDGE INFRASTRUCTERS

The knowledge infrastructure and advanced Information and communications technology (ICT) infrastructures have been emphasised in innovation studies (Klein Woolthuis et al. 2005). Negro et al. (2012a) reported a gap between knowledge creation (Function 2) at universities and the practical needs of industry. The cooperation between research institutions (academic and industrial) is insignificant, and there is a lack of strategic direction to overcome the problem (Foxon et al. 2005). The research institutions often have the knowledge to solve technical problems which is not diffused due to lack of information exchange (Function 3) with the industry, resulting in the problems being unsolved in practice (Bergek 2002).

ii) INSTITUTIONAL PROBLEMS (HARD AND SOFT)

Institutions (section 3.3.3ii) are a crucial signpost of actors' behaviour and performance towards the innovative development process. Carlsson and Jacobsson (1997) distinguished between 'hard' and 'soft' institution failure where other researchers referred to 'formal' and 'consciously created' versus 'informal' and 'spontaneously evolved' institutions failure. This study will follow the work of (Klein Woolthuis et al. 2005; Negro et al. 2012a) who adopted the terms 'hard institution problems' and 'soft institution problems':

a. HARD INSTITUTION PROBLEMS

Hard institutions refer to rules and regulations in the form of formal, written, and consciously created institutions. They are classified as 'hard' because they are specific, explicit and enforceable. Although the absence of these institutions hinders innovation; the extra rigid institutions such as bureaucracy could imply negative effects (Klein Woolthuis 2010; Negro et al.

2012a). The following problems related to hard institutions were reported in the literature:

- 'Stop and go' policy': this problem was noted by Negro et al. (2012a) for about 37 cases of volatile regulatory decisions and subsidy schemes. For instance, subsidy schemes for RETs in the Netherlands were stopped and reintroduced in different forms every two years from 1981 to 2011 (Negro et al. 2007; Suurs 2009). A similar issue was observed in the UK for wind, PV, biomass, and marine energy (Foxon et al. 2005; Foxon and Pearson 2007; Praetorius et al. 2010).
- 'Shift of policy makers regimes': similar to the 'stop and go' policy. An example was presented from the UK for micro-CHP (micro combined heat and power) where funding was initialised to meet energy security challenges. Then a policy shift towards liberalisation and privatisation of the energy market dominated the policy debate (Praetorius et al. 2010, cited in Negro et al. 2012a).
- Lack of institutional support during the so-called 'valley of death' was also observed as a hard institutional problem. The valley of death is the preceding phase to emerging new technology into the market. The R&D support schemes in the UK have been observed emphasising small efforts and niche markets for demonstration projects and pre-commercial trials for RETs. There was a problematic gap however, between the current R&D initiatives and 'near commercial' support to overcome the valley of death. Therefore, many RETs were jammed in the R&D or demonstration stage (Foxon et al. 2005; Winskel et al. 2013).

b. SOFT INSTITUTION PPROBLEMS

The soft institutions refer to values, cultures, habits, mutual agreement, social norms and entrepreneurial spirit within organisations shaping actors' preferences, behaviours and public policy objectives (Smith 2000). These institutions are informal and often implicit. They could stimulate innovation development if they value creativity and change, otherwise the institutions would hinder innovation (Klein Woolthuis 2010; Negro et al. 2012a).

For instance, the creation of legitimacy (Function 7) is the social acceptance for a new technology which comes under soft institutions. While creating legitimacy at the emergence of new technology is often a tedious and slow process, various actors are involved in forming a socio-political process of legitimation either as advocators or by counteracting resistance. According to Negro et al. (2012a), the advocatory and counteracting trends for RETs have no stereotypical bounds to specific actor groups in the innovation system.

The soft institutional problems seem to occur less than the hard problems. This could be attributed to the lack of capabilities by actors (Negro et al. 2012a) (section 3.3.6iv).

iii) INTERACTION PROBLEMS (TOO STRONG AND TOO WEAK)

The interaction process (3.3.5) links the system components and TIS functions for cooperation and interactive learning. The modern market structure requires relations that *"persist through time and involve inter-firm cooperation in the development and design of products"* (Smith 1999, cited in Klein Woolthuis et al. 2005, p. 613). Interaction problems could evolve in either of two directions: too strong or too weak as blocking mechanisms to the development of RETs (Jacobsson and Johnson 2000; Bergek 2002).

a. TOO STRONG INTERACTIONS

Strong interaction failures were expressed by Carlsson and Jacobsson (1997) as being the 'blindness' that evolves in very close relations between actors. The excessive strength among incumbent actors facilitated 'lock-in' to dominant products. Furthermore, this type of relationship allows 'wrong directions' that lead to failure of diffusing appropriate knowledge due to lack of information exchange. The dominating groups with too strong interactions could block new entrants to the market (Klein Woolthuis et al. 2005). This example was reported by Dutch construction entrepreneurs where new entrepreneurs had failed to interact with large-scale project developers. The interaction and selection criteria were based on a rigid basis of historic relations (Klein Woolthuis 2010). This keeps revolving the same routine of knowledge 'lock-in' with neither a chance of knowledge creation (Function 2) nor knowledge diffusion (Function 3).

b. TOO WEAK INTERACTIONS

The weak interactions refer merely to the poor linkage between the components of the innovation system. This weakness often causes inappropriate interactive learning that leads to a possible failure of adopting new technologies by entrepreneurs. The poor interaction would furthermore lead to inaccurate visions of the future of technology development. These altogether would hinder the innovation development and research efforts (Carlsson and Jacobsson 1997, cited in Klein Woolthuis et al. 2005).

iv) CAPABILITY PROBLEMS

Capability often refers to the appropriate knowledge and know-how that actors possess to engage in innovation development. The competency of this knowledge, particularly the technical knowledge, is necessary for entrepreneurs to encounter a successful development of a new product. Organisational and marketing skills are furthermore essential for those entrepreneurs to manage the process of innovative development that lead to a successful introduction of a product into the market (Klein Woolthuis 2010). Different categories of capability problems as found by Negro et al. (2012a) could be categorised in the following four themes:

a. LACK OF TECHNOLOGICAL KNOWLEDGE

Actors, such as policy makers and designers, often lack the appropriate technological knowledge. This might result in determining a wrong technological choice, inefficient design or malfunctioning technology. This theme of capability problems, for instance, was reported for large wind turbines by Jacobsson and Johnson (2000) in Sweden and Verbong and Geels (2007). Further examples were reported by Raven and Verbong (2004) for over-dimensional heat pumps and large-scale biomass pilot plants and by Negro et al. (2008) for inappropriate development of biomass gasification in the Netherlands (Negro et al. 2012a).

b. LACK OF ENTREPRENEURIAL ORGANISATIONAL EXPERIENCE

This refers to the lack of ability by entrepreneurs to lobby together, to attain legitimacy support (Function 7). Entrepreneurs were most commonly noticed competing at the early stage of innovation development rather than forming a coalition or alliance. This type of competition increases the challenges towards regulations, resources and creating a niche market. Another issue often reported is the incapability of entrepreneurs to formulate realistic expectations. The inaccurately optimistic expectations, particularly when not fulfilled, leads to a mistrust by innovation actors (Negro et al. 2012a) and leads to misguidance of search (Function 4).

c. LACK OF MARKET DEMAND ARTICULATION

This theme refers to end users who cannot generate enough demand. Most end users infrequently buy new technologies (e.g. a dwelling owner who replaces the boiler once in 30 years). Those actors lack the capability to formulate a demand due to their lack of experience (Johnson and Jacobsson 2000). Thereafter, Negro et al. (2012a) recommended inducement by intermediaries to formulate the demand.

d. LACK OF SKILLED STAFF

The lack of skilled staff frequently occurs in the occasions of radical difference between emerging and the existing technologies. The new technological trajectory requires amendment to current educational and training syllabuses which usually takes time to incorporate as well as for skilled staff to graduate. Moreover, snowballing development of innovative technologies is likely to employ the available trained staff creating shortage in skilled staff (Negro et al. 2012a). This phenomenon becomes more severe for small and medium enterprises with limited funds and staff resources (Klein Woolthuis et al. 2005).

An increasing scarcity of skilled technicians and installation experts was observed by (Negro et al. 2012b) in the Dutch PV innovation system. This lack of skilled personnel has lasted since 2003. The Dutch PV sector has been sedentary since then, and predicted by experts in the field to take several years before a substantial take-off (Sinke 2007, cited in Negro et al. 2012a).

v) MARKET POWER PROBLEMS

The market, in an established status, plays the role of a selective tool of innovation development. New technology might be susceptible to high cost and uncertainties at the emergence into the market over the incumbent industries (section 3.3.4v). In the absence of bridging segments to reduce the gap between new and established technologies, new technology might be jammed or remain incompetent (Negro et al. 2012a). The market structure therefore dominates the degree of the quality and quantity of new emerging technologies. This is known as ‘market power’ (Klein Woolthuis 2010).

Most of the energy markets are dominated by fossil fuel that left a fractional chance for the renewable energy technologies to breakthrough. This domination was gained from their long periods of technological learning and economies of scale that made the fossil fuel technologies cheap, well-known, efficient and socially preferred (Negro et al. 2012a). Therefore, it would be unfair to compare the market structure of the incumbent fossil fuel technologies to the yet immature RETs. The following market structure problems were reported by researchers for RETs as raised by Negro et al. (2012a) and Klein Woolthuis (2010):

- The RETs were found to be mismatched with the current central electricity grid with a large-scale paradigm of generation.
- The robust advocates to incumbent energy technologies escalate the expectations level from RETs which reduces the chances of success and competence.
- The incumbent firms, in general, hesitate to adopt renewable technologies and deliberately attempt to block the emergence of new RETs into the market. This is due to their influential capacity in the policy making place and lobbying.

3.4 SUMMARY

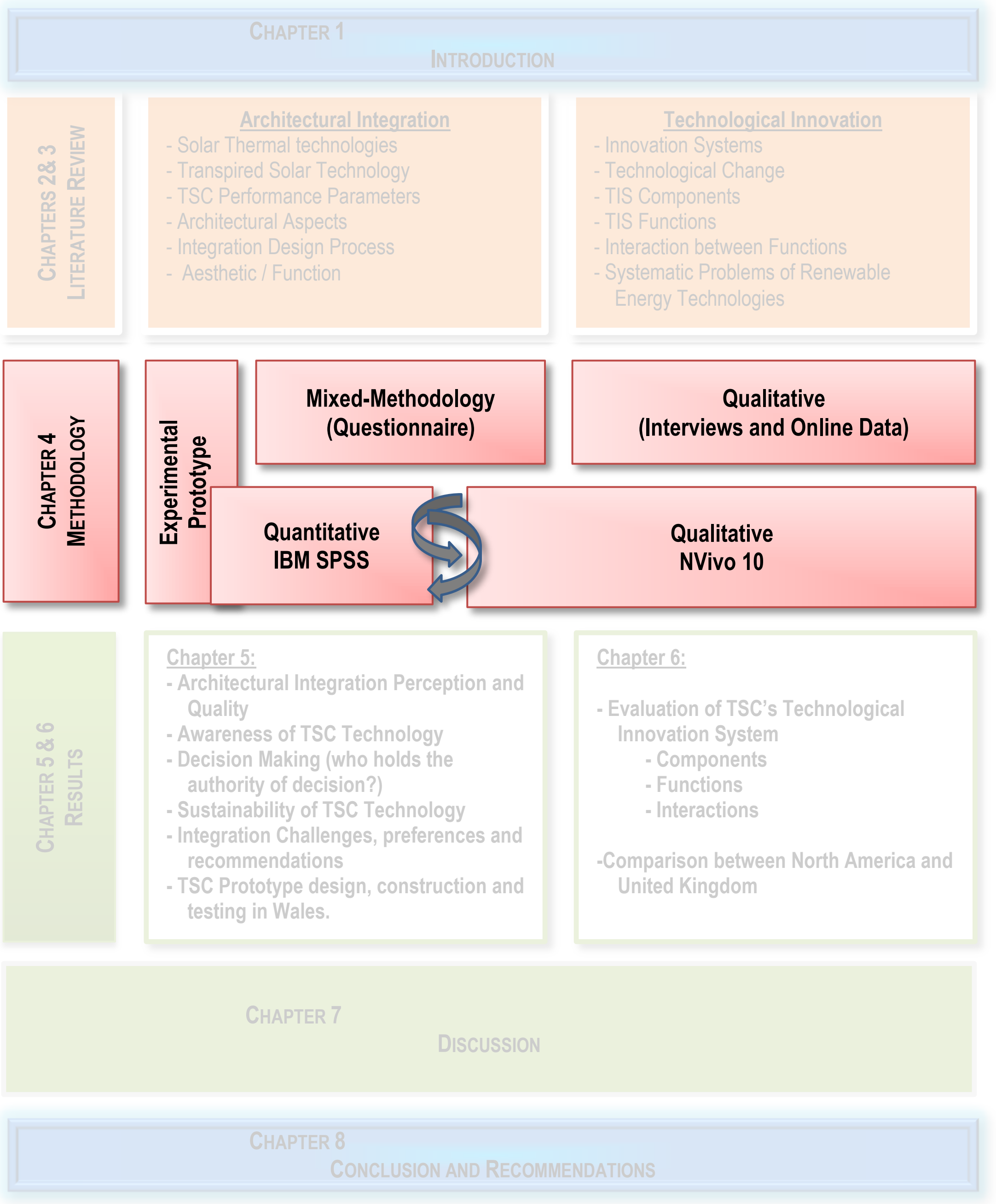
Building-integrated TSC is associated with the architecture of building envelopes. Therefore, architectural integration of solar thermal technologies was described from literature to understand the current configurations of solar thermal in architecture. To the knowledge of the researcher, there was no related research available specific to TSC technology in terms of architectural integration. The current BIST applications are mostly not aesthetically well-designed as explained in section 3.2.3. In addition to the gap between the technical performance of TSC and social acceptance (section 1.2), there seems a gap in design process itself. Therefore, IDP was introduced as a suitable process to facilitate appropriate integration of solar technology. Furthermore, the role of the architect in the design process was described along with the phase of technological integration and development. This will be considered in detail in chapters 5 and 7.

Interrelated to architectural integration is the socio-technical part of the development. TIS technology was found to adequately address such a technical change and furthermore has been used to investigate related energy and technology studies as described in section 3.3. The theoretical parameters, literatures and structures of TIS were described to provide a context for the research work to follow as directed by Bergek et al. (2008). In the context of the aim and objectives of this research, innovation studies could outline the challenges and opportunities for developing TSC technology in the UK. This offers the potential of drawing relevant lessons from the North American example to drive socio-technical change in solar thermal research and design.

CHAPTER 4 ||

RESEARCH

METHODOLOGY



4.1 OUTLINE

The methodology being adopted in this research was briefly introduced in section 1.5. This chapter purposes to identify the most appropriate methods to employ in the research that best satisfy the aim and objectives. Quite a few research methods are deemed possible to conduct this study and considered; as found adopted in previous related studies (section 4.2) or deemed suitable to serve the aim and objectives of this study. However, this study has interdisciplinary research aim and multi-dimensional objectives. Therefore, there is no individual comprehensive method which completely satisfies both research directions: architectural integration and technological innovation development. The methods being considered can be divided into disqualified and qualified methods as follow, however, certain methods were better qualified in a combination, namely the quantitative and qualitative methods that were adopted under the frame of mixed-method:

Methods which were disqualified:

- Case study (section 4.2.1) to satisfy part of the aim and objective 'v' which was revised late on. The case study method was excluded as an accessible case (project) was not attained within the timeframe of this research in spite of approaching relevant organisations within the UK. However, there were a very limited number of possible case studies within the UK due to limited number of TSC installations (section 2.4.1).
- Simulation (section 4.2.5) to satisfy the pre-heating part of the research aim, objective 'v' and further early objectives that were revised and substituted later on. This method was considered until a late stage in this study. It was eventually excluded due to a number of reasons including: the absence of credible software to simulate TSC and absence of empirical data for comparison.

Methods which were utilised:

- Mixed-method (section 4.4) to satisfy the objectives of the first interrelated research direction 'architectural integration'. After reviewing the strengths and shortcomings of quantitative (section

4.2.3) and qualitative (4.2.4) research methods, they were combined in a mixed-method that offset their individual weakness. This was considered to provide the most comprehensive analysis of the research hypothesis (section 4.4.1).

- Experimental field study (prototype) (sections 4.2.2 and 4.5) to satisfy the pre-heating part of the research aim and objective 'v'. It was also chosen as a supplementary method to the main research direction, architectural integration, as a 'learning by doing' tool, especially the design and construction part of it. Prototyping and testing the TSC was deemed to add significance to the survey results.
- Qualitative method (sections 4.2.4 and 4.6) to satisfy the objectives of the second interrelated research direction 'technological development'. Although the qualitative method was addressed earlier within the mixed-method, it was to be further conducted individually through analysis of semi-structured interviews and other secondary data (section 6.2). The selection of this method was derived from the absence of entrepreneurs in the questionnaire where they hold significant importance in developing TSC technology (section 4.6). Therefore, grasping their perceptions and views about TSC deployments, development and knowledge diffusion was deemed necessary to determine the challengers, barriers and current status of the technology.

This chapter comprises the foremost relevant research methods which are introduced in section 4.2 whereas the determination of the research methodology of this study was introduced in section 4.3. The adopted mixed-method for architectural integration along with related issues including questionnaire design and statistical analysis are described in section 4.4. The supplementary experimental prototype is described separately in section 4.5. The qualitative method being adopted for the technological innovation is already included within the mixed-method. However, the interview design and data collection for technological development are described in section 4.6.

4.2 ASSOCIATED RESEARCH METHODOLOGIES

In order to properly identify the appropriate method, a review of methodologies adopted in related literature is presented first, followed by specific information on the methods selected for this work. The following methods were used in previous studies and are potentially applicable for inclusion in this research; both architectural integration and technological innovation development.

4.2.1 CASE STUDY

Case study research is defined as *"...an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident"* (Yin 2003, p. 13, cited in Ellinger et al. 2005, p. 328).

Case studies have been used as an implicit methodology in Probst and Roecker (2011). The researchers used a case study of a European project SOLABS to explore the architects' wishes of a novel unglazed solar thermal collector. Case studies of TSCs at US military installations were used in research by Brown (2009) as an umbrella of other research methodologies. The researcher aimed to investigate the economic and environmental viability of the technology for an air force energy scheme using nine facility and warehouse buildings at the Department of Defence.

Other case studies and demonstration projects were used for conducting qualitative surveys which are highlighted in sub-section (4.2.4). However, using a case study methodology in this thesis to address the research ideological aim and objectives requires certain challenging necessities which include the following:

- Full access permission to an existing building with a TSC system in operation, located within Wales.
- Cooperation of the occupants, project architect, TSC specialist and contractor. However, this could be a problematic task within residential buildings where residents desire quiet and rest.

- Unlimited access to the relevant available information including integration issues, energy consumption, operation constraints, and design loads. For a refurbished building, further information about energy schemes and consumption rates before and after TSC installation would be very useful.
- Appropriate instruments to measure temperature, wind speed, air flow, solar irradiation and other weather data that would be used to estimate TSC effectiveness and efficiency.

Accordingly, the result could be validated via computer modelling or correlated with related other cases, even if in different climates. A verification of TSC manufacturers' trading information (section 2.4) was deemed useful for knowledge exchange. However, in spite of approaching relevant organisations within the UK, permission to examine an accessible project was not possible within the timeframe of this research.

4.2.2 EXPERIMENTAL/FIELD STUDY

Experimental methodology is often used for scientific researches where a simulated mock-up is built to conduct the necessary experiments and measurements. The experimental method can manipulate a particular variable at a time to determine its effects on the other hypothesis parameters. It has several drivers including: the non-availability of full access to a real case study; control of the variable parameters; immature technologies which have to be tested prior to actual application. This method of research often occurs either in a laboratory, like chemical and physical reactions, or in the field, as for construction associated issues. Ellinger et al. (2005) mentioned that experimental research in the industrialised world has focused on improving technologies of building.

Using experimental methodology, Van Decker et al. (2001) installed nine TSC test plates (Table B-9 in Appendix B) and further correlated their experimental data with a previous study of Kutscher (1994). Fleck et al. (2002) used two TSC prototypes, and monitored the performance using a measurements model '81000 Young sonic anemometer' which records solar irradiation on the horizontal surface, temperature, flow rate and other relevant measures. The sonic anemometer recorded three air velocity components every five minutes: along the wall; towards the collector and vertical flow. Kozubal et al. (2008) built a prototype TSC module (see Fig. 2-16). Further experiments to evaluate TSC performance were conducted by Cordeau and Barrington (2011), Chan et al. (2011) and Gawlik and Kutscher (2002).

For this field of study, experiment methodology often focuses on technical issues of TSC, like performance, wind effects and effectiveness. It is not appropriate to investigate the human dimension of architectural integration using experimental methodology; nevertheless, building an experimental prototype would add dimensional benefits of ‘learning by doing’ onto parameters of design, construction (section 3.2.3ii) and knowledge creation (section 3.3.4ii). Moreover, it can be used to verify technical operation measures of the technology.

4.2.3 QUANTITATIVE

Quantitative research methodology often represents precise pieces of research measurements and analysis. The technique of data collection in this research design comprises numbers and statistics (Jenkins 2009). The *“quantitative research paradigm…is empirical in nature; it is also known as the scientific research paradigm”* as suggested by Atieno (2009, pp. 13-18), cited in Jenkins (2009). Probst and Roecker (2007) adopted quantitative analysis to a questionnaire. Quantitative statistics were presented for the rating of case studies. Related quantitative analysis were further used by Horvat and Dubois (2012) and Horvat et al. (2011).

This study could be conducted through either structuring a statistical model (i.e. questionnaire) or collecting the obtainable statistical data from former similar research. However, collecting existing data seems impossible due to the lack of previous research studies in this particular research zone. Therefore, statistical modelling is deemed an achievable option which satisfies the perception of architectural integration targeting human dimension, and architect participants in more focus (section 1.2).

4.2.4 QUALITATIVE

Qualitative research often aims to gain insight of sampled people's attitude, behaviour, concerns, challenges, aspirations, culture or lifestyles. Qualitative research is defined as *"a form of systematic empirical inquiry into meaning"* (Shank 2002, p. 5, cited in Ospina 2004, p. 1281). The term systematic stands for 'planned, ordered and public', whereas the term empirical means the perception of others' sensitive experiences. The method design identifies four key components: emphasis on natural settings; focus on interpretation and meaning; focus on participants' own circumstances sense; and the use of multiple techniques (Ellinger et al. 2005). This provides further analysis of the statistics and numbers of quantitative research, the method of conducting qualitative research includes: in-depth interviews, open-ended surveys and feedback forms.

Previous related researches include Rossi et al. (2009) who used observations and interviews, Lundgren et al. (2004) who interviewed participants in the Nordic countries and Thomsen et al. (2005) who conducted a qualitative performance survey of twelve demonstration projects in different countries. Similar to the quantitative research methods discussed previously, qualitative is a possible methodology for the both directions of this study. It could be achieved through conducting a questionnaire or interviews with architects and specialists.

4.2.5 SIMULATION

The methodology of simulation research is often appropriate to composite researches such as energy prospects. Specific computer software or groups of mathematical equations are usually used to simulate complicated models to facilitate a comprehensive study. Even easier than the experimental method in this study, simulation allows the manipulation of one variable at a time to predict its effects within the other parameters. More than half of the available researches on TSC have adopted simulation methodology. Almost all of them simulated technical parameters of the technology such as: performance, heat transfer and wind effects.

Kutscher et al. (1993) was one of the first to adopt simulation research for TSC. Two-dimensional commercial computational fluid mechanics (CFD) software was used by Gunnewiek et al. (1996), Gunnewiek et al. (2002), Dymond and Kutscher (1997) and Wang et al. (2006). A three-dimensional CFD simulation was used by Arulanandam et al. (1999). Simulation methodology using Transient System Simulation Software (TRNSYS) was conducted by Maurer (2004) and Delisle (2008). Brown (2009) has conducted simulation methodology using RETScreen® software in his study to evaluate the thermal performance of TSC.

Simulation is foreseen as a useful methodology to predict TSC performance and operational challenges. To achieve this purpose, the following few set-ups have to be satisfied:

- Credible simulation software to predict the TSC performance and effectiveness parameters.
- The availability of comparable data, either published data or field work measurements.
- A proper validation or correlation regime; this could be conducted experimentally either in the laboratory or in field work.

4.3 DETERMINATION OF RESEARCH METHODOLOGY

Determining appropriate methodology is a challenging task. It has to tackle the research variables and provide a useful approach to solving the problem (Ismail 2005). There is no individual best methodology which satisfies the research aim and objectives. It is deemed appropriate therefore to divide the research methodology into two interrelated strands connected to the two main research directions:

1) The first strand deals with architectural integration which mainly explores human desires perception and preferences relating to TSC (section 4.4) and supplementary prototypes experimental units (section 4.5).

A number of methods were considered under to conduct this strand as outlined in the introduction (section 4.1). The disqualified methods were:

- Case study (section 4.2.1) that was excluded due to not attaining as an accessible case (project) within the timeframe.

- Simulation (section 4.2.5) that was excluded due to the absence of credible software to simulate TSC and absence of empirical data for comparison.

Methods which were utilised for this strand are:

- Mixed-method (section 4.4) that combine quantitative and qualitative research methods to offset individual weakness of each sub-method. This was considered to provide the most comprehensive analysis of the research hypothesis.
- Experimental field study (prototype) (sections 4.2.2 and 4.5) that was also chosen as a supplementary method that adding significance to the survey results as a 'learning by doing' tool, especially the design and construction part of it.

2) The second one relates to the technological innovation development of TSC that analyses the TIS components, functions and interaction between functions in the UK and North America (section 4.6).

   This strand was conducted through qualitative method (sections 4.2.4 and 4.6) through analysis of semi-structured interviews and other secondary data in addition to relevant data from the questionnaire (section 6.2).

Architectural science research studies are often interdisciplinary; therefore, it is deemed reasonable that the ideology of this study comprises multidisciplinary strategies where subservient methods are applicable.

4.4 ARCHITECTURAL INTEGRATION – MIXED-METHODOLOGY

The aforementioned qualitative and quantitative research methods have, to some extent, a strong relevance to the first research direction in this study. To the author's knowledge, this is the first study focused specifically on the architectural integration of TSC. The focal point here is to grasp an insight of the architects' perception of the TSC technology as well as the challenges and limitations to integration. The research parameters being explored in this direction include:

- Awareness of transpired solar technology.
- Architects' perceptions, recommendations and preferences.
- Architectural integration of TSC or PV/TSC in terms of location in buildings, positions, orientation, size, specifications, efficiency, performance and function.
- TSC and PV/TSC aesthetics and function.
- Buildings type, size, and function.

Accordingly mixed-methodology, which comprises quantitative and qualitative design, is deemed the most appropriate approach to address architectural integration of TSC. According to Ellinger et al. (2005), it represents the integration of two or more methods. Each sub-method complements the strengths of the other, and substantially offsets their weakness. Although there are different definitions of mixed-methodology, Tashakkori and Teddlie (1998, pp. 17-18) defined mixed-methodology as the studies that *"combine the qualitative and quantitative approaches into the research methodology of a single study or multiphase study"*. According to Creswell (2006), mixed-methodology is a research design with philosophical assumptions and methods of enquiry. The data collection and analysis is guided by these philosophical assumptions in a mixture of quantitative and qualitative approaches.

The mixed-method research is therefore being adopted in this study due to the complexity of the research. Therefore, a combination of both methods provides the most comprehensive understanding and analysis of the research hypothesis. Conducting mixed-method research requires certain steps: feasibility of the methodology; rationale; data collection strategies and designs; specific questions; data collection and analysis; and writing results.

Methods of collecting data in mixed-methodology include structured interviews, surveys (questionnaires), and observations. The questionnaires can be conducted in interviews, via post mail, via email, or by using web-based survey questionnaire design. Interviews can take place either through face-to-face meetings or through other technology and could be:

unstructured (i.e. during daily conversations); semi-structured (using interview guide); group meetings; or individual (an in-depth interview). Data collection can either be concurrent (Fig. 4-1) or sequential design (Driscoll et al. 2007).

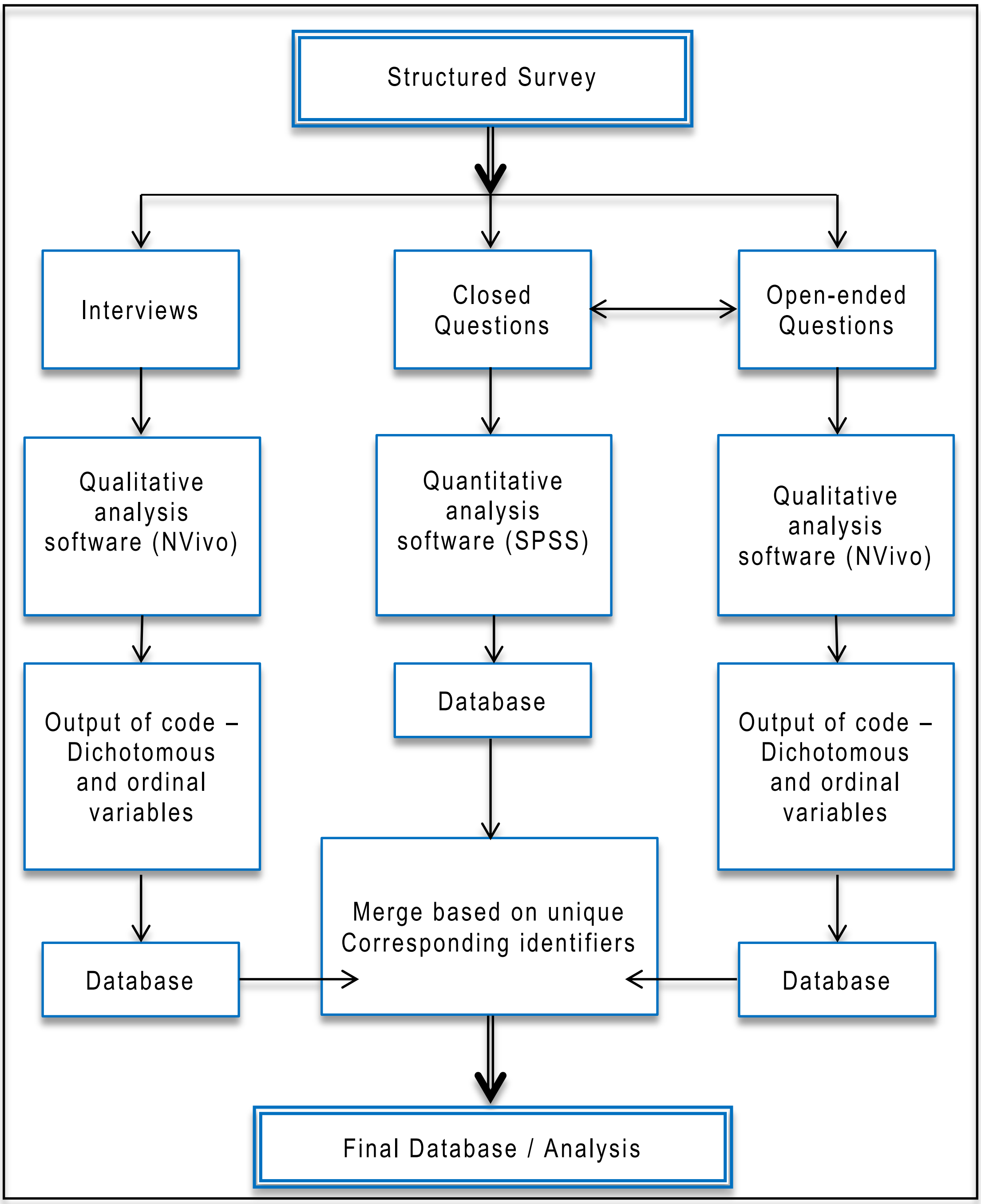


Figure 4-1: Concurrent Design of the mixed-methodology, inspired from (Driscoll et al. 2007)

Mixed-methodology has three different potential design approaches in terms of reporting the results according to Creswell (2006):

- Merge quantitative and qualitative for the results.
- Connect either of the data into another for the results; or
- Embed either of them into another to get the results.

Mixed-methodology has pragmatic advantages for complex research problems while it provides a more comprehensive insight of the study. It furthermore takes advantage of the strengths of both qualitative and quantitative methods where this combination leads to better understanding of research problems rather than either approach alone.

The following sub-sections summarise the selected technology and software packages for mixed-methodology design.

i) WEB-BASED SURVEY - SURVEYGIZMO

The web-based survey questionnaire design is more efficient than the rest of the traditional questionnaire techniques in terms of tracking system, accuracy, and data collection. There are many service providers which range from free usage to costly providers; however, most of them have pricing and service options.

The features of a number of potential web-based surveys' facilitators were compared. These include Lime Survey (www.limesurvey.org), Survey Monkey (www.surveymonkey.com), Esurvey Pro (www.esurveyspro.com) and SurveyGizmo (www.surveygizmo.com). SurveyGizmo was selected because of the free Student-Edition, 24 hours online live help service, the variety of question types, image uploading and other features.

ii) QUANTITATIVE DATA ANALYSIS SOFTWARE - SPSS

Quantitative analysis is the process of interpreting the output data statistically. This deals with the closed-end survey questions. Due to the amount of data to be analysed and to pursue accuracy, the use of reputable analysis software was deemed appropriate. IBM SPSS (www.ibm.com/spss) has been selected to run the quantitative analysis in this study. Statistical Product and Service Solutions (SPSS), provided by International Business Machines Corporation (IBM), is among the oldest and most popular software packages for quantitative data analysis. It is extremely powerful with built-in assistance for users. The latest available version is 'IBM SPSS Statistics 20'.

Validity and reliability: SPSS conducts various commands of input, transformation, analysis and output data validity such as internal and external validity. These options of validating statistics and data include: measures used; design and settings; and concurrent and predictive validity. The software is also reliable in the method it is offered as well as in its predictive data.

iii) QUALITATIVE DATA ANALYSIS SOFTWARE - NVIVO

Qualitative data, usually in the form of words, has gained increasing interest by researchers while there is more of a shifting towards qualitative paradigms in the last decades (Miles and Huberman 1994; Packer 2010). Qualitative Data Analysis (QDA) comprises a set of methods for organising, displaying, processing, summarising, and interpreting non-numeric data. Computer assisted qualitative data analysis software (CAQDAS) saves analysis time. The advantages of CAQDAS include: speeding up the coding process; analysing the complex relationships of data; providing a formal writing structure; storing development notes; and adding more conceptual and theoretical thinking about the data analysis. However, there are also a few criticisms which include a fear that the increasing use of CAQDAS will distance researchers from their data. This might result in a convergence towards a single homogeneity and orthodoxy of data analysis (Barry 1998).

NVivo 10 was selected which has powerful text query tools, for example, it enables the search function for exact and synonym words to broadly test theories. Its workspace is designed based on the Microsoft Office user interface guidelines to be more familiar and provide easy access to project materials.

Validity and reliability: The software outputs have been validated and proved reliable in published research in scientific journals. Among those research studies are Koh (2011), Raitt (2007) and Gibbs (2002).

4.4.1 QUESTIONNAIRE

The questionnaire (Appendix A) was designed to address the research aim and objectives (section 1.4) by analysing the perceptions and challenges of a wide population of architects and other building professionals in relation to integrating transpired solar technology (TSC) in building envelopes. These professions were identified as having a great potential impact on the diffusion of TSC as highlighted in section 1.3. The questions were designed to shed light on information either reported or perceived from the literature review (sections 2.4, 2.5 and 3.2).

A pilot study targeting a few experts in the field was used to improve the survey before the final version was issued (section 4.4.1iii). The questionnaire contained five sections (section 4.4.1i) which are described below. Questions types and rhythm (section 4.4.1ii) were varied to avoid boredom and bias and specialist questions were only asked if appropriate awareness had already been indicated.

Both qualitative and quantitative methods were used to assess the survey, given the mix of closed and open-ended questions.

i) QUESTIONNAIRE STRUCTURE

The survey was structured in five sections in order to control the management of data collection and ease the analysis; these sections were: 1) introduction, 2) personal information, 3) integration examples, 4) architectural integration of TSC, and 5) key issues.

1. INTRODUCTION

Introductory information (aim and purpose of the survey) was provided to guide the participant through the survey. This section illustrated that the survey had ethics approval from the Research Ethics Committee of the Welsh School of Architecture (EC1203.114 – Appendix E). It also highlighted necessary information regarding the possible timing, nature of contribution, voluntary participation, the option of withdrawal and the contact details. This information was also typically available in the invitation email that was sent to the participants.

2. SECTION A: PERSONAL INFORMATION

The introduction was followed by personal information questions which would enable the responses to be analysed with respect to geography, profession, working field, experience and existing awareness of TSC technology. The geographic location of the participant has also been verified by the web-based survey tool as a confirmatory measure of reliability.

3. SECTION B: REAL INTEGRATION EXAMPLES

This section was preceded by illustrative schematic graphs of TSC and hybrid (PV/TSC) installations. The examples were selected from Canada, USA, and Europe to illustrate integration of TSC and hybrid TSC (including PV). The participant was invited to assess the example in terms of multi-functionality and aesthetics. The images were selected based on the criterion of clarity and relation to the statement being tested. The participants were also given the opportunity to express their views on other related issues for each example.

4. SECTION C: ARCHITECTURAL INTEGRATION OF TRANSPIRED SOLAR COLLECTORS

These questions were categorised in groups that addressed similar subjects. The participants could express their opinions on building integration for a variety of building types and integration schemes. Those respondents who indicated an existing awareness of TSC were also invited to answer questions relating to commercially available TSC products. Further questions elicited preferences and recommendations about general integration of solar thermal.

5. SECTION D: KEY ISSUES

This final section offered an opportunity for participants to indicate key issues, challenges and barriers which had not previously been covered in the survey. This section was followed by the acknowledgement and ‘thank you’ page.

ii) QUESTION DESIGN

Having developed subject groupings to elicit the participants' understanding and views on the drivers and barriers to TSC, a variety of question formats were used including Likert scale, multiple-choice, dichotomous, and open-ended questions. The Likert scale terminology was developed by the psychologist Likert (1932) as a psychometric itemised rating scale. It was commonly applied in surveys to measure attitudes and perceptions (Fink 2003; Marsdden and Wright 2010). Multiple-choice questions were used to ascertain the perceptions of the participant where there was no prior indication from the literature of the likely answers.

iii) PILOT SURVEY

A pilot study was conducted to identify any amendments required before launching the survey. Seventeen building professionals participated in the pilot, ten of whom made recommendations. The participants represented the targeted participants; architects, engineers and researchers. The pilot study was used to confirm the reliability and validity of the questionnaire. The pilot survey lasted for eight days in April 2012. The recommendations focused on logistical issues and revision of questions to ensure clarity and lack of bias. One difficulty was in ensuring that the questions relating to building regulations were appropriate for international participants as well as UK participants.

Some pilot participants commented that the survey was lengthy. After consulting with relevant experts, it was decided to retain all the questions, but to re-arrange them to ensure the maximum benefit from each participant, even those who did not fully complete the survey. Moreover, six questions were only posed to adequately informed participants in order to minimise the survey length for unaware participants.

iv) LAUNCH AND DISTRIBUTION

The questionnaire was launched on 16th May 2012 and was accessible for 77 days following an extension of 17 days. The data collection was stopped thereafter due to reaching a satisfactory number of responses and moreover, many of the targeted busy professionals were deemed to be in summer vacation following 1st August 2012. It was distributed to a large population of architects, engineers, academics and other professionals in the building industry in a variety of countries. Although a survey of clients' perceptions (section 3.3) would be useful, they are difficult to identify in the absence of a professional organisation for clients. Nevertheless, consulting architects were deemed to reflect clients' perception within their participation. It was also considered that clients would be unlikely to have a detailed understanding of integration schemes and further technical characteristics.

Distribution was focused on countries with long heating seasons and potential integrations of TSC, primarily Canada, USA, UK and mainland Europe. Efforts were made to contact as many people as possible within the targeted groups. This decision was based on the recommendation "[always] *select more participants than you need, particularly if you are using a sample of humans. People ... notoriously ... don't turn up when they are supposed to ... and don't fill out questionnaires properly"* (Pallant 2011, p. 4). This was taken to heart, particularly since the targeted population were presumably busy professionals with extensive workloads.

Invitations were sent to more than 46,240 people via direct email contact. Of these, approximately 19,750 were architects and 11,105 were engineers in the UK, Canada and USA. The remaining 15,385 represented architects, engineers and other professions from mainland Europe and beyond. The list of invitations was filtered carefully to avoid any duplicated email addresses; however, there was potential for more than one invitation to reach participants with two or more different email addresses. Additional indirect invitations were sent through networks such as LinkedIn, and professional associations such as the UK Architects Registration Board (ARB), UK Royal Institute of British Architects (RIBA), the Royal Architectural Institute of Canada (RIAC), and the American Institute of Architects (AIA) as shown in Table 4-1. Responses were controlled by single individual use per the Internet Protocol (IP) address to prevent multiple submissions.

Table 4-1: Examples of the sources that have been used to transmit email assesses from, for direct invitations

<table>
<tr><th></th><th>Architects</th><th>Engineers and Others</th></tr>
<tr><td>United Kingdom</td><td>Academia (883)
- Welsh School of Architecture, Cardiff University
- Architectural Association (AA) School of Architecture
- Bath University
- Sheffield University
- The Glasgow School of Art
- UK Surrey University

Professional (5,054)
- Architects Registration Board (ARB)
- Royal Institute of British Architects (RIBA)
- Royal Incorporation of Architects in Scotland (RIAS)
- Architecture Centre Network
- Association of Consultant Approved Inspectors</td><td>Academia (352)
- School of Engineering Cardiff University
- Greenwich University, System Engineers
- Sheffield University
- The Glasgow School of Art
- UK Surrey University
- Bath University

Professional (3,057)
- Chartered Institution of Building Services Engineers (CIBSE)
- Chartered Institute of Building (CIOB)
- Association of Building Engineers (ABE)
- Construction Industry Council (CIC)</td></tr>
<tr><td>Canada</td><td>Academia (288)
- Dalhousie University, Faculty of Architecture and Planning
- University of Manitoba, Faculty of Architecture
- University of Toronto, John H. Daniels Faculty of Architecture, Landscape, and Design
- Laval University, Faculty of Planning, Architecture, Arts and Design
- University of Calgary, Faculty of Environmental Design

Professional (2,096)
- Royal Architectural Institute of Canada (RAIC)
- American Institute of Architects (AIA), Canadian members
- Architectural Institute of British Colombia (AIBC)
- Ontario Association of Architects (OAA)
- Northwest Territories Association of Architects (NWTAA)
- Manitoba Association of Architects (MAA)</td><td>Academia (334)
- University of Waterloo, Faculty of Engineering
- Faculty of Applied Science and Engineering, University of Toronto
- University of British Columbia, Engineering
- University of Alberta, Faculty of Engineering
- McGill University, Faculty of Engineering
- McMaster University, Faculty of Engineering

Professional (1,943)
- Engineers Canada
- Canadian Solar Industries Association (CanSIA)
- Solar and Sustainable Energy Society of Canada Inc
- National Renewable Energy Laboratory (NREL) - Canadian listings</td></tr>
</table>

Table 4-1 Continued: Examples of the sources that have been used to transmit email assesses from, for direct invitations

	Architects	Engineers and Others
United States of America	**Academia (656)** - Harvard University - Yale School of Architecture (YSOA) - University of Virginia, School of Architecture - University of Pennsylvania, School of Design - University of Cincinnati, School of Architecture and Interior Design - Cornell University, Department of Architecture - College of Environmental Design, University of California, Berkeley - Sci-arc University **Professional (10,773)** - American Institute of Architects (AIA)	**Academia (1,489)** - Arizona State University, Engineering School - Massachusetts Institute of Technology - Binghamton University - College of Engineering at Colorado State University - Princeton University - Washington University - Brown University **Professional (3,930)** - National Society of Professional Engineers - Leadership in Energy and Environmental Design (LEED) - National Renewable Energy Laboratory (NREL) - Arizona Society of Professional Engineers - Association of Energy Engineers - California Society of Professional Engineers - Florida Engineering Society - Institution of Mechanical Engineers - Nevada Society of Professional Engineers - New York State Society of Professional Engineers - Texas Society of Professional Engineers
Mainland Europe	**Academia (2,304 minimum)** - TU Delft University, Energy - Netherlands - Zurich University, Department of Architecture - Munich University of Applied Sciences - Escuela Técnica Superior de Arquitectura de Madrid in Spain - University of Applied Sciences in Germany - The Faculty of Architecture in Alghero, Italy - Università degli Studi di Brescia, Italy - Higher Trade School of Hannover, Faculty of Architecture and Landscape Sciences **Professional (12,822)** - Royal Institute of British Architects (RIBA), European contacts - Architects Council of Europe (ACE) - Professional Associations in many European Countries	
Literature Review, Authors and Research Contributors (259)		

v) VALIDITY AND RELIABILITY

Validity and reliability are the means of ensuring good measuring. Validity is broadly defined as *"the extent to which a measurement method measures what it is intended to"* (McDowell and Newell 1987, p. 330, cited in Fawcett 2007). Validity could be tested in a number of methods to determine the effectiveness of question design towards the concept being assessed. These methods might be face validity, content validity, criterion or construct validity (Fawcett 2007). The face and content validity, which are subjective measures of the questions in accordance with pre-existing theory or experience, were ascertained during the pilot stage of the questionnaire. Further content validity was ascertained by the participants, especially those who sent completed responses of the questionnaire. A few notes were made in regards to the language of some questions.

Construct validity could be used to ensure the meaningfulness of the questions to measure that which was intended to be measured in accordance to pre-existing theory (Litwin 1995). This was not relevant to the questionnaire purpose which was designed to perceive understanding, challenges and recommendations with limited pre-existing information.

The reliability is known as the degree of stability of data or observation when repeating a measurement of identical conditions. The reliability of a survey could be assessed in three forms: test-retest reliability, alternate-form reliability, and/or internal consistency reliability (Litwin 1995). The test-retest assessment was not possible as it measures the stability of two timely different responses from an individual participant that was to be excluded by the IP controlling technique of the survey tool. Alternative-form reliability measures two differently worded questions for responses that produce a similar concept or evolve a comparable response (Litwin 1995). This was indirectly ascertained for certain questions such as question 29 that examined the participant's familiarity of commercial TSC technology and the awareness of the same participant in question seven. Further discussion has been included in section 5.10.1.

Internal consistency reliability is applied to a group of items that were combined to form a single scale rather than one item. It reflects the complementation of the items in measuring different aspects of the same variable or quality (Litwin 1995). The internal consistency reliability is commonly expressed in the form of a correlation coefficient called Cronbach's alpha (α) which examines the degrees of correlation between several questions intended to measure the same underlying concept and has to exceed 0.70 for good reliability (Litwin 1995). This test could only be ascertained after receiving responses, therefore, the reliability was checked following the receipt of the first 100 responses. The Cronbach's alpha (α) was calculated using 'SPSS'. Table 4-2 shows the calculated (α) for several themes being tested. Since all four cases tested exceed 0.70, it is indicated that the survey is internally consistent and therefore reliable.

Table 4-2: Cronbach's Alpha Reliability Statistics

Cases being tested	Cronbach's α	Items tested
Decision Making (Section 5.5.3)	.710	18
Integration Examples (Section 5.6)	.858	14
Architectural Integration Quality (Section 5.7)	.722	20
Sustainable Characteristics (Section 5.8)	.705	7

4.4.2 STATISTICAL ANALYSIS

Statistical analysis of quantitative data reinforces confidence in the results in comparison to the non-statistical analysis presented in other relevant surveys. This drawback was acknowledged by Horvat et al. (2011) in relation to their survey of the digital tools used for solar design (section 3.2.2i). The statistics add significance value to the data; it quantifies the possible differences or similarities in data using proven and robust techniques. It can furthermore, infer a conclusion about population from a small subset sample of the population; this is particularly suitable for large survey pools (Field 2009) like this study.

Specific statistical tests are applicable for certain data types. The question design and data collected pre-determined the type of statistical analytic tests undertaken. Statistical analyses were performed using the

SPSS package. Non-parametric tests are ideal for nominal (categorical) and ordinal (ranked) variables (Field 2009; Pallant 2011) such as those generated by this survey. The most suitable tests to be carried out for the data of this study were '*Pearson's Chi-square test'*, '*Spearman's correlation coefficient'* and "Mathematical Mean" which are described hereafter.

i) PEARSON'S CHI-SQUARE TEST

Pearson's Chi-square test is also called the Chi-square test for independence. It is used to explore the significance of a relationship and the association between two categorical variables. This is based on a comparison of observed results with ideally expected frequencies. The Pearson's Chi-square (χ^2) is given by (Field 2009):

$$\chi^2 = \sum \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \tag{4-1}$$

Where 'O' is the observed data, 'E' is the expected data, 'i' represents the rows in the contingency table and 'j' represents the columns. The statistics can thereafter be checked against a distribution with known properties. The Chi-square values are drawn from a cross-tabulation of the two categorical variables. A degree of freedom (df) for the distribution is calculated as $(r-1)(c-1)$ where r represents the number of rows and c represents the number of columns. The assumptions of the Pearson's Chi-square test are: random samples; independent observations where each respondent or case is counted once; and the frequency of each cell is greater than five. If the last assumption is not achieved, the Pearson's Chi-square test will be violated and considered invalid for that particular analysis.

As Pearson's Chi-square explores the significance of association between variables, the null hypothesis of the test is that the variables are independent. The conventional value of significance, p (the asymp. Sig. value), must be less than 0.05 in order to reject the null hypothesis and then gain confidence that the variables are in some way related. Otherwise, the hypothesis of variables independency is to be accepted (Field 2009).

Effect size: *"the strength of the difference between groups, or the influence of the independent variable"* (Pallant 2011, p. 207). Statistics can also be used to determine the effect size. The most commonly used one for 2 x 2 tables is '*phi coefficient'* which ranges from 0 to 1, with the higher value indicating a stronger association between the two variables. For larger tables, Cramer's V is commonly used which takes into account the degree of freedom (Pallant 2011). Table 4-3 shows different criteria of the size of effect.

Table 4-3: Different criteria for the effect size (Pallant 2011, p. 210)

Number of Variable Categories / Cells	Effect Size		
	Small	Medium	Large
Two	.01	.30	.50
Three	.07	.21	.35
Four	.06	.17	.29

Reporting the results: the importance of reporting Chi-square results is the determination of the association's significance between variables. The Pearson's Chi-square test is often represented by the following term: $\chi^2(df, respondents) = Pearson's\ Chi - square\ value, p,\ effect\ size$.

ii) SPEARMAN'S CORRELATION COEFFICIENT

Spearman's correlation coefficient is a non-parametric bivariate correlation test usually known as Spearman's-rho and represented as 'rho'. It is a useful statistical technique that determines the correlational strength and direction between variables. The value of Spearman's-rho ranges from (-1) to (+1) where the sign in front indicates the direction of the relation, with ±1 representing perfect correlation. Zero represents no relation indicating that the variables are independent which is the null hypothesis. Table 4-4 shows guideline values for the correlation coefficient. The level of association is therefore given by (Spearman's-rho) whereas the statistical significance 'p' in the correlation is an indication of the confidence in the results rather than strength of relationship. However, 'p' value should be less than 0.05 to gain confidence (Field 2009; Pallant 2011).

Table 4-4: Guidelines of correlation coefficient (Cohen 1988, cited in Pallant 2011)

Correlation Coefficient	Negative Correlation	Positive Correlation
Small	-.10 to -.29	.10 to .29
Medium	-.30 to -.49	.30 to .49
Large	-.50 to -1.0	.50 to 1.0

Coefficient of determination: the significance of the difference between correlation coefficients is often calculated manually as the option is not available using SPSS. The rho values are to be converted into a standard score form (referred to as z_r score) which are tabulated against rho values (Table C-1 in Appendix C). The following equation estimates z_{obs} where N is the respondent numbers according to Pallant (2011):

$$z_{obs} = \frac{z_{rho1} - z_{rho2}}{\sqrt{\frac{1}{N_1 - 3} + \frac{1}{N_2 - 3}}} \qquad (4\text{-}2)$$

There will be significant difference between the two correlation coefficients if the value of z_{obs} is less than -1.96 or greater than +1.96.

Reporting the results: when reporting Spearman's correlation coefficient, there is a need for '*rho*' value and 'p' value. The rho value is often written to two decimal places without the leading zero before the decimal point (.xx), as it does not exceed one.

iii) MATHEMATICAL MEAN

The mathematical mean was used in particular Likert scale questions; those are the rating of the example projects (section 5.5.3) and factors influencing sustainability of TSC (section 5.7.2). To simplify understanding of the ranking scale, the Likert scale was weighted by numerical scale of ±100 (-100, -50, 0, +50, +100) in order to report the respondents rating in percentage form. This weighting scale was a direct conversion from the original Likert scale being accessed by the participants in the survey (-2) very poor, (-1) poor, (0) neutral, (+1) good, and (+2) perfect. This method of weighting was inspired by Probst and Roecker (2011) and was used similarly. The Likert scale is non-continuous data, which might not sometimes match the principle rule of mean value. The statistical mode or median could also have been used, however, it represents the most frequently selected rather than the ranking. Furthermore, experts were consulted who confirmed the suitability of using the statistical mean in this case as statistical tests have a degree of subjectivity. Therefore, this technique was used to represent an indicative visualisation of the rank among the rated examples.

4.5 EXPERIMENTAL FIELD STUDY (PROTOTYPE)

The experimental field study is supplementary to the main research direction, architectural integration of TSC. As inferred from section 4.2.2, prototyping and testing the TSC experimentally adds significance to the survey results. After investigating the options, the only feasible option was to design and build a prototype testing rig (Appendix D). The prototype was sourced through the **s**ustainable **b**uilding **e**nvelope **d**emonstration (SBED) project (www.sbed.cardiff.ac.uk). The following are motivations to select the experimental prototype to match or mismatch the survey results as well as to verify the data being reported in the literature (section 2.5):

- Develop a more thorough understanding and hands-on experience of the issues to be considered when installing a TSC.
- In prototype, a number of different scenarios can be presented by manipulating different positions and configurations of TSC. This assists in understanding the impact these may have. However, this is beyond the contents of this study due to timeline commitment.
- Independent practical assessment of TSC performance. This helps effective decision making in planning for wider use of TSC.

4.5.1 PROTOTYPE LOCATION

A suitable location for the prototype as a testing project was required. This location would be away from possible vandalism or accidental damage.

Most importantly, the south direction should be unobstructed to gain the most solar irradiation. The top roof of Bute Building, the home of the Welsh School of Architecture (WSA) was found to be a feasible setting. It is located in the city of Cardiff at Latitude 51.4 ºN, Longitude 3.1 ºW. The prototype was designed to include four TSC units with each collector maintaining the same approximate area of 1.08m^2 per unit, but with different schematic settings. Three of the panels have the same circumference except the fourth, the square panel (Fig. 4-2). The units were constructed by the researcher with the assistance of sustainable building envelope demonstration (SBED) team members. Design and construction of the prototype is further detailed in section 5.10 and Appendix D. The south facing orientation was achieved using a rope with the shadow line at noon.

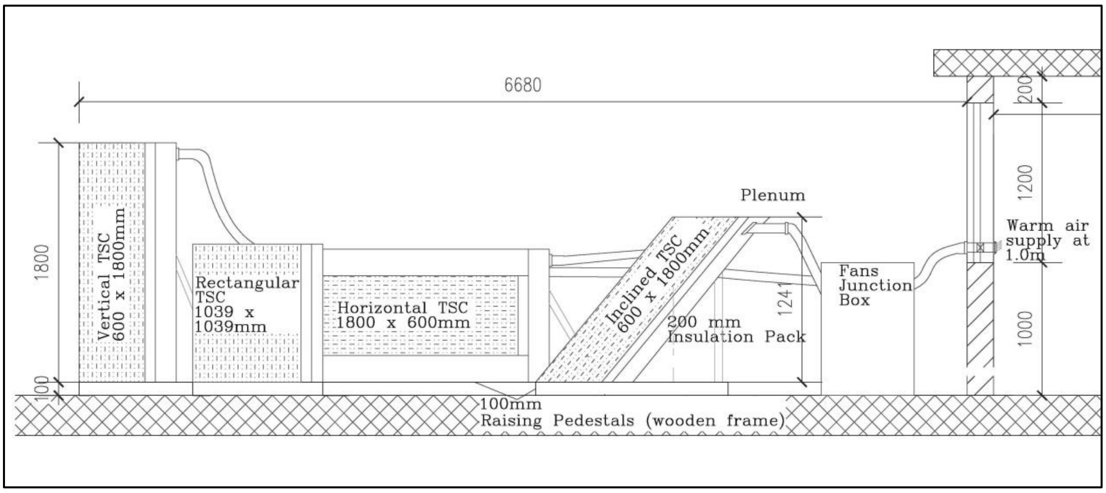


Figure 4-2: South-east elevation shows schematic TSC prototype units

4.5.2 EXPERIMENTAL PARAMETERS

The experimental research parameters being explored are divided into two types as follows:

<u>Variables:</u>

- Temperatures of ambient air (Tamb)
- Collector's surface temperature (Tcol)
- Ambient wind speed and direction
- Air flow in the plenum

- Solar irradiation at a vertical surface (Sol)

Measurable Outputs:

- Output temperature at the exit from the TSC (Tout)
- Supply temperature at the entry of the room (Tsup)
- Temperatures in the TSC plenum

The locations of measurement instruments are shown in figure 4-3. The effectiveness was therefore manually calculated using equation 2-3 as a function of outputs. Furthermore, efficiency of the TSC was calculated using equation 2-6. The fan was off most of the time while the data was being collected which leaves the air flow rate under the condition of buoyancy effect.

Figure 4-3: Schematic diagram shows the location of measurements, author

4.5.3 METEOROLOGICAL MEASUREMENTS

The monitoring devices were agreed, ordered and managed by the SBED team. Table 4-5 presents descriptions of the instruments being used, pictures of the devices can be found in Appendix D.

Table 4-5: Description of the meteorological measurement instruments

Instrument	Description and Accuracy
Air Temperatures (ambient, collector, output and supply)	
PT100	- Used for ambient, output and supply temperatures. - Measures −20 to +200 °C range. - Has a standard tolerance of ±0.15 + 0.002x[t°C]

CS215
 	
(it further measures relative humidity)
	- Used for ambient and supply temperatures.
	- Measures −40 to +70 °C range.
	- Accurate at the following ranges:
	  - ±0.4°C from 5° to 40°C
	  - ±0.9°C over -40°C to +70°C

Type-T thermocouple sensors	- Used for collector's surface, output and cavity temperatures. - Measures −200 to +350 °C range. - Has a tolerance of ±1.0°C as a standard with a special of ±0.5°C limits of error. - The sensitivity of Type-T is about 43 μV/°C.
Wind Speed and Direction	
A100R Switching Anemometer	- Included in the weather station (Fig. D-7, Appendix D). - Measures from 0.2m/s to >75m/s maximum wind speed. - Accurate to ±0.1m/s for 0.3-10m/s, ±1% for 10-55m/s and ±2% for wind speed >55m/s.
PT100	- Included in the weather station. - Operates up to a maximum wind speed >75m/s. - Covers 360° full circle continuous rotation. - Accurate to ±2° obtainable in steady winds over 5m/s. - Assigns compass direction (i.e. NNE, WSW...). - Linearity error is 0.5% of full scale output

Table 4-5 Continued: Description of the metrological measurement instruments

Instrument	Description and Accuracy
Air Flow	

Sontay AV-DSP: Single-Point Multi-Range Air Velocity Transmitter	- Located before the fan, in the duct.
	- Measures output range of 0 to 32m/s
	- Accurate 3% of range:
	    - ±0.12 m/s (0 to 4 m/s)
	    - ±0.24 m/s (0 to 8 m/s)
	    - ±0.48 m/s (0 to 16 m/s)
	    - ±0.96 m/s (0 to 32 m/s)
	- Operates under temperature range of -10° to +50°C.

Solar Irradiation	
Kipp and Zonen's CMP3 pyranometer	- Located vertically top side of the vertical TSC unit. - Measures up to 2000W/m^2 maximum irradiance. - The sensitivity of CMP3 is 5 to 20 m µV/W/m^2. - Operates under temperature range of -40° to +80°C. - Non-linearity error: ±2.5% between 0 and 1000W/m^2. - Maximum error attributes to temperature dependence is ±5% (-10° to +40°C).
Data Logger	
Campbell CR1000	- A one is at the fan table. - Records the data from all the measurement instruments it reads from the multiplexers on each panel. - Operates under temperature range of -25° to +50°C. - Analog Inputs: 16 single-ended or 8 differentials individually configured. - Analog Resolution: 0.33 µV

4.5.4 DATA VALIDITY

Many of the monitoring instruments have been validated by previous research within the Welsh School of Architecture (WSA) and elsewhere. For example, Kipp and Zonen pyranometers were used in Meier (2000), Stevenson (2007) and Badache et al. (2012). Instruments which had not been previously validated were tested by using two different devices, from different brands, to perform the same function. The ambient temperature for example, was measured by an individual PT100 near the TSC unit and also recorded through the weather station using a built-in device. Figure 4-4 shows an example of the difference between the two readings.

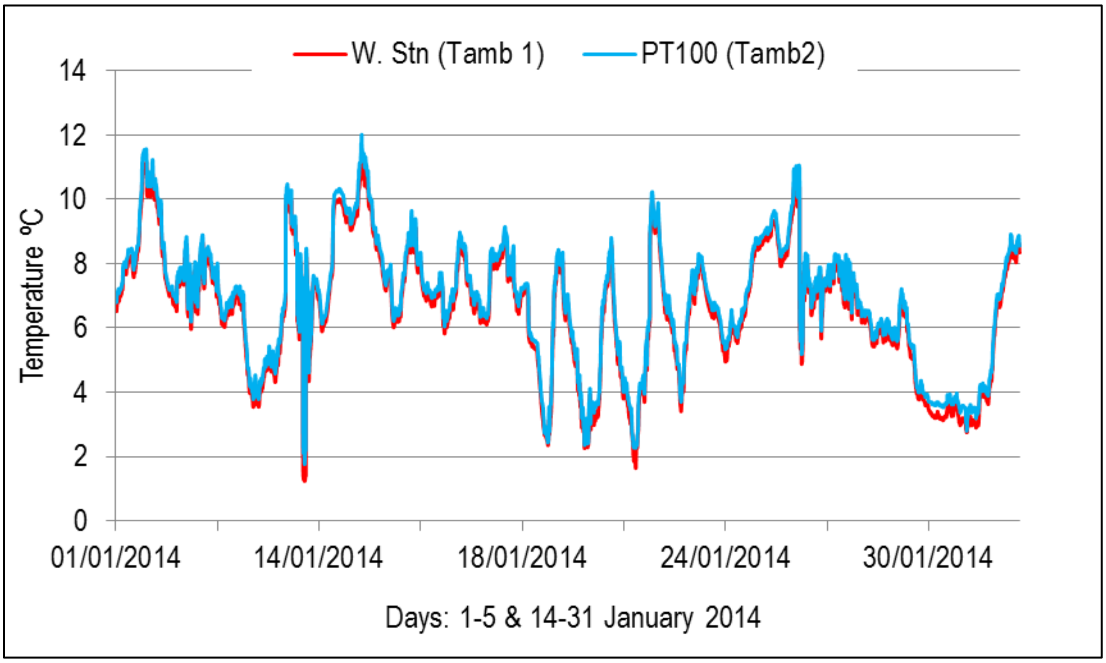


Figure 4-4: Data validation for two readings of the ambient temperature using the weather station built-in temperature device and an individual PT100 sensor next to the collector

The difference in ambient temperature readings reached a maximum of 0.83°C in certain occasions, however, the average difference is 0.25°C. The PT100 records for all temperature readings were used in the data analysis (section 5.10.3) in order to minimise the possible calibration error through using the same device type. Similarly, the output temperature of the TSC and the supply temperature next to the supply point to the office on the roof were also measured using PT100 and CS215 sensors. The average difference in the readings was 0.46°C although higher differences had been recorded at certain occasions, especially at mid-day with high solar irradiation. This difference remains within the tolerance range shown in Table 4-5 above. Dual measurements procedure was followed in many readings and remained in operation for almost the entire period of data recording. Furthermore, in certain areas, multiple sensors were used in order to allow for instrumental failure.

4.5.5 MONITORING PERIOD

The monitoring started in the late summer of 2013 and remained through the winter of 2013/2014. The monitoring started after delays due to logistic issues in delivering the TSC units and financial and compliance issues in procuring monitoring devices and other relevant materials such as insulation, ducting and framing.

The data was collected over two extended periods, from which relevant datasets were selected for analysis. The first period was from 2nd August until 20th September 2013, with sampling at 5 minute intervals. The second collection period was from 4th December to 31st January 2014 at 30 second intervals.

4.6 INTERVIEWS AND QUALITATIVE DATA

This section is related to the second main research direction, technological innovation development of TSC. The research parameters being explored include:

- Status of knowledge creation and diffusion (i.e. academic research, research and development (R&D), patent, conferences, media).
- Entrepreneurial activities (i.e. entrants into the market).
- Actors, institutions and networks available to deploy TSC.
- Current status in the market and technical issues.
- Satisfaction of TIS functions and the interaction between these functions.

The information from the questionnaire indicated that TSC is ready to become fully commercialised; the process of commercialisation and further development needs to be analysed systematically through technological innovation system (section 3.3). Having addressed the research aim through undertaking a questionnaire and a prototype project, further investigation was required to examine the entrepreneurs' vision towards the existing status and future development of TSC. Targeting TSC entrepreneurs originated from their significant importance as the principal actors in the TIS where innovation system would not function without them (section 3.3.4i). Furthermore, TSC entrepreneurs deemed to hold most of the knowledge contexts about the TSC technology. Unlike architects and designers, the entrepreneurs were not directly approached to take part in the questionnaire; rather, they were approached through semi-structured interviews. In order to further address the research aim and objectives (section 1.4), an interview was designed to analyse the perceptions of TSC entrepreneurs in the UK and North America.

As architects and other buildings professionals were perceived to have significant impact on the potential knowledge development about TSC (section 1.2), the entrepreneurs were perceived as having significant impact on progressing this technology (section 3.3.4). The questions and layout were influenced by the literature review (section 3.3) and were further improved following a pilot study that targeted professionals in the field as highlighted afterwards (section 4.5.2).

4.6.1 INTERVIEW GUIDE

An interview guide of questions (Appendix F) was developed around the technological innovation structural components (section 3.3.3) and functions (section 3.3.4) of TSC technology. The guide was used in a purposely flexible manner. Some of the designed questions were not necessarily posed to each interviewee whereas additional questions were inserted in some interviews; the questions were also not asked in the same order.

4.6.2 PILOT INTERVIEWS

Similar to the pilot questionnaire (section 4.4.1iii), pilot interviews were conducted locally. As a result of this, improvements to the questions design and context were made. It also confirmed the reliability and validity of the interviews. This also provided an estimate of the approximate time required to carry out the interview and allowed the researcher to practice his interviewing techniques. The pilot interviews provided an opportunity to adjust and re-structure the interview guide and context. Four experts in TIS from Cardiff University participated; they were all researchers with records of published works and/or workshops in the field of TIS.

Positive outcomes were retrieved from the participants that enriched the context and flow of the interview guide. The pilot study strengthened the researcher's confidence of a 'good-to-go' approach in order to launch the real interviews.

4.6.3 SELECTION OF INTERVIEWEES

TSC entrepreneurs were targeted. Participant entrepreneurial personnel with different responsibilities and background were targeted in order to diversify the insights of the collected data to the largest possible extent. Contact details of appropriate UK based interviewees were mainly retrieved from the official websites of TSC entrepreneurs (section 2.4.4). Additional contacts were recommended by Cardiff University researchers working on TSC related projects (e.g. SBED). The next phase was targeting North American TSC entrepreneurs. Entrepreneurial firms were invited to participate in interviews through their official contact email and cold telephone calling as retrieved from their official websites (section 2.4.4); the only accessible method of contact for almost all the North American entrepreneurs. A number of contact details of entrepreneurial personnel were retrieved from the professional network 'LinkedIn'. Those were identified per their current or previous employer if listed as a TSC provider in section 2.4.4 and furthermore by searching the words 'transpired solar'.

The aim was to achieve theoretical saturation on all topics from interviewees until the collected data are stable enough (Lincoln and Guba 1985). The main factor in sampling was, however, the appropriateness of the participants to contribute to the research topic (Bowen 2008).

4.6.4 ETHICAL MEASURES

Ethics approval was sought before interviews took place, which was obtained from the Research Ethics Committee at the Welsh School of Architecture on 7th May 2013 under reference number EC1305.149 (Appendix F). This approval was mentioned in the body of the email invitation to all the participants. The interviewees were briefed of the research's aim, dimensions, interview length and the use of data. A fully-detailed consent form was given to the interviewees with regard to the way in which interviews were conducted and use of the data.

4.6.5 EXECUTION OF THE INTERVIEWS

The interviews were conducted on a one-to-one basis. Table 4-6 shows a brief list of the completed interviews conducted. Where interviews could not be progressed they have not been included in the analysis as they lack the consent form (Appendix F) which was deemed incompliant with the ethical consideration process. Entrepreneurs from Canada were also invited to participate, but only one reply was received.

Table 4-6: Brief list of the interviewees (completed interviews)

Interviewee	Date	Country	Mean of conduct
Interviewee 1	29th May 2013	UK	Telephone Call
Interviewee 2	29th May 2013	UK	Telephone Call
Interviewee 3	4th Jun 2013	UK	Face-to-face
Interviewee 4	15th Oct 2013	USA	Telephone Call
Interviewee 5	15th Oct 2013	Canada	Email

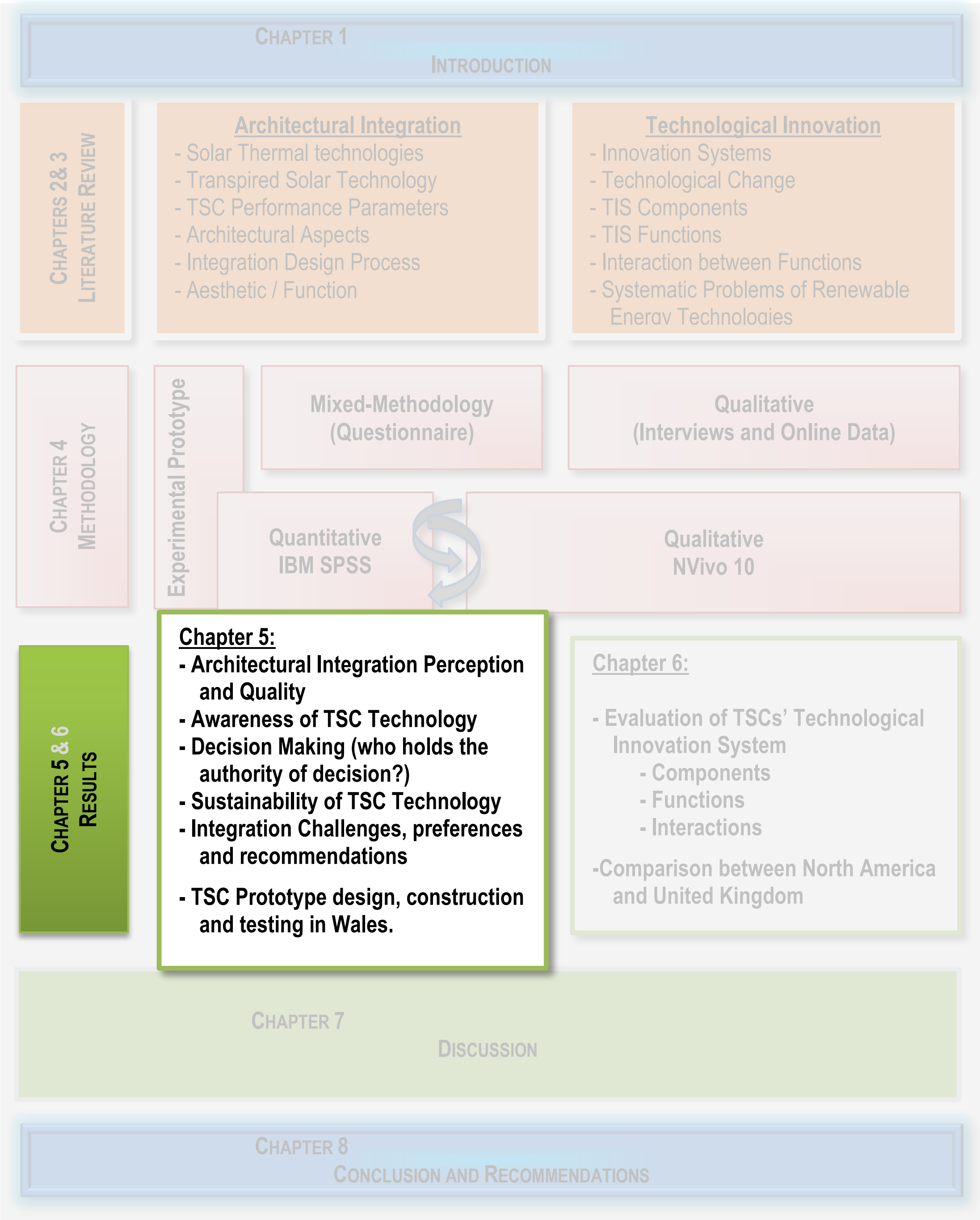
The interviewees were all from TSC manufacturing and were given time to elaborate their views without interruption by the interviewer/researcher. Each interview lasted about thirty minutes, and was audio-recorded. The location, timing and the comportment of each interview were decided by the interviewees themselves.

4.7 CONCLUSION

The scope of this study covers interdisciplinary topic which needed a combination of approaches. A variety of possible methods were explored to find the appropriate methodology that satisfies the aim and objectives of the study within the pre-defined time frame. This study considers transpired solar collectors not just as a specific technology but including the human dimensions of the technology. This led to the selection of methods related to social exploration. The scope was divided into two interrelated strands, architectural integration of TSC in buildings and technological innovation development; these both remain within the human dimension exploration. A mixed-methodology was designed particularly for the architectural integration which was further supplemented by an experimental prototype, whereas only the qualitative method was used for the TIS analysis. The experimental prototype method was deemed a supportive tool of hands-on experience which was confirmed by respondents during the study (i.e. section 3.3.4ii). The prototype was furthermore recommended as a knowledge creation and diffusion tool in the TIS literature and moreover by interviewees during the progress of this study. The appropriate tools have been selected for analysing the quantitative and qualitative data arising from these techniques.

CHAPTER 5 ||

ARCHITECTURAL INTEGRATION



5.1 INTRODUCTION TO RESULTS AND DISCUSSION

The results in this study are divided into two chapters followed by a chapter of discussion. This chapter has been tailored to analyse the responses to the architectural integration survey described in section 4.4.1. Chapter 6 is tailored to analyse the interviews and other secondary data related to TSC TIS development. The aims and objectives defined in section 1.4 are listed below. Against each one, the relevant results and discussion section are noted. The research aim is to provide insight into architecturally integrating transpired solar thermal technologies in buildings for space heating in temperate regions, and clarify its potential contribution to pre-heating ambient air in Wales.

This aim includes an investigation of the limited adoption of integrating and deploying TSC in building envelopes despite its apparent technical competitiveness which is addressed in this chapter (sections 5.6 to 5.9). Further insight is moreover highlighted in chapter 6 and further elaborated in detail in the discussion on the barriers to integration (section 7.5). The aim also includes that socio-economic concerns of technological innovative development are explored at entrepreneurial level in the UK and North America; this was addressed in chapter 6 as highlighted in objectives vi, vii and viii below).

The TSCs' potential contribution to pre-heating ambient air in Wales was clarified in section 5.10, as also highlighted in objective (v) below.

The research objectives are as follows (repeated from chapter 1 with the corresponding results and discussion section in chapters 5, 6 and 7):

Architectural Integration of TSC:

i) Examine the existing awarness of the TSC (sections 5.4.1 and 7.2) and verify the role of the architect as a principal decision maker who facilitates integrating the technology in design (sections 5.4.3, 5.9.2 and 7.3). This includes verifying the decision making actors and elucidating the integrated design process (IDP) which produces more consolidated architectural outputs (sections 5.4.3, 5.9.2 and 7.3.3).

ii) Investigate different functional and aesthetic integration preferences of TSC and hybrid PV/TSC, and find out the preferable optimum architectural integration scheme for architects and end-users (sections 5.5, 5.6 and 7.4).

iii) Understand the architects' perceptions and recommendations of building-integrated transpired solar thermal technologies (sections 5.5, 5.6 and 7.5).

iv) Identify the needs of architects, engineers, and building professionals for improved architectural integration quality and flexibility of solar thermal energy (section 5.6, 5.9 and 7.4), in a form of design prerequisites (section 7.7).

v) Gain insight into the constructability and integration practise of the TSC through design, planning and building a prototype project. The protoype project to be furthermore practically tested to clarify the potential usefulness of TSC technology for space heating in Wales (section 5.10).

<u>Technological Innovation Development (TIS) of TSC:</u>

vi) Evaluate the technological innovative development of TSC in the UK at the entrepreneurship level (i.e. sections 6.3.1ii, 6.4.1ii 6.4.5ii and 6.5.2) and compare it to the North American case (i.e. section 6.6 and 7.6) using interviews as the main source of data and other secondary data sources (section 6.2).

vii) Identify the barriers of integrating the TSC (section 7.5), and highlight potential enablers to integrating and deploying TSC technology for researchers, entrepreneurs and policy-makers to consider for further improvement and technological development (section 7.6 which further builds on section 7.5, it builds on sections 5.6, 5.7, 5.9, 6.4, 6.5, and 6.6).

viii) Investigate the contribution of the technological innovation system to the development, diffusion and utilisation of transpired solar collectors (i.e. sections 7.5.2, 7.5.5, 7.6.1, 7.6.4, and 7.6.7).

The remainder of this chapter presents the results relating to architectural integration.

5.2 PARTICIPATION OUTLOOK

The total number of returned questionnaires was 1,734; of which 938 (54.1%) were completed, 357 (20.6%) partially filled, and 439 (25.3%) empty and disqualified replies. The questionnaire was considered empty if question seven was not reached, and disqualified if it contained jargon words; however, only one individual case was recorded as disqualified whereas the rest were empty.

The distribution of the responses is illustrated in Table 5-1. It shows the direct and indirect campaigns and the complete, incomplete and empty responses. Although the response rate is never expected to be 100% (Baruch 1999), the response rate fluctuated from 1.3% to 18.5%. The overall response rate of 3.3% from direct invitations seemed fairly low. However, the total number of responses was the highest yet in comparison with relevant previous studies that targeted architects and building practitioners.

The received responses in Probst and Roecker (2011) were 170 (around 11.3% response rate) from mainland Europe (section 3.2.3iii) whereas the number of responses in Farkas and Horvat (2012) in Task 41 was 903 (section 3.2.2i). The response rate in Horvat et al. (2011) fluctuated from 1.8% to 26% with an overall rate of 5.9%. Nevertheless, there is no standard benchmark for minimum acceptable response rates in academic researches as highlighted by Baruch (1999).

Table 5-1: Response rate of the questionnaire divided by invitation campaigns (direct and indirect invitations) n/a: not available

Country	Categories		Invitations	Complete	Partial	Empty	Total	Response Rate
United Kingdom	Architect	Academia	883	20	7	9	**36**	**4.1%**
		Professional	5,054	124	53	38	**215**	**4.3%**
	Engineer	Academia	352	33	10	7	**50**	**14.2%**
		Professional	3,057	95	33	25	**153**	**5.0%**
Canada	Architect	Academia	288	10	2	6	**18**	**6.3%**
		Professional	2,096	37	16	12	**65**	**3.1%**
	Engineer	Academia	334	8	4	0	**12**	**3.6%**
		Professional	1,943	30	13	14	**57**	**2.9%**
United States	Architect	Academia	656	10	2	4	**16**	**2.4%**
		Professional	10,773	206	61	25	**292**	**2.7%**
	Engineer	Academia	1,489	22	9	10	**41**	**2.8%**
		Professional	3,930	33	10	10	**53**	**1.3%**
Mainland Europe		Academia	2,304	64	33	40	**137**	**5.9%**
		Professional	12,822	131	57	144	**332**	**2.6%**
Literature Review	Architect	Academia	259	10	0	10	**48**	**18.5%**
		Professional		3	0			
	Engineer	Academia		16	4			
		Professional		5	0			
Sub-Total (Direct Invitations)			46,240	*857*	*314*	*354*	1,525	3.3%
Facebook	Architect	Academia	n/a	3	3	16	**30**	**n/a**
		Professional		2	2			
	Engineer	Academia		1	1			
		Professional		1	1			
LinkedIn	Architect	Academia	n/a	6	3	45	**135**	**n/a**
		Professional		27	11			
	Engineer	Academia		6	0			
		Professional		19	18			
Referrals	Architect	Academia	n/a	2	1	24	**44**	**n/a**
		Professional		5	0			
	Engineer	Academia		1	3			
		Professional		8	0			
Total				**938**	**357**	**439**	**1,734**	**n/a**

5.3 DEMOGRAPHY OF RESPONDENTS

The initial survey questions established categories which could be used in categorising responses from the rest of the survey. Three professional categories were established: architects, engineers (29.0% mechanical, 14.1% energy, 14.1% civil and construction, 11.1% building services, and the rest 31.7%) and others (lecturers, researchers, designers, architectural specialists, building physicists, contractors, and energy advisors). These groups form the main criterion of analysing responses to many of the questions. The distribution of these categories in the respondent population is illustrated in figure 5-1.

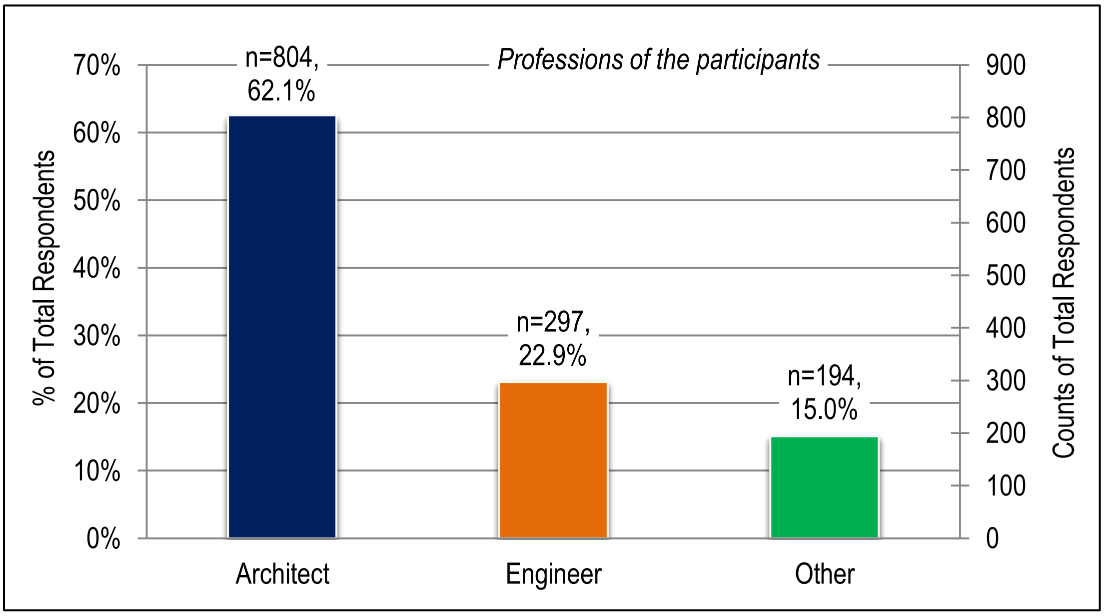


Figure 5-1: Distribution of respondents according to profession

In terms of work field, the largest respondent group was consultancy (49.3%, n=638); of which 72.6% were architects. The next largest respondent group was academia (22.6%, n=293) of which 38.9% were architects. The remaining defined groups were contractors (9.8%), local government (3.2%) and national government (3.1%). The ‘other’ sectors contained designers, and development advisors (Fig. 5-2).

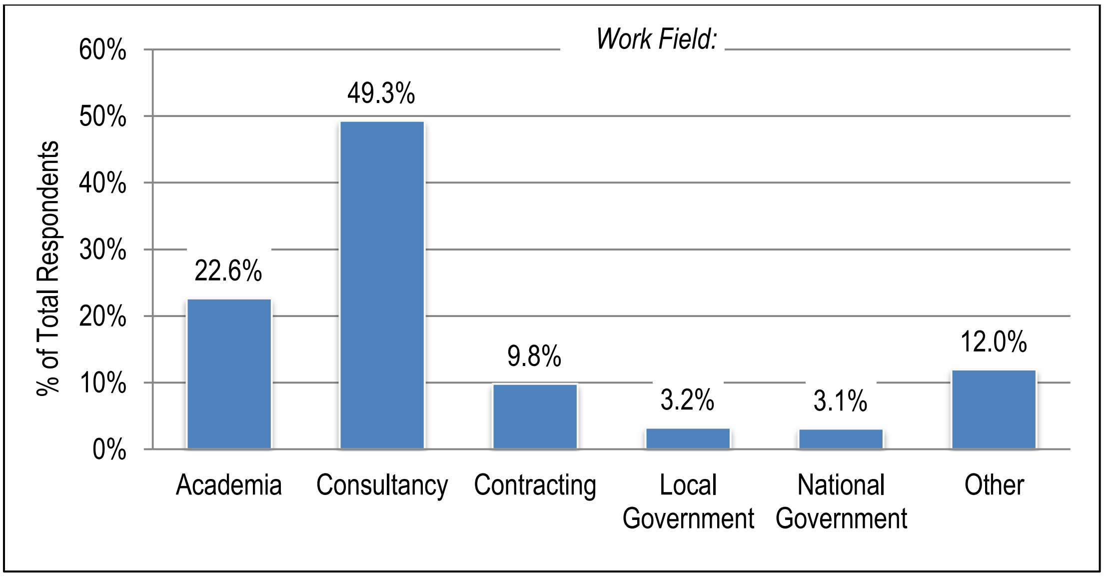


Figure 5-2: Distribution of respondents according to work field (Table C-3, Appendix C)

The majority of respondents (64.6%, n=836) had more than 15 years of experience in the field (Fig. 5-3) indicating high levels of expertise in the responses. They represent reasonable evaluation of the technology due to experience. However, this does not undermine the input of the remaining respondents who are likely to represent updated knowledge and ambition.

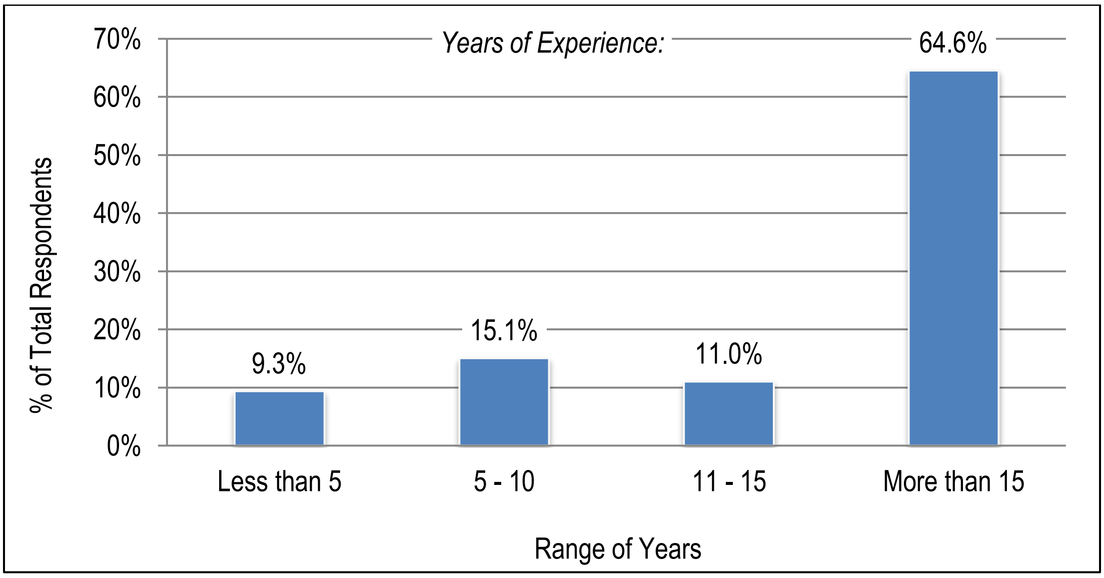


Figure 5-3: Distribution of respondents according to their years of experience (Table C-4, Appendix C)

The respondents were distributed across 73 countries. The majority of participants were based in the USA, UK, and mainland Europe (24.6-29.5%

each) with a less significant response from Canada (9.6%) as shown in figure 5-4. Approximately half of the mainland Europe response was from Italy, Ireland, Germany, France, Spain, Switzerland, Austria and the Netherlands. Other countries represented South America, the Middle East, Africa, and Australia.

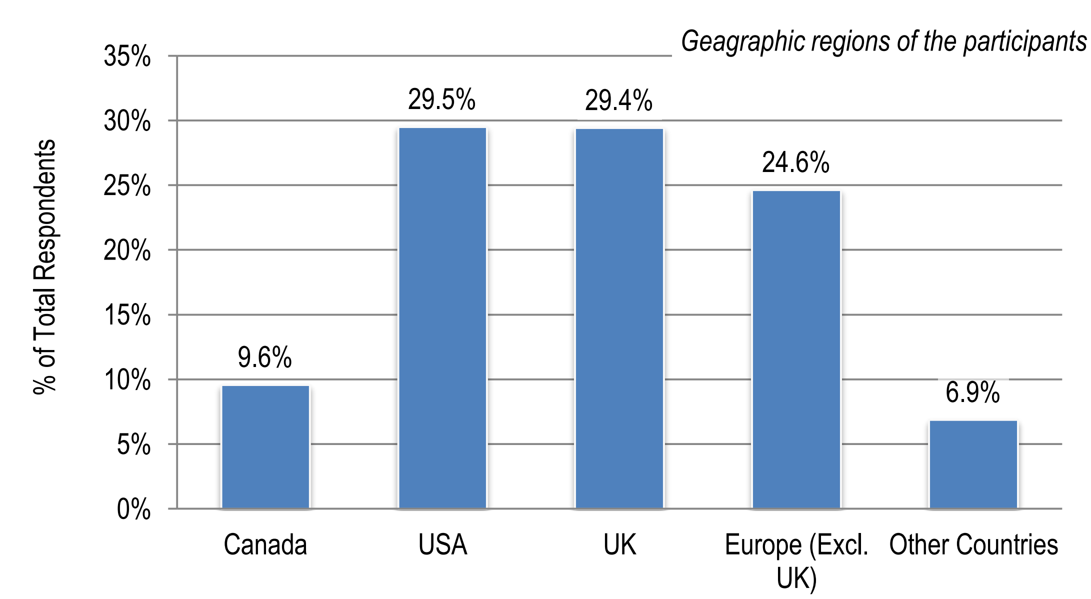


Figure 5-4: Location groups of survey respondents (Table C-2, Appendix C)

Along with the geographic distribution of the respondents, climatic zones distribution was analysed. The climatic zones boundaries were regarded as per Köppen climate classification that is an empirical system based on features of native vegetation, average temperatures profile and the seasonality of precipitation. The classification was further amended by the German climatologist Rudolf Geiger (Pidwirny 2006; Peel et al. 2007; patil 2011; Belda et al. 2014). Köppen classified the world's climate into five basic climate groups with 29 sub-climate zones. The main groups are as follow (Fig. 5-5):

- Group A: Tropical climates: Constant high temperatures along the year (above 18°C).
- Group B: Dry (arid and semiarid) climates: Precipitation is usually less than threshold with average annual temperature above 18°C.

- Group C: Temperate and subtropical climates: An average temperature above 10ºC in the warmest seasons and between -3ºC and 18ºC in the coldest months.
- Group D: Continental climates: An average temperature above 10ºC in the warmest months versus a below -3ºC in the coldest months.
- Group E: Polar and alpine climates: An average annual temperature below 10ºC.

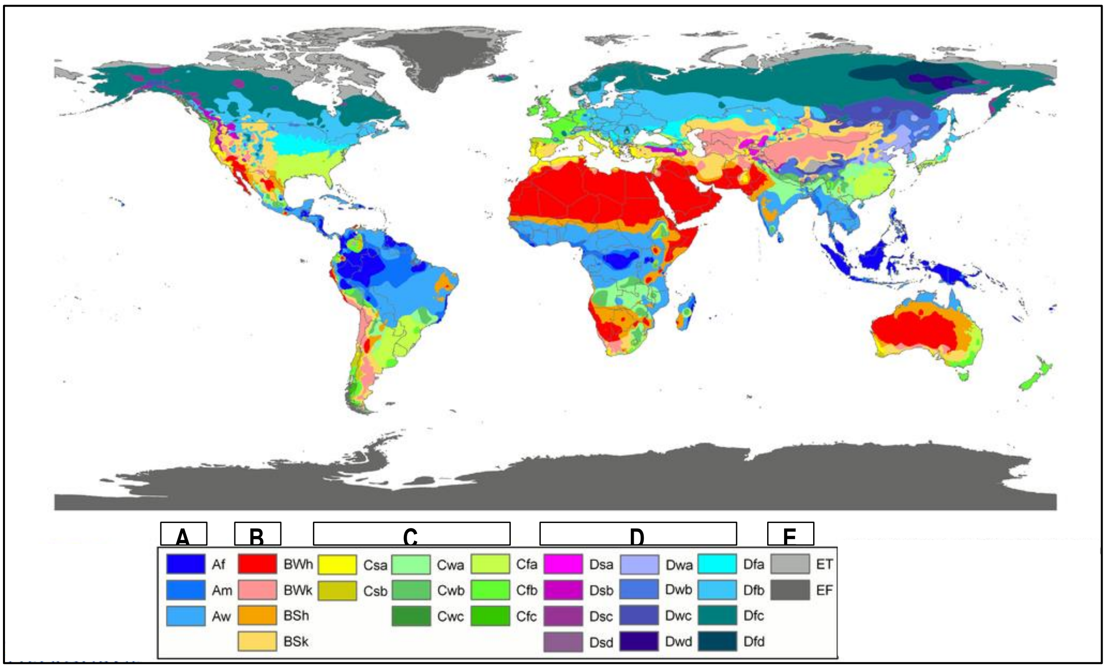


Figure 5-5: World map of Köppen -Geiger climate classification (Peel et al. 2007).

Sub-climate zones have slight variances within each main group; these differences include level of humidity and dryness, length of seasons and temperature bands. Analysing the sub-zones was deemed not practical in this study as violates the Pearson's Chi-square test statistical rules due irregular distribution of responses (section 4.4.2i). Group E was excluded from the analysis as achieved no responses. The majority of responses were from temperate climates, group C (64.9%, n=833) followed by continental climate, group D (25.6%, n=328). Tropical climate respondents, group A were 2.5%, n=30 versus 7.0%, n=90 respondents from dry climate zone, group B. Due to ambiguity over respondents' city, 12 respondents within

USA were not classified into any climate zone and excluded from relevant analysis that leads to a total response number of 1,283 within this category.

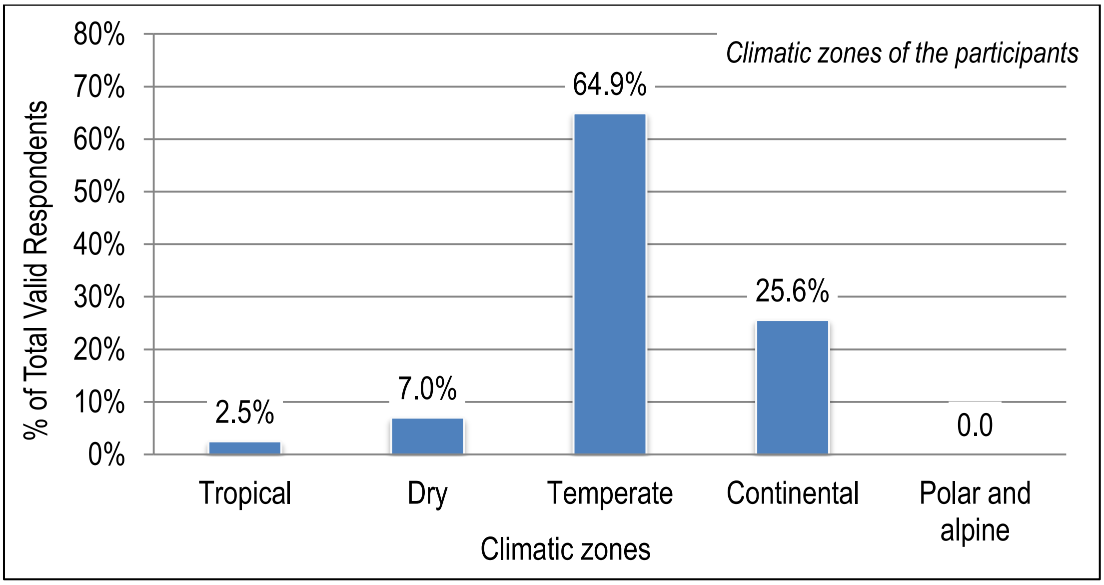


Figure 5-6: Climate zone groups of survey respondents

It was found that 30.7% of respondents had achieved a Bachelor's degree, with another 60.4% achieving postgraduate qualifications. The architects comprised the highest number of survey participants having a Master's degree within a profession (49.1%). The participants with PhD credentials within the profession of engineers (25.9%) and others (27.8%) were almost three times each that of the architect participants (9.2%) as presented in figure 5-7.

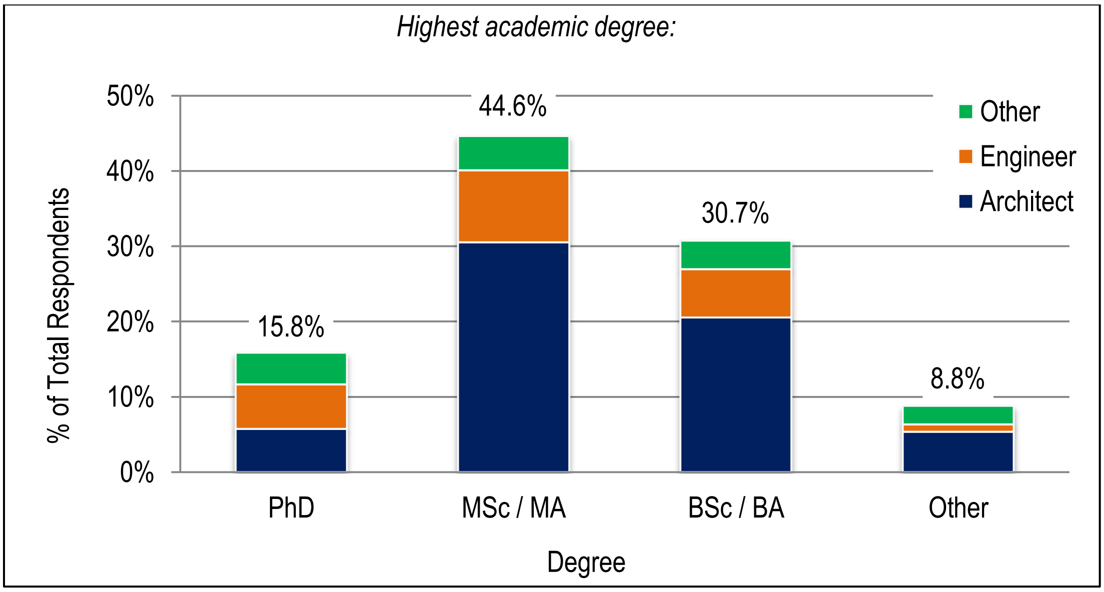


Figure 5-7: Highest academic degree of participants (Table C-5,Appendix C)

The participants were asked to identify the type of projects they were involved in from the survey options: commercial, residential, institutional and industrial, with a provision for participants to add further types. The participants had the option to tick as many boxes as were applicable.

In decreasing order, the participants were found working on residential building types (58.6%), followed by commercial (54%), institutional (42.9%) and industrial (21.1%). Other projects (20.2%) included healthcare, public and community projects (Fig. 5-8).

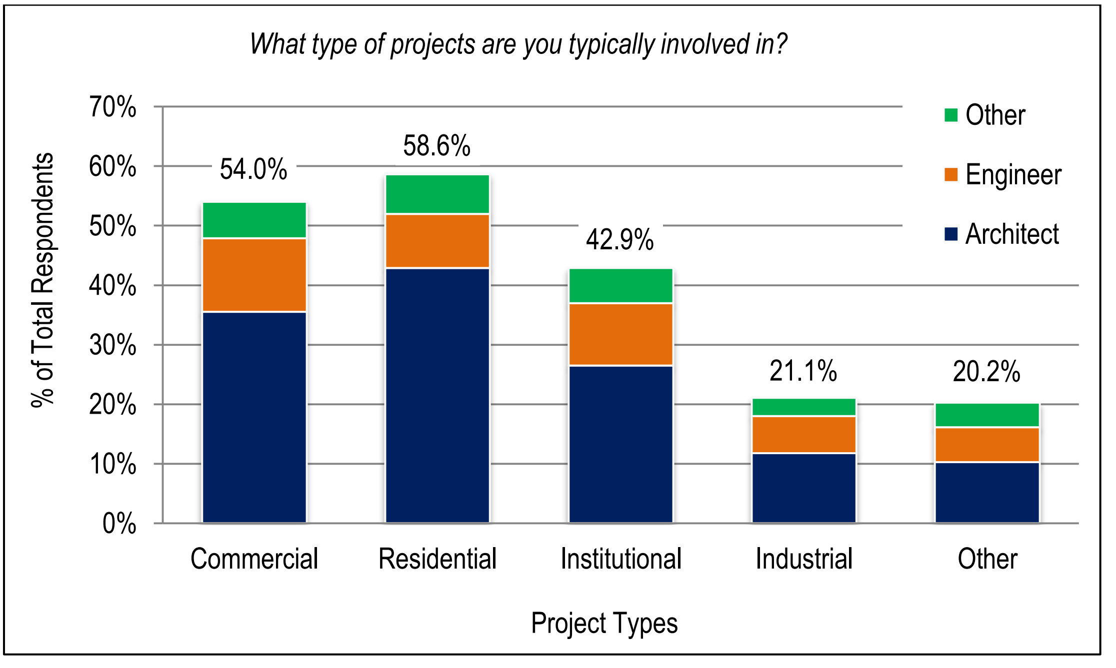


Figure 5-8: Project involvement of the participants (Table C-6, Appendix C)

Although the majority of respondents are architects, the response to this survey is less biased than other relevant surveys like Farkas and Horvat (2012) and Horvat et al. (2011), it is nearly identical to Probst and Roecker (2011) percentage wise but not in numbers of participants. The engineers and others together were almost one third of the total respondents which form a reasonable balance of unbiased results.

The lower percentage of participants from mainland European countries was reasonable especially when considering population density, focus of questionnaire distribution, and the fact that the questionnaire was written and distributed only in English, which is not the first language in any of these countries.

Notably, the respondents were required to indicate their country of practice, although, the web-based tool was assigned to verify geographic country and city individually, using proxy determination in order to confirm the validity of responses. The proxy information was missing in few cases, and in other fewer cases, was not matching. The missing proxy addresses were confirmed individually through an IP address locater website. However, the non-matching cases were considered valid responses as they could be interpreted due to temporary residents or visitors in different countries at the time of participation in the questionnaire. Some respondents may have indicated the country where they practised their profession rather than countries of residence. Overall, more than 92% of the answers were recognised as geographically identical.

The knowledge of the respondent's field of work (Fig. 5-2 above) determines the value of the answers. Although all working fields are important, some may have more influence in decision making. The relatively high number of consultants, along with some developers, strengthens the validity of the data due to their direct relationship with the decisions. The participants from academia support the reliability of the analysis as they focus more on the factual aspects and performance of such a technology. The robust variety of participants' project experience (residential, commercial, and institutional) supports the reliability of the data, especially for the six allocated questions of domestic and non-domestic buildings.

5.4 BUILDING-INTEGRATED SOLAR ENERGY

Questions were designed to establish the respondents' awareness of TSC in particular and their views on the contribution of solar energy to a sustainable built environment in general. This was followed by an exploration of the participants' views on the influence which building professionals have on decision making in relation to integrating TSC in building envelopes.

5.4.1 AWARENESS OF TRANSPIRED SOLAR TECHNOLOGY

The existing awareness of TSC technology was considered within three categories: expert, aware, and unaware. Commercial brands of TSC were listed to ease recognition. Since this question was crucial to the survey, the survey was considered empty if this question was not answered. Very few participants considered themselves to be experts in this field (1.7%, n=22). The remainder were evenly split between 'unaware' and 'aware' as shown in figure 5-9.

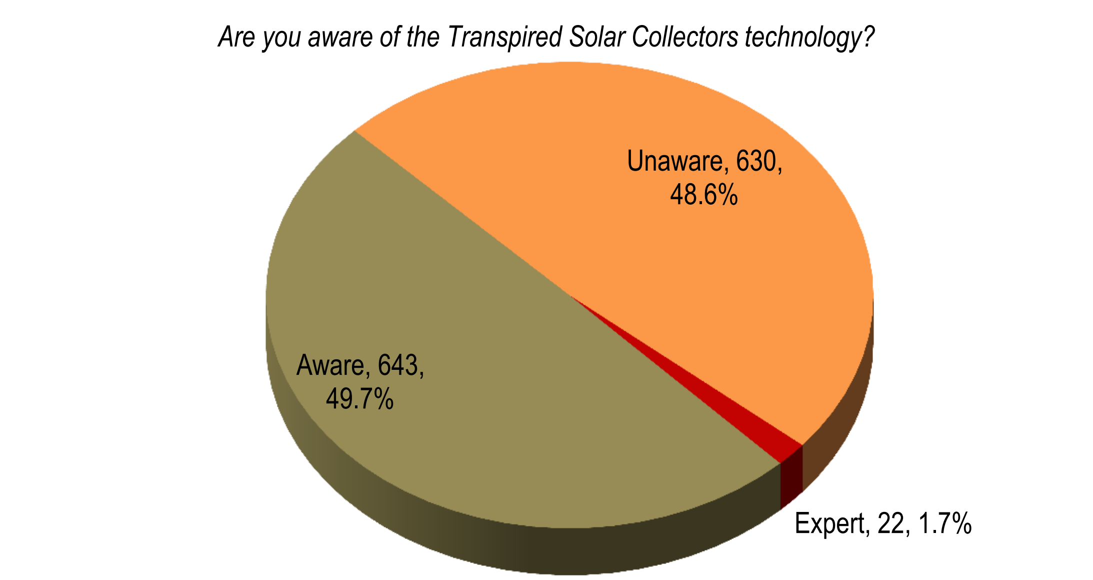


Figure 5-9: Awareness of transpired solar collectors (Table C-7, Appendix C)

There were more engineer experts in TSC (4.7%, n=14 of the total engineer respondents) than other professions. However, the expert group was so small it could not be statistically analysed in isolation; it violates the Pearson's Chi-square rules. Both expert and aware respondents were grouped into one category called 'overall awareness'. There is no statistically significant association between awareness, in general, and respondents' profession $[\chi^2(2, n = 1295) = 5.68, p = .058]$ where $(\chi^2(df, respondents) = Pearson's\ Chi - Square\ value, p\ , effect\ size$ as described in section 4.4.2.

In terms of geographic regions, a higher proportion of Canadian participants were expert or aware (71.0%, n=88) than for any other countries. This was followed by mainland Europe (53.3%, n=170). Among

European countries; the highest rates of awareness were recorded in Greece (81.8%, n=9), Norway (70%, n=7), Italy (67.6%, n=23), and Switzerland (64.7%, n=11). The UK participants recorded a moderate overall awareness almost similar to mainland Europeans at 52.8%, n=201. The responding USA professionals had the lowest awareness with 41.4%, n=158 (Table C-8 and C-9 in Appendix C). Statistically, there is a significant association between awareness and respondents geographic region $[\chi^2(4, n = 1295) = 35.38, p < .0001,\ \text{Cramer's V} = .165]$ (Table C-9, Appendix C).

In terms of climate zones, the highest awareness was found in continental climatic zones, group D, (57.6%, n=189). This was followed by: temperate zones, group C, (49.7%, n=414); dry zones, group B, (48.9%, n=44); and tropical zones, group A, (43.8%, n=14). There was no statistical significant association between awareness and respondents climatic zone $[\chi^2(3, n = 1283) = 7.017,\ p = .07,\ \text{Cramer's V} = .074]$. However, this awareness could relate to knowledge of an existing technology rather than practical experience as discussed in section 7.2.

When examining awareness in relation to project involvement, there was a relative association of respondents' awareness of TSC. Most of the expert respondents were involved in research or design of industrial projects (50%, n=11 within the expertise participants). Similarly, those who were involved in industrial projects recorded the highest awareness rate (56.0%, n=153) (Table C-10, Appendix C).

In terms of expert respondents, the academia field showed the highest rate of experts (50% within expert respondents) followed by consultancy where 31.8% of expert respondents were working (Table C-11, Appendix C). Notably, an expert respondent who was classified as 'other' was working in both academia and consultancy which increases each of the above two rates by 4.5% each. Three academic experts of TSC were involved in industrial projects.

In terms of overall awareness, the fields of consultancy and academia recorded 53.9% and 52.2% respectively. This was followed by participants working in government and contracting with around 47.5% overall awareness. However, there is no statistically significant association between the field of work and general awareness of TSC (Table C-12, Appendix C).

5.4.2 CONTRIBUTION OF SOLAR ENERGY TECHNOLOGIES TO SUSTAINABLE BUILT ENVIRONMENT

The participant's perception of the contribution of solar energy technologies towards a sustainable built environment was analysed. As shown in figure 5-10, 91.4% (n=996) out of 1,090 respondents agreed that solar energy technologies made a positive contribution towards the creation of a sustainable built environment. Statistically, there was no significant association between this opinion and the participant's profession, work field, academic degree, climatic zones, geographic regions, or years of experience. Furthermore, there was almost no correlation between the positive contribution of solar energy and overall awareness of TSC. This means that this variable is independent and represents a general vision of most participants.

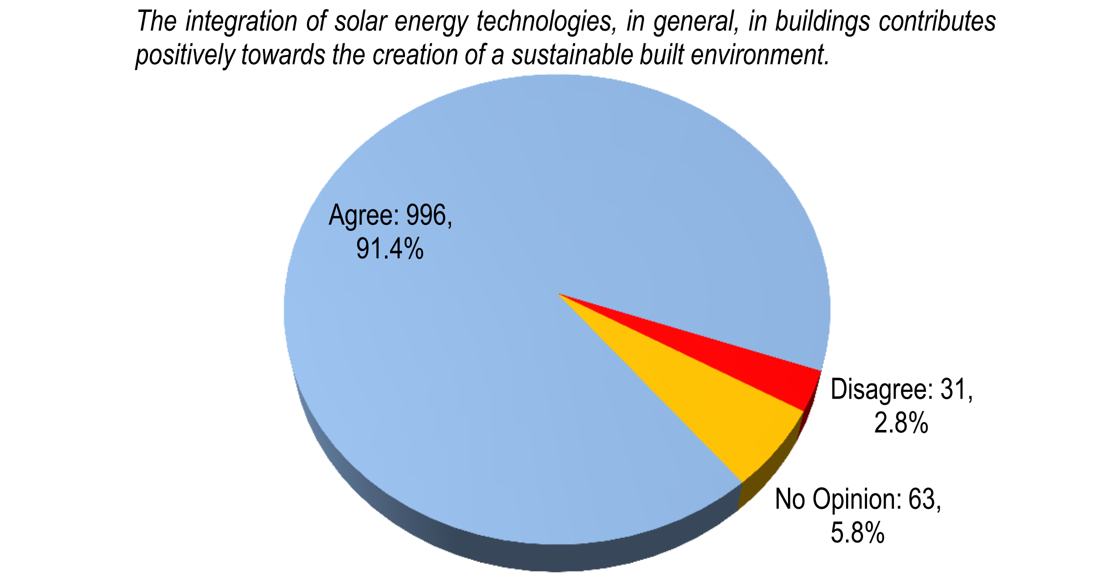


Figure 5-10: Positive contribution of integrated solar energy technologies towards the creation of a sustainable built environment

Qualitative Analysis: When survey participants were offered the opportunity to respond to questions with comments and notes it was expected that comments would address issues related to the contribution of solar energy towards a sustainable built environment. However, many participants took the chance to express their perceptions and opinions in solar energy challenges and other relevant issues. To indicate the participants' pre-existing perceptions, the main themes of these comments are noted here with further comments as appropriate in this and the following chapters. Figure 5-11 represents four of the most common themes, which are described below.

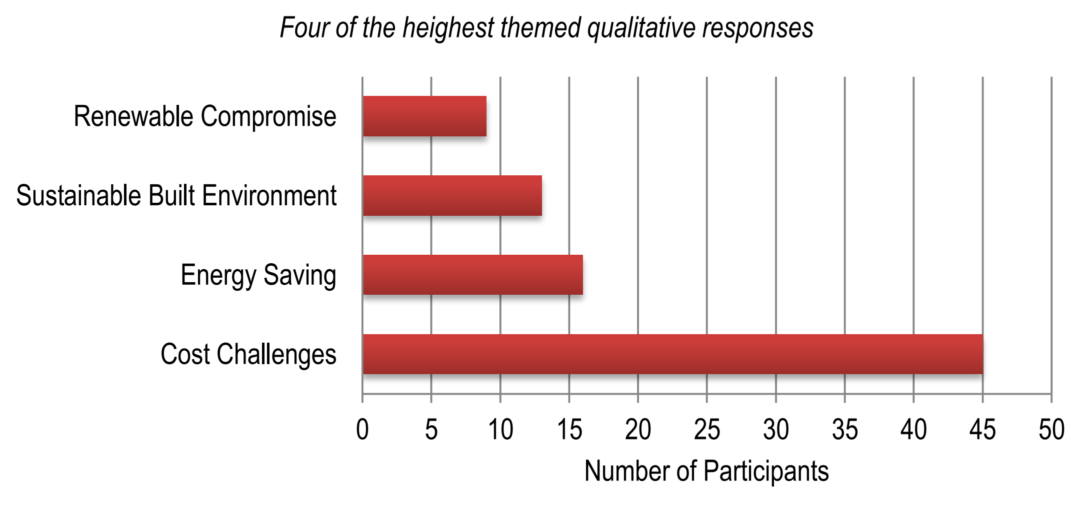


Figure 5-11: Four of the highest themes of the comments showing the number of participants

Further participants were found to be cautious of focusing on solar thermal technologies at the expense of other renewable energy sources or sustainable features, although they agreed it contributed to a sustainable built environment. Other participants defined sustainable design and the goal of solar energy in sustainable design. In general, the comments showed deep knowledge by most commenting participants on the topic of solar technologies. Some participants were found narrowly linking solar energy to PV, especially when they mentioned the high cost of PV technology. This may be due to social and cultural differences as highlighted in due course.

5.4.3 DECISION MAKING IN RELATION TO TSC IMPLEMENTATION

The decision making process in relation to domestic (i.e. dwelling) and non-domestic (i.e. office) buildings was explored. Further to this, the decision making process in relation to the integration of TSC in buildings (i.e. façade and roof) was explored.

i) TSC IMPLEMENTATION IN DOMESTIC DWELLINGS

As shown in figure 5-12, the client is considered to have the major say in TSC utilisation for domestic dwellings (74.2%, n=778). However, multiple answers were accepted for this question and the architect was also considered to have a major influence in the decision (50%, n=524).

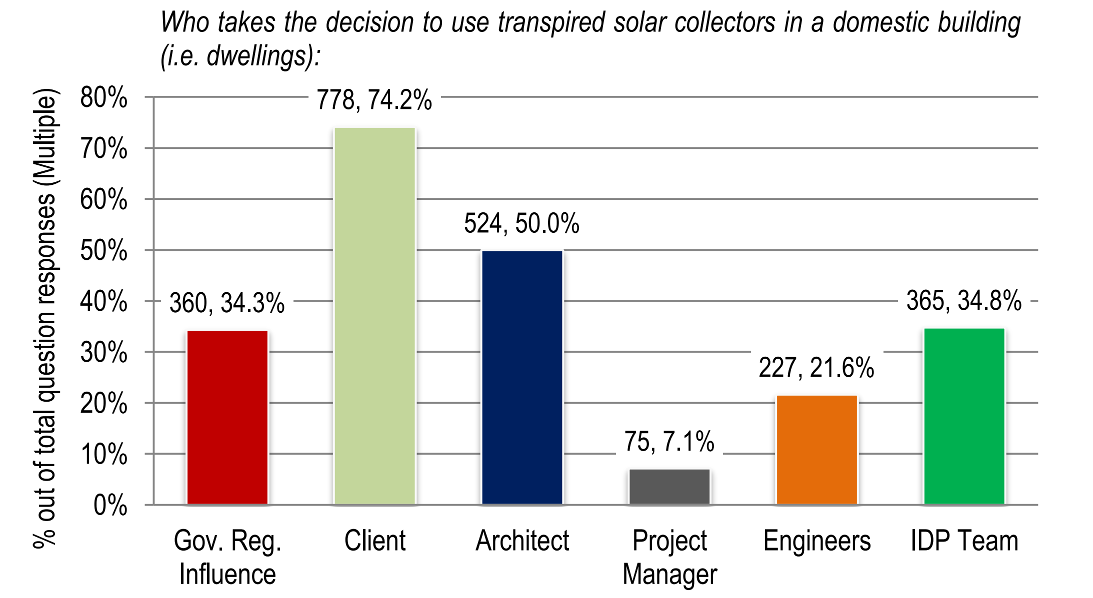


Figure 5-12: Authority of decision to use TSCs in domestic buildings (number of participant, percentage of total responses of a multiple answer question)

There is a statistically significant association between respondent profession and the selection of 'client' as a main decision maker $[\chi^2(2, n = 1049) = 10.26, p = .006,\ \text{phi} =\ .099]$ and also those who selected 'architect' $[\chi^2(2, n = 1049) = 20.71, p < .0001,\ \text{phi} =\ .141]$. In both cases, the majority of respondents were architects. This reflects a true picture of the client's position in decision making, as the architects principally deal with the clients. Although, there might be some bias in selecting 'architect' as decision makers by architect respondents, the effect size is small. Furthermore, the 'engineer' and 'other' respondents had a quite similar percentage of selecting 'architect' which adds confidence to the results.

Further significant association was recorded between profession and 'government regulation influence' $[\chi^2(2, n = 1049) = 9.11, p = .01,\ \text{phi} = .093]$. The 'other' respondents accumulated 19.1% for 'government regulation influence' versus 16.9% by engineers and 14.2% by architect respondents. Another significant association was recorded between profession and 'engineering' $[\chi^2(2, n = 1049) = 12.96, p = .002,\ \text{phi} =\ .111]$. The engineer respondents accumulated 13.4% for 'engineering' versus 8.8% from architects and 8.8% by other respondents. The effect size remains statistically small which means there is no bias to be reported.

On the other hand, there was no association between profession and those who selected IDP, meaning that all professions have similar views on the ranking of IDP in the decision making process. There was no significant association recorded with climate zones for any of the selections.

In terms of geographic regions, there were significant associations with government influence, client and architect, versus no association with engineering, IDP and project manager. Architects were more likely to be selected by American respondents (55.7%, n=180) than in the other geographical regions. The response of other geographical regions, in decreasing order, were mainland Europe (53%), UK (47.1%), other countries (41.1%) and Canada (39%), $[\chi^2(4, n = 1049) = 13.36, p = .01,\ \text{phi} =\ .113]$ (Table C-15, Appendix C). On the other hand, mainland European respondents recorded the highest selection rate of 'government regulation influence' (43.3%, n=107) followed by the UK (39.9%, n=122) versus the least in the USA (21.1%, n=68). The British, other countries and Canadian respondents ranked 39.9%, 39.7% and 34% respectively $[\chi^2(4, n = 1049) = 39.23, p < .0001,\ \text{phi} =\ .193]$ (Table C-16, Appendix C).

ii) TSC IMPLEMENTATION IN NON-DOMESTIC BUILDINGS

For non-domestic buildings (Fig. 5-13) the authority of the client remained at the top (58.7%, n=609) with increasing importance of the IDP team (49.9%, n= 517). The IDP team involves all the disciplines with the architect assuming a substantial role within the team (section 3.2.2). This further increases the authority of the architect as a decision maker who came in the third priority (42.5%, n=441).

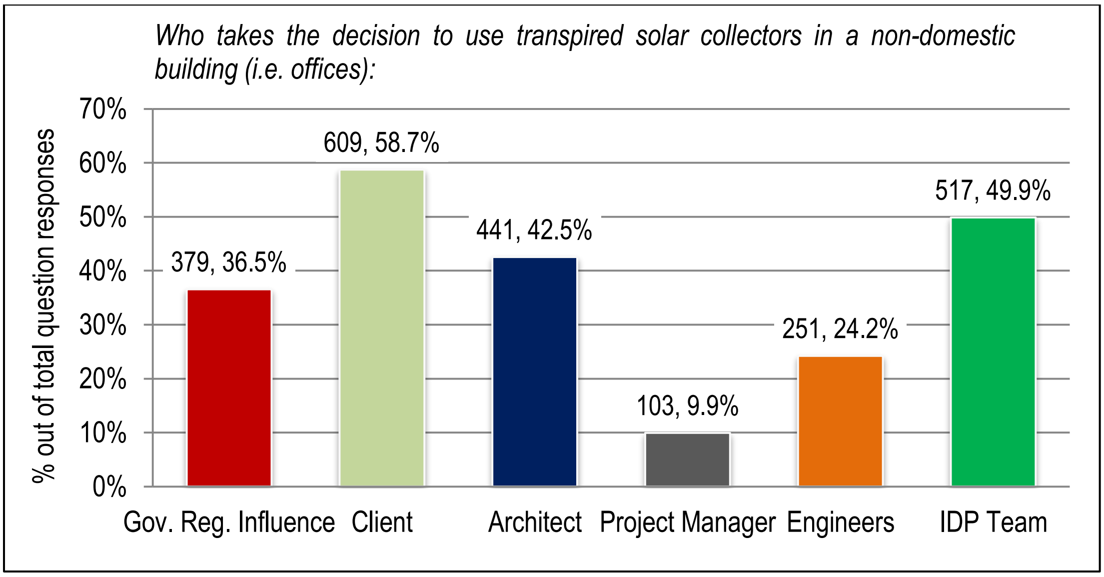


Figure 5-13: Authority of decision to use TSC in non-domestic buildings (number of participant, percentage of total responses of a multiple answer question)

Statistically, there was no association between participant profession and the responses 'government regulation influence', 'architect', and 'integration design team'. A significant association was noticed between participant profession and the selection of 'client'. Most of the selectees were architects. More engineers selected the option of engineers as a decision maker for incorporating TSC technology on non-domestic buildings. This might have some bias, however, the effect size was small $[\chi^2(2, n = 1037) = 15.22, p < .0001,\ \text{phi} = .121]$ (Table C-17, Appendix C).

There was a significant association between participant experience and the selection of 'government regulation influence' $[\chi^2(3, n = 1037) = 18.03, p < .0001,\ \text{phi} = .131]$. Less experienced participants were found to rely more on government regulation: 48.9% (n=44) of the total participants with less than five years of experience indicated government influence, versus 32.2% (n=219) by those who had more than 15 years of experience (Table C-18, Appendix C).

For climate zones, there was no association with the selection of architect, client government regulations, engineers and IDP, however, there was a possible association for 'project managers'; however, this is not a statistically validated conclusion as the number selections for 'project managers' from tropical zones was less than the statistically expected count. The majority of those who selected 'project managers' were from temperate zones (54.9%, n=56) followed by 28.4%, n=29 from continental zones, then 12.7%, n=13 from dry zones and finally 3.9%, n=4 from tropical zones.

Geographically, there was a statistically significant association with government regulation influence [$\chi^2(4, n = 1037) = 29.26, p < .0001,\ \text{phi} = .168$]. The American respondents recorded the least influence by government (24.6%, n=78) versus the highest in the UK (43.2%, n=134) and other countries (44.8%, n=30). Among Canadian participants, 38.4% were found to be influenced by government regulation, and 40.6% of the mainland European respondents (Table C-19, Appendix C).

iii) THE INTEGRATION OF TSC

The principal decision maker for applying the integration scheme was also explored. In this case, the architect was seen as the key decision maker for the integration scheme (63.8%, n=679) as shown in figure 5-14. The IDP team were considered the second most influential (43%, n=458) followed by the client (36.8%, n=392). Government influence and the project manager were considered the least influential, with 19.1% and 8.5% respectively.

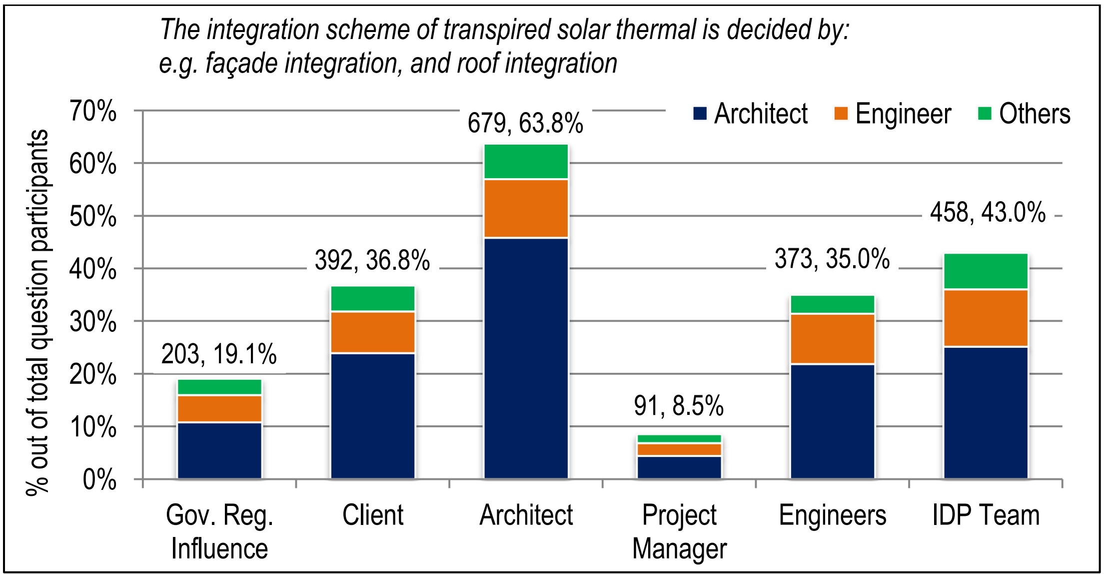


Figure 5-14: The decision maker of TSC integration scheme (number of participant, percentage of total responses of a multiple answer question)

A significant association was noticed between participant profession and the selection of architect [$\chi^2(2, n = 1065) = 54.74,\ p < .0001,\ \text{phi} = .227$]. It is apparent that 72% of respondents within the profession of architects selected 'architect' as a decision maker, versus 50.7% of respondents from other professions and 48.6% of engineers (Table C-20, Appendix C). Another significant association was noticed between participant profession and IDP selection [$\chi^2(2, n = 1065) = 10.03, p = .007,\ \text{phi} = .097$]. The other professions (52.1%, n=74) and engineers (47.3%, n=116) generally emphasised the influence of the IDP Team more than in the case of the architecture professions (39.5%, n=268) (Table C-21, Appendix C).

In terms of climate zones, there was a significant association with the selection of architect [$\chi^2(3, n = 1056) = 8.57,\ p = .036,\ \text{phi} = .09$]. The continental zones' participants (66.8%, n=187) followed by the tropical zones (66.7%, n=18) and then the temperate zones (64.1%, n=433) emphasised more value to the selection of architect than the dry zones' participants (48.6%, n=36). On the other hand, the dry zones' participants recorded the highest emphasis on selecting IDP (63.5%, n=47) versus 40.7-48.1% for other climatic zones [$\chi^2(3, n = 1056) = 14.36,\ p = .002,\ \text{phi} = .117$].

In terms of geographic regions, the UK participants recorded the lowest selection of 'architect' as a decision maker for integrating TSC (57.3%, n=181) versus 58.9%, n=43 for other countries, 60.0%, n=60 for Canada, 68.2%, n=223 for the USA and 69.1%, n=172 for mainland Europe [$\chi^2(4, n = 1065) = 12.93,\ p = .012,\ \text{phi} = .012$].

Qualitative Analysis: Comments addressed both domestic and non-domestic buildings together. Most of the comments were explanations of the selection of decision maker. Some commentaries added a 'developer' as a decision maker in lieu of client in some projects: *"could also be the developer"*. The client's decision was however linked to various factors including budget: *"Clients make the budget allocation decisions"* and advice by specialist: *"Clients on the advice of professionals"* that confirm the role of the architect as usually the first hand advisor in the case of integrating technologies. Many participants tried to define the role of the architect in projects: *"... leads team* [and] *makes recommendations"* to the client and other team members as stated an architect from tropical climatic zome in the USA. *"The Architect is in a prime position - if they have the skill set to understand this technology - to recommend it to client and argue for* [its] *inclusion"* as stated by an academic architect from Wales, mild temperate climatic zone. The role of the architect is further discussed in sections 5.4.3iii and 5.6.2iii.

Cost was also related to government incentives. *"Government inducements also support a* [client's] *decision to install if they can see offset costs or payback"* according to a consulting architect from England, whereas others saw incentives as necessary to encourage the diffusion of renewable energy. Government incentives are discussed in more detail in sections 6.3.2, 6.4.6, 7.5.4 and 7.6.4.

Comments in relation to integration of TSC focused on the allocation of resources such as skilled installers, appropriate technology, and early phase of integration *"...education and early integration is key* [factor]*".*

5.5 INTEGRATION OF TSC AND HYBRID PV/TSC

The integration of TSC is a particularly interesting topic. Integration can be considered in relation to aesthetics (i.e. the beauty and visual appearance of the integration within the building envelope). It can also be considered in relation to its 'multi-functionality' as an architectural design element (i.e. energy generation plus wall cladding, roofing, shading device). Both of these factors were explored by asking participants to rate images of seven existing buildings which incorporate TSC or hybrid PV/TSC projects on a Likert scale.

Seven examples of TSC integration were presented to represent common types of installation. The buildings presented were divided into categories referring to the type of TSC integration. Each building has been assigned a short ID to ease presentation of information within graphs; this is presented in brackets after the building's full name in the following descriptions, along with the reasons for inclusion. Images of the buildings are presented in this section.

TSC and hybrid PV/TSC integration to building facade:

- Ann Arbor Municipal Building, USA (Ann)

The integration of TSC in this institutional building is invisible. This was expected to help correlate the outcomes with one of the questions regarding the preference of invisibility versus visibility of integration (section 5.6.3i) and the use of dummy panels (section 5.6.3ii).

- The Currents Residences, Canada (Curr)

The selection of a residential building allowed full representation of the building types to which TSC can be integrated. The colour of the TSC, moreover, matched the façade colour in a harmonised architectural design

- Northern Arizona University, USA (Ariz)

In contrast to the Ann Arbor Municipal Building, the featured use of TSC in this façade allowed a comparison with the 'invisibility' of the Ann Arbor Municipal Building. This is discussed in relation to aesthetics in section 5.6.3i.

- Group Dion Offices, Canada (Dion)

A commercial building was also deemed important to include in the questionnaire to enrich the variety of building types. The seemingly contradictory colour and position of TSC to the façade design was attractive to explore in terms of 'applied' versus 'integrated' technologies, as described in section 3.2.3 and further explored in section 5.6.2.

- Ste Marguerite Bourgeoys School, Canada (Marg)

From the apparently accessible PV/TSC imagery examples, the (Marg) building was chosen as it provided a clear image that illustrated the concept of PV/TSC hybrid integration.

TSC and hybrid PV/TSC integration to building roof:

- Renault Dealership, Spain (Rena)

  This was chosen to represent installations outside Canada and the USA.

- Turner Fenton School, Canada (Turn)

  (Turn) was chosen due to its clarity in representing the roof integration of hybrid PV/TSC.

5.5.1 FAÇADE INTEGRATION OF TRANSPIRED SOLAR COLLECTORS

Five of the examples presented related to façade integration of TSC, one of which also incorporated PV. The responses to these examples are described below in decreasing order starting from the highest rated for both multi-function and aesthetics.

i) ANN ARBOR MUNICIPAL BUILDING, USA (ANN)

This government building in the USA includes dummy cladding in order to conceal the TSC panels (Fig. 5-15). Almost 78.9% of the respondents agreed that the example rated 'good' or 'perfect' for multi-functionality; while 73.8% gave a similar response on aesthetic integration (Fig. 5-16 and Table 5-2).

Figure 5-15: Façade integration of TSC (Ann), Ann Arbor Municipal Building, USA, InSpire wall (ATAS 2010)

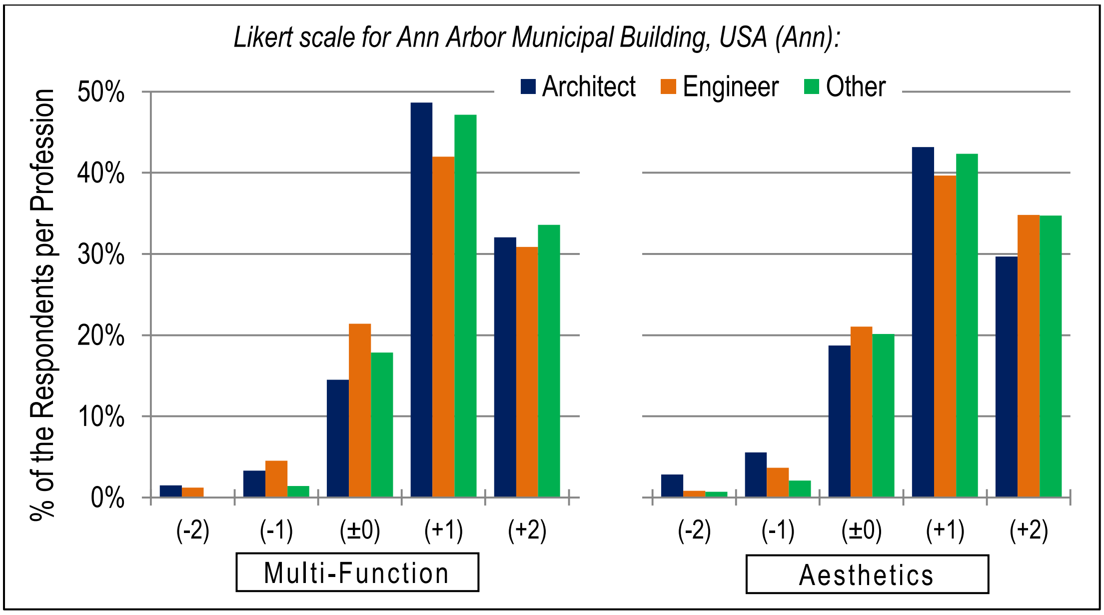


Figure 5-16: Likert scale rating by respondents of (Ann) building for multi-function and aesthetics

Table 5-2: Likert scale rating counts and percentages of (Ann) building for multi-function and aesthetics responses

Multi-functionality					
Likert Scale		**Architect**	**Engineer**	**Other**	**Total**
Very Poor (-2)	Count	10	3	0	13
	% within Profession	1.5%	1.2%	0.0%	1.2%
Poor (-1)	Count	22	11	2	35
	% within Profession	3.3%	4.5%	1.4%	3.3%
Neutral (0)	Count	97	52	25	174
	% within Profession	14.5%	21.4%	17.9%	16.6%
good (+1)	Count	325	102	66	493
	% within Profession	48.7%	42.0%	47.1%	46.9%
perfect (+2)	Count	214	75	47	336
	% within Profession	32.0%	30.9%	33.6%	32.0%
Total	Count	668	243	140	1051
	% within Profession	100.0%	100.0%	100.0%	100.0%

Aesthetics					
Likert Scale		**Architect**	**Engineer**	**Other**	**Total**
Very Poor (-2)	Count	19	2	1	22
	% within Profession	2.8%	.8%	.7%	2.1%
Poor (-1)	Count	37	9	3	49
	% within Profession	5.5%	3.6%	2.1%	4.6%
Neutral (0)	Count	125	52	29	206
	% within Profession	18.7%	21.1%	20.1%	19.5%
good (+1)	Count	288	98	61	447
	% within Profession	43.2%	39.7%	42.4%	42.2%
perfect (+2)	Count	198	86	50	334
	% within Profession	29.7%	34.8%	34.7%	31.6%
Total	Count	667	247	144	1058
	% within Profession	100.0%	100.0%	100.0%	100.0%

Using Spearman's Correlation, there was a strong direct relation between multi-function and aesthetics for architects $(\text{rho} = .53, p < .0001)$ versus medium correlation for the other professions $(\text{rho} = .40, p < .0001)$ (Table C-23, Appendix C). In other words, most of the architects who rated 'good' for multi-function, gave a similar response for aesthetics. This trend was also evident among engineers and other professions, but was less pronounced. This was evidenced by applying eq. (4-2) from which z_{obs} is found to equal 2.47 concluding a statistically significant difference in the strength of the correlation coefficients between multi-function and aesthetics for architects, and the other professions. This means that the architects had more diverse views on the aesthetics than other professions.

It was not possible to investigate the statistical association for the imagery examples with climatic zones and most of the other demographic data of the respondents (sections 5.5.1 and 5.5.2) as the inputs did not satisfy the Pearson's Chi-square test statistical rules due the distribution of responses (section 4.4.2i).

Qualitative Analysis: Many of the comments attributed to this image were fascinating; architects that rated both branches as 'good' or 'perfect' from various climatic zones and various geographic regions contributed, writing: *"... fully integrated"*, *"truly integrated"*, *"hides to become part of general façade"*, *"imperceptible presence"*, *"...seamless integration"* and *"...'camouflage' technology"*. Other comments were advisory: *"... integrate curves to avoid monotony"* by an academic architect from tropical zone.

Engineers were more neutral and noted the need for more information about the function, performance and construction of the technology. an engineer from a dry climatic zone further commented: *"Beauty is in the eye of the beholder - as long as the life cycle is proven - CO_2, embodied energy and money not just capital (first cost) expenditure but operational costs and disposal costs - the whole life of the building - not just a '5 year' payback period"*.

Although there was a purpose behind assessing the aesthetics and multi-functionality in the survey separately, some participants did not approve of the division. An American architect from a temperate climatic zone commented *“strive for aesthetic and function as a hand in glove”*. Further participants viewed the aesthetics of the building as a result to the function: *“form follows function”* is a mantra uttered by Louis Sullivan (Sullivan 1918, pp. 403-409, cited in Guimerá and Sales-Pardo 2006, p. 1) as previously mentioned in section 3.2.1.

Some participants would have preferred further information in order to make a judgement: *“... the piece of architecture appears to be arbitrary, albeit it is difficult to pass a robust comment without understanding the plan form and building setting”* was noted by a consulting architect from England, mild temperate zone, who rated both multi-function and aesthetics as ‘poor’. This participant has acknowledged the need to know the function for a true judgement; however, this was not an option without significantly extending the survey (as discussed in section 4.4.1iii).

A key point which appeared in relation to this building is the question of hiding technology or featuring it, and the use of dummy panels. The unity and harmony of the design integration of TSC within the building envelope, was a possible reason for its high ratings for aesthetics. This subject was discussed in section 3.2.4 and is more fully addressed later in the survey (sections 5.6.3i and 5.6.3ii).

ii) THE CURRENTS RESIDENCES, CANADA (CURR)

A mixed-use residential building that included a TSC integrated as a tall panel into one portion of the façade (Fig. 5-17). Almost 76.7% of respondents agreed that the example rated ‘good’ or ‘perfect’ for multi-functionality, while 67.9% gave a similar response on aesthetic integration (Fig. 5-18 and Table 5-3).

Figure 5-17: Façade integration – TSC (Curr), The Currents Residences, Canada (SolarWall n.d.)

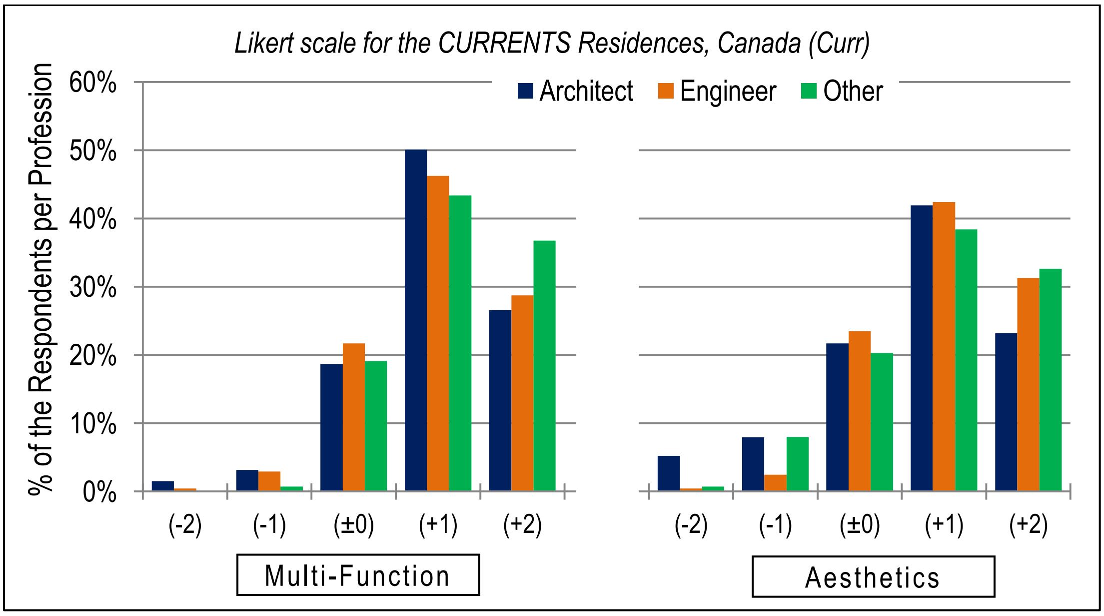


Figure 5-18: Likert scale rating by respondents of (Curr) for Multi-function and Aesthetics

Table 5-3: Likert scale rating counts and percentages of (Curr) for multi-function and aesthetics responses

Multi-functionality					
Likert Scale		**Architect**	**Engineer**	**Other**	**Total**
Very Poor (-2)	Count	10	1	0	11
	% within Profession	1.5%	0.4%	0.0%	1.1%
Poor (-1)	Count	21	7	1	29
	% within Profession	3.2%	2.9%	0.7%	2.8%
Neutral (0)	Count	124	52	26	202
	% within Profession	18.7%	21.7%	19.1%	19.4%
good (+1)	Count	332	111	59	502
	% within Profession	50.1%	46.3%	43.4%	48.3%
perfect (+2)	Count	176	69	50	295
	% within Profession	26.5%	28.8%	36.8%	28.4%
Total	Count	663	240	136	1039
	% within Profession	100.0%	100.0%	100.0%	100.0%
Aesthetics					
Likert Scale		**Architect**	**Engineer**	**Other**	**Total**
Very Poor (-2)	Count	35	1	1	37
	% within Profession	5.2%	0.4%	0.7%	3.5%
Poor (-1)	Count	53	6	11	70
	% within Profession	7.9%	2.5%	8.0%	6.7%
Neutral (0)	Count	145	57	28	230
	% within Profession	21.7%	23.5%	20.3%	21.9%
good (+1)	Count	280	103	53	436
	% within Profession	41.9%	42.4%	38.4%	41.6%
perfect (+2)	Count	155	76	45	276
	% within Profession	23.2%	31.3%	32.6%	26.3%
Total	Count	668	243	138	1049
	% within Profession	100.0%	100.0%	100.0%	100.0%

The Spearman's Correlation indicated a strong direct relation between multi-function and aesthetics for architects $(\text{rho} = .59, p < .0001)$ and for the other professions $(\text{rho} = .57, p < .0001)$ (Table C-27, Appendix C). By applying eq. (4-2), the z_{obs} equals to 0.57 which concludes no significant difference in the strength of the correlation coefficients between multi-function and aesthetics for architects and the other professions. This means that a high rating for aesthetics was likely to be accompanied by a high rating for multi-functionality.

Qualitative Analysis: A few commentary participants have not rated the imagery example. The main theme of comments for this example was ‘early consideration and design compatibility’. Participants commented that this example of TSC integration was a *“...successful application of the technology on a compatible building type”*, “*blends in well with overall design”* and *“well integrated into the overall building design”*. A few comments indicated that they did not recognise the TSC unit in the example and considered this as a good integration example that let them rate aesthetics as ‘perfect’. On the other hand, an academic architect and a consultant from England, mild temperate climate, raised a concern of shading that might affect the performance.

iii) NORTHERN ARIZONA UNIVERSITY, USA (ARIZ)

An institutional building in Northern Arizona University, USA has a TSC integrated into one of the façades as a decorative and energy generating element (Fig. 5-19). About 72.6% of the respondents agreed that the example rated ‘good’ or ‘perfect’ for multi-functionality, while 64.4% gave a similar response on aesthetic integration (Fig. 5-20 and Table 5-4).

Figure 5-19: Façade integration – TSC (Ariz), Northern Arizona University Distance Learning Center, USA (CA Group 2011)

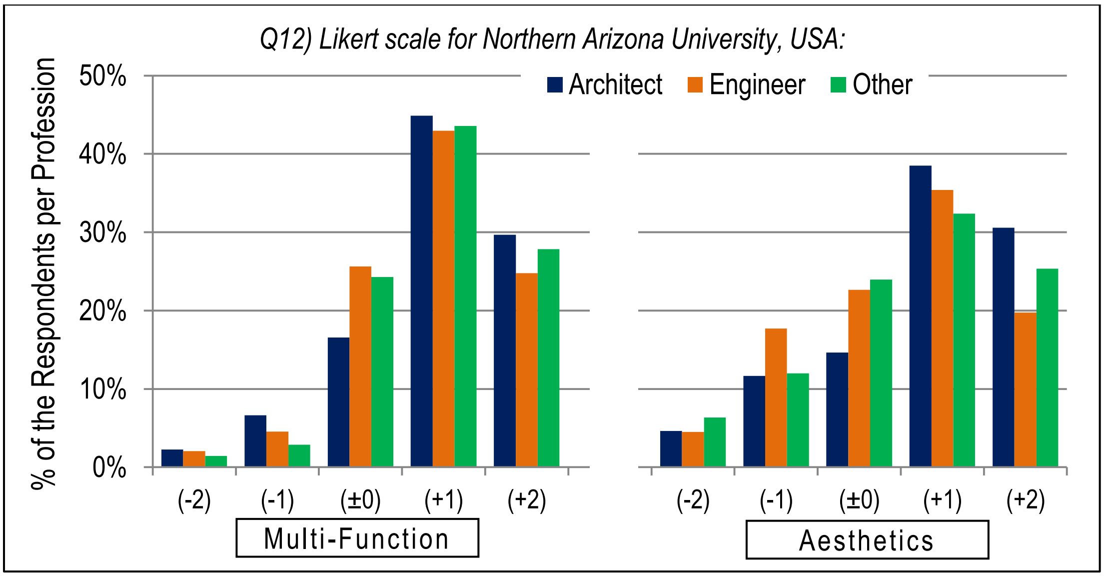


Figure 5-20: Likert scale rating by respondents of (Ariz) for multi-function and aesthetics

Table 5-4: Likert scale rating counts and percentages of (Ariz) for multi-function and aesthetics responses

Multi-functionality					
Likert Scale		**Architect**	**Engineer**	**Other**	**Total**
Very Poor (-2)	Count	15	5	2	22
	% within Profession	2.3%	2.1%	1.4%	2.1%
Poor (-1)	Count	44	11	4	59
	% within Profession	6.6%	4.5%	2.9%	5.6%
Neutral (0)	Count	110	62	34	206
	% within Profession	16.6%	25.6%	24.3%	19.7%
good (+1)	Count	298	104	61	463
	% within Profession	44.9%	43.0%	43.6%	44.3%
perfect (+2)	Count	197	60	39	296
	% within Profession	29.7%	24.8%	27.9%	28.3%
Total	Count	664	242	140	1046
	% within Profession	100.0%	100.0%	100.0%	100.0%
Aesthetics					
Likert Scale		**Architect**	**Engineer**	**Other**	**Total**
Very Poor (-2)	Count	31	11	9	51
	% within Profession	4.6%	4.5%	6.3%	4.8%
Poor (-1)	Count	78	43	17	138
	% within Profession	11.6%	17.7%	12.0%	13.1%
Neutral (0)	Count	98	55	34	187
	% within Profession	14.6%	22.6%	23.9%	17.7%
good (+1)	Count	258	86	46	390
	% within Profession	38.5%	35.4%	32.4%	37.0%
perfect (+2)	Count	205	48	36	289
	% within Profession	30.6%	19.8%	25.4%	27.4%
Total	Count	670	243	142	1055
	% within Profession	100.0%	100.0%	100.0%	100.0%

As for the Ann Arbor Municipal Building, the Spearman's Correlation indicated a strong direct relation between multi-function and aesthetics for architects $(\text{rho} = .59, p < .0001)$ versus medium direct correlation for the other professions $(\text{rho} = .32, p < .0001)$ (Table C-24, Appendix C). By applying eq. (4-2), the z_{obs} is equal to 5.35 which concludes a statistically significant difference in strength of the coefficients between multi-function and aesthetics for architects, and the other professions; that is similar to the result for the Ann Arbor Municipal Building described previously.

Qualitative Analysis: Some participants commented *"as previous"* or gave similar comments to those they had indicated for the Ann Arbor Municipal Building.

Nevertheless, a new theme of comments appeared for this example, where both architects and engineers regarded the example as having 'low architectural value'. Participants viewed the technology as an additional element to the envelope: *"...a bolt-on rather than part of fabric"*, *"tacked-on"*, *"...stuck on at the last moment, and there is no sense of proportion"* and *"looks like an afterthought";* these expressions were from participants from various climatic zones. Those comments corresponded to ratings of the aesthetics as 'poor' or 'very poor', although indicating the multi-functionality as 'neutral' or 'good'. These comments confirmed Probst and Roecker (2007) findings that solar energy integrations that were considered in the design phase were generally considered as more aesthetically pleasing than those added later in the process (section 3.2). The architectural aesthetics of the example was albeit largely considered as acceptable as a *"clearly dominant design feature"*, wrote an architect from England, mild temperate climatic zone. This theme will be considered further in sections 5.6.2 and 5.6.3.

iv) GROUP DION OFFICES, QUEBEC, CANADA (DION)

On this commercial building in Quebec, the TSC has been integrated into the building envelope with a different colour and rhythm to the rest of the façade (Fig. 5-21). About 62.1% of the respondents rated the building as 'good' or 'perfect' for multi-functionality but only 36.1% of the respondents rated the building as 'good' or 'perfect' for aesthetics. Architects provided more ratings of 'very poor', or 'poor' for aesthetics than other professions (Fig. 5-22 and Table 5-5).

Figure 5-21: Façade integration – TSC (Dion), Group Dion, Offices, Quebec - Canada (MatrixAir n.d.)

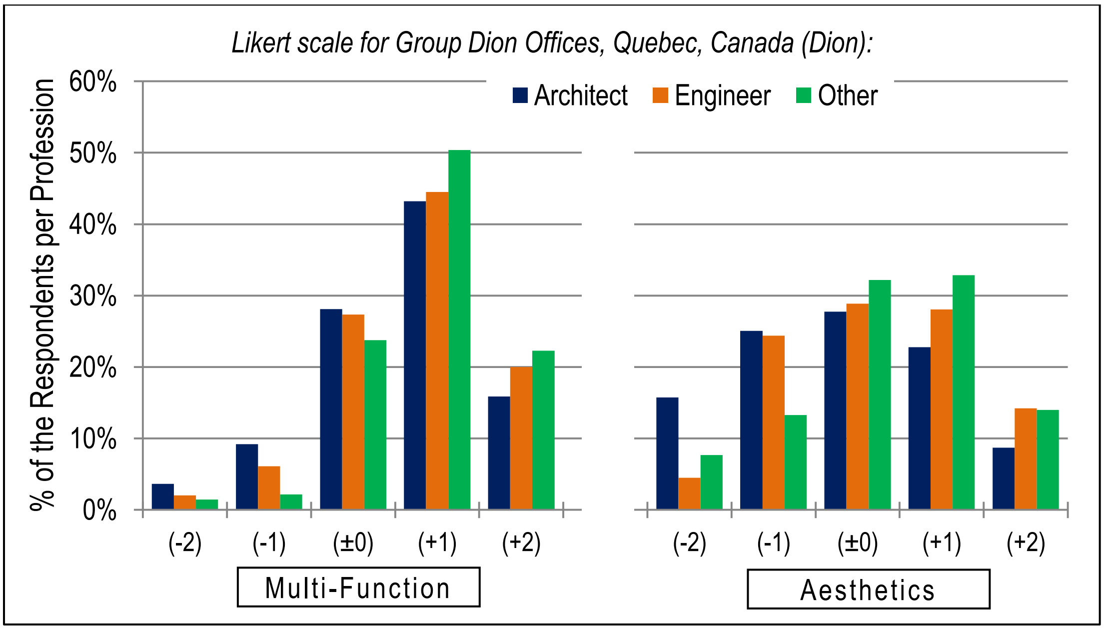


Figure 5-22: Likert scale rating by respondents of (Dion) for multi-function and aesthetics (Table C-25, Appendix C)

Table 5-5: Likert scale rating counts and percentages of (Ariz) for multi-function and aesthetics responses

Multi-functionality					
Likert Scale		**Architect**	**Engineer**	**Other**	**Total**
Very Poor (-2)	Count	24	5	2	31
	% within Profession	3.6%	2.0%	1.4%	3.0%
Poor (-1)	Count	61	15	3	79
	% within Profession	9.2%	6.1%	2.2%	7.6%
Neutral (0)	Count	186	67	33	286
	% within Profession	28.1%	27.3%	23.7%	27.3%
good (+1)	Count	286	109	70	465
	% within Profession	43.2%	44.5%	50.4%	44.5%
perfect (+2)	Count	105	49	31	185
	% within Profession	15.9%	20.0%	22.3%	17.7%
Total	Count	662	245	139	1046
	% within Profession	100.0%	100.0%	100.0%	100.0%
Aesthetics					
Likert Scale		**Architect**	**Engineer**	**Other**	**Total**
Very Poor (-2)	Count	105	11	11	127
	% within Profession	15.7%	4.5%	7.7%	12.0%
Poor (-1)	Count	167	60	19	246
	% within Profession	25.0%	24.4%	13.3%	23.3%
Neutral (0)	Count	185	71	46	302
	% within Profession	27.7%	28.9%	32.2%	28.6%
good (+1)	Count	152	69	47	268
	% within Profession	22.8%	28.0%	32.9%	25.4%
perfect (+2)	Count	58	35	20	113
	% within Profession	8.7%	14.2%	14.0%	10.7%
Total	Count	667	246	143	1056
	% within Profession	100.0%	100.0%	100.0%	100.0%

Using Spearman's Correlation, there was a strong direct relation between multi-function and aesthetics for architects $(\text{rho} = .58, p < .0001)$ and for other professions $(\text{rho} = .55, p < .0001)$ (Table C-26, Appendix C). By applying eq. (4-2), the z_{obs} equals to 0.84 which concludes no significant difference in the strength of the coefficients between multi-function and aesthetics for architects and the other professions, different to the two preceding imagery examples. This means that the trend of rating by architects for aesthetics was largely similar to rating the multi-function; this was noticed similarly for engineers and others.

Qualitative Analysis: The theme 'low architectural value' which arose for the Northern Arizona University example resurrected for this one also. Again the TSC in the example was seen as an additional element that was forced into the envelope, and if anything was considered an even more severe example: *"...applied and not integral..."*, *"...very top-heavy and ... an afterthought"*, *"too busy and not integrated into the building geometry"*, *"Clumsy"*, *"...brutal"*, *"...add-on with a little lipstick"* and *"seems forced...".* These comments were received by representatives of all professional categories; however, some engineers mentioned the need for further information about performance to judge the multi-functional role of TSC in the envelope, as was discussed in the previous examples.

v) ST MARGUERITE BOURGEOYS SCHOOL, CANADA (MARG)

The St Marguerite Bourgeoys School example includes a PV/TSC integrated into the upper part of the façade in a different colour to the rest of the building envelope (Fig. 5-23). The example was rated 'good' or 'perfect' for multi-functionality by 61.9% of respondents, while 35.5% gave a similar response on aesthetics (Fig. 5-24 and Table 5-6).

Figure 5-23: Façade integration – PV/TSC (Marg), St Marguerite Bourgeoys School, Ontario–Canada (SolarWall n.d.)

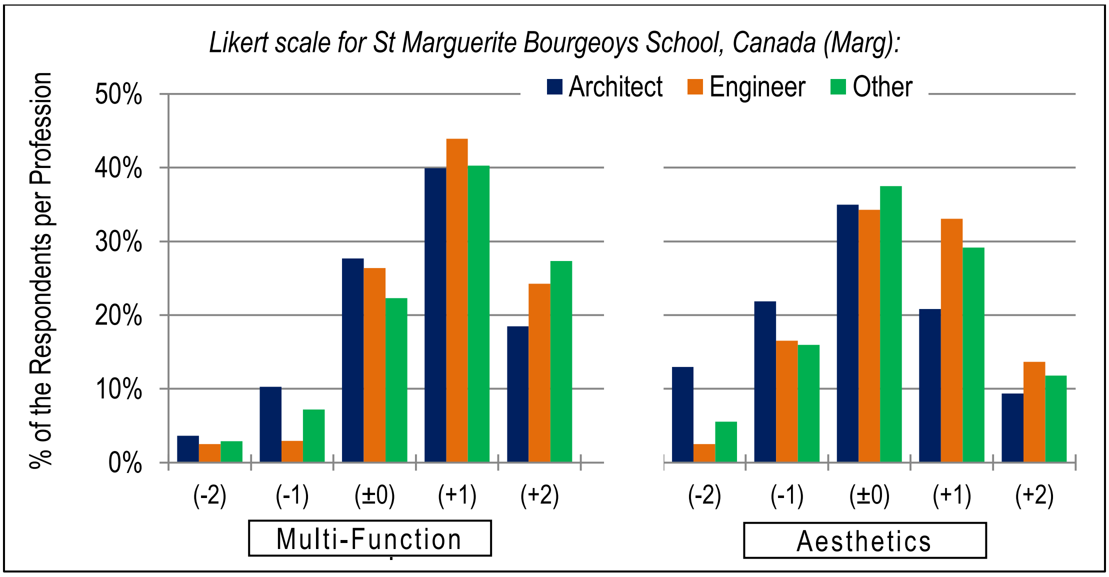


Figure 5-24: Likert scale rating by respondents of (Marg) for multi-function and aesthetics

Table 5-6: Likert scale rating counts and percentages of (Marg) for multi-function and aesthetics responses

Multi-functionality					
Likert Scale		**Architect**	**Engineer**	**Other**	**Total**
Very Poor (-2)	Count	24	6	4	34
	% within Profession	3.6%	2.5%	2.9%	3.3%
Poor (-1)	Count	68	7	10	85
	% within Profession	10.3%	2.9%	7.2%	8.2%
Neutral (0)	Count	183	63	31	277
	% within Profession	27.7%	26.4%	22.3%	26.7%
good (+1)	Count	264	105	56	425
	% within Profession	39.9%	43.9%	40.3%	40.9%
perfect (+2)	Count	122	58	38	218
	% within Profession	18.5%	24.3%	27.3%	21.0%
Total	Count	661	239	139	1039
	% within Profession	100.0%	100.0%	100.0%	100.0%
Aesthetics					
Likert Scale		**Architect**	**Engineer**	**Other**	**Total**
Very Poor (-2)	Count	86	6	8	100
	% within Profession	13.0%	2.5%	5.6%	9.5%
Poor (-1)	Count	145	40	23	208
	% within Profession	21.9%	16.5%	16.0%	19.8%
Neutral (0)	Count	232	83	54	369
	% within Profession	35.0%	34.3%	37.5%	35.2%
good (+1)	Count	138	80	42	260
	% within Profession	20.8%	33.1%	29.2%	24.8%
perfect (+2)	Count	62	33	17	112
	% within Profession	9.4%	13.6%	11.8%	10.7%
Total	Count	663	242	144	1049
	% within Profession	100.0%	100.0%	100.0%	100.0%

Using Spearman's Correlation, there was a strong direct relation between multi-function and aesthetics for architects $(\text{rho} = .55, p < .0001)$ and for other professions $(\text{rho} = .50, p < .0001)$ (Table C-28, Appendix C). By applying eq. (4-2), the z_{obs} equals to 1.06 which concluded no significant difference in the strength of the correlation coefficients between the trend of multi-function and aesthetics for architects, and the other professions. Therefore, most of the participants had similar rating trends for both multi-functionality and aesthetics. The architects, in an individual significant difference from other professions, rated the aesthetics integration as poor.

Qualitative Analysis: As for the Northern Arizona University and Group Dion Offices the theme of 'low architectural value' was prevalent. The comments included descriptions of the TSC unit in this example as *"...obtrusive and heavy"*, *"...*[not] *integrated with anything"*, *"...'bolt-on' element"*, *"...afterthought"*, *"...fitted ... after the building was commissioned"*, and *"... tacked-on single-function element".* As before, this confirms the findings of Probst and Roecker (2007) in regards to the poor quality of current solar thermal installations as explained in sections 3.2.4, and will be examined further in sections 5.6.2 and 5.6.3. However, not everyone disapproved of the integration example. A consulting architect from a temperate climatic zone in the USA mentioned that the TSC in this location "*makes use of* [mechanical] *screen". This comment* was supported by a Canadian architect from a continental climatic zone: *"looks like an enclosure for mechanical equipment"*. That is related to the use of TSC as a multi-functional element in order to hide mechanical installations on the roof section. This aspect of multi-functionality will be explored further in section 5.6.1.

5.5.2 ROOF INTEGRATION OF TRANSPIRED SOLAR COLLECTORS

i) RENAULT DEALERSHIP SPAIN (RENA)

The Renault dealership example was chosen to illustrate the concept of roof integration. This commercial building in Spain comprised a TSC installed onto the roof with a collection duct (Fig. 5-25). The example was rated 'good' or 'perfect' for multi-functionality by 61.7% of respondents, while 33.4% gave a similar response on aesthetic integration (Fig. 5-26 and Table 5-8).

Figure 5-25: Roof integration – TSC duct, (Rena), Renault dealership, Spain (SolarWall n.d.)

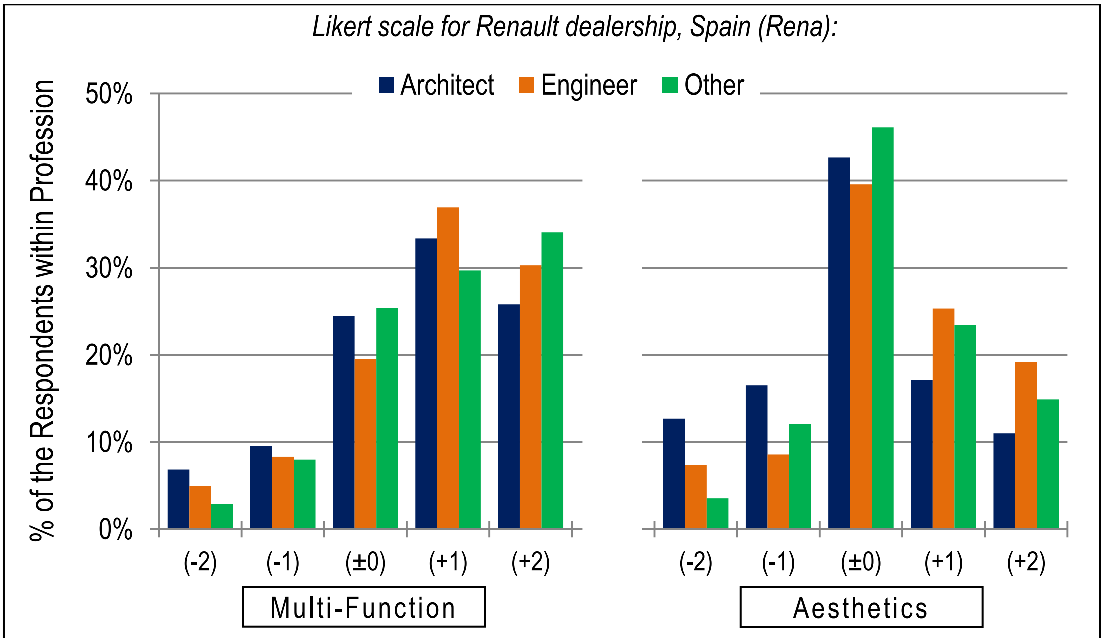


Figure 5-26: Likert scale rating by respondents of (Rena) for multi-function and aesthetics

Table 5-7: Likert scale rating counts and percentages of (Rena) for multi-function and aesthetics responses

Multi-functionality					
Likert Scale		**Architect**	**Engineer**	**Other**	**Total**
Very Poor (-2)	Count	45	12	4	61
	% within Profession	6.8%	5.0%	2.9%	5.9%
Poor (-1)	Count	63	20	11	94
	% within Profession	9.6%	8.3%	8.0%	9.1%
Neutral (0)	Count	161	47	35	243
	% within Profession	24.4%	19.5%	25.4%	23.4%
good (+1)	Count	220	89	41	350
	% within Profession	33.4%	36.9%	29.7%	33.7%
perfect (+2)	Count	170	73	47	290
	% within Profession	25.8%	30.3%	34.1%	27.9%
Total	Count	659	241	138	1038
	% within Profession	100.0%	100.0%	100.0%	100.0%
Aesthetics					
Likert Scale		**Architect**	**Engineer**	**Other**	**Total**
Very Poor (-2)	Count	83	18	5	106
	% within Profession	12.7%	7.3%	3.5%	10.2%
Poor (-1)	Count	108	21	17	146
	% within Profession	16.5%	8.6%	12.1%	14.0%
Neutral (0)	Count	279	97	65	441
	% within Profession	42.7%	39.6%	46.1%	42.4%
good (+1)	Count	112	62	33	207
	% within Profession	17.1%	25.3%	23.4%	19.9%
perfect (+2)	Count	72	47	21	140
	% within Profession	11.0%	19.2%	14.9%	13.5%
Total	Count	654	245	141	1040
	% within Profession	100.0%	100.0%	100.0%	100.0%

The rating was generally positive for multi-function but was very low for aesthetics. The architects were in agreement with other professions for rating multi-function. The architects however were statistically different from other professions in rating the aesthetic integration of this roof installation of TSC between poor and neutral $(\chi^2(8, n = 1040) = 37.54,\ p < .0001, \text{Cramer's V} = .134)$. Using Spearman's Correlation, there was a medium direct relation between multi-function and aesthetics for both the architects $(\text{rho} = .48, p < .0001)$ and the other professions $(\text{rho} = .42, p < .0001)$ (Table C-29, Appendix C). By applying eq. (4-2), z_{obs} equals to 1.17 which concludes no significant difference in the strength of the correlation coefficients between multi-function and aesthetics for architects, and the other professions.

Qualitative Analysis: The theme of 'low architectural value' re-appeared again strongly in the comments for this example. The comments were similar to the previous examples, with an additional comment *"... just array ..."* as the architectural design had no unique harmony to the concept of this particular building and could be installed in a field. The TSC was seen as too functional rather than as aesthetically integrated with the design. This is an additional confirmation of the literature review in section 3.2.

With regards to roof installations, the TSC was appreciated as hidden from sight as a stand-alone unit rather than an integration: *"...a roof application… invisible from the ground"*, *"at least hidden from view…"*, *"has no aesthetic effect, therefore perfect solution"*, *"hidden from public"*, *"not visually apparent to normal viewer"* and *"out of sight"*. These issues relating to functional and aesthetic integration preferences will be further discussed in section 5.6.2.

ii) TURNER FENTON SCHOOL, CANADA (TURN)

Turner Fenton School in Canada (Fig. 5-27) represents a roof installation of hybrid PV/TSC. The example was rated 'good' or 'perfect' for multi-functionality by 60.1% of respondents while 28.7% gave a similar response on aesthetic integration. Figure. 5-28 and Table 5-10 show multi-functions and aesthetics rating

Figure 5-27: Roof integration – PV/TSC (Turn). Turner Fenton School, Ontario - Canada, (SolarWall n.d.)

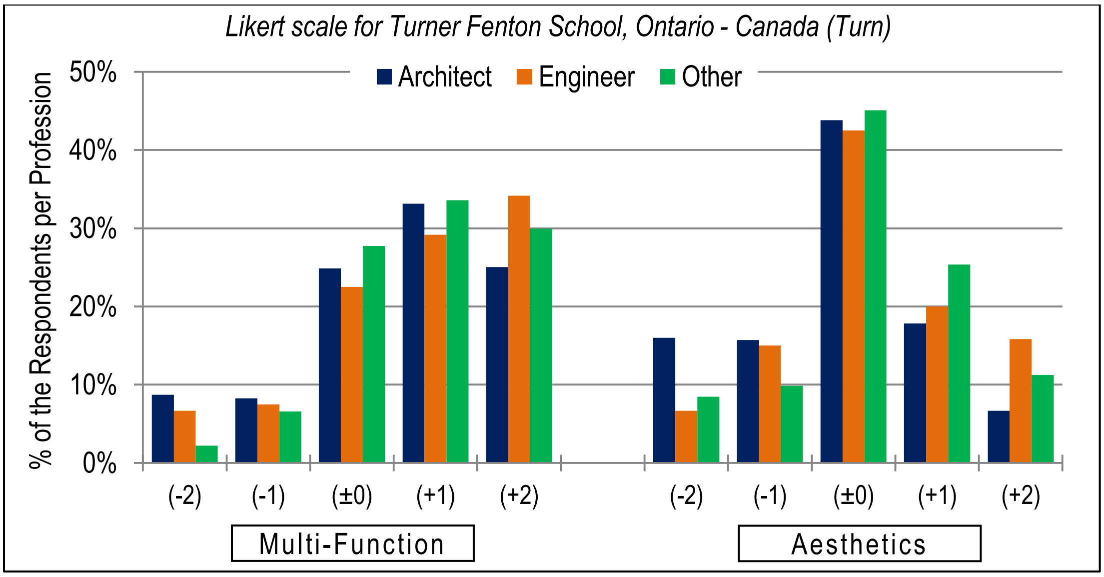


Figure 5-28: Likert scale rating by respondents of (Turn) for multi-function and aesthetics

Table 5-8: Likert scale rating counts and percentages of (Turn) for multi-function and aesthetics responses

Multi-functionality					
Likert Scale		**Architect**	**Engineer**	**Other**	**Total**
Very Poor (-2)	Count	57	16	3	76
	% within Profession	8.7%	6.7%	2.2%	7.4%
Poor (-1)	Count	54	18	9	81
	% within Profession	8.2%	7.5%	6.6%	7.8%
Neutral (0)	Count	163	54	38	255
	% within Profession	24.9%	22.5%	27.7%	24.7%
good (+1)	Count	217	70	46	333
	% within Profession	33.1%	29.2%	33.6%	32.3%
perfect (+2)	Count	164	82	41	287
	% within Profession	25.0%	34.2%	29.9%	27.8%
Total	Count	655	240	137	1032
	% within Profession	100.0%	100.0%	100.0%	100.0%

Aesthetics					
Likert Scale		**Architect**	**Engineer**	**Other**	**Total**
Very Poor (-2)	Count	106	16	12	134
	% within Profession	16.0%	6.7%	8.5%	12.8%
Poor (-1)	Count	104	36	14	154
	% within Profession	15.7%	15.0%	9.9%	14.8%
Neutral (0)	Count	290	102	64	456
	% within Profession	43.8%	42.5%	45.1%	43.7%
good (+1)	Count	118	48	36	202
	% within Profession	17.8%	20.0%	25.4%	19.3%
perfect (+2)	Count	44	38	16	98
	% within Profession	6.6%	15.8%	11.3%	9.4%
Total	Count	662	240	142	1044
	% within Profession	100.0%	100.0%	100.0%	100.0%

Similar to the Renault dealership example, the architects were in agreement with other professions for multi-functions rating. The architects however, were statistically in significant difference from other professions in rating the aesthetic integration of the PV/TSC as poor to neutral ($\chi^2(8, n = 1044) = 37.26, p < .0001, \text{Cramer's V} = .134$).

Using Spearman's Correlation, there was a medium direct correlation between multi-function and aesthetics for both the architects ($\text{rho} = .48, p < .0001$) and the other professions ($\text{rho} = .42, p < .0001$) (Table C-30, Appendix C). By applying eq. (4-2), z_{obs} was equal to 1.17 which concludes no significant difference in the strength of the correlation coefficients between multi-function and aesthetics for architects, and the other professions. Therefore, the aesthetics rating was increasing along with multi-functionality for many participants

Qualitative Analysis: Again, the theme of 'low architectural value' was predominant, closely followed by the theme of 'out of sight' installation. The comments were similar to those for the Renault Dealership example section 5.5.2i. The question of shading that was raised in relation to the Currents Residences re-appeared in relation to this example, as approximately 90% of the TSC is covered by PV. Overall, the hybrid system was appreciated as satisfying the dual function of space heating and electricity supply, with comments such as: *"Extra marks for combining PV with TSC"* and *"Good combination of PV and using heat generated for thermal transpiration"* as stated by respondents from Canadian continental and Welsh temperate climatic zones respectively. The hybrid system will be further investigated in section 5.6.2ii.

5.5.3 OVERALL RATING

The mathematical mean (section 4.4.2iii) was calculated statistically to allow more detailed comparison of the multi-functionality and aesthetic ratings for the seven examples (Fig. 5-29a). The engineers and other professions were grouped into one category due to their comparatively small individual weight, to allow comparison with the architects as illustrated in figure 5-29b.

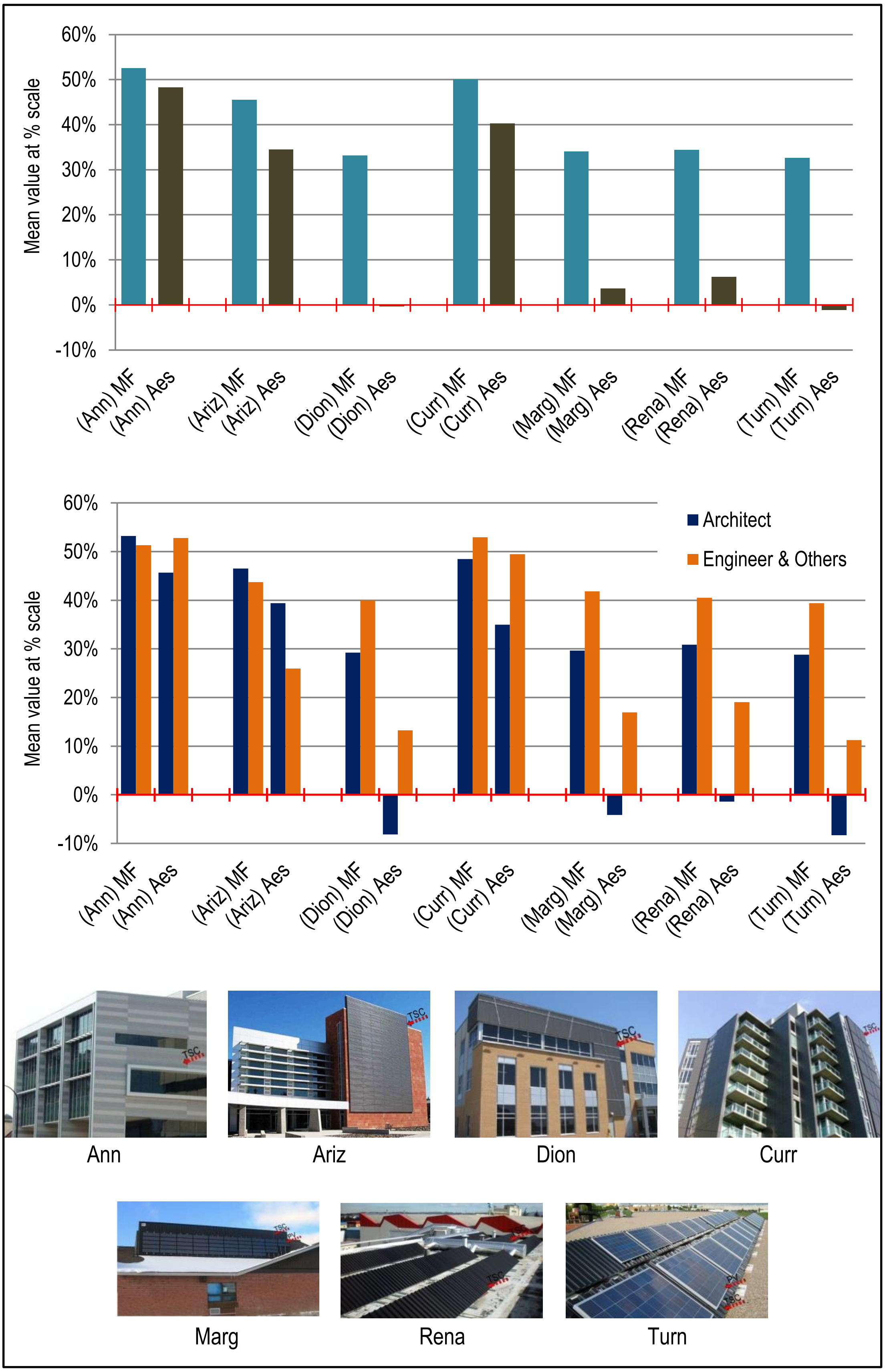


Figure 5-29: (a) Mathematical mean of the rating for multi-functionality (MF) and aesthetics (Aes), **(b)** Mathematical mean of multi-functionality (MF) and aesthetics (Aes) ratings for profession categories, and **(c)** the images representing the selected buildings (Table C-22, Appendix C)

The overall rating for the (Ann) example was the highest among the imagery examples being tested; this was followed by the (Curr) in second place for both its multi-function and aesthetics; the third overall rating was given to (Ariz). The architect respondents were more positive in rating this example than others in terms of multi-function and aesthetic appearance.

Statistically, the aesthetic rating of the examples was significantly associated with profession apart from in relation to the Group Dion Offices which recorded a relative agreement between architects, engineers, and other professions. The rating of multi-functionality was found to be independent of profession apart from the Group Dion Offices, St Marguerite Bourgeoroys School and Turner Fenton School where architects were likely to be less convinced that a positive rating was appropriate than the other professions.

Generally there was no association with professional experience except for in relation to the aesthetic ranking of Group Dion Offices and the Currents Residences. Professionals with less than 10 years' experience were more positive in rating the Group Dion Offices than the participants with more experience. The opposite held true for aesthetic ranking of the Currents residences.

In term of geographic regions, there was general agreement on the aesthetic rating apart from in relation to the Group Dion Offices where Canadian and the USA participants typically rated the integration as 'good' whereas mainland European and British participants typically viewed it as 'poor'. Similarly for the St Marguerite Bourgeoys School, the American participants rated the aesthetics as 'poor' whereas other nationalities generally rated the aesthetics as 'good'.

5.6 ARCHITECTURAL INTEGRATION QUALITY

Architectural integration quality was identified as an area for investigation in the literature review (section 3.2.3). This concept is investigated here in three categories: functional, constructive and aesthetic.

5.6.1 FUNCTIONAL ASPECTS

The multi-functional role of TSC integration was considered as the combining of architectural design elements and energy generation technologies. Following on from the multi-functionality rating of the examples presented in section 5.5, questions were posed to assess the perception and the value of the multi-functional role of integration. These include:

- Rating the functional priority of TSC technology.
- Rating the priority given to TSC versus other energy generating technologies in a new residential building.
- Rating the priority given to TSC versus other energy generating technologies in an existing residential building.

i) FUNCTIONAL PRIORITY

The functional priority to be selected when including a TSC in a building was addressed in relation to:

a. Function as an energy generator
b. Aesthetics
c. Multi-function as an architectural design element that satisfies technical purpose in addition to the aesthetics of integration.

Out of 957 respondents, 71.6% (n=685) rated the multi-functional role as the highest priority, followed by function (68.4%, n=655) and then aesthetics (49.9%, n=478). Participants also suggested economics, cost effectiveness, sustainability, and lifecycle as priorities to be considered (Fig. 5-30).

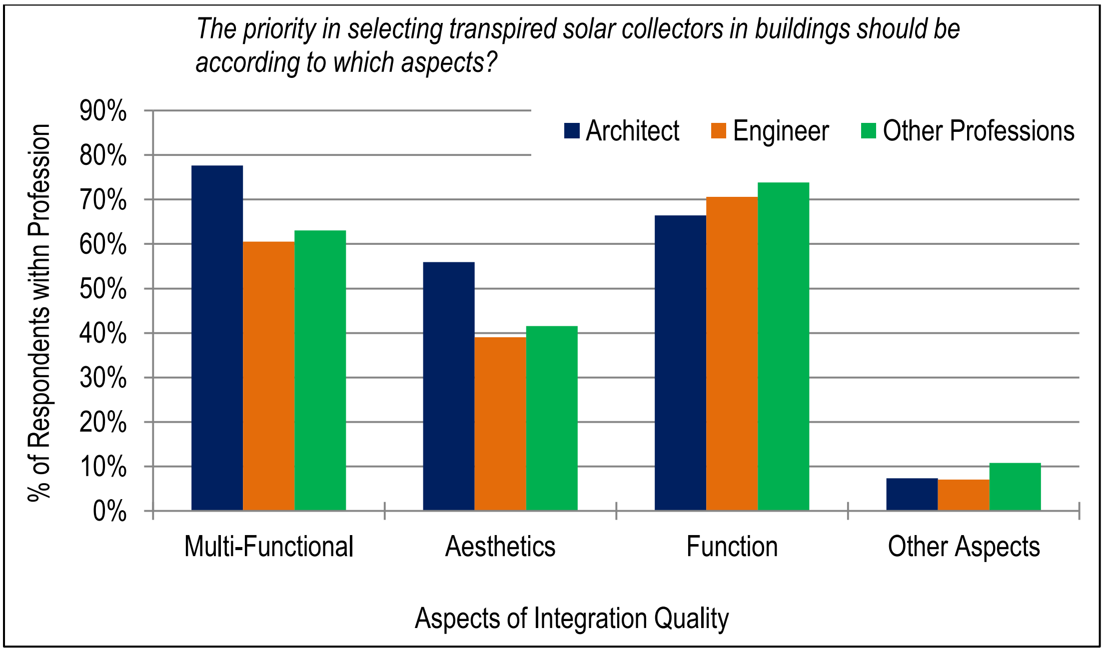


Figure 5-30: Functional priority aspects of selecting TSC in building integration, selecting more than one choice was available to participants (Tables C-31 and C-32, Appendix C)

There was a significant association between professions and the selection of multi-function $[\chi^2(2, n = 957) = 29.09, p < .0001, \text{Phi} = .174]$. Architects were found to prioritise the multi-functional role more than others. Architects also prioritised aesthetics more than other professions $[\chi^2(2, n = 957) = 23.10, p < .0001, \text{Phi} = .155]$. However, there was no association in priority selection with geographic location, climatic zone, work field or experience.

Qualitative Analysis: Some participants considered multi-functionality as an automatic result of appropriate architectural integration *"...good architectural feature will have multiple functions"* as mentioned by a consulting architect. A consultant from England added an additional condition to the diktat of Louis Sullivan (section 3.2.1)*: "Form should always follow function, as long as it is suitable, effective and efficient"*. This was supported by an American consulting engineer from tropical climatic zone *"... form and aesthetics follows function - and multi-function is a way to adapt and be flexible... for survival".* Other participants considered the three selections to work together in a one level priority *"all of these things should work together"* and *"...a collective integration of all"* whereas a Canadian academic architect from continental climatic zone mentioned the need of a balance between factors: *"It has to be a balance between functional, construction and formal (aesthetic) qualities".* A few comments suggested sequentially numbering the selections according to the priority which was not part of the questionnaire design. This might read as a limitation to this question, however, the option of selecting more than one choice would cover this limitation.

In a differentiation of integration position and scheme, an architect respondent from a continental climatic zone in the USA mentioned that *"If* [TSC] *is on a roof and* [cannot] *be seen, aesthetics does not come into play...but if it is part of the facade, aesthetics for the building itself and its neighbors is essential".* This reiterates similar comments identified in section 5.5 and will be explored further in sections 5.6.2 and 5.6.3. On the other hand, an academic from a mild humid temperate climatic zone in the Netherlands stated: *"Aesthetics should be given more attention (increases the adoption of the technology)".*

Although architects treated aesthetics as the least priority following to multi-functional role and function of the technology, some participants remain to think that "architects and planners will be swayed by the aesthetics" as stated a low carbon consultant from the mild temperate England climate.

ii) RATING PRIORITY OF TSC VERSUS OTHER ENERGY GENERATING TECHNOLOGIES IN A NEW RESIDENTIAL BUILDING

The prioritisation of TSC versus other appropriate energy generating technologies in a new residential building was explored. The other technologies were Photovoltaic (PV), hybrid (PV/TSC), solar water heating (DHW), wind energy (Wind) and ground source heat pumps (GHP). Solar water heating (DHW) accumulated the first choice (70.39%, n=642) followed by ground source heat pumps (GHP) (58.99%, n=538), and hybrid PV/TSC as the third option (56.36%, n=514). PV was the fourth choice (53.4%, n=487) followed by TSC (39.36%, n=359) as the fifth and wind in sixth place with 15.24% by 139 participants (Fig. 5-31).

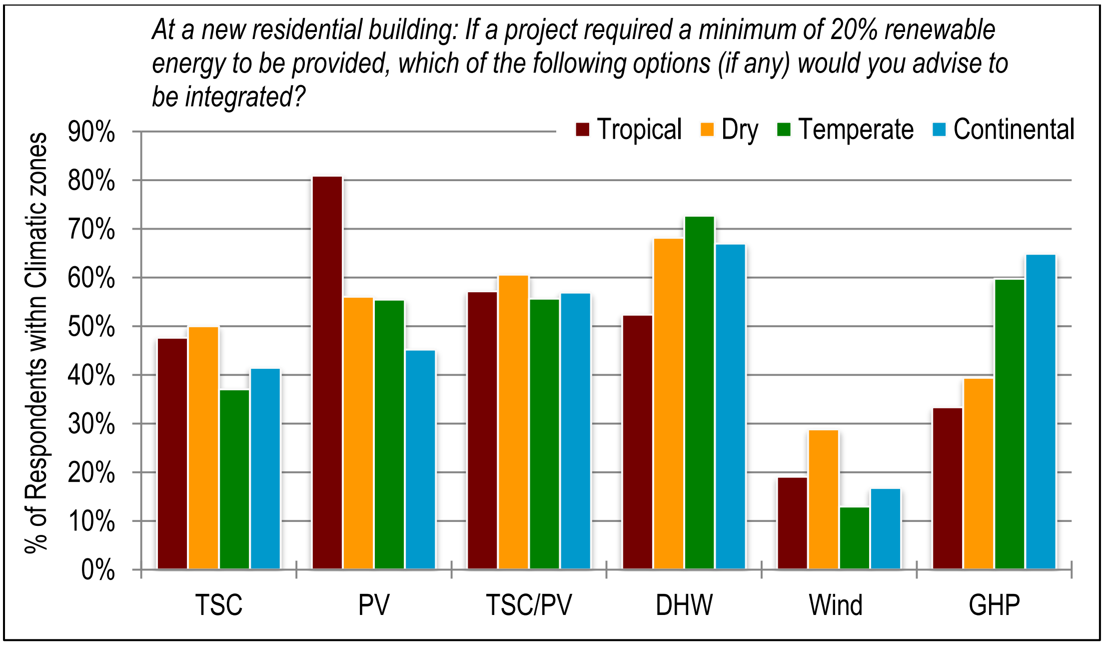


Figure 5-31: Technology selection preferences for new residential buildings per climatic zone, DHW: solar domestic hot water, GHP: ground source heating pump (Table C-33, Appendix C shows with professions and a slightly higher total responses due to the 12 cases excluded from climatic zones as aforementioned)

The selection between technologies had no association with profession except for GHP $[\chi^2(2, n = 920) = 11.99, p = .002, \text{Phi} = .114]$ (Table C-34, Appendix C) which was preferred by architects (63.3%, n=367). The selections of PV, wind and GHP were associated with climatic zones. The tropical climate participants (81.0%, n=17) were highly committed to select PV than dry (56.1%, n=37), temperate (55.5%, n=325), and continental climate (45.2%, n=108), $[\chi^2(3, n = 912) = 14.07,\ p = .003, \text{Phi} = .124]$. Wind energy was preferred in dry climatic zones (28.8%, n=19) more than tropical (19.0%, n=4), continental (16.7%, n=40) and temperate climatic zones (13.0%, n=76) $[\chi^2(3, n = 912) = 12.36,\ p = .006, \text{Phi} = .116]$. GHP was preferred in continental (64.9%, n=155) and temperate zones (59.7%, n=350) more than dry (39.4%, n=26) and tropical zones (33.3%, n=7), $[\chi^2(3, n = 912) = 19.71,\ p < .001, \text{Phi} = .147]$.

The selections of TSC, PV, wind and GHP were associated with geographic location (Fig. 5-32). The participants from other countries (50%, n=29), USA (46.3%, n=133) and Canada (43.7%, n=38) were more committed to select TSC than mainland Europe (29.9%, n=67) and Britain (36.7%, n=97), $[\chi^2(4, n = 920) = 13.38,\ p = .001, \text{Phi} = .141]$. For PV technology, the participants from other countries (62.1%, n=36), Britain (62.1%, 164), and USA (54.7%, n=157) were more dedicated to select PV technology than Canada (43.7%, n=38) and Europe (44.2%, n=99), $[\chi^2(4, n = 920) = 20.91,$ $p < .0001, \text{Phi} = .151]$. Wind energy was preferred in other countries (22.4%, n=13) and USA (20.9%, n=60). GHP was preferred in USA (67.6%, n=194) more than Canada, UK, Europe and other countries (24.1%, n=14).

There was no statistical association between choice of technology and experience, academic degree or project involvement.

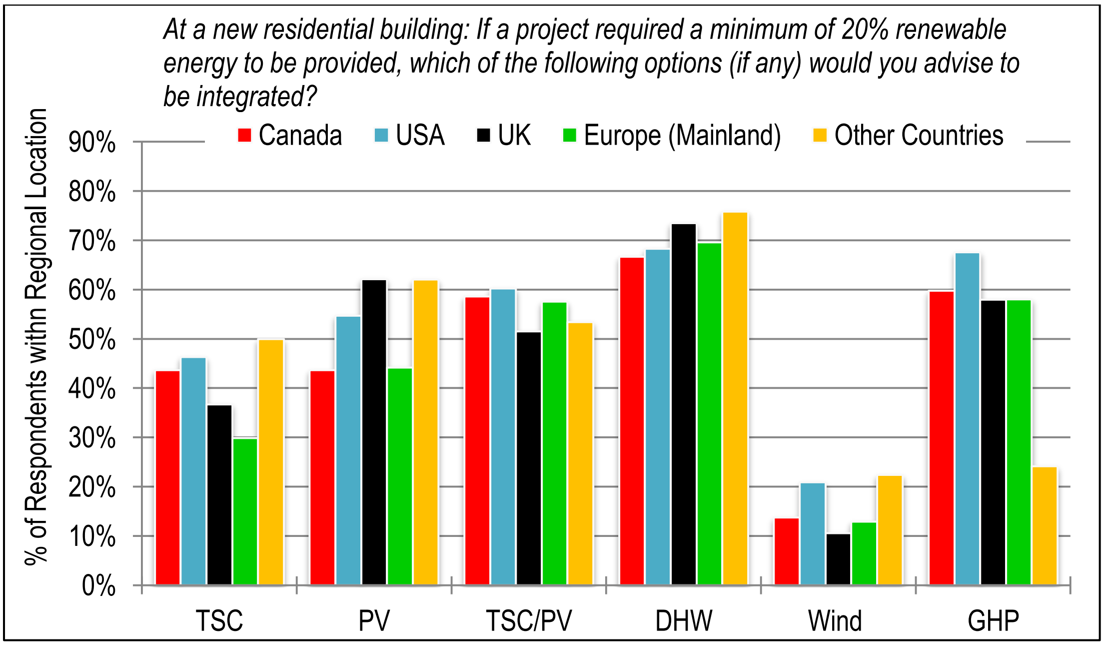


Figure 5-32: Technology selection preferences for new residential buildings per geographic region, DHW: domestic hot water, GHP: ground source heating pump (Tables C-35, C36, Appendix C)

Qualitative Analysis: Participants were invited to explain the reason for their selection. The main themes in this response have been represented in figure 5-33. 'Cost effectiveness and return on investment' was the most common reason given, followed by 'fear of new technologies', 'simplicity and flexibility', 'security and affordability' and 'government incentives'. Other, less obvious reasons included 'renewable compromise' and 'knowledge diffusion'. The first three key themes are described below.

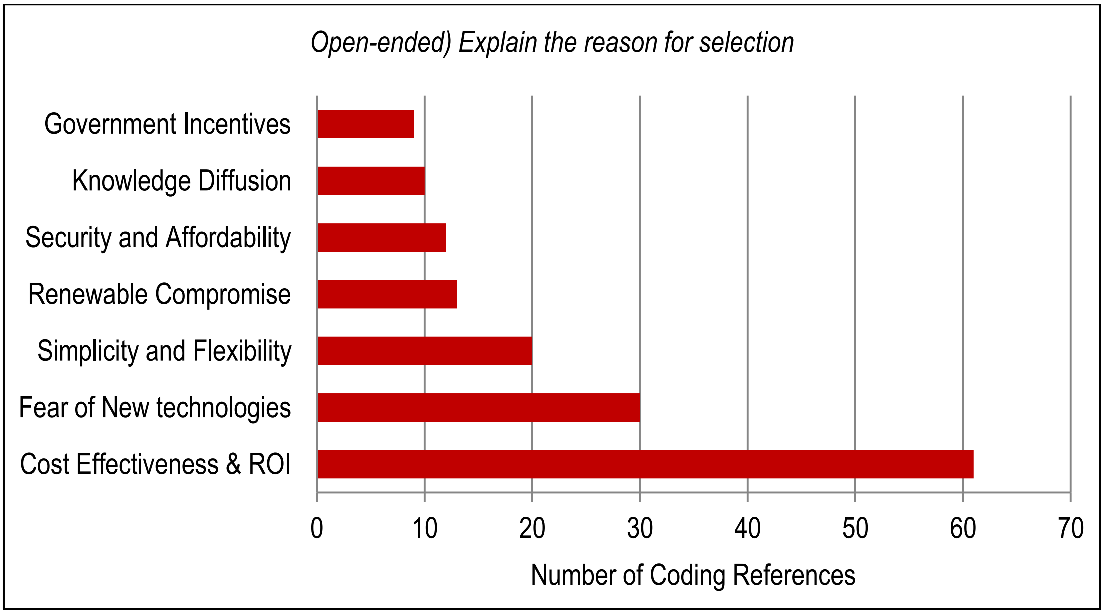


Figure 5-33: Seven of the highest themes being coded from the comments showing the number of participants

Cost effectiveness and return on investment: The cost concerns varied but mostly linked to *"A decision should always be based upon cost…"* as mentioned by a consultant from the mild humid temperate UK climate. An engineer from the UK mentioned that *"Actual recommendation depends on return for investment*". An academic architect from humid continental Connecticut in the USA also mentioned that: *"...payback time would be primary issues".* Some participants commented on a ground source heat pump as an expensive and not affordable technology, although some of those participants selected GHP as a choice to be included in new residential buildings. Participants wrote: *"... ground source heat pumps are too expensive at the moment"* a Scottish architect, "[from experience] *ground source heat pumps are very efficient but are expensive"* English consulting architect and "[geothermal is] *highly effective, but is typically more expensive for the typical suburban home"* a Canadian consulting architect from the humid continental Nova Scotia climate. For wind, the participants seemed concerned about high cost: *"Wind energy has significant cost implications with a long payback period"* commented a Canadian consulting architect from the humid continental Ontario climate zone. In terms of solar water heating, the participants appreciated the affordable cost: *"...solar hot water is the most cost effective strategy"* a Canadian architect from continental climatic zone, *"Solar water has rapid payback and good efficiency but is not so good visually"* a consulting architect from England, the mild humid temperate climate. These comments regarding cost effectiveness support the need for cost savings as highlighted in the literature review (sections 2.3 and 3.2).

The TSC was mentioned by a few participants who were aware of the technology as cost effective *"...relatively low cost and low impact technology"* a consulting architect from England, *"... cheap and easy way to offset space heating"* a Canadian academic engineer from a continental climatic zone, and *"...one of the fastest to payback* [technologies]*"* a TSC expert academic engineer from Wales. These comments contradict Hestnes (1996) that active solar space heating is not cost effective technologies (section 3.2). The contributions of the participants in this paragraph confirm what has been highlighted in sections 2.3 and 2.4 (McLaren et al. 1998; Resouce Smart Business 2007; Hall et al. 2011) that TSC is a low cost technology in spite of the common understanding of TSC as a non-affordable technology (section 5.5.2).

<u>Fear or reluctance of new technology:</u> Many participants were found to be committed to technologies that they have experience of and familiarity with. A Canadian architect from a continental climatic zone selected DHW and GHP because, as he/she stated *"...I have done this with great success"*. Another selection of PV and DHW by a consulting architect from the warm humid temperate District of Columbia in the USA was because it is *"Best understood now"*. Further comments were similarly repeated:

- *"... not aware ... of the TSC systems, that is why I would go for the highly mature technologies..."* English academic architect,
- *"...I am familiar with the* [PV and GHP] *technology from previous projects"* American architect from continental climatic zone and similarly Welsh academic architect, the temperate climate,
- "[solar water heating is] *most commonly available and recognized"* American architect from temperate climate,

- "[solar water heating are widely] *tested and well known technologies"* Belgium architect from temperate climatic zone, and
- *"balance of proven* [versus] *new technologies"* Canadian architect from continental climatic zone.

"People do not like to take risks with what to them is unfamiliar or unproven technology", stated a consulting engineer from England. This issue is further analysed in section 6.4.4.

Simplicity and flexibility: this theme relates to 'fear of new technologies', where selection is based on the simplicity and flexibility of the technology. Participants reasoned their selection as: *"ease of installation…"*, *"easy to incorporate"*, *"easy-to-use"*, "[DHW] *is simplest technology"*, *"easy to integrate into the building envelope"*, *"...more flexible option",* and *"...attainable with less complication"*. These reasons were given for different technologies that infer the simplicity and flexibility is subjective to experience and familiarity. Therefore, simplicity and flexibility is appreciated as an enabler to the usage of TSC technology as well as other renewable energy sources.

Some pragmatic responses included: *"could be any, depending on contingent conditions"* from an English academic, *"residential covers a very wide range of building types, from senior citizen accommodation through to apartments"* English consulting architect, *"...case by case basis"* and *"...case and location dependent"*. However, the question was set up to investigate the pre-existing preferences of technology options in order to identify the current ranking of TSC technology as an available market product. Certainly, consideration should be given to location, orientation, budget and so forth, as indicated in sections 3.2.2 and 5.4.3ii.

iii) RATING PRIORITY OF TSC VERSUS OTHER ENERGY GENERATING TECHNOLOGIES IN AN EXISTING RESIDENTIAL BUILDING

Similar to the previous section, the prioritisation of TSC versus other appropriate energy generating technologies in an existing residential building was explored. As in the last section, the other technologies were Photovoltaic (PV), hybrid (PV/TSC), solar water heating (DHW), wind energy (Wind) and ground source heat pumps (GHP). Similar to new buildings, DHW was the first choice (70.7%, n=639). However, differently for existing homes, the second choice was PV (56.7%, n=513). The third choice was hybrid PV/TSC (46.0%, n=416), followed by GHP (37.7%, n=341). The TSC was ranked fifth (28.2%, n=255) followed by wind energy as the least ranking of 14.6% and 132 participants (Fig. 5-34).

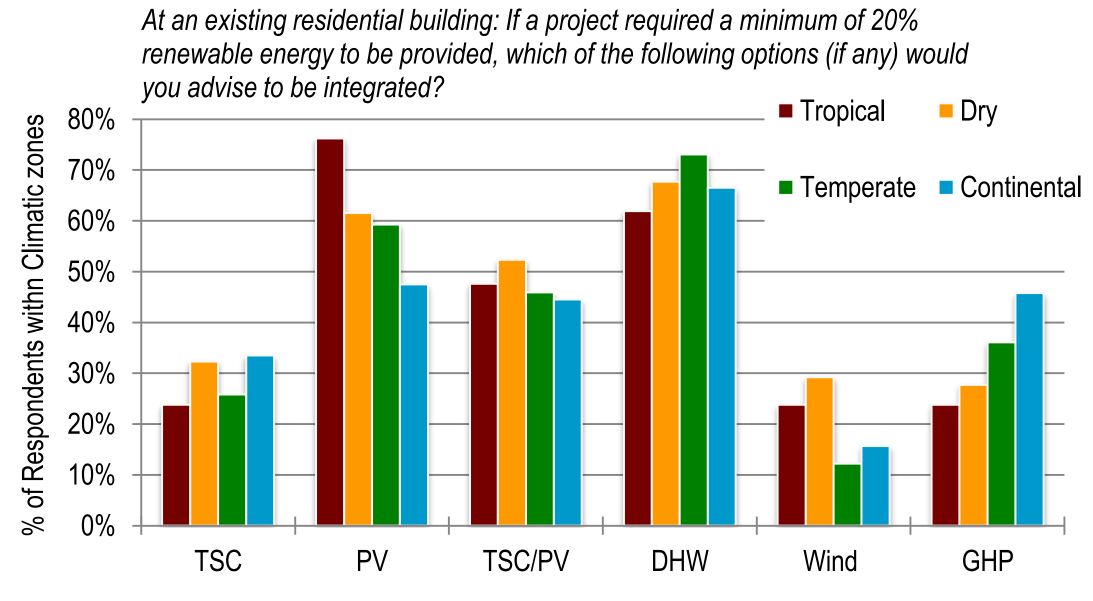


Figure 5-34: Technology selection preferences for existing residential buildings per climatic zone (Table C-37, Appendix C)

Similar to new buildings, the selections of PV, wind and GHP were associated with climatic zones. The tropical climate participants (76.2%, n=16) were highly committed to select PV than dry (61.5%, n=40), temperate (59.3%, n=345), and continental climate zones (47.5%, n=112), $[\chi^2(3, n = 904) = 13.65,\ p = .003, \text{Phi} = .123]$. Wind energy was preferred in dry climatic zones (29.2%, n=19) more than tropical (23.8%, n=5), continental (15.7%, n=37) and temperate climatic zones (12.2%, n=71) $[\chi^2(3, n = 904) = 15.49,\ p = .001, \text{Phi} = .131]$. GHP was preferred in continental (45.8%, n=108) and temperate zones (36.1%, n=210) more than dry (27.7%, n=18) and tropical zones (23.8%, n=5) $[\chi^2(3, n = 904) = 11.67,\ p = .009,\ \text{Phi} = .114]$.

There was also a statistical association in selecting TSC, PV, wind and GHP with geographic location. The Canadian (39.5%, n=34) and USA (33.2%, n=95) participants led the commitment towards TSC versus British participants (25.4%, n=66), Europeans (22.9%, n=51) and other counties (22.8%, n=13). For PV technology, the British participants were the most dedicated to use PV (66.5%, n=173) versus the Canadians (47.7%, n=41) who were the least committed. The participants from the USA were ranked second (57.7%, n=165) followed by the participants from other countries (54.4%, n=31) and then mainland Europe (49.8%, n=111) as the second from last (Fig. 5-35).

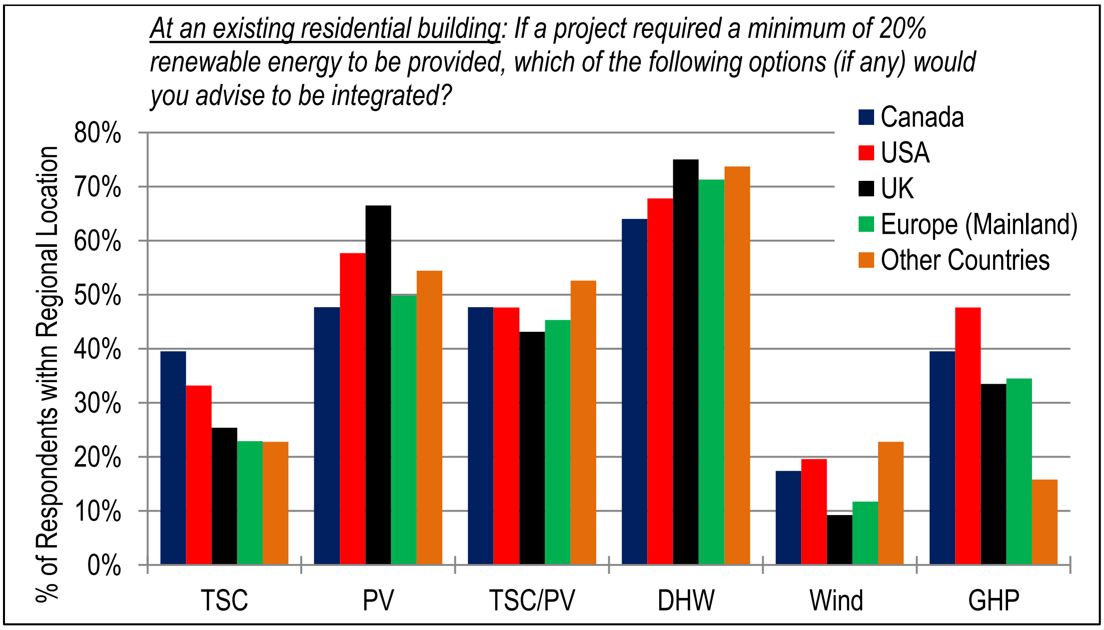


Figure 5-35: Technology selection preferences for existing residential buildings per geographic region

Qualitative Analysis: Similar to the previous section, participants were invited to explain the reason for their selection. The main themes from the previous section ‘cost effectiveness and ROI’, ‘fear of new technologies’ and ‘simplicity and flexibility’, all featured in this response, along with ‘site characteristics’ and ‘building type and function’. The theme of ‘simplicity and flexibility’ came top followed by ‘site characteristics’ and then ‘cost effectiveness and ROI’. Figure 5-36 shows the ranking of the main five themes.

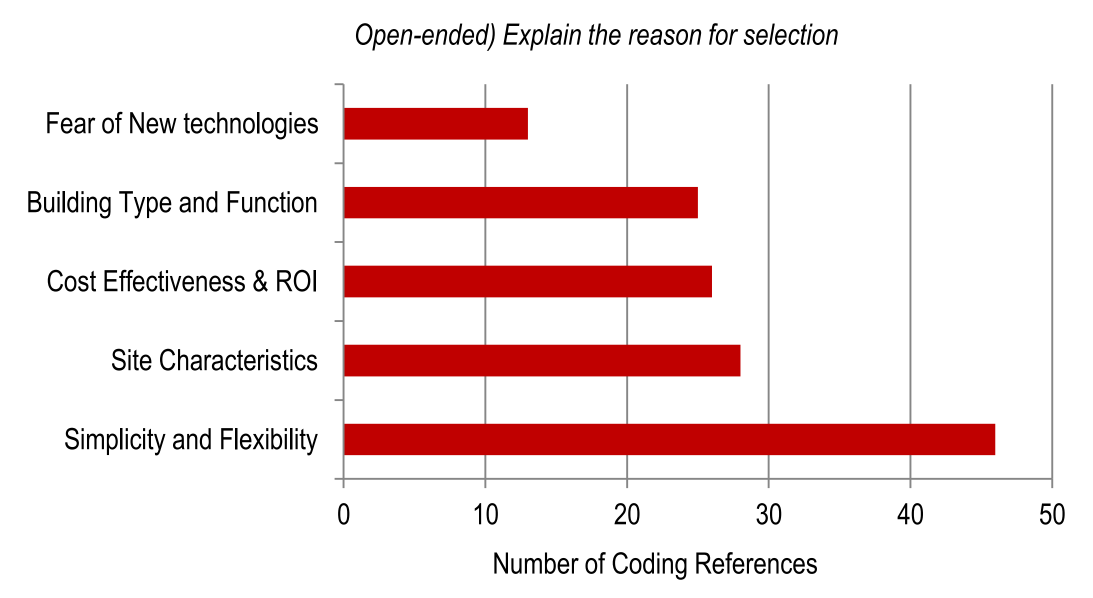


Figure 5-36: Five of the highest themes being coded from the comments showing the number of participants

Simplicity and flexibility: Participants were keen to use a technology that is easy and simple to integrate in order to reduce possible damage during the integration. Although TSC ranked equally as a potential technology for both new and existing buildings, the volume of responses supporting TSC for existing buildings was less than that for new buildings. This is likely due to a cautious approach to integration in an existing dwelling. Furthermore, the volume of responses supporting PV/TSC selection was lower for existing buildings than for new buildings, probably due to the same reason of integration simplicity as shown in figures 5-33 and 5-36 above. The comments were similar to those reported for section 5.7.1ii. They revolve around the *"ease of integration"* and *"simple technology"* albeit the respondents have assigned this ease or simplicity for *"existing buildings"* such as *"...easily be retrofitted"* and *"ease of adaption of existing envelope"*. These comments referred mainly to PV and DHW technologies as an additional installation rather than a surgical integration *"easily added to existing roofs"* in order to avoid damage during installation as aforementioned. GHP was considered "...[not easily] *added to an existing building".*

Site Characteristics: Some participants considered renewable energy technologies as not easy to be applied on existing buildings as mentioned a Canadian architect from continental climatic zone. Others noted that the selection of a technology to be used for existing buildings depends on the site characteristics. The comments were such as: *"...depends on the location of the building and the situation on site..."*, *"...depends on* [geographic] *location"*, *"...location dependent", "...depending on contingent conditions"*, *"...depends on site specifics..."*, and *"...depends on the location of the building - use local resources"*. These case to case differences were noted in section 3.2.4.

Other participants have similarly conditioned the use of the technology to the type of the existing building and the function to be satisfied from renewable energy installation.

The two other themes shown in figure 5-36 were similar to those discussed for new buildings (section 5.6.2ii).

5.6.2 CONSTRUCTION ASPECTS

The construction aspects often combine both function and aesthetics; however, it is considered a transformational path that builds-up the function towards the form as described in section 3.2.3ii. Construction aspects are explored in terms of:

- TSC position on building related to building type (non-domestic and domestic buildings).
- Building status (i.e. new design or refurbishment).
- Local authority guidelines for traditional buildings.
- Stage of building when integration is considered.

i) TSC POSITION ON BUILDING RELATED TO BUILDING TYPE (NON-DOMESTIC AND DOMESTIC BUILDINGS)

The integration scheme incorporating functional and aesthetic aspects was explored in relation to the position on the building envelope and building type (i.e. non-domestic and domestic buildings). The question was designed to reflect the possible schemes of integration identified in section 2.4.3. It also builds on the TSC integration examples (section 5.6), by exploring the theoretical concept of architectural integration.

Non-domestic buildings: the integration scheme of roof PV/TSC was ranked the highest (71.6%, n=624) followed by the façade PV/TSC integration scheme (59.4%, = 518). The integration of TSC in the façade (52.4%, n=457) was the third ranked followed by the TSC on the roof (45%, n=392) as the last choice that the participants would recommend for non-domestic buildings (Fig. 5-37). Statistically, there was a significant association between the selection of TSC in the façade and climatic zones. Dry climatic zone's respondents (35.9%, n=23) were the least committed to use TSC façade. The other zones were as follow: continental (59.2%, n=132), tropical (52.4%, n=11) and temperate zone (51.3%, n=286). There was no significant association in the selection within professions, geographic regions, or experience which means that almost all respondents were in statistical agreement with the ranking apart from dry climatic zone with the selection of TSC façade.

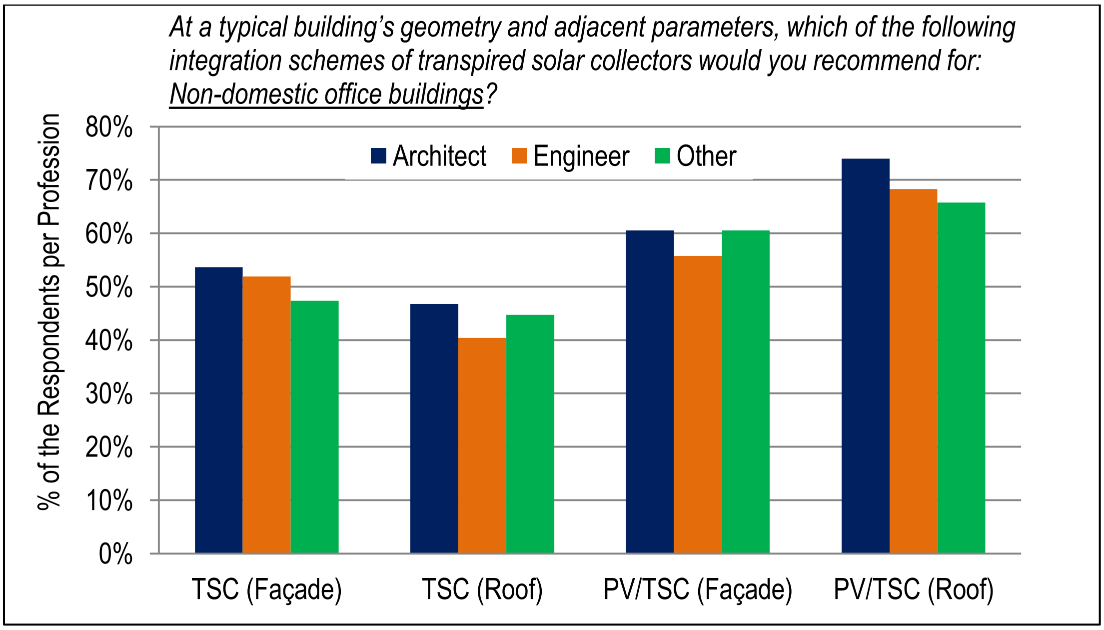


Figure 5-37: Recommended integration scheme of TSC at non-domestic scale

Domestic buildings: Similar to non-domestic buildings, the respondents selected the roof PV/TSC scheme (75.9%, n=656) as the highest, with a slightly higher percentage than for non-domestic. In a noticeable difference in the strength of selection, the roof TSC (50.9%, n=440) ranked the second choice. In a further noticeable change, the participants selected the façade TSC (36.9%, n=319) to rank the third, whereas the PV/TSC façade (35.4%, n=306) ranked the least (Fig. 5-38). There was almost no association with geographic regions, climatic zones and profession in the selection; architects were, however, more committed to the type of TSC roof integration than engineers.

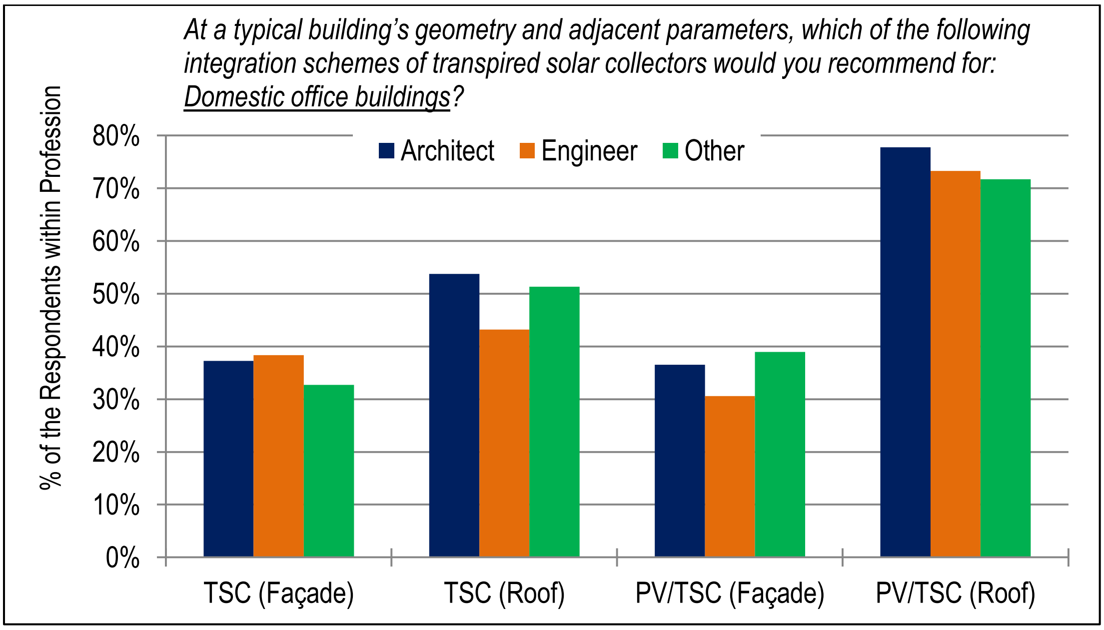


Figure 5-38: Recommended integration scheme of TSC at domestic scale

Qualitative Analysis: 'Building type and function' was the most common theme followed by 'site characteristics' and then 'location, size and orientation'. The participants preferred the hybrid function of PV/TSC which supplies space heating and electricity. The integration scheme in non-domestic buildings seemed driven by function, as the two highest favoured selections were the hybrid systems. The selection in the domestic buildings on the other hand was driven by aesthetics, particularly the invisibility of the technology (section 3.2.4), where the two top choices became the roof integration schemes.

Building type and function: Many participants mentioned that the selection is different in design practice rather than providing a theoretical answer. Although most of them have expressed their preference of an integration scheme, they indicated that the selection might change depending on design, site, the use of building, and the purpose of the integration. Examples of such comments were": *"depending on integrated design intent"*, *"case and location dependent"*, *"...project specific"*, *"building types"* and "[the] *scheme depends entirely upon the objectives of the project"*.

Site characteristic: Some participants use of the technology was indicated as being dependent on 'site characteristics' (section 5.7.1iii), including 'location, size and orientation' of the technology and also 'concept compatibility'. These themes are all interrelated with the architectural design, particularly within the IDP process (section 3.2.2).

Further participants differentiated between the domestic and non-domestic buildings. A Greek architect, from a temperate mediterranean climate, mentioned that non-domestic buildings have more flexibility of integration than domestic buildings. A Canadian engineer from the humid continental Ontario climatic zone wrote: "[there is not] *enough room on a domestic roof for both TSC and PV"* whereas an academic continental Canadian engineer mentioned that office buildings have *"plenty of wall space for TSC and generally flat roofs where PV can be rack mounted"*.

ii) INTEGRATION PREFERENCE OF TSC IN RELATION TO BUILDING STATUS

Building on previous indications that respondents consider TSC to be more viable for new buildings than existing ones, this aspect was addressed directly to evaluate the support for using TSC in new design versus refurbished buildings. There was strong support for the integration of TSC in both new designs and refurbishment projects (62.6%, n=596). This position was stronger within the architects than within the engineers and other professions. New design alone was further supported by 28.6% (n= 272) of the participants, however, the category refurbished buildings alone was the least preferred (2.0%, n=19) as shown in figure 5-39. There was no statistical association with any of respondents' demographics.

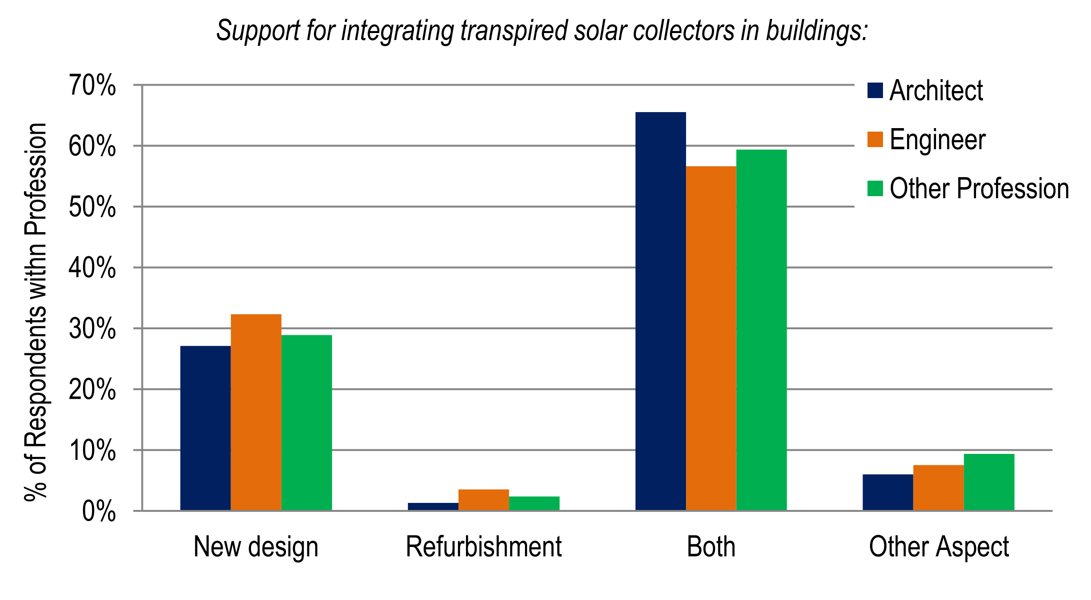


Figure 5-39: The support for TSC integration in new and refurbished buildings (Table C-38 in Appendix C)

Qualitative Analysis: participants expressed the importance of other issues beyond that of easy selection between new and refurbished buildings. These issues included *"depends on the status of project"*, *"economic feasibility"* or lack of support by legislators. Similar to the findings in section 5.6.2i, some participants considered integration in refurbished buildings as difficult to justify in terms of cost and aesthetics versus new design building where the TSC would properly fit within the envelope and technical contexts, especially if considered at the early stage of design (section 3.2.3ii, 5.4.3ii and 5.6.1i).

iii) LOCAL AUTHORITY GUIDELINES FOR TRADITIONAL BUILDINGS

Harmonising TSC within the architectural concept was presumed as a true statement to be tested in the existence of local authority planning guidelines for traditional buildings. This route for investigation was inspired by the study of PV integrations carried out by Lundgren et al. (2004). The majority of survey respondents (55.5%, n=522) agreed with the statement "It is often difficult to harmonise transpired solar collectors with the architectural concept, when local authority design guidelines are set-up for traditional buildings”. However, 21.3% (n=200) participants disagreed with the statement, while 23.2% (n=218) participants had ‘no opinion’ (Fig. 5-40).

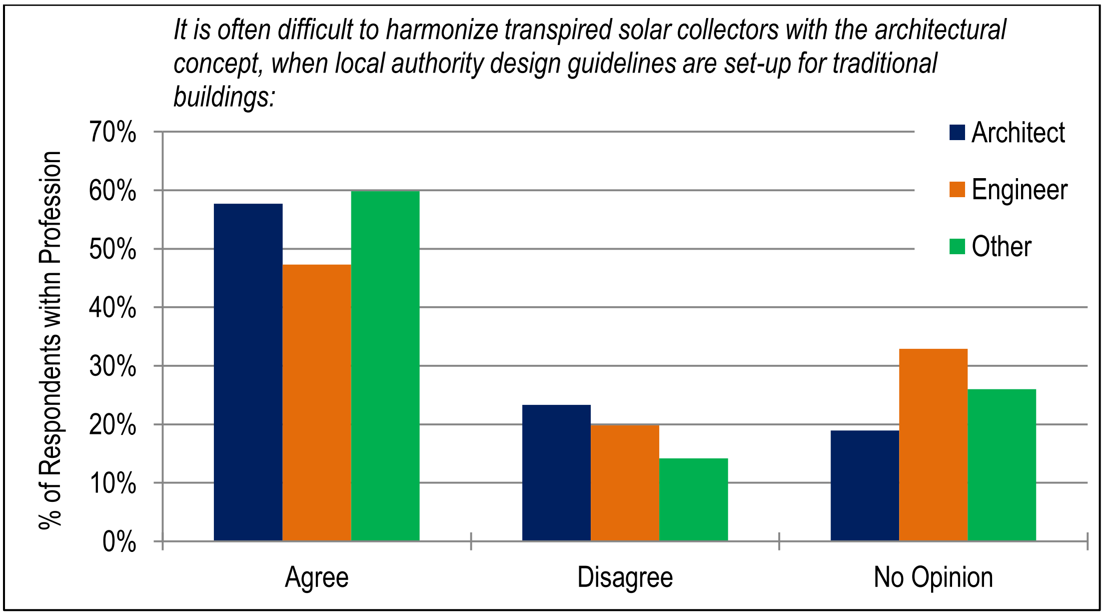


Figure 5-40: Harmonising TSC within the architectural concept of traditional buildings (Table C-39, Appendix C)

There was a statistically significant association with profession in the selection $[\chi^2(4, n = 940) = 22.06, p < .0001, \text{Cramer's V} = .108]$. Engineers were found in less agreement with the statement than architects and other professions; however, more engineers responded with ‘no opinion’. The architectural concept is usually managed by the architect, the design facilitator (section 3.2.2). Therefore, finding 23.4% of the respondent architects in disagreement with the statement being tested was a positive sign towards potential integration of TSC in traditional buildings. Albeit a low percentage, this increases the chances of accepting the challenge of integration in the design. Even though, there are many participants in agreement with the statement being tested who requested amendment to local authority regulations as discussed hereafter. No association with climatic zones were recorded.

Furthermore, there were more Europeans (62.1%, n=141) than others in agreement of the statement, whereas, Canadian respondents (42%, n=37) were the least in agreement with the statement $[\chi^2(8, n = 940) = 22.57, p =$

$.004, \text{Cramer's V} = .110$]. There were many Canadians however with no opinion. The respondents from other countries (59.6%, n=34), the UK (57.2%, n=158) and the USA (52.1%, n=152) respectively, were in the upper middle of agreement with the statement being tested (Table C-40, Appendix C).

This could be interpreted due to more traditional buildings in Europe than Canada (Humphreys and Sykes 1980), therefore building professionals in Europe have more practical awareness of traditional building circumstances than Canadian respondents. Another possibility however could be that Canadian respondents enjoy the challenge of integration, especially when they are highly committed to the TSC technology (section 5.4.1).

Qualitative Analysis: The most common theme of comments was 'local authority planning legislation' followed by 'role of architect' and then 'historical and existing buildings'. Other themes were found similar to previous questions such as 'low architectural value' and 'acceptance by consumer' and 'knowledge diffusion' (i.e. section 5.5).

Local authority planning legislation: There were two groups expressing contradictory opinions towards local authority regulations. One group opposed the current legislation, while another group supported the legislation. Another group invited architects to adapt themselves to the current legislation. The group opposing the current planning legislation was noticeably stronger than the others. *"Planning is a major hindrance to integration of new technology generally - mostly backward looking and conservative in approach"*. This opinion was stated by a consulting architect from Wales, whereas another academic architect from Nigeria mentioned that the regulations are rigid and outdated without provision for the future. A consulting architect from the USA asserted that *"local codes are behind the times in many cases and they do not understand how these options can be aesthetically pleasing".* This opinion was echoed by two academic architects from the USA and agreed with by another consulting architect from Wales. Another academic from a continental climatic zone in the USA stated that *"...local authorities* [should] *embrace the progression of design development* *and sustainability".* The above participants were all in agreement with the statement being tested.

"Some [local authorities] *are more understanding than others"*, this comment inferred differences between authorities according to a consultant from England who also agreed with the survey statement in question. A consultant from Canada who disagreed with the survey statement asserted that "[most] *municipalities will adapt their rules to accommodate renewable energy".* Furthermore, a consulting engineer from England perceived acceptance of new technologies in the design guidelines. This category remains neither supportive nor in contention to local authority legislation. An architect from the national government in Canada acknowledged that *"...most design guidelines are highly prescriptive and based on looks rather than values*" therefore, local authorities *"...encourage design guidelines that are non-prescriptive, that promote performance rather than aesthetics".* The participants within this category acknowledged the need for change but believed that local authorities will address the need.

Nonetheless, an academic architectural historian from Wales trusted the local authority as a guardian on the public preference: "[local] *authority guidelines are likely to take greater account than architects tend to of local people's aesthetic preferences"*. However, a consulting architect from England (who disagreed with the statement being tested) emphasised the responsibility on the designer rather than the local authority: *"if the design is strong and the systems sensitively incorporated then there shouldn't be any problem with the* [local authority]". An architect working in local government in England stated that their *"...planning officer is receptive to* [integration] *ideas but* [integrations have] *to look right".* Therefore, *"...local authorities would work* [with] *the designer and not* [against]" as stated by a consulting architect from the USA. Therefore, a comprehensive retrofitting design on traditional buildings should traverse the local authority legislation as long as the latter welcomes pleasing work that allows competent architects to succeed. The local authority regulations either outdated or updated should be combined with the architectural and environmental development needs in order to *"...master renewable energies"* as stated by an engineer from France.

Architect's role: As discussed under 'local authority planning legislation' above, particular emphasis has been put on the architect to get the integration successfully accepted by both local authority and public. Some participants tried to define the role of the architect in the integration (section 5.4.3i) and others emphasised this role in addressing the challenge towards a successful design as *"...refurbishment may be a very tricky task for an architect"*, Greek architect. *"That is where skills and creativity comes in play and* [make] *a difference between good architect and engineer and the bad ones"* as stated by an academic architect from Canada and confirmed similarly by many others, such as a consulting engineer from the Netherlands and architect from the USA. Therefore, the harmony of TSC integration within architectural concept were seen dependent on the architects and their *"...ability to traverse the* [local authority] *guidelines"* as stated by a consulting architect from the USA.

Historical versus non-historical: Further participants differentiated between traditional buildings whether listed as historical buildings or not. Most of the participants in this theme either in agreement or disagreement with the statement being tested, specified the difficulty of integrating TSC technologies with historical buildings: *"...difficult in Conservation Areas and listed buildings"*, commented a consulting architect from Scotland. Furthermore, an architect from the Welsh local government when responding to the statement being tested on local authority design guidelines and harmonising TSC in architectural concept, felt that it was *"only really an issue in Conservation Areas"*. Similarly an architect from Italy felt difficulties arose in integrating TSC technologies: *"only in historic buildings"*. Some others however deemed to manipulate the benefits from integration such as a consulting architect from England who stated: "[the] *solution is to locate discretely in a way that neither jeopardises visual integrity* [nor] *operational performance".* This manipulation was addressed in this study in variant form such as the functional priority in selecting TSC (section 5.6.1i) and the preference of integration in relation to building status (section 5.6.2ii).

iv) STAGE OF BUILDING WHEN INTEGRATION IS CONSIDERED

The appropriate stage to consider integration within was explored. It was found 83.2% (n=779) of participants recommended that the TSC be integrated into the building envelopes at the architectural design stage rather than a later stage (1.1%, n=10). However, 15.7% (n=147) of participants believed that the decision should be left to the project team as each project could have different circumstances (Fig. 5-41).

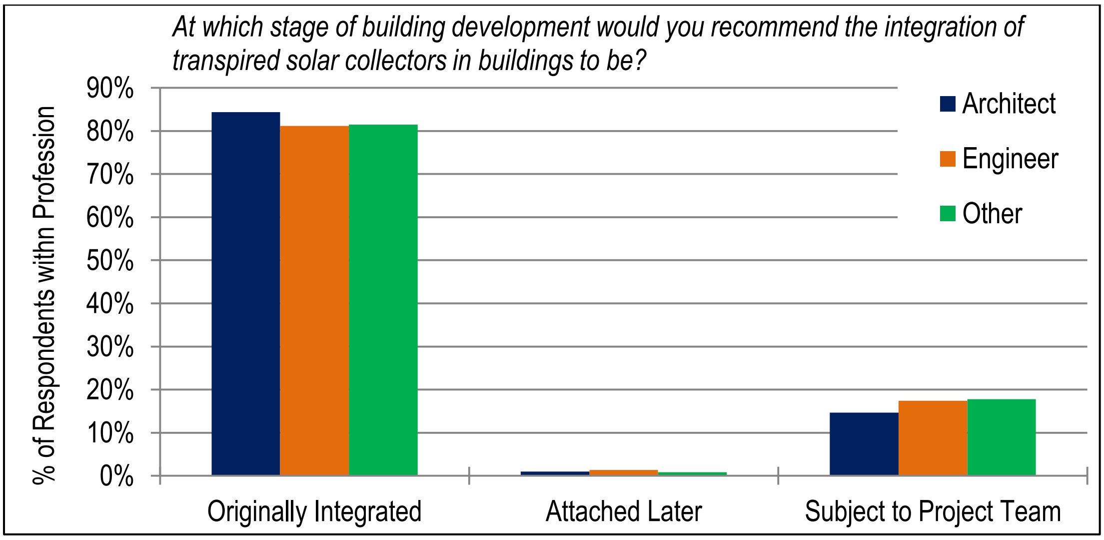


Figure 5-41: The recommended development stage of integrating TSC in buildings (Table C-41, Appendix C)

Statistically, no significant association was found between the selection of integration stage of TSC and any of the professions, climatic zone, geographic groups, experience or academic degree of the participants. Furthermore, no significant association was found with awareness of the TSC technology. This means that all respondents were in a statistical agreement in the ranking.

Qualitative Analysis: The most common theme for comments was 'early consideration and design compatibility'. This theme was strongly stressed in this question although it has also been considered in previous sections (5.5 and 5.6.2i). As the vast majority of the respondents preferred integration of TSC at the design stage, most of the comments expressed support for original integration *".......or as early as possible for full integration into the design"*. All aspects of renewable energy technologies as part of

"...environmental responsibility [have] *to be considered at the outset of every project ...",* according to a consulting architect from England. This was also stressed by a consulting architect from Scotland who said: *"...sustainable elements ... should be integrated at the beginning as part of the overall concept"* in order to avoid *"...bolt-on afterthought";* (discussed in section 5.6.3) and was stressed by other respondents. Otherwise, late integration was deemed to be *"...a compromise"* with other functions or design elements according to an architect from the USA.

Potential integration for existing buildings: Either the late integration of TSC technology was selected by a few participants as an option, or participants preferred to leave the project design team to decide how to introduce it, especially for existing buildings. An architect at the national government of Canada, continental climatic zone, who selected the option of attaching TSC at a later stage justified his selection due to his belief "...[to] *become stewards of the existing built environment rather than trying to build our way out of climate change"*. This direction transmits a potential integration of TSC, as well as other renewable energy technologies in the existing buildings, especially that the existing buildings outweigh the newly design buildings in number as highlighted in sections 1.3.3 and 3.2.

Non-systematic design process: On the other hand, the integration was seen as a complicated design process that cannot be prejudged *"...until one picks up a pencil, programme in hand, the specific context or setting of the project known, and start to work"* rather than a simplistic answer of the question as mentioned by an architect from the continental New York climate in the USA. This statement supports a non-systematic design process.

5.6.3 AESTHETICS

Aesthetics of TSC integration is considered under the following topics:

- Invisibility or feature
- Use of dummy panels
- Colour selection
- Aesthetics of light colours versus TSC performance.

i) INVISIBILITY OR FEATURE

It was found that 43.6% (n=402) of the participants preferred invisible integration of TSC, while 28.4% (n=262) preferred a clearly featured integration, while 28.1%, n=259 of the participants had the choice of 'no opinion'. Many participants mentioned that decisions must be made on a case to case basis and others indicated that both clearly featured and invisible designs are possible options (Fig. 5-42).

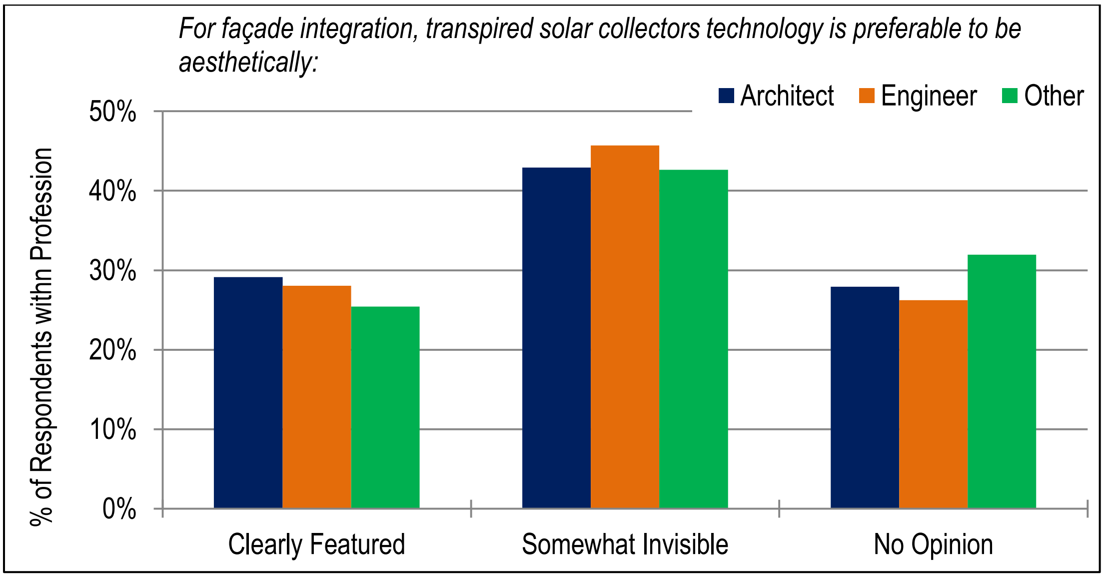


Figure 5-42: The preference of aesthetic integration of TSC in façade (Table C-42 in Appendix C)

There was no association in selection with profession, climatic zone or geographic region. However, the respondents from temperate climatic zones (46.3%, n=272) were the highest in preference of invisibility whereas the dry and tropical zones' participants (39.1%, n=34) highly preferred a clearly featured integration. Similarly, the British participants (49.1%, n=130) were the highest in favour of invisibility whereas the participants from other countries group (37.9%, n=22) where the highest in favour of clear feature integration.

Qualitative Analysis: This aspect of the survey attracted significant comment, which justifies the importance of aesthetics as an 'invisible incentive'. The main themes of the comments included 'concept compatibility', 'location, size and orientation', 'knowledge diffusion', 'prototype technologies' and 'building type and function'. The majority of the comments (62%, n=106) were made by participants who selected 'no opinion' in figure 5-42 above; 63% out of them were from temperate climatic zones, 26.5% from continental and 8.5% from dry zones in addition to one response from tropical zone and one response from the USA having no identified climatic zone. The majority of those respondents strongly agreed that the selection *"depends"* on many contexts (Fig. 5-43) including site characteristics, building type, function, location of the project and design concept. This dependent approach agrees with the basis of the recommended guidelines in section 3.2.4. Some of those participants however, mentioned that the integration has to be well incorporated in the concept design *"...irrespective of its visibility"*, stated a consultant architect from the mediterranean climate of California, a temperate climatic zone in the USA.

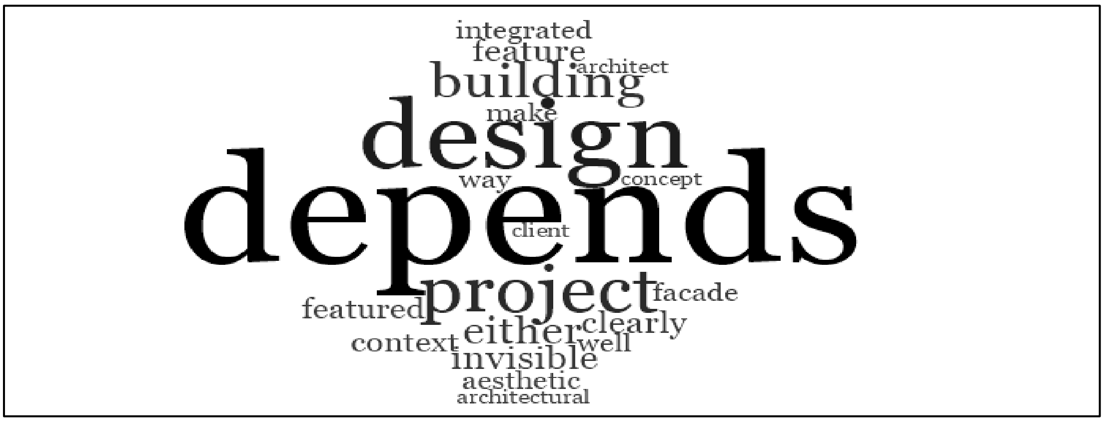


Figure 5-43: The 20 most frequent words included in the comments on invisibility or featured integration of TSC

Participants who preferred invisible integration gave their reasons. Although a few of them mentioned the dependence on the project, an academic architect from Canada, humid continental climatic zones, wondered "[why] *should solar components stand out like a sore thumb…"*. Another reason was presented that featured technologies *"... reduce the market value of ... property*", stated a Greek engineer from the national government, from a temperate climatic zone. This in turn would not be in favour of clients when they decide to resell their properties. This was notably defended by an engineer from the New Mexican dry cold dessert climate in the USA who preferred the invisible integration of TSC: "*the days of showing off solar panels are passed,* [it is the] *time to just accept them"*.

On the other hand, participants in favour of featuring technologies also gave their reasons. A consulting architect from the mild humid temperate Amsterdam in the Netherlands mentioned that *"well designed* [technology has to be] *recognisable"*. Others would recommend using the integrated technology as *"an environmental statement"* or a *"teaching tool"* or *"provides a green message". Many of the commenters considered that TSC is difficult to be hidden and therefore hiding it might result in an incompatible design. Therefore, some mentioned that *"if you've got it, flaunt it"*, Belgium architect from the mild humid temperate Brussels and *"make a* [statement] *of what is being done"* academic architect from Wales.

ii) USE OF DUMMY PANELS

Dummy panels can be used to facilitate architectural unity where only a small percentage of the façade is required to provide adequate heat, or to match the functional unit on the sun facing façade. It was found that 47.6% (n=446) participants were in strict opposition to the use of dummy panels in design versus a limited number (8.2%, n=77) who were in agreement recommending the use of dummy panels. The remaining 44.2% (n=414) of respondents would sometimes recommend dummy panels (Fig. 5-44).

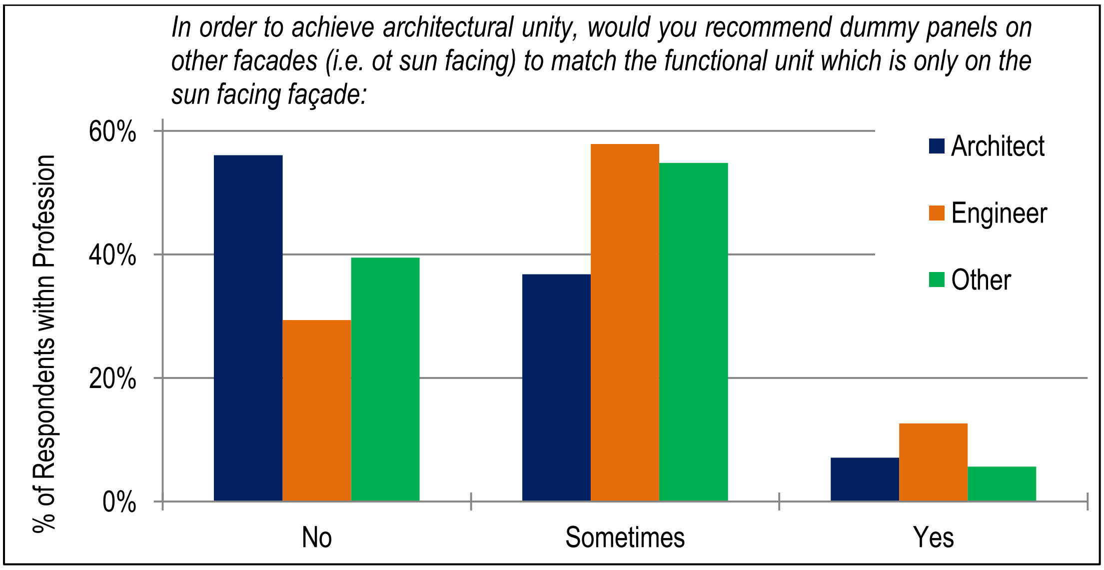


Figure 5-44: The recommended use of dummy panels to achieve architectural unity (Table C-43, Appendix C)

Statistically, there was a significant association between the selection and the profession [$\chi^2(4, n = 937) = 53.12, p < .0001, \text{Cramer's V} = .168$]. The architects were mostly in a strict opposition to the use of dummy panels (56.1%, n=332) followed by other professions (39.5%, n=49) and then the engineers (29.4%, n=65). Investigating the statistical association with climatic zones and geographic locations was not reported as the inputs did not satisfy Pearson's Chi-square rules (4.4.2i). However, the participants from tropical climatic zones (61.9%, n=13) had the strongest disagreement with the use of dummy panels followed by continental (53.8%, n=129), temperate (45.6%, n=274) and in the end the participants from dry climatic zones (37.9%, n=25). In terms of geographic regions, the Canadian participants were in the highest rejection of using dummy panels (56.3%, n=49) followed by the Americans (54.3%, n=159), the mainland Europeans (44.7%, n=101) and then the British respondents (43.6%, n=119) whereas the other countries participants had the lowest percentage of rejection (31%, n=18).

Qualitative Analysis: Participants in support of using dummy panels considered using them as they *"...can help in the overall appearance"* stated an academic from Wales. Others had a conditional acceptance of using dummy panels on office buildings. A considerable number of respondents who opposed the use of dummy panels in the design were found open to the possibility of using them dependent on the circumstances and design concept. However, others considered dummy panels *"...could misinform the public"* as stated by an academic engineer from a continental climatic zone in Canada or *"...wasteful..."* according to an academic from a dry hot dessert climate in Arizona in the US and another architect from a temperate zone in Belgium, and could *"...increase cost"* as per an academic from the mild temperate Guildford in England.

Some participants who favoured the use of dummy panels (63.2%, n=79) gave comments to support their position. Apart from a few who related the decision to design circumstances, most of the comments were more biased towards avoiding the use of dummy panels:

- *"Architectural design should* [always] *be honest",* consulting architect England, temperate climatic zone, who had more than 15 years' experience.
- "[Buildings] *should be didactic and used as a learning tool. We don't put solar shading where not required, so why bother with dummy panels",* consulting architect from Wales, temperate climatic zone.
- *"'Dummy' panels are not in harmony with the principle of sustainability - i.e. optimum use of resources"*, consulting architect from England, temperate climatic zone, who had more than 15 years' experience
- *"Dummy panels would be a design failure",* consulting architect from Canada, the temperate British Columbia climatic zone, who had more than 15 years' experience.
- *"This would be poor design to assume this statement"*, architect from USA, the humid continental Fort Wayne temperate climatic zone in Indiana. who had more than 15 years' experience

This strict opposition to the use of dummy panels contradicts the highest rating of the Ann Arbor building (section 5.5.1i) which uses dummy panels. This concludes that theoretical rules could be traversed in favour of well-designed examples. This confirms, *"Aesthetics are subjective"* as stated by a few participants. It also supports the argument that design is a 'non-systematic process' as reported in section 5.6.2iv, and therefore the architectural design as a creative process compromises certain theoretical beliefs in order to produce a well-designed piece of work.

iii) COLOUR SELECTION

At least one manufacturer provides TSC panels in a range of 24 colours. This colour range was presented for the consideration of the participants; 66.1% (n=601) of participants were satisfied with the available range of colours. However, a significant association was found between the response and the profession of the respondents $[\chi^2(2, n = 909) = 31.10,\ p < .0001, \text{Phi} = .185]$; 40.5% (n=234) of the architect respondents were not satisfied with the available standard colours (Fig. 5-45). The additional colours required included: white; yellow; warm colours; stone and earth; and standard RAL colours (www.ralcolor.com) that is the European standard classic colours. Other than this, there was no statistical association with any other demographics of the respondents.

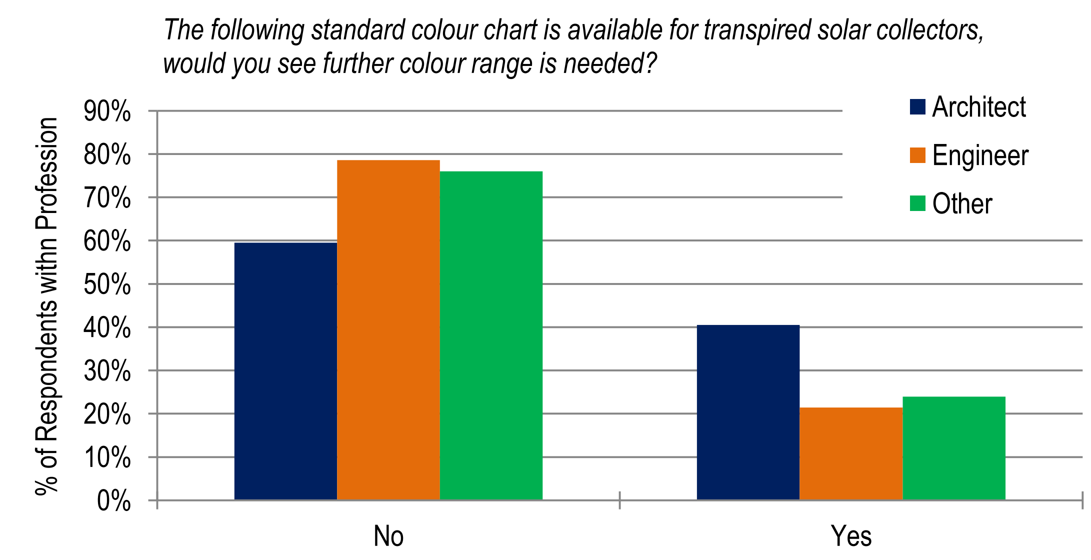


Figure 5-45: The need for further colour range than the available standard colour chart (Table C-44, Appendix C)

Qualitative Analysis: Comments from participants who required additional colours favoured increasing the options as *"a bigger variety will provide a better aesthetic result"*. The other respondents who were satisfied with the available range of colours considered the current range as good to start with, as stated by the architect from the national government in the UK. Others, especially engineers, were satisfied with the current range of colours since efficiency *"...out-weighs issues of colour"*. However, this stance was refuted by an academic from Australia, the mild humid temperate Canberra, who considered *"architectural aspects outweigh thermal performance"*.

iv) Aesthetics of Light Colours Versus TSC Performance

The colour range available does not feature many pale colours because of their low absorptivity as explained in section 2.4.2. Therefore, it was worthwhile to examine the coherence between the available high efficiency darker TSC colours and aesthetics. Results show that 36.2% (n=334) of respondents did not see any contradiction between using the current standard colour chart and the aesthetics of design. However, there was a similar number 35.9% (n=331) who found a possible issue and 18.0% (n=166) who definitely found an issue between the current standard colour chart and the aesthetics of design (Fig. 5-46). The selections have neither statistical association with profession nor with climatic zones.

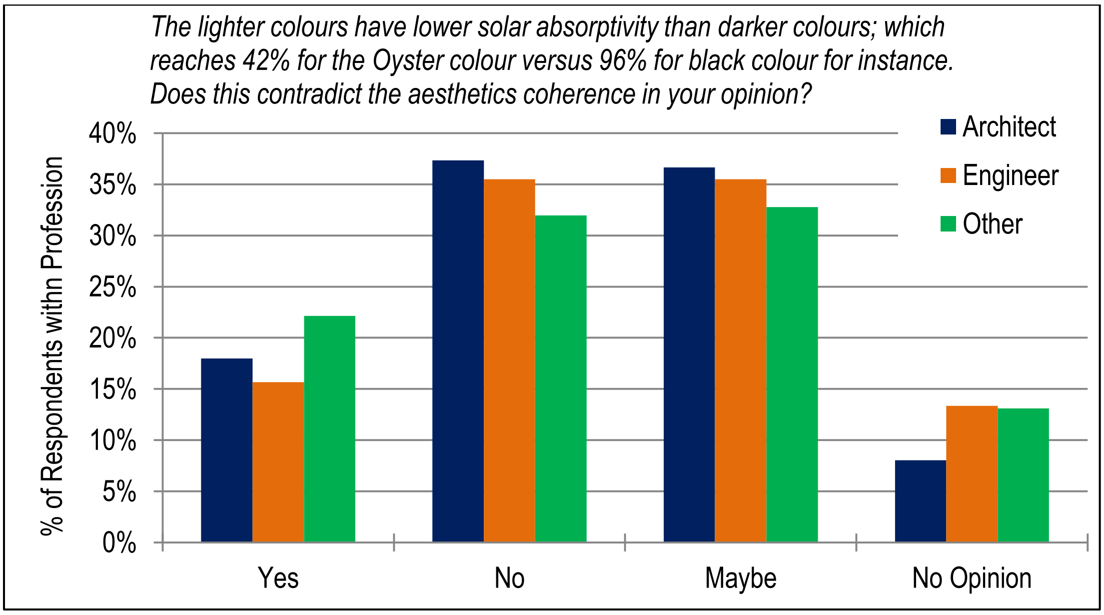


Figure 5-46: Contradiction between the currently available standard TSC colour chart and design aesthetics (Table C-45, Appendix C)

Qualitative Analysis: The comments reflected those in the colour selection above; however, more restraints were found in responses in favour of performance to outweigh light colours. Few of the comments indicated that the architect should better adapt the concept design to match the dark colours. An academic engineer from Wales, for instance, stated that *"aesthetic coherence and energy generation are two separate issues, which have to be reconciled for individual buildings"*. Overall, as derived from section 5.6.3iii and this section, further colours remain required; especially by architects and building designers. Furthermore, the availability of a wide range of colours was recommended by Probst and Roecker (2007) for good aesthetic preference as noted in section 2.4.5i.

5.7 SUSTAINABLE CHARACTERISTICS

The sustainability of buildings as well as products is an integral part of the whole building design as explained in section 3.2.2. Therefore this topic was explored covering the following subjects:

- Sustainability of TSC - perception
- Factors influencing sustainability of TSC
- Technical characteristic features

5.7.1 SUSTAINABILITY OF TSC: PERCEPTION

The perception of transpired solar thermal's contribution to the sustainable built environment as a comparatively low cost renewable energy was explored. It was found that 78.6% (n=729) respondents viewed TSC as a low cost renewable energy technology which contributes towards the creation of a sustainable built environment as shown in figure 5-47.

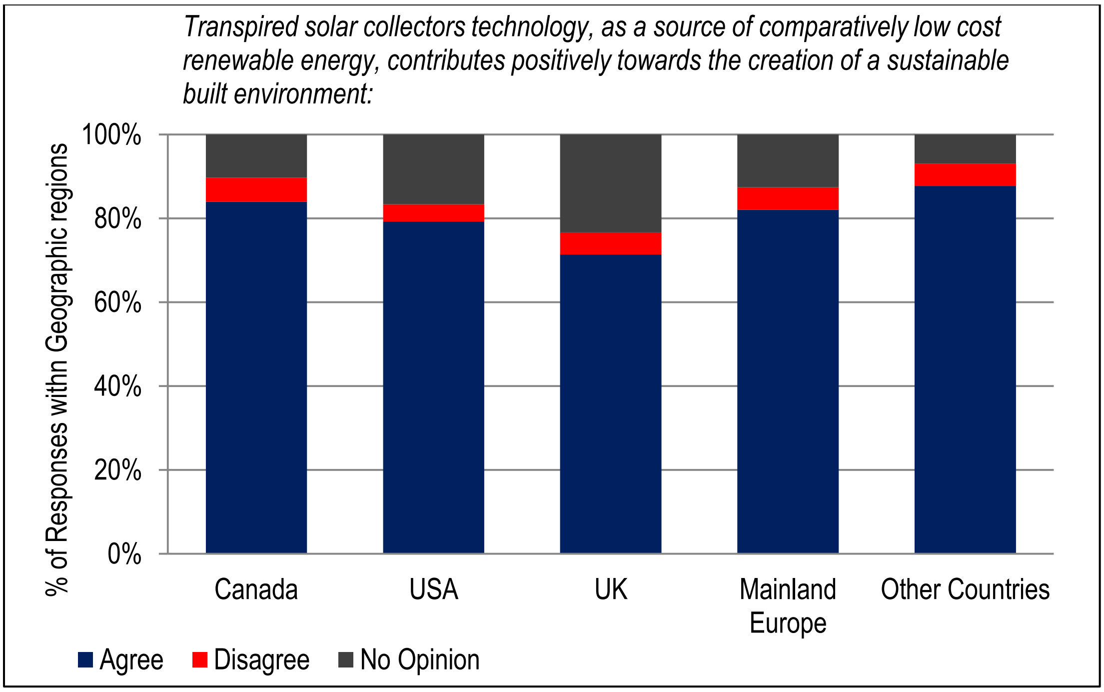


Figure 5-47: TSC, as a source of comparatively low cost renewable energy, contributes positively towards the creation of a sustainable built environment (Table C-46, Appendix C)

There was no significant association with profession, climatic zones, academic degree, work filed or years of experience. A statistical association with geographic regions was noticed. A higher percentage of positive responses were forthcoming from the Middle East and Australia (87.7%, n=50) than from the UK (71.4%, n=192). The respondents from Canada (83.9%, n=73) mainland Europe (82%, n=182) and the USA (79.2%, n=232) were placed between these two groups as regards their positive view of TSC towards the creation of a sustainable built environment. However, a higher proportion of the UK participants had no opinion (23.4%, n=63) in comparison with other regions (16.7% USA, 12.6% mainland Euorpe, 10.3% Canada, and 7.0% other countries).

Qualitative Analysis: Similar to many of the previous questions, especially section 5.4.2, a considerable number of the comments were themed under ‘cost effectiveness’. It seems that many participants believe that sustainability equals cost increase. Admittedly, the wording of the question seems multifaceted and lets participants focus on cost more than the contribution towards sustainable built environment. A Canadian engineer agreed with the statement being tested on condition that *“as long as more cost effective efficiency measures are given higher priority”.* An academic engineer from England agreed subject to the *“element of sustainability* [being considered], *economic sustainability may be a big issue”*. Further participants were keen to see successful demonstration projects (i.e. consulting architect from a temperate climatic zone in the USA) and access independent scientific reports on real projects (i.e. consulting architect from England) that show specific measures of this contribution towards sustainability. Few responses stressed the potential benefits of TSC towards energy saving in particular, rather than sustainability in general, which is a wider term. Selective factors that could influence the sustainability of TSC were however explored in section 5.7.2.

5.7.2 FACTORS INFLUENCING SUSTAINABILITY OF TSC

Sustainability is a broad field, therefore six factors were rated to establish which was perceived to be most important by the participants. This was established by calculating the mathematical mean of the responses (section 4.4.2iii). Energy saving was rated as the most important, with a mean value of 81.3% (n=935). This was followed by indoor thermal comfort at a mean value of 66.7% (n= 928) as shown in figure 5-48. Notably, there was no statistical association with profession.

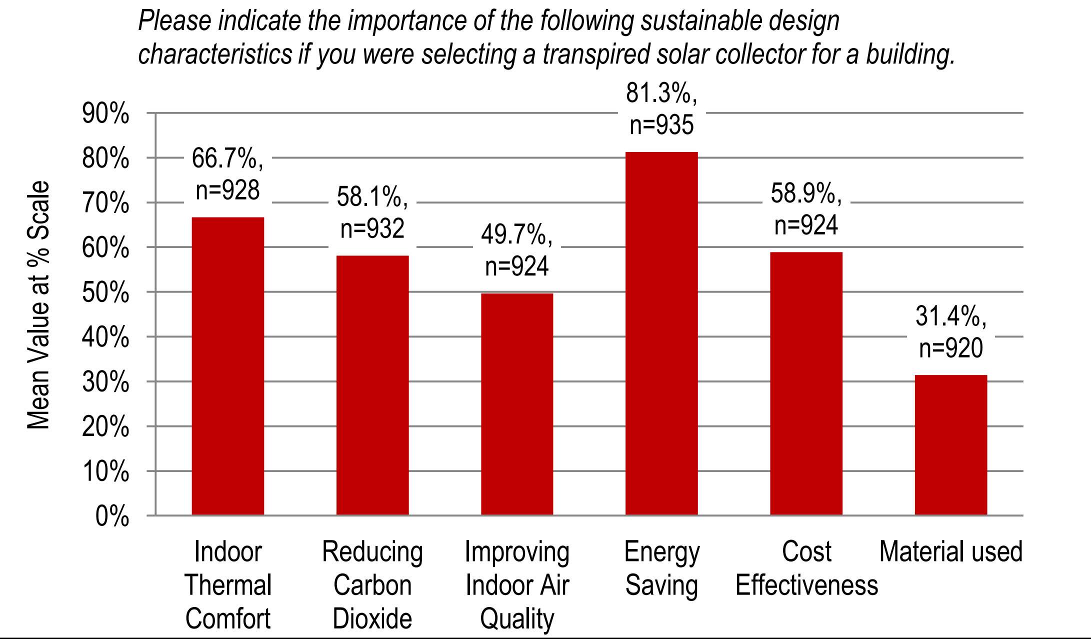


Figure 5-48: Mathematical mean value of the overall rating of sustainable characteristics at a ±100 scale (Fig. C-1 and Table C-47, Appendix C)

There was a strong direct correlation noticed between indoor thermal comfort and improving indoor air quality for architects $(\text{rho} = .55, p < .0001)$ and for the other professions $(\text{rho} = .53, p < .0001)$ (Table C-48, Appendix C). By applying eq. (4-2), z_{obs} is equal to 0.41 which concludes no significant difference in the strength of the correlation coefficients between indoor thermal comfort and improving indoor air quality for architects, and the other professions. Pearson's Chi-square test cannot be conducted due to a lower distribution of responses in certain ratings (section 4.4.2i).

Qualitative Analysis: Although ranking was aimed from the question, many participants expressed the view that all factors were of similar importance.

- *"All these considerations are important to achieving a holistic and integrated sustainable solution"*, a consulting architect from England who had more than 15 years' experience.

- *"All factors have to be considered within an overall building performance"*, another consulting architect from England.
- *"All these elements are almost equally important, since they are the foundation of a sustainable building"*, an architect from Greece, temperate climatic zone.
- *"All these elements are equally important if a building is to truly be designated 'sustainable'"*, contractor from USA, a dry cold semi-arid climatic zone in Utah, who had more than 15 years' experience.

Further comments related to the ranking priority of the factors to project context that vary from case to case. However, the ranking might also differ acording to the background (i.e. business type, level of responsibility, characterestics of the experience) of the respondent which is outside the scope of this study. The following summary highlights the qualitative analysis of the heighest four factors:

Energy Saving

Participants had also commented on energy saving at other stages of the questionnaire. These confirm both the importance of energy saving as well as the validity of question design. A Canadian architect, from the humid continental Halifax, who was searching the market for an appropriate PV technology to integrate into a façade, mentioned that the search *"... so far has resulted in disappointing power output generated by such an application".* Whereas, a consulting Londoner architect, from the mild temperate Climate in the UK, with more than 15 years of professional experience, as well as personal experience of installing PV panels on the roof of his/her own house in about 2011 has noticed *"...sustained reduction in* [the] *electrical usage of circa 25%"*, however this participant supplemented that [there] *is of course an initial financial penalty of the installation cost, which many cannot afford".* A consulting architect from the USA, the humid continental New York climatic zone, considered the effective engineering design for TSC should *"... achieve real energy savings…".*

Further participants tackled inclusion of the embodied energy of the technologies as part of energy saving as well as cost saving. Respondents' perception was highly influenced by the high embodied energy for PV; in which they generalised for solar energy technologies:

- *"I...have reservations regarding embodied energy. e.g. PV sourced from China, transportation, raw material production and manufacture..",* an architect from the local government in Wales, mild temperate climatic zone.
- *"Solar is the last thing I would add due to costs and the embodied energy in the panels",* a Californian consulting architect from the USA, a mediterranean temperate climatic zone, who had more than 15 years' experience.
- *"...embodied energy and manufacturing process of many PV cells brings into question the real worth of these technologies",* a Londoner consulting engineer from England, mild temperate climate.
- The selection of TSC *"...depends on the embodied energy",* two participants from Wales, mild temperate climate, and one from Australia, warm humid temperate climate of Brisbane.

<u>Thermal Comfort</u>

Thermal comfort was ranked second and accompanied by the following comments:

- *"Indoor air quality and thermal comfort are non-negotiable design parameters...",* a consulting architect from Canada, the mediterranean temperate climate of Vancouver in British Columbia.
- *"Thermal comfort can be subject to personal adaptation with clothing and culture of the use environment",* consulting engineer from New Jersey in the USA, humid continental climatic zone, who had more than 15 years' experience.

Cost Effectiveness

Participants had also commented on cost issues at other stages of the questionnaire. Although it is ranked as the third most important factor in terms of sustainability, overall cost was the most frequently addressed issue as represented in the word cloud (Fig. 5-49).

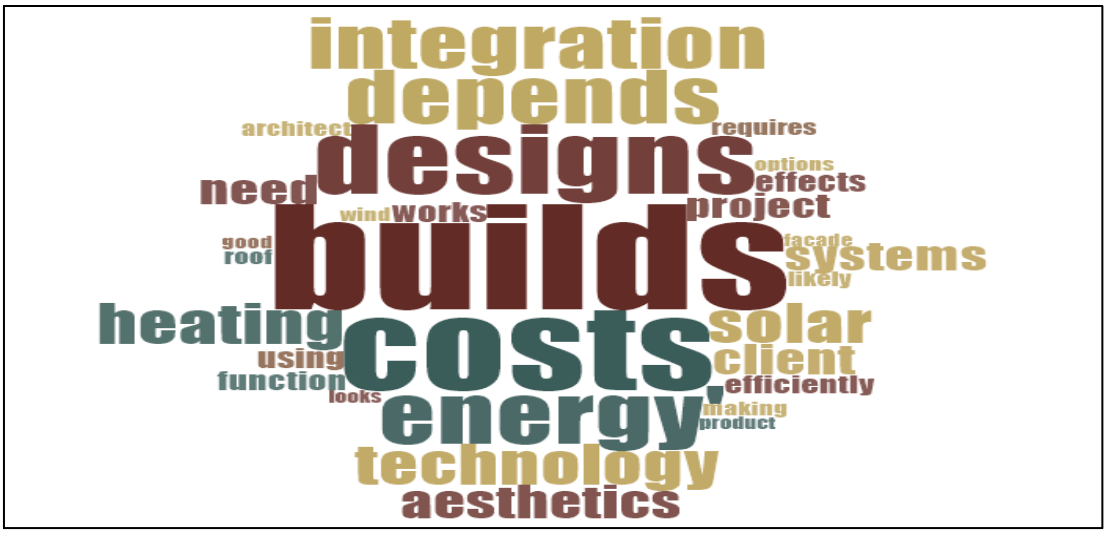


Figure 5-49: The 30 most frequent words included in the entire qualitative data of the survey

Many participants exhibited concern over the capital cost of solar energy; furthermore, the majority of the annotations were found evolving around cost effectiveness that include rate of return (ROI) and life cycle analysis (LCA). A Canadian engineer with more than 15 years of experience at Ontario national government, the humid continental climate in Ottawa, agreed the contribution of solar energy to the sustainable built environment but added that *"... take-up is low because of initial cost, lack of contractors who promote technology and perceived complication in maintenance and operation".* Another consulting architect from the USA with 15 years of experience, climatic zone not identified, mentioned that *"cost benefit analysis remains unfavorable to my clients: greater benefit still seems too subjective to most clients"*. *"Cost effectiveness should also include the cost of maintenance"* stated a consulting architect from the USA, a dry cold semi-arid climatic zone in Utah. Initial cost and ROI were considered by several participants as key challenges to the deployment and knowledge diffusion of TSC.

A number of participants agreed that solar energy contributes to the sustainable built environment *“as long as it can be competitive and the installation cost is affordable…”* as a TSC expert consulting engineer from Quebec in Canada, the humid continental climate of Montereal, has stated. Another problem evident from the respondents in certain countries such as the USA and Canada is the comparative lower cost of conventional energy sources. Another Canadian architect, from the continental climatic zone of Quebec with more than 15 years of experience, at national government stated that *“energy costs in Canada are comparatively low which makes payback for investment in solar energy problematic”*. This issue was typically addressed by TSC entrepreneurs as discussed in chapter 6.

On the other hand there were comments supportive to solar thermal as cost competitive already, as mentioned by a consulting architect from Scotland, mild temperate climate, “[solar thermal] *technologies for water heating have a reasonable payback period and can be successfully integrated in most housing”.* An American architect from the continental climate of New York stated that “*integration of any technology into Building - as opposed to ""bolt-on"" - is always the least costly/highest performing way to go”*. This comment however has a basis of support in the literature as illustrated in section 3.2.3 and discussed further in chapter 7.

Carbon dioxide reduction

CO_2 reduction ranked fourth, and was partially addressed in previous research such as (Shah et al. 2009). The importance of CO_2 reduction was expressed in section 1.3 as a driver to encourage the deployment of renewable technologies in general and TSC for space heating in particular. Further investigations on CO_2 reduction remains recommended; however, that is beyond the scope of the study.

5.7.3 CHARACTERISTIC TECHNICAL FEATURES

Six characteristic features of TSC technology were assessed in terms of importance when sourcing the technology. It was found that 46% (n=423) of respondents considered reliability to be the most important factor. Reliability was defined as constant performance and efficiency which could exceed 75% (Fig. 5-50) and 27.1% (n=240) of respondents considered low capital cost to be the most important factor. This relates to the selection of cost effectiveness in section 5.7.2. The other characteristics were found to be of low importance in comparison with those mentioned above. However, these could be essential supportive features to be considered in research and development. There was no significant association between the respondents' professions, experience, climatic zone, geographic region, academic degree, or awareness of TSC.

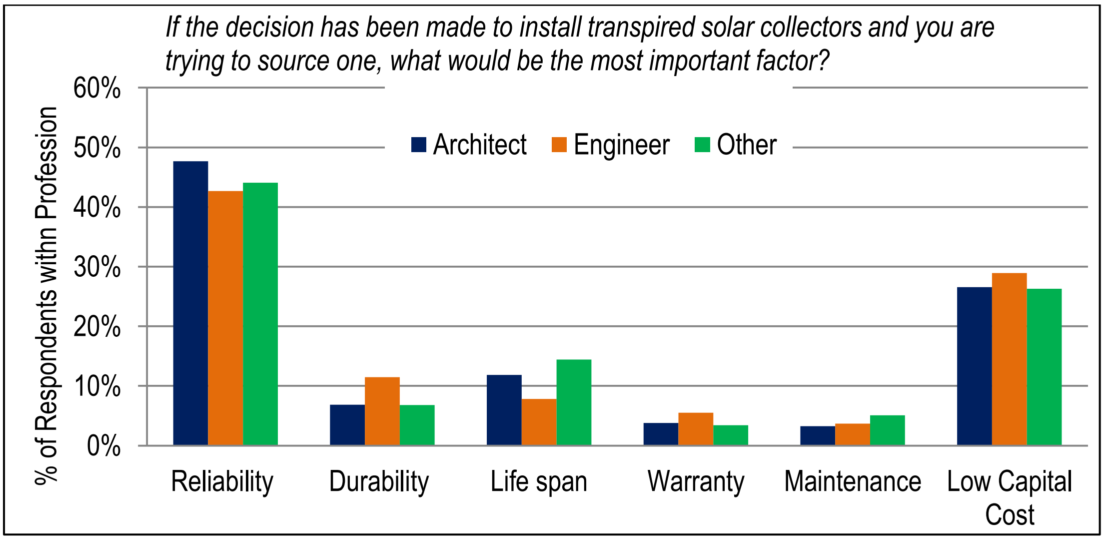


Figure 5-50: The importance of considering some characteristic features when sourcing TSC technology (Table C-49, Appendix C)

Qualitative Analysis: The comments were varied according to the viewpoint of the participant. Therefore, the comments were themed within the characteristic features shown in the figure above. Almost one-third of the comments were made by respondents who had prioritised 'reliability'. Participants tried to link life span and maintenance to reliability: *"life span and reliability are related"* stated an architect from the tropical climate of Florida in the USA. In an expression of the significance of reliability, a consulting architect from a dry climatic zone who had more than 15 years' experience, stated that *"reliability trumps cost, as if it is reliable it will pay back as promised".* Several comments were found, however, expressing the importance of all the features together without a compromise to drop any of them.

"Everything is driven by budget", stated a consulting architect from Scotland, in explanation of his reason for the selection of 'low capital cost'. Participants who favoured low capital cost were mainly focusing on the argument of payback period. Some of them fixed a target of 5 years for payback period whereas others were not convinced of the 12 years maximum period of payback. *"I doubt we would get a payback in less than 12 years"*, stated a consulting architect from Canada, the humid continental Manitoba climate, who had more than 15 years' experience. This again refers to the creation and dissemination of information which has been addressed in chapter 6.

Similarly, life span selectors argued the optimum time of life span. "*Any element that only lasts 25 years is not sustainable,* [it is] *green wash*" stated an academic architect from the mild humid temperate climate of London in England who had more than 15 years' experience. Life span might *"...be primary for ... institutional* [and] *industrial clients*" stated a consulting architect from a non-identified climatic zone in the USA. A consulting project manager participant from England also stated that "*lifecycle costing is fundamental in terms of return on capital"*.

5.8 HEAT DIFFUSION

The key part of a TSC is the supply of heated air into the indoor spaces. Methods of doing this in domestic and non-domestic buildings were considered by those participants who had expressed an awareness of TSC.

Domestic Buildings:

The respondents considering domestic dwellings showed support for both HVAC and direct flow distribution of the heated air, however, HVAC was slightly preferred (47%, n=218) with no significant association between professions, experience or academic degree (Fig. 5-51).

Invistigating the significance association between the responses and climatic zones was not possible due to a lack of selections by tropical participants for other techniques. After excluding the 'other techniques' selection, there was no statistical association of the responses with the climatic zones of the respondents. However, the tropical respondents recorded the highest preference towards HVAC (62.5%, n=5) followed by dry zones (56.2%, n=18) and continental zones (53.4%, n=70). The temperate climate respondents were the least in preference of using HVAC for domestic dwellings (42.7%, n=125) nonetheless, they recorded the highest preference for direct mechanical ventilation (43.7%, n=128) and furthermore they ranked the highest to search for alternative techniques (13.7%, n=40).

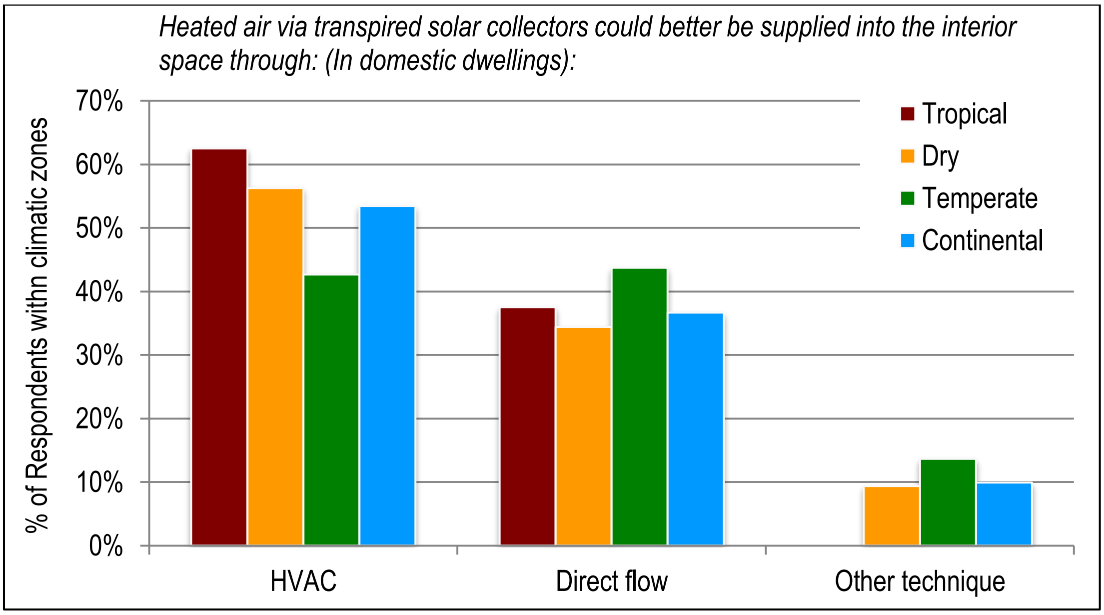


Figure 5-51: Preferences of supplying the heated air to interior spaces for domestic dwellings per climatic zone

There was a significant association between the selection and the respondent's geographic location, however, this association was noticed after excluding the regional category of 'other countries' due to its violation of the Chi-square principle for this reduced data set: $[\chi^2(6, n = 435) = 23.20, p = .001, \text{Cramer's V} = .163]$. The Canadian respondents showed the the highest preference of HVAC (63.3%, n=38) followed by the Americans (55.8%, n=67) while the British respondents were the least enthusiastic to HVAC (36.0%, n=50). In contrast, the direct flow system was most favoured by the British respondents (49.6%, n=69) for domestic dwellings and the least likely to be selected by the Canadians (33.3%, n=20) (Fig. 5-52).

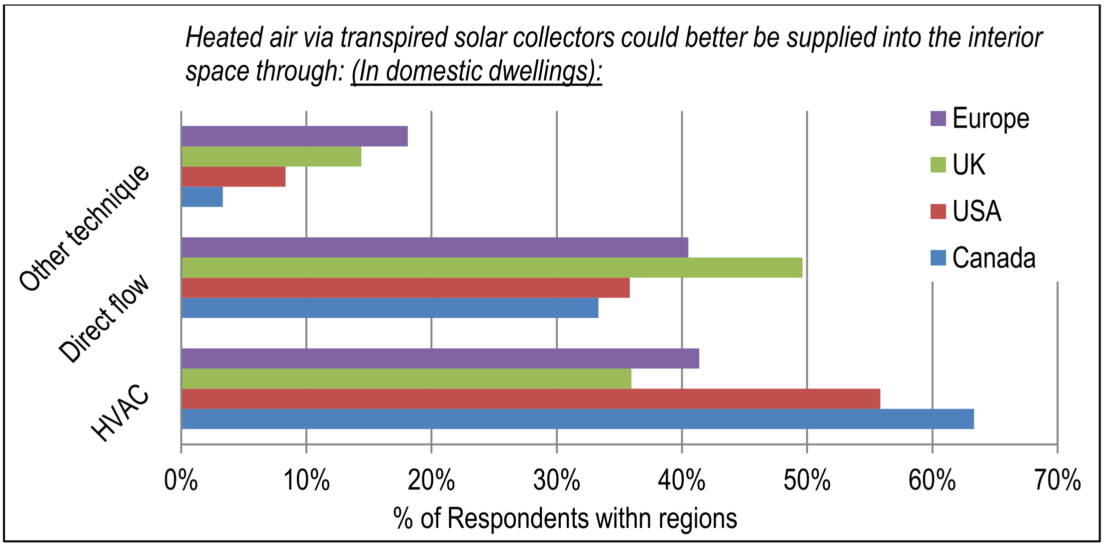


Figure 5-52: The regional preferences of supplying the heated air to interior spaces for dwellings (Table C-51, Appendix C)

Non-domestic Buildings:

Unlike the domestic dwellings, the respondents of non-domestic office buildings were mostly inclined to use HVAC (70.8%, n=327) as shown in figure 5-53.

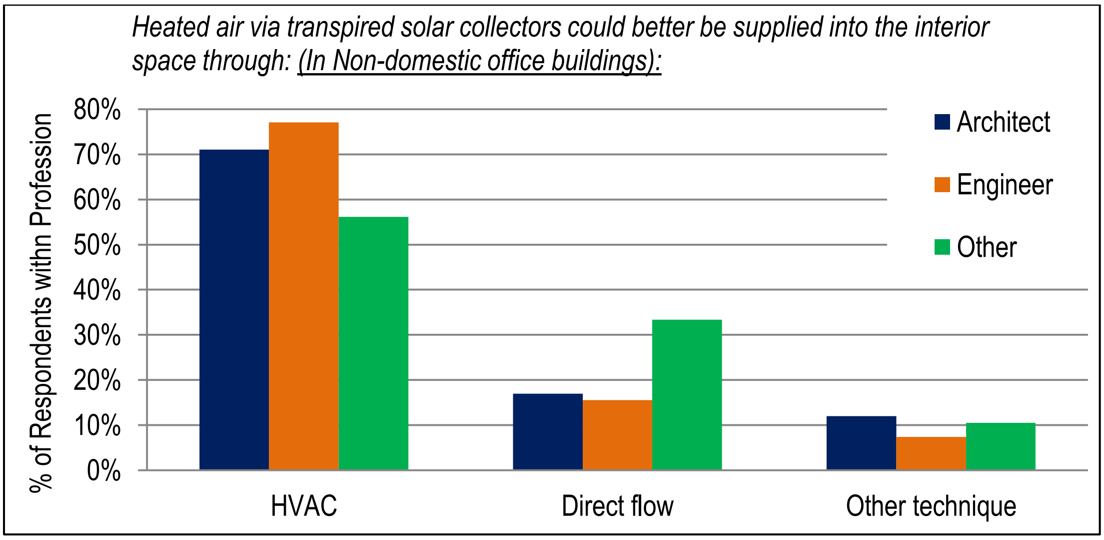


Figure 5-53: Preferences of supplying the heated air to interior spaces for non-domestic office buildings per profession (Table C-52, Appendix C)

There was a significant association with profession, particularly 'others' who were comparatively less enthusiastic towards the use of HVAC and more postive towards the direct flow: $[\chi^2(6, n = 435) = 23.20,\ p = .001,$ $\text{Cramer's V} = .163]$. The numbers of respondent engineers and architects who selected the use of HVAC for non-domestic office buildings increased remarkably from domestic dwellings by 56.7% and 63.5% respectively. Although it seems apparent that the ‘other’ respondents maintained relatively similar percentages for each option of heated air supply for both domestic and non-domestic buildings, almost half of those respondents had different selections for each case.

At the geographic regional scale, a similarity of significance to the domestic dwellings was found for non-domestic office buildings where Canadians (83.1%, n=49) and Americans (72.6%, n=85) supported the use of HVAC more than the mainland Europeans (68.1%, n=77) and the British (65.2%, n=92). Both the mainland European and the British respondents were more supportive of the use of the direct flow system to supply the heated air than the Americans and the Canadians: $[\chi^2(6, n = 430) = 13.39, p = .037, \text{Cramer's V} = .125]$ (Table C-53 in Appendix C).

For climatic zones significance, the input data did not satisfy the Pearson’s Chi-square rules even after reducing the options to HVAC and direct flow. Unlike the domestic buildings, the respondents from continental climatic zones showed the highest commitment towards the use of HVAC in non-domestic buildings (78.1%, n=100) followed closely by dry climate (77.4%, n=24). The temperate climate participants became the third (67.5%, n=197) whereas the tropical zones’ participants recorded 62.5%, n=5 maintaining the exact same percentage for dwellings. Although all other zones were increased from domestic, the highest jump noticed between domestic and non-domestic was at the temperate zone where the percentage increased by 24.8%.

The topic of air supply was further investigated to consider integration for existing buildings where HVAC sytems had not previously been installed.

For the existing dwelling case, the majority of respondents (65.3%, n=309) would accept the use of direct flow (Fig. 5-54). However, 23.9% (n=113) of respondents would pursue the installation of a HVAC system. A further 10.8% (n=51) of the respondents were divided into four groups: the first group would consider alternative options such as a heat exchanger and ductless split system (29.5%); a second group would avoid using TSC (13.7%); a third group linked the integration to the project circumstances (39.2%), while the rest (17.6%) expressed no opinion. There was no significant association of the selctions with profession, climatic zone or geographic region; that was examined after excluding the inputs options that violates the Pearson's Chi-square rules.

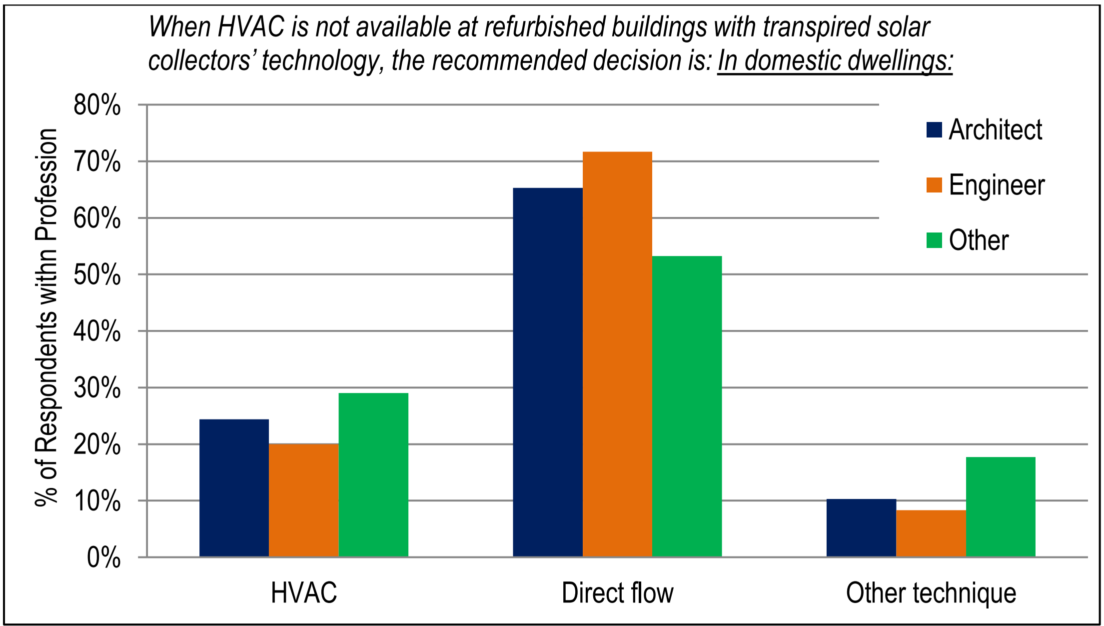


Figure 5-54: Preferences of supplying the heated air to interior spaces for domestic dwellings when HVAC is not originally available.

When considering existing non-domestic buildings, 47.4% (n=221) of the respondents favoured direct flow distribution, while 42.3% (n=197) favoured HVAC (Fig. 5-55). Although the 'other professions seemed more dedicated to direct flow than architects and engineers, there is no statistically significant association to profession, nor to the geographic region. Similar to the existing domestic dwellings, there were 10.3%, n=48 respondents who preferred to avoid using either direct flow or installing new HVAC. This category had almost the same distribution of responses as for the existing domestic dwelling. Similar to the existing domestic units, there was no significant association of the selctions with profession, climatic zone or geographic region as was examined after excluding the inputs options that violates the Pearson's Chi-square rules.

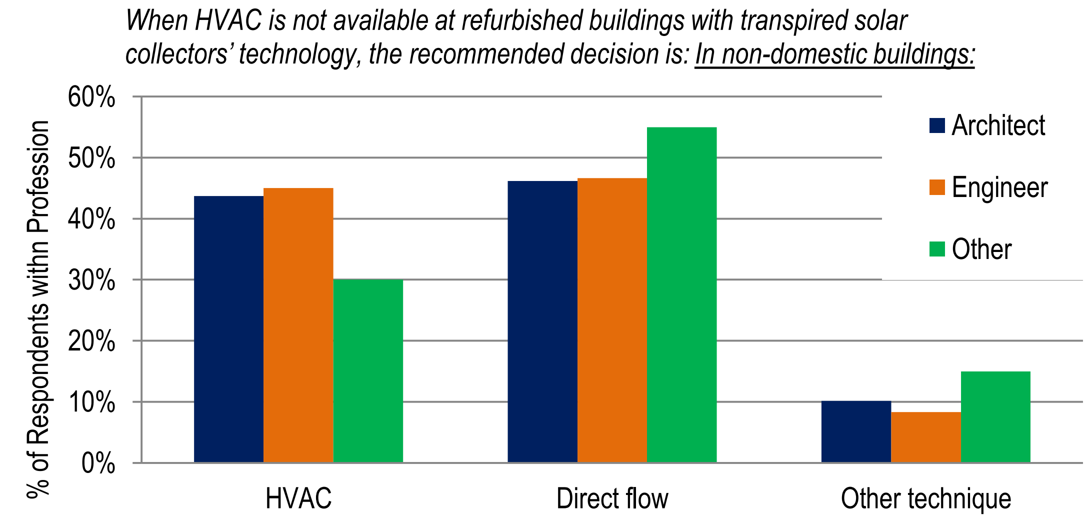


Figure 5-55: Preferences of supplying the heated air to interior spaces for non-domestic office buildings when HVAC is not originally available.

Qualitative Analysis: The comments in this section were only made by participants who expressed their awareness of TSC. Nevertheless, few participants mentioned their need of further knowledge about TSC in order to correctly participate with this topic. Some participants, however, stated that the selection for new and existing domestic and non-domestic buildings depends on the *"...overall design philosophy. No particular system is best"* as stated by a consulting architect from Wales. Further dependence was linked to the quality of the ambient air, the available space and other specific contexts.

British respondents mostly favour direct flow as aforementioned. This seems due to unfamiliarity with the HVAC system in the UK, especially that many people consider *"HVAC* [is] *only appropriate if cooling is a requirement"* which is not generally the case in the UK, as expressed by participants such as an academic from England and architects from Scotland. Nevertheless, the new generations seem to encourage heat supply through HVAC especially as "[a] *number of very poor installations have used direct flow..."* therefore, *"... TSC should always be supported by the HVAC system as a rule"*, stated a TSC expert engineer from the UK.

5.9 DEVELOPMENT OF TSC

In spite of its three decades since patenting, TSC technology remains with limited worldwide installation. Further technological change and innovation development is required; therefore, perceptions regarding current acceptance and future development suggestions and guidlines were explored.

5.9.1 THE CURRENT COMMERCIAL TSC

A group of questions were introduced to draw a more detailed assessment of current commercial TSC products. These included:

- Market awareness
- Satisfaction level
- Drawbacks

i) MARKET AWARENESS

It was found that 64.8% (n=324) of respondents were aware of commercially available brands of TSC, of which SolarWall® was the most well-known and 31.6% (n=158) of the respondents did not recognise any commercial product (Fig. 5-56). Notably, the most unfamiliarity with commercial products was found in Europe (40.2%, n=51) versus the least unfamiliarity in Canada (19.1%, n=13) (Tables C54 and C-55, Appendix C).

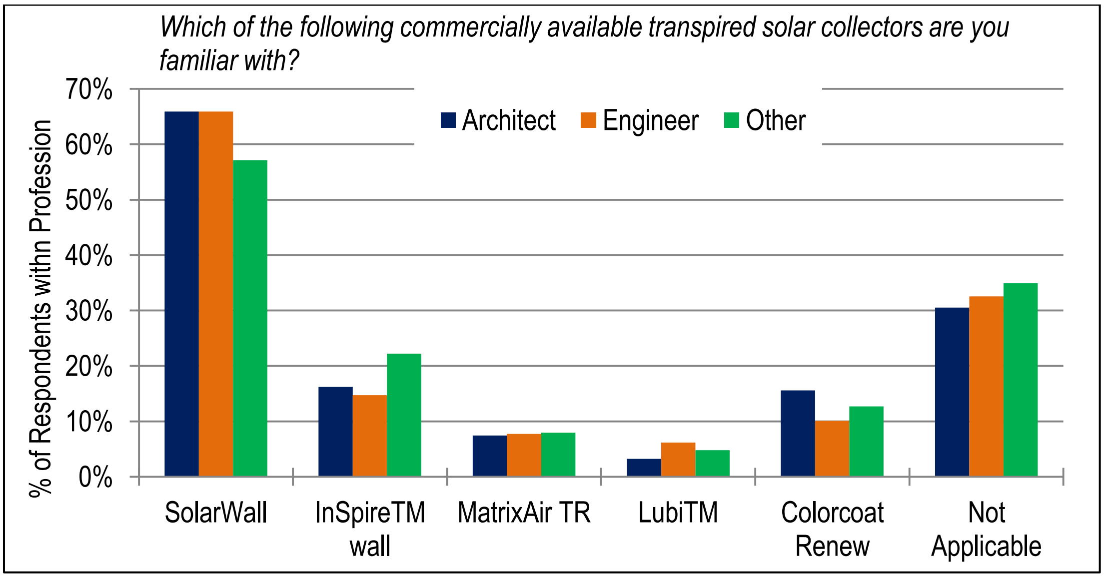


Figure 5-56: Market awareness of the current TSC technology makes

Although there was no association with profession, the geographic region had a significant association with the selection of SolarWall®, Inspire TM Wall, Colorcoat Renew®, and 'not applicable' choice among selections. For SolarWall®: $[\chi^2(4, n = 500) = 10.76, p = .029, \text{ Phi} = .147]$, the Canadian respondents were the most aware (79.4%, n=54) versus the least awareness in the mainland Europeans (56.7%, n=72) (Table C-56, Appendix C). For Colorcoat Renew®: $[\chi^2(3, n = 469) = 27.60, p < .0001, \text{ Phi} = .243]$, 27 respondents of 'other countries' were excluded due to violation of Pearson's Chi-square rule. The most awareness was found in the UK (24.7%, n=37) versus no awareness in Canada (nil) (Table C-57, Appendix C).

There was a significant association between the selection of Colorcoat Renew® and the participants from temperate climatic zones following to excluding the participants from tropical and dry zoned to satisfy the Chi-square test rules. This association refers to the geographic entity, as explained above, of the UK within the temperate climatic zones whereas the UK participants form around 46% of the total temperate climate respondents.

Some of those who were unaware of commercial products mentioned that they were aware of the theory, and some other respondents indicated that they did not use any products in projects. This question was designed to confirm the awareness level previously indicated in the survey (section 5.4.1). If the percentage of participants who selected 'not applicable' is strictly interpreted, the previous level of awareness would be reduced by 30%. However, this could better be interpreted as a low level of TSC awareness or a differentiation between 'awareness' and 'familiarity' as discussed in section 7.5.4ii.

ii) LEVEL OF SATISFACTION

In order to understand the need for research and development of TSC, the satisfaction level with current technology was explored. It was found that 64.5% (n=209) of the respondents considered the current technology at a neutral level, while 24.4% (n=79) were satisfied with the technology and 11.1% (n=36) were unsatisfied with the current level of the TSC technology and commercial products (Fig. 5-57).

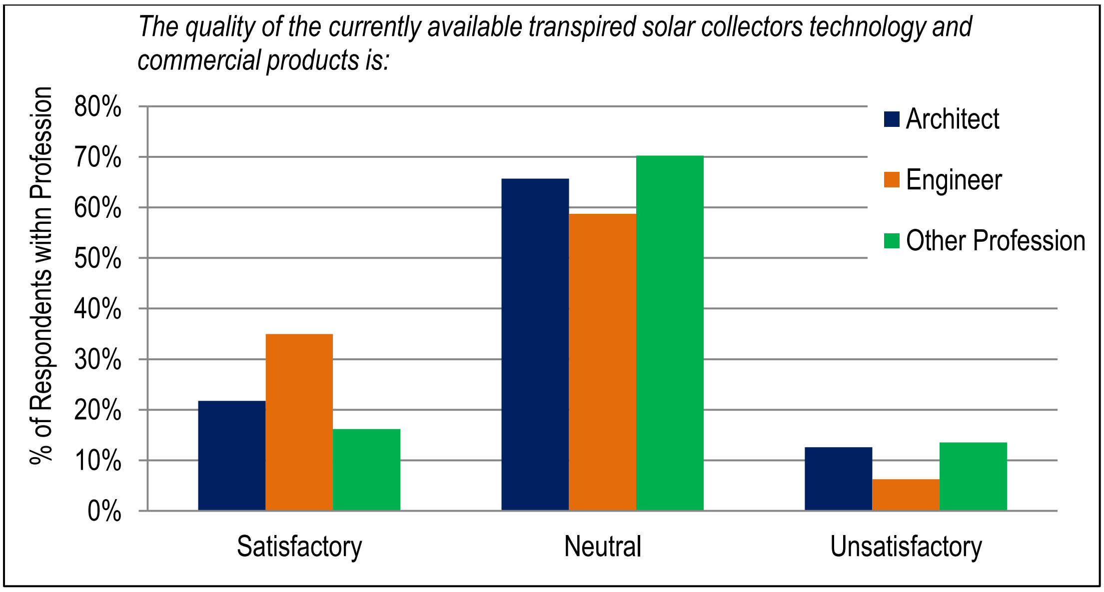


Figure 5-57: Satisfaction level of the quality of the current TSC technology per profession

Although the engineers looked to be more satisfied than architects and others, there was no statistically significant association with profession. Also there was no significant association with climatic zones. In terms of statistical association between the satisfaction level and the geographic region, there was some association $[\chi^2(6, n = 301) = 12.70, p = .048, \text{Cramer's V} = .145]$. The Canadians were the most satisfied respondents (37%, n=17) whereas the British were the least satisfied (16.1%, n=15) as shown in figure 5-58.

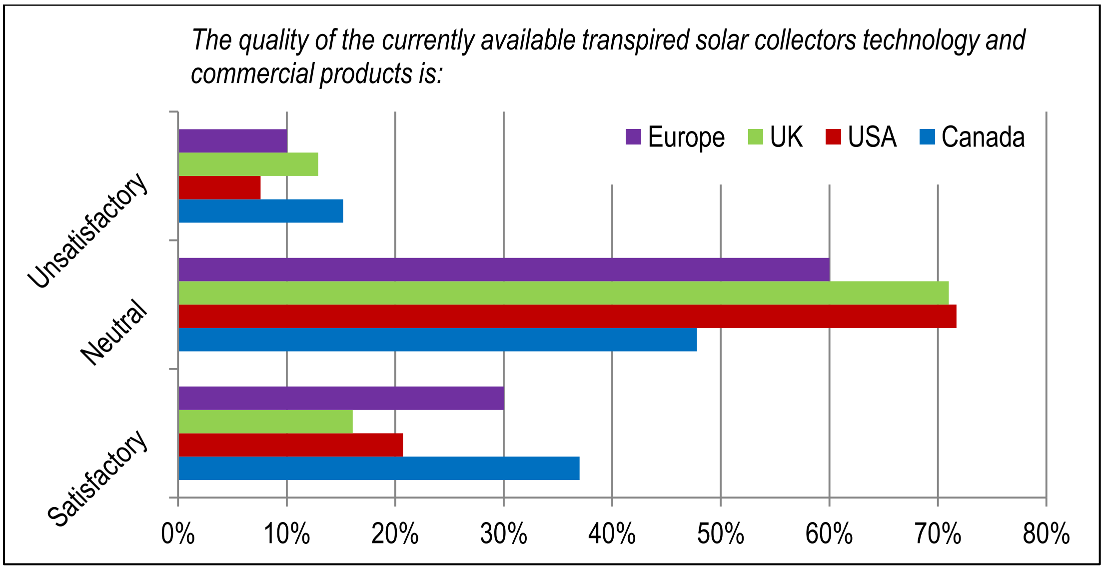


Figure 5-58: Satisfaction level of the quality of the current TSC technology per geographic region (Table C-58, Appendix C)

Qualitative Analysis: The majority of the comments were themed in relation to awareness and knowledge dissemination. Many participants felt that there were problematic areas with current TSC quality and recommended that further research remains required. Some of the respondents, who showed satisfaction of the statement being tested, added:

- *"Generally the products have not addressed maintenance or cleaning issues"*, consultant from England, temperate climate, who had 15 years' experience.
- *"...difficult to control and expensive. Passive systems designed into the building fabric are far better choices"*, consulting architect from the humid continental climate of New York in the USA who had 15 years' experience.

Few participants who selected the 'neutral' level of satisfaction shared the same concern towards lack of knowledge diffusion in addition to their established caution towards cost issues:

- *"Information about full range of products and systems is not widely distributed in professional journals"*, academic architect from Canada, continental climate, who had 15 years' experience.

Unsatisfied participants shared similar comments especially about the capital cost.

iii) POSSIBLE DRAWBACKS

The participants were asked whether, from their work experience, they were aware of any drawbacks with TSC at the design phase. Results show that 59.6% (n=169) of the participants indicated they were sometimes made aware of TSC drawbacks at the design phase, while 10.8% (n=32) were definitely aware of possible drawbacks (Fig. 5-59). However 32.3%, n=96 of the respondents were not informed of any drawbacks which could be interpreted as low enthusiasm towards prioritising TSC selection as illustrated in section 5.5.1. There was no significant statistical association between the answers and any of participants' profession, climatic zone or geographic region.

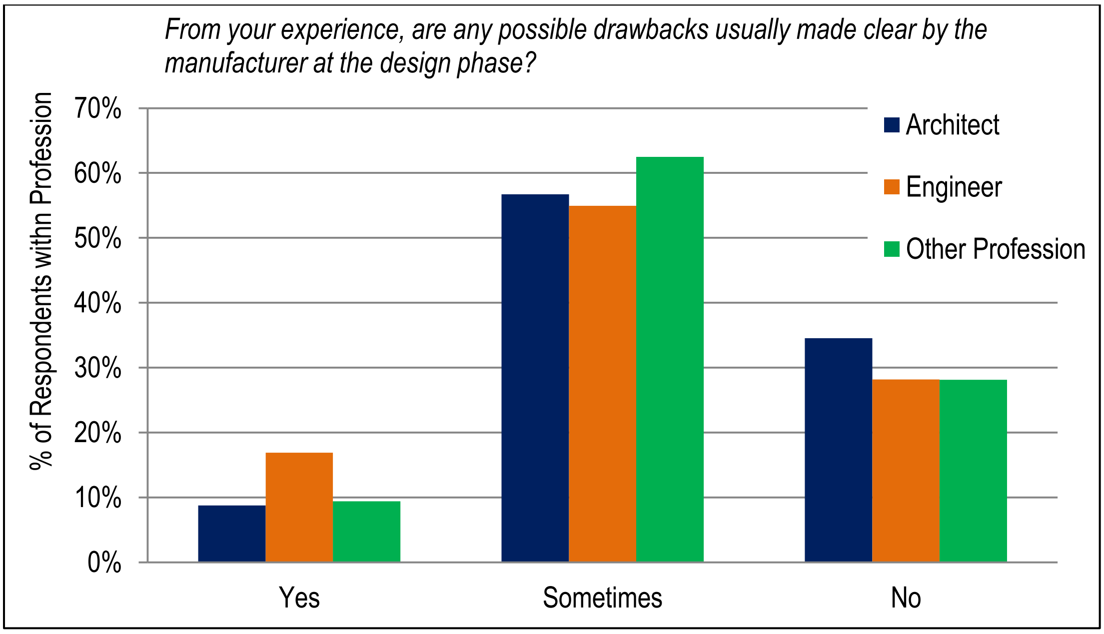


Figure 5-59: The clear communication of possible drawbacks of TSC technology by manufacturer at design phase

Qualitative Analysis: The lack of knowledge diffusion was apparently expressed in the above section (5.9.1ii). This shortcoming *"... causes a big problem when* [the architect is] *trying to educate the client because trust is lost"* as stated by a Canadian renewable energy consultant, from continental climate, who mentioned that he/she was not made aware of any possible drawbacks at the design phase. As a result, TSC remains *"...not fully understood at this stage within* [countries such as] *UK"* as stated by a consulting engineer from England.

Mistrust in the manufacturers or trades were noticed from the comment due to technology push from the market. An academic architect from the humid continental climate of Quebec in Canada mentioned that manufacturers will never *"...focus on any drawbacks"*. *"Sales people will say almost anything to close a sale"*, stated a consulting architect from the USA, the warm humid temperate Alabama climate, who had more than 15 years' experience. An architect from the national government in England who had more than 15 years' experience agreed the same: *"the manufacturer always tries to conceal any drawbacks".* This was why independent technical reports were needed as reported in section 5.7.1 and elaborated furthermore in sections 6.4.3 and 6.4.4.

5.9.2 FURTHER DEVELOPMENT FACILITATOR

Similar to any developing technology, TSC must receive further research and development for better deployment. In the light of commercial awareness, satisfaction, and drawbacks, there needs to be a facilitator(s) who could lead the future integration and development of TSC technology in building envelopes. This point has been explored and three possible options were listed for classification as shown in figure 5-60. However, an option of 'no further actions required' was added to avoid any question bias. The respondents showed relative conjunction for the three options: 68.6% (n=345) for integrated design team (IDP), 59.4% (n=299) for research and design teams (R&D), and 58.4% (n=294) for architects.

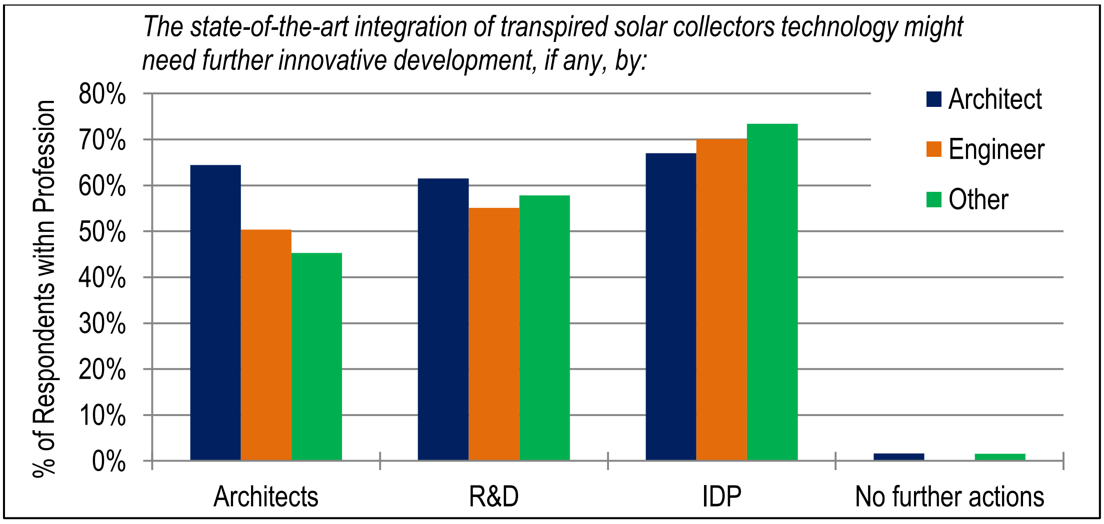


Figure 5-60: The facilitator for further innovative development of TSC integration (Table C-59, Appendix C)

A statistical significant association was noticed between selecting architect and the profession: $[\chi^2(2, n = 503) = 12.53, p = .002, \text{ Phi} = .158]$ where the architects (64.45, n=201) were more biased to nominating themselves to lead the innovative mission than engineers (50.4%, n=64) and others (45.3%, n=29) (Table C-60, Appendix C). Another significant association was noticed between selecting architect and the geographic region: $[\chi^2(4, n = 503) = 10.51, p = .03, \text{ Cramer's V} = .145]$ where the participants from other countries (69.7%, n=23), mainland Europe (66.1%, n=84) and Canada (62.1%, n=41) emphasised more influence on the architect than the USA participants (56.8%, n=71). These regions all together swayed the architect to pursue further development to TSC more than the British respondents (49.3%, n=75) who came in the end. Other than that, there was no significant association with participants' demographics.

Qualitative Analysis: Many of the respondents expressed opinions that the improvement and development needs to involve all possible actors: *"all parties involved - there is always room for improvement"*, stated an academic engineer from continental climatic zone in Canada. Participants added to the given list actors such as façade consultants and clients. Participants also stressed collaboration (Swiss engineer, continental climate) and communication (Canadian architect, continental climate) between parties where people can exchange knowledge and experience (Greek architect, temperate climate). A consulting architect from the USA, continental climatic zone, also expressed the significance of *"...feedback from the users"* for better improvement.

5.9.3 TECHNICAL PRESENTATIONS AND DEMONSTRATION

A suggestion was presented to the participants, in order to assess the need for knowledge creation and diffusion as an example. Technical presentations and demonstrations as part of continued professional development (CPDs) and seminars was agreed helpful by 64.8% (n=616) of the respondents. Furthermore, 23.7% (n=225) of the respondents found a potential success through technical presentation and demonstration (Fig. 5-61). These activities were elaborated in detail in sections 6.4.2 and 6.4.3.

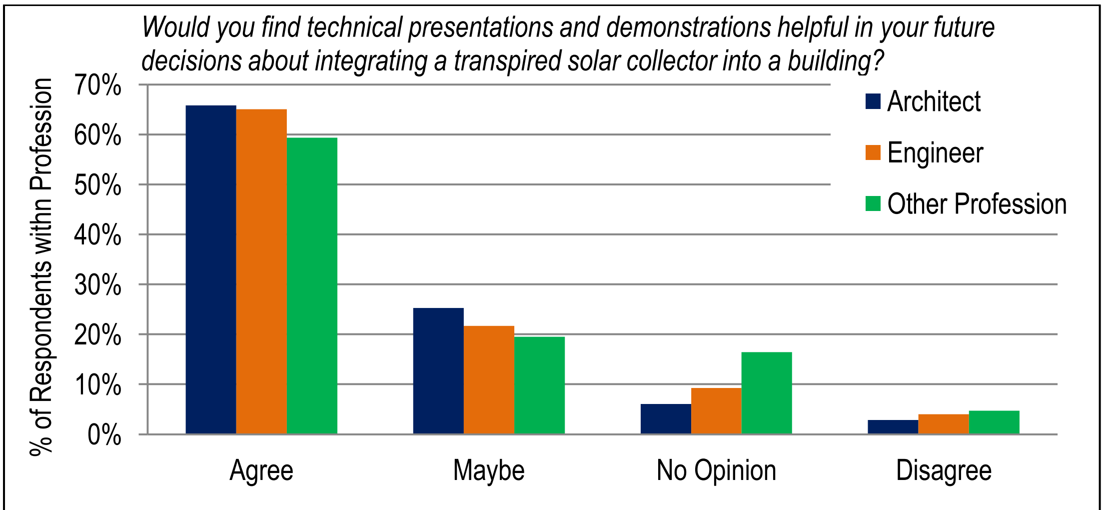


Figure 5-61: Technical presentations and demonstrations are helpful for decisions of integrating TSC into a building (Table C-61, Appendix C)

Qualitative Analysis: Following agreement that presentations and demonstrations about TSC would be helpful, a participant, from a continental climatic zone, stated that *"hands-on experiences"* always help. Others stressed the need for free access to education which constituted a key to the development. *“Understanding the potential use and application of products is essential to appropriate specification”*, stated a consulting architect from England. Participants, however, felt that any disseminated information had to be independent, auditable, real project information to avoid any potential bias, reinforcing the mistrust reported in section 5.9.1iii. A similar trend of independent knowledge was stressed by participants who disagreed with the statement being tested. The need for presentations and demonstrations *“... would depend upon who was giving them... Manufacturer...will be biased”*, stated an academic architect from Wales who had a PhD degree and more than 15 years’ experience. Overall, *“any tech*[nical] *presentation needs to be addressed to a specific niche/solution”*, stated a Canadian renewable energy consultant from a continental climatic zone.

The quantitative and qualitative results, in sections 5.9.2 and 5.9.3, both emphasise the spirit of teamwork that is increasingly growing within IDP process. The additional actors strengthen the involvement of IDP teams that was cited from Cole (2008) as illustrated in section 3.2.2. The need for networking and knowledge exchange to manage technological change encourages investigation of the technological innovation system (TIS) in order to manage the needed improvement in a systematic process. This in turn has been reported in the literature (section 3.3) and will be investigated in detail in chapter 6.

5.10 EXPERIMENTAL PROTOTYPE OF TRANSPIRED SOLAR COLLECTORS

As explained in the methodology (section 4.5), an experimental prototype TSC rig was built on the roof of Bute Building (Appendix D) through the sustainable building envelope design (SBED) project. In the light of the above questionnaire analysis, the prototype project in this study was considered to have multifaceted benefits; these include:

- Acquiring 'hands-on experience' of the design, construction and integration parameters of TSC technology being investigated and analysed theoretically through the questionnaire.
- Conducting an independent investigation on the potential effectiveness and efficiency of TSC technology in Wales, UK.

5.10.1 TSC RIG DESIGN

Four TSC prototypes were designed to have the same surface area. Three rectangular units with a dimension 1,800mm x 600 mm x 200mm (plenum depth); one of them was installed vertically, the second one horizontally and the third was inclined at 45° inclination. The dimensions were based on the work of Badache et al. (2012). The fourth unit is a square of 1,039mm x 1,039mm x 200mm design dimensions. All the panels are south facing, side-by-side, and have quite large gaps between them to avoid shading which was simulated through Ecotect software (Fig.5-62).

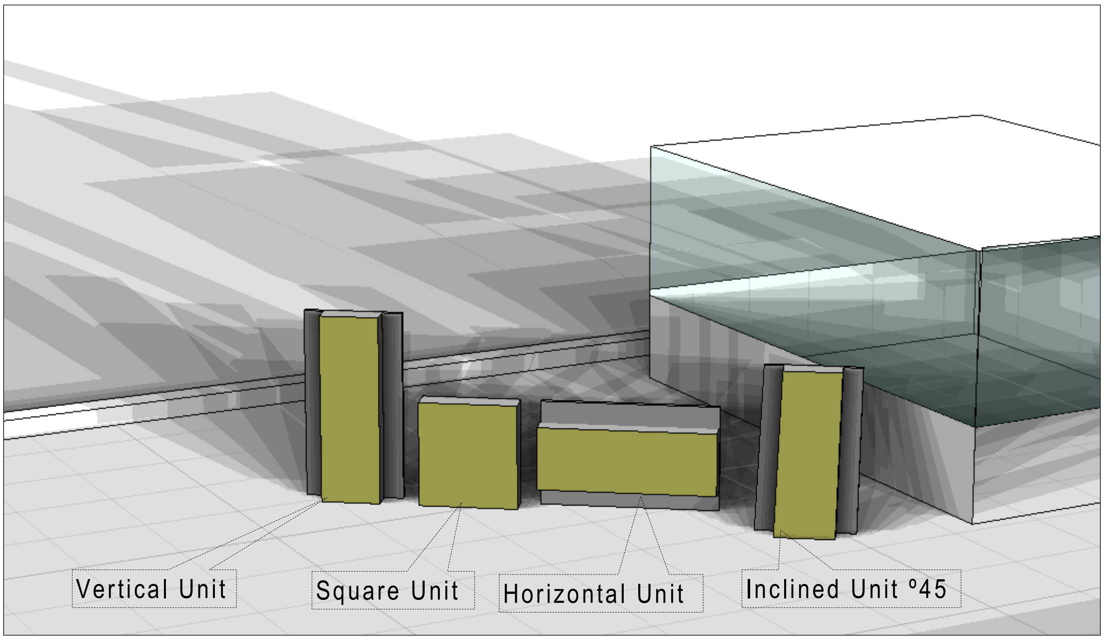


Figure 5-62: Example of shading study of TSC prototypes on 23rd December

A wooden structure was constructed to support the TSC. The backside of the TSC was fabricated from a 200mm thick composite insulation panel. The sides, top and bottom were covered by 50mm polystyrene to reduce heat loss from the plenum.

The vertical unit was completed and generating data within the time scale of this study. The others are being completed for further investigation (beyond the scope of this study) by the SBED team. The design and construction processes of the four panels added valuable practical experience which is in short supply, as indicated in sections 5.5 and 5.6. Due to certain legislative issues including permissions and funding, the prototype had to be stand-alone. The perforation diameter is 1mm and porosity is 0.0143. The commercially available collector material exhibits a rectangular pitch arrangement (20mm x 22.5mm) although a triangular arrangement was originally recommended in the study by Van Decker et al. (2001) (section 2.5.2). The collector material is steel (0.7mm thick) with a black organic coating (Fig. 5-63).

Figure 5-63: TSC prototype assembled, the profile used is shown in the top-right corner (photo was taken by SBED team)

5.10.2 PROTOTYPE DATA ANALYSIS

The data was collected prior to insulating the ducting which connected the prototype to the office; the 'no insulation' would affect the supply temperature as explained in sections 5.10.2ib. The data was collected by the

SBED team. The experimental research parameters are variables and measurable outputs (section 4.4.2); the results in this section are divided into four parts:

- Measurable outputs:
    a. Output temperature
    b. Supply temperature
- Effect of variables on measurable outputs:
    a. Effect of solar irradiation
    b. Effect of wind speed and air flow
- Heat exchange effectiveness (calculated output)
- Efficiency (calculated output)

i) MEASURABLE OUTPUTS:

This section presents output temperature (Tout) and supply temperature (Tsup) over a range of dates which include sunny and cloudy days to assess overall performance. In this section, relations of these measurable outputs to other variables (i.e. ambient and collectors' temperature) are investigated; with sunny and cloudy times being identified.

a. OUTPUT TEMPERATURE (Tout)

The output temperature is a measurable variable that is affected by various climatic variables (i.e. solar irradiation) in addition to design variables of the TSC (i.e. geometry and conductivity of the collector). This section introduces examples of the behaviour of output temperature during autumn and winter days. The output temperature at the exit point was almost always higher than the ambient temperature during the months of August and September 2013. Figure 5-64 shows the output temperature (Tout) in relation to the ambient (Tamb) and collectors' temperature (Tcol) and solar irradiation (Solar) on the partly sunny 19th September 2013.

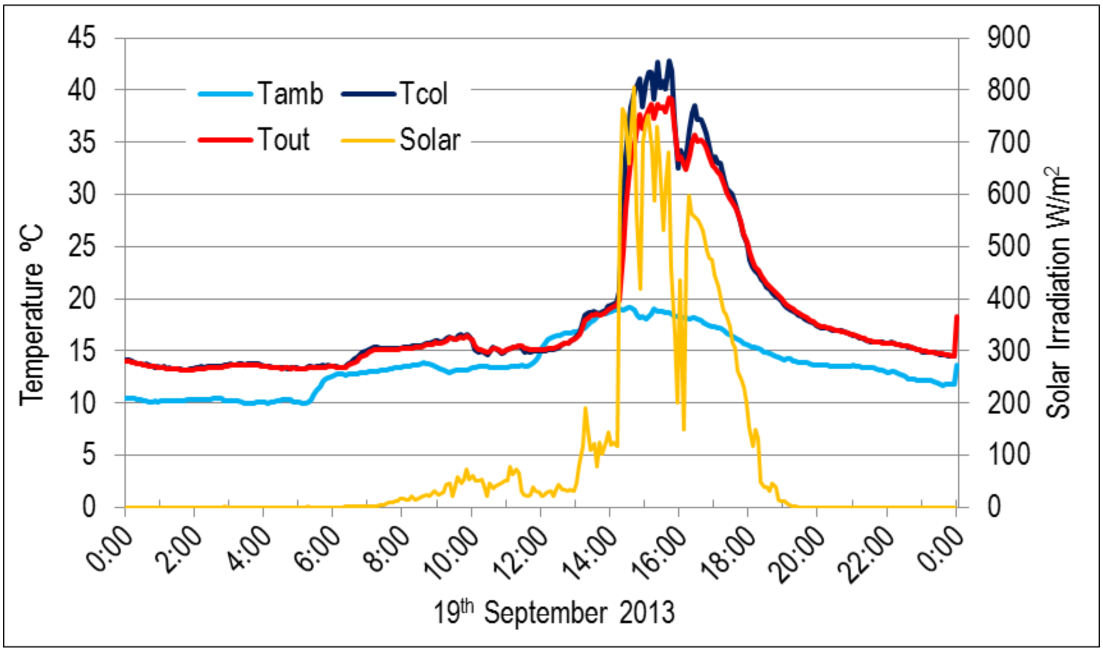


Figure 5-64: TSC temperatures and solar irradiation on 19th September 2013 (partly sunny)

Figure 5-65 shows the output and ambient temperature on the partly cloudy 27th December 2013 whereas; figure 5-66 shows the output and ambient temperature on 16th January 2014 which was a mostly cloudy day.

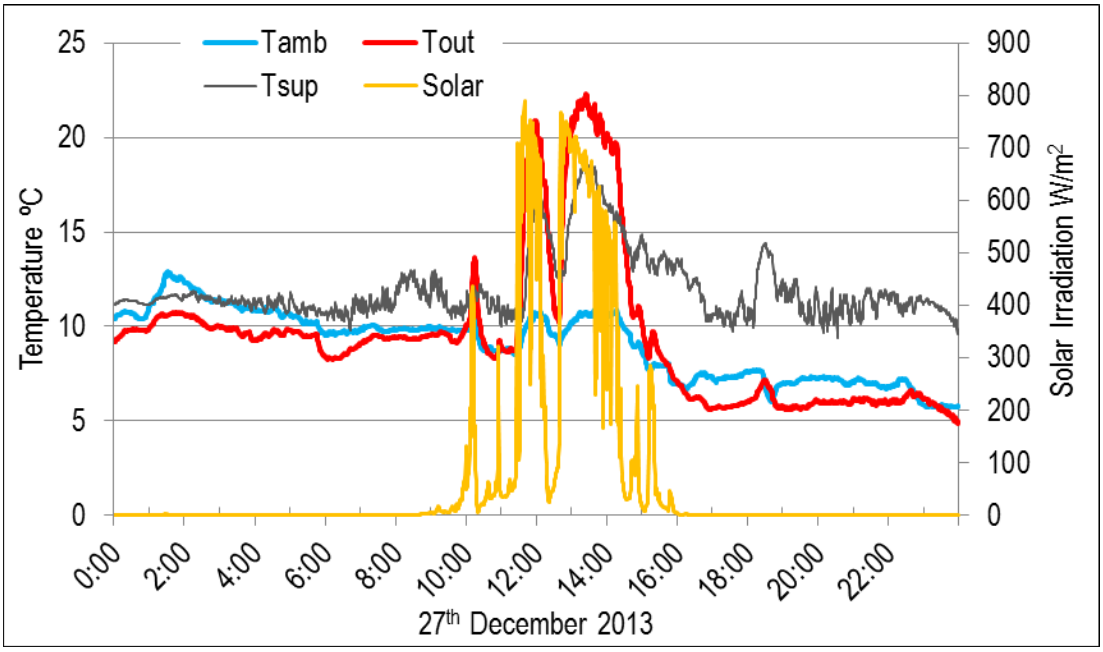


Figure 5-65: TSC temperatures and solar irradiation on 27th December 2013 (partly cloudy)

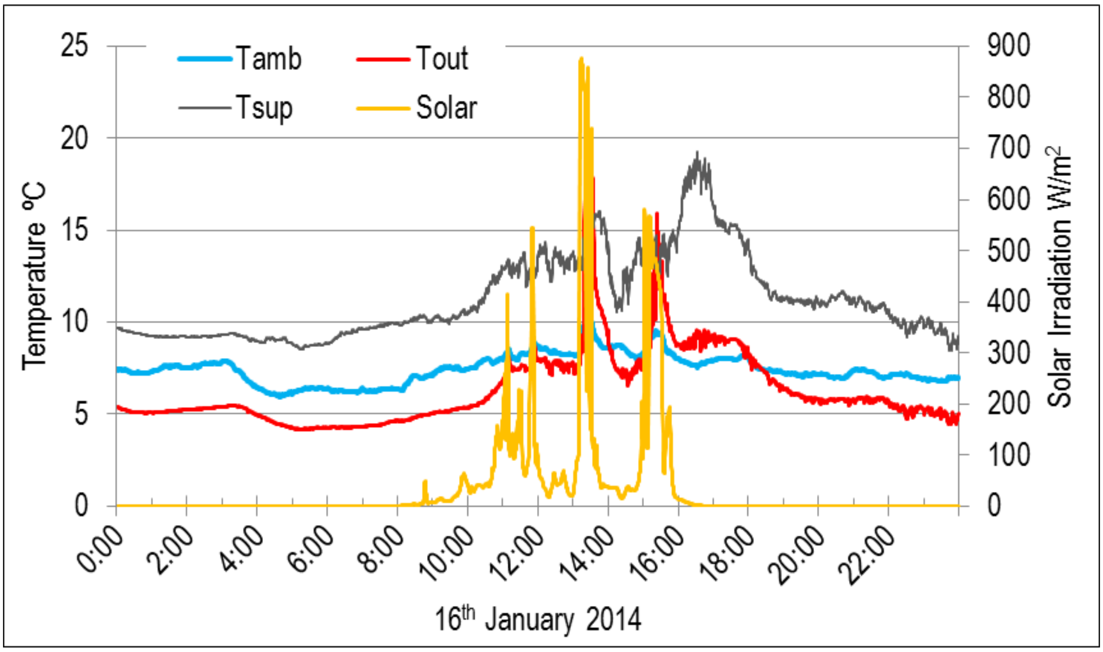


Figure 5-66: TSC temperatures and solar irradiation on 16th January 2014 (mostly cloudy)

The output temperature reaches as high as 38°C during the day time in September on sunny days. The temperature is high enough to cause overheating as the needed maximum indoor temperature is 23°C (CIBSE 2006; Ferrari and Zanotto 2012). However, heated air can be directed to the bypass when not required, so over heating is unlikely to be an issue (section 2.4.2).

Unlike September and the summer when the sun sets late in the day (Fig. 5-64 above), the output temperature in the winter has more chances to drop below the ambient temperature (Figs. 5-65 and 5-66 above). The low output temperatures occur when the sun is not shining and particularly at early morning and night time. This would be one of the reasons that TSC remains within the context of office and industrial buildings and almost excluded from dwellings where night and early morning heating is in more demand.

b. SUPPLY TEMPERATURE (Tsup)

The readings of Tsup were not made available in the summer/autumn data as the instruments were procured and installed at a later stage. As shown in figures 5-65 and 5-66 above, the supply temperature to the office area (15-18˚C) was lower than the TSC output temperature (18-21°C) when the sun is high. This is likely to be due to heat loss in the ducting due to lack of insulation. However, this phenomenon is not significant where it was found occurring about 5.1% times during the period of data collection in December and 0.8% times in January. When the output temperature is below 15°C, the supply temperature is often higher than the TSC output temperature (Figs. 5-64, 5-66 above and 5-67).

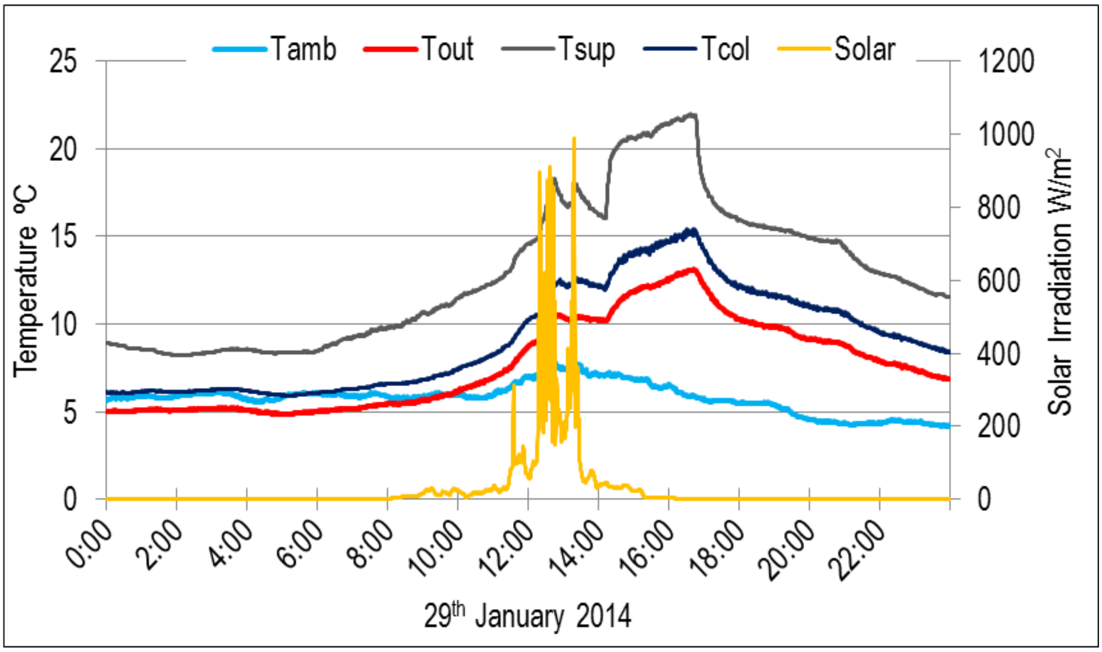


Figure 5-67: TSC temperatures and solar irradiation on 29th January 2014

A possibility of higher supply temperature than the output temperature, especially between 6:00 and 18:00, might be due to heating air from the room feeding back into the duct. Furthermore, when there is high solar irradiation, this is likely to be due to solar gain into the ducting (Chiras 2002). This phenomenon takes time to disappear, which might relate to thermal mass where the supply temperature appears to have a slower response to high solar irradiation than output temperature. As shown in figure 5-67 above, temperatures at 14:00 o'clock are increasing following decreasing solar irradiation. This behaviour corresponds to air flow rate in the duct which indicates a strong effect of air flow on temperature increase (Fig. 5-68) as explained in section 5.10.2iib. There is a slower reaction by temperatures to the drop in air flow which would be interpreted to thermal mass of the steel and the duct.

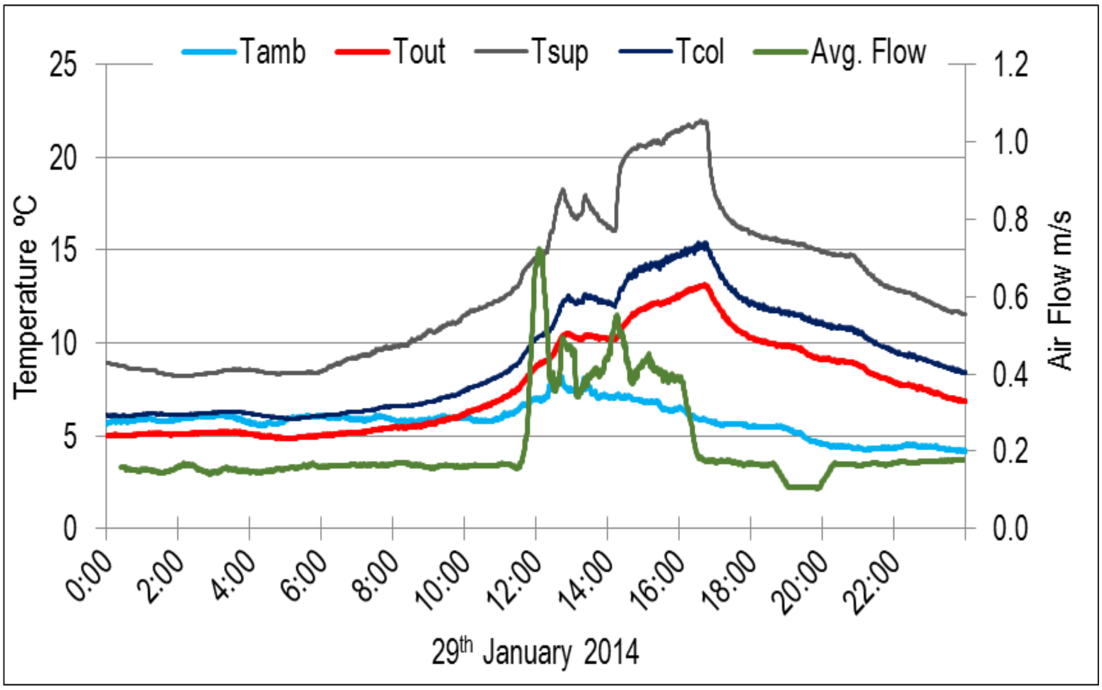


Figure 5-68: TSC temperatures and air flow rate in the duct on 29th January 2014

Overall, the supply temperature into the room exceeded the ambient temperature in the collected data. There are several complex factors that play significant roles in the relation between the supply temperature, TSC output temperature and ambient temperature. These factors include:

- length of the ducting,
- duct material,
- duct and TSC size,
- duct insulation thickness,
- shading of the ducting, and
- fan speed and ON/OFF control.

These factors and the entire investigation of the relations between these temperatures are beyond the scope of this study however, it is important to highlight their impact.

ii) EFFECT OF VARIABLES ON MEASURABLE OUTPUTS

These measurable temperature outputs are affected by certain variables (sections 2.5.2, 4.4.2, 5.2.4, 5.5.3 and 5.5.5). The geometry and conductivity are beyond the scope of this analysis as the collected data belongs to one prototype unit. The effect of the solar irradiation variable is analysed over the data collection period (section 4.4.3). Similarly, the effects of wind speed and air flow recorded variables are analysed. The variation in air flow was mostly unplanned where the fan was off most of the time during data collection and the air flow rate was under the buoyancy effect.

a. EFFECT OF SOLAR IRRADIATION

Solar irradiation is the most significant factor for TSC performance as noticed from the above figures and as explained in the literature from previous studies (section 2.5.4). Figure 5-69 shows the average output temperature as a function of solar irradiation in the period from 4th to 31st December 2013.

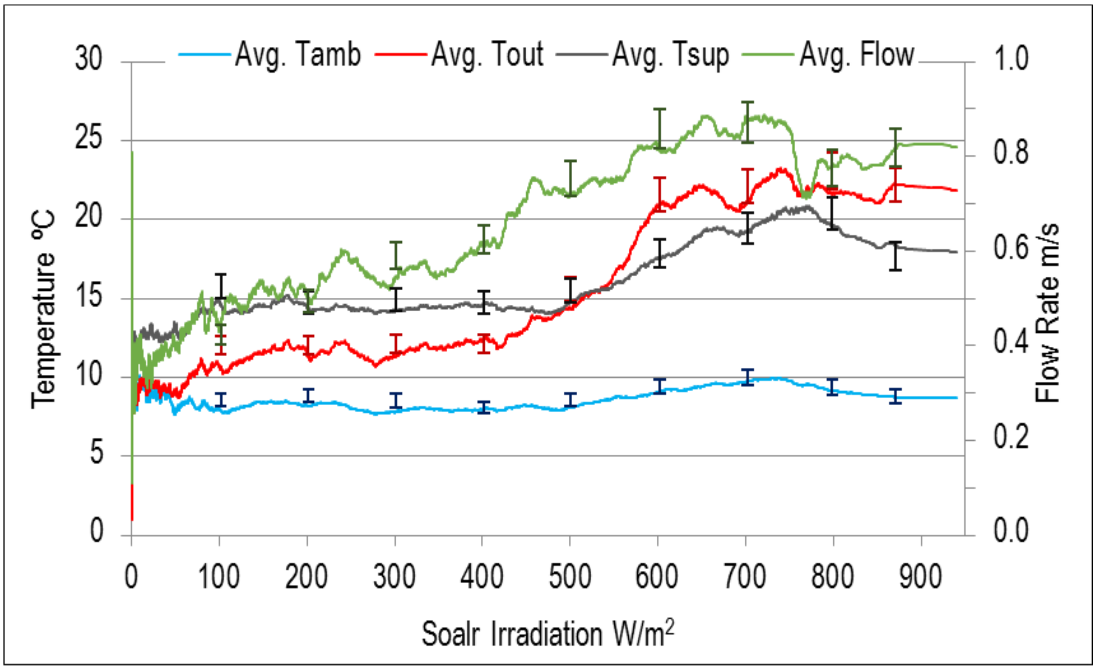


Figure 5-69: Relations between output and supply TSC temperatures and ambient temperature with solar irradiation between 4th and 31st December 2013. Variance bars indicate max-min range for each parameter.

The output temperature starts rising at 60W/m² of solar irradiation; this increase continues cumulating gradually. The ambient temperature peaks at approximately 710-730W/m² of solar irradiation. The output temperature increases significantly from approximately 400-600W/m², and then plateaus. However, the supply temperature peaks at approximately 750W/m². This is quite different to Ben-Amara et al. (2005) where the temperature peaked at about 1100 W/m². However, the climatic condition in their study in Tunisia, the northernmost bulge of Africa, is generally hot and arid unlike the temperate conditions in the UK. The behaviour of TSC temperatures, particularly output temperature, is found accompanying air flow rate in the duct (section 5.10.2iib).

Overall, the output temperature reaches a maximum difference of 16 °C from the ambient temperature at 760 W/m² in September, then plateaus (Fig. 5-70). In figure 5-69 above, the supply temperature peaks at 760 W/m² of solar irradiation. The same applies to the December and January readings as shown in figures 5-71 and 5-72 (section 5.10.2iib). However, in January the peak occurs at 800W/m² of solar irradiation.

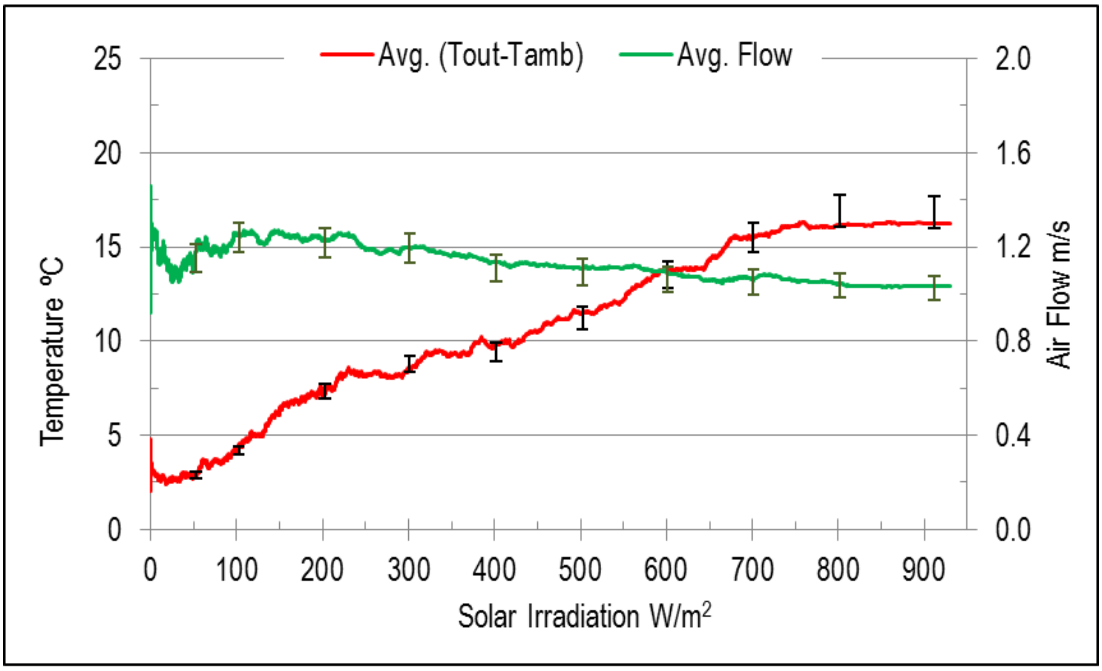


Figure 5-70: Output temperature rise as a function of solar irradiation and air flow during 1st to 20th September 2013

The analysis shows the effect of solar irradiation on output temperature rise over ambient temperature. As solar irradiation rises above 60W/m^2, output temperature increases to 16˚C above ambient temperature in autumn (Fig 5-70 above) and 12˚C above ambient temperature in winter. That confirms the findings of previous studies such as Gunnewiek et al. (1996), Ben-Amara et al. (2005), Wang et al. (2006) and Chan et al. (2011) as described in section 2.5.4.

The ideal range of solar irradiation for the TSC to function (producing a temperature rise of 10ºC above ambient) is therefore greater than 400 W/m^2 in Wales. The maximum solar irradiation recorded is 941 W/m^2 in December. Many of the previous studies (Gunnewiek et al. 1996; Wang et al. 2006; Leon and Kumar 2007; Badache et al. 2012) analysed a solar irradiation range of 400-900 W/m^2 (section 2.5.4).

b. EFFECT OF AIR FLOW AND WIND SPEED

The flow rate inside the duct seems to have an effect on the overall performance of the TSC as perceived from the effect of suction velocity in the literature (section 2.5.5) and as mentioned by Badache et al. (2012). The usual average air flow in the duct ranged between 0.1-0.9m/s with an average of 0.33m/s. Figure 5-71 shows output and supply temperature rise over ambient temperature in relation to air flow between 4th and 31st December 2013.

TSC temperature trends were found significantly in harmony to air flow in winter (Figs. 5-67, 5-69 above and 5-71) with a slower response to solar irradiation. The relation between air flow and temperature trends is interpreted due to the buoyancy effect where higher solar irradiation creates hotter air in the collector which drives a stronger air flow. Figure 5-72 further shows a temperature rise during 1st to 5th and 14th to 31st January 2014 in relation to air flow and wind speed.

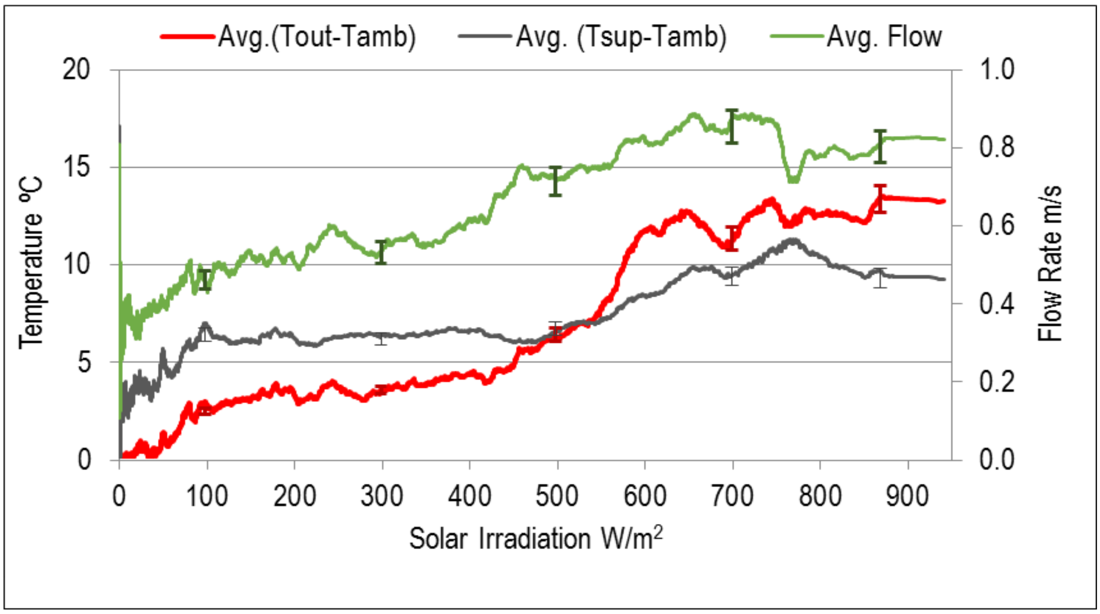


Figure 5-71: Effect of flow rate and solar radiation on TSC output and supply temperatures rise over ambient temperature during 4th to 31st December 2013

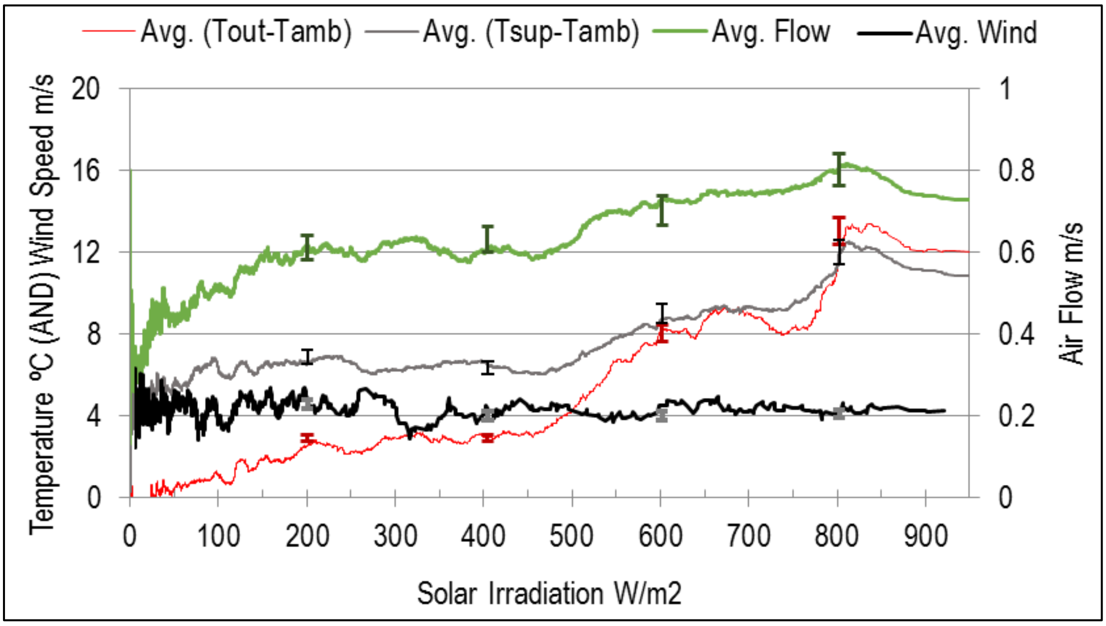


Figure 5-72: Effect of flow rate, wind speed and solar radiation on TSC output and supply temperatures rise over ambient temperature during 1st to 5th and 14th to 31st January 2014

Output temperature rise over ambient temperature in September (Fig. 5-70 above) was found to not correspond to air flow, while having a direct correlation with solar irradiation; the temperature continued rising despite the constant decrease of air flow in the duct. The same trend was noticed in the August data.

As shown in figure 5-72 above, air temperature rise and flow rate is found to be affected inversely by wind speed. Figure 5-73 further details this effect for the data being collected in January 2014. The maximum instantaneous wind speed recorded was 19.5m/s in December and January where the maximum average recorded was in January of 9.8m/s with an overall average of 2.3m/s.

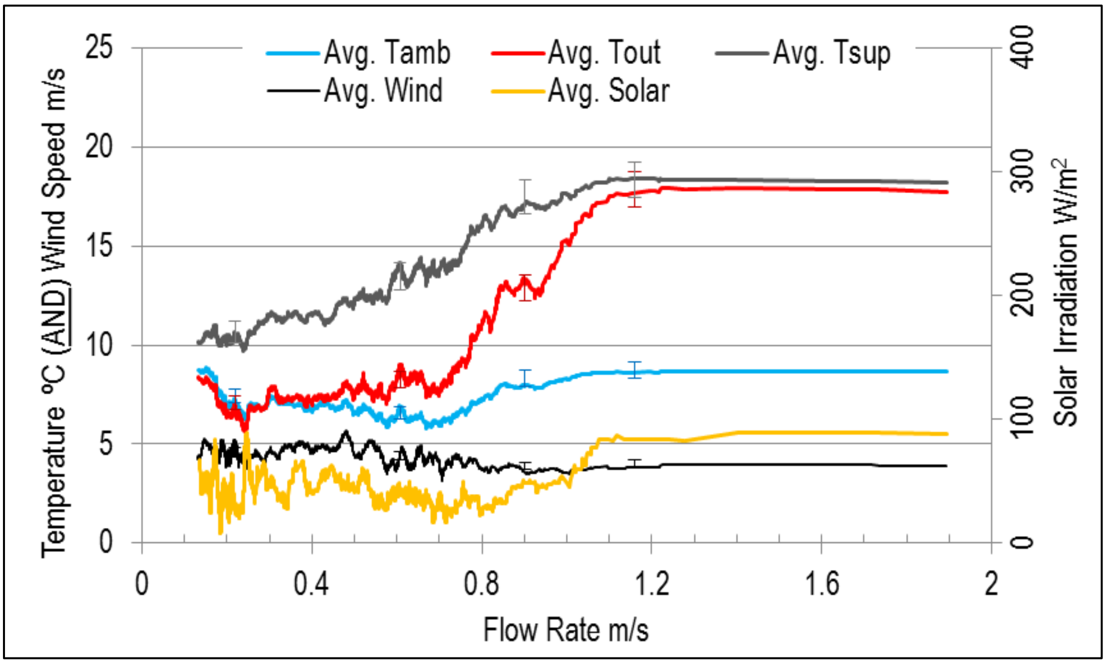


Figure 5-73: The effect of wind speed on flow rate and TSC temperatures during 1st to 5th and 14th to 31st January 2014

Referring to figure 5-72, the air flow is found to be lower than 0.8m/s when the average wind speed is higher than 4m/s. As average wind speed stabilises at approximately 4m/s, the air flow increases to 1.9m/s. At this point, the output and supply temperatures also stabilise. The highest flow rate was recorded around zero wind speed. The wind direction was recorded and is predominantly from the west and south west at this location. Unfortunately, it was not possible to isolate the impact of wind direction on the system. Analysis of the wind speed from the south and impinging directly onto the collector face did not show a significant effect of wind speed on the resulting output temperature during 1st to 5th and 14th to 31st January 2014 (Fig. 5-74).

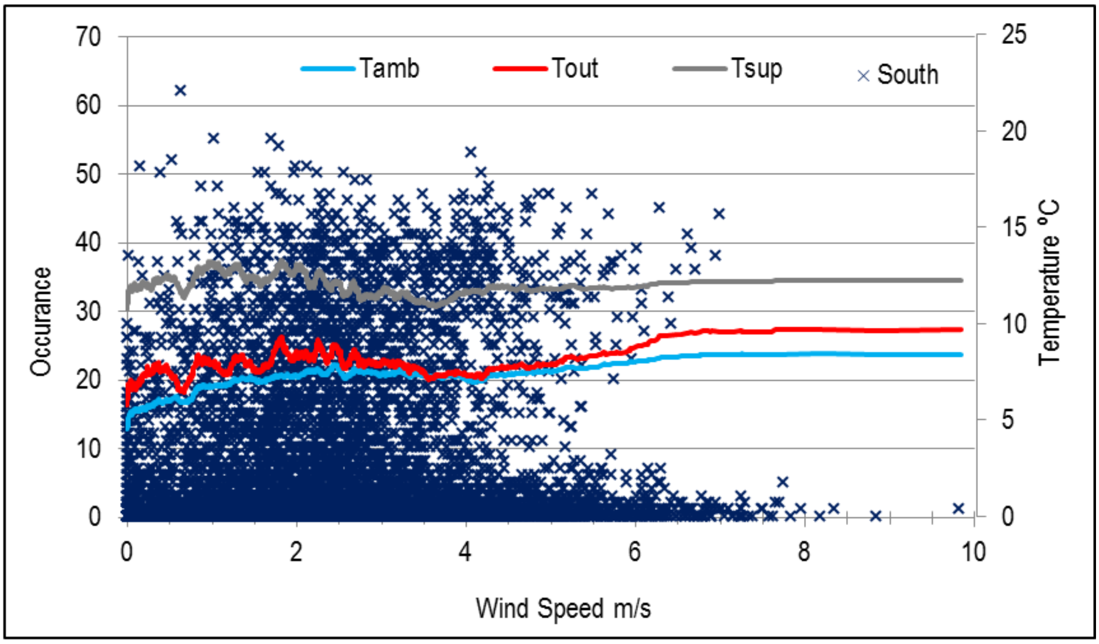


Figure 5-74: Wind blowing directly onto the collector as a function of wind speed and show temperatures (January 2014)

iii) HEAT EXCHANGE EFFECTIVENESS ϵ_{HX}

The heat exchange effectiveness, *"the ratio of the actual temperature rise of air as it passes through the absorber plate to the maximum possible temperature rise"* (Leon and Kumar 2007, p. 67)., was highlighted as being significant by many of the TSC researchers as reported in section 2.5.6. The effectiveness is calculated using equation 2-3, and further explored in relation to solar irradiation on the collector and air flow in the duct. Figure 5-75 shows the effectiveness from 2nd August to 20th September in relation to solar irradiation and flow rate. The heat exchange effectiveness has a minimal inverse relation with solar irradiation when effectiveness reaches 0.75; as it increases with the decrease of solar irradiation. Figure 5-76 represents another effectiveness scenario during 1st to 5th and 14th to 31st January 2014.

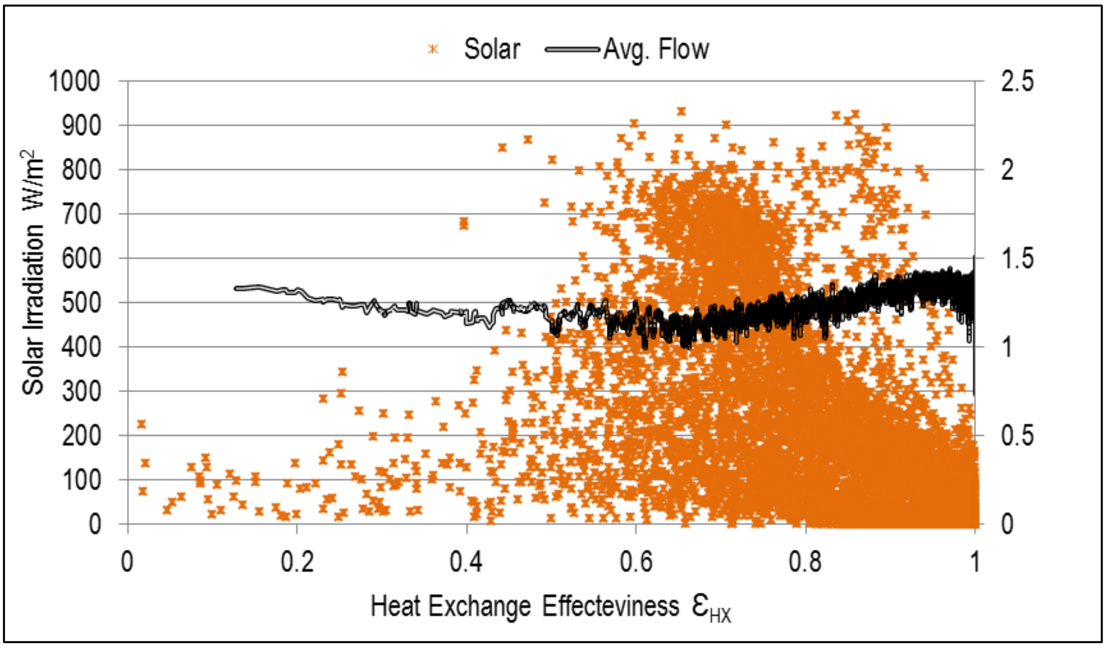


Figure 5-75: Effectiveness in relation to solar radiation and flow rate in the duct from 2nd August to 20th September 2013

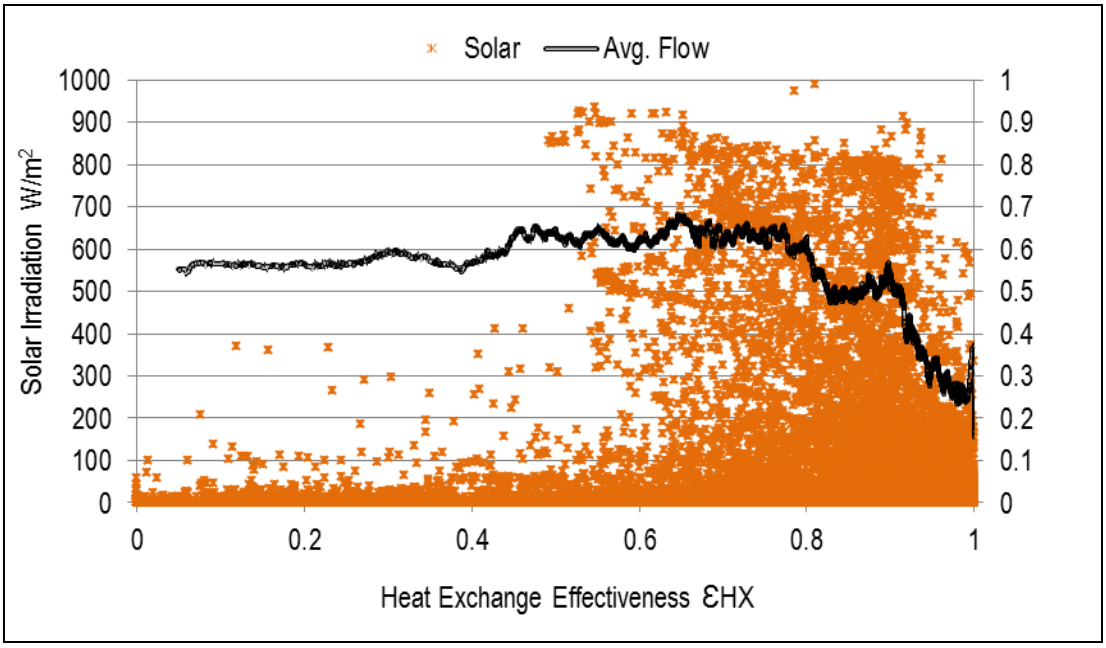


Figure 5-76: Effectiveness in relation to solar radiation and flow rate in the duct during 1st to 5th and 14th to 31st January 2014

High flow rate and low solar irradiation represents effectiveness values of 0 to 0.5. However, effectiveness between 0.5 and 0.8 corresponds with high solar irradiation and an almost steady flow rate in the plenum. Effectiveness of 0.8-0.9 is represented by even higher solar irradiation and a decreasing flow rate. The increase in effectiveness with decreased solar irradiation and increased flow rate confirms the finding of Wang et al. (2006). However, the inverse relation with flow rate after 0.8 effectiveness contradicts Wang et al. (2006) who mentioned a minimal effect of flow rate after 0.8 effectiveness.

During the data collection, the supply temperature was delivered through a non-insulated duct. This allowed heat loss which was compensated for when solar irradiation increased above 540W/m^2 in December and 640W/m^2 in January (section 5.10.2ib). The calculation of the ϵ_{HX} depends on ambient and collector temperature variables, and the TSC output temperature (section 2.5.6) which are all measured prior to the duct. The effectiveness calculations therefore are not affected by heat loss or gain by the duct.

Heat loss and gain in the ducting affect the supply temperature and need to be considered in the usual context of a TSC. In this circumstance the ducting would be inside the building so solar heat gains would be unlikely and any duct heat loss would feed into the space requiring heating. The air flow controlled by the fan speed also affects the overall supply of the temperature (section 5.10.2ib).

The supplied temperature into the building is neither considered in the calculation of effectiveness (eq. 2-3) nor efficiency (eq. 2-4) equations. It must nonetheless be considered as being an intrinsic parameter of indoor space heating and energy saving.The supply temperature should replace the output temperature in the equation 2-4 and would be better represented as:

$$\epsilon_{HX} = \frac{T_{sup} - T_{amb}}{T_{coll} - T_{amb}} \quad (5\text{-}1)$$

iv) EFFICIENCY η

The efficiency of TSC, *"the ratio of the useful heat delivered by the solar collector to the total solar energy input on the collector surface"* (Leon and Kumar 2007, p. 67), was tackled by many of the TSC researchers as reported in section 2.5.7. The efficiency is calculated using equation 2-4 and 2-5, and further explored in relation to solar irradiation on the collector and air flow in the duct. The following parameters were adopted in calculating mass flow rate in equation 2-5:

p: 1.247 kg/m3 (www.engineeringtoolbox.com at 10ºC)

A_{cs} : 0.018 m2; where the pipe diameter is 150mm

v_o: corresponds to the air flow rate in the duct

C_p: 1.006 kj/kg dry air/ºC (Cordeau and Barrington 2011)

This method of calculation, using the duct cross sectional area and the flow rate in the duct, was followed in Badache et al. (2012). Although other studies used suction velocity on the perforation hole (i.e. Kutscher et al. (1993), Van Decker et al. (2001) and Gunnewiek et al. (2002) as highlighted in section 2.5.5).

Figure 5-77 shows the efficiency of TSC during the period from 2nd August to 20th September 2013.

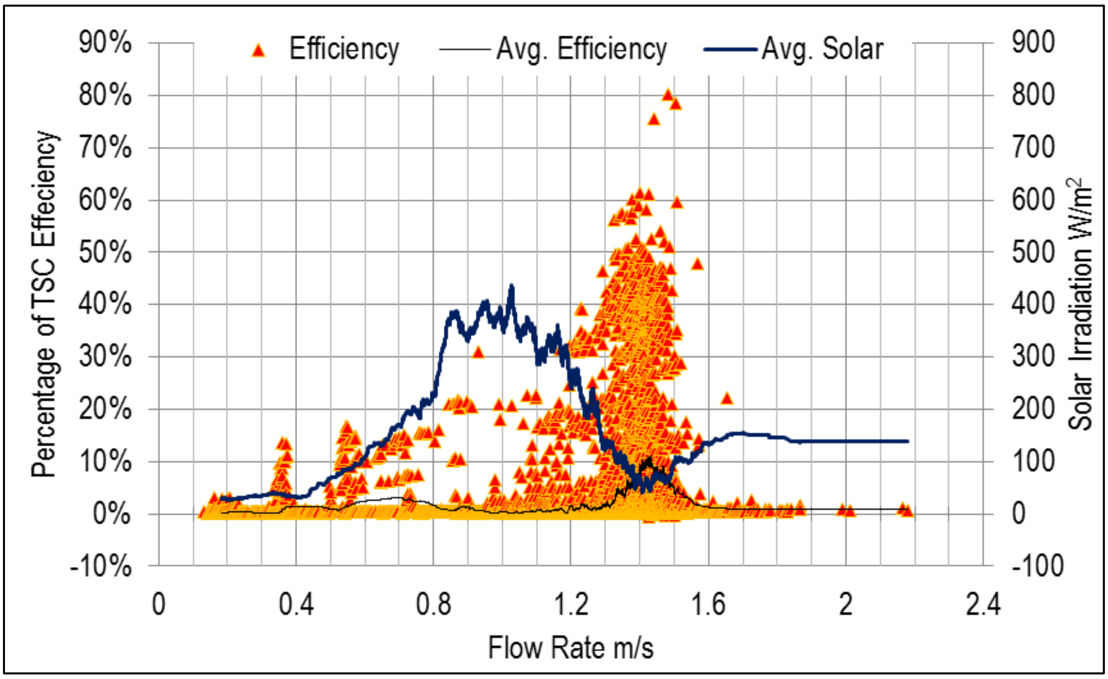


Figure 5-77: Efficiency in relation to solar radiation and flow rate in the duct from 2nd August to 20th September 2013

Figure 5-77 confirms the inverse relation of efficiency with solar irradiation as found by Fleck et al. (2002) in section 2.5.7; the efficiency increases significantly following the decrease of solar irradiation and vice versa. The efficiency is directly affected by flow rate, however, this effect reverses beyond a 1.45m/s flow rate in the duct. The maximum average efficiency in this period was around 11% with the highest instantaneous efficiency recorded as 80%. Reaching 80% corresponds to previous studies including McLaren et al. (1998), Gawlik et al. (2005) and Kozubal et al. (2008) in sections 2.4.5 and 2.5.7. However in the prototype system of this study, this high efficiency rate is found to be an occasional occurrence rather than a typical achievement.

Figure 5-78 shows a 0.55m/s minimum flow rate required in the duct to avoid flow reversal in this study, where the efficiency rate is below zero. However this minimum might differ according to TSC size, duct size and length as highlighted in section 2.5.5 in regards to the minimum surface suction velocity. The efficiency increases significantly with the flow rate increase until flow reaches almost between 0.8 and 1.0m/s. This relation confirms the findings of Badache et al. (2013) where the maximum efficiency was acheived wihin the band of 0.6 and 1.0m/s.

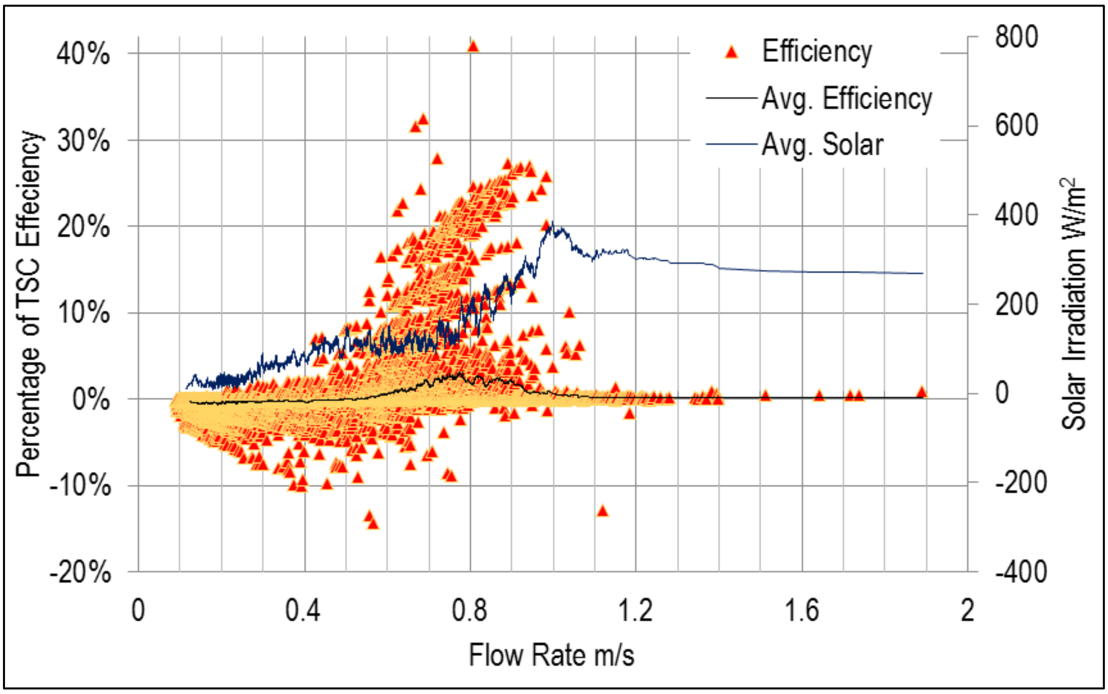


Figure 5-78: The efficiency as a function of flow rate in the duct and shows average solar irradiation during 1st to 5th and 14th to 31st January 2014

There is a direct relation between efficiency and solar irradiation before flow rate reaches 0.75m/s. In a lower strength to August and September (Fig. 5-77 above), the efficiency has an inverse relation with solar irradiation beyond a 0.75m/s flow rate. Similar to figure 5-76, the efficiency remained directly affected by flow rate before it reversed at 0.75m/s. The maximum average efficiency in January was below 5%, whereas the highest instantaneous efficiency recorded 41%.

Similar to effectiveness (section 5.10.2iii), the supplied temperature must be considered as being an intrinsic parameter of indoor space heating and energy saving. T_{sup} should replace T_{col} in eq. 2-5 and would be better represented as:

$$\eta = \frac{\dot{m} C_p (T_{sup} - T_{amb})}{I_c A_c} \qquad (5\text{-}2)$$

5.11 CONCLUSION

This chapter comprised the bulk of analysis addressing the research aims and most of the objectives. Two methodologies were used in the analysis of this chapter; the majority of the chapter addressed the mixed-method (quantitative and qualitative) analysis of the survey. It also covered the secondary methodology of an experimental prototype. Through the mixed-method, the research objectives i, ii, iii and iv were addressed and satisfied as highlighted in the introduction of this chapter whereas objective v is satisfied through the experimental prototype method. This chapter contains the results, discussion will follow in chapter 7.

For the survey, the results were arranged, coded and analysed using either statistical analysis for quantitative data or theming for qualitative data. The data was reported in topic sections. The key points are illustrated in figures, with tables of data available in Appendix C for further reference. The key findings of the questionnaire are further discussed in chapter 7 and also concluded in chapter 8.

In terms of the experiment, the original plan included the investigation of four units, however, issues beyond the control of the researcher meant that only one unit could be analysed within the time constraints. Nevertheless, a significant amount of data was generated by the prototype TSC. The effectiveness results from TSC protoype are considered to be promising. The TSC efficiency was found reaching 41% in winter and 80% in autumn, however these records remain occasional where the maximum average effeciency is below 5% and 11% for winter and autumn respectively.

Neverheless, TSC is found to be capable of considerably raising air temperature above the ambient temperature. In September air temperature was increased by a maximum of 16ºC above ambient temperature, (Fig. 5-69) while in winter the air temperature was increased by a maximum of 12ºC above ambient temperature (Fig. 5-72).

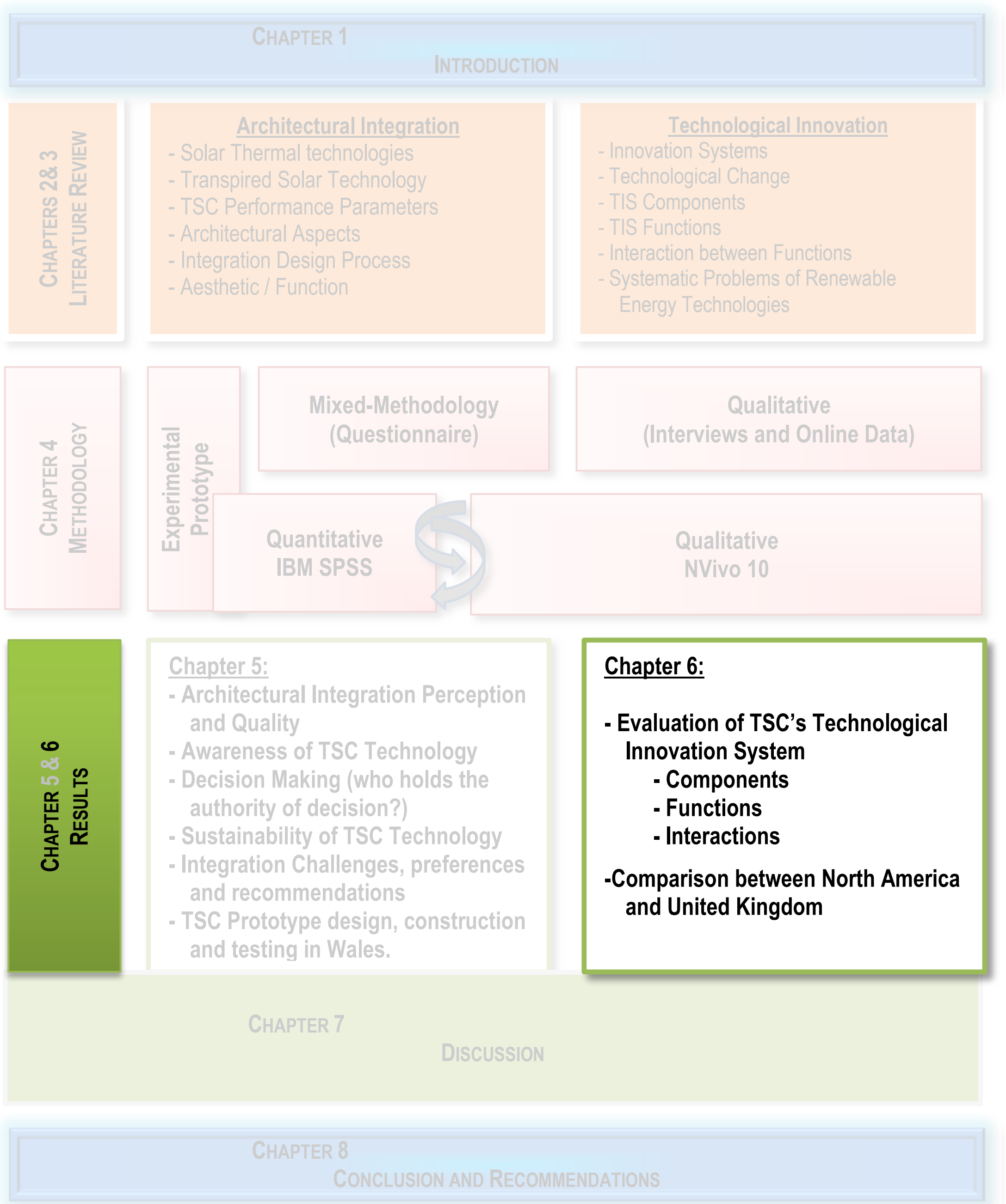
The current estimation of effectiveness and efficiency affects the decision making of sourcing TSC where the function of the technology for energy generation was found to be the top priority (section 5.6.1i). This implies that the ability to provide useful heat to a building is more important to the survey respondents than other factors including reliability. The current estimations of efficiency furthermore adds to the mistrust in manufacturers' data where respondents were found to perceive these data as biased advertisements to increase sales (section 5.9.1iii).

The information from the survey indicates that TSC is a technology which is yet to become fully commercialised. Therefore, chapter 6 focuses on analysing the barriers of TSC development through TIS analysis from the entrepreneurs' point of view and other secondary online data. The approriate analysis of the barriers could lead to the identification of potential enablers to support the deployment of the technology.

CHAPTER 6 ||

TECHNOLOGICAL

INNOVATION DEVELOPMENT



6.1 INTRODUCTION

In this chapter, the focus lies on the development and diffusion of TSC technology in the UK and North America as a promising renewable energy technologies for space heating. Canada has been a frontrunner in the development and diffusion of TSC, followed closely by the USA. This trend is in sharp contrast to the UK situation where there are limited installations. Both regions have the goal to create a strong environmental and economic sector around renewable technologies that contribute to sustainable energy production (REN21 2013).

By mapping and measuring the key processes within the technical innovation system (TIS), it could be possible to identify the drivers and barriers that trigger or hamper developing TIS specific to transpired solar technology in the UK (objectives 1.4iii and 1.4vii). These drivers and barriers could be considered by researchers and entrepreneurs to further research and develop TSC performance. This approach could moreover be adopted by policy makers in order to accelerate the diffusion and adoption of solar thermal technologies in general and TSC in particular.

6.2 DATA COLLECTION, ORGANISATION AND ANALYSIS

Interviews (Appendix F) constitute the main stream of data collection for this qualitative analysis of TIS relating to TSC. Further secondary data (i.e. newspapers, published papers, government and company websites) were collected and assessed in order to support the qualitative analysis and to strengthen any shortcomings of the interview data, especially since the number of Canadian interviewees was low. Moreover, the respondents' comments and texts in the questionnaire (Appendix A) were analysed as secondary data. The use of secondary data has been validated as the approach has been used in previous TIS studies such as Bergek (2002), Negro et al. (2007), Vidican et al. (2012), Klein Woolthuis et al. (2013), and Vasseur et al. (2013).

The interview audio-recordings were transcribed verbatim. All the data were treated as equally important. The data transcribed from the five completed interviews yielded over 16,000 words.

The secondary data in the North American market amounted to 45 documents, mainly relating to Canada. These included annual reports and statistics on solar thermal technologies, news about TSC technology, government incentive plans, TSC manufacturers' information and activities, and academic papers, workshops and reports. In the UK market, the secondary data consisted of 23 documents which included news about TSC technology, government incentive plans, workshops and reports.

The following data analysis of this chapter is influenced by the work of Vasseur et al. (2013) who compared photovoltaic TIS in Japan and the Netherlands. The analysis was furthermore inspired by the studies of Vidican et al. (2012) and Lai et al. (2012). The structure of this analysis, as well as the aforementioned studies, was guided by Bergek et al. (2008) as reported in the introduction of section 3.3. The analysis also follows the structure of technological innovation system literature (sections 3.3.3 to 3.3.5). It starts with defining the structural components of TIS for TSC (6.3.1) in North America and the UK, then investigates the fulfilment of the TIS functions (6.3.2) and ends by highlighting the major interactions between TIS functions in both regions being compared. The data were qualitatively themed in these categories using the Qualitative Software (NVivo 10). The analysis of this chapter mainly corresponds to research objectives 1.4vi, 1.4vii and 1.4viii).

6.3 STRUCTURAL COMPONENTS OF TRANSPIRED SOLAR INNOVATION SYSTEM

The structural components of TSCs' TIS were themed individually for each category (North America and UK) in relation to the following components: actors, institutions and networks. TSC development in North America is more advanced than the UK which is in an early stage of emergence; the more established TIS yields limited data for TSC at the earlier emerging stage in North America. Therefore, the following data themes (including section 6.4) reflect the current status of TSC in both regions and highlight the status of TSC at the emergence time in North America whenever possible.

6.3.1 ACTORS (FIRMS, ORGANISATIONS, AUTHORITIES AND INDIVIDUALS)

The actors, primary and secondary, as defined in section 3.3.3i were identified for each region in terms of existing and potential players as follows:

i) ACTORS IN NORTH AMERICA

Although the North American region combines the USA and Canada, the actors in both countries were mostly dissimilar. The different actors of each country are illustrated individually wherever appropriate. There is however a large number of active actors in both countries.

In the Canadian market, there are four entrepreneurs (section 2.4.4) concentrating their activities in two provinces (Ontario and Quebec). Governmental organisations play a strong role in the development of TSC, these organisations include the Natural Resources of Canada (NRCan) (Interviewee 5). NRCan has the Renewable and Electrical Energy Division which takes the lead for developing and implementing policies to increase the deployment of renewable energy technologies for heat generation at the federal level. Another division is CanmetENERGY (the clean energy research and technology development agency), undertakes research and development in renewable energy technologies (IEA 2010). A non-profit organisation plays a role in the Canadian market called the Solar and Sustainable Energy Society of Canada (SESCI) that encourages advance use and awareness of solar and sustainable energy in Canada (SESCI n.d.). The main academic actors playing a research role in TSC include the University of Waterloo in Ontario (Arulanandam et al. 1999; Delisle 2008), Concordia University in Montreal (Candanedo et al. 2009; Athienitis et al. 2011), the University of Alberta and Queen's University in Kingston (Fleck et al. 2002). Further actors include the supply chain, designers and policy makers.

In the USA, there is one national entrepreneur (section 2.4.4); however, the Canadian manufacturers and suppliers are primary actors in the American market as well. Governmental organisations such as the US Department of Energy (US DOE) have called TSC *"the most reliable, best-performing, and lowest cost solar heating for commercial and industrial* *buildings available on the market today"* (Riegger 2011). The US Department of Energy's National Renewable Energy Laboratory (NREL) and the American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc. (ASHRAE), in addition to R&D Magazine, play roles as actors in the TIS system of TSC (Riegger 2011; Barnes 2013). Organisations like Green Building organisations and energy engineer trade associations were reported also as actors by Interviewee 4, in addition to academic actors including North Carolina State University which was involved in TSC research as applied to agriculture. The association of Leadership in Energy and Environmental Design (LEED) plays a role by listing TSC products as eligible to receive LEED credits when integrated in buildings. Further newspaper organisations such as Reuters where found reporting entrepreneurial activities of TSC (Reuters 2013).

ii) ACTORS IN THE UNITED KINGDOM

In comparison to the North American market, a lower number of active actors were found in the UK market, with an increasing number of potential supply chain entrants (Interviewee 1). There are two local entrepreneurs, one representing the branch of a foreign entrepreneur (section 2.4.4). An academic association with premier involvement in TSC research and application is Cardiff University - Welsh School of Architecture (WSA). Further universities with published research in TSC are the University of Nottingham (Chan et al. 2011) and the University of Surrey (Hall et al. 2011). The Building Research Establishment (BRE) was found as an actor where they installed one of the early demonstration panels of TSC. The Department of Energy and Climate Change (DECC), plays a role in TSC development through incentive plans, particularly Green Deal.

Potential organisations include the Technology Strategy Board (Interviewee 1) which drives innovation by helping businesses and researchers to collaborate on science and engineering (www.innovateuk.org). Further actual actors include the supply chain (i.e. technology development partners, coatings technologies, roofing and walling manufacturers, mechanical and electrical designers and contractors), the contract specification chain, architects, legislators, clients and developers.

6.3.2 INSTITUTIONS (RULES AND REGULATIONS)

The institutions as defined in section 3.3.3ii were themed for each region in terms of legal and customary regulations as follows:

i) INSTITUTIONS IN NORTH AMERICA

Codes and standards helped development of the TSC research and market in Canada and the USA. Incentive plans were allocated to encourage the use of TSC as part of renewable heat technologies. In Canada, the incentive plans included federal consumer incentives ecoENERGY for renewable heat from NRCan to industrial, commercial and institutional (ICI) sectors. The ecoENERGY plan ended on 31st March 2011 (IEA 2010; CanSIA n.d.). Consumer support remains available for TSC in many provinces. This includes, for instance, a 15% rebate of the installed cost of a solar air heating system in the Nova Scotia and Ontario solar thermal heating initiative (OSTHI). Furthermore, municipal areas like the town of Caledon in the province of Ontario set-up a green development programme that provides discounts for the use of TSC technology. Further institutions that encouraged the use of the TSC include a ‘road map’ that constitutes a collective commitment by provinces and territories to increase energy efficiency and the use of solar energy by 2025. It was anticipated that such an increase would be facilitated through:

> *...Improvements to building codes, broader regulation of energy-consuming products, green building policies for new government-funded facilities, and home energy audits and retrofit assistance* (IEA 2010, p. 12).

Similarly in the USA, the 30% federal tax incentive, which remains effective, is helping the TSC diffusion and development as mentioned by Interviewee 4. Furthermore, different States have different encouragement plans and incentives towards the use of renewable energy technologies.

i) INSTITUTIONS IN THE UNITED KINGDOM

A few institutions related to TSC were expected to be in effect in the UK market due to its emerging status. Interviewee 1 stated that "*…there are no recognised or established standards for transpired solar collectors or their performance".* The 2003 UK Energy White Paper determined goals for UK energy policy including cutting CO_2 emissions by 60% by 2050 and ensuring adequate and affordable heating for every home (Foxon and Pearson 2007). The target was thereafter increased to 80% by 2050 (DECC 2011a; Parkes 2012). A road map was published by DECC in 2012 which includes solar thermal energy (DECC 2012). This road map however, included neither solar air heating nor TSC technology, but included biomass and ground source heating pumps instead. TSC was only included within solar thermal energy in approximately June 2013 when the DECC listed TSC for Green Deal 'Golden Rule' incentives (Hough et al. 2014).

6.3.3 NETWORKS (LEARNING NETWORKS AND ADVOCACY COALITIONS)

The networks as introduced in section 3.3.3iii were themed for each region in terms of learning networks and advocatory coalitions as follows:

ii) NETWORKS IN NORTH AMERICA

The networks and collaborations seemed well-established in both Canada and the USA. TSC actors are furthermore willing to join collaborations and venture relations with other supply chain firms, competitors, research centres and government. TSC actors, however, are cautious in these relations as mentioned by Interviewee 4: *"…we're cautious but still open to possibilities, working with other companies in order to develop the technology and move it"*.

The Canadian Solar Industries Association (CanSIA) was established in 1992 as a national trade association that represents approximately 650 solar energy companies and organisations throughout Canada. CanSIA intensifies the development, efficiency and ethics of professional Canadian solar energy industry towards a sustainable, clean energy future (CanSIA n.d.). Furthermore, the Canadian Standard Association (CSA) provides lists of accepted solar collector products and manufacturers in Canada including TSC technology (CSA n.d.). The NREL also co-developed the concept of TSC and installed TSC units on the NREL new Platinum LEED rated Research Support Facility in 2010 in an encouraging act to knowledge diffusion (Barnes 2013).

Advocatory coalitions were apparent with universities as highlighted in section 6.3.1i. Furthermore, growing communications were reported by Interviewee 1 with designers, green building organisations and energy engineer trade associations. This communication builds up a stronger advocatory coalition.

iii) NETWORKS IN THE UNITED KINGDOM

As the TSC remains at the early emerging stage in the UK, most of the learning networks remain hypothetical. The majority of collaboration associations are with supply chain actors (section 6.3.1ii), particularly for cladding systems and coatings technologies. Networks are needed for UK local entrepreneurs to achieve faster efficiency of TSC than when working independently as became apparent from interview 1.

Numerous technology or product dominated associations (i.e. photovoltaic systems) are involved in various aspects of solar or renewable energy industries in the UK, which do not include TSC technologies. The TSC entrepreneurs are *"...still both individually and collectively, a relatively small voice in this area"* (Interviewee 1).

Similar to the cautiousness in North America, the UK entrepreneurs exercised circumspection during networking, as mentioned by Interviewee 2. Therefore, certain information is being retained from exchange via networks by actors. Further networking was successfully apparent with DECC (Interviewees 2 and 3) that resulted in the inclusion of TSC technology in the Green Deal 'Golden Rule' incentives (Hough et al. 2014).

The advocatory coalition networks were more apparent in the UK than North America, although only a small number of relations were identified due to the limited number of actors in the UK. The apparent networks identified are with LCRI and Welsh government funding for a project named the Sustainable Building Envelope Centre (SBEC) (www.sbec.eu.com). Another project is sustainable building envelope design (SBED) which is developing pilot TSC installations for further study (www.sbed.cardiff.ac.uk).

The renewable energy actors were, moreover, urged to network in order to achieve the UK's goal by the Energy Minister, Charles Hendry, when he said: *"We need very strong co-operation between the companies in the sector for where they can use their joint skills to help drive down costs"* (Parkes 2012, p. 27).

6.4 SYSTEM FUNCTIONS FULFILMENT OF TRANSPIRED SOLAR THERMAL

Hekkert et al. (2007) and Bergek et al. (2008) recommended investigating the fulfilments of each TIS function. This research should therefore investigate the interaction between those functions (section 6.5). This analysis sequence allows the drawing of lessons from the North American case, and identification of barriers to knowledge diffusion, which in turn helps to find enablers of development and knowledge diffusion (section 7.6). The qualitative data were considered according to each function as follows. However, few data intersect between two functions (i.e. knowledge creation and knowledge diffusion).

6.4.1 FUNCTION 1: ENTREPRENEURIAL ACTIVITIES

As introduced in section 3.3.4i, the activities below mainly relate to new entrepreneurial entrants or activities, expansions in development or demonstration projects.

i) ENTREPRENEURIAL ACTIVITIES IN NORTH AMERICA

Since the innovation development of TSC in the late 1980s, several entrepreneurial activities have taken place, such as investigating different materials of the TSC outer panel collector (section 2.4.4), geometry and pitch arrangements, conductivity experiments, and performance measures (section 2.5). The growing market has encouraged further entrants to join the TSC actors to compete and/or collaborate in the market (section 2.4.4).

Recently, solar air heating technology has become established in North America, particularly in Canada; therefore, only a few entrepreneurial activities were being themed specifically for TSC. These activities were mainly in the form of patented system advancements and development.

Figure 6-1 shows a pioneering advancement named 'SolarWall 2-Stage' which is introduced as a high performance solar air heating technology that was patented in 2010 (Hollick 2010). The 2-Stage was claimed to deliver up to 50+% more energy than a conventional TSC as tested by independent laboratories. It was furthermore presented as the most suitable technology for solar space heating applications (SolarWall 2012).

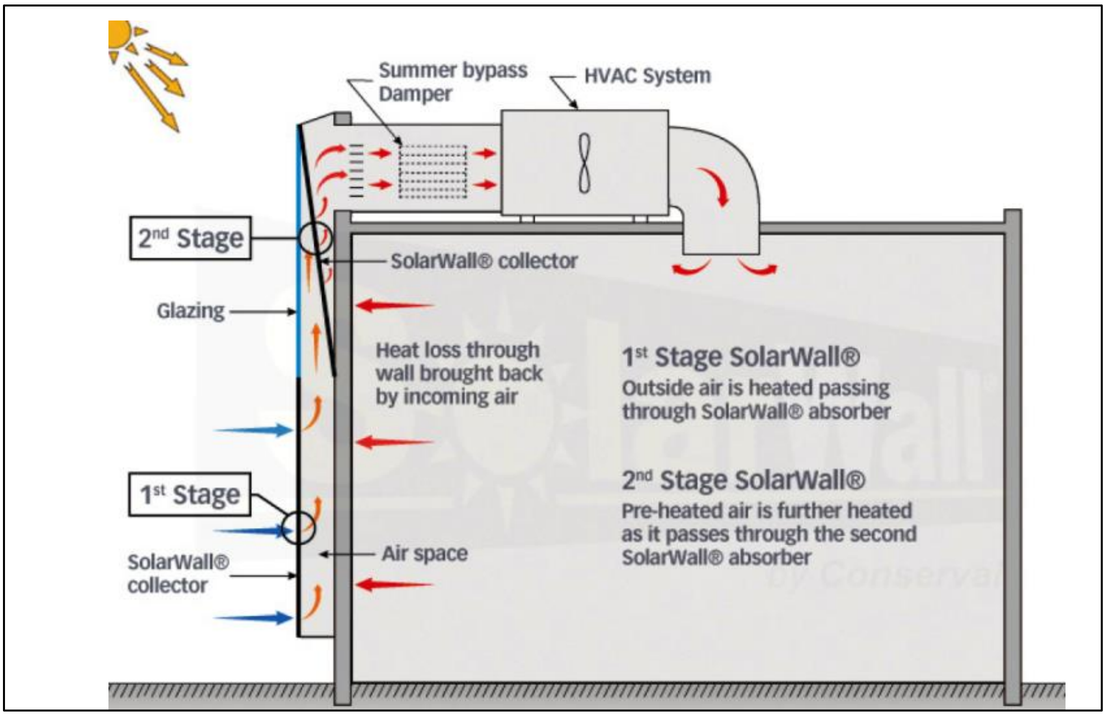


Figure 6-1: SolarWall 2-Stage - high performance solar air heating system (SolarWall 2012)

Further activities included NightSolar® (Fig. 6-2) which provides night and summer cooling in addition to air pre-heating (SolarWall 2013). Roof-mounted TSC with integrated thermal storage capacity was also presented as a pioneering entrepreneurial activity (Enerconcept n.d.).

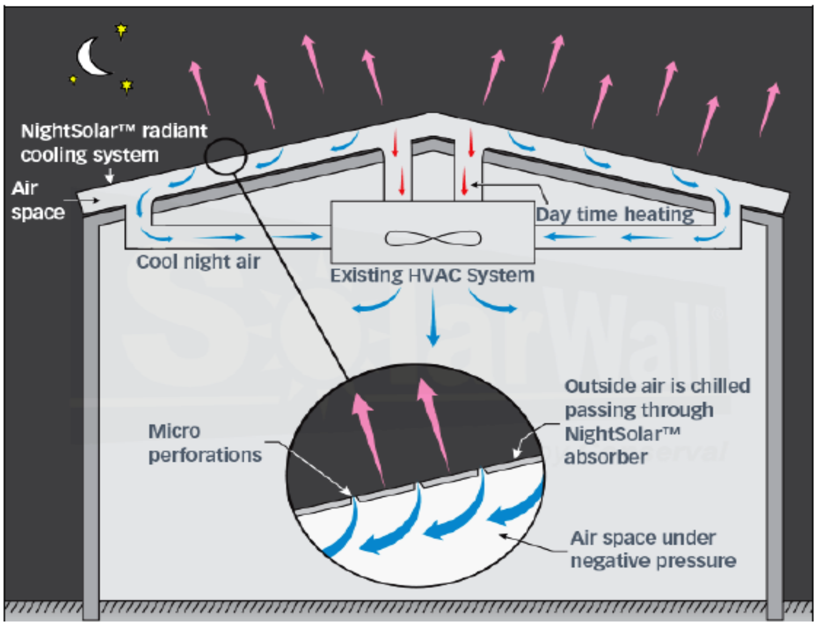


Figure 6-2: NightSolar® - solar heating & cooling system (SolarWall 2013)

Moreover, RETScreen software was developed as a design tool to assist in calculating and specifing TSC technology. The software is being constantly developed and updated by NRCan (www.retscreen.net). Further entrepreneurial activities could exist, as new information becomes available all the time.

ii) ENTREPRENEURIAL ACTIVITIES IN THE UNITED KINGDOM

Being almost at the emergent stage, the entrepreneurial activities of TSC in the UK were expected to be limited (Hekkert and Negro 2009). However, in reality, activities were found to be more extensive and ambitious than expected. It was found that actors within the UK were committed to achieving within three to five years, approximately 30 years of North American TSC experience (Interviewee 3). These activities included demonstration projects such as the TSC wall installed at the BRE research centre, the SBEC project in Shotton and SBED project (section 6.3.3ii).

The SBED project, for instance, aims to design, prototype and monitor the performance of TSCs on eight buildings representing four different types of building use within Wales (Collinson 2013). As part of the SBED project, TSC prototype units were constructed to conduct pre-testing of monitoring equipment that will be used later for full-scale building applications.

As part of trials to effectively include TSC in domestic buildings, figure 6-3 shows a 9m^2 TSC at the Rhondda Cynon Taf (RCT) dwelling home in Aberdare that was retrofitted in 2010 (section 2.4.1) which seems to be the first domestic application to utilise TSC technology. Furthermore, a 24m^2 TSC at the 'solar house' in Great Glen, Leicestershire has been announced as the first domestic application to utilise larger TSC technology (Building 2013).

Figure 6-3: RCT home - Cwmbach, Aberdare after completion of Retrofit (Tattersall et al. 2012)

TSC actors have developed a *"…software package that allows other people to use it to design and to specify* [TSC] *technologies…"* which has been made available online. The software is named the sustainable building estimation tool (SBET) and has been developed through SBEC to address some of the issues of existing software such as RETScreen and 'Swift' (Cho et al. 2012).

6.4.2 FUNCTION 2: KNOWLEDGE CREATION

As introduced in section 3.3.4ii, the activities below mainly relate to R&D activities and investment, patents, or the level of academic knowledge creation.

i) KNOWLEDGE CREATION IN NORTH AMERICA

The first step in knowledge creation was the production of TSC patents by Hollick (1985) and Hollick and Peter (1997) as highlighted in section 2.4.1. Considerable knowledge has been created since the innovation, in the form of academic research, patents, and entrepreneurial research and design activities that came with pioneering development (section 6.4.1i). The recent patents include modular transpired solar air collector (Wilkinson and Ionescu 2010), curved transpired solar air heater (Ryan 2010), perforated transparent glazing for heat recovery and solar air heating (Vachon 2013) and two-stage cooling (Hollick 2013), in addition to the two examples in section 6.4.1i.

The North American entrepreneurs have kept their R&D in-house (Interviewee 4) for many reasons. A major reason for this has been information protection, as Interviewee 5 showed concern regarding patent violation which has occurred within the TSC industry. This violation discourages knowledge creation and *"...has the potential to stymie investment"*. The constant R&D activities retain a competitive TSC technology in the North American local and international markets. The prototype, design and integration of TSC furthermore *"... is educational and cultural change leads to actions"* as stated by a consulting architect from USA with more than 15 years of experience.

ii) KNOWLEDGE CREATION IN THE UNITED KINGDOM

"Understanding the potential use and application of products is essential to appropriate specification" stated a consulting architect from England with more than 15 years of experience. A number of academic studies were created at universities such as Cardiff University and the University of Surrey (section 6.3.1ii). Further R&D is being conducted at the SBEC focusing on research, development and pre-commercialisation (Interviewee 3). These activities are counted as 'learning by researching'. Interviewee 2 however believes that applied research is:

> *...much closer to the market and* [attempts should be made] *to take a product or a technology to the market; ...if better alternative*

solutions are available, then that will encourage research and development and obviously eventual deployment in the marketplace.

Demonstration projects (section 6.4.1ii) were constructed in collaboration with supply chain actors. The author of this study collaborated with the SBED research team on the design of the prototype rig (section 5.10). The prototype TSC aimed to furnish the SBED research team with the necessary confidence and knowledge of testing the full-scale TSC applications within the project. The prototype was also made accessible for the researcher to learn and experiment. The prototype is therefore a 'learning by doing' practice that contributes to knowledge creation in the field of TSC.

6.4.3 FUNCTION 3: KNOWLEDGE DIFFUSION

As introduced in section 3.3.4iii, the activities below relate to knowledge exchange via events and networks, the nature of networking between actors and the kind of knowledge being shared.

i) KNOWLEDGE DIFFUSION IN NORTH AMERICA

More than 20 peer reviewed academic publications through North American universities and research centres (section 2.5), a number of learning networks between the actors (section 6.3.3i) and periodic reports indicate that knowledge diffusion in North America is taking place. Further potential collaboration between North American actors could occur (Interviewees 4 and 5) to exchange knowledge, conduct research, and develop TSC; however, this is limited by the requirements of entrepreneurs for secrecy (section 6.4.1i). The North American entrepreneurs therefore, became more focused on protecting their own knowledge rather than exchanging knowledge with other actors, particularly competitive entrepreneurs. This caution may have been a factor in some invited participants to this research not taking part (section 4.5.6), however, targeted survey participants remain of busy professionals (section 4.4.1v).

For example, CanSIA provides education and networking opportunities for the Canadian member actors, in addition to knowledge exchange with policy makers in the form of recommendations (CanSIA n.d.). Four education seminars are offered by ATAS (the American entrepreneur, section 2.4.4) in collaboration with the American Institution of Architects on the continuing education system (AIA-CES). The Solar and Sustainable Energy Society of Canada also assisted in facilitated exchange of up-to-date knowledge through chapter meetings, public events and education, national and regional conferences, exhibitions, and workshops (SESCI n.d.). Moreover, newspaper organisations were involved in reporting entrepreneurial activities and high profile TSC installations such as an installation on the NREL (Reuters 2013).

In spite of the seemingly busy activities towards knowledge diffusion, North American respondents to the questionnaire, especially architects, mentioned a lack of technical data and absence of accessible independent studies for public perusal. A Canadian architect from local government also stated *“*[a lack] *of demonstrated success in local climate …”* where the contracting architect from the USA mentioned the need for further *“knowledge* [diffusion] *of* [TSC’s] *product installation and performance”.* These issues and a few similar were agreed by almost 30 North American respondents to the questionnaire.

ii) KNOWLEDGE DIFFUSION IN THE UNITED KINGDOM

In confirmation of the importance of knowledge diffusion, Interviewee 1 mentioned that his firm became aware of TSC technology and in turn incorporated TSC in their business plan once the technology became ‘patent free’ (25 years after the patent registration in the mid-1980s).

Since the first UK TSC publication by Hall et al. (2011), almost five peer reviewed academic studies were published through universities (section 2.5 and section 6.3.1ii). Further to research, Cardiff University is developing continuous professional development (CPD) training on TSCs through Welsh Energy Sector Training (WEST). Part of this will be delivered in conjunction with the Cardiff University Centre for Lifelong Learning. The course covers basic principles and potential use of TSC and targets designers, architects, engineers, building energy assessors and construction project managers (Cardiff University n.d.).

A number of respondents to the questionnaire stressed the importance of knowledge diffusion for the development of TSC through certain measures such as prototypes: *“buildings should be didactic and used as a learning tool”* stated a consulting architect from Wales. Independent reports of the consumers’ testimonials and feedback were also found to be required, as mentioned by an academic from Wales: *“scientific data needed, i.e. user experience across a sufficiently wide sample”*. Further comments revolved around the absence of knowledge, the need for true understanding of the TSC mechanism and benefits and access to technical data and successful prototype projects.

6.4.4 FUNCTION 4: GUIDANCE OF THE SEARCH

As introduced in section 3.3.4ivm the activities below mainly relate to visions, expectations, success/failure stories, regulations or policy plans.

i) GUIDANCE OF THE SEARCH IN NORTH AMERICA

It is evident that TSC technology in the USA and Canada became a well-known solar thermal technology option (section 6.3.2i). This diffusion was accompanied by targeted vision from the governments towards the use of renewable technologies that in turn reduce CO_2 emissions. The Canadian government, for instance, aims to widely deploy solar energy throughout Canada by 2025 and in doing so, to create more than 35,000 jobs. Furthermore, IEA (2012) issued a roadmap vision for solar technologies including solar collectors for space heating in the building sector by 2050. The roadmap provides specific goals, and indicates the expected installed annual capacity and displaced GHG. These visions encourage investment in TSC technology in the North American market. It furthermore strengthens confidence towards further research projects. The province of Ontario in Canada, for instance, targets to reduce CO_2 emissions by 80% by 2050 (REN21 2013).

The recommendation of using TSC by independent research associations and government offices such as US DOE and ASHRAE (section 6.3.1i) helped the development and adoption of TSC technology. The codes were also found to encourage deployment of TSC such as the requirement of fresh air in the ventilation code to avoid 'sick building syndrome' (Riegger 2011). Successful TSC projects and large landmark installations have included installation on the NREL (section 6.4.1i), the Ford Motor Company assembly plant in Canada (section 2.4.1), and North America's largest SolarWall system of 2008 (11,000 ft^2) at Owens Corning's Toronto area insulation manufacturing facility (Renewable Energy 2009). These projects and stories encourage further adoption by architects and clients. The inclusion of TSC in the LEED certification criterion moreover attracts architects and designers. Testimonials and feedback (i.e. the ones published on www.solarwall.com) strengthen the confidence of TSC deployment actions. Moreover, the vision of the actors themselves is significantly crucial to the TSC development. Interviewee 4 expected "*...to see an explosion of adoption of this technology in the marketplace".*

The solar industry is nevertheless considered by the Canadian government as an established component which has already achieved market competitiveness, therefore, government incentives would no longer be needed (CanSIA 2010). The other energy sources, on the other hand, remain either supported (i.e. PV) or cheap (i.e. gas) especially that *"...fossil fuels ... have enjoyed decades of basically tremendous subsidies that have created an unequal playing field*" said Interviewee 4.

ii) GUIDANCE OF THE SEARCH IN THE UNITED KINGDOM

Despite reasonable perception of TSC awareness in the UK (section 5.4.1), the implementations remain limited (6.4.1ii). The entrepreneurs see themselves having the potential structures and the organisational capability to develop and diffuse the use of TSC. They are aware of the requirements of architects and legislators who *"...want ... technically proven* [system] *that has been demonstrated in practice on perhaps another project"* (Interviewee 1). This awareness guides the entrepreneurial path towards compliance of design and regulatory requirements. Interviewee 3 went farther in classifying the clients into three different groups for TSC deployment:

> ... [the first might] *be just purely compliance, they need to put enough renewables on a building to get building permissions, others will see the economic value of it, and then there is a third set who are more altruistic and want to extend the sustainability agenda as far as they can*.

The importance of having a successful prototype was attributed by Interviewee 1 to the fact that *"...it's very rare that people like to be guinea pigs* [testing] *or the first person ... to try a solution".*

The collaboration with academic actors such as Cardiff University through either research projects (i.e. SBEC) or demonstration implementations (i.e. SBED) (section 6.4.1ii) inspires researchers to conduct further research of TSC and gives confidence to legislators to support the technology. Following positive sessions of dialogue with DECC, the latter included the TSC in the Green Deal 'Golden Rule' incentives (Hough et al. 2014) (section 6.3.2ii).

Hence, further government support seems optimistically anticipated by TSC actors in the UK. The UK government has put a vision through to cut CO_2 emissions by 80% by 2050 (DECC 2011a; Parkes 2012) (section 6.3.2ii). Moreover, the invitation of the Minister Charles Hendry, for renewable energy actors to network (section 6.3.3ii) empowers market competitiveness and enables knowledge exchange.

The announcement of breakthrough TSC implementations included the 'solar house' in Great Glen (section 6.4.1ii) and UK's largest TSC installation at Marks & Spencer in 2013 (Section 2.4.1, Table 2-1). Similar to North America, these announcements encourage potential adoption by architects and clients and contribute to confidence of TSC deployment.

6.4.5 FUNCTION 5: MARKET FORMATION

As introduced in section 3.3.4v, the activities being themed below mainly relate to market status, market demand and actions towards uncertainties.

i) MARKET FORMATION IN NORTH AMERICA

The TSC in North America is deemed well-established and the technology is incumbent in that market. The Canadian solar thermal technologies that are actively growing across Canada and the USA include evacuated tube, unglazed and glazed liquid and air collectors (CanSIA 2010). Figure 6-4 shows a historical annual trend of solar thermal domestic collector sales.

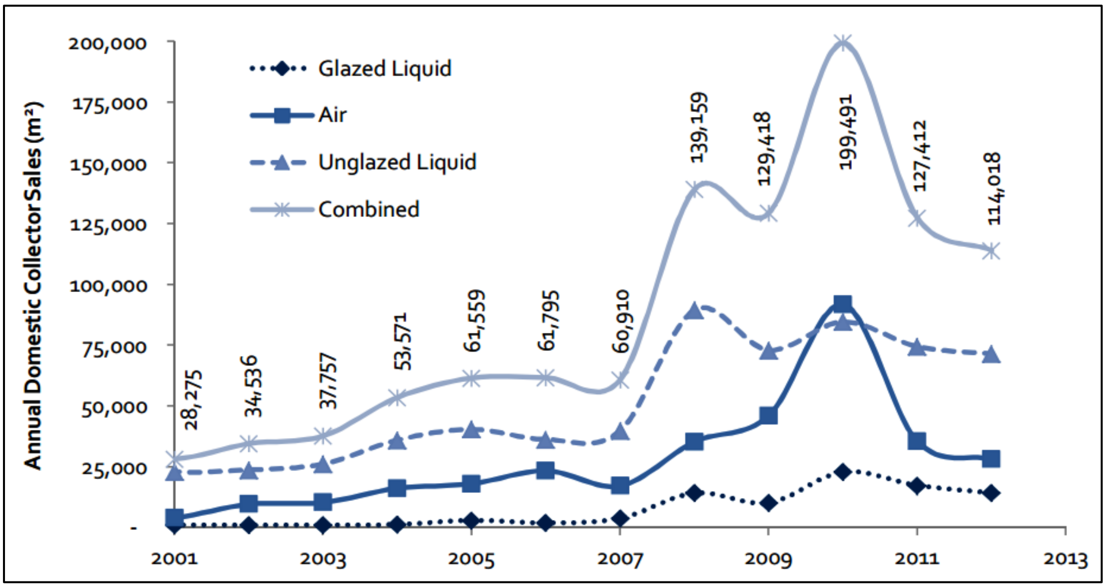


Figure 6-4: Historical annual trend of solar thermal domestic collector sales m^2 (NRCan 2013)

The Canadian solar thermal market witnessed a continuous growth from 2000 to 2007 at an average annual rate of 16%. The market during that period was dominated by liquid solar collectors which accounted for almost 70% of the annual market. It was in 2008 when solar air heating encountered significant growth following the re-introduction of the federal ecoENERGY for renewable heat from NRCan and a number of complementary programmes at the provincial level (6.3.2i). In 2010, solar thermal air comprised almost 50% of the solar thermal market share. Due to the end of ecoENERGY by 2011, solar air heating declined significantly in the local market. Therefore, the Canadian solar thermal industry was growing in the decade ending 2010 due to subsidy plans, and entrepreneurs have been left now to compete internationally (NRCan 2012; CanSIA 2013; Richardson 2013). Interviewee 5 commented on the withdrawal of support by the Canadian federal government stating that:

> *...Those who would like to install transpired solar collectors are always taken aback by the lack of federal and provincial funding for the technology. This takes away from the confidence they might feel in the technology.*

The exports of TSC accounted for 12,620m² (33% of the total solar thermal market share) in 2012 following a steady increase since 2009 where the export was only 2,813m² (50%). The export figures dropped from 2008 to 2009, which could be explained by the increase in domestic sales for the same period. The domestic installations almost doubled from 17,056m² in 2007 to 34,135m² in 2008, and again doubled from 48,144m² in 2009 to 99,769m² in 2010. Thereafter the domestic installations dropped dramatically to 28,444m² in 2012 (Fig. 6-5) (NRCan 2013). Interviewee 5 confirmed increased sales in other markets stating that *"...we focus our energies on markets where there is incentive money available".*

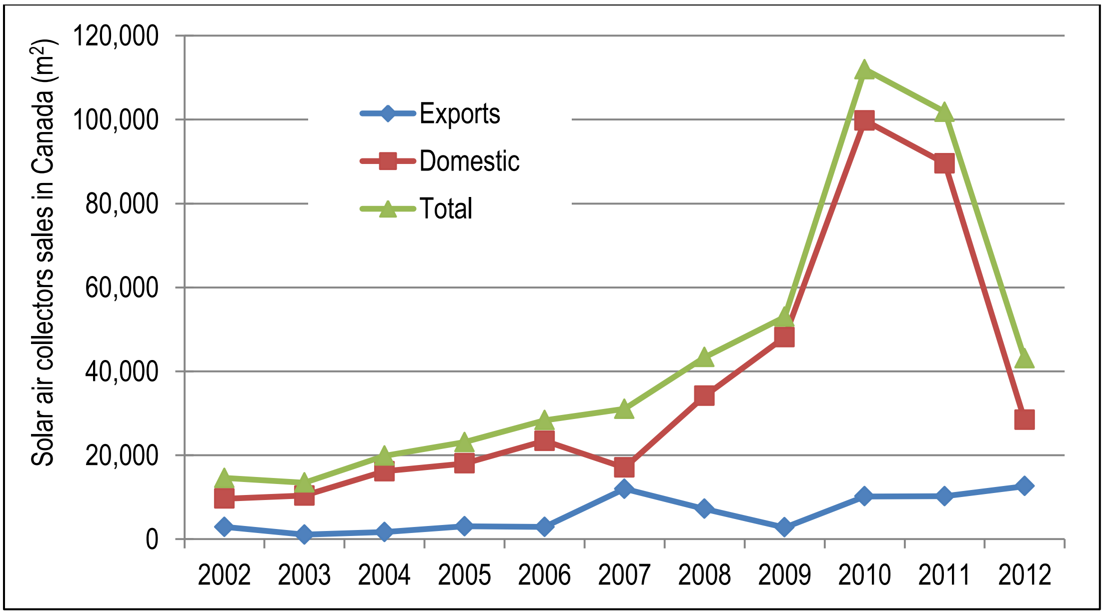


Figure 6-5: Historical solar air heating installations in Canada from 2002 to 2012, gathered from NRCan survey reports including NRCan (2012), NRCan (2013) and Richardson (2013)

The primary obstacle in the North American market is the return-on-investment for TSC. Due to the precipitous drop of natural gas prices (possibly related to increased gas availability from hydraulic fracturing in USA), the TSC ROI timeframe increased to eight to ten years, where before it was three to five years. This is more applicable in retrofit projects that are currently using natural gas for their heat (Interviewee 4). A consultant from Canada stated that TSC requires government involvement *"...as natural gas is so inexpensive currently".* Interviewee 5 confirmed the problem, stating that the *"...challenge is always with an acceptable payback".* The payback was themed as a high concern in the questionnaire responses that were reported in chapter 5 (i.e. sections 5.4.2 and 5.5.2).

ii) MARKET FORMATION IN THE UNITED KINGDOM

There are three distinct phases of market formation within a TIS, that of a nursing, bridging and mature market (Lai et al. 2012). The current size of TSC installations (section 2.4.1), entrepreneurial activities (section 6.4.1ii) and size of effective drivers and actors (section 6.3.1ii) within the UK places the TSC market in a transitional phase from a nursing market to bridging market. Despite the very slow market, the number of TSC projects and activities in the UK is increasing (sections 2.4.1 and 6.4.1ii). Government support remains essential at this stage. This statement is agreed by interviewed entrepreneurs and surveyed researchers, government respondents and architects in the UK. As yet, the supply chain is "*...fragmented in the sense that there was no one lead contractor who could offer the whole package".* (Interviewee 2).

6.4.6 FUNCTION 6: RESOURCE MOBILISATION

As introduced in section 3.3.4vi, the activities below mainly relate to human resources, available funding and asset changes.

i) RESOURCE MOBILISATION IN NORTH AMERICA

Albeit the resource mobilisation comprises both human resources and financial resources, most of the data focuses on the financial aspects of TSC development. The major resource mobilisation concerns revolve around government support and public funding. The government support was in the form of subsidy plans such as ecoENERGY in Canada, and federal tax incentives in the USA (section 6.3.2i, 6.4.1i and 6.4.5i). Interviewee 5 stated that *"...the lack of governmental support for TSC projects makes the Canadian market a very uncertain one for TSC. Without government funding, TSC will not enjoy wide-scale adoption".* Interviewee 4 furthermore expressed the need for government support stating that *"...* [what] *helped to develop the market* [in the USA] *is the federal tax incentive, the 30% tax incentive for those who choose to invest in installing the technology on their building".* Nonetheless, most of the TSC manufacturers in North America are doing their in-house R&D as they can bear the associated financial burden of research and development (Interviewee 4).

In terms of human capital, there are no specific statistics on employment in solar air heating in North America. The workforce in the Canadian solar industry is targeted to be 35,000 jobs by 2025 (section 6.4.4i). The province of Ontario, for instance, is targeting 6,400 jobs in solar industry by 2020, out of a provincial plan of 27,000 in the Clean Energy Plan 2.0 (Weis et al. 2010). Education seminars and courses (section 6.4.3i) help a proficient fulfilment of such jobs and strengthens the capability of the workforce.

ii) RESOURCE MOBILISATION IN THE UNITED KINGDOM

Government support in the UK, as explained in section 6.3.2ii, remains in the very early stages. Further potential resource mobilisations were built up according to this anticipation of government support to increase the national level. Some government funding for research and development was available through Welsh government funding for the SBEC project (section 6.3.3ii). Further funding was made available through the Welsh government to research and diffuse the use TSC in Wales. The TSC entrepreneurs were still expected to make a significant contribution to the research and prototyping fund (Interviewees 1 and 3).

Certain actors in the UK intend to encourage the deployment and awareness of TSC through education and training. Cardiff University, for example, is developing relevant CPD through WEST (section 6.4.3ii). The development of the software (SBET) that is being made available to supply chain and other actors (section 6.4.1ii) is a good example of potential resource mobilisation that encourages the deployment and knowledge exchange of TSC technology in the UK and mainland Europe (Interviewee 3).

6.4.7 FUNCTION 7: LEGITIMACY

As refers to the social acceptance and advocacy grouping, this function was explained in section 3.3.4vii. The activities below mainly relate to public perception, legitimacy versus demand, behaviour, media and lobbying groups.

i) LEGITIMACY IN NORTH AMERICA

There is no well-known consumer party or buyer-seller coalition from the available data. In spite of the importance of the lobbying activities, it often occurs behind closed doors (Vasseur et al. 2013). The advocatory coalitions of solar energy technologies instead, are apparently active in the USA and Canada. The existence of international organisations such as Solar Air Heating World Industry Association (SAHWIA) and national groups like CanSIA and CSA (section 6.3.3i) enriches lobbying activities towards the support of researching and deploying solar energy in general, and TSC in particular. The collaboration with academia adds further significant strength to the legitimacy acceptance of TSC technology. The end-users usually trust the academic research as independent. The consumers often treat the manufacturers' reports as profit driven and biased as noted from the questionnaire results.

On the other hand, the drop of natural gas prices (section 6.4.5i) as the incumbent source for heating represents an indirect resistance to the deployment of TSC technology in the USA and Canada.

Exchanging experience and feedback of the end-users who deployed the TSC (section 6.4.4i) benefits public perception and increases deployment, especially if these testimonials are trustworthy and positive. Interviewee 5 stated that *"the general perception of those that have installed it is that they are very happy with it. We conduct satisfaction surveys which indicate this and also have many repeat customers".* Awareness and perception in Canada and the USA were discussed in chapter 7.

ii) LEGITIMACY IN THE UNITED KINGDOM

The TSC industry in the UK remains quite far from forming legitimate lobbies, due to the formative phase of the emerging technology. Interviewee 2 stated that "[it is] *very early days to be honest ... it hasn't gone out on a big scale"*. The end-users, designers and policy makers need to see successful prototypes and independent performance reports as mentioned by Interviewee 1 (section 6.4.4ii). Nonetheless, the entrepreneurs with a few other actors in the UK try actively to shape a potential lobby (Interviewee 3). This approach by the entrepreneurs is influenced by the many available European and UK organisations or trade associations who are dominated by certain systems or technologies like PV and biomass. The TSC entrepreneurs feel they have *"...a relatively small voice in this area"* (Interviewee 1). The TSC actors in the UK focus furthermore on end-users through connections with *"...people who have ... the voice of the customer and voice of ... supply chain..."* (Interviewee 2).

6.5 INTERACTION BETWEEN TECHNOLOGICAL INNOVATION FUNCTIONS

Following on from the investigation of functional fulfilment, the strengths and weaknesses of interaction between the functions for TSC TIS development must be assessed. This section evaluates the major interaction patterns in North America as a leading example, and then considers the UK situation. After identifying the stage of development in each region, the key interaction patterns are reported.

6.5.1 FUNCTION INTERACTIONS IN NORTH AMERICA

The TSC in Canada and the USA is in the growth phase of TIS development. A number of virtuous cycles have been identified:

<u>Knowledge development cycle</u> (Fig. 6-6): starting from strong guidance (+Function 4) through road maps, future targets, and recommendations to deploy solar thermal such as by CanSIA and ASHRAE to encourage knowledge creation (+Function 2). The R&D and prototype experience (+Function 2) increased knowledge diffusion through networks (+Function 3). Therefore, the advocatory coalition (+Function 7) gained confidence and

positive perception about TSC which lead to high expectation of the technology which has been considered in the road maps (+Function 4). This in turn reinforces academic and applied research and education course design (+Function 2) which supports knowledge exchange through academia and trade collaborations (+Function 3).

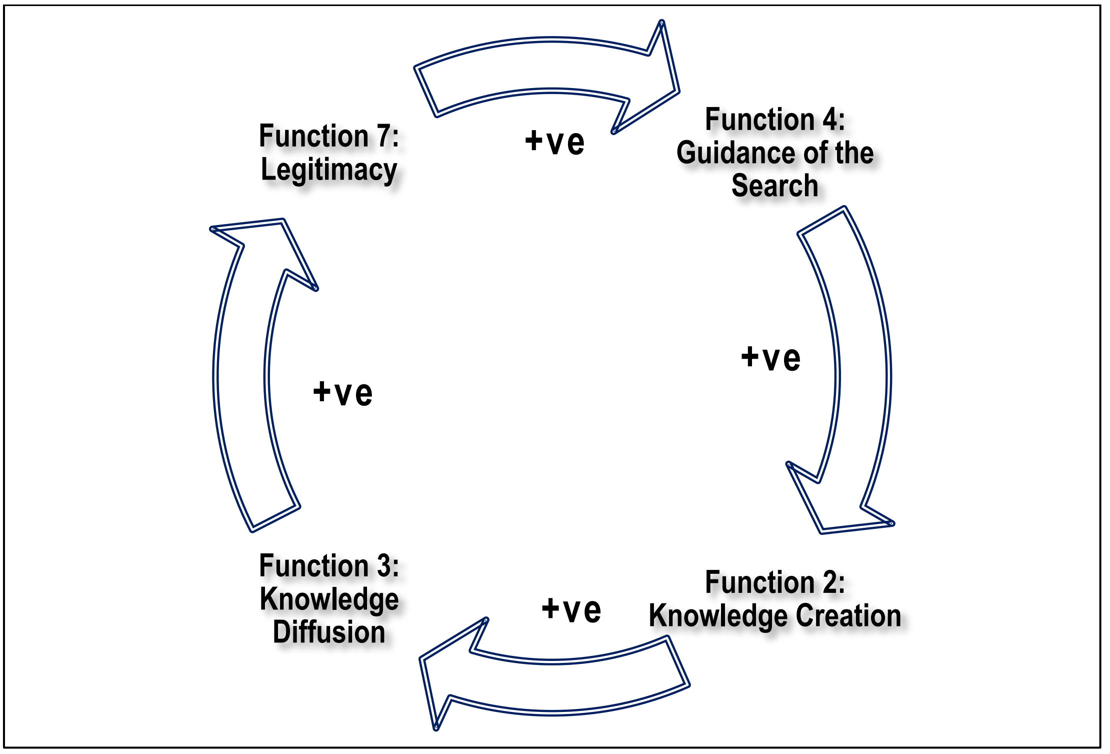


Figure 6-6: Virtuous knowledge development cycle in North America, author

Implementation development cycle (Fig. 6-7) started from strong guidance (+Function 4) which supports financial support resources (+Function 6) such as provincial support and the 30% tax incentive: this influenced growth of the TSC market (+Function 5). The growth in the local market and the growing export shares (+Function 5) increased the chances for patents and advanced TSC development (+Function 1). This also opened new markets and entrepreneurial opportunities. The increasing entrants strengthened the lobbying (+Function 7) which increased the guidance of the search and expectations (+Function 4) that support the financial supporting plans (+Function 6) for further growth in the TSC market (+Function 5).

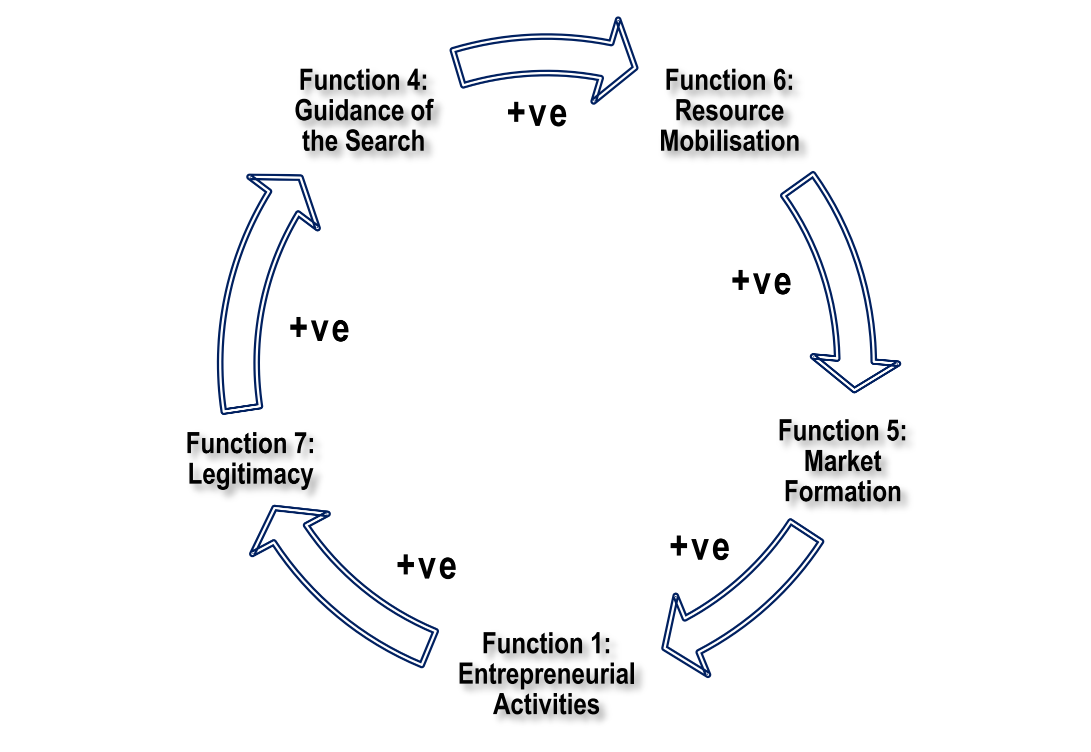


Figure 6-7: Virtuous implementation cycle in North America, author

However, in Canada, a vicious implementation development cycle (Fig. 6-8) was noticed due to the stoppage of the ecoENERGY federal incentives plan as a financial resource (-Function 6).

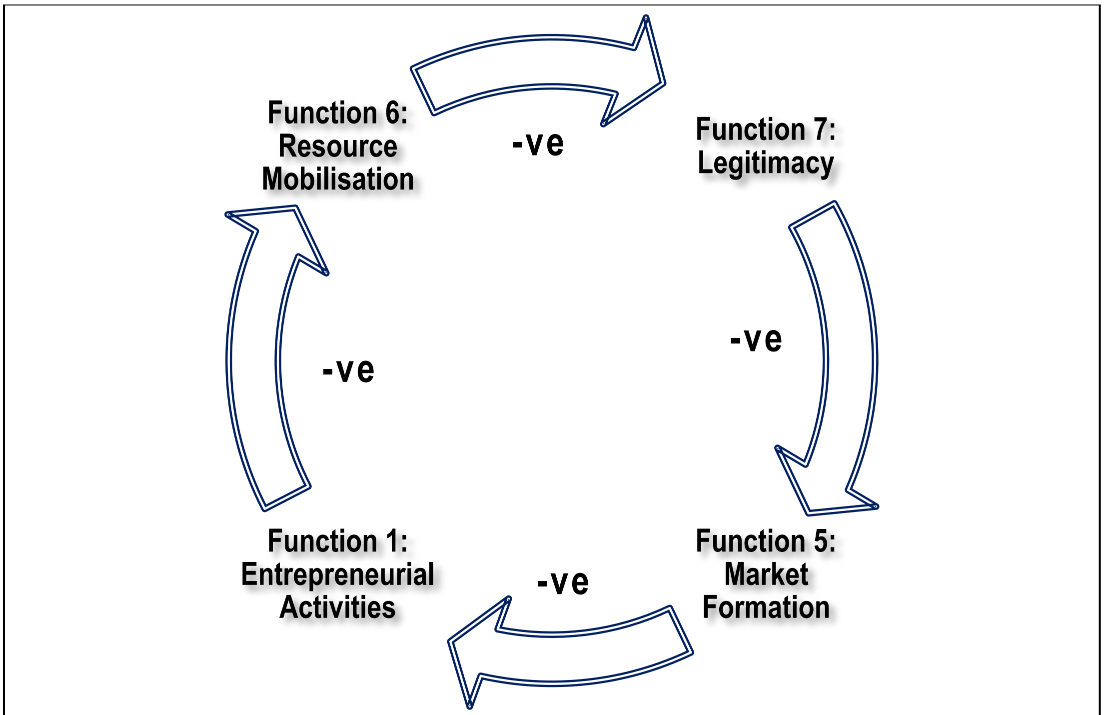


Figure 6-8: Vicious implementation cycle in Canada, author

This interruption, due to the stoppage of the ecoENERGY federal incentives plan as a financial resource (-Function 6), affected the deployment of the technology by end-users (-Function 7) which in turn decreased the demand in the local market (-Function 5). The decreased demand would therefore exclude new entrants to the marketplace (-Function 1) and might push existing small entrepreneurs to exit the market or change business. Accordingly, government support for research and deployment (-Function 6) will be shifted to other technologies which in turn shifts the attention of the public (-Function 7).

An offshoot of the vicious cycle just described follows. The decrease in deployment by the public (-Function 7) increased export activities (+Function 5) which grew in response, that in turn influenced positive international knowledge diffusion (+Function 3) developing a virtuous cycle. However, this pattern is not included in the above vicious cycle.

6.5.2 FUNCTION INTERACTIONS IN THE UNITED KINGDOM

In the UK the TSC remains in the formative phase of TIS. The evaluation of the TIS functions in the UK indicates a promising potential of knowledge creation through active TSC entrepreneurial activities. Other functions show low active fulfilment, which is expected for a system in the formative phase. These functions are knowledge diffusion, market formation, resource mobilisation and legitimacy. However a number of activities are potentially fulfilling those functions, as described earlier (section 6.4). A few distinct interactions were observed from the collected data.

Almost similar to North America, a virtuous knowledge development cycle (Fig. 6-9) was noticed starting from guidance (+Function 4) through the UK vision to cut CO_2 emissions by 80% by 2050. This vision triggers resource mobilisation by employing or developing workforce (+Function 6). Therefore, knowledge creation through academic research and R&D is encouraged (+Function 2) which in turn encourages new supply chain entrants (+Function 1). This leads to knowledge exchange (+Function 3) that increases expectation and guidance (+Function 4). The further expectations influence the inducement of government support plans such as Green Deal

(+Function 6) which increases R&D and patents (+Function 2) and leads to well-developed and competitive technologies (+Function 1). The advancement of TSC products leads to advanced knowledge exchange with supply chain and more training courses through academia (+Function 3) which strengthens the guidance and expectations from TSC technology (+Function 4).

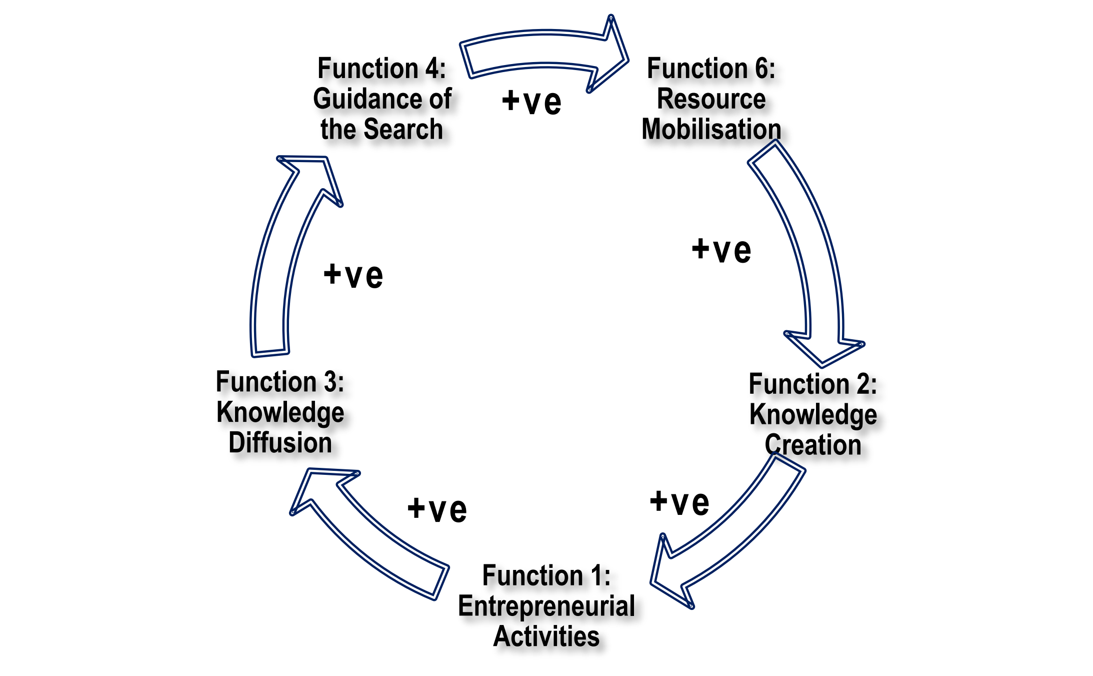


Figure 6-9: Virtuous knowledge development cycle in the UK, author

A potential vicious pattern was also observed. For example, the absence of codes and regulations (-Function 6) affects the research and knowledge creation (-Function 2) which in turn discourages entrepreneurial activities such as new entrants into the market (-Function 1). This pattern remains notional at this emerging stage of TSC, therefore, it has not been formally identified as a vicious cycle in this chapter. The need for codes and regulations is however highlighted in the enablers to technology deployment in chapter 7.

6.6 SUMMATIVE COMPARISON BETWEEN NORTH AMERICA AND THE UNITED KINGDOM OF THE TSC TIS

Having investigated the different structures and aspects of the TIS in North America and the UK for TSC technology, there are distinct differences between the regions. Over the last three decades, North America has established research and market components versus the recent launch of the TSC in the UK. The UK actors however seem committed to reducing the gap within five years, in order to lead the European marketplace for TSC technology. Table 6-1 presents a concluding comparison between both regions based on the aforementioned analysis of TIS structural components. Table 6-2 presents a comparison of the functions, whereas Table 6-3 compares the interaction between functions in North America and the UK.

Table 6-1: Comparison of TSC TIS structural components in North America and United Kingdom

Components	North America	United Kingdom
Actors	- Large number and size with substantial resources and capabilities. - Entrepreneurs focus on both local market and export.	- Limited number. - Focus on the local market with an open eye on the European market.
Institutions	- Multi-purpose and various incentive plans. - Encouraging building codes. - Stoppage to the Canadian federal subsidies plan after TSC maturity encouraged exports but decreased local adoption of TSC in Canada.	- One incentive plan 'Green Deal'. - No particular established standards or codes for TSC.
Networks	- Strong trade and learning networks. - Cautious communications due to market competition and IPP.	- Active potential learning networks with supply chain and research. - Knowledge exchange however remains limited. - Potential political networks. - Starting advocatory coalition networks with academia and competitors.

Table 6-2: Comparison of TSC TIS functions in North America and United Kingdom

Functions	North America	United Kingdom
Function 1: Entrepreneurial Activities	- Accumulation of numerous activities since the 1980s. - New entrants. - Further system advancements like SolarWall 2-Stage and NightSolar®. - Constant development and revision of RETScreen software. - Function is fulfilled.	- A few prototype projects. - Ambitious and committed to shorten the North American experience. - Busy entrepreneurial diary. - Encouraging supply chain to enter the market. - Launch of SBET software. - Function is almost fulfilled; however, there is an absence of new entrants.
Function 2: Knowledge Creation	- Several patents and advancement of TSC were recorded. - Independent entrepreneurs' in-house R&D. - Further research through universities and government organisations. - Function is fulfilled.	- A few 'learning by researching' activities through ties with Cardiff University. - An access to 'learning by doing' for some supply chain actors and researchers. - Function is fulfilled.
Function 3: Knowledge Diffusion	- Education courses are available through professional collaboration. - The entrepreneurs became highly cautious and veered towards knowledge protection versus knowledge exchange. - Limited international knowledge exchange. - Function is fulfilled.	- Potential desire for knowledge exchange with limited number of publications. - CPD is available through Academia. - Low active fulfilment of the function.

Table 6-2 Continued (1): Comparison of TSC TIS functions in North America and United Kingdom

Functions	North America	United Kingdom
Function 4: Guidance of the Search	- Vibrant road maps that include solar thermal technologies which in turn trigger research and investment in TSC. - TSC is supported by independent research and certifying associations (USDOE, ASHRAE and LEED). - Certain degree of discouragement by the stoppage of the Canadian federal incentive plan 'ecoENERGY'. - Function is almost fulfilled despite the Canadian federal subsidies stoppage.	- Optimistic road map but has no clear plan for solar energy future. - No specific vision of TSC apparent from government. - Low active fulfilment of the function.
Function 5: Market Formation	- Almost incumbent technology. - Reasonably large and dominant local market. - Growing export share to international market. - Function is fulfilled.	- Fragmented supply chain actors focusing on the local market. - Low number of installations. - Low active fulfilment of the function.
Function 6: Resource Mobilisation	- Fully independent self-funding for the in-house R&D. - Several funds remain available in the form of incentive plans. - Growing targets of future human resources. - Specific education courses are available. - Function is fulfilled.	- Potential availability of research and prototyping funding. - The entrepreneurs share part of R&D funding. - Introduction of incentive plan 'Green Deal'. - Low active fulfilment of the function.

Table 6-2 Continued (2): Comparison of TSC TIS functions in North America and United Kingdom

Functions	North America	United Kingdom
Function 7: Legitimacy	- Apparent vision by government increases confidence of entrepreneurs and end-users. - Existence of strong international and national advocatory coalition organisations. - There is indirect counteractive resistance due to low cost of natural gas. - A number of end-user testimonials and feedback are published through the entrepreneurs. - Function is fulfilled.	- General understanding of the end-users, policy makers and designers requirements. - Potential plans of trade lobbying. - Limited successful feedback stories are ready to be verbally conveyed to potential beneficiaries but nothing written yet. - Limited active fulfilment of the function.

Table 6-3: The interaction of TIS functions is compared between North America and United Kingdom

Interactions	North America	United Kingdom
Virtuous **(major cycles)**	- Knowledge development cycle was recorded starting from guidance of the search (Fig. 6-7). - Implementation development cycle was recorded starting also from guidance of the search (Fig. 6-8). - An offshoot of the vicious cycle below; export activities were increased (+Function 5) encouraging knowledge diffusion (+Function 3).	- Knowledge development cycle was recorded starting from guidance of the search (Fig. 6-10). - Some other potential cycles were noticed at weak interactions yet.
Vicious **(major cycles)**	- Vicious implementation cycle was noticed in Canada due to the stoppage of the federal incentive plan. That starts from resource mobilisation (Fig. 6-9).	- There is a cycle starting from guidance of the search due to the absence of TSC specific codes and regulations. It affects knowledge creation (-Function 2) and therefore entrepreneurial activities (-Function 1).

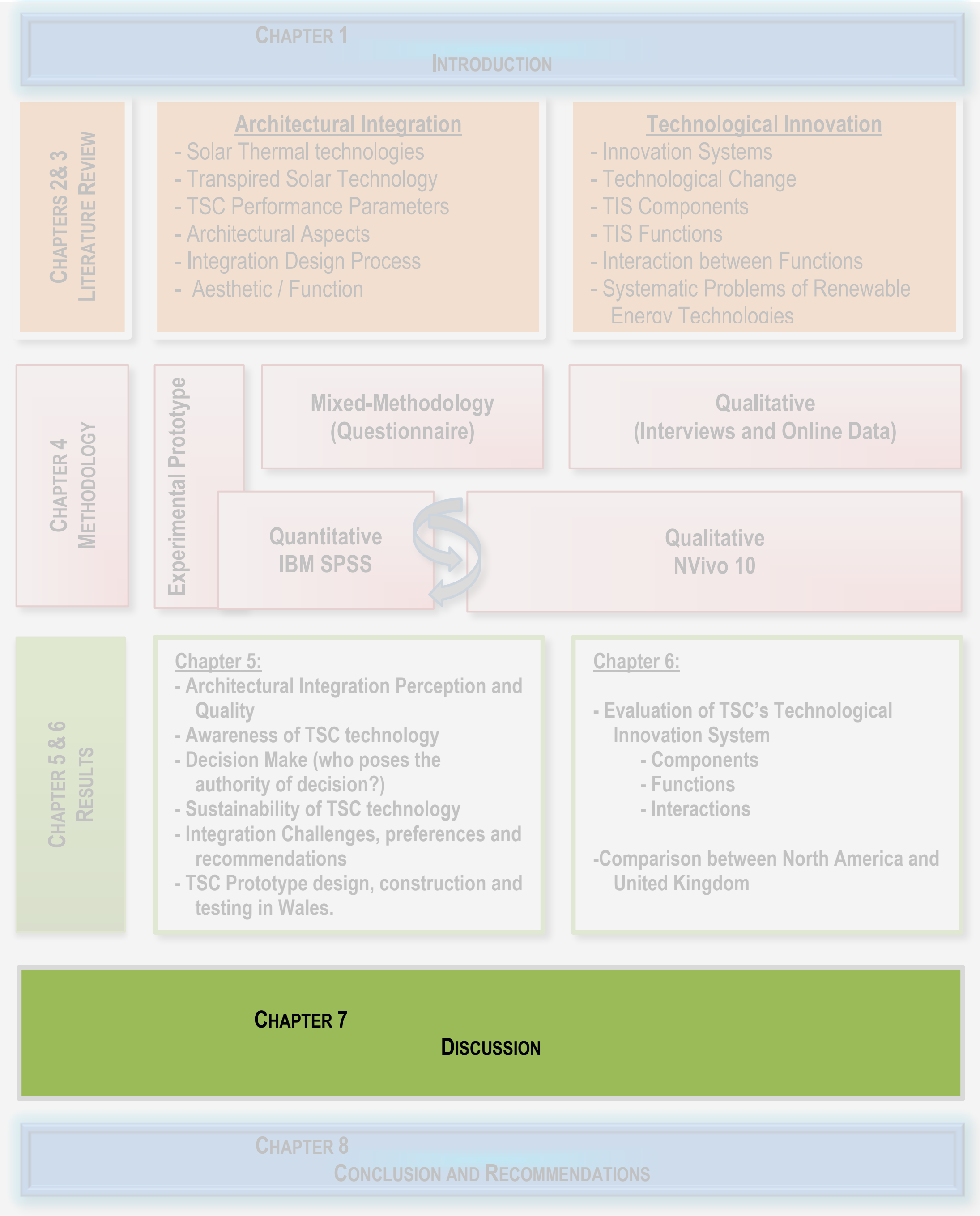
6.7 SUMMARY

This chapter has examined the fulfilment of TIS structural components, functions and the important interactions between these functions. Almost all the TIS functions have been actively fulfilled in North America versus many functions that were potentially fulfilled for TSC technology in the UK. There are several barriers to the TSC growth in the UK which have been identified (chapter 7), however, certain barriers exist in North America as well. The North American region has been considered as a leading successful example of TSC development although a few drawbacks exist (e.g. uncertainty in government support and cautious knowledge exchange). On the other hand, the TSC in the United Kingdom remains at a formative stage.

The comparison of the whole TSC TIS helps to draw lessons in the form of enablers to technological deployment, which could be adopted by UK entrepreneurs, researchers and policy makers to respond faster to address the development of TSC. These will be discussed in chapter 7.

CHAPTER 7 ||

DISCUSSION



7.1 INTRODUCTION

This chapter provides summative discussion of the main findings from analysis in chapters 5 and 6. To show satisfaction of the research aim and objectives (section 1.4), the discussion is structured in sections that represent one or more objectives. It starts with discussing 'awareness' of the technology (section 7.2) that is deemed to be low within the design team and therefore hindering development of the transpired solar collector (TSC). The roles of decision making stakeholders are discussed in section 7.3: the role of the architect is verified as a design facilitator and the integrated design process (IDP) elucidated as a means to produce more consolidated architectural outputs (objective 1.4i). Section 7.4 discusses major terms of architectural integration although some discussion on this topic was included in chapter 5; this is to satisfy investigation of different integration preferences of TSCs and hybrid PV/TSCs (objective 1.4ii).

In response to objective 1.4vii, barriers to integration and knowledge diffusion are discussed in section 7.5. This is followed by section 7.6 which highlights a set of potential enablers to integrating and deploying TSC technology. A set of potential architectural design prerequisites (section 7.7) is briefed to 'identify needs of architects, engineers, and building professionals for improved architectural integration quality and flexibility of solar thermal energy' as stated in objective 1.4iv.

7.2 AWARENESS OF TRANSPIRED SOLAR TECHNOLOGY

Having surveyed design team members and other actors, the existing lack of awareness of TSC technology was examined to verify the hypothesis that lack of awareness is hindering the deployment of the technology in architecture (section 1.2 and objective 1.4i). The rate of overall awareness level of worldwide survey respondents was 51.4% (n=665) including 1.7% (n=22) experts. According to Bird and Sumner (2011), costumer awareness for renewable power in the US was increased from 66% in 2007 to 71% in 2010 versus 38% to 73% for carbon footprint and 23% to 36% for carbon offset in the same years. In UK, 47% UK were reported not aware of air source heat pumps (globalwarmingisreal 2012). Awareness of one or more renewable energy type in Finland for example was 95.2% versus 52.4% appreciate importance of green energy as reported by E. Moula et al. (2013) in their research of social acceptability of renewable energy. These renewable energy types were hydropower, wind, solar biomass, biofuel and geothermal energy sources.

The comparatively high expertise rate of engineers presented in section 5.4.1 was not surprising as they represented mechanical and energy fields. Such engineers are expected to attain comprehensive knowledge of such technologies, especially when they integrate it into buildings; whereas architects would be expected to be interested in general specification and integration schemes, rather than have detailed knowledge about performance and mechanism.

The high awareness of Canadian participants (71.0%) was, to some extent, expected as TSC technology was patented and innovated in Canada. Canada furthermore is the home country of the chief four TSC providers as illustrated in section 2.4.4. The low rate of awareness by American respondents (41.4%) on the other hand, could be attributable to the fact that space heating is less of a requirement in the south-western part of the USA where there is a stronger focus on cooling rather than heating. This was reflected in some respondents’ comments from states in the south-western part of the USA such as Arizona, the eastern part of California, Hawaii, Florida and South Carolina. The participants from those tropical and dry states (Ramirez 2008) were almost 18% of the total USA respondents, with overall awareness of about 30%. Furthermore, the temperate regions where almost 45% respondents reside have warm humid temperate climate unlike the UK mild temperate climate. Nonetheless, participants in a few eastern states with mostly continental climate such as Pennsylvania and New Jersey were found to have a low rate of awareness (below 40%). This could be related to planning guidelines in those states, but this needs further investigation which is beyond the scope of this research. Overall, there was no strong statistical association between climatic regions and the awareness within the USA.

The relatively high awareness among participants working on industrial projects may be related to the fact that most of the existing TSC installations are on industrial buildings. A possible reason for the higher rate of awareness in consultancy is that consultants are often targeted by entrepreneurs and suppliers to market their products. The consultants and designers are therefore the first step on the knowledge diffusion phase of innovation as indicated in sections 5.4.3 and 6.4.2. Academics are continuously exploring new technologies and furthermore, knowledge creation often starts from academic research. Therefore, consultants and academics are usually expected to be up-to-date with innovative building technologies.

It should be recognised that there is a high commitment towards the contribution of solar energy technologies to a sustainable built environment (91.4%) as presented in section 5.4.2. Participants in relevant surveys such as Horvat et al. (2011) and Farkas and Horvat (2012) showed more than 80% support for the importance of solar energy in architectural practices. This high rate of agreement might constitute a bias. It can be presumed that most of the participants have an interest in the survey's subject or they would not participate, as pointed out by Baruch (1999) in section 5.2. Only a few invitees replied to their invitation by stating their inability to participate as the topic was not of their interest. Furthermore, solar energy is of increasing interest to building industry specialists following the establishment of accreditation standards, such as LEED.

7.3 DECISION MAKING

It is deemed fundamental to identify the actors who make the decision to integrate TSC technology. Identifying decision makers corresponds to objective 1.4i. The proper identification would provide direction of the research, development and deployment paths and strategies of the technology. A list of possible decision makers was explored and the actor categories found to have the most significant influence on the decision making process (i.e. client, architect and IDP team) are discussed further below. Further actors remain essential, especially entrepreneurs, policy makers and researchers whose roles were highlighted in chapters 3, 5 and 6.

7.3.1 CLIENT

The client, or the developer, was found to be the principal decision maker for accepting the use of TSCs in a building. The role of the client is decisive, especially when the decision involves cost, budget allocation, aesthetics and energy saving. This feature of the client was apparent from the results in section 5.4.3 (Figs. 7-1 and 7-3). The client as an ultimate decision maker was confirmed earlier by Cole (2008) (section 3.2.2, Fig. 3-3). The client's decision often follows the recommendation of the architect, engineer or project manager (section 5.4.3iii). This finding confirms the literature by BC GBR (2007) and Larsson et al. (2002) in section 3.2.2i in regards to the role of the architect: this is discussed in further detail in section 7.3.2.

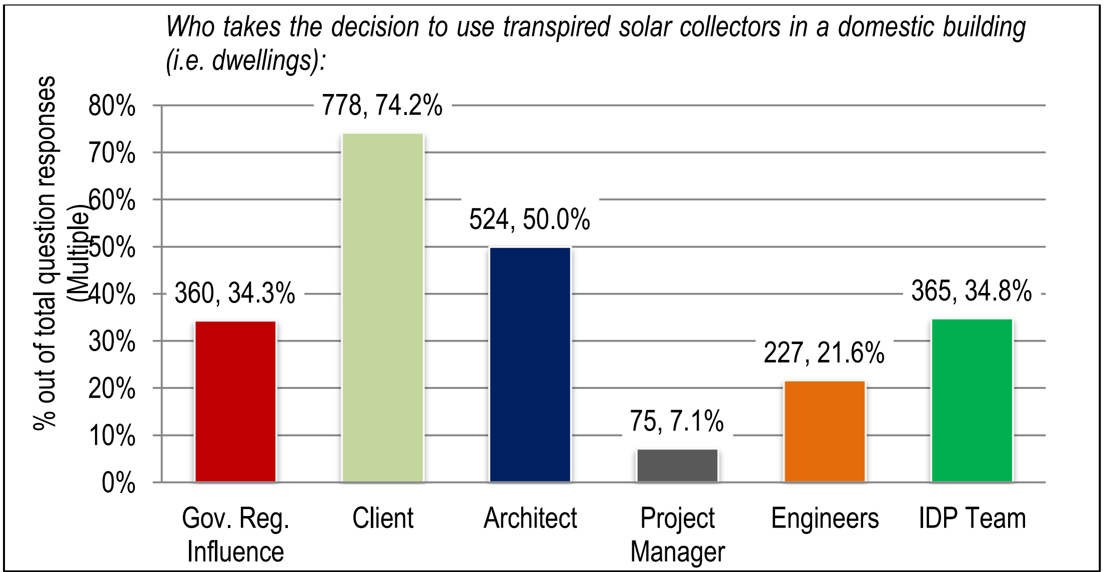


Figure 7-1: Authority of decision to use TSCs in domestic buildings (number of participants, percentage of total responses of a multiple answer question) presented in Fig. 5-12

Acknowledging the significant role of clients in achieving acceptance of new technology, entrepreneurs classified clients into three types (section 6.3.1ii):

1. those who wished to comply with regulations for renewables,

2. those aware of the economic value of TSCs,
3. sustainability stewards.

Working on such classifications might help entrepreneurs to create development plans to meet different motivations.

In the survey of Farkas and Horvat (2012) clients were found to be disinterested in financing solar technologies (section 3.2.2i). This study has further found that clients have several reasons behind this non-interest:

- lack of awareness or familiarity,
- reluctance to include new technology,
- absence of successful and accessible prototypes,
- cost effectiveness.

This will be further discussed as barriers to deployment in section 7.5.

7.3.2 ARCHITECT

The role of the architect is seen as particularly key where they are principally deemed to be design facilitators (section 1.2); this was explored in this study. The architect is usually the first hand facilitator in integrating technologies (Fig. 7-2).

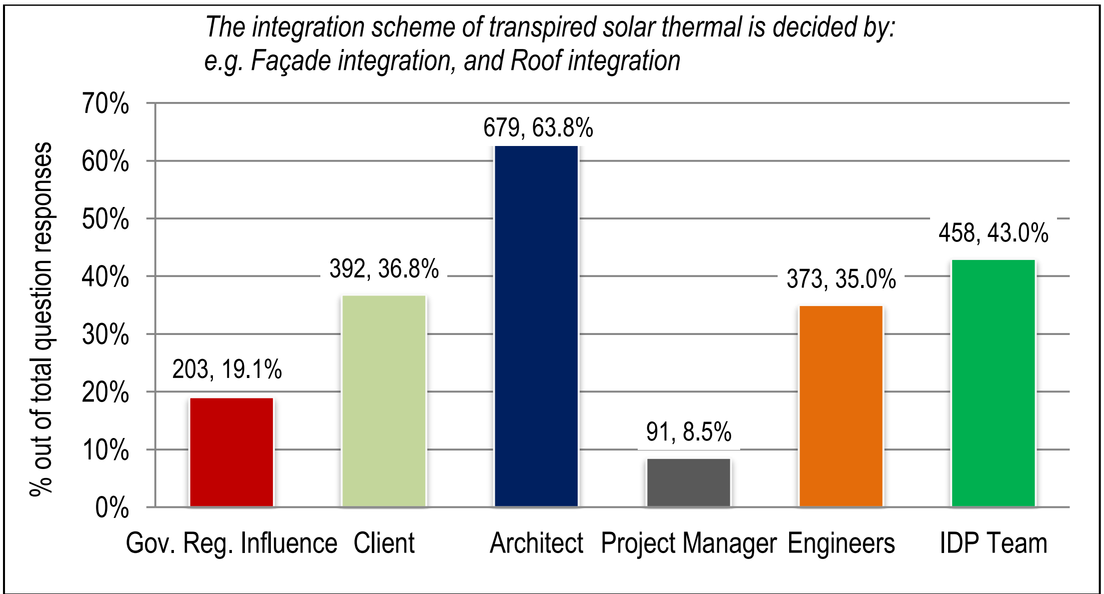


Figure 7-2: The decision maker of transpired solar thermal integration scheme (number of participants, percentage of total responses of a multiple answer question) presented in Fig. 5-15

The architect was also found to be the key decision maker on configurations such as location, orientation, position and size, which have a strong impact on the potential integration of solar technologies generally and TSCs in particular.

The architect is generally responsible for addressing aesthetics in design, multi-functional materials of the building envelope, function of integrated technology, indoor healthy environment, maintenance, and compliance with local authority regulations. This, moreover, confirms the statement of Prowler and Vierra (2008) and Cole (2008) in section 3.2.2 that the realm of the architect extends beyond integrating technological elements to include public acceptance, social influence and environmental context.

Moreover the architect is a design team leader and makes recommendations to the client. In this role, the architect has strong input into the decision making process (section 5.4.3). The architect was previously acknowledged by BC GBR (2007) as entirely responsible for the design concept and often initiates, coordinates, and leads the IDP team (section 3.2.2i).

7.3.3 INTEGRATED DESIGN PROCESS (IDP)

The differences between the conventional design process and the integrated design process (IDP) were explained in section 3.2.2. In particular, the importance of the IDP team in large, complex non-domestic buildings was reflected by the respondents in the results. The IDP team was considered to have more authority than the architect, although less than the client, when deciding to source TSC technology (Fig. 7-3). However, the architect was considered to have more authority than the IDP team in this matter for domestic buildings. The importance of IDP teams in non-domestic over domestic buildings was expected due to the complexity of many non-domestic buildings.

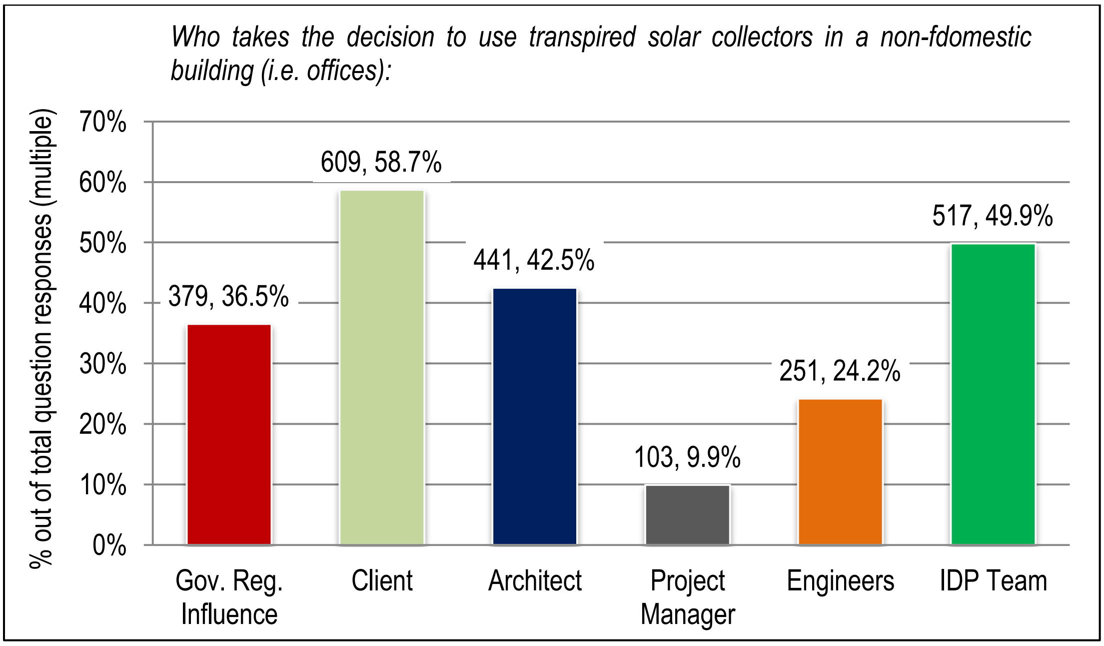


Figure 7-3: Authority of decision to use TSCs in non-domestic buildings (number of participants, percentage of total responses of a more than one answer selection question), presented in Fig. 5-13

The role of the architect in the design process was perceived differently among the respondents in relation to the rules and concept of the IDP process. A similar difference was reported in the survey of Horvat et al. (2011) for larger and more complex over smaller and less complex projects considering solar applications. The participants in Horvat et al. (2011) reportedly favoured consulting a multidisciplinary IDP team over an individual architect.

It became apparent that there is increasing interest in IDP in architectural design and a perception that it encourages better integration schemes for the TSC and other building-integrated renewable technologies. The use of IDP is especially important when there are holistic design objectives (accessibility, aesthetics, cost effectiveness, function, historic preservation, productivity, security and sustainability) noted by Prowler and Vierra (2008) in section 3.2.2. The analysis of IDP in this study corresponds to indirectly elucidating the process which produces more consolidated architectural outputs (objective 1.4ii).

7.4 INTEGRATION OF TSC IN ARCHITECTURE

A conclusion from section 5.6.2ii was that the TSC could be an acceptable technology for integration in both new and refurbished buildings. The following topics are relevant to architectural integration that correspond to the objectives below:

- Investigate different functional and aesthetic integration preferences of TSCs and hybrid PV/TSCs, and find out the preferable optimum architectural integration scheme for architects and end-users (objective 1.4ii).
- Understand the architects' perceptions and recommendations of building-integrated transpired solar thermal technologies (objective 1.4iii).
- Identify the needs of architects, engineers, and building professionals for improved architectural integration quality and flexibility of solar thermal energy (objective 1.4iv), in a form of design prerequisites.

7.4.1 VISUAL PERCEPTION

It was apparent from the analysis and explanations in the results (section 5.5) that there is a general acceptance of TSC integration in building envelopes, particularly for facades. Although the hybrid TSC/PV example of St Marguerit Bourgeoys School was considered almost unacceptable due to the fact that the panels seemed to be additional to the façade, further well-designed integrated examples attained a better rate of acceptance. The roof integrations were not highly favoured by architects in terms of aesthetics and were generally ranked 'neutral'. Albeit comments clarified that 'neutral' was considered as meaning 'just good' for some instances; although that was not its planned meaning in the survey. Therefore, the participants inferred that architects would accept roof integrations as long as the roof was out of sight. This corresponds to aesthetic preferences of integration in the research object being targeted (objective 1.4i).

The examples presented in this study were more advanced than the two previous TSC examples presented to European architects by Probst and Roecker (2011);. one of which was a hangar and the other a gymnasium. Therefore, architectural integration of TSCs in residential and commercial buildings seems promising, especially if the integration fits well with the architectural design concept.

Aesthetics was considered less important than the functional and multi-functional role even by architects; however, it remains an integral part of design integration. The 'invisible incentive' appeared to be a strong driver behind the rating of the examples presented in section 5.5 and the accompanying comments. As an incentive, it leads the acceptance, creation and diffusion of integration development which contributes to the overall acceptance of TSC: the technology that remains undervalued as described in section 3.2.3iii. The support for the 'invisible incentive' was evident in the top rating given to invisible TSC integration in the Ann Arbor Municipal Building (section 5.5.1i) among other examples.

The selection of invisibility versus featured integration of TSCs (section 5.6.3i) was highly influenced by the architectural style that the respondents, especially the architects, would like to follow. This might also indicate the followers of high-tech or post-modern architecture style for instance. The High-tech style emerged in the 1970s as a bridge between modern and post-modern styles of architecture. The High-tech style supports the incorporation of industrial and technological elements into building design as an expressed feature. In the 1980s, the High-tech style became barely distinguished from the post-modern style as many of its ideas were absorbed into the language of the post-modern architectural schools (Hitchcock and Wurster 1937; Jencks 1977; Davies 1988). Although the influence of architectural styles is not within the scope of this study, it could usefully be considered in further studies especially if the aim was to develop various possible methods of integration.

Architects were most likely to oppose the use of dummy panels (section 5.6.3ii). However, dummy panels were incorporated in the Ann Arbor Municipal Building (section 5.5.1i) which had the highest rate of aesthetic acceptance over all the examples presented. This decision is likely to be influenced by the architectural style of design.

7.4.2 POSITION PREFERENCE OF TSC

The introduction of imagery examples helped understanding of the visual perception of architects and other building professionals prior to evaluating their theoretical perception. The roof TSC/PV was the top preference for both domestic and non-domestic buildings in theoretical concept (section 5.6.2i). However, this contradicts the response to imagery examples of TSC/PV roof integration (section 5.5.2ii) which had the lowest ratings of the seven examples being tested. It is possible that the roof installation was preferred due to the invisibility of the installation, especially since roofs are usually out of sight, which was mentioned by many respondents in the results (sections 5.6.4 and 5.6.5). Furthermore, the roof is generally an unused space; therefore, there will be no complication for the façade design which adds to simplicity and flexibility (sections 5.6.1ii and 5.6.1iii) of technology integrations as well as envelope design. Moreover, the roof was considered an option by some participants due to the possibility of achieving an optimum angle of incidence, as mentioned by a consulting engineer from England.

Participant architects, engineers and other building academics and professionals expressed their theoretical preference for the roof integration scheme of hybrid TSC/PV technology for both domestic and non-domestic buildings. Façade integration however, was more acceptable for non-domestic buildings than domestic. Nonetheless, well-designed integration schemes remain which deviate from this rule; as was the case in the Currents Residence example of TSC façade integration (section 5.5.1ii) which was rated by the respondents as the second highest for both aesthetics and multi-function. *"For domestic it would depend on whether we are dealing with multi-residential or family houses ..."* according to a Scottish engineer at National Government with more than 15 years of experience.

The outcomes regarding position preference form a theoretical guidance of architectural design in correspondence to the research objective of investigating preferences of TSCs and hybrid PV/TSCs (objective 1.4i). Overall, there is no conclusive agreement on a common acceptable method of integration. The TSC positioning preferences relate to integration aesthetics which remains the subjective driver behind the evaluation of integration schemes. This confirms the findings of Probst and Roecker (2011) that solar thermal aesthetics are usually perceived as an indefinite and subjective matter (section 3.2.3).

7.4.3 PHASE OF INTEGRATION

As mentioned from the literature, most of the current solar installations in general and TSCs in particular were added later, either late in the design process or once the building was constructed, onto building envelopes. The respondents to the survey of Farkas and Horvat (2012), indicated that Building Added Solar Thermal (BAST) was the most applied active solar energy in architectural integration. This trend was not preferred by architects and building stakeholders (section 3.2.3).

This study further explored this point and found strong support for early integration (i.e. sections 5.4.3ii and 5.6.2iv). TSCs are considered suitable for integrating within the envelope, especially if considered at the early stage of design. Participants have extended this for all renewable energy technologies and sustainable elements considered at the outset of design. Achieving early integration of technology in buildings was found to satisfy design compatibility. The early integration was recommended to take place at the concept design (i.e. sections 5.6.2 and 5.6.3) which corresponds to stage 2 'concept design' in RIBA plan of work (RIBA 2013). An earlier consideration could also take place at RIBA stage 1 'strategic definition' or stage 1 'preparation and brief' when preparing the project role table and assembling teams who have relevant experience in the technology. The consideration might be delayed for a reason, however, key decision should be agreed on before 'technical design', stage 4. This was mentioned by a participant from England with 15 years of experience: *"this ideally should be* *discussed at concept stage as is a potential issue with planning and* [façade] *treatments - key decision should be agreed prior to RIBA Stage E design"* that corresponds to stage 4 in the revised RIBA (2013). The decision of integrating the technology must however take place at any stage before construction, RIBA stage 5. This would be applicable for new builkdings and before the re-construction for refurbished/existing building. The integration and design development is likely to span on the procurement route between RIBA stages 2 'concept design' and 3 'developed design' whereas technical detailing processes occur at stage 4 'technical design'.

Early integration furthermore avoids *"...bolt-on afterthought"* which undermines public perception of building-integrated technologies (section 3.2.3). It *"...saves a lot of construction, design and planning time, if the aim is to integrate the TSCs into the design as opposed to installing it as a separate entity"* as stated by an academic engineer from Canada. The early integration of a technology in buildings was also recommended by (Hestnes 1999), Yudelson (2009) and Horvat et al. (2011) in section 3.2.3ii.

7.4.4 RATING PRIORITY IN RELATION TO RENEWABLE TECHNOLOGIES

Among a list of technologies including solar hot water, ground source heat pump, TSC, PV and hybrid TSC/PV, solar water heating was the preferred technology considered for integration in domestic and non-domestic buildings (section 5.6.1ii and iii). The preference for solar water heating refers to its establishment in residential buildings (Hawkey 2012) if compared to the experience of TSCs and PV. This indicates that further technological development (section 3.3) is needed to help knowledge diffusion of TSC and PV technologies. This study however is concerned with TSC technology, therefore chapter 6 analysed the development TIS of TSC technology.

7.4.5 MAINTENANCE EASE AND CLEANLINESS

Maintaining and Cleaning the cavity could occur through removing the sides of the TSC (they are screwed panels). Furthermore, the collector units come in 600mm-wide sheets fixed to the grid channels; these collector panels can be removed for cleaning and maintenance and then reinstated. The holes however can be washed without panels being removed. Maintenance ease and cleanliness analysed and discussed as a challenge in sections 5.7.2, 5.9.1ii and 7.3.2. It was therefore listed to be further improved in section 7.6.1 and also listed to be further considered in as a design pre-requisite under simplicity and flexibility in section 7.7ii. Furthermore, Maintenance ease and cleanliness are recommended to be considered in the Operation and Maintenance manuals and agreements must be available by manufacturers (section 7.6.2 and 7.6.3).

7.5 BARRIERS TO INTEGRATION, KNOWLEDGE DIFFUSION AND DEPLOYMENT

The barriers were grouped under five categories (Fig. 7-4) and are introduced and discussed below.

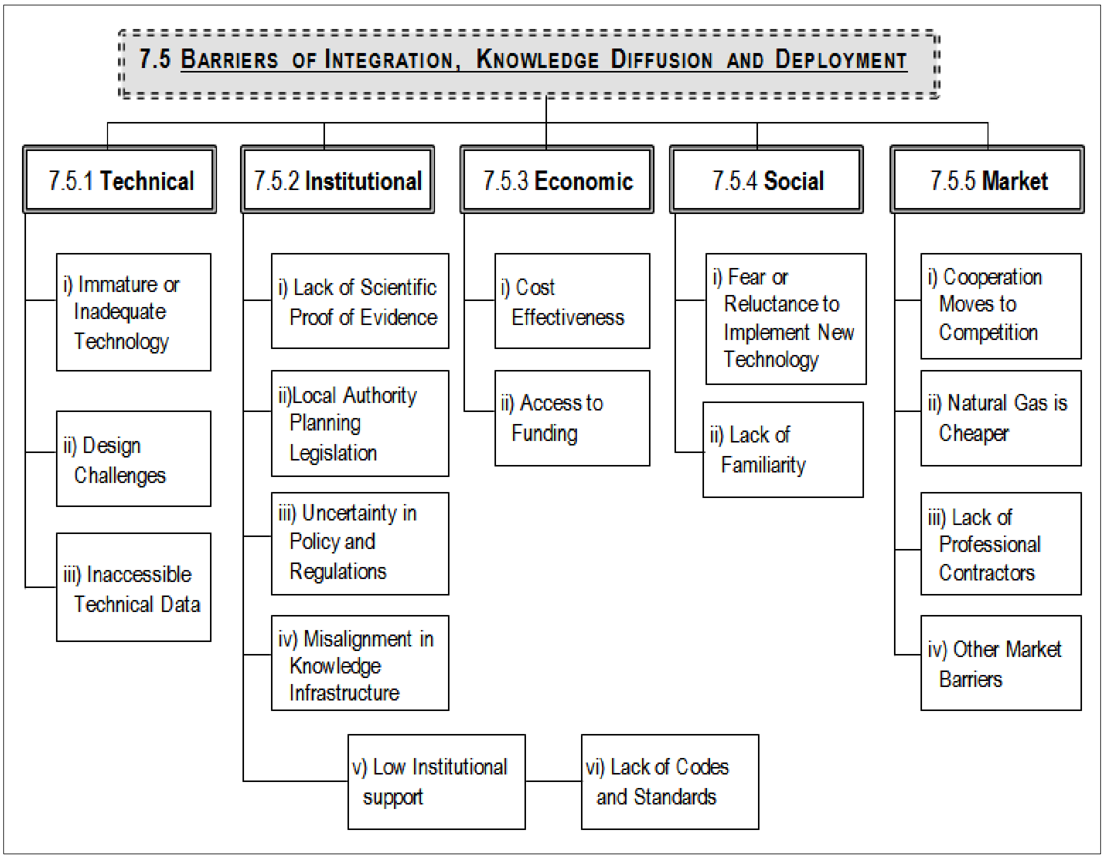


Figure 7-4: The barriers to integrating and deploying TSC technology in building envelopes and marketplace

This study aims to provide insight into architecturally integrating transpired solar thermal technology in buildings; this includes an investigation of the limited adoption of integrating and deploying TSCs (section 1.4). The study is also designed to identify the barriers to integrating TSCs (objective 1.4vii). Information was derived from both the surveyed participants in chapter 5 and the analysed qualitative data in chapter 6 (interviewed entrepreneurs, online related data and survey commentary text).

7.5.1 TECHNICAL BARRIERS

The technical barriers are often related to the status of the TSC technology in terms of development and maturity. These barriers include:

i) IMMATURE OR INADEQUATE TECHNOLOGY

Certain respondents considered the TSC as an immature technology in need of further research and development. Those participants were keen to consider alternative mature technologies instead (section 6.5.1ii). This was also admitted by TSC entrepreneurs who mentioned that TSCs, especially in the UK, need further research and development in order to achieve a competent technology. Further research and development was also confirmed as a requirement by IEA (2012) for almost all solar thermal technologies. The TSC currently needs incentive plans to stand in the market (sections 6.4.2 and 6.4.4). In Canada, the demand for the technology dropped severely following the stoppage of the ecoENERGY incentive plan (section 6.4.5i). Across the USA and Canada, TSC technology is also facing diffusion difficulties in the face of decreased gas prices (section 6.4.7i). Participants in regions with short heating seasons (section 7.2) or those who are less used to mechanical ventilation (section 5.8) consider TSCs as inadequate for their environment. The Canadian entrepreneurs are continuing to develop their products to meet some of these requirements, as evidenced by patents for NightSolar® (SolarWall 2013) (6.4.1i) and two-stage cooling (Hollick 2013) (6.4.2i).

ii) DESIGN CHALLENGES

The TSC has certain design requirements that should be satisfied for appropriate performance; these requirements include orientation, location, shading issues, suitability to heritage buildings, and early consideration in the design stage to avoid poor application. Most of these requirements were highlighted in sections 2.4.5, 3.2.4, 5.5 and 5.6. These requirements were considered as challenges within a multi-faceted design process by survey respondents. For example, TSC was seen as competing with daylight by blocking the elevation. The challenges would increase when designing in cities and towns as ensuring free shadowing in future is not an easy task. Installations may be ineffective in the future if new buildings caused shading.

iii) INACCESSIBLE TECHNICAL DATA

The absence of technical data affects knowledge diffusion and decreases the chance of deploying and improving TSC technology. Architects and designers were keen to access technical data (section 5.9.3) for consideration in design; otherwise, the TSC is excluded as an option. Manufacturers' reports were not considered to contain trustworthy technical data (section 6.4.3) as they were seen by designers and engineers as pushing towards increasing sales (section 5.9.1iii). Entrepreneurs nonetheless were reluctant to release the bulk of their technical data due to market competition and IPP issues (sections 6.3.3 and 6.4.3).

7.5.2 INSTITUTIONAL BARRIERS

Here institutions refer to organisational rules, regulations and information (section 3.3.3ii). The following institutional barriers were found to be the strongest hindrance to TSC knowledge diffusion and deployment:

i) LACK OF INDEPENDENT SCIENTIFIC PROOF OF EVIDENCE

End-users, architects and other stakeholders were found to mistrust the manufacturers (section 5.9.1iii). Therefore, there was strong demand for independent scientific proof based on real projects (section 5.7.1). This proof is needed to confirm manufacturers' claims in terms of CO_2 reduction, energy saving, reliability, and suitability of the technology for the purpose of space heating. The need for independent proof and successful demonstration projects was further admitted by entrepreneurs (sections 6.4.3 and 6.4.4). The end-users usually trusted academic research as independent knowledge (section 6.4.7i). The experimental prototype of this study (section 5.10) was therefore conducted to provide preliminary independent evidence that would be accessible by researchers and design stakeholders.

ii) LOCAL AUTHORITY PLANNING LEGISLATION

The local authority was found to have a significant role in diffusing, deploying and integrating TSC and solar thermal technologies (section 5.4.3). The role of the local authority was debated in regards to integrating TSCs with traditional buildings (section 5.6.2iii). Certain respondents were keen to follow local authority rules, while others sought further amendments to the current rules in order to open the doors for renewable energy integration in building envelopes. A third group of respondents were relying on the architect to accept the challenge and to traverse authority rules to avoid further delays in amending local authority rules. Similar findings were reported by Lundgren et al. (2004) in their study of PV in the Nordic countries and in the Netherlands. Nonetheless, the participants in this study were from varied regions in the world and argued that change is required at government or designer level.

iii) UNCERTAINTY IN POLICY AND REGULATIONS

Policy and regulations can be significant drivers to knowledge diffusion (section 7.5.2ii), but only if the regulations support the technology consistently. In Canada, TSC technology suffered a setback when it was no longer included in government incentive plans (section 6.4.5i). In the UK, inclusion of TSCs in Green Deal instead of the Renewable Heat Incentive programme was also considered a setback (section 6.3.2ii). Similar 'stop and go' policies have been applied to renewable energy technologies in many countries since 1981 (Negro et al. 2012a) (section 3.3.6iia).

This uncertainty affects the users' confidence in the technology. According to Parkes (2012), uncertainty is the most significant hurdle towards development especially after establishing momentum in the right direction. That uncertainty is a barrier, especially for renewable energy and new technologies, was reported by several researchers including Vasseur et al. (2013), Leete et al. (2013), Foxon and Pearson (2007) and Painuly (2001) (section 7.5.4i).

iv) MISALIGNMENT IN KNOWLEDGE INFRASTRUCTURE

There is fundamental research being conducted in universities, nonetheless, there is a gap of knowledge between academia and practice (section 6.4.2ii). This gap has previously been reported by Negro et al. (2012a) in relation to renewable technologies generally . This gap includes:

- The inability of translating good research findings into industrial products.
- Differentiation between strategic directions in industrial and academic research. This was reported by Interviewee 1 and confirms the findings of Foxon et al. (2005) who mentioned that *"lack of strategic directions in research fails to increase the cooperation between universities and industry".*

This gap is not universal however; the industrial-academic relationship for TSCs in the UK seems promising. These ties apply activities of 'learning by doing' (i.e. SBED project) and 'learning by researching' (i.e. SBEC). That inspires researchers to develop further TSC research and gives confidence to legislators to support the technology (section 6.4.1ii).

v) LOW INSTITUTIONAL SUPPORT

New technologies often need support to establish their position in the market (section 3.3.3iii). Government support was therefore highlighted as helping the adoption and deployment of TSCs (section 6.4.4i). It was further stressed by UK participants as essential at the current stage (section 6.4.5ii). North American entrepreneurs regarded their governments as not seriously supporting TSC technology due to lack of research funding and effective incentive plans (section 6.4.6i).

The inclusion of TSCs in the Green Deal indicates some support from the UK government (section 6.4.6ii). This inclusion might indicate that policy makers have a degree of confidence in the technology, however stronger support is advocated by UK entrepreneurs (section 6.3.2ii). Government associations expect further evidence of performance (section 7.5.2i) in order to include TSCs in the government incentive plan. Therefore, the level of support is not necessarily a sole obligation of government, rather there is a responsibility on actors such as entrepreneurs and researchers to provide appropriate evidence. Regardless of the reasons, low government support was found to be a hard institutional barrier (section 3.3.6iia). This issue has also been experienced by the marine energy sector in the UK (Leete et al. 2013).

vi) LACK OF CODES AND STANDARDS

Regulatory codes (i.e. building planning and market trading) have helped diffusion in North America to a certain degree (section 6.3.2i); however, there remain no specific codes to encourage building integration of renewable energy in general or TSCs in particular. Similarly in the UK, the absence of codes and standards supporting renewable energy (sections 6.3.2ii and 6.5.2) discourages knowledge creation and further development of TSC technology. This barrier was reported by Painuly (2001) as a *"lack of regulatory framework"* which leads to a volatile market.

7.5.3 ECONOMIC BARRIERS

The economics of integrating the technology is significant when considering energy saving, security and affordability. Therefore, participants frequently link cost issues to their responses (sections 5.4.1, 5.6.1 and 6.3.1). There are several economic barriers which sometimes differ from clients, to policy makers, to entrepreneurs, according to their specific interest in TSC technology. Three of the most common concerns hindering research, development and deployment of TSCs are described below:

i) COST EFFECTIVENESS

TSC manufacturers and a few relevant researchers have contended the technology is affordable in cost (McLaren et al. 1998; Resouce Smart Business 2007; Hall et al. 2011) (sections 2.3 and 2.4). The participants in this study had a general perception that all solar technologies are costly, which adversely reflected on TSCs (5.6.1 and 5.7.2). This perception could be based on old data relating to high capital cost of solar thermal absorbers in the 1970s (Kulkarni 1994, cited in Qu et al. 2010) (section 2.3.2iii). Another possibility is that the participants were influenced by the high capital cost of PV panels (Kok 2009) (section 2.3.2iv).

Adding to the cost effectiveness concerns, the economic depression in 2008 found to have a probable impact on the diffusion of TSC as highlighted out by a few of the participants including an architect England and another from Scotland which was supported by architects from the USA.

Although TSC technology is proposed by TSC entrepreneurs as an option to reduce the ROI timeframe (section 2.4.3), this knowledge does not appear to be well-diffused to the relevant actors. However, in North America the benefit of ROI is decreasing with the removal of incentive plans (section 7.5.2) and cheaper natural gas sources (section 6.4.5i). Classifying cost effectiveness as a barrier confirms Painuly (2001) who listed barriers to renewable technologies as *“economically not available”* and *“high cost of capital”*.

ii) ACCESS TO DEVELOPMENT FUNDING

Another challenge towards development is the access to institutional funding for research and development. Although the North American entrepreneurs were keeping their R&D in-house (section 6.4.6i), they acknowledged that institutional funding is a necessity for breakthrough in developing and deploying TSCs in the market. In spite of the potential availability of funding (section 6.4.6ii), UK research on TSC technology needs further financial support due to its emerging status in the marketplace. The ‘access to finance’ was reported as a challenging barrier towards the development of renewable technologies by Parkes (2012). Furthermore, researchers in renewable energy such as Painuly (2001) highlighted the lack of access to capital, Foxon et al. (2005) described the crucial need for *“both targeted and flexible support for R&D”* for UK renewable technologies, and Leete et al. (2013) discussed the need of financial support mechanisms in the UK to seize the opportunity of developing and deploying marine renewable energy.

A further challenge is ‘high investment requirements’ in TSCs which confirms Painuly’s (2001) findings that *“high up-front capital costs for investors”* is a barrier of renewable development. The high investment versus the stated limited affordability capabilities of entrepreneurs encouraged the collaboration of supply chain actors (sections 6.4.1ii and 6.4.2ii) and academia in the UK (section 6.3.3ii) unlike the North American situation where the entrepreneurs are carrying out R&D in-house (section 6.4.6i).

7.5.4 SOCIAL BARRIERS

The deployment and diffusion of TSC technology (similar to any product) is conditional on a successful relationship with humans in society. This category includes barriers that relate to social acceptance of the technology. Acceptance here refers to regarding the available TSC technology as suitable or adequate for use and adoption. The consumers, end-users, legislators and designers, generally accepted the technical and aesthetic quality of the current TSC (section 5.9.1ii) but were hesitant to recommend using it in buildings (sections 5.6.1ii and 5.6.1iii). Participants were mostly influenced by existing applications. This influence has a basis of support in the literature (section 3.2.3) and in the questionnaire results (section 5.6.2iv). In addition to awareness level (section 7.2) and consumer acceptance, there are various factors behind this low acceptance. These are described below:

i) FEAR OR RELUCTANCE TO IMPLEMENT NEW TECHNOLOGY

It is apparent that the decision to select a technology is related to previous experience (sections 5.6.1ii and 6.4.4ii). This issue was highlighted in the literature review as a barrier to the diffusion of new technology versus incumbent technologies (section 3.3.5). People often regard their successful experience as the basis for future actions. Those people can repeat similar actions in a similar context with ease and simplicity; although this might lead to routine activities that lack challenge, especially in architectural integration of TSC. The design challenge was arguably regarded as a drawback (section 7.5.1ii) whereas others regarded it as encouragement to improved design (section 7.5.2ii).

The fear of new technology increases in absence of independent reports (section 7.5.2i) that imprints the perception of technological immaturity (section 7.5.1i) in spite of the fact that TSC was reported as a proven technology by researchers such as McLaren et al. (1998) and Hall et al. (2011) (section 2.4.1) and as claimed by manufacturers (section 2.4.4).

ii) LACK OF FAMILIARITY

The lack of appropriate knowledge (sections 5.9.3, 6.4.3, 7.5.1ii and 7.5.2i) and knowledge exchange (sections 5.9.1 and 6.4.4) leads to unfamiliarity in TSCs by clients and/or the design team. Familiarity must exceed basic awareness (section 7.5.2) and must include a degree of either theoretical or practical knowledge on TSC mechanism, performance, design requirements and proven examples. This was apparent from the high response rates of awareness in TSCs (section 5.4.1) versus the low rates of familiarity and further development needs (section 5.9.1). The low rate of familiarity was furthermore reported by entrepreneurs as 'little market awareness' by government and other TIS actors (section 6. 4.3ii).

For example, the percentage of awareness within the UK for the local based Colorcoat Renew product (24.7%, n=37 in section 5.9.1i) is rather low. This low awareness might be due to the recent launch, year 2012, of

Colorcoat Renew® in comparison to the SolarWall® in Canada and the USA that was launched in the 1980s (section 2.4.1).

7.5.5 MARKET BARRIERS

Several barriers were found to hinder the development of TSCs in the marketplace. The following discussion includes the most significant of these barriers:

i) COOPERATION MOVES TO COMPETITION

The major barrier was the apparent 'cooperation moves to competition' between entrepreneurs which hinders the cooperation between TSC actors (section 6.3.3i). It is a difficult situation since entrepreneurs are always looking for an innovative edge to gain market recognition. Conversely, 'lack of competition' was listed as a barrier by Painuly (2001) for other renewables whereas Negro et al. (2012a) mentioned that competition at an early stage increases the challenges of establishing a niche market (section 3.3.6iv).

ii) NATURAL GAS IS CHEAPER

The second barrier that limits the deployment of TSC is the cheap prices and infrastructure of gas for indoor heating. This was an issue in Canada and the USA (section 6.4.5i) but not for the UK. Even without a significant reduction in gas costs, the barrier, "*favour to conventional energy*", was reported by Painuly (2001) under market distortions for other renewable technologies and by Klein Woolthuis (2010) for the Dutch construction industry (section 3.3.6ia). Although this might relate to the familiarity of incumbent technologies, the lower gas process hinders development of TSC technology.

iii) LACK OF PROFESSIONAL CONTRACTORS

Severe shortage was noticed of the professional contractors who could be expert in installing and maintaining TSCs. The supply chain in the UK remains fragmented where there is no sole contractor who can take responsibility of offering the whole package of TSCs in buildings (section 6.4.5ii). This moreover adds to a problem of accountability and liability (guarantees and warranties). The more disciplines involved in the design and installation, the less control over the construction and performance of the technology. The lack of an 'overall' professional was classified as a barrier hindering the development of other renewable technologies by Painuly (2001) and as a technical barrier by Foxon et al. (2005) for several renewables in the UK and by Leete et al. (2013) for marine energy in the UK.

iv) OTHER MARKET BARRIERS

Further minor barriers include technology push from sellers who target increased sales regardless of the suitability of the technology for the purpose (section 5.9.1iii), intellectual protection (IP) (section 7.5.1iii), highly controlled energy sector, lock-in (section 3.3.6iii), restricted access to technology and technology security and affordability (section 5.6.1ii). Similar barriers were also found for other renewable energy technologies as mentioned by Painuly (2001), Foxon et al. (2005), Klein Woolthuis (2010) and Negro et al. (2012a) (sections 3.3.6iv and 3.3.6v).

7.6 ENABLERS TO KNOWLEDGE DIFFUSION AND DEPLOYMENT

Having established the barriers, the next stage is to propose a set of potential enablers to assist in knowledge exchange and deployment of TSCs in the UK, and achieve consumers' satisfaction and acceptance. This meets objective 1.4vii '...highlight potential enablers to integrating and deploying TSCs technology for researchers, entrepreneurs and policy makers to consider for further improvement and technological development'. Those enablers would remain applicable to other geographic areas and renewable energy technologies. As there are numerous possible enablers (Appendix G), a few key potential enablers have been discussed for each barrier category previously identified (section 7.5).

7.6.1 INCREMENTAL IMPROVEMENTS (TECHNICAL AND ENTREPRENEURIAL ENABLER)

The continuous technical improvement of TSC is evidenced by recent patents such as two-stage heating and cooling and NightSolar (section 6.4.1i and 6.4.2i). Nonetheless, the requirement for further technical development is admitted by entrepreneurs in North America and the UK in order to improve the performance of TSCs for space heating in terms of carbon reduction, output cost, and payback. New dimensions of development seem necessary, either by new entrepreneurs or by incumbent firms, to expand the available renewable technology options. These are better developed through actors' collaboration and knowledge exchange than through this study. Collaboration is particularly important in a sector such as this which requires multi-discipline input of skills including from academia and the supply chain. This in turn would guide the appropriate research direction and speed up the development process.

Existing technical barriers (section 7.5.1) could be overcome by further improvement in aspects including performance, suitability for dwellings, maintenance ease (section 5.9.1ii) and compact and effective thermal storage of the excess heat. Developments could also ease the duties of designers and supply chain (i.e. pre-engineered modules in section 6.4.2ii). The development should take place in line with consumer feedback (section 6.4.7) and regulatory codes and standards (sections 6.3.2i and 7.6.3v).

7.6.2 INFORMATION AND AWARENESS CAMPAIGNS (SOCIAL AND INSTITUTIONAL ENABLER)

There is a need for further knowledge creation and diffusion (section 5.9.3); however, this information is better received from independent parties such as the government, academia or not-for-profit firms. The need for further knowledge diffusion was acknowledged by entrepreneurs in North America and the UK (section 6.4.3). Information and awareness campaigns were also recommended for other renewable technologies by Coenen and Díaz López (2010) and Painuly (2001). These campaigns would be conducted through conferences, exhibitions, and workshops (Hekkert et al. 2007; Hekkert and Negro 2009) as described in sections 3.3.4iii and 6.4.3i.

7.6.3 SKILLED STAFF (ENTREPRENEURIAL AND INSTITUTIONAL ENABLER)

The awareness campaigns (section 7.6.2) have to include training and education for potential end-users, designer architects and engineers, researchers and supply chain. Philibert (2006) stressed the need for outreach and training programmes to raise awareness of solar thermal technologies. A few education courses are available (section 6.4.3), however, further specialised and intensive training programmes remain needed (sections 5.4.3iii and 5.9.3).

Although the interviewed entrepreneurs did not mention shortage in skilled professionals, CPD training sessions for relevant professionals would be advantageous for development of TSC. The type of training required was not specified in the gathered data and may be difficult to implement, given the cautious manner of treating information which has developed in North America (section 6.4.1i). Further to discussion in section 7.5.5iii, lack of skilled staff was reported by Klein Woolthuis et al. (2005) for SMEs and by Negro et al. (2012b) in the Dutch PV innovation system (section 3.3.6ivd).

7.6.4 GOVERNMENT SUPPORT (INSTITUTIONAL ENABLER)

Government support is essential in the UK (section 7.5.2v) especially since the technology remains at an emerging stage. The federal tax incentive in the USA is continuing to help TSC development there. The ecoENERGY subsidy helped development in Canada until TSC was considered to have reached the status of a mature technology and government support was dropped (section 6.4.5i) and a possibility of political persuasion as discussed in 7.5.2iii. Therefore, subsidy and incentive plans would be recommended for deployment of TSC technology as long as other factors are satisfied in terms of consumer acceptance and policy makers' satisfaction with the technology (section 7.5.2i). Government incentives were recommended by Philibert (2006) as a policy to overcome barriers of deploying solar thermal technology, and by (Painuly 2001) as a measure to overcome the barrier of deploying renewable energies.

Other than the government, other institutional support is recommended such as non-government organisations. Further support through investment by institutions seems worthy especially in R&D which is beyond the capabilities and resources of the current entrepreneurs (section 6.4.6). Institutional investment would increase the interest in developing an appropriate technology that satisfies local needs for space heating. Institutional investment in renewable technologies was also suggested by Gallagher et al. (2012).

7.6.5 NEW CODES AND STANDARDS (INSTITUTIONAL ENABLER)

Further to financial support, policy makers should identify and introduce appropriate codes and standards (section 5.6.2iii and 7.5.2ii) that permit, as necessary, the development of renewable technologies such as TSC. For example, the current building regulations for the ventilation code, document F (HM Government 2010) defines ventilation as the inducement of fresh outdoor air to replace stale indoor air, with no particular identification to a minimum quality or amount of such fresh outdoor air. Therefore, it is important to identify adequate levels of fresh outside air requirements and quality through mechanical ventilation, especially for domestic buildings to avoid ‘sick building syndrome’ (section 6.4.4i). This would include the updating of codes that currently discourage TSC integration. The need for updated codes was also recommended by Philibert (2006) for solar thermal technologies.

Further codes could protect the potential solar installations from future blockage to receive direct solar radiation. This would be similar to the solar rights Act by the State of California launched in 1978 where the laws protect homeowners’ access to the sun for their installed solar applications from blockage by neighbours (Go solar California n.d).

A dialogue is needed between local authority planners and local architects to overcome any barrier that affects the beneficial deployment of TSC technology in buildings (section 7.5.2ii). This dialogue seemed

"...difficult to achieve..." as stated by an architect from local government in Wales, however, efforts to implement such a positive dialogue remains essential.

7.6.6 RESEARCH AND DEVELOPMENT (INSTITUTIONAL ENABLER)

"Just a few years ago we were told it was impossible for green power to replace aging nuclear stations.... Today, however, it's clear we can" (Weis et al. 2010). Therefore, current drawbacks of TSC technology or its integration in buildings could be resolved in the future with enough effort. There is a strong demand to define the appropriate path of research that reduces the gap between universities and industry in order to speed up the correct development process of technology (7.5.2iii and 7.6.1). Research and development was recommended by Painuly (2001) as a measure to overcome barriers affecting the development of renewable energy technologies.

7.6.7 DEMONSTRATION PROJECTS (ENTREPRENEURIAL ENABLER)

Attractive, successful and accessible prototypes would increase the acceptance of the technology; *"nothing convinces like success* [in a] *... demonstration project..."* according to an academic architect from Montreal who had over 15 years' experience. There is an increasing demand for successful prototype and business case examples (sections 5.7.1, 5.9.3 and 6.3.3ii). However, participants considered demonstration by manufacturers as a bias. For this reason, projects such as SBED and SBEC in the UK (section 6.4.21ii), and the TSCs installed in the National Renewable Energy (NREL) building in the USA (section6.4.3i) would be appropriate examples, especially if these projects and their data are accessible. The experimental prototype in this study would also play a role of knowledge diffusion when the outcomes of this research are made available and also when the TSCs units are accessed by Cardiff University students. Support of research, development and demonstration was recommended by Philibert (2006) as a policy to overcome the barrier to developing solar thermal technologies.

7.7 ARCHITECTURAL DESIGN PREREQUISITES

Architects and designers were often targeted by entrepreneurs and potential legislators to help knowledge diffusion and deployment of TSC technology (chapters 5 and 6). They were also confirmed as the key design facilitator in integrating TSCs in buildings (section 7.3.2). However, architects lack guidelines to deploy and architecturally integrate TSCs or to exchange knowledge with clients. Available design guidelines (section 3.2.4) are prominently technical as they relate to operational sides of the technology, nevertheless, the available guidelines remain limited. The proposal of a defined set of architectural directions specific to TSC integration in buildings would help the uptake of the technology. It would also ensure that future TSC integration would be socially and technically satisfactory in terms of aesthetics and multi-function. Therefore, a comprehensive list of design directions would benefit designers considering integrating TSC technology in a building's design and moreover ease the designers' mission. Identifying design prerequisites would also benefit entrepreneurs, researchers and policy makers to participate with necessary development towards encouraging better design requirements. The following recommendations were drawn directly from the findings, or interpreted from the data presented throughout this study, as design prerequisites to assist forming a comprehensive list of architectural design directions.

i) EARLY PHASE INTEGRATION

The early integration of TSC technology in the architectural design is recommended and has multi-faced benefits (chapter 5 and section 7.5.3), that include:

- The provision of a well-studied integration scheme and avoidance of 'bolt-on' applications of the technology which often occur at a later stage (section 5.6.1i).
- TSC integration is compatible with the concept of the building design (sections 5.6.2i and 5.6.3i).

- It is possible to achieve appropriate orientation and positioning to gain the maximum possible solar irradiation.

The early integration of solar energy was confirmed as significantly important by Horvat et al. (2011) (section 3.2.2ii). Therefore, it is recommended to start consideration (stage 2 in RIBA work plan) of TSC and any other technology at the concept design stage.

a. SIMPLICITY AND FLEXIBILITY

In spite of its claimed operational simplicity (section 2.3.2iib), respondents stressed the importance of simple and flexible technology. Simplicity and flexibility of TSCs (sections 5.6.1ii and 5.6.1iii) were found to enhance confidence in design and reduce fear of implementing new technologies (section 7.5.4i). The simplicity includes ease of integration in buildings in order to reduce possible damage during installation and maintenance, especially for existing buildings. It, moreover, includes operation and use. The flexibility includes various design options and modularity. Entrepreneurs in the UK are working to develop pre-engineered designs (section 6.4.2ii) to improve TSC simplicity and flexibility, particularly for architectural design.

ii) PASSIVE DESIGN IN PRIORITY

Mechanical space heating is certainly required for countries with long heating seasons including the UK, Canada, mainland Europe and several American states. However, passive design techniques (i.e. insulation), should be given first priority in design (section 5.9.1ii). The satisfaction of successful passive techniques further reduces mechanical heating requirements; which in turn saves more energy, reduces the required envelope area and increases affordability. The combination of passive features and TSC technology for space heating was studied by researchers such as Hestnes (1996) and Clesle (2010) under ‘Solar Architecture’ (section3.2.3).

iii) AVOID SHADOWING THE BUILDING

Shading to the TSC constitutes a potential barrier to the design and integration of TSCs in buildings. This was noted for the Currents Residences (section 5.5.1ii) and Turner Fenton School (section 5.5.2ii) and discussed in section 7.5.1ii. The same was recommended by Lisell et al. (2009) (section 3.2.4) as a design guideline. It was followed as a design guideline in this study when locating the TSC prototype units (section 5.10.1). Therefore, the allocation of TSC in the design should avoid current and (where possible) future shadowing to the technology in order to achieve the calculated performance. Future protection is preferably to be supported by bylaws as discussed in section 7.6.5.

iv) DESIGN ASSISTED TOOLS

A few software programmes simulate the performance of TSC; RETScreen, SBET and TRNSYS (sections 6.4.1i and 6.4.6ii). Architects and designers are not familiar with these softwares, which is a key challenge to the development of TSC. RETScreen was reportedly used in the conceptual phase by 17% of respondents in Horvat et al. (2011) with a convincing level of satisfaction. The available software programmes remain, however, not validated as accurate tools for modeling TSC. In particular RETScreen has been critised by some entrepreneurs as not accurate.

v) LOCAL AIR QUALITY

Derived from the needs to provide fresh air into indoor spaces in order to avoid ‘sick building syndrome’, the air outside the TSCs must be clean. Positioning TSCs adjacent to car parking, for example, would draw exhaust fumes into the indoor environment (Brown 2009),similar situations would be next to main streets, congested suburban areas and industrial facilities. Therefore a different arrangement is necessary; that might include re-positioning TSCs or inducing an appropriate air filtering technology.

vi) LOCATION AND OTHER CONSIDERATIONS

Consideration should be given to building type and function in terms of previous successful TSC installations. Although this would favour warehouse and industrial buildings (Brown 2009) due to prominent installations, while more integration examples on residential and other building types are required (section 7.6.7). Site characteristics also play an important role in relation to the available solar radiation, neighbourhood, and requirements of authority regulations. All these factors would affect the design of TSCs in terms of orientation, TSC size versus available space in the appropriately oriented façade. Moreover, further attention has to be given to the integration harmony of solar technology in accordance to the city design guidelines, especially relating to traditional architecture.

7.8 SUMMARY

Many barriers that hinder the research, development and/or deployment of TSCs were, directly or indirectly, perceived and communicated. These barriers were combined from the architectural integration survey data in chapter 5 and TSC TIS data analysis in chapter 6. The most substantial barriers were discussed in this chapter and where appropriate, comparisons were drawn with related studies. Many of the barriers that hinder TSCs were found to be common with other renewable technologies such as water heating, wind energy, PV and marine energy.

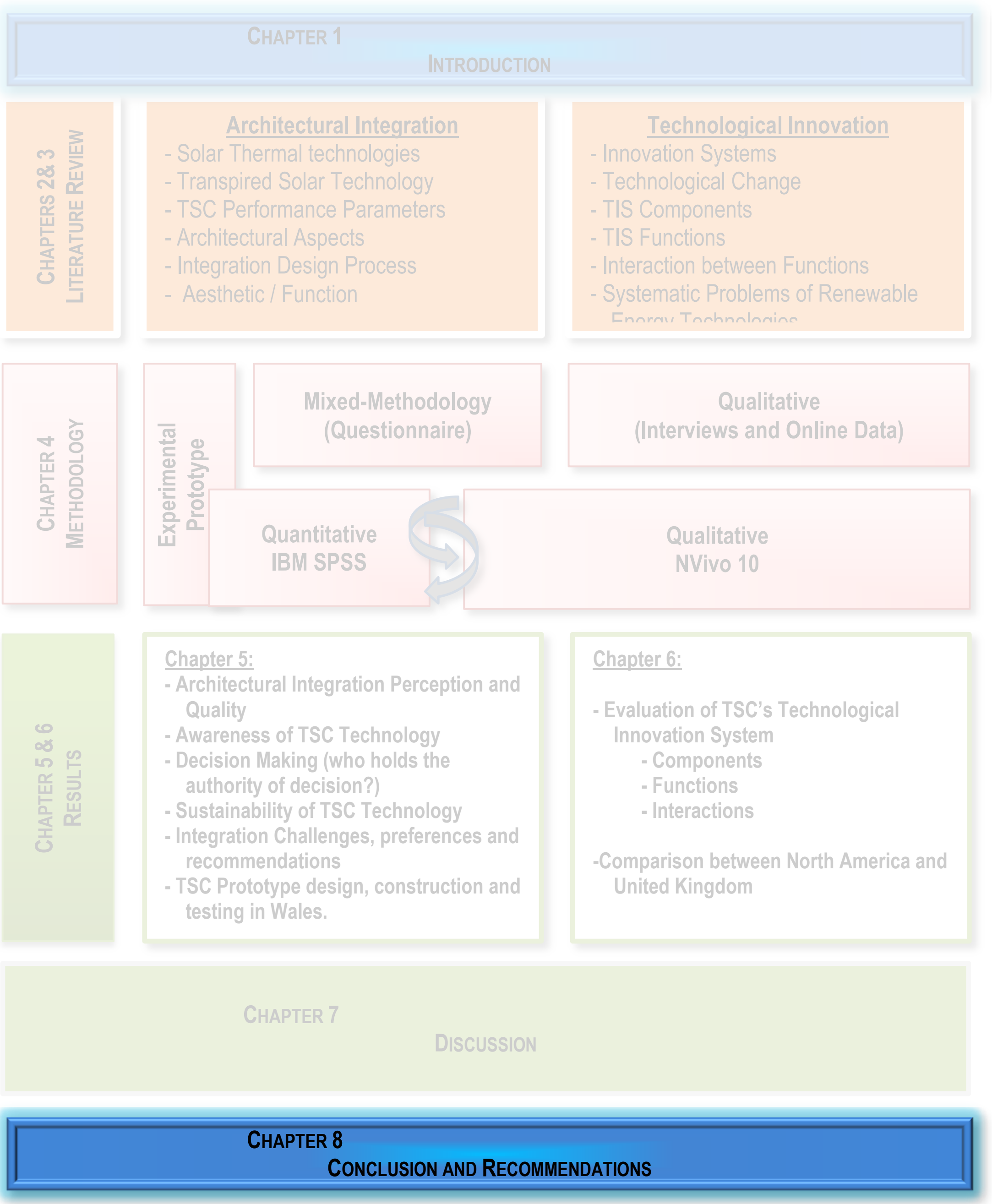
A potential set of enablers (section 7.6) were suggested based on recommendations by participants in this study, or researchers from relevant studies, or were derived by the author based on the needs identified (section 7.5). Evaluating and comparing the TSC TIS in the UK with North America (objective 1.4vi) has helped to identify examples which could be encompassed in the enablers adding confidence to their effectiveness. This has addressed objective 1.4viii 'investigate the contribution of the technological innovation system to the development, diffusion and utilisation of TSC'. Albeit some lessons were encompassed in barriers (i.e. sections

7.5.2iii, 7.5.2vi, 7.5.5i), others were apparent in the enablers; (i.e. sections 7.6.1, 7.6.4, 7.6.7).

A set of architectural design prerequisites was included as it was perceived to meet the requirements of architects and designers who need to understand the parameters of TSC integration.

CHAPTER 8 ||

CONCLUSION AND RECOMMENDATIONS



8.1 OVERVIEW

This chapter comprises the conclusion of the research. Following this brief overview it highlights the main research motivation (section 8.2) in the light of the research aim and objectives identified in section 1.4. It outlines the results from chapters 5 and 6 along with the discussion in chapter 7. Limitations of the research, as approached and experienced, are identified (section 8.3). The main research findings are identified (section 8.4). Section 8.5 comprises recommendations for future research works as identified from the findings. Section 8.6 provides the closing remarks to this study.

The aim and objectives of this thesis were fulfilled through the research design and methodology. The results and discussion provided insight into architecturally integrating and deploying transpired solar thermal technology in buildings in selective regions with long heating seasons, including the UK, Canada, USA and mainland Europe. Potential contributions of the TSC to pre-heating ambient temperature of the technology were clarified through an experimental prototype project in Wales. Further insight into limitations of deployment was afforded by a comparative analysis between the North America, as a TSC business leader, and the UK, where TSC is at emerging stage. This comparison was conducted using the technological innovation system analysis.

8.2 RESEARCH MOTIVATION

The effect of climate change is accumulating, CO_2 emissions are escalating (section 1.3.1) and energy consumption is significantly increasing and threatening energy security (section 1.3.2). As a result, the built environment is predicted to be affected in terms of construction methodologies, design features and regulations. This will impact on economic activities, inhabitants and society’s cultural heritage; all of which present challenges for researchers, architects and policy makers.

Space heating is found to consume about two-thirds of domestic energy and emits around one-fourth of overall CO_2 emissions (section1.3.4). In the context of switching space heating to renewable energy, TSC is presented as a solar technology that pre-heats the ambient air and supplies it into indoors spaces for heating. The technology is almost mature in North America (Hollick 1985; Hall et al. 2011) but has recently been introduced to the UK (section 2.4.1). The market penetration of the technology has remained low in both UK and North America. TSC technology is accordingly not yet ready to satisfy the switch from conventional energy sources on its own despite its apparent technical competitiveness. This study therefore explores the reasons for the yet low penetration of TSC and further explores the preferences and perceptions of architectural integration of TSC in buildings (section 1.2).

8.3 LIMITATIONS OF THE RESEARCH

In spite of the successful experience in satisfying the research aim and objectives, limitations were inevitably experienced along the research work. It is deemed important to highlight these limitations for further research to consider or overcome when necessary. The limitations were related to:

8.3.1 LANGUAGE OF THE QUESTIONNAIRE

The questionnaire was designed and distributed in English where most of the targeted countries (UK, Canada and USA) have English as an official and first language. It was also deemed reasonably used in other countries; however, the rate of participation in mainland Europe was lower than expected. This was interpreted to a few reasons that include English is not the first language of the mainland Europe respondents (section 5.3). This would be listed as a limitation of the research if compared to Farkas and Horvat (2012) where they have distributed their survey in the native language of each of the 14 different participating countries. Nevertheless, the total number of respondents in this study is higher than that of Farkas and Horvat (2012) in a shorter time frame.

8.3.2 LACK OF RESPONSE BY POSSIBLE INTERVIEWEES

Following data collection from architects, engineers, researchers and other stakeholders through questionnaires, TSC entrepreneurs were targeted to better analyse the technological innovation system development (TIS).

The Canadian entrepreneurs were targeted as they hold the patents and they encompass four commercial brands of TSC (section 2.4.4). The UK interviews were arranged and conducted as planned and also the one interview with the USA entrepreneur. With the exception of the one written reply (section 4.5.5), Canadian entrepreneurs showed reluctance to collaborate in spite of the several reminders. This reluctance was, however, interpreted as a protection of information and cautiousness of networking, as highlighted in section 6.3.3i. In response to this limitation a few actions were adopted to support the qualitative analysis and to strengthen any shortcomings of the interview data including:

- The USA case was included to compare North America versus the UK in lieu of Canada versus the UK as originally planned.
- Forty-five data documents (i.e. newspapers, published papers, workshop notes, government and company websites) were collected and analysed for North America as a secondary source of information.
- Twenty-three data documents were collected and analysed for the UK as a secondary source of information.
- The qualitative analysis was supported by relevant qualitative data from the questionnaire.

8.3.3 PARTIAL COMPLETION OF TSC PROTOTYPE

The experimental prototype TSC on the roof of Bute Building was designed, comprising of four units at different settings (section 5.10.1); these units were sourced, assembled and constructed. It was aimed to compare the outputs between these settings to clarify optimum configuration of TSC integration in building envelopes. However, issues beyond the control of the researcher meant that only one unit could be analysed within the time constraints. Nevertheless, a significant amount of data was generated by the prototype TSC.

Although the location of the TSC prototype was away from possible vandalism or accidental damage; limited and controlled access to the roof necessitated that construction of the units took a longer time (around six months) than expected. Part of this limitation related to the safety precaution of assembling the units in the university's laboratory prior to dismantling each unit and re-constructing it on the roof.

8.4 RESEARCH FINDINGS

The findings in this study are derived from the research motivation. The research aims were to

- Provide insight into architecturally integrating transpired solar thermal technologies in buildings for space heating in temperate regions (findings 8.4.1 and 8.4.2).
- Clarify TSC's potential contribution to pre-heating ambient air in Wales (findings 8.4.3).
- Investigate the limited adoption of integrating and deploying TSC in building envelopes (chapter 7) despite its apparent technical competitiveness (findings 8.4.1 and 8.4.2).
- Explore the socio-economic concerns of technological innovative development at entrepreneurial level in the UK and North America (findings 8.4.2).

The findings in this study correspond furthermore to the objectives which are noted against each finding as relevant: Architectural Integration of TSC:

i) Examine the existing awareness of the TSC (finding 1) and verify the role of the architect as a principal decision maker who facilitates integrating the technology in design. This includes verifying the decision making actors and elucidating the integrated design process (IDP) which produces more consolidated architectural outputs. (finding 2).

ii) Investigate different functional and aesthetic integration preferences of TSC and hybrid PV/TSC, and find out the preferable optimum architectural integration scheme for architects and end-users (finding 3).

iii) Understand the architects' perceptions and recommendations of building-integrated transpired solar thermal technologies (findings 3 and 4).

iv) Identify the needs of architects, engineers, and building professionals for improved architectural integration quality and flexibility of solar thermal energy (finding 3 and 4), in a form of design prerequisites (section 7.7).

v) Gain insight into the constructability and integration practise of TSC through design, planning and building a prototype project. The protoype project to be furthermore practically tested to clarify the potential usefulness of TSC technology for space heating in Wales (findings 13, 14 and 15).

Technological Innovation Development (TIS) of TSC:

vi) Evaluate the technological innovative development of TSC in the UK at the entrepreneurship level and compare it to the North American case, using interviews as the main source of data and other secondary data sources (findings 5 to 12).

vii) Identify the barriers of integrating TSC (elaborated in section 7.5), and highlight potential enablers to integrating and deploying TSC technology for researchers, entrepreneurs and policy makers to consider for further improvement and technological development (elaborated in section 7.6).

viii) Investigate the contribution of the technological innovation system to the development, diffusion and utilisation of transpired solar collectors (i.e. findings 6, 7 and 12).

The research findings are summarised below in three sections related to the method being conducted.

8.4.1 ARCHITECTURAL INTEGRATION OF TSC IN BUILDING ENVELOPES

The topic of architectural integration covers a variety of contexts related to decision making, design preferences and process, the match or mismatch between the technology and building type. Further technical issues related to the development of TSC such as sustainability, market awareness and method of heat diffusion were also investigated. All these investigations correspond to the research aim of providing insight into architecturally integrating TSC in buildings. They also correspond to the first set of objectives (sections 1.4i–1.4vi) as noted below against each one.

The data were collected through a questionnaire which was analysed quantitatively and qualitatively. The major findings related to architectural integration are described below.

FINDING 1: AWARENESS

The general awareness by participants of TSC technology in terms of existence and purpose, was 51.4% (section 5.4.1) which seems sufficient to facilitate deployment of TSC as long as it is found to function satisfactorily.

A reduced number of participants were familiar with the commercially available TSC products (section 5.9.1i). Relatively few respondents considered the currently available TSC products to be satisfactory in terms of performance, aesthetics, and cost (section 5.9.1ii).

FINDING 2: DECISION MAKING

The client is considered to be the ultimate decision maker for selecting the type of technology to be integrated. The client has the yes/no answer for integrating TSC in a building (section 7.3.1).

Ranked second, the architect was considered to be the design facilitator who would advise the client on types of technology in the first place. Following the client's acceptance, the architect would decide the type of integration, position and size (section 7.3.2). The role of the architect with the IDP team along with the design process is also considered important, especially for non-domestic buildings (section 7.3.3).

FINDING 3: INTEGRATION PREFERENCES

The preferences for an optimum TSC architectural scheme were investigated. The preferences extend beyond the design and construction of TSC and remain subjective. Although the preferences were expressed in theory; those preferences were contradicted when specific examples were presented leading to a conclusion of 'no common agreement' or 'subjective preferences' (section 7.4.2). Overall, there was general agreement that:

- The roof hybrid TSC/PV was the preferred integration option (sections 5.6.2i and 5.6.2ii). Although specific examples of these were considered to have poor aesthetics, it was considered that roof tops were less visible and aesthetics were less important (section 7.4.2).
- TSC integration should be considered as early in the design process as possible (section 5.6.2iv).
- Multi-functional performance in building envelopes is always favoured and function outweighs aesthetics even by architects (section 5.6.1i).
- 'Invisible' integration of TSC was preferred (section 5.6.3i). A stated preference was made for the avoidance of dummy panels. However, ratings of examples indicated that installations which incorporated dummy panels were rated as having good aesthetic properties (section 5.6.3ii).

FINDING 4: SELECTION PREFERENCES

These preferences relate to choices between technologies when the decision has been taken to source a renewable energy technology:

- Domestic hot water is the most selected choice. Options included TSC, PV/TSC, wind energy and ground source heating. Participants cited familiarity with its existence and performance as influencing choice (section 5.6.1ii).
- Although sustainability is a broad term which reflects economic and social aspects, participants considered that TSC sustainability focused on energy saving followed by indoor thermal comfort (section 5.7.2).

- Reliability, defined as 'constant performance and efficiency which could exceed 75%' was the ultimate feature considered when sourcing TSC technology. It was followed by low capital cost defined as 'payback within 2 - 12 years' (section 5.7.3).

8.4.2 TECHNOLOGICAL INNOVATION SYSTEM OF TSC

New products or services often fail in the market due to local unsuitability (Truong 2013). Therefore, new insights into innovations have to be developed and diffused within the cumulative context of an innovation system (Lai et al. 2012). The main source of data used for TSC TIS analysis was through interviews held with entrepreneurs in the UK and North America. Secondary sources of data were used to clarify and reinforce responses which arose from interviews. The data was analysed qualitatively following the analysis structure derived from Bergek et al. (2008). The major findings are summarised below:

FINDING 5: TSC TIS STRUCTURE

These findings relate to the analysis of the structural components of TIS (actors, institutions and networks):

- The actors in North America were larger in number, size and capabilities than in the UK. In North America, entrepreneurs focus on both the local market and export, while in the UK they have a stronger local focus (section 6.3.1 and Table 6-1).
- The North American institutions (regulations, codes etc.) include encouraging building codes in addition to many governmental incentive plans. However, in the UK only one recent incentive plan 'Green Deal' has been introduced (section 6.3.2 and Table 6-1).
- The networks of trading and learning in North America are robust and long-established versus limited networking in the UK. However, both North American and British actors are cautious about communication due to concerns about market competition and IPP (section 6.3.3 and Table 6-1).

FINDING 6: ENTREPRENEURIAL ACTIVITIES

The TSC technology was launched in Canada in the 1980s, since when numerous activities have occurred including patents, system advancements, and successful business cases. Given the short period of activity in the UK, the situation seems satisfactory with ambitious prototyping activities, but there are no patents emerging in this market (section 6.4.1 and Table 6-2).

FINDING 7: KNOWLEDGE EXCHANGE

The level and volume of the exchanged knowledge remains unsatisfactory for architects, end-users and other stakeholders. Knowledge is considered the key to success, technology development and deployment. Entrepreneurs are cautious about knowledge exchange in spite of their potential willingness to cooperate with other actors (sections 6.4.2, 6.4.3 and Table 6-2).

FINDING 8: GUIDANCE OF THE SEARCH

The TSC technology is not determined in the UK road map in terms of specific targeted visions of take up. The absence of a specific vision by the government for TSC will hamper its emergence status. Policy makers as well as designers need tangible evidence to be convinced by the performance of the technology (section 6.4.4 and Table 6-2).

FINDING 9: MARKET FORMATION

The North American entrepreneurs are targeting local and international marketplaces including the UK where they have a few installations. That adds a new dimension into the research and development of TSC in order to suit other weather conditions and to match different standards and codes in different countries. The UK entrepreneurs remain focused on a national market with potential plans for targeting mainland Europe in the future (section 6.4.5 and Table 6-2).

FINDING 10: RESOURCE MOBILISATION

The North American entrepreneurs are fully independent in terms of research funding and in-house R&D. Entrepreneurs in the UK contribute part of the research funding, but collaborate with the government and other actors to increase the validation of TSC. Lack of skilled staff was not reported as an issue by the interviewed entrepreneurs; however, participants in the survey saw it as a barrier to development (sections 6.4.6, 7.6.3 and Table 6-2).

FINDING 11: LEGITIMACY

TSC as a solar thermal technology is part of a strong advocatory coalition in North America in spite of the indirect resistance resulting from cheap gas prices. The accessible end-users' feedback and testimonials reflect a level of satisfaction. These might be biased as they were published by manufacturers; however, they remain a good indication of knowledge exchange in forming legitimacy. Legitimacy in the UK remains under development (section 6.4.7 and Table 6-2).

FINDING 12: INTERACTION BETWEEN TIS FUNCTIONS

The TIS functions in North America were actively fulfilled versus potential fulfilment in the UK, which is appropriate to the formative stage of development. There was a good level of interaction between TIS functions in North America; two virtuous cycles were triggered versus a vicious one (section 6.5.1). In the UK, one major virtuous cycle was triggered with a possibility of a small number of minor vicious and virtuous cycles (section 6.5.2). The functions fulfilment and their interactions were analysed and compared in the UK and North America (Table 6-3). This provided insight into barriers to TSC development (section 7.5). Once barriers had been identified, enablers could be developed for future development and deployment of TSC (section 7.6). The barriers and their corresponding enablers included:

- Immature or inadequate technology (section 7.5.1i) that could be enabled through incremental improvement (section 7.6.1) and research and development (section 7.6.6).
- Fear or reluctance to implement new technology (section 7.5.4i) and low familiarity (section 7.5.4ii) that could be enabled through information and awareness campaigns (section 7.6.2) and demonstration projects (section 7.6.7).
- Lack of professional contractors (section 7.5.5iii) who could be enabled through training of skilled staff (section 7.5.3).
- Low institutional support (section 7.5.2v) that could be enabled through government support (section 7.5.4) and new codes and standards (section 7.5.5).

8.4.3 POTENTIAL CONTRIBUTION OF TSC

The potential contribution of TSC to the environment in terms of the supplied heat was investigated through an experimental prototype project. The outputs of the TSC unit were recorded, collected and analysed along with the weather data. Due to the 'hands-on experience' gained during the construction of the units which provided grounding for analysing the survey data, this work was considered within the architectural integration strand of the research. The following findings relate to the output temperature, effectiveness and efficiency of the TSC.

Finding 13: Effect of Solar Irradiation on Output Temperature

The output temperature was found to be positively related to solar irradiation. The output temperature was always higher than the ambient temperature when solar irradiation was above 60 W/m^2. The output temperature would increase significantly when solar irradiation was above 400W/m^2. The effect of solar irradiation was however found more significant on temperature rise in autumn than winter (section 5.10.2iia).

FINDING 14: EFFECT OF AIR FLOW AND WIND SPEED ON OUTPUT TEMPERATURE

Wind speed higher than 4m/s induced lower air flow in the plenum (less than 0.8m/s). The output temperature starts increasing as well as the duct air flow after wind speed decreases below 4m/s as an average. Air flow in the duct was found to be in a significant harmony with an output temperature rise versus a lower significance on supply temperature rise over ambient temperature in winter. The relation between air flow and temperature trends is interpreted due to buoyancy effect where higher solar irradiation creates hotter air in the collector which drives stronger air flows. The harmony of air flow to temperature rise is, however, minimal in autumn and summer where solar irradiation has the greatest effect (section 5.10.2iib). A 0.55m/s minimum flow rate is found to be required in the duct to avoid flow reversal in winter for the range being studied (section 5.10.2iv).

FINDING 15: HEAT EXCHANGE EFFECTIVENESS

The effectiveness of TSC “the ratio of the actual temperature rise of air as it passes through the absorber plate to the maximum possible temperature rise” (Leon and Kumar 2007) is found to increase with the decrease of solar irradiation and the increase of the flow rate till the effectiveness reaches 0.8. After the effectiveness reached 0.8, an inversal relation starts with the flow rate in a contradiction to Wang et al. (2006) who mentioned a minimal effect of flow rate after 0.8 effectiveness. (section 5.10.3v).

FINDING 16: TSC EFFICIENCY

The efficiency of TSC, “the ratio of the useful heat delivered by the solar collector to the total solar energy input on the collector surface” (Leon and Kumar 2007, p. 67) is found to increase significantly following the decrease of solar irradiation and vice versa. The efficiency is directly affected by flow rate in the duct, however, this effect reverses beyond a certain point (i.e. 1.45m/s flow rate in January). The maximum average efficiency in January was below 5%, with the highest instantaneous efficiency recorded as 41%.

On the other hand, the maximum average efficiency from 2nd August to 20th September 2013 was around 11%, with the highest instantaneous efficiency recorded as 80% (section 5.10.2iv). Although these figures are lower than the efficiencies reported for commercial TSCs, it should be borne in mind that they refer to a prototype which is smaller in size and does not benefit from the same levels of insulation which would exist on a commercially installed, building-integrated system.

8.5 RECOMMENDATIONS FOR FURTHER RESEARCH

The following potential paths would be recommended for further research and investigation as a continuation of this study.

8.5.1 INDOOR ENVIRONMENT (THERMAL COMFORT AND INDOOR AIR QUALITY)

In addition to its mechanism of heating indoor spaces, the TSC is proposed as a technology that supplies fresh air which satisfies certain requirements for healthy indoor spaces. The research would identify the potential contribution of TSC technology to satisfactory parameters of indoor environment. These parameters are determinants of the tangible usefulness of TSC which should include:

- Thermal comfort satisfaction: Fanger's model is found appropriate and accepted for design and moderate field assessment of indoor thermal comfort (Lin and Deng 2008 cited in Djongyang et al. 2010; Tzempelikos et al. 2010). It would be also advised to investigate the adaptive model of thermal comfort that is adopted by EN15251 for a free-running building (i.e. mixed mode buildings with mechanical ventilation and operable windows) (Nicol and Humphreys 2010).
- Indoor air quality and its associated indoor CO_2 level in comparison to the standard recommendation (i.e. ASHRAE) per occupant.

8.5.2 EXAMINATION OF THE STUDY OUTCOMES

It is recommended that the barriers, enablers and design guidelines presented in this study are further evaluated. This might be through surveys and in-depth interviews. This study would include the following objectives:

- The validity of each barrier in different contexts (i.e. specific countries and building types) as it might deviate with time and location.
- The match or mismatch applicability of the barriers to other renewable energy technologies.
- The priority of addressing the barriers and the association between the prioritisation and different actors, professions and locations.
- The suitability of the proposed enablers for TSC, and their potential applicability to other solar thermal and renewable technologies.
- Architects and entrepreneurs could be specifically targeted for their opinions on the suggested design guidelines.

8.5.3 COMPARATIVE CASE STUDY FOR OPTIMUM POSITIONING

Research objective ii, related to investigating the optimum scheme of integration, was satisfied in this study through conducting questionnaire. This could be further explored experimentally.

A comparative study between various settings (different azimuth, wall and roof mounted units, small and large collector areas) was deemed beneficial for the the UK context. This is influenced by having ‘hands-on experience’ through ‘learning by doing’ (section 6.4.2ii) and independent evidence (section 7.5.2i). The study would aim to evaluate the performance and effectiveness of the prototypes simultaneously. Such a comprehensive study is not available to the knowledge of the researcher. Kozubal et al. (2008) partially compared an experimental stand-alone inclined unit to output efficiency figures for an in-operation wall mounted TSC; however, the comparison was conducted under two different conditions and methods.

8.5.4 INFLUENCE OF ARCHITECTURAL STYLE

The architectural style is briefly discussed as a potential influence to the architectural preference of integrating technologies in building envelopes (section 7.4.1). It would be interesting to survey and interview architects in order to investigate the association between the architectural style they usually follow and the parameters of integrating technologies in buildings.

The survey might aim to develop various possible methods of integration or define various groups of designers in order to be included in research development. It would be recommended to include statistical analysis of the style followed (i.e. high-tech and post-modern architecture style). The effect of the style on integration would also be studied versus the potential deviation in the design concept to suit certain technology integration requirements when there is a conflict between the both.

8.6 CLOSING REMARKS

Being derived from the efforts to diminish climate change, transpired solar technology is presented as an alternative to conventional energy for space heating. The limited integration and deployment of TSC was noted in the publications reviewed, which also commend the operation and performance of the technology. Multi-disciplinary research was deemed an appropriate approach to satisfy the aim and objectives of this research.

In a satisfactory achievement to the research aim, this study provided insight into various aspects of integrating and deploying TSC in buildings. These aspects included:

- Understanding the outlook of relevant actors (i.e. architects, policy makers, researchers) including general awareness and market familiarity with TSC technology.
- Identifying the ultimate decision makers for sourcing and integrating TSC technology, along with the necessary role of each decision maker and the stage related to decision. This included the grounds of preferences in selecting a technology for deployment and integration by clients and architects.
- Investigating preferences of integration schemes (i.e. roof or wall position of TSC in buildings), phase, aesthetics and multi-functions.
- Identifying possible barriers that hinder the integration and deployment of TSC and suggesting corresponding enablers to overcome these barriers.

- Analysing the development of TSC through the technological innovation system as a specific analysis system that could outline the challenges and opportunities for developing TSC technology in the UK.
- Comparing the formative development stage of TSC in the UK with the mature status in North America, in order to draw enabling lessons that could diminish the possible barriers.
- Gaining hands-on experience through planning, designing, constructing and testing an experimental prototype TSC project.

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APPENDIX A ||

QUESTIONNAIRE

Architectural Integration of Transpired Solar Thermal

Introduction

Dear Participant,

You are kindly invited to participate in a research study for a PhD degree in architecture by completing this questionnaire survey. The study investigates the architectural integration and environmental benefits of transpired solar thermal in building envelopes at residential sector. The overall aim of the study is to provide insight into the limitation of architecturally integrating transpired solar collectors (TSC) for space heating in buildings, and clarify its role in satisfying thermal comfort and energy saving at residential sector. This questionnaire is directed to architects, engineers, and professionals engaged in design and construction to survey their perception of the acute problematic shortage of integrating transpired solar thermal in building envelopes.

This is an anonymous questionnaire and will be exclusively used for academic purposes. Completing the survey may require approximately 20 minutes. Your participation is entirely voluntary and that you can withdraw from the survey at any time without giving a reason, also, you can save your progress from the top of any page and return to the survey later.

Nevertheless, I highly appreciated your complete participation which will add a valuable contribution to the study and the solar architecture. You are invited to provide your contact details at the end of the survey if you would like to receive a copy of the survey results. The information you provide will be treated and published totally anonymously. Your contact details will not be used in the reporting or analyses in any way. This survey has been approved by the Research Ethics Committee of the Welsh School of Architecture (EC1203.114) on 26-Mar-2012.

If you have any questions about this survey please do not hesitate to contact me. I am happy to respond to any queries you may have.

Thank You very much in advance for your cooperation and help.

Thanks & Regards,

Hasan Alfarra
Ph.D Candidate in Architecture
Cardiff University - UK
Mob: +44 7414 10 3260
hajfarra@hotmail.com
Alfarrah@cardiff.ac.uk

Section A: Personal Information

1) Profession:*

( ) Architect
( ) Engineer, please specify (i.e. mechanical, civil, energy...): _________*
( ) Other, please specify: _________________*

2) Work Field:*

( ) Academia
( ) Consultancy
( ) National Government
( ) Local Government
( ) Contracting
( ) Other: _________________

3) Years of Experience:*

( ) Less than 5
( ) 5 - 10
( ) 11 - 15
( ) More than 15

4) Location*

( ) Afghanistan	( ) East Timor	( ) Luxembourg	( ) San Marino
( ) Albania	( ) Ecuador	( ) Macau	( ) Sao Tome and Principe
( ) Algeria	( ) Egypt	( ) Macedonia	( ) Saudi Arabia
( ) Andorra	( ) El Salvador	( ) Madagascar	( ) Senegal
( ) Angola	( ) Equatorial Guinea	( ) Malawi	( ) Serbia
( ) Antigua and Barbuda	( ) Eritrea	( ) Malaysia	( ) Seychelles
( ) Argentina	( ) Estonia	( ) Maldives	( ) Sierra Leone
( ) Armenia	( ) Ethiopia	( ) Mali	( ) Singapore
( ) Australia	( ) Fiji	( ) Malta	( ) Slovakia
( ) Austria	( ) Finland	( ) Marshall Islands	( ) Slovenia
( ) Azerbaijan	( ) France	( ) Mauritania	( ) Solomon Islands
( ) Bahamas, The	( ) Gabon	( ) Mauritius	( ) Somalia
( ) Bahrain	( ) Gambia, The	( ) Mexico	( ) South Africa
( ) Bangladesh	( ) Georgia	( ) Micronesia	( ) South Korea
( ) Barbados	( ) Germany	( ) Moldova	( ) Spain
( ) Belarus	( ) Ghana	( ) Monaco	( ) Sri Lanka
( ) Belgium	( ) Greece	( ) Mongolia	( ) Sudan
( ) Belize	( ) Grenada	( ) Montenegro	( ) Suriname

( ) Benin
( ) Bhutan
( ) Bolivia
( ) Bosnia and Herzegovina
( ) Botswana
( ) Brazil
( ) Brunei
( ) Bulgaria
( ) Burkina Faso
( ) Burma
( ) Burundi
( ) Cambodia
( ) Cameroon
( ) Canada
( ) Cape Verde
( ) Central African Republic
( ) Chad
( ) Chile
( ) China
( ) Colombia
( ) Comoros
( ) Congo, Democratic Republic of the
( ) Congo, Republic of the
( ) Costa Rica
( ) Cote d'Ivoire
( ) Croatia
( ) Cuba
( ) Cyprus
( ) Czech Republic
( ) Denmark
( ) Djibouti
( ) Dominica
( ) Dominican Republic
( ) Guatemala
( ) Guinea
( ) Guinea-Bissau
( ) Guyana
( ) Haiti
( ) Holy See
( ) Honduras
( ) Hong Kong
( ) Hungary
( ) Iceland
( ) India
( ) Indonesia
( ) Iran
( ) Iraq
( ) Ireland
( ) Italy
( ) Jamaica
( ) Japan
( ) Jordan
( ) Kazakhstan
( ) Kenya
( ) Kiribati
( ) Kosovo
( ) Kuwait
( ) Kyrgyzstan
( ) Laos
( ) Latvia
( ) Lebanon
( ) Lesotho
( ) Liberia
( ) Libya
( ) Liechtenstein
( ) Lithuania
( ) Morocco
( ) Mozambique
( ) Namibia
( ) Nauru
( ) Nepal
( ) Netherlands
( ) Netherlands Antilles
( ) New Zealand
( ) Nicaragua
( ) Niger
( ) Nigeria
( ) North Korea
( ) Norway
( ) Oman
( ) Pakistan
( ) Palau
( ) Palestine
( ) Panama
( ) Papua New Guinea
( ) Paraguay
( ) Peru
( ) Philippines
( ) Poland
( ) Portugal
( ) Qatar
( ) Romania
( ) Russia
( ) Rwanda
( ) Saint Kitts and Nevis
( ) Saint Lucia
( ) Saint Vincent
( ) Samoa
( ) Swaziland
( ) Sweden
( ) Switzerland
( ) Syria
( ) Taiwan
( ) Tajikistan
( ) Tanzania
( ) Thailand
( ) Timor-Leste
( ) Togo
( ) Tonga
( ) Trinidad and Tobago
( ) Tunisia
( ) Turkey
( ) Turkmenistan
( ) Tuvalu
( ) Uganda
( ) Ukraine
( ) United Arab Emirates
( ) United Kingdom - England
( ) United Kingdom - Wales
( ) United Kingdom - Scotland
( ) United Kingdom - NI
( ) United States
( ) Uruguay
( ) Uzbekistan
( ) Vanuatu
( ) Venezuela
( ) Vietnam
( ) Yemen
( ) Zambia
( ) Zimbabwe

5) Highest academic degree:*

( ) PhD
( ) MSc / MA
( ) BSc / BA
( ) Other: _________________

6) What type of projects are you typically involved in?*

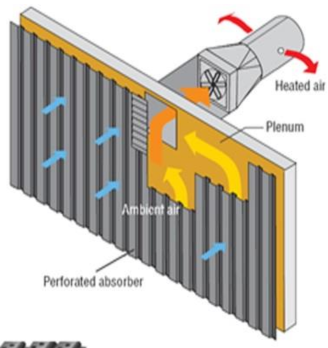
[ ] Commercial
[ ] Residential
[ ] Institutional
[ ] Industrial
[ ] Other

7) Are you aware of the Transpired Solar Collectors technology?*

( ) Unaware
( ) Aware
( ) Expert

Note for the following sections:
The integrated Transpired Solar Collectors (TSC) for façade and/or roof provides space heating in cold seasons (Figure. 1). The technology can possibly supply fresh air in hot seasons through a bypass opening, however, this fresh air is easily avoided if expected to cause summer overheating, and the fan shuts-down.

Fig 1: Schematic diagram for Transpired solar collectors (TSC) = Space Heating



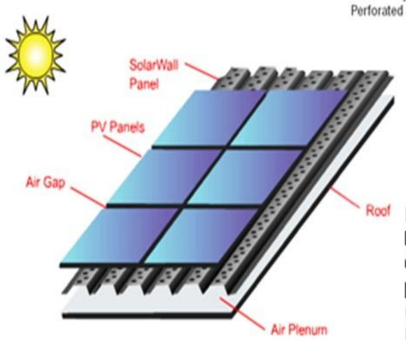


Fig 2: Schematic diagram for Transpired solar collectors with photovoltaics on the top (PV/TSC) = Hybrid Heating + Electricity

When Transpired Solar Collectors are combined with Photovoltaic panels (PV/TSC), the hybrid provides both space heating and electricity (Figure. 2).

The area of Transpired Solar Collectors for space heating in the hybrid is reduced as it is replaced by Photovoltaic for electricity generation.

Section B: Real Integration Examples

8) The integration of solar energy technologies, in general, in buildings contributes positively towards the creation of a sustainable built environment.*

( ) Agree
( ) Disagree
( ) No Opinion

Comments:
____
____

9) Who does take the decision to use Transpired solar collectors in a building:

(You can select more than 1 option)

9a: For Domestic buildings (i.e. dwellings):

[ ] Government Regulation Influence
[ ] Client
[ ] Architect
[ ] Project Manager
[ ] Engineering (includes mechanical integrating team)
[ ] Integration Design Team (which involves all the above)

9b: For Non-Domestic buildings (i.e. offices):

[ ] Government Regulation Influence
[ ] Client
[ ] Architect
[ ] Project Manager
[ ] Engineers
[ ] Integration Design Team (which involves all the above)

Comments:
____
____

10) The integration scheme of transpired solar thermal is decided by: e.g. Façade integration, and Roof integration

[ ] Architect
[ ] Client
[ ] Government Regulation Influence
[ ] Project Manager
[ ] Engineers (includes mechanical integrating team)
[ ] Integration Design Team (which involves all the above)

Comments: ___________________________________

The following questions (11-17) contain selective integration images of transpired solar collectors (TSC) and hybrid Photovoltaics with Transpired Solar (PV/TSC) for Commercial/Institutional and Residential buildings. Please tick your appropriate rating scale for each integration scheme in terms of Multi-functional role* and Aesthetics.**

Multi-functional role: as an architectural design element (i.e. cladding, shading device, roof tile…) in addition to its purpose of energy generation.

*****Aesthetics: the beauty and the visual appearance of the integration within the building envelope context.***

The rating scale is interpreted as: (-2) is very poor, (-1) is poor, (0) is Neutral, (+1) is good, and (+2) is perfect.

Façade integration – TSC (Non-domestic Governmental Building). Ann Arbor Municipal Building, USA. InSpire wall (atas, 2010)

11) Please tick your appropriate rating scale

Multi-Functional Role

( ) -2 ( ) -1 ( ) 0 ( ) +1 ( ) +2

Aesthetics

( ) -2 ( ) -1 ( ) 0 ( ) +1 ( ) +2

Comments:

____
____
____

Façade integration – TSC (Non-domestic Institutional Building). Northern Arizona University, Distance Learning Center, USA. (SolarWall®, 2009)

12) Please tick your appropriate rating scale

Multi-Functional Role

( ) -2 ( ) -1 ( ) 0 ( ) +1 ( ) +2

Aesthetics

( ) -2 ( ) -1 ( ) 0 ( ) +1 ( ) +2

Comments:

____
____
____

Façade integration – TSC (Non-domestic Commercial Building). Group Dion, Offices, Quebec - Canada. (MatrixAir, 2010)

13) Please tick your appropriate rating scale

Multi-Functional Role

( ) -2 ( ) -1 ( ) 0 ( ) +1 ( ) +2

Aesthetics

( ) -2 ( ) -1 ( ) 0 ( ) +1 ( ) +2

Comments:

____
____
____

Façade integration - TSC (Mixed-use Residential Building). The CURRENTS Residences, Canada, (solarwall, n.d)

14) Please tick your appropriate rating scale

Multi-Functional Role

( ) -2 ( ) -1 ( ) 0 ( ) +1 ( ) +2

Aesthetics

( ) -2 ( ) -1 ( ) 0 ( ) +1 ( ) +2

Comments:

____
____
____

Façade integration – PV/TSC (Non-domestic Institutional Building). Ste Marguerite Bourgeoys school, Ontario - Canada (Solarwall, n.d)

15) Please tick your appropriate rating scale

Multi-Functional Role

( ) -2 ( ) -1 ( ) 0 ( ) +1 ( ) +2

Aesthetics

( ) -2 ( ) -1 ( ) 0 ( ) +1 ( ) +2

Comments:

____
____
____

Roof integration – TSC duct, (Non-domestic Commercial Building). Renault dealership, Spain (Solarwall, n.d)

16) Please tick your appropriate rating scale
Multi-Functional Role
( ) -2 ( ) -1 ( ) 0 ( ) +1 ( ) +2

Aesthetics
( ) -2 ( ) -1 ( ) 0 ( ) +1 ( ) +2
Comments:
____
____
______

Roof integration – PV/TSC (Non-domestic Institutional Building). Turner Fenton School, Ontario - Canada, (Solarwall, n.d)

17) Please tick your appropriate rating scale
Multi-Functional Role
( ) -2 ( ) -1 ( ) 0 ( ) +1 ( ) +2

Aesthetics
( ) -2 ( ) -1 ( ) 0 ( ) +1 ( ) +2
Comments:
____
____
______

Section C: Architectural integration of Transpired solar collectors

18) The priority in selecting transpired solar collectors in buildings should be according to which aspects?

*(You can select more than 1 option)**

[ ] Multi-Functional (as an architectural design element)
[ ] Aesthetics
[ ] Function (as energy generating device)
[ ] Other
Comments: ______________________________

TSC: Transpired Solar Collectors. PV/TSC: Hybrid (Transpired Solar Collectors and Photovoltaic Panels).

19) At a typical building's geometry and adjacent parameters, which of the following integration schemes of transpired solar collectors would you recommend for?

(You can select more than 1 option)

Non-domestic office buildings

[ ] TSC (Façade)
[ ] TSC (Roof)
[ ] PV/TSC (Façade)
[ ] PV/TSC (Roof)

Domestic residential buildings

[ ] TSC (Façade)
[ ] TSC (Roof)
[ ] PV/TSC (Façade)
[ ] PV/TSC (Roof)

Comments:

____
____
____
____

20) At a new residential building: If a project required a minimum of 20% renewable energy to be provided, which of the following options (if any) would you advise to be integrated?

*(You can select more than 1 option)**

[ ] Transpired Solar Collector (TSC)
[ ] Photovoltaic (PV)
[ ] Hybrid (PV/TSC)
[ ] Solar Water Heating
[ ] Wind Energy
[ ] Ground Source heat pump

Please explain the reason of your selection:

____
____

21) <u>At an existing residential building:</u> If a project required a minimum of 20% renewable energy to be provided, which of the following options (if any) would you advise to be integrated?

*(You can select more than 1 option)**

[ ] Transpired Solar Collector (TSC)
[ ] Photovoltaic (PV)
[ ] Hybrid (PV/TSC)
[ ] Solar Water Heating
[ ] Wind Energy
[ ] Ground Source heat pump

Please explain the reason of your selection:

____
____

22) You would support integrating transpired solar collectors in buildings for:*

( ) New design
( ) Refurbishment
( ) Both
( ) Other: _______________

23) It is often difficult to harmonise transpired solar collectors with the architectural concept, when local authority design guidelines are set-up for traditional buildings:

(You can select 1 answer)

( ) Agree
( ) Disagree
( ) No Opinion

Comments:

____
____

24) At which stage of building development would you recommend the integration of transpired solar collectors in buildings to be?

(You can select 1 answer)

( ) Originally integrated into the architectural design
( ) Attached at later stage
( ) Subject to project team decision as differs from a project to another

Comments:

____
____

25) For façade integration, transpired solar collectors technology is preferable to be aesthetically:

(You can select 1 answer)

( ) Clearly Featured
( ) Somewhat Invisible
( ) No Opinion

Comments:

____
____
____
____

26) In order to achieve architectural unity, would you recommend dummy panels on other facades (i.e. Not sun facing) to match the functional unit which is only on the sun facing façade:

(You can select 1 answer)

( ) Yes
( ) Sometimes
( ) No

Comments:

____
____
____

27) Transpired solar collectors technology, as a source of comparatively low-cost renewable energy, contributes positively towards the creation of a sustainable built environment:

(You can select 1 answer)
( ) Agree
( ) Disagree
( ) No Opinion

Comments:

____
____
____

28) Please indicate the importance of the following sustainable design characteristics if you were selecting a transpired solar collector for a building.

(-2) is not important at all, (-1) is not important, (0) is Neutral, (+1) is important, and (+2) is significantly important

	-2	-1	0	+1	+2
Indoor Thermal Comfort	( )	( )	( )	( )	( )
Reducing Carbon Dioxide (CO2) and Climate Change	( )	( )	( )	( )	( )
Improving Indoor Air Quality	( )	( )	( )	( )	( )
Energy Saving	( )	( )	( )	( )	( )
Cost Effectiveness	( )	( )	( )	( )	( )
Material used (Metal / Polycarbonate), as recycled product	( )	( )	( )	( )	( )

Comments: *(You may provide separate comments for different types of building (e.g domestic residential and, non-domestic office, institutional...)*

____
____

29) Which of the following commercially available transpired solar collectors are you familiar with?

(You can select more than 1 option)
[ ] SolarWall®
[ ] InSpireTM wall
[ ] MatrixAir TR
[ ] LubiTM
[ ] Colorcoat Renew®
[ ] Not Applicable

Comments:

____
____
____

30) The quality of the currently available transpired solar collectors technology and commercial products is:

(You can select 1 answer)
( ) Satisfactory
( ) Neutral
( ) Unsatisfactory
( ) No Opinion

Comments:

____
____
____

31) The state-of-the-art integration of transpired solar collectors technology might need further innovative development, if any, by:

(You can select more than 1 option)
[ ] Architects
[ ] Research and design teams
[ ] Integration design teams
[ ] No further actions required

Comments *(please specify the needed development, if any):*

____

32) From your experience, are any possible drawbacks usually made clear by the manufacturer at the design phase?

(You can select 1 answer)
( ) Yes
( ) Sometimes
( ) No
( ) Not Applicable

Comments:

____

33) If the decision has been made to install transpired solar collectors and you are trying to source one, what would be the most important factor?

(You can select 1 answer)
( ) Reliability (constant performance and efficiency which could exceed 75%)
( ) Durability (capability of withstanding)
( ) Life span (approximately 40 years)
( ) Warranty (approximately 25 years)
( ) Maintenance (committed service contract)
( ) Low Capital Cost (to reduce the payback 2 - 12 years)

Comments: *(You may provide separate comments for different types of building (e.g domestic residential and, non-domestic office, institutional…)*

____

34) Would you find technical presentations and demonstrations helpful in your future decisions about integrating a transpired solar collector into a building?

*(You can select 1 answer)**
( ) Agree
( ) Disagree
( ) Maybe
( ) No Opinion

Comments:

____

35) The following standard colour chart is available for transpired solar collectors, would you see further colour range is needed.

( ) Yes, specify colour(s): _________________
( ) No

Comments:
____
____
____
____
____
____
____
_

36) The lighter colours have lower solar absorptivity than darker colours; which reaches 42% for the Oyster colour versus 96% for black colour for instance. Does this contradict the aesthetics coherence in your opinion?

(You can select 1 answer)
( ) Yes
( ) No
( ) Maybe
( ) No Opinion

Comments:
____
____

37) Transpired solar collectors might be useful in providing summer cooling, would you recommend a dual function through conversion to:

(You can select more than 1 option)
[ ] Solar chimney
[ ] Act as sun shading device
[ ] Dual function is not recommended
[ ] Other, please specify:

Comments:
____
____

38) Heated air via transpired solar collectors could better be supplied into the interior space through:

In Domestic dwellings:

( ) HVAC (Heat, Ventilation, and Air Conditioning)
( ) Direct flow (mechanical ventilation)
( ) Other technique,

Please specify: ________________

In Non-domestic office buildings:

( ) HVAC (Heat, Ventilation, and Air Conditioning)
( ) Direct flow (mechanical ventilation)
( ) Other technique,
Please specify: ________________

Comments:

____
____
____
____
____

39) When HVAC is not available at refurbished buildings with transpired solar collectors' technology, the recommended decision is:

In Domestic dwellings:

( ) Install new HVAC system
( ) Direct flow (mechanical ventilation)
( ) Other technique,
Please specify: ________________

In Non-domestic office buildings:

( ) Install new HVAC system
( ) Direct flow (mechanical ventilation)
( ) Other technique,
Please specify: ________________

Comments:

____
____
____

Section D: Key Issues

40) From your experience, what are the Key issues and barriers for architecturally integrating transpired solar collectors in Domestic residential buildings, and Non-domestic office buildings?

____
____
____

41) Please give any further comments here:

____
____
____
____

42) I appreciate your feedback. If you would like to receive a copy of the survey results, please provide your contact details.

Name: ____
Title: ____
Email Address: ____
Phone Number: ____

Thank You!

Thank you for taking this survey and sharing your experience and opinions. I appreciate your response which is very important to me.

APPENDIX B ||

SOLAR ENERGY

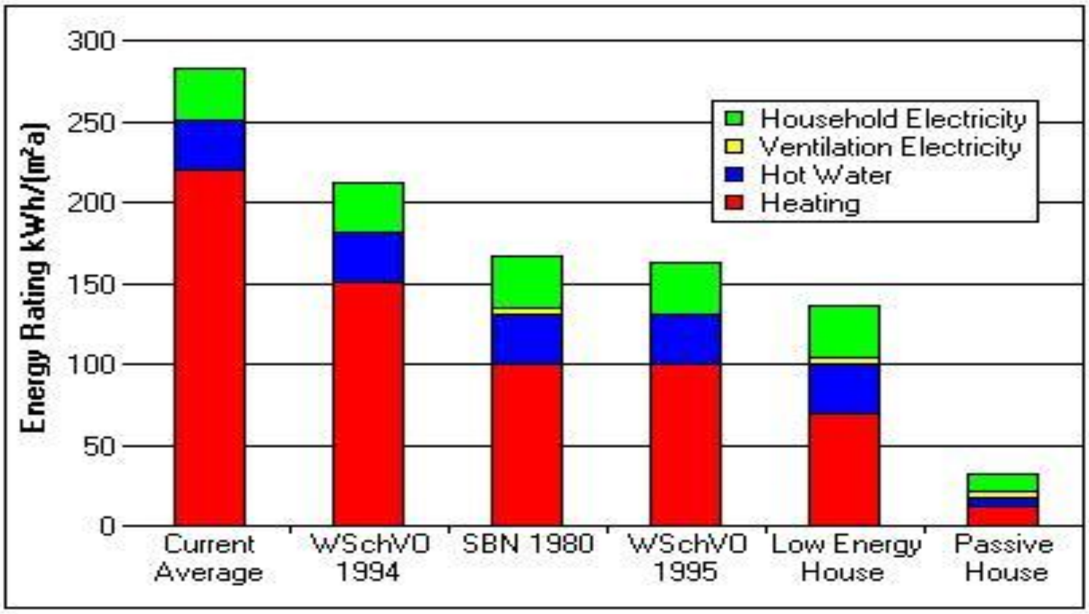


Figure B-1: Comparison of Energy Ratings of Homes, (Alter 2009) WSchVO: German Heat Protection Regulation , SBN: Swedish Construction Standard

Table B-1: Basics of passivHaus Standards in UK, (Alter 2009)

Compact form and good insulation:	All components of the exterior shell of the house are insulated to achieve a U-factor that does not exceed 0.15 W/(m²K) (0.026 Btu/h/ft²/°F).
Southern orientation and shade considerations:	Passive use of solar energy is a significant factor in passive house design.
Energy-efficient window glazing and frames:	Windows (glazing and frames, combined) should have U-factors not exceeding 0.80 W/(m²K) (0.14 Btu/h/ft²/°F), with solar heat-gain coefficients around 50%.
Building envelope air-tightness:	Air leakage through unsealed joints must be less than 0.6 times the house volume per hour.
Passive preheating of fresh air:	Fresh air may be brought into the house through underground ducts that exchange heat with the soil. This preheats fresh air to a temperature above 5°C (41°F), even on cold winter days.
Highly efficient heat recovery from exhaust air using an air-to-air heat exchanger:	Most of the perceptible heat in the exhaust air is transferred to the incoming fresh air (heat recovery rate over 80%).
Energy-saving household appliances:	Low energy refrigerators, stoves, freezers, lamps, washers, dryers, etc. are indispensable in a passive house.
Total Energy demand for space heating and cooling:	Less than 15 kw/m2/yr

Table B-2: Solar heating and cooling technologies by active and passive designs (Chan et al. 2010)

Type	Heating	Cooling
Passive solar Without using active mechanical devices; the system do not use or uses only small amount of external energy	. Able to gain or trap heat through passive solar energy. Heat from solar radiation is absorbed, stored or used to preheat ventilation air. . Solar collectors: building components such as facade or roof.	. Generates and channels airflows, hence remove heat and create cooling effects; natural ventilation is among the most common type. . Devices: building components such as facade or roof.
Active solar Uses electrical or mechanical equipment, such as pumps and fans, to increase the usable heat in a system	. Uses solar collector where the absorber component absorbs solar radiation energy, converts into heat, and transfers the heat to a transport medium or fluid that flowing through the collector. The collected solar energy is hence carried from the fluid to a heat exchanger or storage tank that satisfying heating needs. . Solar collectors: devices such as flat plate, parabolic tough or evacuate tube.	. Uses the collected solar heat as energy source of air-conditioners, commonly known as solar assisted air-conditioning systems. . Devices: chillers such as absorption and adsorption chillers, solid or liquid desiccant systems.

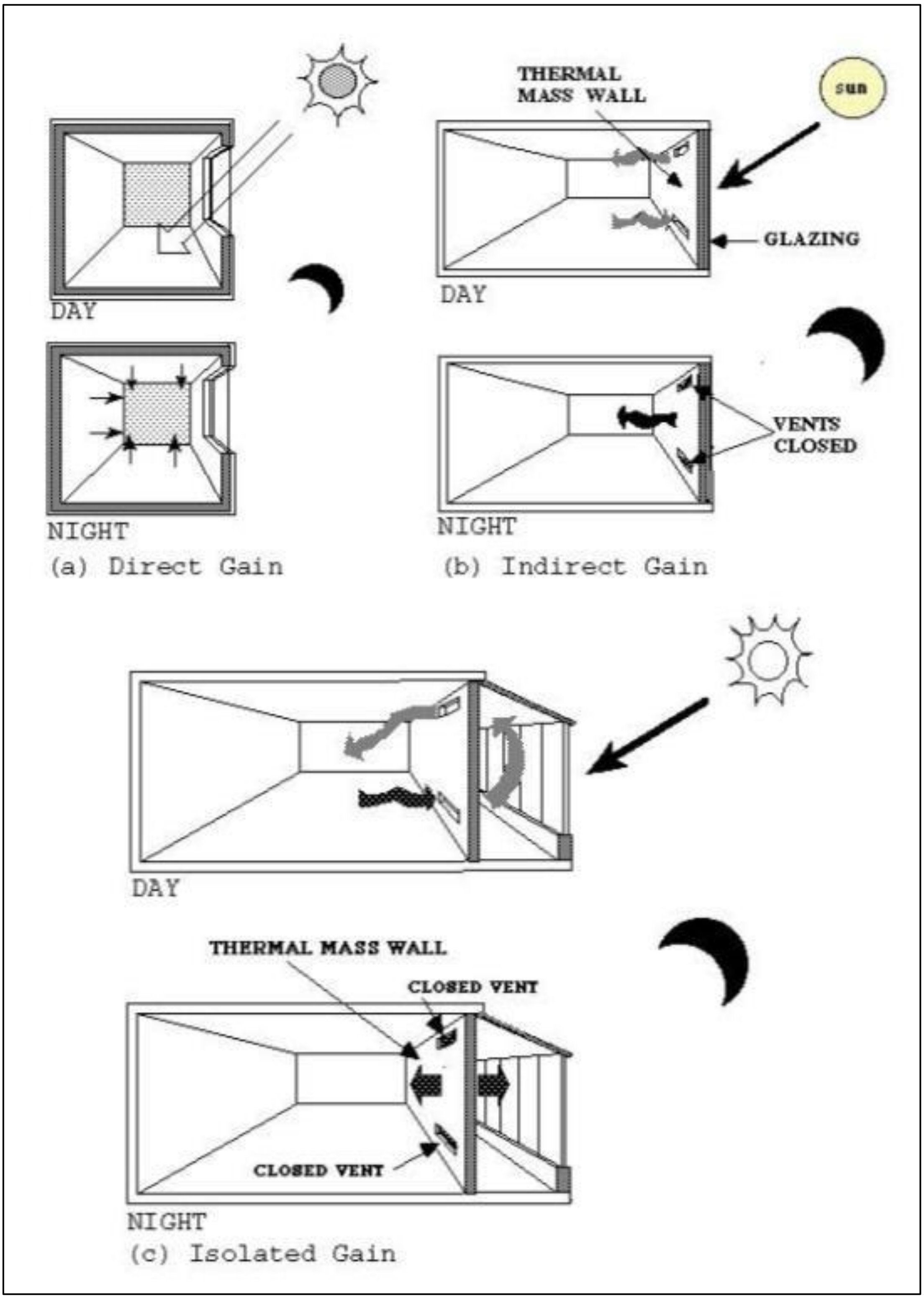


Figure B-2: Passive solar heating three configurations (Christensen 2009)

Table B-3: Advantages and disadvantages of two types of solar chimney, (Shi and Chew 2012)

Type	Advantages	Disadvantages
Vertical solar chimney	. The external glass gain sun radiation, solar collector is not needed. . The air flow in chimney could go upward directly without bends. . Easier to be control with inlet and outlet for different climatic condition. . Stack height is not restricted by roof height.	. Insulation is needed to prevent direct heat transfer between chimney and interior room because of high temperature and high contact area. . Barriers are strictly prevented because the solar gained wall is lower than roof solar collector.
Roof solar chimney	. Very large collector areas easily achieved. . May be more aesthetically pleasing than a tower. . No additional towers needed. . Likely to be cheaper than a tower design. . Easier to retrofit.	. Stack height is restricted by roof height. . Heat transfer between heated air and glass is higher than for a vertical surface. . Additional bends create greater pressure-losses. . Incorporation of thermal mass may be more difficult.

Table B-4: Types of PV cells (Abu-Hijleh lecture BUiD, 2010)

Type of Cell	Construction	Cell Efficiency *	Module Efficiency	Current Stage of Development
Monocrystalline Silicon	Uniform crystalline structure - single crystal	24%	13-17%	Industrial production
Polycrystalline (multi-crystalline) silicon	Multi-crystalline structure - different crystals visible	18%	11-15%	Industrial production
Amorphous silicon	Atoms irregularly arranged. Thin film technology	11-12%	5-8%	Industrial production
Gallium-arsenide	Crystalline cells	25%	**	produced exclusively for special applications (e.g. space craft)
Gallium-arsenide, gallium-antimony & others	Tandem (multi-junction cells, different layers sensitive to different light wavelengths)	25-31%	**	Research and development stage
Copper-indium-diselenide	Thin Film, various deposition methods	18%	10-12%	Industrial production
Cadmium-telluride & others	Thin film technology	17%	9-10%	Ready to go into production
Organic solar cells	Electrochemical principle based	5-8%	**	Research and development stage - not commercially available

** Cell efficiency is based on laboratory samples, and is invariably higher than module efficiency. From the practical point of view of evaluating systems, the module efficiency should be used*

*** Not available in module form*

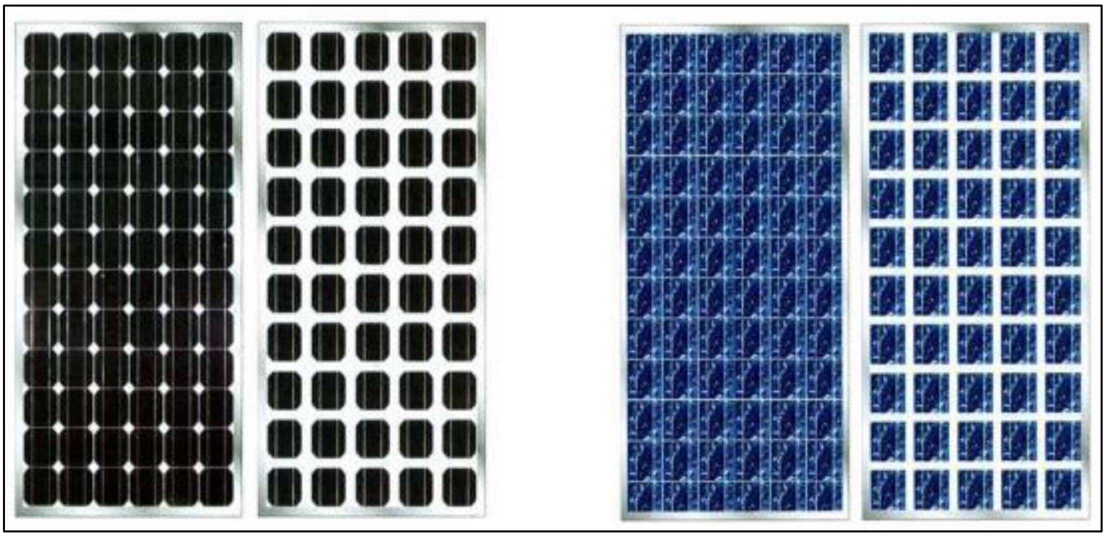


Figure B-3: Opaque and semi-transparent mono-crystalline (left) and polycrystalline PV module (Abu-Hijleh lecture BUiD, 2010)

Table B-5: Characteristics of the test plates for Van Decker et al. (2001)

Plate no.	Plate material	Hole pitch P (mm)	Hole Diameter D (mm)	Plate thickness t (mm)	Plate thermal conductivity k (W/mK)
1	Alum.*	16.89	1.6	0.86	186
2	Alum.*	16.89	1.6	0.86	186
3	PVC**	16.89	1.6	1.69	0.149
4	S. Steel***	13.33	1.6	1.57	15.12
5	PVC**	13.33	0.79	3.11	0.149
6	PVC**	8	1.2	6.51	0.149
7	PVC**	24	3.6	1.6	0.149
8	S. Steel***	24	3.6	0.57	15.12
9	PVC**	6.67	0.93	1.97	0.149

***Alum.: aluminium; **PVC: polyvinyl chloride; ***S. Steel: stainless steel.**

Table B-6: Input parameters and their values used in the study, (Leon and Kumar 2007)

S. No.	Input parameter	Range
1	Approach velocity	0.02–0.03 m/s
2	Solar radiation	400–900 W/m2
3	Ambient temperature	30 °C
4	Wind velocity	1.2 m/s
5	Pressure drop across the absorber	25–80 Pa
6	Plenum depth	120 mm
7	Pitch (triangular)	12–24 mm
8	Perforation diameter	0.80–1.55 mm
9	Absorber material	Mild steel
Design parameters used for reference collector		
1	Solar absorptance	0.95
2	Thermal emittance	0.85
3	Pitch	20 mm
4	Perforation diameter	1.25 mm

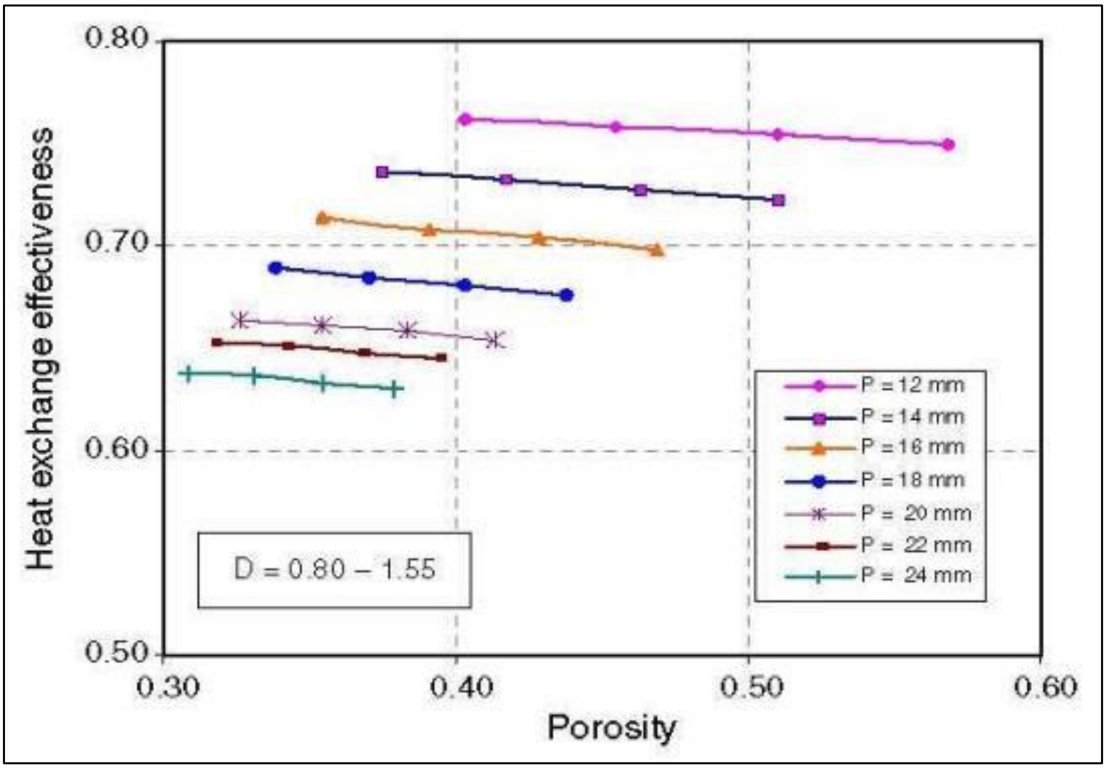


Figure B-4: Effect of porosity on heat exchange effectiveness, for an approach velocity of 0.025 m/s, (Leon and Kumar 2007)

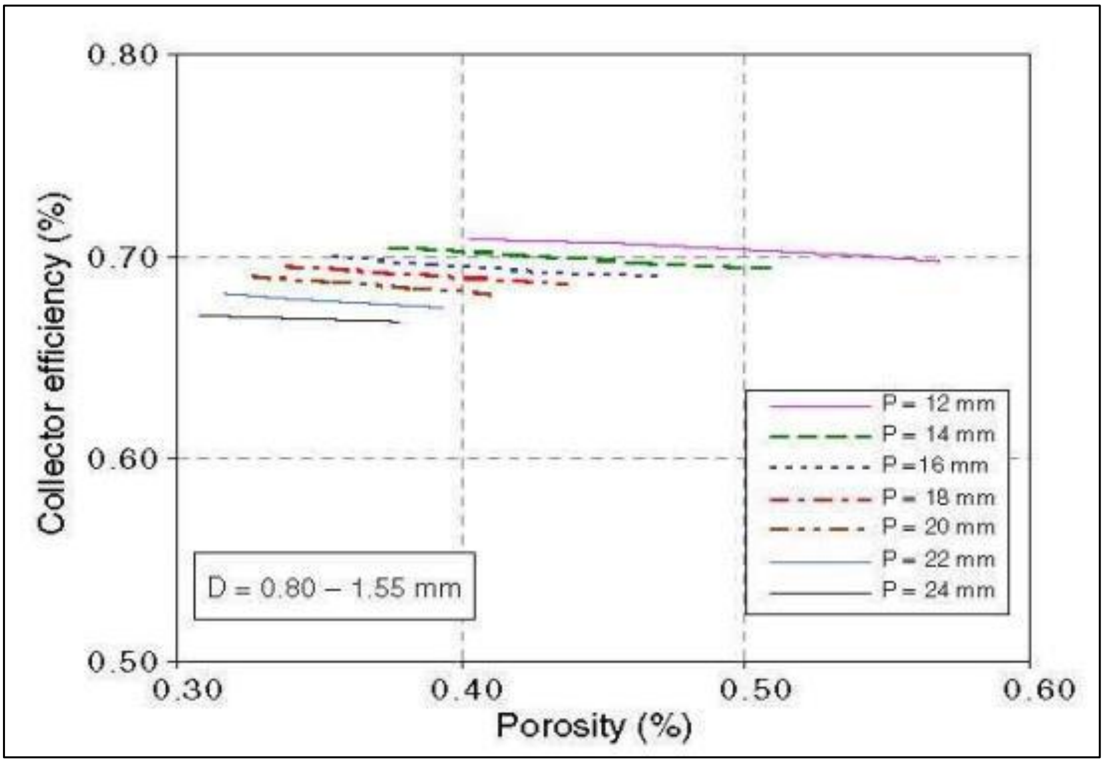


Figure B-5: Effect of porosity on collector efficiency, for an approach velocity of 0.025 m/s, (Leon and Kumar 2007)

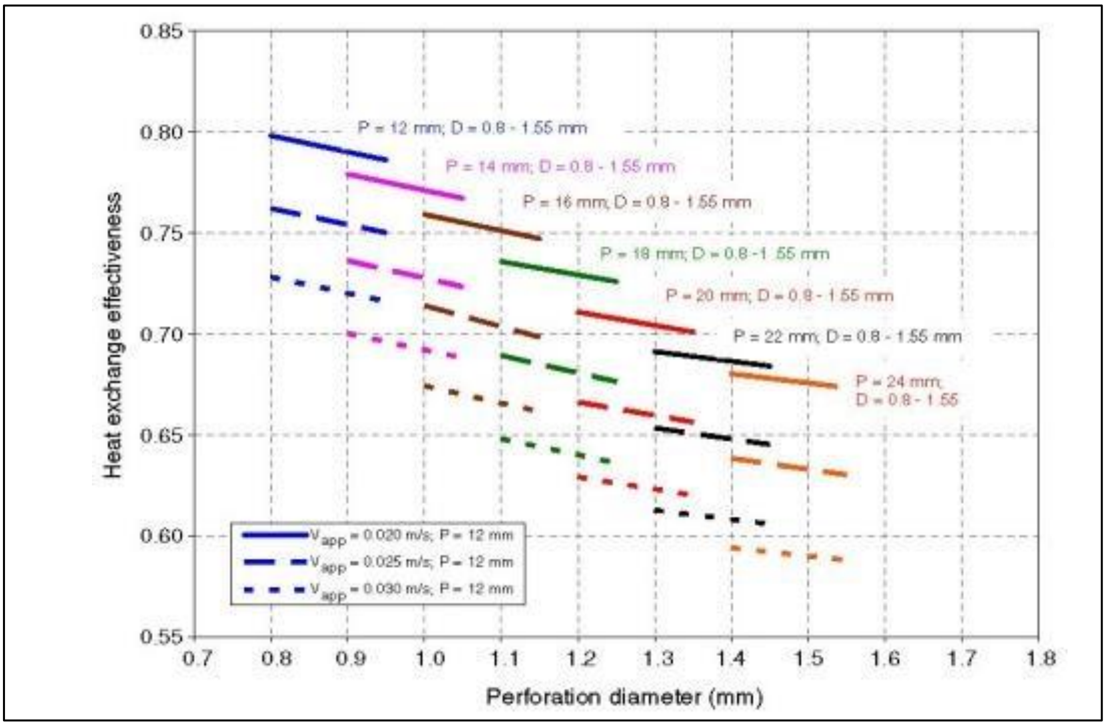


Figure B-6: Heat exchange effectiveness as a function of collector pitch and perforation diameter, (Leon and Kumar 2007)

Table B-7: TSCs research parameters, (Motahar and Alemrajabi 2010)

Parameter*	value
Collector height (m)	2.44
Collector length (m)	1.83
Plenum depth (m)	0.0762
Hole diameter (m)	0.00159
Hole pitch (m)	0.0214
Absorptivity of collector	0.9
Emissivity of collector	0.9
***When one parameter is varied, the others are kept constant.**	
Ambient Temperature =10 °C , Room Temperature = 20°C , Approach velocity = 0.02 m/s, wind speed = 1.2 m/s, Incident solar radiation = 800 W / m^2 , Corrugation factor = 1	

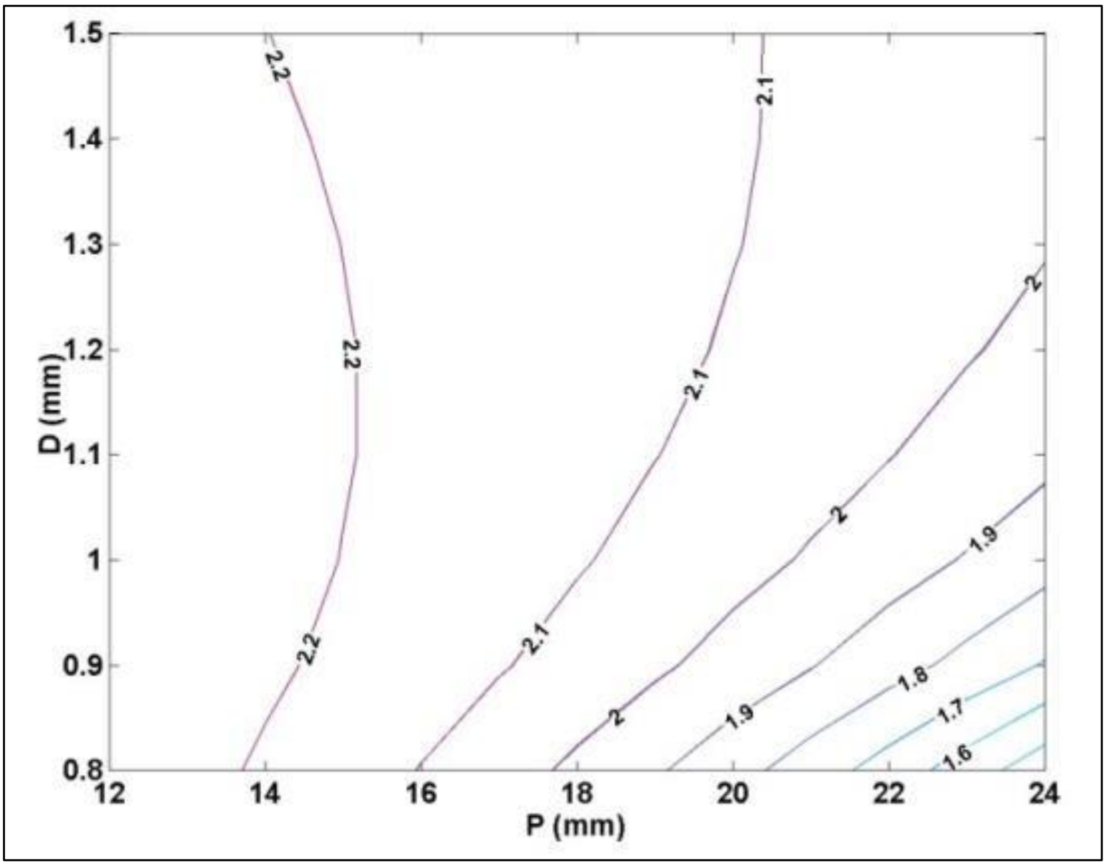


Figure B-7: Exergy efficiency contours in various perforation diameter and pitch, (Motahar and Alemrajabi 2010)

Table B-8: Commercial technical specification, Lubi, Enerconcept Technologies: www.enerconcept.com.

System General data	**SI**
Peak instantaneous efficiency	80,7%
Maximum power output	800 W/m^2
Air flow range per panel	5-50 m^3/h
Operation mode	outside air, open-loop
Maximum temperature increase	45°C
Stagnation temperature	110°C
Max. pressure drop. @ 30 cfm (50 m^3/h) per panel	125 Pa
Solar absorptance (black absorber)	
Hemispheric emissivity (black absorber)	
Solar transmittance of polycarbonate	
Test standard	0,95
Date of testing in SRCC-accredited laboratory	0,88
Efficiency drop due to wind	0,86
Lubi™ Panel	CSA-F-378
Length	904mm
Height	320mm
Overall panel depth	8,3 mm
Perforations - number	906
Perforations - diameter	2 mm
Perforations - distance c/c	16 mm
Spacers for horizontal thermal expansion	4
Spacers for vertical thermal expansion	2
Maximum thermal expansion (longitudinal)	7,5 mm
Material	UV-treated polycarbonate
Surface finish	smooth, with matt back side

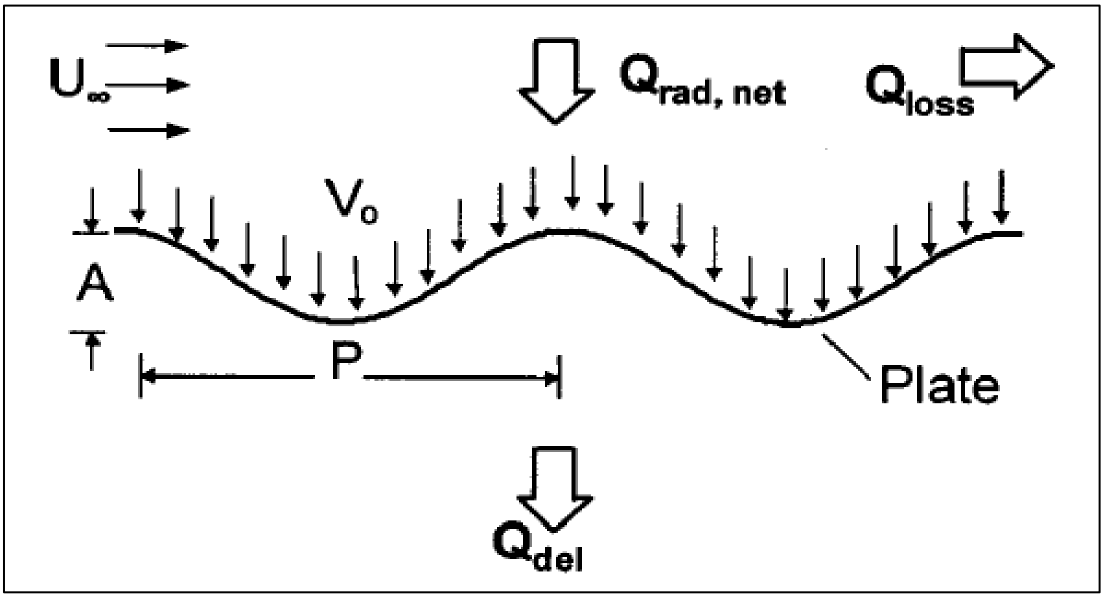


Figure B-8: Sinusoidal corrugated plate geometry. A: amplitude; P: wavelength, (Gawlik and Kutscher 2002)

Table B-9: Plate geometries, (Gawlik and Kutscher 2002)

Plate designation	Amplitude (cm)	Pitch (cm)	Aspect ratio
Base case	1.42	6.68	0.213
Low aspect-1	1.42	13.4	0.106
Low aspect-2	0.71	6.68	0.106
High aspect	1.42	3.34	0.426

Table B-10: Parameters for the experiment tests, (Chan et al. 2011)

Parameter	Value/ range
Solar radiation intensity (I), W/m^2	300 - 800
Suction velocity (vs), m/s	0.03 - 0.05
Plenum depth (d), m	0.25
Pressure drop across the collector (ΔP), Pa	12 - 36
Pitch (P), m	0.012
Hole diameter (D), m	0.0012
Height of the collector (H), m	2.0
Width of the collector (W), m	1.0

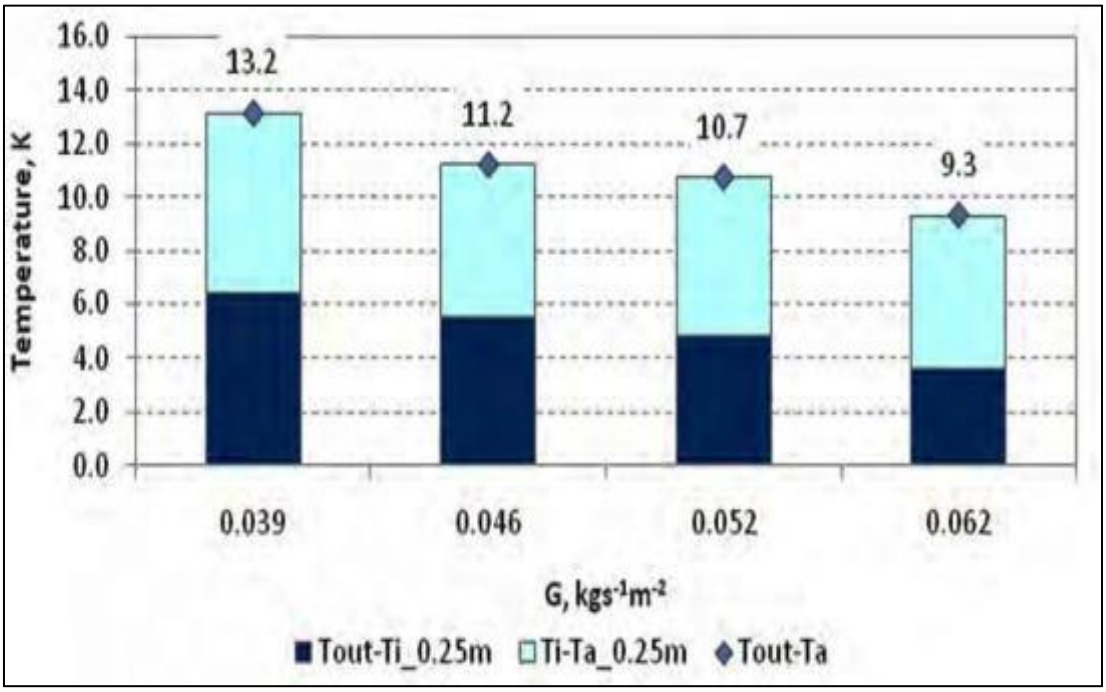


Figure B-9: Results of total, normal and vertical temperature rise at different suction mass flow rates, (Chan et al. 2011)

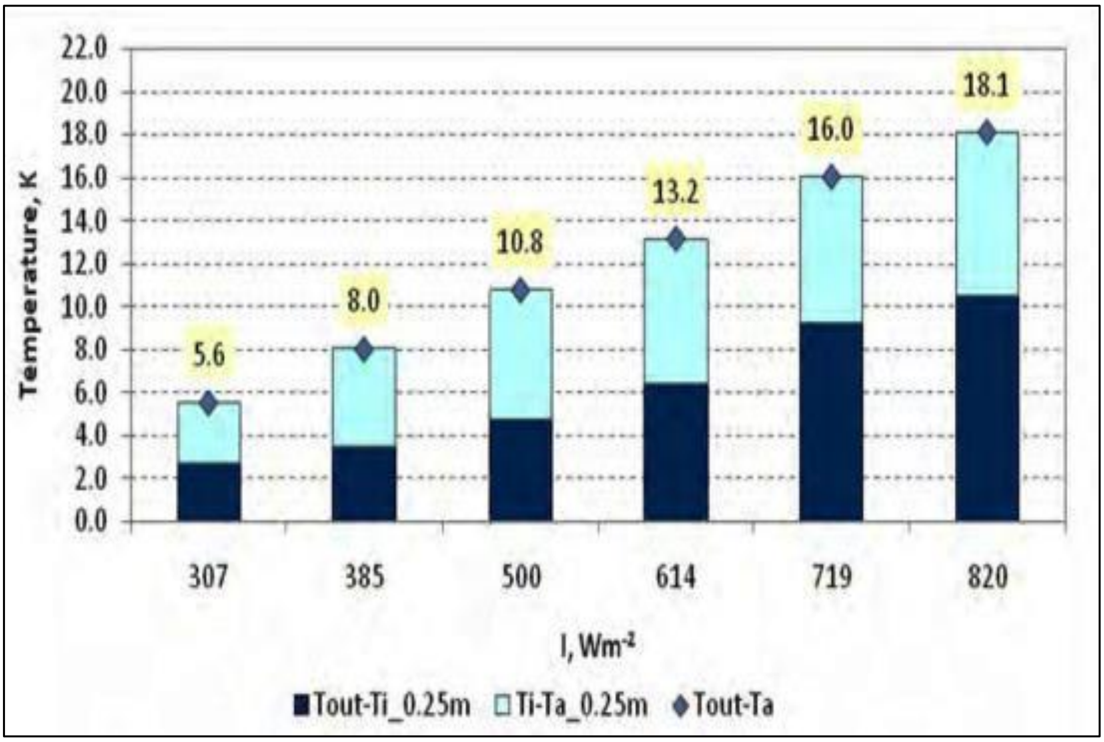


Figure B-10: Results of total, normal and vertical temperature rise at different solar radiation intensities, (Chan et al. 2011)

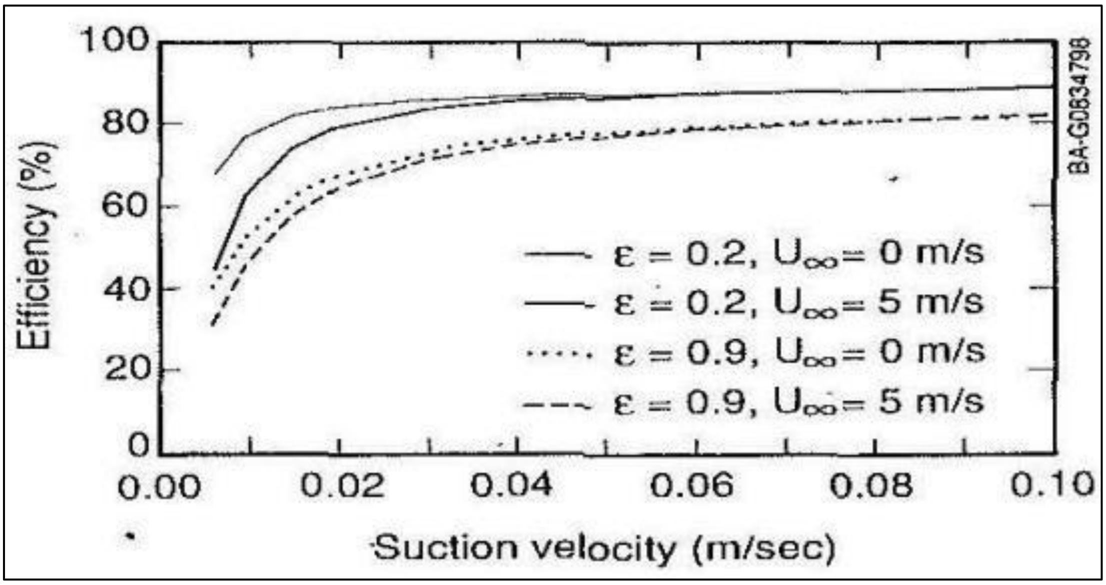


Figure B-11: Predicted efficiency of vertical TSCs as a function of suction velocity, absorber emissivity, and wind speed, (Kutscher et al. 1993)

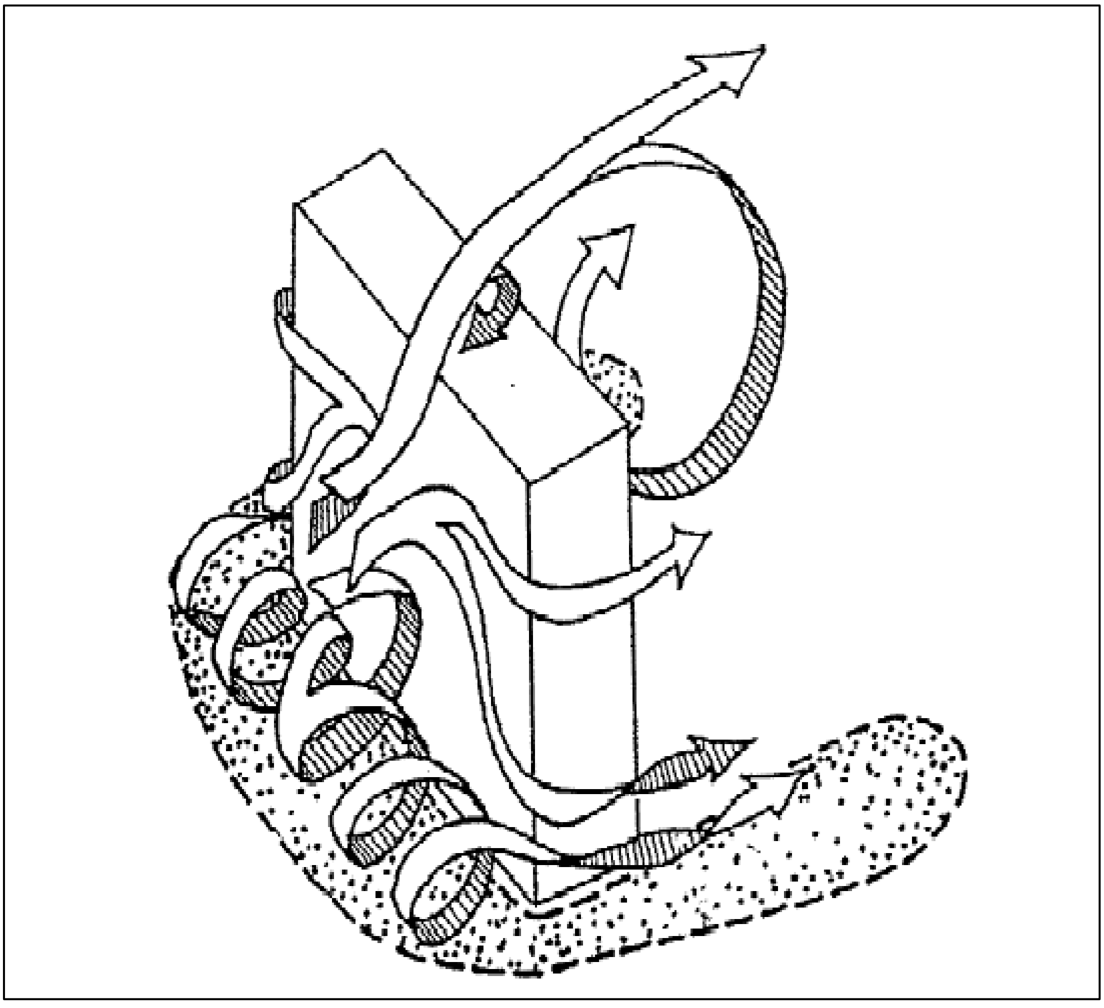


Figure B-12: Schematic representation of typical large scale flow patterns around a building with wind incident normal to one wall, (Fleck et al. 2002)

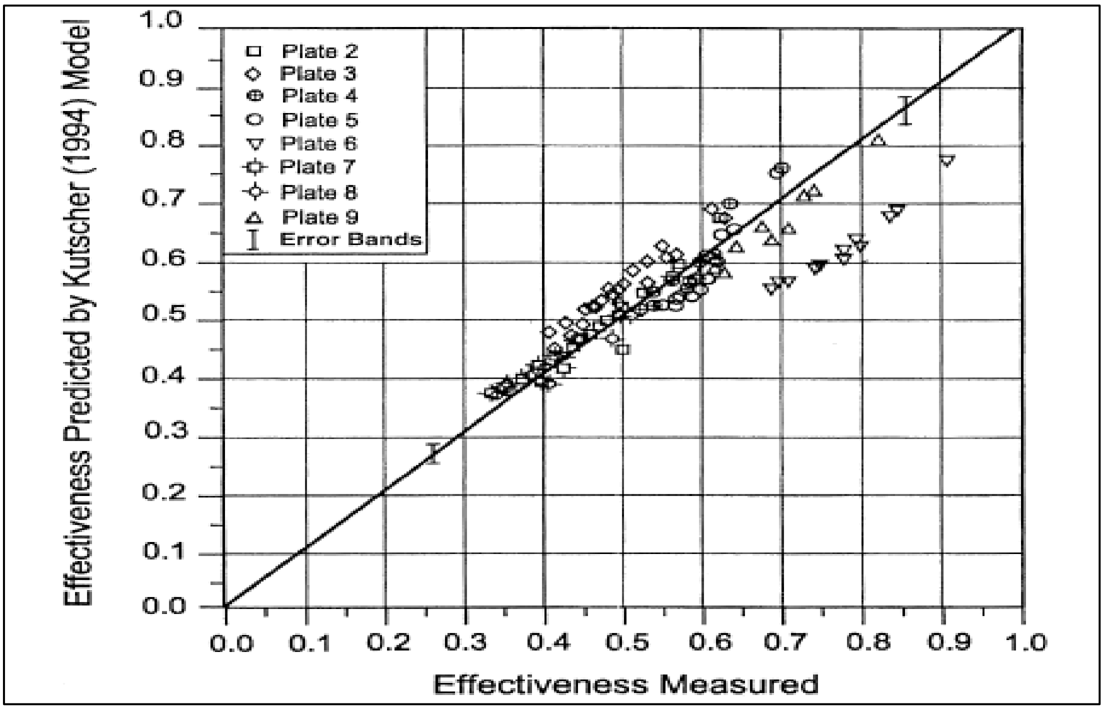


Figure B-13: Comparison of the measured effectiveness with the corresponding effectiveness predicted using the model of Kutscher (1994), (Van Decker et al. 2001)

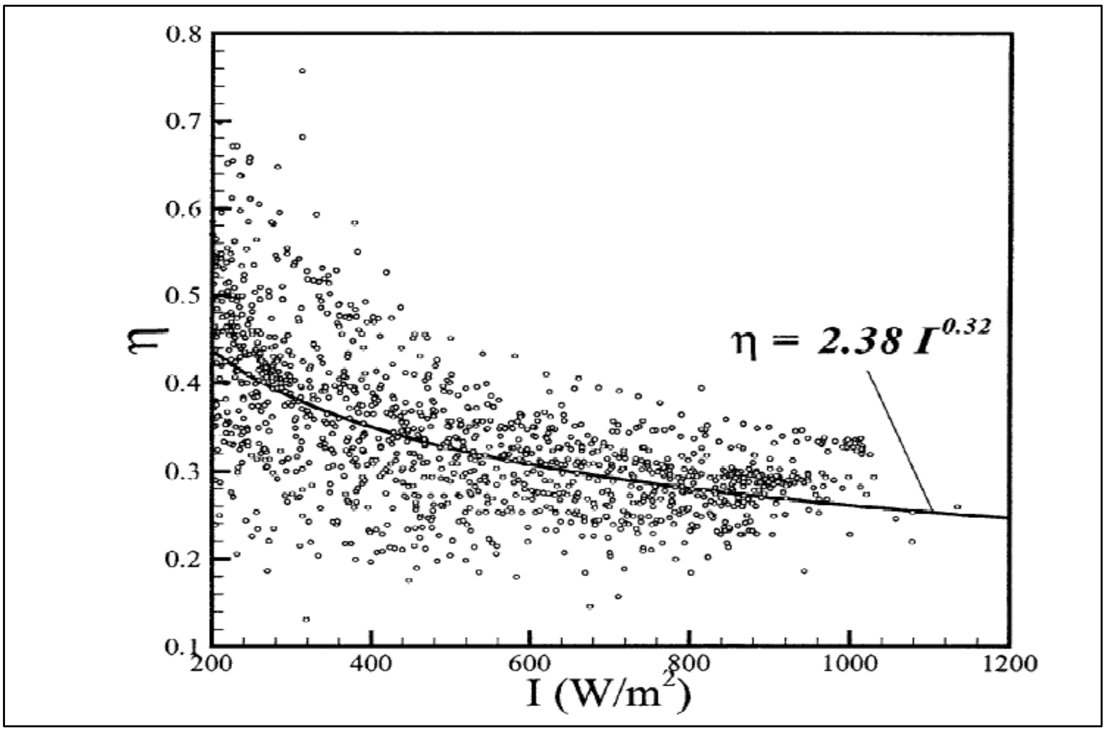


Figure B-14: Decreasing TSCs efficiency with increasing solar irradiation, (Fleck et al. 2002)

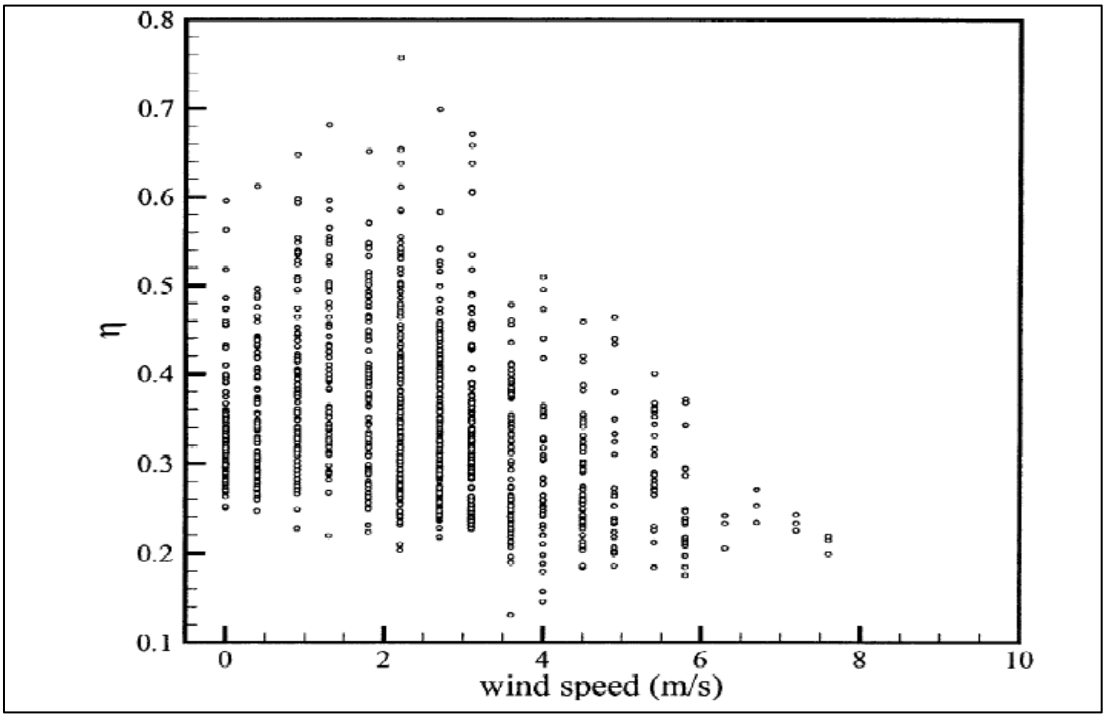


Figure B-15: TSCs efficiency and mean wind speed (5 min averages measured on a 10 m mast) indicating peak efficiency at around 1.5m/s, (Fleck et al. 2002)

Table B-11: Specifications of the two plate geometries studied, (Gawlik et al. 2005)

Plate designator	Plate 5	Plate 8
Hole diameter (mm)	3.2	1.6
Distance between hole centres (mm)	13.5	27
Porosity (%)	5	0.3
Thickness (mm)	1.6	1.6

Table B-12: Summary of the experimental results for two plate geometries and two plate materials, (Gawlik et al. 2005)

Mass flux (kg/s-m²) ±2%	Plate 5				Plate 8			
	Aluminum		Styrene		Aluminum		Styrene	
	ΔT (°C) ±0.5°C	η (%)	ΔT (°C) ±0.5°C	η (%)	ΔT (°C) ±0.5°C	η (%)	ΔT (°C) ±0.5°C	η (%)
0.02	26.5	63±4	26.4	63±4	26.2	63±4	24.8	60±3
0.04	15.7	76±5	15.7	75±5	16.0	77±5	15.8	75±5
0.06	11.3	82±6	10.7	77±5	11.7	84±6	11.6	83±6

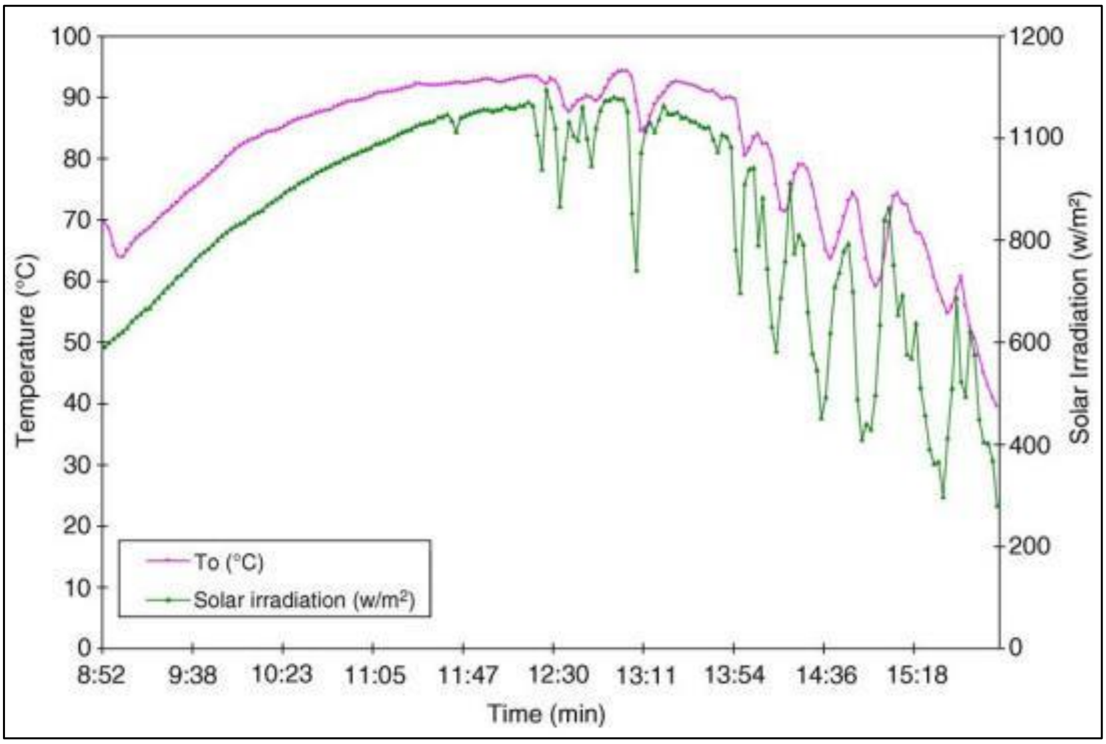


Figure B-16: TSCs outlet temperature to solar radiation fluctuation at a sunny daytime, (Ben-Amara et al. 2005)

Table B-13: Effectiveness of different types of solar air collector, (Wang et al. 2006)

TYPE	Flat Collector		Unglazed Untranspired Collector		Transpired Collector		Solar
Plenum Width (mm)	200	50	200	50	200	50	
Effectiveness	0.51	0.788	0.47	0.62	0.7	0.72	

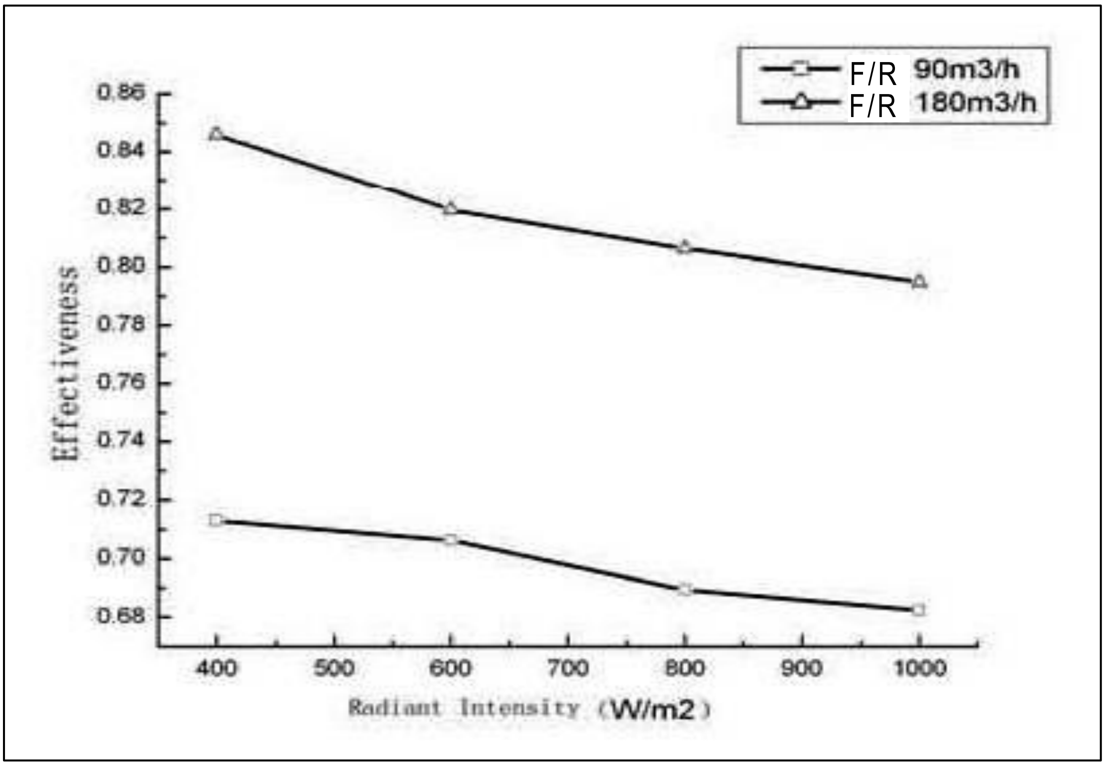


Figure B-17: CFD results in the form of Effectiveness versus Solar irradiation (Radiant Intensity) F/R: Flow Rate, (Wang et al. 2006)

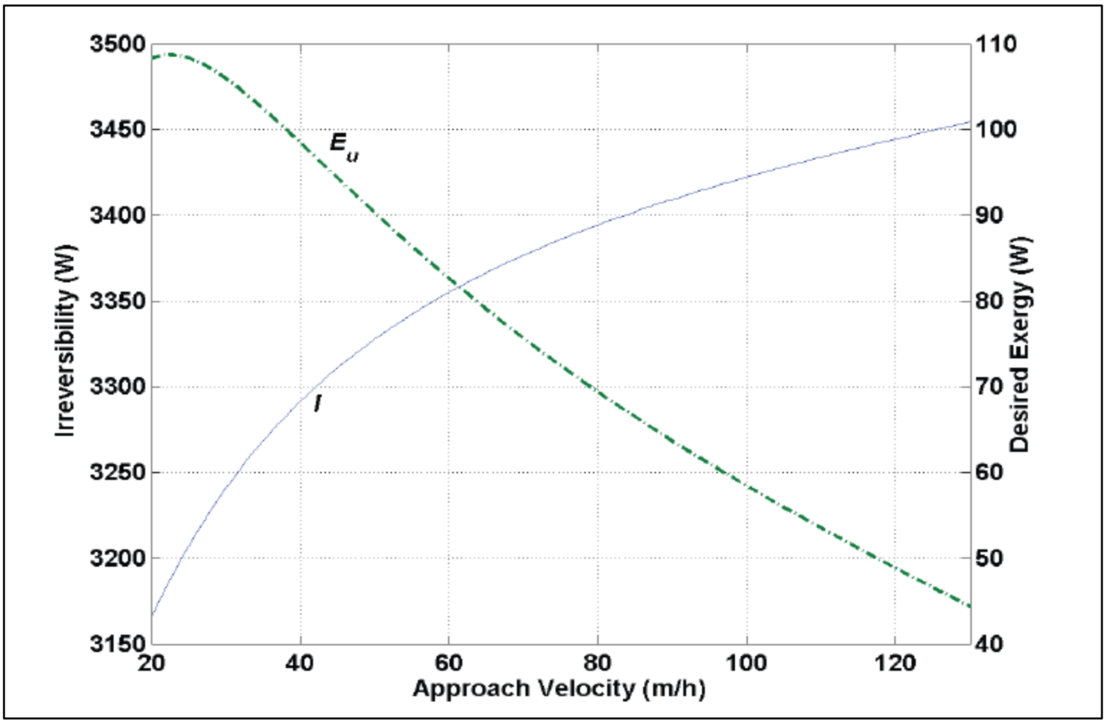


Figure B-18: Variation of desired exergy and TSCs irreversibility with approach velocity, (Motahar and Alemrajabi 2010)

Table B-14: Summary of selective core team members' roles among the seven IDP phases, (BC GBR 2007)

	Phase 1: Pre-Design	Phase 2: Schematic Design	Phase 3: Design Development	Phase 4: Construction Documentation	Phase 5: Bidding, Construction, Commissioning	Phase 6: Building Operation	Phase 7: Post-Occupancy
Client or Owner's Representative	• Hire motivated & experienced team. • Communicate project vision & goals.	• Work with team in decision-making processes. • Assist with external funding requests.	• Help team make decisions that confirm goals & reflect lifecycle thinking.	• Help the team ensure that decisions made in previous stages are not lost with value engineering process.	• Ensure that the owner & users become involved & excited about progress of project.	• Coordinate operations staff and user training.	• Work with owner to execute monitoring and Building Performance Evaluation (BPE).
Project Manager (PM)	• Work with the client to kick- start the project and coordinate the team	• Ensure effective communication between team	• Help the team stay on schedule and on budget. • Ensure new team members have necessary information.	• Help the team stay on schedule and on budget. • Ensure new team members have necessary information.	• Help the team stay on schedule and on budget. Ensure new team members have necessary information	• Ensure a seamless handover to the client	N/A
Architect	• Ensure that other consultants are part of early consultations, especially on building form & programming.	• Work with the design facilitator to schedule charities early to gain maximum benefit.	• Coordinate strategies and present cohesive information on pros and cons of design solutions	• Ensure all sustainable design features are well documented in so contractors can easily follow requirements.	• Work with the contractor to ensure compliance with new strategies/ technologies.	• Participate in user and operations staff training to ensure proper handover.	• Perform or participate in BPE. • Work to spread information on results within industry.
IDP Facilitator / Champion	• Work with PM and architect to set up initial goal setting workshops.	• Facilitate workshops. • Ensure adequate documentation is provided so the team know their deliverables & goals.	• Continue to facilitate workshops – evolve the format to reflect the progress of the design process	• Continue to facilitate workshops – evolve the format to reflect the progress of the design process	N/A	N/A	• Work with BPE team to help them understand how IDP goals were set, what they were, etc

Table B-14 Continued: Summary of selective core team members' roles among the seven IDP phases, (BC GBR 2007)

	Phase 1: Pre-Design	Phase 2: Schematic Design	Phase 3: Design Development	Phase 4: Construction Documentation	Phase 5: Bidding, Construction, Commissioning	Phase 6: Building Operation
Structural Engineer	• Consider impact of structural choices on form & massing.	• Consider the impact of structural choices on daylighting potential, materials' environmental impacts… etc.	• Provide input into life-cycle and durability discussions.	• Ensure that durability & sustainable of requirements, materials construction systems…	• Work with the contractor to ensure compliance with new strategies/ technologies.	• Participate in user and operations staff training to ensure proper handover.
Mechanical Engineer with expertise in energy analysis and simulation (may need to be more than one person)	• Provide feedback on impact of massing & orientation on mechanical systems and energy performance. • Work with the design team to find climate-specific opportunities & features that could assist the building operation.	• Provide input into the discussions on envelope performance, energy targets, and other building components that impact mechanical systems. • Help the team to understand the local micro-climate can impacts on the building. • Assist with setting an energy benchmark	• Provide input into or perform life-cycle calculations and energy use calculations & discussions. • Refine system choices to stay within the established energy targets. • Perform simulations to examine thermal comfort and daylighting performance.	• Work with design team to refine system choices to stay within the established energy targets. • Simulate thermal comfort and daylighting performance. • Ensure that equipment selections, adhesive choices, materials selections, and construction methods reflect sustainable goals.	• Ensure compliance with new strategies/ technologies. • Design and coordinate the construction and monitoring of experimental mock-ups before full-scale construction • Quantify energy impact of changes during construction.	• Participate in commissioning and operations to ensure proper handover and to understand energy optimization options.
Green Design Specialist	• Bring broad knowledge of green design strategies to the table	• Help team identify potential green design strategies.	• Direct team to green design resources	• Review specifications to ensure design intent still met.	• Deliver or participate in contractor and sub-training on green design and certification	N/A
General Contractor orConstruction Manager	• Engage in the project as early as possible. • Help design team to understand constructability issues associated with site & specific program requirements.	• Help the design team to understand how goals can be met most easily with construction technologies available.	• Work with the design team to accurately cost differences in construction methods, materials, etc. based on current market conditions	• Help the team with specification language to ensure that green requirements are easily understood & implemented.	• Take charge to ensure that green strategies are executed & documented by all sub-trades. • Help coordinate on-site education with the design team	• Work with the design team to ensure that a smooth handover to facilities staff is possible. • Help with education of users and facilities staff

APPENDIX C ||

SPSS ANALYSIS

Table C-1: Transformation of r to z, (Pallant 2011)

r	z_r	r	z_r	r	z_r	r	z_r	r	z_r
.000	.000	.200	.203	.400	0.424	.600	.693	.800	1.099
.005	.005	.205	.208	.405	0.430	.605	.701	.805	1.113
.010	.010	.210	.213	.410	0.436	.610	.709	.810	1.127
.015	.010	.215	.218	.415	0.442	.615	.717	.815	1.142
.020	.015	.220	.224	.420	0.448	.620	.725	.820	1.157
.025	.020	.225	.229	.425	.454	.625	.733	.825	1.172
.030	.025	.230	.234	.430	.460	.630	.741	.830	1.188
.035	.030	.235	.239	.435	.466	.635	.750	.835	1.204
.040	.035	.240	.245	.440	.472	.640	.758	.840	1.221
.045	.045	.245	.250	.445	.478	.645	.767	.845	1.238
.050	.050	.250	.55	.450	.485	.650	.775	.850	1.256
.055	.055	.255	.261	.455	.491	.655	.784	.855	1.274
.060	.060	.260	.266	.460	.497	.660	.793	.860	1.293
.065	.065	.265	.271	.465	.504	.665	.802	.865	1.313
.070	.070	.270	.277	.470	.510	.670	.811	.870	1.333
.075	.075	.275	.282	.475	.517	.675	.820	.875	1.354
.080	.080	.280	.288	.480	.523	.680	.829	.880	1.376
.085	.085	.285	.293	.485	.530	.685	.838	.885	1.398
.090	.090	.290	.299	.490	.536	.690	.848	.890	1.422
.095	.095	.295	.304	.495	.543	.695	.858	.895	1.447
.100	.100	.300	.310	.500	.549	.700	.867	.900	1.472
.105	.105	.305	.315	.505	.556	.705	.877	.905	1.499
.110	.110	.310	.321	.510	.563	.710	.887	.910	1.528
.115	.116	.315	.326	.515	.570	.715	.897	.915	1.557
.120	.121	.320	.332	.520	.576	.720	.908	.920	1.589
.125	.126	.325	.337	.525	.583	.725	.918	.925	1.623
.130	.131	.330	.343	.530	.590	.730	.929	.930	1.658
.135	.136	.335	.348	.535	.597	.735	.940	.935	1.697
.140	.141	.340	.354	.540	.604	.740	.950	.940	1.738
.145	.146	.345	.360	.545	.611	.745	.962	.945	1.783
.150	.151	.350	.365	.550	.618	.750	.973	.950	1.832
.155	.156	.355	.371	.555	.626	.755	.984	.955	1.886
.160	.161	.360	.377	.560	.633	.760	.996	.960	1.946
.165	.167	.365	.383	.565	.640	.765	.1.008	.965	2.014
.170	.172	.370	.388	.570	.648	.770	1.020	.970	2.092
.175	.177	.375	.394	.575	.655	.775	1.033	.975	2.185
.180	.182	.380	.400	.580	.662	.780	1.045	.980	2.298
.185	.187	.385	.406	.585	.670	.785	1.058	.985	2.443
.190	.192	.390	.412	.590	.678	.790	1.071	.990	2.647
.195	.198	.395	.418	.595	.685	.795	1.085	.995	2.994

Table C-2: Distribution of respondents in a crosstabulation of profession and location

Location		Profession			Total (1,295)
		Architect	Engineer	Other	
Afghanistan	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Algeria	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Argentina	Count	0	0	1	1
	% within Profession	0.0%	0.0%	0.5%	0.1%
Australia	Count	8	1	1	10
	% within Profession	1.0%	0.3%	0.5%	0.8%
Austria	Count	10	2	2	14
	% within Profession	1.2%	0.7%	1.0%	1.1%
Bahrain	Count	0	1	0	1
	% within Profession	0.0%	0.3%	0.0%	0.1%
Bangladesh	Count	2	0	0	2
	% within Profession	0.2%	0.0%	0.0%	0.2%
Belgium	Count	8	1	0	9
	% within Profession	1.0%	0.3%	0.0%	0.7%
Belize	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Brazil	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Canada	Count	67	31	26	124
	% within Profession	8.3%	10.4%	13.4%	9.6%
Chile	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
China	Count	1	0	1	2
	% within Profession	0.1%	0.0%	0.5%	0.2%
Congo, Democratic Republic	Count	0	1	0	1
	% within Profession	0.0%	0.3%	0.0%	0.1%
Congo, Republic of the	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Costa Rica	Count	0	0	1	1
	% within Profession	0.0%	0.0%	0.5%	0.1%
Cyprus	Count	3	1	1	5
	% within Profession	0.4%	0.3%	0.5%	0.4%
Czech Republic	Count	2	0	0	2
	% within Profession	0.2%	0.0%	0.0%	0.2%
Denmark	Count	5	1	0	6
	% within Profession	0.6%	0.3%	0.0%	0.5%
Egypt	Count	2	0	0	2
	% within Profession	0.2%	0.0%	0.0%	0.2%
Estonia	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Ethiopia	Count	1	0	1	2
	% within Profession	0.1%	0.0%	0.5%	0.2%

Table C-2 Continued 1: Distribution of respondents in a crosstabulation of profession and location

Location		Profession			Total (1,295)
		Architect	Engineer	Other	
Finland	Count	2	1	0	3
	% within Profession	0.2%	0.3%	0.0%	0.2%
France	Count	13	6	6	25
	% within Profession	1.6%	2.0%	3.1%	1.9%
Germany	Count	13	7	6	26
	% within Profession	1.6%	2.4%	3.1%	2.0%
Greece	Count	8	3	0	11
	% within Profession	1.0%	1.0%	0.0%	0.8%
Hong Kong	Count	1	1	0	2
	% within Profession	0.1%	0.3%	0.0%	0.2%
Hungary	Count	3	0	0	3
	% within Profession	0.4%	0.0%	0.0%	0.2%
India	Count	1	3	1	5
	% within Profession	0.1%	1.0%	0.5%	0.4%
Indonesia	Count	1	0	1	2
	% within Profession	0.1%	0.0%	0.5%	0.2%
Iran	Count	1	1	0	2
	% within Profession	0.1%	0.3%	0.0%	0.2%
Ireland	Count	24	1	2	27
	% within Profession	3.0%	0.3%	1.0%	2.1%
Italy	Count	25	8	1	34
	% within Profession	3.1%	2.7%	0.5%	2.6%
Kuwait	Count	0	1	0	1
	% within Profession	0.0%	0.3%	0.0%	0.1%
Lebanon	Count	2	0	0	2
	% within Profession	0.2%	0.0%	0.0%	0.2%
Lithuania	Count	0	1	0	1
	% within Profession	0.0%	0.3%	0.0%	0.1%
Luxembourg	Count	0	2	0	2
	% within Profession	0.0%	0.7%	0.0%	0.2%
Malaysia	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Malta	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Mauritius	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Mexico	Count	1	2	1	4
	% within Profession	0.1%	0.7%	0.5%	0.3%
Netherlands	Count	28	22	15	65
	% within Profession	3.5%	7.4%	7.7%	5.0%
New Zealand	Count	1	0	1	2
	% within Profession	0.1%	0.0%	0.5%	0.2%
Nigeria	Count	2	0	0	2
	% within Profession	0.2%	0.0%	0.0%	0.2%
Norway	Count	6	2	2	10
	% within Profession	0.7%	0.7%	1.0%	0.8%

Table C-2 Continued 2: Distribution of respondents in a crosstabulation of profession and location

Location		Profession			Total (1,295)
		Architect	Engineer	Other	
Pakistan	Count	5	0	0	5
	% within Profession	0.6%	0.0%	0.0%	0.4%
Palestine	Count	2	1	1	4
	% within Profession	0.2%	0.3%	0.5%	0.3%
Poland	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Portugal	Count	6	2	1	9
	% within Profession	0.7%	0.7%	0.5%	0.7%
Qatar	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Romania	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Russia	Count	0	0	1	1
	% within Profession	0.0%	0.0%	0.5%	0.1%
Saudi Arabia	Count	1	2	0	3
	% within Profession	0.1%	0.7%	0.0%	0.2%
Serbia	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Sierra Leone	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Singapore	Count	1	1	0	2
	% within Profession	0.1%	0.3%	0.0%	0.2%
Slovenia	Count	0	3	4	7
	% within Profession	0.0%	1.0%	2.1%	0.5%
South Africa	Count	0	0	2	2
	% within Profession	0.0%	0.0%	1.0%	0.2%
South Korea	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Spain	Count	15	6	3	24
	% within Profession	1.9%	2.0%	1.5%	1.9%
Sweden	Count	6	1	2	9
	% within Profession	0.7%	0.3%	1.0%	0.7%
Switzerland	Count	4	9	4	17
	% within Profession	0.5%	3.0%	2.1%	1.3%
Syria	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Taiwan	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Thailand	Count	0	2	0	2
	% within Profession	0.0%	0.7%	0.0%	0.2%
Turkey	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Ukraine	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%

Table C-2 Continued 3: Distribution of respondents in a crosstabulation of profession and location

Location		Profession			Total (1,295)
		Architect	Engineer	Other	
United Arab Emirates	Count	8	3	1	12
	% within Profession	1.0%	1.0%	0.5%	0.9%
United Kingdom – England	Count	105	91	46	242
	% within Profession	13.1%	30.6%	23.7%	18.7%
United Kingdom - Wales	Count	48	14	16	78
	% within Profession	6.0%	4.7%	8.2%	6.0%
United Kingdom - Scotland	Count	43	7	4	54
	% within Profession	5.3%	2.4%	2.1%	4.2%
United Kingdom - North Ireland	Count	4	3	0	7
	% within Profession	0.5%	1.0%	0.0%	0.5%
United States	Count	292	52	38	382
	% within Profession	36.3%	17.5%	19.6%	29.5%
Uruguay	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Uzbekistan	Count	1	0	1	2
	% within Profession	0.1%	0.0%	0.5%	0.2%
Venezuela	Count	1	0	0	1
	% within Profession	0.1%	0.0%	0.0%	0.1%
Total	Count	**804**	**297**	**194**	**1295**
	% within Profession	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Table C-3: Crosstabulation of work field and profession

Work Field		Profession			Total
		Architect	Engineer	Other	
Academia	**Count**	114	99	80	293
	% within Work Field	38.9%	33.8%	27.3%	100.0%
	% within Profession	14.2%	33.3%	41.2%	22.6%
Consultancy	**Count**	463	132	43	638
	% within Work Field	72.6%	20.7%	6.7%	100.0%
	% within Profession	57.6%	44.4%	22.2%	49.3%
Contracting	**Count**	86	18	23	127
	% within Work Field	67.7%	14.2%	18.1%	100.0%
	% within Profession	10.7%	6.1%	11.9%	9.8%
Local Government	**Count**	26	10	6	42
	% within Work Field	61.9%	23.8%	14.3%	100.0%
	% within Profession	3.2%	3.4%	3.1%	3.2%
National Government	**Count**	15	13	12	40
	% within Work Field	37.5%	32.5%	30.0%	100.0%
	% within Profession	1.9%	4.4%	6.2%	3.1%
Other	**Count**	100	25	30	155
	% within Work Field	64.5%	16.1%	19.4%	100.0%
	% within Profession	12.4%	8.4%	15.5%	12.0%
Total	**Count**	**804**	**297**	**194**	**1295**
	% within Work Field	**62.1%**	**22.9%**	**15.0%**	**100.0%**
	% within Profession	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Table C-4: Crosstabulation of year of experience and profession

Years of Experience		Profession			Total
		Architect	Engineer	Other	
Less than 5	Count	48	39	34	121
	% within Experience	39.7%	32.2%	28.1%	100.0%
	% within Profession	6.0%	13.1%	17.5%	9.3%
5 - 10	Count	98	63	34	195
	% within Experience	50.3%	32.3%	17.4%	100.0%
	% within Profession	12.2%	21.2%	17.5%	15.1%
11 - 15	Count	82	32	29	143
	% within Experience	57.3%	22.4%	20.3%	100.0%
	% within Profession	10.2%	10.8%	14.9%	11.0%
More than 15	Count	576	163	97	836
	% within Experience	68.9%	19.5%	11.6%	100.0%
	% within Profession	71.6%	54.9%	50.0%	64.6%
Total	Count	**804**	**297**	**194**	**1295**
	% within Experience	**62.1%**	**22.9%**	**15.0%**	**100.0%**
	% within Profession	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Table C-5: Crosstabulation of highest academic degree and profession

Highest academic degree		Profession			Total
		Architect	Engineer	Other	
PhD	Count	74	77	54	205
	% within Highest academic degree	36.1%	37.6%	26.3%	100.0%
	% within Profession	9.2%	25.9%	27.8%	15.8%
MSc / MA	Count	395	124	59	578
	% within Highest academic degree	68.3%	21.5%	10.2%	100.0%
	% within Profession	49.1%	41.8%	30.4%	44.6%
BSc / BA	Count	266	83	49	398
	% within Highest academic degree	66.8%	20.9%	12.3%	100.0%
	% within Profession	33.1%	27.9%	25.3%	30.7%
Other	Count	69	13	32	114
	% within Highest academic degree	60.5%	11.4%	28.1%	100.0%
	% within Profession	8.6%	4.4%	16.5%	8.8%
Total	Count	**804**	**297**	**194**	**1295**
	% within Highest academic degree	**62.1%**	**22.9%**	**15.0%**	**100.0%**
	% within Profession	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Table C-6: Crosstabulation of project type involvement and profession

Project Type		Profession			Total
		Architect	Engineer	Other	
Commercial	Count	460	160	79	699
	% within Project involvement	65.8%	22.9%	11.3%	100.0%
	% within Profession	57.2%	53.9%	40.7%	
Residential	Count	555	118	86	759
	% within Project involvement	73.1%	15.5%	11.3%	100.0%
	% within Profession	69.0%	39.7%	44.3%	
Institutional	Count	343	136	76	555
	% within Project involvement	61.8%	24.5%	13.7%	100.0%
	% within Profession	42.7%	45.8%	39.2%	
Industrial	Count	152	81	40	273
	% within Project involvement	55.7%	29.7%	14.7%	100.0%
	% within Profession	18.9%	27.3%	20.6%	
Other	Count	133	76	53	262
	% within Project involvement	50.8%	29.0%	20.2%	100.0%
	% within Profession	16.5%	25.6%	27.3%	

Table C-7: Crosstabulation of awareness of TSC and profession

Awareness		**Profession**			**Total**
		Architect	Engineer	Other	
Expert	Count	6	14	2	22
	% within Awareness	27.3%	63.6%	9.1%	100.0%
	% within Profession	0.7%	4.7%	1.0%	1.7%
Aware	Count	402	154	87	643
	% within Awareness	62.5%	24.0%	13.5%	100.0%
	% within Profession	50.0%	51.9%	44.8%	49.7%
Unaware	Count	396	129	105	630
	% within Awareness	62.9%	20.5%	16.7%	100.0%
	% within Profession	49.3%	43.4%	54.1%	48.6%
Total	Count	804	297	194	1295
	% within Awareness	62.1%	22.9%	15.0%	100.0%
	% within Profession	100.0%	100.0%	100.0%	100.0%

Table C-8: Crosstabulation of awareness of TSC within Geographic region

Awareness	Geographic Region					Total
	Canada	USA	UK	Europe	Other Countries	
Expert						
Count	4	3	4	6	5	22
% within Awareness	18.2%	13.6%	18.2%	27.3%	22.7%	100.0%
% within Geographic Region	3.2%	.8%	1.0%	1.9%	5.6%	1.7%
% of Total	0.3%	0.2%	0.3%	0.5%	0.4%	1.7%
Aware						
Count	84	155	197	164	43	643
% within Awareness	13.1%	24.1%	30.6%	25.5%	6.7%	100.0%
% within Geographic Region	67.7%	40.6%	51.7%	51.4%	48.3%	49.7%
% of Total	6.5%	12.0%	15.2%	12.7%	3.3%	49.7%
Unaware						
Count	36	224	180	149	41	630
% within Awareness	5.7%	35.6%	28.6%	23.7%	6.5%	100.0%
% within Geographic Region	29.0%	58.6%	47.2%	46.7%	46.1%	48.6%
% of Total	2.8%	17.3%	13.9%	11.5%	3.2%	48.6%
Total						
Count	124	382	381	319	89	1295
% within Awareness	9.6%	29.5%	29.4%	24.6%	6.9%	100.0%
% within Geographic Region	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
% of Total	9.6%	29.5%	29.4%	24.6%	6.9%	100.0%

Table C-9: General awareness (two categories of overall awareness which represents both expert and aware respondents, and unaware due to Chi-square statistical rules) in a crosstab with geographic region.

General awareness of TSC	Geographic Region					Total
	Canada	USA	UK	Europe	Other Countries	
Overall awareness						
Count	88	158	201	170	48	665
% within General awareness	13.2%	23.8%	30.2%	25.6%	7.2%	100.0%
% within Geographic Region	71.0%	41.4%	52.8%	53.3%	53.9%	51.4%
% of Total	6.8%	12.2%	15.5%	13.1%	3.7%	51.4%
Unaware						
Count	36	224	180	149	41	630
% within General awareness	5.7%	35.6%	28.6%	23.7%	6.5%	100.0%
% within Geographic Region	29.0%	58.6%	47.2%	46.7%	46.1%	48.6%
% of Total	2.8%	17.3%	13.9%	11.5%	3.2%	48.6%
Total						
Count	124	382	381	319	89	1295
% within General awareness	9.6%	29.5%	29.4%	24.6%	6.9%	100.0%
% within Geographic Region	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
% of Total	9.6%	29.5%	29.4%	24.6%	6.9%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	35.380[a]	4	.000
Likelihood Ratio	36.102	4	.000
Linear-by-Linear Association	.000	1	.988
N of Valid Cases	1295		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 43.30.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.165	.000
	Cramer's V	.165	.000
N of Valid Cases		1295	

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Table C-10: Crosstabulation of TSC awareness within project involvement

Project Involvement	Awareness of Transpired Solar Collectors technology						Total	
	Expert		Aware		Unaware			
	Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %
Commercial	12	1.7%	384	54.9%	303	43.3%	699	100.0%
Residential	15	2.0%	393	51.8%	351	46.2%	759	100.0%
Institutional	10	1.8%	305	55.0%	240	43.2%	555	100.0%
Industrial	11	4.0%	153	56.0%	109	39.9%	273	100.0%
Other	6	2.3%	113	43.1%	143	54.6%	262	100.0%

Table C-11: Crosstabulation of TSC awareness within working field

Work Field		Awareness of Transpired Solar Collectors technology			Total
		Expert	Aware	Unaware	
Academia	Count	11	142	140	293
	% within Work Field	3.8%	48.5%	47.8%	100.0%
	% within Awareness	50.0%	22.1%	22.2%	22.6%
	% of Total	0.8%	11.0%	10.8%	22.6%
Consultancy	Count	7	337	294	638
	% within Work Field	1.1%	52.8%	46.1%	100.0%
	% within Awareness	31.8%	52.4%	46.7%	49.3%
	% of Total	0.5%	26.0%	22.7%	49.3%
Contracting	Count	2	58	67	127
	% within Work Field	1.6%	45.7%	52.8%	100.0%
	% within Awareness	9.1%	9.0%	10.6%	9.8%
	% of Total	0.2%	4.5%	5.2%	9.8%
Local Government	Count	0	20	22	42
	% within Work Field	0.0%	47.6%	52.4%	100.0%
	% within Awareness	0.0%	3.1%	3.5%	3.2%
	% of Total	0.0%	1.5%	1.7%	3.2%
National Government	Count	1	18	21	40
	% within Work Field	2.5%	45.0%	52.5%	100.0%
	% within Awareness	4.5%	2.8%	3.3%	3.1%
	% of Total	0.1%	1.4%	1.6%	3.1%
Other	Count	1	68	86	155
	% within Work Field	0.6%	43.9%	55.5%	100.0%
	% within Awareness	4.5%	10.6%	13.7%	12.0%
	% of Total	0.1%	5.3%	6.6%	12.0%
Total	**Count**	**22**	**643**	**630**	**1295**
	% within Work Field	**1.7%**	**49.7%**	**48.6%**	**100.0%**
	% within Awareness	**100.0%**	**100.0%**	**100.0%**	**100.0%**
	% of Total	**1.7%**	**49.7%**	**48.6%**	**100.0%**

Table C-12: General awareness in a crosstab and Pearson's Chi-square with work field

Work Field	General Awareness of TSC		Total
	Overall Awareness	Unaware	
Academia			
Count	153	140	293
% within Work Field	52.2%	47.8%	100.0%
% of Total	11.8%	10.8%	22.6%
Consultancy			
Count	344	294	638
% within Work Field	53.9%	46.1%	100.0%
% of Total	26.6%	22.7%	49.3%
Contracting			
Count	60	67	127
% within Work Field	47.2%	52.8%	100.0%
% of Total	4.6%	5.2%	9.8%
Local Government			
Count	20	22	42
% within Work Field	47.6%	52.4%	100.0%
% of Total	1.5%	1.7%	3.2%
National Government			
Count	19	21	40
% within Work Field	47.5%	52.5%	100.0%
% of Total	1.5%	1.6%	3.1%
Other			
Count	69	86	155
% within Work Field	44.5%	55.5%	100.0%
% of Total	5.3%	6.6%	12.0%
Total			
Count	665	630	1295
% within Work Field	51.4%	48.6%	100.0%
% of Total	51.4%	48.6%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.999[a]	5	.306
Likelihood Ratio	6.003	5	.306
Linear-by-Linear Association	4.333	1	.037
N of Valid Cases	1295		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 19.46.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.068	.306
	Cramer's V	.068	.306
N of Valid Cases		1295	

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Table C-13: Crosstabulation of solar technologies in general and Profession (Q8)

Solar technologies		Profession			Total
		Architect	Engineer	Other	
Agree	Count	630	231	135	996
	% within Solar technologies	63.3%	23.2%	13.6%	100.0%
	% within Profession	92.0%	90.9%	89.4%	91.4%
	% of Total	57.8%	21.2%	12.4%	91.4%
Disagree	Count	20	10	1	31
	% within Solar technologies	64.5%	32.3%	3.2%	100.0%
	% within Profession	2.9%	3.9%	.7%	2.8%
	% of Total	1.8%	.9%	.1%	2.8%
No Opinion	Count	35	13	15	63
	% within Solar technologies	55.6%	20.6%	23.8%	100.0%
	% within Profession	5.1%	5.1%	9.9%	5.8%
	% of Total	3.2%	1.2%	1.4%	5.8%
Total	Count	685	254	151	1090
	% within Solar technologies	62.8%	23.3%	13.9%	100.0%
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	62.8%	23.3%	13.9%	100.0%

Table C-14: Authority of decision to use TSC in domestic buildings (Q9A)

Decision making categories	Profession		
	Architect	Engineer	Other
	Count	Count	Count
Government Regulation Influence	209	91	60
Client	514	159	105
Architect	370	99	55
Project Manager	34	23	18
Engineering	130	72	25
Integration Design Team (which involves all the above)	220	94	51

Table C-15: Selection of Architect as a decision maker at domestic buildings in a crosstab and Pearson's Chi-square test with geographic region

Q9A: Architect	Geographic Region					Total
	Canada	USA	UK	Europe	Other Countries	
Checked						
Count	39	180	144	131	30	524
% within Q9A: Architect	7.4%	34.4%	27.5%	25.0%	5.7%	100.0%
% within Region	39.0%	55.7%	47.1%	53.0%	41.1%	50.0%
% of Total	3.7%	17.2%	13.7%	12.5%	2.9%	50.0%
Std. Residual	-1.5	1.5	-.7	.7	-1.1	
Unchecked						
Count	61	143	162	116	43	525
% within Q9A: Architect	11.6%	27.2%	30.9%	22.1%	8.2%	100.0%
% within Region	61.0%	44.3%	52.9%	47.0%	58.9%	50.0%
% of Total	5.8%	13.6%	15.4%	11.1%	4.1%	50.0%
Std. Residual	1.5	-1.5	.7	-.7	1.1	
Total						
Count	100	323	306	247	73	1049
% within Q9A: Architect	9.5%	30.8%	29.2%	23.5%	7.0%	100.0%
% within Region	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
% of Total	9.5%	30.8%	29.2%	23.5%	7.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.362[a]	4	.010
Likelihood Ratio	13.425	4	.009
Linear-by-Linear Association	.014	1	.907
N of Valid Cases	1049		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 36.47.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.113	.010
	Cramer's V	.113	.010
N of Valid Cases		1049	

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Table C-16: Selection of 'government regulation influence' in decision making at domestic buildings in a crosstab and Pearson's Chi-square test with geographic region

Q9A: Government Regulation Influence	Geographic Region					Total
	Canada	USA	UK	Europe	Other Countries	
Checked						
Count	34	68	122	107	29	360
% within Q9A: Gov. Reg. Influence	9.4%	18.9%	33.9%	29.7%	8.1%	100.0%
% within Geog. Region	34.0%	21.1%	39.9%	43.3%	39.7%	34.3%
% of Total	3.2%	6.5%	11.6%	10.2%	2.8%	34.3%
Std. Residual	-.1	-4.1	1.7	2.4	.8	
Unchecked						
Count	66	255	184	140	44	689
% within Q9A: Gov. Reg. Influence	9.6%	37.0%	26.7%	20.3%	6.4%	100.0%
% within Geog. Region	66.0%	78.9%	60.1%	56.7%	60.3%	65.7%
% of Total	6.3%	24.3%	17.5%	13.3%	4.2%	65.7%
Std. Residual	.0	2.9	-1.2	-1.7	-.6	
Total						
Count	100	323	306	247	73	1049
% within Q9A: Gov. Reg. Influence	9.5%	30.8%	29.2%	23.5%	7.0%	100.0%
% within Geog. Region	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
% of Total	9.5%	30.8%	29.2%	23.5%	7.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	39.230[a]	4	.000
Likelihood Ratio	40.958	4	.000
Linear-by-Linear Association	19.278	1	.000
N of Valid Cases	1049		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 25.05.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.193	.000
	Cramer's V	.193	.000
N of Valid Cases		1049	

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Table C-17: Selection of 'engineers' in decision making at non-domestic buildings in a crosstab and Pearson's Chi-square test with profession

Q9B: Engineers	Profession			Total
	Architect	Engineer	Other	
Checked				
Count	137	82	32	251
% within Q9B: Engineers	54.6%	32.7%	12.7%	100.0%
% within Profession	21.0%	33.5%	22.9%	24.2%
% of Total	13.2%	7.9%	3.1%	24.2%
Std. Residual	-1.7	2.9	-.3	
Unchecked				
Count	515	163	108	786
% within Q9B: Engineers	65.5%	20.7%	13.7%	100.0%
% within Profession	79.0%	66.5%	77.1%	75.8%
% of Total	49.7%	15.7%	10.4%	75.8%
Std. Residual	.9	-1.7	.2	
Total				
Count	652	245	140	1037
% within Q9B: Engineers	62.9%	23.6%	13.5%	100.0%
% within Profession	100.0%	100.0%	100.0%	100.0%
% of Total	62.9%	23.6%	13.5%	100.0%

Chi-Square Tests			
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	15.223a	2	.000
Likelihood Ratio	14.528	2	0.001
Linear-by-Linear Association	3.618	1	0.057
N of Valid Cases	1037		
a 0 cells (0.0%) have expected count less than 5. The minimum expected count is 33.89.			

Symmetric Measures			
		Value	Approx. Sig.
Nominal by Nominal	Phi	.121	.000
	Cramer's V	.121	.000
N of Valid Cases		1037	

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Table C-18: Selection of 'government regulation influence' in decision make at non-domestic buildings in a crosstab and Pearson's Chi-square test with years of experience

Q9B: Government Regulation Influence	Years of Experience				Total
	Less than 5	5 - 10	11 - 15	More than 15	
Checked					
Count	44	71	45	219	379
% within Q9B: Gov. Reg. Influence	11.6%	18.7%	11.9%	57.8%	100.0%
% within Years of Experience	48.9%	46.1%	39.8%	32.2%	36.5%
% of Total	4.2%	6.8%	4.3%	21.1%	36.5%
Std. Residual	1.9	2.0	.6	-1.9	
Unchecked					
Count	46	83	68	461	658
% within Q9B: Gov. Reg. Influence	7.0%	12.6%	10.3%	70.1%	100.0%
% within Years of Experience	51.1%	53.9%	60.2%	67.8%	63.5%
% of Total	4.4%	8.0%	6.6%	44.5%	63.5%
Std. Residual	-1.5	-1.5	-.4	1.4	
Total					
Count	90	154	113	680	1037
% within Q9B: Gov. Reg. Influence	8.7%	14.9%	10.9%	65.6%	100.0%
% within Years of Experience	100.0%	100.0%	100.0%	100.0%	100.0%
% of Total	8.7%	14.9%	10.9%	65.6%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	18.026a	3	.000
Likelihood Ratio	17.739	3	.000
Linear-by-Linear Association	17.64	1	.000
N of Valid Cases	1037		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 32.89.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	0.132	.000
	Cramer's V	0.132	.000
N of Valid Cases		1037	

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Table C-19: Selection of 'government regulation influence' in decision make at non-domestic buildings in a crosstab and Pearson's Chi-square test with geographic region

Q9B: Government Regulation Influence	Geographic Region					Total
	Canada	USA	UK	Europe	Other Countries	
Checked						
Count	38	78	134	99	30	379
% within Q9B: Gov. Reg.	10.0%	20.6%	35.4%	26.1%	7.9%	100.0%
% within Geographic Region	38.4%	24.6%	43.2%	40.6%	44.8%	36.5%
% of Total	3.7%	7.5%	12.9%	9.5%	2.9%	36.5%
Std. Residual	.3	-3.5	1.9	1.0	1.1	
Unchecked						
Count	61	239	176	145	37	658
% within Q9B: Gov. Reg.	9.3%	36.3%	26.7%	22.0%	5.6%	100.0%
% within Geographic Region	61.6%	75.4%	56.8%	59.4%	55.2%	63.5%
% of Total	5.9%	23.0%	17.0%	14.0%	3.6%	63.5%
Std. Residual	-.2	2.7	-1.5	-.8	-.8	
Total						
Count	99	317	310	244	67	1037
% within Q9B: Gov. Reg.	9.5%	30.6%	29.9%	23.5%	6.5%	100.0%
% within Geographic Region	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
% of Total	9.5%	30.6%	29.9%	23.5%	6.5%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	29.261[a]	4	.000
Likelihood Ratio	30.269	4	.000
Linear-by-Linear Association	10.825	1	.001
N of Valid Cases	1037		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 24.49.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.168	.000
	Cramer's V	.168	.000
N of Valid Cases		1037	

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Table C-20: Crosstabulation and Pearson's Chi-square test between profession and the selection of architect in decision of TSC integration scheme (Q10)

The integration scheme of TSC is decided by Architect:	Profession			Total
	Architect	Engineer	Other	
Checked				
Count	488	119	72	679
% within Architect Selection	71.9%	17.5%	10.6%	100.0%
% within Profession	72.0%	48.6%	50.7%	63.8%
% of Total	45.8%	11.2%	6.8%	63.8%
Std. Residual	2.7	-3.0	-1.9	
Unchecked				
Count	190	126	70	386
% within Architect Selection	49.2%	32.6%	18.1%	100.0%
% within Profession	28.0%	51.4%	49.3%	36.2%
% of Total	17.8%	11.8%	6.6%	36.2%
Std. Residual	-3.6	3.9	2.6	
Total				
Count	678	245	142	1065
% within Architect Selection	63.7%	23.0%	13.3%	100.0%
% within Profession	100.0%	100.0%	100.0%	100.0%
% of Total	63.7%	23.0%	13.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	54.741[a]	2	.000
Likelihood Ratio	54.131	2	.000
Linear-by-Linear Association	43.340	1	.000
N of Valid Cases	1065		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 51.47.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.227	.000
	Cramer's V	.227	.000
N of Valid Cases		1065	

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Table C-21: Crosstabulation and Pearson's Chi-square test between profession and the selection of Integration Design Team in decision of TSC integration scheme (Q10)

Integration Design Team	Profession			Total
	Architect	Engineer	Other	
Checked				
Count	268	116	74	458
% within Integration Design Team	58.5%	25.3%	16.2%	100.0%
% within Profession	39.5%	47.3%	52.1%	43.0%
% of Total	25.2%	10.9%	6.9%	43.0%
Std. Residual	-1.4	1.0	1.7	
Unchecked				
Count	410	129	68	607
% within Integration Design Team	67.5%	21.3%	11.2%	100.0%
% within Profession	60.5%	52.7%	47.9%	57.0%
% of Total	38.5%	12.1%	6.4%	57.0%
Std. Residual	1.2	-.9	-1.4	
Total				
Count				
% within Integration Design Team	63.7%	23.0%	13.3%	100.0%
% within Profession	100.0%	100.0%	100.0%	100.0%
% of Total	63.7%	23.0%	13.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	10.034[a]	2	.007
Likelihood Ratio	9.991	2	.007
Linear-by-Linear Association	9.872	1	.002
N of Valid Cases	1065		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 61.07.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.097	.007
	Cramer's V	.097	.007
N of Valid Cases		1065	

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Table C-22: Mean of respondents rating questions 11-17. (MF=Multi-function), (Aes=Aesthetic)

	Project theme	N	Min.	Max.	Sum	Mean	Std. Deviation
Total	Q11MF	1051	-100	100	55200	52.52	42.659
	Q11Aes	1058	-100	100	51100	48.3	46.97
	Q12MF	1046	-100	100	47600	45.51	47.107
	Q12Aes	1055	-100	100	36400	34.5	57.329
	Q13MF	1046	-100	100	34700	33.17	47.611
	Q13Aes	1056	-100	100	-300	-0.28	59.1
	Q14MF	1039	-100	100	52050	50.1	41.41
	Q14Aes	1049	-100	100	42200	40.23	50.733
	Q15MF	1039	-100	100	35400	34.07	49.941
	Q15Aes	1049	-100	100	3800	3.62	55.912
	Q16MF	1038	-100	100	35700	34.39	57.194
	Q16Aes	1040	-100	100	6450	6.2	56.378
	Q17MF	1032	-100	100	33700	32.66	58.799
	Q17Aes	1044	-100	100	-1200	-1.15	55.465
	Valid N (listwise)	922					
Profession	Project theme	N	Min.	Max.	Sum	Mean	Std. Deviation
Architect	Q11MF	668	-100	100	35550	53.22	42.690
	Q11Aes	667	-100	100	30450	45.65	48.898
	Q12MF	664	-100	100	30900	46.54	48.149
	Q12Aes	670	-100	100	26400	39.40	56.819
	Q13MF	662	-100	100	19350	29.23	49.075
	Q13Aes	667	-100	100	-5450	-8.17	59.817
	Q14MF	663	-100	100	32150	48.49	42.282
	Q14Aes	668	-100	100	23350	34.96	53.600
	Q15MF	661	-100	100	19600	29.65	50.883
	Q15Aes	663	-100	100	-2750	-4.15	57.334
	Q16MF	659	-100	100	20350	30.88	58.204
	Q16Aes	654	-100	100	-900	-1.38	56.692
	Q17MF	655	-100	100	18850	28.78	59.880
	Q17Aes	662	-100	100	-5500	-8.31	55.134
	Valid N (listwise)	595					

Table C-22 Continued: Mean of respondents rating questions 11-17. (MF=Multi-function), (Aes=Aesthetic)

Profession	Project theme	N	Min.	Max.	Sum	Mean	Std. Deviation
Engineer	Q11MF	243	-100	100	11750	48.35	45.197
	Q11Aes	247	-100	100	12850	52.02	44.126
	Q12MF	242	-100	100	10150	41.94	46.083
	Q12Aes	243	-100	100	5850	24.07	56.469
	Q13MF	245	-100	100	9100	37.14	45.808
	Q13Aes	246	-100	100	2850	11.59	55.309
	Q14MF	240	-100	100	12000	50.00	40.654
	Q14Aes	243	-100	100	12350	50.82	41.403
	Q15MF	239	-100	100	10100	42.26	45.521
	Q15Aes	242	-100	100	4700	19.42	49.843
	Q16MF	241	-100	100	9550	39.63	55.680
	Q16Aes	245	-100	100	4950	20.20	55.718
	Q17MF	240	-100	100	9200	38.33	59.543
	Q17Aes	240	-100	100	2800	11.67	54.785
	Valid N (listwise)	208					
Other	Q11MF	140	-50	100	7900	56.43	37.379
	Q11Aes	144	-100	100	7800	54.17	41.603
	Q12MF	140	-100	100	6550	46.79	43.750
	Q12Aes	142	-100	100	4150	29.23	58.722
	Q13MF	139	-100	100	6250	44.96	40.956
	Q13Aes	143	-100	100	2300	16.08	55.539
	Q14MF	136	-50	100	7900	58.09	37.624
	Q14Aes	138	-100	100	6500	47.10	47.862
	Q15MF	139	-100	100	5700	41.01	50.452
	Q15Aes	144	-100	100	1850	12.85	52.138
	Q16MF	138	-100	100	5800	42.03	53.779
	Q16Aes	141	-100	100	2400	17.02	49.580
	Q17MF	137	-100	100	5650	41.24	50.329
	Q17Aes	142	-100	100	1500	10.56	52.535
	Valid N (listwise)	119					

Table C-23: Spearman's Correlation between Q11 sub-sections (multi-function and aesthetics) with profession as a split control

Two Categories (Architects vs Engineers and Others)			Q11: Multi-Functional Role	Q11: Aesthetics
Spearman's rho				
Architect	Q11: Multi-Functional Role	Correlation Coefficient	1.000	.527**
		Sig. (2-tailed)		.000
		N	668	664
	Q11: Aesthetics	Correlation Coefficient	.527**	1.000
		Sig. (2-tailed)	.000	
		N	664	667
Engineers and Others	Q11: Multi-Functional Role	Correlation Coefficient	1.000	.402**
		Sig. (2-tailed)		.000
		N	383	382
	Q11: Aesthetics	Correlation Coefficient	.402**	1.000
		Sig. (2-tailed)	.000	
		N	382	391
**. Correlation is significant at the 0.01 level (2-tailed).				

Table C-24: Spearman's Correlation between Q12 sub-sections (multi-function and aesthetics) with profession as a split control

Two Categories (Architects vs all Others)			Q12: Multi-Functional Role	Q12: Aesthetics
Spearman's rho				
Architect	Q12: Multi-Functional Role	Correlation Coefficient	1.000	.589**
		Sig. (2-tailed)		.000
		N	664	661
	Q12: Aesthetics	Correlation Coefficient	.589**	1.000
		Sig. (2-tailed)	.000	
		N	661	670
Engineers and Others	Q12: Multi-Functional Role	Correlation Coefficient	1.000	.322**
		Sig. (2-tailed)		.000
		N	382	379
	Q12: Aesthetics	Correlation Coefficient	.322**	1.000
		Sig. (2-tailed)	.000	
		N	379	385
**. Correlation is significant at the 0.01 level (2-tailed).				

Table C-25: Crosstabulation and Chi-square of Q13 multi-function and aesthetics in a control of two categories profession Group Dion, offices, Quebec - Canada

Q13: Multi-Functional Role		Two Categories (Architects vs Other professions)		Total
		Architect	Engineers and Others	
Very Poor	Count	24	7	31
	% within Q13: Multi-Functional Role	77.4%	22.6%	100.0%
	% within Two Categories (Architects vs all Others)	3.6%	1.8%	3.0%
	% of Total	2.3%	.7%	3.0%
Poor	Count	61	18	79
	% within Q13: Multi-Functional Role	77.2%	22.8%	100.0%
	% within Two Categories (Architects vs all Others)	9.2%	4.7%	7.6%
	% of Total	5.8%	1.7%	7.6%
Neutral	Count	186	100	286
	% within Q13: Multi-Functional Role	65.0%	35.0%	100.0%
	% within Two Categories (Architects vs all Others)	28.1%	26.0%	27.3%
	% of Total	17.8%	9.6%	27.3%
Good	Count	286	179	465
	% within Q13: Multi-Functional Role	61.5%	38.5%	100.0%
	% within Two Categories (Architects vs all Others)	43.2%	46.6%	44.5%
	% of Total	27.3%	17.1%	44.5%
Perfect	Count	105	80	185
	% within Q13: Multi-Functional Role	56.8%	43.2%	100.0%
	% within Two Categories (Architects vs all Others)	15.9%	20.8%	17.7%
	% of Total	10.0%	7.6%	17.7%
Total	Count	662	384	1046
	% within Q13: Multi-Functional Role	63.3%	36.7%	100.0%
	% within Two Categories (Architects vs all Others)	100.0%	100.0%	100.0%
	% of Total	63.3%	36.7%	100.0%

Table C-25 Continued: Crosstabulation and Chi-square of Q13 multi-function and aesthetics in a control of two categories profession Group Dion, offices, Quebec - Canada

Chi-Square Tests			
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.668[a]	4	.008
Likelihood Ratio	14.298	4	.006
Linear-by-Linear Association	12.376	1	.000
N of Valid Cases	1046		
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 11.38.			

Symmetric Measures			
		Value	Approx. Sig.
Nominal by Nominal	Phi	.114	.008
	Cramer's V	.114	.008
N of Valid Cases		1046	
a. Not assuming the null hypothesis.			
b. Using the asymptotic standard error assuming the null hypothesis.			

Table C-26: Spearman's correlation between Q13 sub-sections (multi-function and aesthetics) with profession as a split control

Two Categories (Architects vs all Others)			**Q13: Multi-Functional Role**	**Q13: Aesthetics**
Spearman's rho				
Architect	Q13: Multi-Functional Role	Correlation Coefficient	1.000	.577**
		Sig. (2-tailed)		.000
		N	662	658
	Q13: Aesthetics	Correlation Coefficient	.577**	1.000
		Sig. (2-tailed)	.000	
		N	658	667
Engineers and Other	Q13: Multi-Functional Role	Correlation Coefficient	1.000	.548**
		Sig. (2-tailed)		.000
		N	384	383
	Q13: Aesthetics	Correlation Coefficient	.548**	1.000
		Sig. (2-tailed)	.000	
		N	383	389
**. Correlation is significant at the 0.01 level (2-tailed).				

Table C-27: Spearman's correlation between Q14 sub-sections (multi-function and aesthetics) with profession as a split control

Two Categories (Architects vs all Others)			Q14: Multi-Functional Role	Q14: Aesthetics
Spearman's rho				
Architect	Q14: Multi-Functional Role	Correlation Coefficient	1.000	.594**
		Sig. (2-tailed)		.000
		N	663	661
	Q14: Aesthetics	Correlation Coefficient	.594**	1.000
		Sig. (2-tailed)	.000	
		N	661	668
Engineers and Other	Q14: Multi-Functional Role	Correlation Coefficient	1.000	.571**
		Sig. (2-tailed)		.000
		N	376	369
	Q14: Aesthetics	Correlation Coefficient	.571**	1.000
		Sig. (2-tailed)	.000	
		N	369	381
**. Correlation is significant at the 0.01 level (2-tailed).				

Table C-28: Spearman's correlation between Q15 sub-sections (multi-function and aesthetics) with profession as a split control

Two Categories (Architects vs all Others)			Q15: Multi-Functional Role	Q15: Aesthetics
Spearman's rho				
Architect	Q15: Multi-Functional Role	Correlation Coefficient	1.000	.549**
		Sig. (2-tailed)		.000
		N	661	655
	Q15: Aesthetics	Correlation Coefficient	.549**	1.000
		Sig. (2-tailed)	.000	
		N	655	663
Engineers and Other	Q15: Multi-Functional Role	Correlation Coefficient	1.000	.497**
		Sig. (2-tailed)		.000
		N	378	375
	Q15: Aesthetics	Correlation Coefficient	.497**	1.000
		Sig. (2-tailed)	.000	
		N	375	386
**. Correlation is significant at the 0.01 level (2-tailed).				

Table C-29: Spearman's correlation between Q16 sub-sections (multi-function and aesthetics) with profession as a split control

Two Categories (Architects vs all Others)			Q16: Multi-Functional Role	Q16: Aesthetics
Spearman's rho				
Architect	Q16: Multi-Functional Role	Correlation Coefficient	1.000	.483**
		Sig. (2-tailed)		.000
		N	659	649
	Q16: Aesthetics	Correlation Coefficient	.483**	1.000
		Sig. (2-tailed)	.000	
		N	649	654
Engineers and Other	Q16: Multi-Functional Role	Correlation Coefficient	1.000	.424**
		Sig. (2-tailed)		.000
		N	379	376
	Q16: Aesthetics	Correlation Coefficient	.424**	1.000
		Sig. (2-tailed)	.000	
		N	376	386

**. Correlation is significant at the 0.01 level (2-tailed).

Table C-30: Spearman's Correlation between Q17 sub-sections (multi-function and aesthetics) with profession as a split control

Two Categories (Architects vs all Others)			Q17: Multi-Functional Role	Q17: Aesthetics
Spearman's rho				
Architect	Q17: Multi-Functional Role	Correlation Coefficient	1.000	.438**
		Sig. (2-tailed)		.000
		N	655	653
	Q17: Aesthetics	Correlation Coefficient	.438**	1.000
		Sig. (2-tailed)	.000	
		N	653	662
Engineers and Other	Q17: Multi-Functional Role	Correlation Coefficient	1.000	.463**
		Sig. (2-tailed)		.000
		N	377	373
	Q17: Aesthetics	Correlation Coefficient	.463**	1.000
		Sig. (2-tailed)	.000	
		N	373	382

**. Correlation is significant at the 0.01 level (2-tailed).

Table C-31: Crosstabulation and Pearson's Chi-square test between profession and the priority of multi-functional selection of TSC (Q18)

Multi-Functional Role		Profession			Total
		Architect	Engineer	Other	
Checked	Count	465	138	82	685
	% within Profession	77.6%	60.5%	63.1%	71.6%
	% of Total	48.6%	14.4%	8.6%	71.6%
Unchecked	Count	134	90	48	272
	% within Profession	22.4%	39.5%	36.9%	28.4%
	% of Total	14.0%	9.4%	5.0%	28.4%
Total	Count	599	228	130	957
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	62.6%	23.8%	13.6%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	29.089[a]	2	.000
Likelihood Ratio	28.536	2	.000
Linear-by-Linear Association	22.009	1	.000
N of Valid Cases	957		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 36.95.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.174	.000
	Cramer's V	.174	.000
N of Valid Cases		957	

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Table C-32: Crosstabulation and Pearson's Chi-square test between profession and the priority of aesthetics selection of TSC (Q18)

Aesthetics		**Profession**			**Total**
		Architect	Engineer	Other	
Checked	Count	335	89	54	478
	% within Profession	55.9%	39.0%	41.5%	49.9%
	% of Total	35.0%	9.3%	5.6%	49.9%
Unchecked	Count	264	139	76	479
	% within Profession	44.1%	61.0%	58.5%	50.1%
	% of Total	27.6%	14.5%	7.9%	50.1%
Total	Count	599	228	130	957
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	62.6%	23.8%	13.6%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	23.103[a]	2	.000
Likelihood Ratio	23.230	2	.000
Linear-by-Linear Association	17.492	1	.000
N of Valid Cases	957		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 36.95.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.155	.000
	Cramer's V	.155	.000
N of Valid Cases		957	

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Table C-33: Crosstabulation between profession and the technology selection at new residential building (Q20)

Technology Selection at New Residential Building			Profession			Total
			Architect	Engineer	Other	
Transpired Solar Collector (TSC)	Checked	Count	225	90	49	364
		Column N %	38.8%	41.7%	39.5%	-
		Table N %	24.5%	9.8%	5.3%	39.6%
	Unchecked	Count	355	126	75	556
		Column N %	61.2%	58.3%	60.5%	-
		Table N %	38.6%	13.7%	8.2%	60.4%
Photovoltaic (PV)	Checked	Count	303	124	67	494
		Column N %	52.2%	57.4%	54.0%	-
		Table N %	32.9%	13.5%	7.3%	53.7%
	Unchecked	Count	277	92	57	426
		Column N %	47.8%	42.6%	46.0%	-
		Table N %	30.1%	10.0%	6.2%	46.3%
Hybrid (PV/TSC)	Checked	Count	327	114	79	520
		Column N %	56.4%	52.8%	63.7%	-
		Table N %	35.5%	12.4%	8.6%	56.5%
	Unchecked	Count	253	102	45	400
		Column N %	43.6%	47.2%	36.3%	-
		Table N %	27.5%	11.1%	4.9%	43.5%
Solar Water Heating (DHW)	Checked	Count	413	155	80	648
		Column N %	71.2%	71.8%	64.5%	-
		Table N %	44.9%	16.8%	8.7%	70.4%
	Unchecked	Count	167	61	44	272
		Column N %	28.8%	28.2%	35.5%	-
		Table N %	18.2%	6.6%	4.8%	29.6%
Wind Energy	Checked	Count	94	25	23	142
		Column N %	16.2%	11.6%	18.5%	-
		Table N %	10.2%	2.7%	2.5%	15.4%
	Unchecked	Count	486	191	101	778
		Column N %	83.8%	88.4%	81.5%	-
		Table N %	52.8%	20.8%	11.0%	84.6%
Ground Source heat pump (GHP)	Checked	Count	367	114	62	543
		Column N %	63.3%	52.8%	50.0%	-
		Table N %	39.9%	12.4%	6.7%	59.0%
	Unchecked	Count	213	102	62	377
		Column N %	36.7%	47.2%	50.0%	-
		Table N %	23.2%	11.1%	6.7%	41.0%

Table C-34: Crosstabulation and Pearson's Chi-square test between profession and the selection of ground source heating pump at new residential building (Q20)

Ground Source heat pump		Profession			Total
		Architect	Engineer	Other	
Checked	Count	367	114	62	543
	% within Profession	67.6%	21.0%	11.4%	100.0%
	% of Total	63.3%	52.8%	50.0%	59.0%
Unchecked	Count	213	102	62	377
	% within Profession	56.5%	27.1%	16.4%	100.0%
	% of Total	36.7%	47.2%	50.0%	41.0%
Total	Count	580	216	124	920
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	63.0%	23.5%	13.5%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.995[a]	2	.002
Likelihood Ratio	11.934	2	.003
Linear-by-Linear Association	11.112	1	.001
N of Valid Cases	920		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 50.81.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.141	.001
	Cramer's V	.141	.001
N of Valid Cases		920	

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Table C-35: Selection of Transpired Solar Collector (TSC) at new residential building buildings in a crosstab and Pearson's Chi-square test with geographic region (Q20)

Transpired Solar Collector (TSC)	Geographic Region					Total
	Canada	USA	UK	Europe	Other Countries	
Checked						
Count	38	133	97	67	29	364
% within Region	43.7%	46.3%	36.7%	29.9%	50.0%	39.6%
% of Total	4.1%	14.5%	10.5%	7.3%	3.2%	39.6%
Std. Residual	.6	1.8	-.7	-2.3	1.3	
Unchecked						
Count	49	154	167	157	29	556
% within Region	56.3%	53.7%	63.3%	70.1%	50.0%	60.4%
% of Total	5.3%	16.7%	18.2%	17.1%	3.2%	60.4%
Std. Residual	-.5	-1.5	.6	1.9	-1.0	
Total						
Count	87	287	264	224	58	920
% within Region	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
% of Total	9.5%	31.2%	28.7%	24.3%	6.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	18.380[a]	4	.001
Likelihood Ratio	18.554	4	.001
Linear-by-Linear Association	5.071	1	.024
N of Valid Cases	920		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 22.95.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.141	.001
	Cramer's V	.141	.001
N of Valid Cases		920	

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Table C-36: Selection of photovoltaic (PV) at new residential buildings in a crosstab and Pearson's Chi-square test with geographic region (Q20)

Photovoltaic (PV)	Geographic Region					Total
	Canada	USA	UK	Europe	Other Countries	
Checked						
Count	38	157	164	99	36	494
% within Region	43.7%	54.7%	62.1%	44.2%	62.1%	53.7%
% of Total	4.1%	17.1%	17.8%	10.8%	3.9%	53.7%
Std. Residual	-1.3	.2	1.9	-1.9	.9	
Unchecked						
Count	49	130	100	125	22	426
% within Region	56.3%	45.3%	37.9%	55.8%	37.9%	46.3%
% of Total	5.3%	14.1%	10.9%	13.6%	2.4%	46.3%
Std. Residual	1.4	-.3	-2.0	2.1	-.9	
Total						
Count	87	287	264	224	58	920
% within Region	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
% of Total	9.5%	31.2%	28.7%	24.3%	6.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	20.931[a]	4	.000
Likelihood Ratio	21.016	4	.000
Linear-by-Linear Association	.033	1	.856
N of Valid Cases	920		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 26.86.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.151	.000
	Cramer's V	.151	.000
N of Valid Cases		920	

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Table C-37: Crosstabulation between profession and the technology selection at existing residential building (Q21)

Technology Selection at Existing Residential Building			Profession			Total
			Architect	Engineer	Other	
Transpired Solar Collector (TSC)	Checked	Count	168	56	35	259
		Column N %	29.1%	26.3%	28.7%	-
		Table N %	18.4%	6.1%	3.8%	28.4%
	Unchecked	Count	409	157	87	653
		Column N %	70.9%	73.7%	71.3%	-
		Table N %	44.8%	17.2%	9.5%	71.6%
Photovoltaic (PV)	Checked	Count	319	132	70	521
		Column N %	55.3%	62.0%	57.4%	-
		Table N %	35.0%	14.5%	7.7%	57.1%
	Unchecked	Count	258	81	52	391
		Column N %	44.7%	38.0%	42.6%	-
		Table N %	28.3%	8.9%	5.7%	42.9%
Hybrid (PV/TSC)	Checked	Count	268	90	62	420
		Column N %	46.4%	42.3%	50.8%	-
		Table N %	29.4%	9.9%	6.8%	46.1%
	Unchecked	Count	309	123	60	492
		Column N %	53.6%	57.7%	49.2%	-
		Table N %	33.9%	13.5%	6.6%	53.9%
Solar Water Heating (DHW)	Checked	Count	412	149	84	645
		Column N %	71.4%	70.0%	68.9%	-
		Table N %	45.2%	16.3%	9.2%	70.7%
	Unchecked	Count	165	64	38	267
		Column N %	28.6%	30.0%	31.1%	-
		Table N %	18.1%	7.0%	4.2%	29.3%
Wind Energy	Checked	Count	86	24	24	134
		Column N %	14.9%	11.3%	19.7%	-
		Table N %	9.4%	2.6%	2.6%	14.7%
	Unchecked	Count	491	189	98	778
		Column N %	85.1%	88.7%	80.3%	-
		Table N %	53.8%	20.7%	10.7%	85.3%
Ground Source Heat Pump (GHP)	Checked	Count	226	72	45	343
		Column N %	39.2%	33.8%	36.9%	-
		Table N %	24.8%	7.9%	4.9%	37.6%
	Unchecked	Count	351	141	77	569
		Column N %	60.8%	66.2%	63.1%	-
		Table N %	38.5%	15.5%	8.4%	62.4%

Table C-38: Crosstabulation between profession and the technology selection at existing residential building (Q21)

Technology Selection at Existing Residential Building		Profession			Total
		Architect	Engineer	Other	
New Design	Count	162	73	37	272
	% within Profession	27.1%	32.3%	28.9%	28.6%
	% of Total	17.0%	7.7%	3.9%	28.6%
	Std. Residual	-.7	1.0	.1	
Refurbishment	Count	8	8	3	19
	% within Profession	1.3%	3.5%	2.3%	2.0%
	% of Total	.8%	.8%	.3%	2.0%
	Std. Residual	-1.1	1.6	.3	
Both	Count	392	128	76	596
	% within Profession	65.6%	56.6%	59.4%	62.6%
	% of Total	41.2%	13.4%	8.0%	62.6%
	Std. Residual	.9	-1.1	-.5	
Other	Count	36	17	12	65
	% within Profession	6.0%	7.5%	9.4%	6.8%
	% of Total	3.8%	1.8%	1.3%	6.8%
	Std. Residual	-.8	.4	1.1	
Total	Count	598	226	128	952
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	62.8%	23.7%	13.4%	100.0%

Table C-39: Crosstabulation and Pearson's Chi-square test for profession and harmonising TSC within the architectural concept of traditional buildings (Q23)

Harmonising TSC within the architectural concept of traditional buildings at Local authority guidelines		Profession			Total
		Architect	Engineer	Other	
Agree	Count	341	105	76	522
	% within Profession	57.7%	47.3%	59.8%	55.5%
	% of Total	36.3%	11.2%	8.1%	55.5%
	Std. Residual	.7	-1.6	.7	
Disagree	Count	138	44	18	200
	% within Profession	23.4%	19.8%	14.2%	21.3%
	% of Total	14.7%	4.7%	1.9%	21.3%
	Std. Residual	1.1	-.5	-1.7	
No Opinion	Count	112	73	33	218
	% within Profession	19.0%	32.9%	26.0%	23.2%
	% of Total	11.9%	7.8%	3.5%	23.2%
	Std. Residual	-2.1	3.0	.7	
Total	Count	591	222	127	940
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	62.9%	23.6%	13.5%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	22.064[a]	4	.000
Likelihood Ratio	21.815	4	.000
Linear-by-Linear Association	3.866	1	.049
N of Valid Cases	940		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 27.02.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.153	.000
	Cramer's V	.108	.000
N of Valid Cases		940	

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Table C-40: Crosstabulation and Pearson's Chi-square test for geographic region and harmonising TSC within the architectural concept of traditional buildings (Q23)

Harmonising TSC within the architectural concept of traditional buildings		Geographic Region					Total
		Canada	USA	UK	Europe	Other Countries	
Agree	Count	37	152	158	141	34	522
	% within Region	42.0%	52.1%	57.2%	62.1%	59.6%	55.5%
	% of Total	3.9%	16.2%	16.8%	15.0%	3.6%	55.5%
	Std. Residual	-1.7	-.8	.4	1.3	.4	
Disagree	Count	20	60	55	49	16	200
	% within Region	22.7%	20.5%	19.9%	21.6%	28.1%	21.3%
	% of Total	2.1%	6.4%	5.9%	5.2%	1.7%	21.3%
	Std. Residual	.3	-.3	-.5	.1	1.1	
No Opinion	Count	31	80	63	37	7	218
	% within Region	35.2%	27.4%	22.8%	16.3%	12.3%	23.2%
	% of Total	3.3%	8.5%	6.7%	3.9%	.7%	23.2%
	Std. Residual	2.3	1.5	-.1	-2.2	-1.7	
Total	Count	88	292	276	227	57	940
	% within Region	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	% of Total	9.4%	31.1%	29.4%	24.1%	6.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	22.567[a]	8	.004
Likelihood Ratio	22.937	8	.003
Linear-by-Linear Association	17.911	1	.000
N of Valid Cases	940		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 12.13.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.153	.000
	Cramer's V	.108	.000
N of Valid Cases		940	

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Table C-41: Crosstabulation for profession and the recommended development stage of integrating TSC in buildings (Q24)

Stage of integrating TSC in buildings		Profession			Total
		Architect	Engineer	Other	
Originally integrated	Count	501	177	101	779
	% within Profession	84.3%	81.2%	81.5%	83.2%
	% of Total	53.5%	18.9%	10.8%	83.2%
Attached later	Count	6	3	1	10
	% within Profession	1.0%	1.4%	.8%	1.1%
	% of Total	.6%	.3%	.1%	1.1%
Subjective	Count	87	38	22	147
	% within Profession	14.6%	17.4%	17.7%	15.7%
	% of Total	9.3%	4.1%	2.4%	15.7%
Total	Count	594	218	124	936
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	63.5%	23.3%	13.2%	100.0%

Table C-42: Crosstabulation for profession and the preference of aesthetic integration of TSC in façade (Q25)

Aesthetic integration of TSC in façade		Profession			Total
		Architect	Engineer	Other	
Clearly Featured	Count	169	62	31	262
	% within Profession	29.1%	28.1%	25.4%	28.4%
	% of Total	18.3%	6.7%	3.4%	28.4%
Somewhat Invisible	Count	249	101	52	402
	% within Profession	42.9%	45.7%	42.6%	43.6%
	% of Total	27.0%	10.9%	5.6%	43.6%
No Opinion	Count	162	58	39	259
	% within Profession	27.9%	26.2%	32.0%	28.1%
	% of Total	17.6%	6.3%	4.2%	28.1%
Total	Count	580	221	122	923
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	62.8%	23.9%	13.2%	100.0%

Table C-43: Crosstabulation and Pearson's Chi-square test for profession and the recommendation of dummy panels to satisfy architectural unity (Q26)

Dummy Panels		Profession			Total
		Architect	Engineer	Other	
Yes	Count	42	28	7	77
	% within Profession	7.1%	12.7%	5.6%	8.2%
	% of Total	4.5%	3.0%	.7%	8.2%
	Std. Residual	-1.0	2.3	-1.0	
No	Count	332	65	49	446
	% within Profession	56.1%	29.4%	39.5%	47.6%
	% of Total	35.4%	6.9%	5.2%	47.6%
	Std. Residual	3.0	-3.9	-1.3	
Sometimes	Count	218	128	68	414
	% within Profession	36.8%	57.9%	54.8%	44.2%
	% of Total	23.3%	13.7%	7.3%	44.2%
	Std. Residual	-2.7	3.1	1.8	
Total	Count	592	221	124	937
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	63.2%	23.6%	13.2%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	53.124[a]	4	.000
Likelihood Ratio	53.953	4	.000
Linear-by-Linear Association	14.922	1	.000
N of Valid Cases	937		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 10.19.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.238	.000
	Cramer's V	.168	.000

N of Valid Cases	937
a. Not assuming the null hypothesis. b. Using the asymptotic standard error assuming the null hypothesis.	

Table C-44: Crosstabulation and Pearson's Chi-square test for profession and the need for further colour range (Q35)

Further colour range		Profession			Total
		Architect	Engineer	Other	
Yes	Count	234	45	29	308
	% within Profession	40.5%	21.4%	24.0%	33.9%
	% of Total	25.7%	5.0%	3.2%	33.9%
	Std. Residual	2.7	-3.1	-1.9	
No	Count	344	165	92	601
	% within Profession	59.5%	78.6%	76.0%	66.1%
	% of Total	37.8%	18.2%	10.1%	66.1%
	Std. Residual	-2.0	2.2	1.3	
Total	Count	578	210	121	909
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	63.6%	23.1%	13.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	31.095[a]	2	.000
Likelihood Ratio	32.283	2	.000
Linear-by-Linear Association	23.901	1	.000
N of Valid Cases	909		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 41.00.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.185	.000

	Cramer's V	.185	.000
N of Valid Cases		909	
a. Not assuming the null hypothesis. b. Using the asymptotic standard error assuming the null hypothesis.			

Table C-45: Crosstabulation for profession and the contradiction between the currently available standard TSC colour chart and design aesthetics (Q36)

Contradiction between the currently available standard TSC colour chart and design aesthetics		Profession			Total
		Architect	Engineer	Other	
Yes	Count	105	34	27	166
	% within Profession	18.0%	15.7%	22.1%	18.0%
	% of Total	11.4%	3.7%	2.9%	18.0%
No	Std. Residual	.0	-.8	1.1	
	Count	218	77	39	334
	% within Profession	37.3%	35.5%	32.0%	36.2%
Maybe	% of Total	23.6%	8.3%	4.2%	36.2%
	Count	214	77	40	331
	% within Profession	36.6%	35.5%	32.8%	35.9%
No Opinion	% of Total	23.2%	8.3%	4.3%	35.9%
	Count	47	29	16	92
	% within Profession	8.0%	13.4%	13.1%	10.0%
Total	Count	584	217	122	923
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	63.3%	23.5%	13.2%	100.0%

Table C-46: Crosstabulation for profession and the contribution of TSC towards the creation of sustainable built environment (Q27)

TSC, as a source of comparatively low-cost renewable energy, contributes to sustainable built environment		Profession			Total
		Architect	Engineer	Other	
Agree	Count	464	173	92	729
	% within Profession	79.0%	79.0%	75.4%	78.6%
	% of Total	50.0%	18.6%	9.9%	78.6%
Disagree	Count	28	11	7	46
	% within Profession	4.8%	5.0%	5.7%	5.0%

	% of Total	3.0%	1.2%	.8%	5.0%
No Opinion	Count	95	35	23	153
	% within Profession	16.2%	16.0%	18.9%	16.5%
	% of Total	10.2%	3.8%	2.5%	16.5%
Total	Count	587	219	122	928
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	63.3%	23.6%	13.1%	100.0%

Table C-47: Mean of respondents rating sustainable characteristics of Q28

Project theme	N	Min.	Max.	Sum	Mean	Std. Deviation
Indoor Thermal Comfort	928	-100	100	61900	66.7	43.40
Reducing Carbon Dioxide	932	-100	100	54150	58.1	50.52
Improving Indoor Air Quality	924	-100	100	45900	49.68	48.43
Energy Saving	935	-100	100	76000	81.28	33.65
Cost Effectiveness	924	-100	100	54400	58.87	48.57
Material used	920	-100	100	28900	31.41	51.23
Valid N (listwise)	906					
Profession: Architect						
Indoor Thermal Comfort	581	-100	100	38950	67.04	44.36
Reducing Carbon Dioxide	583	-100	100	33150	56.86	52.15
Improving Indoor Air Quality	578	-100	100	29300	50.69	48.99
Energy Saving	588	-100	100	47750	81.21	35.74
Cost Effectiveness	580	-100	100	34600	59.66	48.66
Material used	578	-100	100	18650	32.27	51.93
Valid N (listwise)	568					
Profession: Engineer						
Indoor Thermal Comfort	221	-100	100	38950	64.71	44.45
Reducing Carbon Dioxide	223	-100	100	33150	56.28	48.22
Improving Indoor Air Quality	220	-100	100	29300	45.00	50.09
Energy Saving	222	-100	100	47750	79.28	31.53
Cost Effectiveness	220	-100	100	34600	55.00	48.23
Material used	218	-100	100	18650	25.00	47.82
Valid N (listwise)	216					

Profession: Other						
Indoor Thermal Comfort	126	-50	100	8650	68.65	36.73
Reducing Carbon Dioxide	126	-100	100	8450	67.06	46.114
Improving Indoor Air Quality	126	-100	100	6700	53.17	42.31
Energy Saving	125	0	100	10650	85.20	26.20
Cost Effectiveness	124	-100	100	7700	62.10	48.71
Material used	124	-100	100	4800	38.71	52.90
Valid N (listwise)	122					

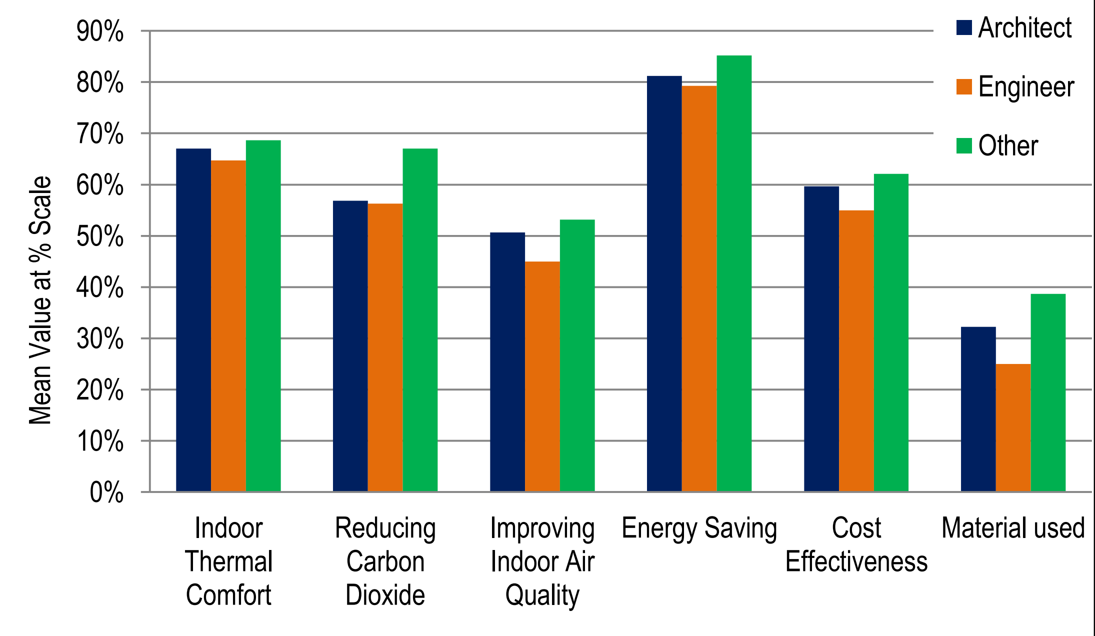


Figure C-1: Mathematical mean value of rating sustainable characteristics at a ±100 scale per profession

Table C-48: Spearman's Correlation between indoor thermal comfort and improving indoor air quality with profession as a split control, Q28

Two Categories (Architects vs all Others)			Indoor Thermal Comfort	Improving Indoor Air Quality
Spearman's rho				
Architect	Indoor Thermal Comfort	Correlation Coefficient	1.000	.548**
		Sig. (2-tailed)		.000
		N	581	574
	Improving Indoor Air Quality	Correlation Coefficient	.548**	1.000
		Sig. (2-tailed)	.000	

		N	574	578
Engineers and Other	Indoor Thermal Comfort	Correlation Coefficient	1.000	.529**
		Sig. (2-tailed)		.000
		N	347	346
	Improving Indoor Air Quality	Correlation Coefficient	.529**	1.000
		Sig. (2-tailed)	.000	
		N	346	346
**. Correlation is significant at the 0.01 level (2-tailed).				

Table C-49: Crosstabulation for profession and the technical factors at sourcing TSC (Q33)

Factors at sourcing TSC		Profession			Total
		Architect	Engineer	Other	
Reliability (constant performance and efficiency which could exceed 75%)	Count	278	93	52	423
	% within Profession	47.7%	42.7%	44.1%	46.0%
	% of Total	30.3%	10.1%	5.7%	46.0%
Durability (capability of withstanding)	Count	40	25	8	73
	% within Profession	6.9%	11.5%	6.8%	7.9%
	% of Total	4.4%	2.7%	.9%	7.9%
Life span (approximately 40 years)	Count	69	17	17	103
	% within Profession	11.8%	7.8%	14.4%	11.2%
	% of Total	7.5%	1.8%	1.8%	11.2%
Warranty (approximately 25 years)	Count	22	12	4	38
	% within Profession	3.8%	5.5%	3.4%	4.1%
	% of Total	2.4%	1.3%	.4%	4.1%
Maintenance (committed service contract)	Count	19	8	6	33
	% within Profession	3.3%	3.7%	5.1%	3.6%
	% of Total	2.1%	.9%	.7%	3.6%
Low Capital Cost (to reduce the payback 2 - 12 years)	Count	155	63	31	249
	% within Profession	26.6%	28.9%	26.3%	27.1%
	% of Total	16.9%	6.9%	3.4%	27.1%
Total	Count	583	218	118	919
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	63.4%	23.7%	12.8%	100.0%

Table C-50: Crosstabulation for profession and the preference of heat supply in domestic dwellings (Q38A)

Heat Supply in Domestic dwellings	Profession			Total
	Architect	Engineer	Other	

HVAC (Heat, Ventilation, and Air Conditioning)	Count	131	56	32	219
	% within Profession	45.3%	47.1%	54.2%	46.9%
	% of Total	28.1%	12.0%	6.9%	46.9%
Direct flow (mechanical ventilation)	Count	117	54	20	191
	% within Profession	40.5%	45.4%	33.9%	40.9%
	% of Total	25.1%	11.6%	4.3%	40.9%
Other technique	Count	41	9	7	57
	% within Profession	14.2%	7.6%	11.9%	12.2%
	% of Total	8.8%	1.9%	1.5%	12.2%
Total	Count	289	119	59	467
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	61.9%	25.5%	12.6%	100.0%

Table C-51: Crosstabulation and Pearson's Chi-square test for geographic region (excluding "Other Countries) and the preference of supplying the heated air to interior spaces for domestic dwellings (Q38A)

Heat Supply in Domestic dwellings		**Geographic Region**				**Total**
		Canada	USA	UK	Europ e	
HVAC (Heat, Ventilation, and Air Conditioning)	Count	38	67	50	48	203
	% within Geographic Region	63.3%	55.8%	36.0%	41.4%	46.7%
	% of Total	8.7%	15.4%	11.5%	11.0%	46.7%
	Std. Residual	1.9	1.5	-1.8	-.8	
Direct flow (mechanical ventilation)	Count	20	43	69	47	179
	% within Geographic Region	33.3%	35.8%	49.6%	40.5%	41.1%
	% of Total	4.6%	9.9%	15.9%	10.8%	41.1%
	Std. Residual	-.9	-.9	1.6	-.1	
Other technique	Count	2	10	20	21	53
	% within Geographic Region	3.3%	8.3%	14.4%	18.1%	12.2%
	% of Total	.5%	2.3%	4.6%	4.8%	12.2%
	Std. Residual	-2.0	-1.2	.7	1.8	
Total	Count	60	120	139	116	435
	% within Geographic Region	100.0%	100.0%	100.0%	100.0 %	100.0%
	% of Total	13.8%	27.6%	32.0%	26.7%	100.0%

Chi-Square Tests			
	Value	df	Asymp. Sig. (2-sided)

Pearson Chi-Square	23.204[a]	6	.001
Likelihood Ratio	24.278	6	.000
Linear-by-Linear Association	16.921	1	.000
N of Valid Cases	435		
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 7.31.			

Symmetric Measures			
		Value	Approx. Sig.
Nominal by Nominal	Phi	.231	.001
	Cramer's V	.163	.001
N of Valid Cases		435	
a. Not assuming the null hypothesis. b. Using the asymptotic standard error assuming the null hypothesis.			

Table C-52: Crosstabulation and Pearson's Chi-square test for profession and the preference of supplying the heated air to interior spaces for non-domestic office buildings (Q38B)

Heat Supply in Non-domestic office buildings		**Profession**			**Total**
		Architect	Engineer	Other	
HVAC (Heat, Ventilation, and Air Conditioning)	Count	201	94	32	327
	% within Profession	71.0%	77.0%	56.1%	70.8%
	% of Total	43.5%	20.3%	6.9%	70.8%
	Std. Residual	.0	.8	-1.3	
Direct flow (mechanical ventilation)	Count	48	19	19	86
	% within Profession	17.0%	15.6%	33.3%	18.6%
	% of Total	10.4%	4.1%	4.1%	18.6%
	Std. Residual	-.6	-.8	2.6	
Other technique	Count	34	9	6	49
	% within Profession	12.0%	7.4%	10.5%	10.6%
	% of Total	7.4%	1.9%	1.3%	10.6%
	Std. Residual	.7	-1.1	.0	
Total	Count	283	122	57	462
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	61.3%	26.4%	12.3%	100.0%

Chi-Square Tests			
	Value	df	Asymp. Sig. (2-sided)

Pearson Chi-Square	11.790[a]	4	.019
Likelihood Ratio	10.801	4	.029
Linear-by-Linear Association	.241	1	.623
N of Valid Cases	462		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 6.05.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.160	.019
	Cramer's V	.113	.019
N of Valid Cases		462	

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Table C-53: Crosstabulation and Pearson's Chi-square test for geographic region (excluding "Other Countries) and the preference of supplying the heated air to interior spaces for non-domestic office buildings (Q38B)

Heat Supply in Domestic dwellings		**Geographic Region**				**Total**
		Canada	USA	UK	Europe	
HVAC (Heat, Ventilation, and Air Conditioning)	Count	49	85	92	77	303
	% within Geographic Region	83.1%	72.6%	65.2%	68.1%	70.5%
	% of Total	11.4%	19.8%	21.4%	17.9%	70.5%
	Std. Residual	1.2	.3	-.7	-.3	
Direct flow (mechanical ventilation)	Count	9	22	32	17	80
	% within Geographic Region	15.3%	18.8%	22.7%	15.0%	18.6%
	% of Total	2.1%	5.1%	7.4%	4.0%	18.6%
	Std. Residual	-.6	.0	1.1	-.9	
Other technique	Count	1	10	17	19	47
	% within Geographic Region	1.7%	8.5%	12.1%	16.8%	10.9%
	% of Total	.2%	2.3%	4.0%	4.4%	10.9%
	Std. Residual	-2.1	-.8	.4	1.9	
Total	Count	59	117	141	113	430
	% within Geographic Region	100.0%	100.0%	100.0%	100.0%	100.0%

% of Total	13.7%	27.2%	32.8%	26.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.388[a]	6	.037
Likelihood Ratio	15.423	6	.017
Linear-by-Linear Association	8.201	1	.004
N of Valid Cases	430		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 6.45.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.176	.037
	Cramer's V	.125	.037
N of Valid Cases		430	

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Table C-54: Crosstabulation between profession and the awareness of commercial TSC products (Q29)

Technology Selection at New Residential Building			Profession			Total
			Architect	Engineer	Other	
SolarWall®	Checked	Count	203	85	36	324
		Column N %	65.9%	65.9%	57.1%	-
		Table N %	40.6%	17.0%	7.2%	64.8%
	Unchecked	Count	105	44	27	176
		Column N %	34.1%	34.1%	42.9%	-
		Table N %	21.0%	8.8%	5.4%	35.2%
InSpire TM Wall	Checked	Count	50	19	14	83
		Column N %	16.2%	14.7%	22.2%	-
		Table N %	10.0%	3.8%	2.8%	16.6%
	Unchecked	Count	258	110	49	417
		Column N %	83.8%	85.3%	77.8%	-
		Table N %	51.6%	22.0%	9.8%	1
MatrixAir TR	Checked	Count	23	10	5	38
		Column N %	7.5%	7.8%	7.9%	-
		Table N %	4.6%	2.0%	1.0%	7.6%
	Unchecked	Count	285	119	58	462
		Column N %	92.5%	92.2%	92.1%	-
		Table N %	57.0%	23.8%	11.6%	92.4%

LubiTM	Checked	Count	10	8	3	21
		Column N %	3.2%	6.2%	4.8%	-
		Table N %	2.0%	1.6%	.6%	0
	Unchecked	Count	298	121	60	479
		Column N %	96.8%	93.8%	95.2%	-
		Table N %	59.6%	24.2%	12.0%	95.8%
Colorcoat Renew®	Checked	Count	48	13	8	69
		Column N %	15.6%	10.1%	12.7%	-
		Table N %	9.6%	2.6%	1.6%	13.8%
	Unchecked	Count	260	116	55	431
		Column N %	84.4%	89.9%	87.3%	-
		Table N %	52.0%	23.2%	11.0%	86.2%
Not Applicable	Checked	Count	94	42	22	158
		Column N %	30.5%	32.6%	34.9%	-
		Table N %	18.8%	8.4%	4.4%	31.6%
	Unchecked	Count	214	87	41	342
		Column N %	69.5%	67.4%	65.1%	-
		Table N %	42.8%	17.4%	8.2%	68.4%

Table C-55: Selection of "Not Applicable" of commercial TSC awareness in a crosstab and Pearson's Chi-square test with geographic region (Q29)

Not Applicable	**Geographic Region**					**Total**
	Canada	USA	UK	Europe	Other Countries	
Checked						
Count	13	38	44	51	12	158
% within Region	19.1%	30.6%	29.3%	40.2%	38.7%	31.6%
% of Total	2.6%	7.6%	8.8%	10.2%	2.4%	31.6%
Std. Residual	-1.8	-.2	-.5	1.7	.7	
Unchecked						
Count	55	86	106	76	19	342
% within Region	80.9%	69.4%	70.7%	59.8%	61.3%	68.4%
% of Total	11.0%	17.2%	21.2%	15.2%	3.8%	68.4%
Std. Residual	1.2	.1	.3	-1.2	-.5	
Total						
Count	68	124	150	127	31	500

% within Region	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
% of Total	13.6%	24.8%	30.0%	25.4%	6.2%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	10.338[a]	4	.035
Likelihood Ratio	10.615	4	.031
Linear-by-Linear Association	8.105	1	.004
N of Valid Cases	500		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 9.80.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.144	.035
	Cramer's V	.144	.035
N of Valid Cases		500	

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Table C-56: Selection of SolarWall of Commercial TSC awareness in a crosstab and Pearson's Chi-square test with geographic region (Q29)

SolarWall®	Geographic Region					Total
	Canada	USA	UK	Europe	Other Countries	
Checked						
Count	54	82	98	72	18	324
% within Region	79.4%	66.1%	65.3%	56.7%	58.1%	64.8%
% of Total	10.8%	16.4%	19.6%	14.4%	3.6%	64.8%
Std. Residual	1.5	.2	.1	-1.1	-.5	
Unchecked						
Count	14	42	52	55	13	176
% within Region	20.6%	33.9%	34.7%	43.3%	41.9%	35.2%
% of Total	2.8%	8.4%	10.4%	11.0%	2.6%	35.2%
Std. Residual	-2.0	-.2	-.1	1.5	.6	
Total						

Count	68	124	150	127	31	500
% within Region	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
% of Total	13.6%	24.8%	30.0%	25.4%	6.2%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	10.756[a]	4	.029
Likelihood Ratio	11.213	4	.024
Linear-by-Linear Association	8.899	1	.003
N of Valid Cases	500		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 10.91.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.147	.029
	Cramer's V	.147	.029
N of Valid Cases		500	

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Table C-57: Selection of Colorcoat Renew of commercial TSC awareness in a crosstab and Pearson's Chi-square test with geographic region (Q29)

Colorcoat Renew®	Geographic Region				Total
	Canada	USA	UK	Europe	
Checked					
Count	0	12	37	16	65
% within Region	0.0%	9.7%	24.7%	12.6%	13.9%
% of Total	0.0%	2.6%	7.9%	3.4%	13.9%
Std. Residual	-3.1	-1.3	3.6	-.4	
Unchecked					
Count	68	112	113	111	404
% within Region	100.0%	90.3%	75.3%	87.4%	86.1%
% of Total	14.5%	23.9%	24.1%	23.7%	86.1%
Std. Residual	1.2	.5	-1.4	.2	

Total					
Count	68	124	150	127	469
% within Region	100.0%	100.0%	100.0%	100.0%	100.0%
% of Total	14.5%	26.4%	32.0%	27.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	27.601[a]	3	.000
Likelihood Ratio	34.826	3	.000
Linear-by-Linear Association	8.668	1	.003
N of Valid Cases	469		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 9.42.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.243	.000
	Cramer's V	.243	.000
N of Valid Cases		469	

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Table C-58: Satisfaction of TSC technology in a crosstab and Pearson's Chi-square test with geographic region (Q30) after excluding "other countries" and "no opinion" respondents to comply with Chai-square rules and the purpose of the question

Quality of the available TSC		Geographic Region				Total
		Canada	USA	UK	Europe	
Satisfactory	Count	17	19	15	21	72
	% within Geographic Region	37.0%	20.7%	16.1%	30.0%	23.9%
	% of Total	5.6%	6.3%	5.0%	7.0%	23.9%
	Std. Residual	1.8	-.6	-1.5	1.0	
Neutral	Count	22	66	66	42	196
	% within Geographic Region	47.8%	71.7%	71.0%	60.0%	65.1%
	% of Total	7.3%	21.9%	21.9%	14.0%	65.1%

	Std. Residual	-1.5	.8	.7	-.5	
Unsatisfactory	Count	7	7	12	7	33
	% within Geographic Region	15.2%	7.6%	12.9%	10.0%	11.0%
	% of Total	2.3%	2.3%	4.0%	2.3%	11.0%
	Std. Residual	.9	-1.0	.6	-.2	
Total	Count	46	92	93	70	301
	% within Geographic Region	100.0%	100.0%	100.0%	100.0%	100.0%
	% of Total	15.3%	30.6%	30.9%	23.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	12.705[a]	6	.048
Likelihood Ratio	12.687	6	.048
Linear-by-Linear Association	.103	1	.748
N of Valid Cases	301		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 5.04.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.205	.048
	Cramer's V	.145	.048
N of Valid Cases		301	

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Table C-59: Crosstabulation between profession and the further creative development (Q31)

Technology Selection at Existing Residential Building			**Profession**			**Total**
			Architect	Engineer	Other	
Architects	Checked	Count	201	64	29	201
		Column N %	64.4%	50.4%	45.3%	64.4%
		Table N %	40.0%	12.7%	5.8%	40.0%
	Unchecked	Count	111	63	35	111
		Column N %	35.6%	49.6%	54.7%	35.6%
		Table N %	22.1%	12.5%	7.0%	22.1%

Research and Design	Checked	Count	192	70	37	192
		Column N %	61.5%	55.1%	57.8%	61.5%
		Table N %	38.2%	13.9%	7.4%	38.2%
	Unchecked	Count	120	57	27	120
		Column N %	38.5%	44.9%	42.2%	38.5%
		Table N %	23.9%	11.3%	5.4%	23.9%
Integration design teams	Checked	Count	209	89	47	209
		Column N %	67.0%	70.1%	73.4%	67.0%
		Table N %	41.6%	17.7%	9.3%	41.6%
	Unchecked	Count	103	38	17	103
		Column N %	33.0%	29.9%	26.6%	33.0%
		Table N %	20.5%	7.6%	3.4%	20.5%
No further actions required	Checked	Count	5	0	1	5
		Column N %	1.6%	0.0%	1.6%	1.6%
		Table N %	1.0%	0.0%	.2%	1.0%
	Unchecked	Count	307	127	63	307
		Column N %	98.4%	100.0%	98.4%	98.4%
		Table N %	61.0%	25.2%	12.5%	61.0%

Table C-60: Crosstabulation and Pearson's Chi-square test between profession and the selection of Architect as to encounter further innovative development of TSC (Q20)

Ground Source heat pump		**Profession**			**Total**
		Architect	Engineer	Other	
Checked	Count	111	63	35	209
	% within Profession	35.6%	49.6%	54.7%	41.6%
	% of Total	22.1%	12.5%	7.0%	41.6%
Unchecked	Count	201	64	29	294

	% within Profession	64.4%	50.4%	45.3%	58.4%
	% of Total	40.0%	12.7%	5.8%	58.4%
Total	Count	312	127	64	503
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	62.0%	25.2%	12.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	12.526a	2	.002
Likelihood Ratio	12.472	2	.002
Linear-by-Linear Association	11.847	1	.001
N of Valid Cases	503		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 26.59.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.158	.002
	Cramer's V	.158	.002
N of Valid Cases		503	

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Table C-61: Crosstabulation and Pearson's Chi-square test for profession and the technical presentations and demonstrations (Q34)

Technical presentations and demonstrations are helpful for decisions		**Profession**			**Total**
		Architect	Engineer	Other	
Agree	Count	393	147	76	616
	% within Profession	65.8%	65.0%	59.4%	64.8%
	% of Total	41.3%	15.5%	8.0%	64.8%
	Std. Residual	.3	.1	-.8	
Disagree	Count	17	9	6	32

	% within Profession	2.8%	4.0%	4.7%	3.4%
	% of Total	1.8%	.9%	.6%	3.4%
	Std. Residual	-.7	.5	.8	
No Opinion	Count	36	21	21	78
	% within Profession	6.0%	9.3%	16.4%	8.2%
	% of Total	3.8%	2.2%	2.2%	8.2%
	Std. Residual	-1.9	.6	3.2	
Maybe	Count	151	49	25	225
	% within Profession	25.3%	21.7%	19.5%	23.7%
	% of Total	15.9%	5.2%	2.6%	23.7%
	Std. Residual	.8	-.6	-1.0	
Total	Count	597	226	128	951
	% within Profession	100.0%	100.0%	100.0%	100.0%
	% of Total	62.8%	23.8%	13.5%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	18.312[a]	6	.005
Likelihood Ratio	16.269	6	.012
Linear-by-Linear Association	.053	1	.818
N of Valid Cases	951		

a. 1 cells (8.3%) have expected count less than 5. The minimum expected count is 4.31.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.139	.005
	Cramer's V	.098	.005
N of Valid Cases		951	

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

APPENDIX D ||

MONITORING PLAN

OF TESTING RIG

INTRODUCTION

This plan describes a programme of monitoring a testing rig of transpired solar collectors (TSC) for air heating. This includes potential location, instruments, layout design, and measurements and observations to be applied and recorded. The aim of monitoring plan is to measure, record, report, and analyse the climatic data around the TSC and the output parameters of TSC during the monitoring period. This experiment has been conducted to assess the real time heated air output from the TSC technology.

PROJECT DESCRIPTION

The testing rig assembly and monitoring was carried out in combination with the “Sustainable Building Envelope Demonstration” (SBED) project funded from the European Regional Development Fund through the Welsh Government. Monitoring was carried out during the winter season of 2013/2014. Four TSC panels were installed on the top roof of the Welsh school of Architecture in Cardiff University. They were sized to feed a room of approximately 15m2 in area (Fig. D-1a and b).

Figure D-1: (a) Bute Building showing the top roof highlighted- Google Perspective, (b) South-West view

The construction and installation of the four TSC panels started in November 2012. Three of the panels have a rectangular shape with dimensions of 600 x 1800mm whereas the forth one is square of 1039 x 1039mm. All the panels are south facing – side-by-side - and have quite large gaps between them to avoid shading. Of the three rectangular panels (Figs. D-2, D-3 and D-4):

a. Is placed vertically with short dimension along the bottom
b. Is placed vertically with short dimension along the side
c. Is inclined at 45ºC with short dimension along the bottom

One fan was positioned so that it could be used to pull air in a controlled manner through any of the panels.

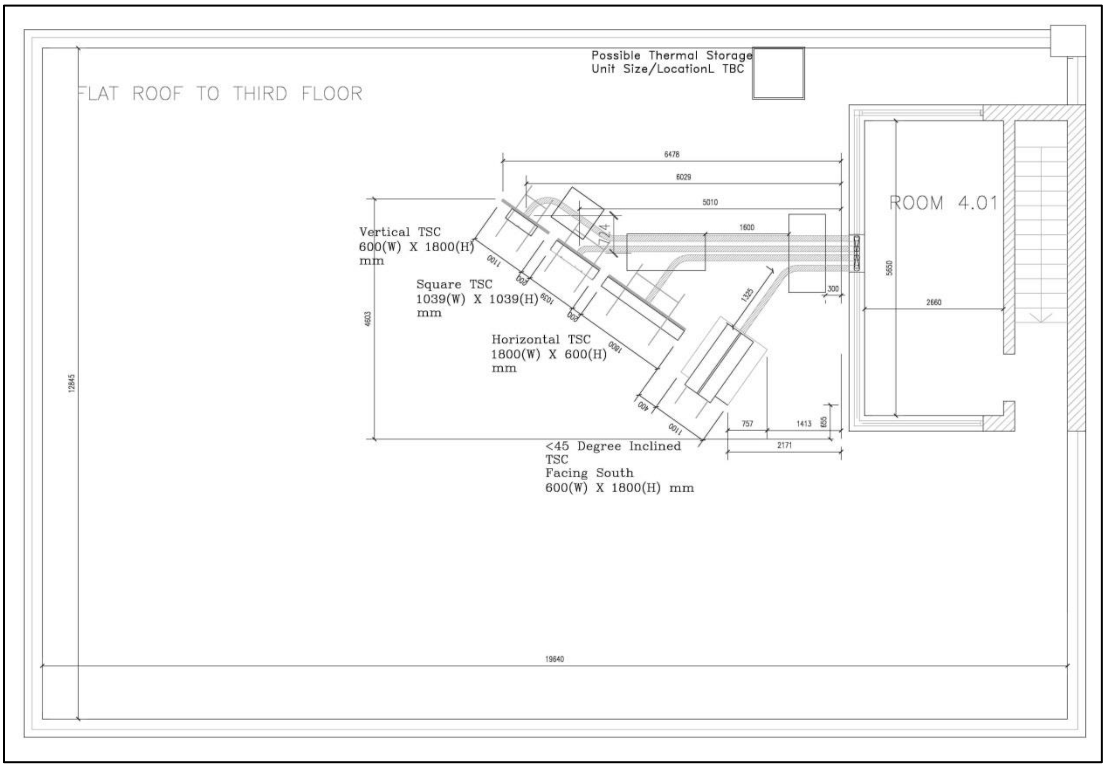


Figure D-2: Layout of the TSC installations on the roof, all panels are facing south

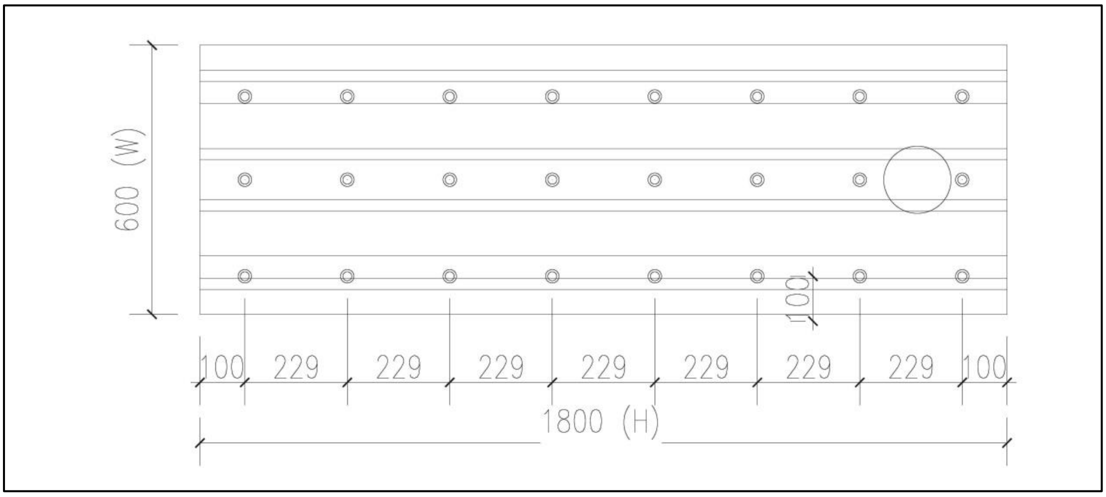


Figure D-3: Frontal elevation of vertical unit shows the used temperature sensor locations inside the plenum

Figure D-4: The sensor locations in the plenum of vertical TSC

The panels are raised 200mm above floor level and placed on a wooden structure (Fig. D-5). The width of the panels is 200mm in addition to the thickness of the thermal insulation. As the panels are installed as stand-alone far from the room fabric, the panels have additional 200mm of thermal insulation at the back (Fig. D-6) to reduce heat loss of the TSC. This thickness was chosen to simulate integration with building façade or roof. The collectors are manufactured from pre-finished steel coated in a black organic paint. The steel thickness is 0.7mm. The pitch is in triangular arrangement; perforation diameter is 12 mm, and porosity 0.3.

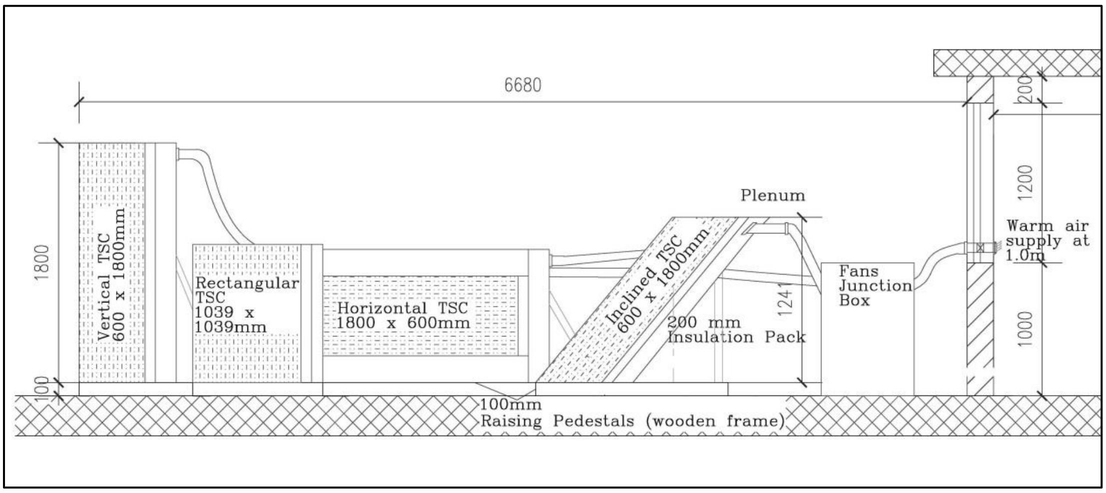


Figure D-5: South-east elevation shows schematic TSC prototype units

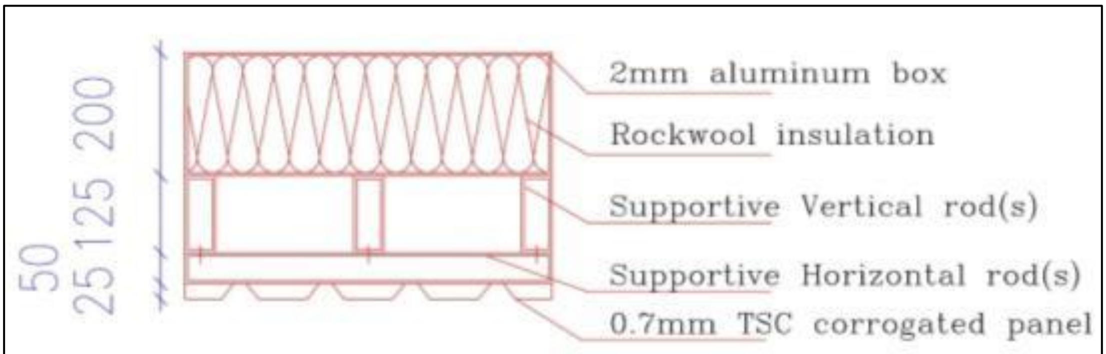


Figure D-6: Typical top view section in TSC installation (Design)

MONITORING INSTRUMENTS

The instruments used for monitoring meteorological conditions and test rig parameters are listed in table D-1.

Table D-1: The needed instruments for investigation

S/N	**Instrument**	**Function**	**Make/model/ Supplier**	**Quantity**
1.	Weather station* (Fig. D-7a,b) (including its data logger)	Record ambient climatic conditions: wind velocity; air temperature; and relative humidity	Campbell scientific (CSI) GRWS100	1
2.	Data loggers	Measurement and control of TSC with scientific computer software which records temperature, relative humidity, carbon dioxide, differential air pressure, air velocity and air flow	(CSI) CR1000 (Fig. D-8) Hobo U12 (excluded proposal) Tinytag Ultra 2 (excluded proposal)	5
3.	Data logger support software	Support software for programming, communications, and data display	SCWin PC200W PC400	1
4.	Solar radiation sensor	On the outer face of the TSC panels: (one for any vertical unit and one for the inclined unit)	Kipp & Zonen's CMP3 pyranometer (Fig.D- 9)	2

Table D-1 Continued: The needed instruments for investigation

5.	Temperature sensors	Measures air temperature: Thermocouple sensors were placed in a grid formation to measure temperature variation within the plenum as shown in Figs D-3 and D-4. In addition a sensor was placed in the supply duct before each fan and one was placed after the fan.	Type-T thermocouple sensor (Fig. D-10)	40+ total
			PT100 (Fig. D-11)	
6.	Single-Point Multi-Range Air Velocity Transmitter	Measures air velocity	Sontay AV-DSP (Fig. D-12)	4
7.	Temperature and relative humidity sensors	Measures temperature and relative humidity: (4) at the beginning of each duct, and (4) at the outer face of each TSC panel.	CS215 (Fig. D-13)	8
			TSI, Velocicalc 9545 (Fig. 14)	
8.	Globe temperature*	Measures indoor globe temperature	BlackGlobe-L (Fig. D-15)	2
9.	Carbon dioxide data logger*	For indoor monitoring	Tinytag CO_2	2
			GMT220 Vaisala (Fig. D-16)	

* Indoor instruments are partially installed and not reported in the thesis as they turned beyond the scope of work

Figure D-7: (a) Existing solar irradiation diffuser (b) Existing weather station – remedial work is required for the relative humidity and temperature sensors

Figure D-8: CR1000 - Measurement and control data loggers

Figure D-9: CMP3 Solar radiation sensor, Protective Glass Dome and solar shield

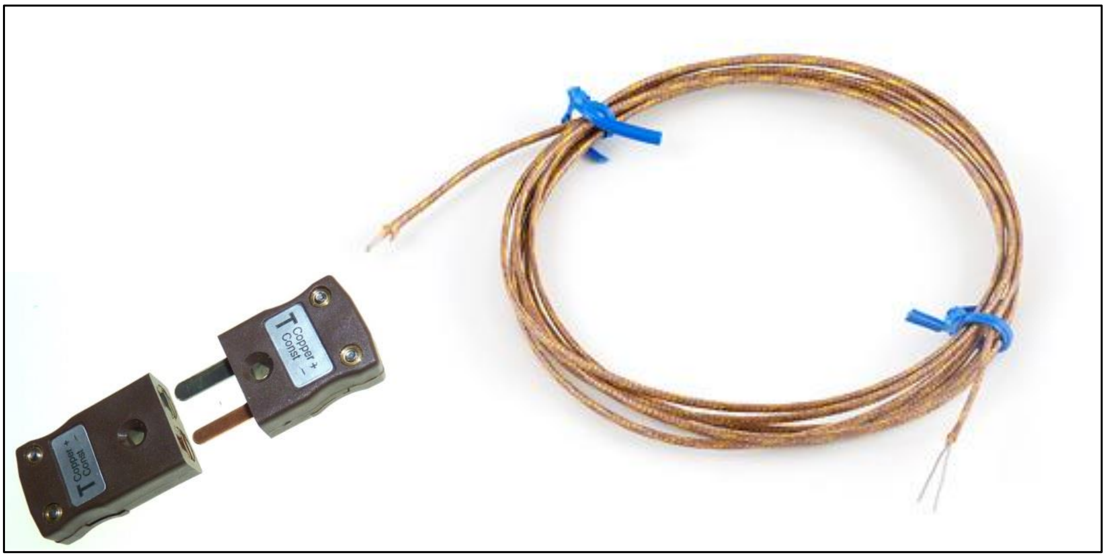


Figure D-10: Type-T thermocouple sensor

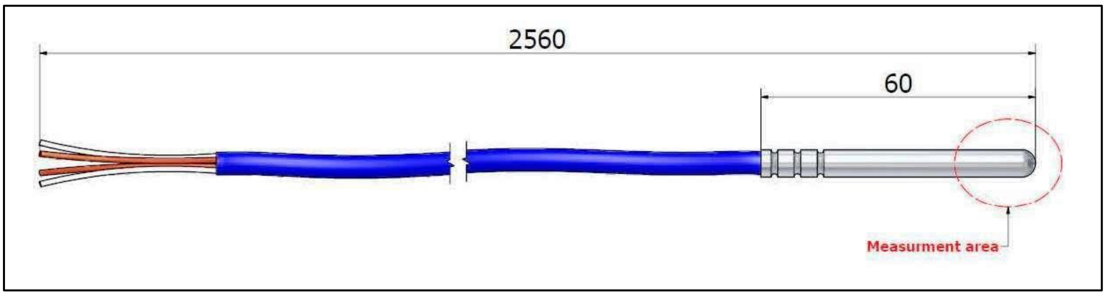


Figure D-11: PT100 thermic element with cable and tip Ø 6

Figure D-12: AV-DSP Single-Point Multi-Range Air Velocity Transmitter

Figure D-13: (a) CS215-L Temperature and Relative Humidity Sensor, (b) HMP155A-L Temperature and Humidity Probe

Figure D-14: VelociCalc® Air Velocity Meter 9545, measures velocity, temperature, and relative humidity; and calculates flow, wet bulb and dew point temperature

Figure D-15: BlackGlobe-L, Temperature Sensor for Heat Stress (Black Globe) uses a thermistor inside

Figure D-16: Vaisala CARBOCAP® carbon dioxide transmitter series GMT220

TSC CONSTRUCTION ITEMS

The table below includes list of the construction items of transpired solar collector (TSC) testing rig on the Bute building roof.

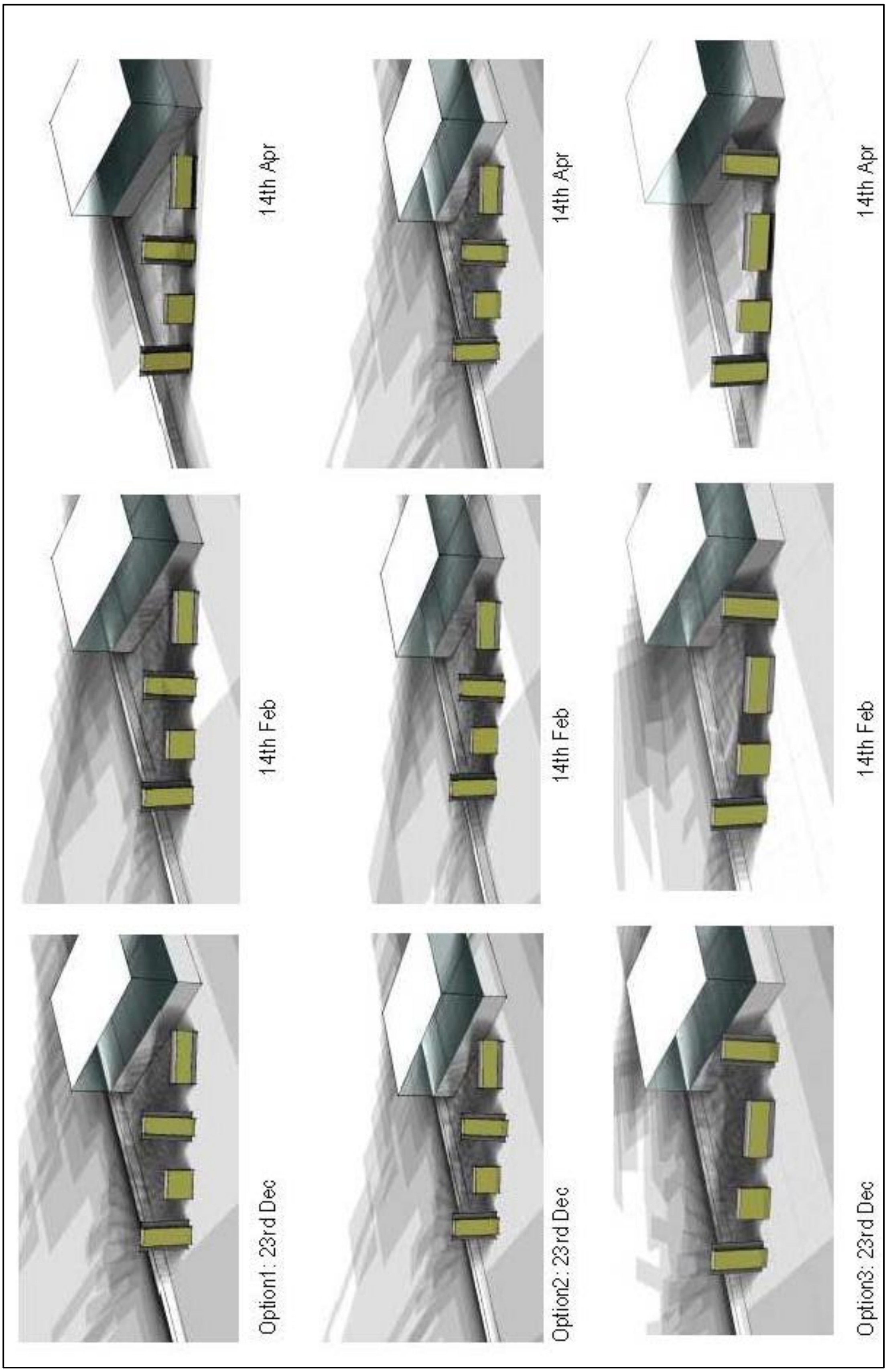
Table D-2: list of the TSC construction items

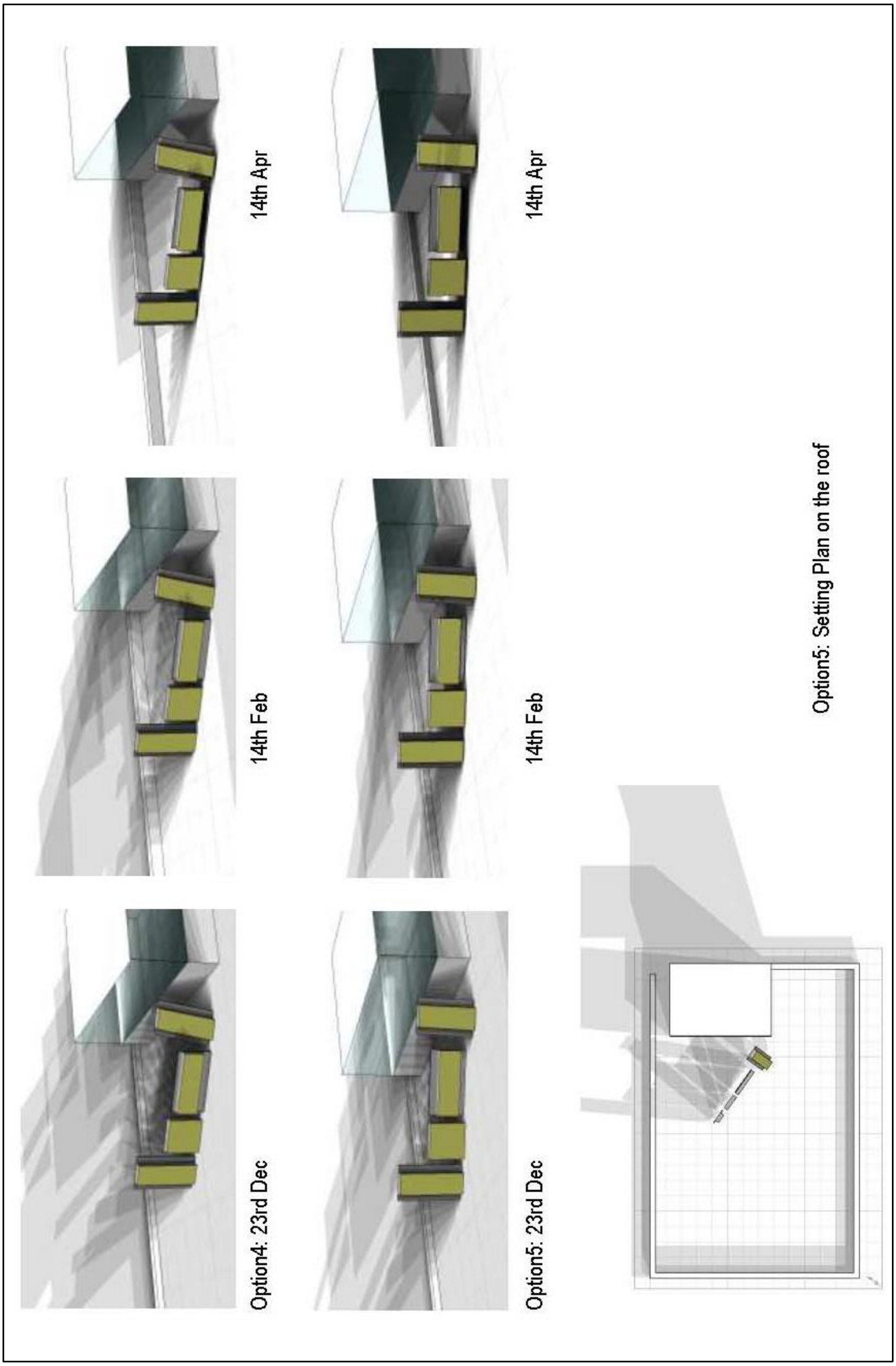
S/N	Description	Qty	Note
1	Unit 1: TSC Colorcoat Renew SC black panel 1039 (width) x 1039 (height) x *0.7 (thickness)* mm including bracket holding channels (to be detailed by the manufacturer). Indicative details in Fig. D-4	1	
	200 mm thick back-up Rockwool insulation enclosed with 1039 (W) x 1039 (H) x 5 (thk)mm galvanized steel.	1	
	Supportive wooden structure to hold the TSC installation.	1	
2	Unit 2: TSC Colorcoat Renew SC black panel 600 (width) x 1800 (height) x 0.7 (thickness) mm including bracket holding channels (to be detailed by the manufacturer). Indicative details in Fig. D-4	1	
	200 mm thick back-up Rockwool insulation enclosed with 600 (w) x 1800 (h) x 5 (thk)mm galvanized steel.	1	
	Supportive wooden structure to hold the TSC installation.	1	

Table D-2 Continued: list of the TSC construction items

S/N	Description	Qty	Note
3	Unit 3: TSC Colorcoat Renew SC black panel 600 (width) x 1800 (height) x 0.7 (thickness) mm installed inclined at 45 degree, including bracket holding channels (to be detailed by the manufacturer). Indicative details in Fig. D-4	1	
	200 mm thick back-up Rockwool insulation enclosed with 600 (w) x 1800 (h) x 5 (thk)mm galvanized steel.	1	
	Supportive wooden structure to hold the TSC installation	1	
4	Unit 4: TSC Colorcoat Renew SC black panel 1800 (width) x 600 (height) x 0.7 (thickness) mm installed inclined at 45 degree, including bracket holding channels (to be detailed by the manufacturer). Indicative details in Fig. D-4	1	
	200 mm thick back-up Rockwool insulation enclosed with 1800 (w) x 600 (h) x 5 (thk)mm galvanized steel.	1	
	Supportive wooden structure to hold the TSC installation	1	
5	Hole to the existing wall, size to accommodate the duct size (about 150 mm) at around 600mm height from floor level	1	
6	Flexible duct 150 mm insulated by 50mm thermal Rockwool to minimize temperature loss	L.M	Length to be confirmed
7	Make-up Fan Unit	1	Specification to TSC manufactured.
8	Internal flue ducting: vertical and horizontal.		To be recommended by the TSC manufacturer
9	Extract fan		
10	Thermal Storage unit		Type and Size to be advised by the TSC manufacturer

SCENARIOS OF LOCATING TSC PANELS ON THE ROOF – SHADING ANALYSIS




Option4: 23rd Dec
14th Feb
14th Apr
Option5: 23rd Dec
14th Feb
14th Apr
Option5: Setting Plan on the roof

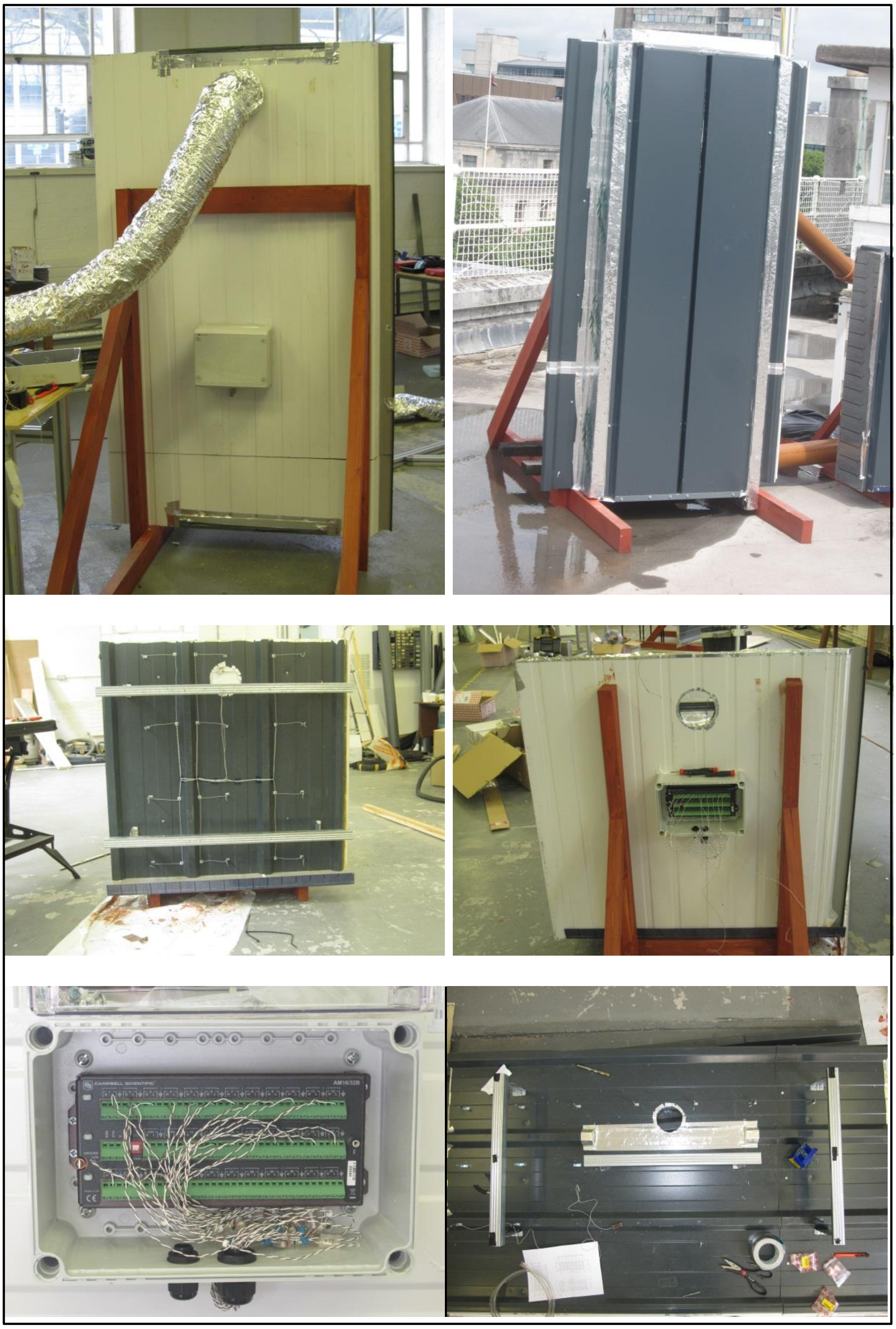


Figure D-17: Progress photos of the TSC prototype

APPENDIX E ||

ETHICS APPROVAL

(QUESTIONNAIRE)

EC1203. 114

WELSH SCHOOL OF ARCHITECTURE
ETHICS APPROVAL FORM FOR STAFF AND PHD/MPHIL PROJECTS

WS

Tick one box:	☐ STAFF √ PHD/MPHIL
Title of project:	The Architectural and Environmental Integration of Transpired Solar Thermal in Commercial and Residential Building Envelopes
Name of researcher(s):	Hasan J. Alfarra
Name of principal investigator	Prof. Phil Jones
Contact e-mail address:	alfarrah@cardiff.ac.uk
Date:	20/02/2012

Participants		YES	NO	N/A
Does the research involve participants from any of the following groups?	• Children (under 16 years of age)		√	
	• People with learning difficulties		√	
	• Patients (NHS approval is required)		√	
	• People in custody		√	
	• People engaged in illegal activities		√	
	• Vulnerable elderly people		√	
	• Any other vulnerable group not listed here		√	
• When working with children: I have read the Interim Guidance for Researchers Working with Children and Young People (http://www.cardiff.ac.uk/archi/ethics_committee.php)				√

Consent Procedure	YES	NO	N/A
• Will you describe the research process to participants in advance, so that they are informed about what to expect?	√		
• Will you tell participants that their participation is voluntary?			√
• Will you tell participants that they may withdraw from the research at any time and for any reason?			√
• Will you obtain valid consent from participants? (specify how consent will be obtained in Box A)[1]			√
• Will you give participants the option of omitting questions they do not want to answer?			√
• If the research is observational, will you ask participants for their consent to being observed?			√
• If the research involves photography or other audio-visual recording, will you ask participants for their consent to being photographed / recorded and for its use/publication?			√

Possible Harm to Participants	YES	NO	N/A
• Is there any realistic risk of any participants experiencing either physical or psychological distress or discomfort?		√	
• Is there any realistic risk of any participants experience a detriment to their interests as a result of participation?		√	

Data Protection		YES	NO	N/A
• Will any non-anonymous and/or personalised data be generated or stored?			√	
• If the research involves non-anonymous and/or personalised data, will you:	• gain written consent from the participants			√
	• allow the participants the option of anonymity for all or part of the information they provide	√		

Health and Safety	YES
Does the research meet the requirements of the University's Health & Safety policies? (http://www.cardiff.ac.uk/osheu/complete_risk_assessment/index.html)	√

If any of the shaded boxes have been ticked, the supervisor must explain in Box A how the ethical issues are addressed.

The list of ethical issues on this form is not exhaustive; if you are aware of any other ethical issue you should make the SREC aware of it.

[1] If any non-anonymous and/or personalised data be generated or stored, *written consent* is required.

A	The Project (provide all the information listed below in a separate attachment)

1. Title of Project
2. Purpose of the project and its academic rationale
3. Brief description of methods and measurements
4. Participants: recruitment methods, number, age, gender, exclusion/inclusion criteria
5. Consent and participation information arrangements - please attached consent forms if they are to be used
6. A clear and concise statement of the ethical considerations raised by the project and how is dealt with them
7. Estimated start date and duration of project

All information must be submitted along with this form to the School Research Ethics Committee for consideration

Researcher's declaration (tick as appropriate)	
• I consider this project to have **negligible ethical implications** (*can only be used if none of the grey areas of the checklist have been ticked*).	√
• I consider this project research to have **some ethical implications**.	
• I consider this project to have **significant ethical implications**	

Signature Hazfarra **Name** Hasan Alfarra **Date** 20/03/12
Researcher or MPhil/PhD student

Signature V. Stevenson **Name** Vicki Stevenson **Date** 22/3/12
Lead investigator or supervisor

Advice from the School Research Ethics Committee

STATEMENT OF ETHICAL APPROVAL

This project had been considered using agreed Departmental procedures and is now approved

Signature **Name** 26/03/12 WOUTER POORTINGA **Date**
Chair, School Research Ethics Committee

ATTACHMENT TO ETHICS APPROVAL FORM:

1. Title of Project

The Architectural and Environmental Integration of Transpired Solar Thermal in Commercial and Residential Building Envelopes

2. Purpose of the project and its academic rationale

The project investigates the perception of architects towards the integration of Transpired Solar Collectors (TSCs) in commercial and residential buildings. The rationale of the project aims to promote the usage of an alternative sustainable source of energy for either space heating or both space heating and electricity in buildings. This new source will substitute the fossil fuel dependency which leads to cleaner and climate friendly built environment. The investigation in the architectural integration part however will focus on the current architects' perception and TSCs technology challenges in order to find the possible means to promote the technology and/or improve it.

3. Brief description of methods and measurements

The PhD project consists of two main parts: Quantitative/Qualitative for architectural integration and Simulation/Field work validation to measure thermal comfort and carbon dioxide reductions via building-integrated TSCs. The Quantitative/Qualitative will be conducted via questionnaire and further interviews with architects, whereas, the simulation will be conducted using simulation software with validating the results experimentally. The questionnaire will be web-based survey and results will be analyzed in terms of certain variables (i.e. function, aesthetics, climate change mitigation, thermal comfort...).

4. Participants: recruitment methods, number, age, gender, exclusion/inclusion criteria

This ethics form applies to the qualitative / quantitative part of architectural integration. The recruitment methods will include distribution by the web-based survey to be used (i.e. Lime Survey) which will be open responses via internet. Participants, architects and engineers, will be contacted via notifications through the web-based survey, emailed, contacted using directory of UK consultants to obtain publicly available contact details, my friends and colleagues, Facebook, my ex-universities…… The invitation numbers will be open till the responses received are in acceptable range. The age will be for adult professional architect and engineers in the construction industry while there will be no gender preferences. There might be an option to exclude builders and manufacturers.

5. Consent and participation information arrangements - please attached consent forms if they are to be used

N/A

6. A clear and concise statement of the ethical considerations raised by the project and how is dealt with them

Any identifiable extracts from the survey will not be published without consensus from the participant.

7. Estimated start date and duration of project

The questionnaire is expected to be sent-out before mid of March 2012 and last till July 2012. They are supposed to be no extension beyond this period as I should start analyzing the results.

ETHICAL MEASURES OF THE QUESTIONNAIRE

Albeit the questionnaire was administered in complete anonymity, ethical measures were taken towards data collection and use. Prior to distribution of the questionnaire, ethical approval was obtained from the Research Ethics Committee at the Welsh School of Architecture on 26th March 2012 under reference number EC1203.114 (Appendix E). This approval was mentioned in the text of the email invitation to all the participants as well as the introduction of the questionnaire. The email invitation included detailed information for the respondents that to satisfy the ethical requirements, these included:

- **Aim and Objective:** the aim and the objectives from the survey as well as the research study were illustrated at the beginning of the email.
- **Voluntary participation:** the participants were informed that they could voluntary participate in the survey. They furthermore were notified that they could withdraw at any time during the process without giving a reason. The software was however designed to automatically save the latest response pre-withdrawal.
- **Reporting:** the participants were informed that the data are to be used for academic research purposes and to be used anonymously.
- **Unsubscribing:** following to the web-link location in the email invitation, all the contacts were offered the opportunity to unsubscribe if they do not wish to receive further reminders.
- **Contact details:** the participants have received the contact email and phone number of the researcher in the body of the email invitation as well as the contact details of the Welsh School of Architecture.
- **Misconduct:** the participants had the chance to complain of any misconduct, if not to address an issue directly to the researcher, either to the Welsh School of Architecture or to the web-based survey administration.

APPENDIX F ||

INTERVIEW AND

THE ASSOCIATED

ETHICS APPROVAL

EC1305.149

WELSH SCHOOL OF ARCHITECTURE
ETHICS APPROVAL FORM FOR STAFF AND PHD/MPHIL PROJECTS

wsa

Tick one box:	☐ STAFF √ PHD/MPHIL
Title of project:	The Architectural and Environmental Integration of Transpired Solar Thermal in Commercial and Residential Building Envelopes
Name of researcher(s):	Hasan J. Alfarra
Name of principal investigator	Prof. Phil Jones – Dr. Vicki stevenson
Contact e-mail address:	alfarrah@cardiff.ac.uk
Date:	29/04/2013

Participants		YES	NO	N/A
Does the research involve participants from any of the following groups?	• Children (under 16 years of age)		√	
	• People with learning difficulties		√	
	• Patients (NHS approval is required)		√	
	• People in custody		√	
	• People engaged in illegal activities		√	
	• Vulnerable elderly people		√	
	• Any other vulnerable group not listed here		√	
• When working with children: I have read the Interim Guidance for Researchers Working with Children and Young People (http://www.cardiff.ac.uk/archi/ethics_committee.php)				√

Consent Procedure	YES	NO	N/A
• Will you describe the research process to participants in advance, so that they are informed about what to expect?	√		
• Will you tell participants that their participation is voluntary?	√		
• Will you tell participants that they may withdraw from the research at any time and for any reason?	√		
• Will you obtain valid consent from participants? (specify how consent will be obtained in Box A)[1]	√		
• Will you give participants the option of omitting questions they do not want to answer?	√		
• If the research is observational, will you ask participants for their consent to being observed?			√
• If the research involves photography or other audio-visual recording, will you ask participants for their consent to being photographed / recorded and for its use/publication?			√

Possible Harm to Participants	YES	NO	N/A
• Is there any realistic risk of any participants experiencing either physical or psychological distress or discomfort?		√	
• Is there any realistic risk of any participants experience a detriment to their interests as a result of participation?		√	

Data Protection		YES	NO	N/A
• Will any non-anonymous and/or personalised data be generated or stored?			√	
• If the research involves non-anonymous and/or personalised data, will you:	• gain written consent from the participants			√
	• allow the participants the option of anonymity for all or part of the information they provide			√

Health and Safety	YES
Does the research meet the requirements of the University's Health & Safety policies? (http://www.cardiff.ac.uk/osheu/complete_risk_assessment/index.html)	√

If any of the shaded boxes have been ticked, the supervisor must explain in Box A how the ethical issues are addressed.

The list of ethical issues on this form is not exhaustive; if you are aware of any other ethical issue you should make the SREC aware of it.

[1] If any non-anonymous and/or personalised data be generated or stored, *written consent* is required.

Box A **The Project** (provide all the information listed below in a separate attachment)
1. Title of Project 2. Purpose of the project and its academic rationale 3. Brief description of methods and measurements 4. Participants: recruitment methods, number, age, gender, exclusion/inclusion criteria 5. Consent and participation information arrangements - please attached consent forms if they are to be used 6. A clear and concise statement of the ethical considerations raised by the project and how is dealt with them 7. Estimated start date and duration of project **All information must be submitted along with this form to the School Research Ethics Committee for consideration**

Researcher's declaration (tick as appropriate)	
• I consider this project to have **negligible ethical implications** (*can only be used if none of the grey areas of the checklist have been ticked*).	√
• I consider this project research to have **some ethical implications**.	
• I consider this project to have **significant ethical implications**	

Signature Hazfarra **Name** Hasan Alfarra **Date** 29/04/13
Researcher or MPhil/PhD student

Signature V Steverson **Name** Vicki Steverson **Date** 1/5/13
Lead investigator or supervisor

Advice from the School Research Ethics Committee

STATEMENT OF ETHICAL APPROVAL
This project had been considered using agreed Departmental procedures and is now approved
Signature **Name** WOUTER POORTINGA **Date** Chair, School Research Ethics Committee

ATTACHMENT TO ETHICS APPROVAL FORM (INTERVIEW):

1. Title of Project

The Architectural Integration and Technological Evaluation of Transpired Solar Thermal in Residential Building Envelopes

2. Purpose of the project and its academic rationale

The project investigates the perception of architects towards the integration of Transpired Solar Collectors (TSCs) in commercial and residential buildings. The rationale of the project aims to provide insight into the limitation of architecturally integrating transpired solar thermal technology for space heating in buildings, and clarify its role in satisfying thermal comfort and energy saving at residential sector. This includes an investigation, in USA, Canada, UK and European continent, of the lack of adoption of integrating transpired solar collectors (TSC) in building envelopes despite its apparent technical competitiveness. The socio-economic side in concerns of technological innovative development is explored at entrepreneurship level in UK. Furthermore, the satisfaction of socio-environmental aspects such as thermal comfort and energy saving is verified, in the Welsh residential sector. This will provide information of whether the TSC technology is useful for space heating in dwellings or it needs further innovative measures.

3. Brief description of methods and measurements

The PhD project consists of two main parts: Quantitative/Qualitative for architectural integration and Field work to measure thermal comfort and carbon dioxide reductions via building-integrated TSCs. The Quantitative/Qualitative will be conducted via questionnaire and further interviews with architects, entrepreneurs, engineers...etc. The questionnaire and interviews are to be conducted following to ethics approval from the research ethics committee from the Welsh School of Architecture. The questionnaire is web-based survey and results are analyzed in terms of certain variables (i.e. function, aesthetics, climate change mitigation, thermal comfort...). The interviews will be semi-structured with entrepreneurs and experts in UK and Canada

4. Participants: recruitment methods, number, age, gender, exclusion/inclusion criteria

A previous ethics approval was obtained for the questionnaire under reference number (EC1203.114) on 26-Mar-2012. This ethics form applies to the interview (qualitative) part of the study, particularly to the technological innovative system development. The recruitment methods will include contacting possible participants via email to agree a convenient time and venue for interviews. Participants will be contacted using directory names who participated in the questionnaire and/or recognized as experts in the field. The focus in UK will be in the unique entrepreneur in the country which is [**manufacturer name**] in addition to few academics. The interview numbers will be likely 6 for UK and about the same in Canada. In Canada, the interviews may focus on assessment of research recommendations and results in addition to the evaluation of technological innovation development.

5. Consent and participation information arrangements - please attached consent forms if they are to be used

A consent form will be signed by the participant at the beginning of the interview. The interviews will be recorded using a digital Dictaphone voice recorder. Consent form is attached.

6. A clear and concise statement of the ethical considerations raised by the project and how is dealt with them

Any identifiable extracts from the interviews will not be published without consent from the participant.

7. Estimated start date and duration of project

The interviews in UK are expected to be conducted during May 2013. In Canada, the interviews are expected to be carried out as a start of September 2013.

INTERVIEW DESIGN:

Email text:

Dear (Participant Name),

You are kindly invited to participate in an interview for a study investigating the barriers facing introduction of Transpired Solar Collectors (TSC) into the market (UK/Canada). This is part of a wider study considering technological evaluation and architectural integration of TSC air heaters into building envelopes at the residential sector. This interview is directed to limited number entrepreneurs, researchers, and professionals engaged in research and development to understand their perception of transpired solar technological innovation development and the acute problematic shortage of integrating the technology in building envelopes.

I appreciate if you would propose a convenient time and venue for the interview; I would highly appreciate if this could take place before end of May 2013.

The interview data will be held and reported anonymously and will be exclusively used for academic purposes. Completing the interview will take approximately 30 minutes. Your participation is entirely voluntary and that you can withdraw from the interview at any time without giving a reason. Nevertheless, I highly appreciated your complete participation which will add a valuable contribution to the study. The information you provide will be treated and published totally anonymously. Your contact details will not be used in the reporting or analyses in any way. This survey has been approved by the Research Ethics Committee of the Welsh School of Architecture (……..).

If you have any questions about this interview please do not hesitate to contact me. Thank You very much in advance for your cooperation and help.

Thanks & Regards,

Hasan Alfarra
Ph.D Candidate in Architecture, Cardiff University - UK
Mob: +44 7414 10 3260
hajfarra@hotmail.com
Alfarrah@cardiff.ac.uk

INTERVIEW GUIDING QUESTIONS

I am interested to talk more about innovation development of transpired solar technology at national level, this include some of the structures and barriers to innovation from both architectural and research side. So I really appreciate your advices and your experience on that.

1. What institutions (public, private, and public-private) or regulations do you feel determine the direction of solar research and development?

2. How do you feel about knowledge creation and protection for companies in this region (UK / Canada)?

3. What kind of networking do you do with other companies, in terms of learning and knowledge diffusion for transpired solar technology? Is there a local, regional or international network(s) of solar companies? What benefits do you get from that?

4. What kind of knowledge - tacit, codified... etc. - are you happy to share (or not share) with other institutions (public, private, and public-private) in the sector? Would your company prefer to act independently due to Information Protection issues?

5. What are the expectations of public and legitimate lobby (architects, local authority, building owners...etc.) from integrating solar energy in buildings, especially with transpired solar collectors? How do you evaluate the satisfaction of the technology by legitimate lobby and public yet?

6. In terms regulating a product to market, what are the difficulties you're facing, particularly for transpired solar collectors? What would you recommend that regulatory bodies should do to assist new products emerging into the market?

7. In terms of marketing an innovative technology: what are the obstacles you're facing for creating a new market for transpired solar collectors? How do you deal with these difficulties?

8. In terms of funding: how have you accessed funding to develop transpired solar collectors? Have you been able to access any public funding? How valuable is external financial support for researching new solar technologies and what are the main barriers in your experience to getting funding for transpired solar collectors?

9. How do you evaluate the future of TSC in this country? What are your recommendations for further research and development?

CONSENT FORM - CONFIDENTIAL DATA

I understand that my participation in this project will involve *investigation of barriers facing the introduction of Transpired Solar Collectors (TSC) into the market which will require approximately 30 minutes of my time. This is part of a study considering architectural integration and technological evaluation of TSC air heaters into building envelopes at the residential sector.*

I understand that participation in this study is voluntary and that I can withdraw from the study at any time without giving a reason.

I understand that I am free to ask any questions at any time. I am free to withdraw or discuss my concerns with Dr. Vicki Stevenson on *StevensonV@cardiff.ac.uk.*

I understand that the information provided by me will be recorded but will be held confidentially, such that only the Principal Investigator can trace this information back to me individually. The information will be retained for up to two year when it will be deleted/destroyed.

I understand that I can ask for the information I provide to be deleted/destroyed at any time and, in accordance with the Data Protection Act, I can have access to the information at any time.

I, ___________________________________ **[PRINT NAME]** consent to participate in the study conducted by Hasan Alfarra, Welsh School of Architecture, Cardiff University with the supervision of Prof. Phil Jones and Dr. Vicki Stevenson.

Signed:

Date:

APPENDIX G ||

NVIVO SUMMARIES

(QUALITATIVE DATA)

The followings are sample of qualitative data summaries for both chapters 5(the questionnaire) and chapter 6 (the interviews and secondary data)

Chapter 5: Sample of analysis summary

Ch5: Reports\\Project Summary Report (1/9)
2014-03-13 12:06 PM

Project Summary
Architectural Integration – Analysis Chapter 5

Hierarchical Name	Item Type	Created On	Modified On
Framework Matrices			
Internals\\Q08 - SolGen	Dataset	2012-12-02 3:46 PM	2013-02-14 11:19 PM
Internals\\Q09 - Decision	Dataset	2012-12-02 3:48 PM	2013-02-14 11:19 PM
Internals\\Q10 - Decision of Integration	Dataset	2012-12-02 3:49 PM	2013-02-15 5:52 PM
Internals\\Q11	Dataset	2012-12-02 3:51 PM	2013-11-15 10:08 AM
Internals\\Q12	Dataset	2012-12-02 3:54 PM	2013-11-15 12:41 PM
Internals\\Q13	Dataset	2013-02-15 7:15 PM	2013-11-17 4:01 PM

Ch5: Reports\\Project Summary Report (2/9)
2014-03-13 12:06 PM

Hierarchical Name	Item Type	Created On	Modified On
Internals\\Q14	Dataset	2012-12-02 3:59 PM	2013-11-17 5:10 PM
Internals\\Q15	Dataset	2012-12-02 4:03 PM	2012-12-02 4:04 PM
Internals\\Q16	Dataset	2012-12-02 4:05 PM	2012-12-02 4:06 PM
Internals\\Q17	Dataset	2012-12-02 4:07 PM	2013-11-17 10:16 PM
Internals\\Q18 - Priority in selection	Dataset	2012-12-02 4:10 PM	2013-11-18 11:48 AM
Internals\\Q19 - IntegScheme	Dataset	2012-12-02 4:15 PM	2013-02-17 6:45 PM
Internals\\Q20 - New Residential	Dataset	2012-12-02 4:17 PM	2013-11-18 3:47 PM
Internals\\Q21 - Existing Residential	Dataset	2012-12-02 4:19 PM	2012-12-02 4:20 PM
Internals\\Q22	Dataset	2012-12-02 4:24 PM	2012-12-02 4:24 PM
Internals\\Q23 - Harmonise with Traditional	Dataset	2012-12-02 4:28 PM	2013-11-21 7:43 AM
Internals\\Q24 - State of integration	Dataset	2012-12-02 4:29 PM	2012-12-02 4:30 PM
Internals\\Q25 - Aesthetic appearance	Dataset	2012-12-02 4:31 PM	2013-02-18 10:17 PM
Internals\\Q26 - Dummy	Dataset	2012-12-02 4:37 PM	2013-02-20 9:31 PM
Internals\\Q27 - sustainability	Dataset	2012-12-02 4:40 PM	2013-02-20 9:56 PM
Internals\\Q28 - sustainable characteristics	Dataset	2012-12-02 4:42 PM	2012-12-02 4:43 PM
Internals\\Q29 - commercial familiarity	Dataset	2012-12-02 4:44 PM	2013-02-18 9:35 PM
Internals\\Q30 - Satisfaction	Dataset	2012-12-02 4:45 PM	2013-02-18 9:09 PM
Internals\\Q31 - Innovative development	Dataset	2012-12-02 4:46 PM	2013-02-24 8:41 PM
Internals\\Q32 - Drawbacks	Dataset	2012-12-02 4:47 PM	2013-02-17 10:34 PM

Ch5: Reports\\Project Summary Report (3/9)
2014-03-13 12:06 PM

Hierarchical Name	Item Type	Created On	Modified On
Internals\\Q33 - Factors	Dataset	2012-12-02 4:48 PM	2013-02-24 9:07 PM
Internals\\Q34 - technical presentations	Dataset	2012-12-02 4:50 PM	2013-02-24 9:17 PM
Internals\\Q35 - Colour	Dataset	2012-12-02 4:51 PM	2013-02-24 9:41 PM
Internals\\Q36 - contradict the aesthetics	Dataset	2012-12-02 4:52 PM	2013-02-24 10:11 PM
Internals\\Q37 - Cooling	Dataset	2012-12-02 4:53 PM	2013-02-24 10:25 PM
Internals\\Q38 - Air supply	Dataset	2012-12-02 4:53 PM	2013-02-24 9:51 PM
Internals\\Q39 - Air Supply at refurbished buildings	Dataset	2012-12-02 4:54 PM	2013-02-24 9:50 PM
Internals\\Q40 - Key issues	Dataset	2013-02-15 7:32 PM	2013-02-25 11:36 AM
Internals\\Q41 - further comments	Dataset	2012-12-02 5:01 PM	2013-02-24 10:34 PM
Memos			
Memos\\Delayed involvement of Experts	Memo	2013-02-15 5:58 PM	2013-02-15 6:06 PM
Memos\\Dummy to hide equipments on roof	Memo	2013-02-15 6:52 PM	2013-02-15 6:54 PM
Memos\\Function vs. Aesthetics	Memo	2013-02-17 6:29 PM	2013-02-17 6:31 PM
Memos\\-ve government interference	Memo	2013-02-14 10:20 PM	2013-02-14 10:27 PM
Models			
Models\\cost effectiveness	Model	2013-11-13 4:09 PM	2013-11-13 4:09 PM
Nodes			
Nodes\\Annotations	Node	2013-02-14 11:33 AM	2013-02-26 6:20 PM
Nodes\\Architectural Design	Node	2013-02-14 10:42 AM	2013-02-20 2:35 AM
Nodes\\Architectural Design\Aesthetics	Node	2013-02-14 10:41 AM	2013-11-15 11:16 AM

Ch5: Reports\\Project Summary Report (4/9)
2014-03-13 12:06 PM

Hierarchical Name	Item Type	Created On	Modified On
Nodes\\Architectural Design\Design Directions	Node	2013-02-14 10:42 AM	2013-02-18 9:02 PM
Nodes\\Architectural Design\Design Directions\Appropriate Technology that fits for purpose	Node	2013-02-14 12:45 PM	2013-02-26 5:40 PM
Nodes\\Architectural Design\Design Directions\Building type and function	Node	2013-02-14 11:35 AM	2013-11-19 5:00 PM
Nodes\\Architectural Design\Design Directions\Concept Compatibility	Node	2013-02-18 10:09 PM	2013-11-19 5:20 PM
Nodes\\Architectural Design\Design Directions\Design assisted tools	Node	2013-02-25 2:19 PM	2013-11-19 4:50 PM
Nodes\\Architectural Design\Design Directions\Dummy Choice	Node	2013-02-15 6:35 PM	2013-11-17 7:23 PM
Nodes\\Architectural Design\Design Directions\IDP	Node	2013-02-14 10:02 PM	2013-02-26 5:43 PM
Nodes\\Architectural Design\Design Directions\Location, Size and Orientation	Node	2013-02-15 6:15 PM	2013-11-19 5:21 PM
Nodes\\Architectural Design\Design Directions\Multi-Function	Node	2013-02-17 3:07 PM	2013-02-20 9:35 PM
Nodes\\Architectural Design\Design Directions\Passive design in priority	Node	2013-02-14 12:22 PM	2013-02-26 6:18 PM
Nodes\\Architectural Design\Design Directions\Replaceable Envelopes	Node	2013-02-14 10:57 AM	2013-02-25 10:46 AM
Nodes\\Architectural Design\Design Directions\Shadowing the Building	Node	2013-02-14 12:00 PM	2013-02-26 4:31 AM
Nodes\\Architectural Design\Design Directions\Simplicity and Flexibility	Node	2013-02-14 10:42 AM	2013-11-19 8:16 AM
Nodes\\Architectural Design\Design Directions\Site characteristics	Node	2013-02-14 11:27 AM	2013-11-19 5:17 PM
Nodes\\Architectural Design\Historical and Existing Buildings	Node	2013-02-14 10:48 AM	2013-02-26 6:19 AM
Nodes\\Architectural Design\Office vs. Residential	Node	2013-02-17 6:55 PM	2013-02-20 9:33 PM
Nodes\\Architectural Design\Thermal Comfort	Node	2013-02-14 11:01 AM	2013-02-24 10:06 PM
Nodes\\Bloom's Model - taxonomy of the cognitive domain	Node	2013-02-18 8:17 PM	2013-02-25 12:14 PM
Nodes\\Bloom's Model - taxonomy of the cognitive domain\1. Awareness	Node	2013-02-18 8:19 PM	2013-02-25 11:43 AM

Ch5: Reports\\Project Summary Report (5/9)

2014-03-13 12:06 PM

Hierarchical Name	Item Type	Created On	Modified On
Nodes\\Bloom's Model - taxonomy of the cognitive domain\2. Knowledge	Node	2013-02-18 8:19 PM	2013-02-25 11:43 AM
Nodes\\Bloom's Model - taxonomy of the cognitive domain\3. Comprehension	Node	2013-02-18 8:19 PM	2013-02-24 8:45 PM
Nodes\\Bloom's Model - taxonomy of the cognitive domain\4. Application	Node	2013-02-18 8:20 PM	2013-02-24 8:45 PM
Nodes\\Bloom's Model - taxonomy of the cognitive domain\5. Analysis	Node	2013-02-18 8:20 PM	2013-02-24 8:45 PM
Nodes\\Bloom's Model - taxonomy of the cognitive domain\6. Synthesis	Node	2013-02-18 8:20 PM	2013-02-24 8:45 PM
Nodes\\Bloom's Model - taxonomy of the cognitive domain\7. Evaluation	Node	2013-02-18 8:20 PM	2013-02-24 8:45 PM
Nodes\\Decision make	Node	2013-02-14 9:56 PM	2013-02-20 10:17 PM
Nodes\\Decision make\Architect's Role	Node	2013-02-14 9:54 PM	2013-02-26 6:17 AM
Nodes\\Decision make\Client's or Developer Role	Node	2013-02-14 9:57 PM	2013-02-25 10:42 AM
Nodes\\Energy Merits	Node	2013-02-14 10:25 AM	2013-02-25 12:46 PM
Nodes\\Energy Merits\Energy Efficiency	Node	2013-02-14 9:56 AM	2013-02-26 5:37 PM
Nodes\\Energy Merits\Energy Saving	Node	2013-02-14 10:54 AM	2013-02-26 5:40 PM
Nodes\\Energy Merits\Energy Security	Node	2013-01-24 1:48 PM	2013-02-26 5:41 AM
Nodes\\Energy Merits\Thermal Storage	Node	2013-02-14 11:03 AM	2013-02-26 6:10 PM
Nodes\\Environmental an Sustainable Merits	Node	2013-02-14 10:26 AM	2013-02-14 10:23 PM
Nodes\\Environmental an Sustainable Merits\Eco-friendly technology	Node	2013-02-14 10:28 AM	2013-02-26 1:04 AM
Nodes\\Environmental an Sustainable Merits\Sustainable Built Environment	Node	2013-01-24 1:47 PM	2013-02-25 12:57 PM
Nodes\\Environmental an Sustainable Merits\Sustainable Characteristics	Node	2013-02-14 12:08 PM	2013-02-26 5:52 AM
Nodes\\Trombe wall form	Node	2013-02-14 11:42 AM	2013-02-14 10:23 PM

Ch5: Reports\\Project Summary Report (6/9)
2014-03-13 12:06 PM

Hierarchical Name	Item Type	Created On	Modified On
Nodes\\TSC Merits	Node	2013-02-14 12:12 PM	2013-02-20 10:17 PM
Nodes\\TSC Merits\Cooling	Node	2013-02-14 12:13 PM	2013-02-25 12:15 PM
Nodes\\TSC Merits\Heating	Node	2013-02-14 12:12 PM	2013-02-18 8:48 PM
Nodes\\TSIS Evolving	Node	2013-02-14 9:38 AM	2013-02-14 10:23 PM
Nodes\\TSIS Evolving\Barriers	Node	2013-02-14 9:34 AM	2013-02-14 10:45 AM
Nodes\\TSIS Evolving\Barriers\Economic Barriers	Node	2014-03-07 8:04 AM	2014-03-07 8:04 AM
Nodes\\TSIS Evolving\Barriers\Economic Barriers\Cost effectiveness & ROI	Node	2013-02-14 9:40 AM	2013-11-19 8:14 AM
Nodes\\TSIS Evolving\Barriers\Environmental Barriers	Node	2014-03-07 8:05 AM	2014-03-07 8:05 AM
Nodes\\TSIS Evolving\Barriers\Environmental Barriers\Disposal of unsustainable material	Node	2013-02-14 11:55 AM	2013-02-26 5:52 AM
Nodes\\TSIS Evolving\Barriers\Institutional Barriers	Node	2014-03-07 8:07 AM	2014-03-07 8:07 AM
Nodes\\TSIS Evolving\Barriers\Institutional Barriers\Lack of independent scientific proof of evidence	Node	2013-02-25 2:22 PM	2013-02-26 5:29 PM
Nodes\\TSIS Evolving\Barriers\Institutional Barriers\Local Authority Planning Legislation	Node	2013-02-14 12:15 PM	2013-11-21 11:42 AM
Nodes\\TSIS Evolving\Barriers\Market Barriers	Node	2014-03-07 8:05 AM	2014-03-07 8:05 AM
Nodes\\TSIS Evolving\Barriers\Market Barriers\Lack of professional contractors and limited competence	Node	2013-02-14 9:41 AM	2013-02-26 5:47 PM
Nodes\\TSIS Evolving\Barriers\Market Barriers\Renewable Compromise	Node	2013-02-14 9:55 AM	2013-02-26 4:22 AM
Nodes\\TSIS Evolving\Barriers\Market Barriers\Technology Push from Sellers	Node	2013-02-14 11:08 PM	2013-02-26 5:40 PM
Nodes\\TSIS Evolving\Barriers\Market Barriers\Technology Security and affordability	Node	2013-02-14 10:35 PM	2013-02-26 6:04 AM
Nodes\\TSIS Evolving\Barriers\Social Barriers	Node	2014-03-07 8:04 AM	2014-03-07 8:04 AM
Nodes\\TSIS Evolving\Barriers\Social Barriers\Acceptance by consumer	Node	2013-02-14 10:59 PM	2013-02-26 5:50 PM

Ch5: Reports\\Project Summary Report (7/9)
2014-03-13 12:06 PM

Hierarchical Name	Item Type	Created On	Modified On
Nodes\\TSIS Evolving\Barriers\Social Barriers\Fear or reluctant to New technologies	Node	2013-02-17 7:57 PM	2013-11-19 8:22 AM
Nodes\\TSIS Evolving\Barriers\Social Barriers\Lack of familiarity either by client or design team	Node	2013-02-14 4:34 PM	2013-02-26 5:50 PM
Nodes\\TSIS Evolving\Barriers\Social Barriers\Low Architectural value	Node	2013-02-17 3:03 PM	2013-11-17 8:43 PM
Nodes\\TSIS Evolving\Barriers\Technical Barriers	Node	2014-03-07 8:05 AM	2014-03-07 8:05 AM
Nodes\\TSIS Evolving\Barriers\Technical Barriers\Design Features	Node	2013-02-25 10:47 AM	2013-02-26 5:49 PM
Nodes\\TSIS Evolving\Barriers\Technical Barriers\Immature or inadequate technology	Node	2013-02-14 4:41 PM	2013-02-26 5:37 PM
Nodes\\TSIS Evolving\Barriers\Technical Barriers\Insufficient Climate - availability of solar radiation or low heating season	Node	2013-02-14 4:41 PM	2013-02-26 5:35 PM
Nodes\\TSIS Evolving\Barriers\Technical Barriers\Lack of systematic design process	Node	2013-02-18 10:11 PM	2013-02-25 12:21 PM
Nodes\\TSIS Evolving\Barriers\Technical Barriers\Low absorptive lighter colours	Node	2013-02-24 9:43 PM	2013-02-25 2:00 PM
Nodes\\TSIS Evolving\Barriers\Technical Barriers\Technical data are not spread	Node	2013-02-14 4:43 PM	2013-02-26 6:21 AM
Nodes\\TSIS Evolving\Barriers\Technical Barriers\undesired overheating	Node	2013-02-24 8:51 PM	2013-02-25 12:21 PM
Nodes\\TSIS Evolving\Enablers	Node	2013-02-14 9:37 AM	2013-02-14 9:37 AM
Nodes\\TSIS Evolving\Enablers\Corporate social responsibility	Node	2013-02-25 2:11 PM	2013-02-26 5:28 PM
Nodes\\TSIS Evolving\Enablers\Cost Competitiveness	Node	2013-02-14 9:49 AM	2013-02-25 1:25 PM
Nodes\\TSIS Evolving\Enablers\Early consideration and design compatibility of integration	Node	2013-02-15 6:00 PM	2013-11-17 5:20 PM
Nodes\\TSIS Evolving\Enablers\Expanding the variety of transpirational schemes will allow for greater design integration to all building types.	Node	2013-02-26 5:32 AM	2013-02-26 5:32 AM
Nodes\\TSIS Evolving\Enablers\Government Incentives	Node	2013-02-14 11:18 AM	2013-02-26 5:25 AM

Ch5: Reports\\Project Summary Report (8/9)
2014-03-13 12:06 PM

Hierarchical Name	Item Type	Created On	Modified On
Nodes\\TSIS Evolving\Enablers\Governmental Policy	Node	2013-02-14 10:59 AM	2013-02-25 2:55 PM
Nodes\\TSIS Evolving\Enablers\Health requirements i.e. fresh air	Node	2013-02-17 8:49 PM	2013-02-26 6:12 AM
Nodes\\TSIS Evolving\Enablers\Hybrid Design	Node	2013-02-14 11:22 AM	2013-02-18 8:59 PM
Nodes\\TSIS Evolving\Enablers\LCA & client's benefit	Node	2013-02-14 12:18 PM	2013-02-26 5:48 PM
Nodes\\TSIS Evolving\Enablers\Local supplier	Node	2013-02-25 10:39 AM	2013-02-26 5:29 PM
Nodes\\TSIS Evolving\Enablers\Maintenance Ease	Node	2013-02-17 6:14 PM	2013-02-26 5:44 PM
Nodes\\TSIS Evolving\Enablers\Prototype - Attractive, Successful and Accessible	Node	2013-02-14 9:43 AM	2013-11-19 4:48 PM
Nodes\\TSIS Evolving\Enablers\Training to Workers and End Users	Node	2013-02-14 10:56 AM	2013-02-26 5:43 PM
Nodes\\TSIS functions	Node	2013-02-14 10:24 PM	2013-02-20 10:17 PM
Nodes\\TSIS functions\F1 Entrepreneurial Activities	Node	2013-02-14 10:26 PM	2014-02-05 7:29 PM
Nodes\\TSIS functions\F2 Knowledge Creation	Node	2013-02-14 10:24 PM	2014-02-05 7:29 PM
Nodes\\TSIS functions\F3 Knowledge Diffusion via Networks	Node	2013-02-14 10:25 PM	2014-02-10 9:16 PM
Nodes\\TSIS functions\F4 Guidance of the Search - Expectations	Node	2013-02-14 10:26 PM	2014-02-05 7:30 PM
Nodes\\TSIS functions\F5 Market Formation	Node	2013-02-14 10:25 PM	2014-02-13 1:50 AM
Nodes\\TSIS functions\F6 Resource Allocation - Mobilization	Node	2013-02-14 10:26 PM	2014-02-07 12:36 AM
Nodes\\TSIS functions\F7 Legitimise - Lobby	Node	2013-02-14 10:25 PM	2014-02-05 7:30 PM

Reports

Reports\\Node Summary Report	Report	2012-12-02 12:12 PM	2012-12-02 12:12 PM
Reports\\project item	Report	2014-03-05 1:59 PM	2014-03-05 1:59 PM
Reports\\Project Summary Report	Report	2012-12-02 12:12 PM	2012-12-02 12:12 PM

Ch5: Reports\\Project Summary Report (9/9)
2014-03-13 12:06 PM

Hierarchical Name	Item Type	Created On	Modified On
Reports\\Source Classification Summary Report	Report	2012-12-02 12:12 PM	2012-12-02 12:12 PM
Reports\\Source Reports	Report	2014-03-05 12:33 PM	2014-03-05 12:33 PM
Reports\\Source Summary Report	Report	2012-12-02 12:12 PM	2012-12-02 12:12 PM
Search Folders			
Search Folders\\All Nodes	Search Folder	2012-12-02 12:12 PM	2012-12-02 12:12 PM
Search Folders\\All Sources	Search Folder	2012-12-02 12:12 PM	2012-12-02 12:12 PM

Ch5: Reports\\Project Summary Report End

Chapter 6: Sample of analysis summary

Ch6: Reports\\Project Summary Report (1/15)

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Project Summary
TIS Analysis Chapter 6

Hierarchical Name	Item Type	Created On	Modified On
Internals\\CH6 Reference PDFs			
Internals\\CH6 Reference PDFs\\25 Energy Efficiency Policy Recommendations - 2011 Update	PDF	2014-01-22 9:25 PM	2014-01-22 9:25 PM
Internals\\CH6 Reference PDFs\\Barriers to renewable energy penetration	PDF	2014-01-22 5:10 AM	2013-09-25 12:38 PM
Internals\\CH6 Reference PDFs\\BARRIERS TO TECHNOLOGY DIFFUSION THE CASE OF SOLAR THERMAL TECHNOLOGIES	PDF	2014-01-22 9:21 PM	2014-01-22 9:22 PM
Internals\\CH6 Reference PDFs\\Study_on_Barriers of PV in buildings	PDF	2014-01-22 9:11 PM	2014-01-22 9:11 PM
Internals\\CH6 Reference PDFs\\Vasseur et al 2013 - A comparative analysis of Photovoltaic	PDF	2014-01-22 5:10 AM	2013-09-23 1:39 PM
Internals\\CH6 Reference PDFs\\www.iea.org_publications_freepublications_publication_Renew_Policies	PDF	2014-01-22 9:11 PM	2014-01-22 9:11 PM
Internals\\CH6 Reference PDFs\\www.iea.org_publications_freepublications_publication_Solar	PDF	2014-01-22 9:11 PM	2014-01-22 9:11 PM
Internals\\NA\\Interview America\\(4) *** 20131015	Doc.	2014-01-09 8:10 PM	2014-01-30 11:26 PM
Internals\\NA\\Interview Canada			
Internals\\NA\\Interview Canada\\(5) *** 20131015	Doc.	2014-01-09 8:10 PM	2014-01-28 11:15 PM
Internals\\NA\\PDF			
Internals\\NA\\PDF\\canada2009	PDF	2014-01-22 9:25 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\CanadairBombardier_Y96_SolarWallCaseStudy	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM

Ch6: Reports\\Project Summary Report (2/15)
2014-03-13 13:39

Hierarchical Name	Item Type	Created On	Modified On
Internals\\NA\\PDF\\CanSIA	PDF	2014-01-22 5:10 AM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\CanSIA's Long-Term Energy Plan Submission to Ontario Energy Ministry _ CanSIA	PDF	2014-01-28 11:47 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\Consumer Incentives _ CanSIA	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\Design & Build With Metal_ Transpired Solar Collector Walls_ Use Solar, Save Green	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\Federal Consumer Incentives _ CanSIA	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\FINAL_TRENDS_v1.02	PDF	2014-01-26 7:49 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\Green Building tips for Net Zero Homes	PDF	2014-01-26 7:49 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\Green Development Program - Town of Caledon	PDF	2014-01-26 7:49 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\https___www.midwestrenew.org_downloads_stcpdfs_AIA_Solar_Space_Heating_Slide_Show	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\IEA - Canada	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\Information for architects & engineers about SolarWall; LEED® points, the world's leading solar air heating green technology, download SolarWall specifications	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\InSpire - Metal Roofing, Walls and Ceilings from ATAS International Inc	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\MatrixAir incentives and programs for non-residential solar air heating systems	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\ontario-green-energy-report-august-web	PDF	2014-01-26 7:49 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\Provincial Consumer Incentives _ CanSIA	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\SESCI _ Solar and Sustainable Energy Society of Canada Inc	PDF	2014-01-22 5:10 AM	2014-01-30 10:54 PM

Ch6 Reports\\Project Summary Report (3/15)
2014-03-13 13:39

Hierarchical Name	Item Type	Created On	Modified On
Internals\\NA\\PDF\\Solar Beyond PV – the Transpired Air Collector Story — Solar Oregon	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\Solar Energy _ Energy Division _ Innovation, Energy and Mines _ Province of Manitoba	PDF	2014-01-26 7:49 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\Solar Thermal _ CanSIA	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\Solar Thermal _ Natural Resources Canada	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\SolarWall 2-Stage - High performance solar air heating system, super-efficient transpired solar collector	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\solarwall around the world1	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\SolarWall Canadian Federal and Provincial Solar Incentives, Grants, Rebates, Tax Exemptions	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\SolarWall Technology Takes Ontario by Storm	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\SolarWall USA Federal and State Solar Incentives	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\solarwall.com_media_images-gov_NightSolar-More	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\The transpired solar collectors (dark wall) is seen on the U.S	PDF	2014-01-26 7:49 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\TranspiredSolarCollectors	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\www.albertatechfutures.ca_LinkClick	PDF	2014-01-22 5:10 AM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\www.asse-plumbing.org_chapters_NOH_SolarEnergy	PDF	2014-01-26 7:49 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\www.cansia.ca_sites_default_files_nrcan_canadi	PDF	2014-01-22 5:10 AM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\www.cansia.ca_sites_default_files_pdf_solar_vi	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\www.cansia.ca_sites_default_files_pdf_survey_o	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\www.cansia.ca_sites_default_files_survey_of_ac	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM

Ch6 Reports\\Project Summary Report (4/15)
2014-03-13 13:39

Hierarchical Name	Item Type	Created On	Modified On
Internals\\NA\\PDF\\www.cleanairpartnership.org_practices_Caledon - SPECKFORD	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\www.cmhc-schl.gc.ca_en_inpr_bude_himu_coedar_upload_OAA_En_aug10	PDF	2014-01-26 7:49 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\www.csagateway.com_irj_servlet_prt_portal_prtm	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\www.davidsuzuki.org_publications_downloads_2004_Smart_Generation_summary	PDF	2014-01-26 7:49 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\www.energy.gov.on.ca_docs_en_making-choices-en	PDF	2014-01-26 7:49 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\www.iea.org_publications_freepublications_publication_Solar_Heating_Cooling_Roadmap_2012_WEB	PDF	2014-01-26 7:49 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\www.manitoba.ca_iem_energy_initiatives_pdf_solarheating	PDF	2014-01-26 7:49 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\www.trca.on.ca_dotAsset_51366	PDF	2014-01-26 7:49 PM	2014-01-30 10:54 PM
Internals\\NA\\PDF\\www1.eere.energy.gov_femp_pdfs_48453	PDF	2014-01-22 9:11 PM	2014-01-30 10:54 PM
Internals\\UK\\Interviews			
Internals\\UK\\Interviews\\(1) *** 20130529	Document	2014-01-09 8:09 PM	2014-01-26 10:40 PM
Internals\\UK\\Interviews\\(2) *** 20130529	Document	2014-01-09 8:10 PM	2014-01-27 1:12 AM
Internals\\UK\\Interviews\\(3) *** 20130604	Document	2014-01-09 8:10 PM	2014-01-09 8:10 PM
Internals\\UK\\PDF			
Internals\\UK\\PDF\\District heating in the UK A Technological Innovation	PDF	2014-01-22 5:10 AM	2013-09-25 12:38 PM
Internals\\UK\\PDF\\Energy efficient products _ Magazine Features _ Building	PDF	2014-01-26 7:49 PM	2014-01-26 7:49 PM
Internals\\UK\\PDF\\green deal pdf	PDF	2014-01-28 10:33 PM	2014-01-28 10:33 PM
Internals\\UK\\PDF\\Green Deal_ New £20M Communities Scheme Launched	PDF	2014-01-26 7:49 PM	2014-01-26 7:49 PM

Ch6 Reports\\Project Summary Report (5/15)
2014-03-13 13:39

Hierarchical Name	Item Type	Created On	Modified On
Internals\\UK\\PDF\\https___workspace.imperial.ac.uk_climatechange_public_pdfs_GranthamJun	PDF	2014-01-26 7:49 PM	2014-01-26 7:49 PM
Internals\\UK\\PDF\\Incentives for renewables __ Save Your Energy	PDF	2014-01-22 9:11 PM	2014-01-22 9:11 PM
Internals\\UK\\PDF\\Investment barriers and incentives for marine renewable energy in the UK	PDF	2014-01-22 5:16 AM	2014-01-22 5:16 AM
Internals\\UK\\PDF\\Learning from experience The development of the Renewables Obligation	PDF	2014-01-22 5:10 AM	2013-09-25 12:38 PM
Internals\\UK\\PDF\\Parkes 2012 - Can the UK meet its renewables targets	PDF	2014-01-22 5:16 AM	2014-01-22 5:16 AM
Internals\\UK\\PDF\\Renewable energy policy in the UK 1990–2003	PDF	2014-01-22 5:10 AM	2013-09-25 12:38 PM
Internals\\UK\\PDF\\Renewable Heat Incentive (RHI) - Increasing the use of low-carbon technologies - Policies - GOV	PDF	2014-01-28 10:17 PM	2014-01-28 10:17 PM
Internals\\UK\\PDF\\The Energy Entrepreneurs Fund	PDF	2014-01-28 10:42 PM	2014-01-28 10:42 PM
Internals\\UK\\PDF\\Towards improved policy processes for promoting innovation in UK	PDF	2014-01-22 5:10 AM	2013-09-25 12:38 PM
Internals\\UK\\PDF\\Transpired Solar Collectors - Green Deal Products	PDF	2014-01-22 9:11 PM	2014-01-22 9:11 PM
Internals\\UK\\PDF\\transpired solar collectors are part of the UUK's Green Deal (2)	PDF	2014-01-26 7:49 PM	2014-01-26 7:49 PM
Internals\\UK\\PDF\\TranspiredSolarCollectors cardiff	PDF	2014-01-26 7:49 PM	2014-01-26 7:49 PM
Internals\\UK\\PDF\\UK innovation systems for new and renewable energy technologies	PDF	2014-01-22 5:10 AM	2013-09-25 12:38 PM
Internals\\UK\\PDF\\What is the Green Deal_	PDF	2014-01-22 9:11 PM	2014-01-22 9:11 PM
Internals\\UK\\PDF\\What is The Green Deal's Golden Rule_ _ Green Deal Golden Rule	PDF	2014-01-22 9:11 PM	2014-01-22 9:11 PM
Internals\\UK\\PDF\\www.cansia.ca_sites_default_files_sites_default_2010_european_solar_thermal_markets	PDF	2014-01-26 7:49 PM	2014-01-26 7:49 PM
Internals\\UK\\PDF\\www.cansia.ca_sites_default_files_sites_default_solar_thermal_markets_in_europe_-_trends_and_market_stat	PDF	2014-01-26 7:49 PM	2014-01-26 7:49 PM
Internals\\UK\\PDF\\www.cibse.org_content_cibsesymposium2012_Presentation055	PDF	2014-01-22 9:11 PM	2014-01-22 9:11 PM

Ch6 Reports\\Project Summary Report (6/15)
2014-03-13 13:39

Hierarchical Name	Item Type	Created On	Modified On
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Memos			
Memos\\entrep. lack the proper communication of architects and building designers. the entrep, simplifies these needs (ya7soroha) in design tool simplicity and system performance whereas the architects evaluate the integration of TSC in a much more complexity	Memo	2014-01-27 12:43 AM	2014-01-27 12:43 AM
Memos\\innovation	Memo	2014-01-30 9:46 PM	2014-03-13 1:38 PM
Memos\\understanding architects	Memo	2014-01-28 8:35 PM	2014-01-28 8:35 PM
Nodes\\Tree Nodes			
Nodes\\Tree Nodes\\Advice to researcher	Node	2012-02-10 7:24 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis	Node	2011-07-22 10:17 AM	2014-01-09 8:03 PM
Nodes\\Tree Nodes\\Analysis\TIS Components	Node	2011-07-13 5:25 AM	2014-01-31 8:58 AM
Nodes\\Tree Nodes\\Analysis\TIS Components\Actors	Node	2011-07-13 4:41 PM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TIS Components\Institutions	Node	2011-07-13 10:15 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TIS Components\Institutions\Academic Research	Node	2011-07-13 6:36 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TIS Components\Networks	Node	2011-07-13 4:41 PM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TIS Functions	Node	2011-07-13 5:19 AM	2014-01-31 8:58 AM
Nodes\\Tree Nodes\\Analysis\TIS Functions\Entrepr Activs	Node	2011-07-13 5:20 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TIS Functions\Guide of Search-Expects	Node	2011-07-13 5:23 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TIS Functions\Knowl Creation	Node	2011-07-13 5:22 AM	2014-03-13 12:53 PM

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2014-03-13 13:39

Hierarchical Name	Item Type	Created On	Modified On
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Nodes\\Tree Nodes\\Analysis\TIS Functions\Mark Form	Node	2011-07-13 5:23 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TIS Functions\Res Alloc-Mobilize	Node	2011-07-13 5:24 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving	Node	2012-02-03 6:33 AM	2014-01-31 8:58 AM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers	Node	2012-02-10 12:13 PM	2014-01-26 8:34 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Economic Barriers	Node	2014-01-22 4:05 AM	2014-01-22 4:08 AM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Economic Barriers\Access to finance	Node	2014-01-28 10:26 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Economic Barriers\Cost effectiveness & ROI	Node	2012-04-26 9:27 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Economic Barriers\High investment requirements	Node	2014-01-22 4:04 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\environmental Barriers	Node	2014-01-22 4:05 AM	2014-01-22 4:05 AM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Institutional Barriers	Node	2014-01-22 4:06 AM	2014-01-31 12:14 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Institutional Barriers\Dissemination of Info	Node	2012-04-27 10:35 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Institutional Barriers\Lack of Codes & Standards	Node	2011-07-22 10:19 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Institutional Barriers\Lack of independent scientific proof of evidence	Node	2014-01-22 3:56 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Institutional Barriers\Local Authority Planning Legislation	Node	2014-01-22 3:52 AM	2014-03-13 12:53 PM

Ch6 Reports\\Project Summary Report (8/15)
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Hierarchical Name	Item Type	Created On	Modified On
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Institutional Barriers\Low Government support	Node	2012-04-26 10:08 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Institutional Barriers\Research Not Applied Enough	Node	2012-02-22 2:47 PM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Institutional Barriers\Uncertainty in Policy and Regulations	Node	2014-01-28 8:07 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Market Barriers	Node	2014-01-22 4:08 AM	2014-01-22 4:08 AM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Market Barriers\Cooperation Moves to Competition	Node	2012-04-26 9:02 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Market Barriers\Gas Infra is Cheaper	Node	2012-04-25 7:30 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Market Barriers\Highly controlled energy sector	Node	2012-04-26 10:33 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Market Barriers\IP & Know-how	Node	2012-02-13 8:39 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Market Barriers\Lack of professional contractors and limited competence	Node	2014-01-22 3:55 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Market Barriers\Lock in	Node	2011-08-10 9:34 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Market Barriers\Restricted access to technology	Node	2012-04-30 10:27 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Market Barriers\SMEs Not Getting Heard	Node	2012-04-30 8:29 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Market Barriers\Technology Push from Sellers	Node	2012-02-22 9:43 AM	2014-03-13 12:53 PM

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2014-03-13 13:39

Hierarchical Name	Item Type	Created On	Modified On
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Market Barriers\Technology Security and affordability	Node	2014-01-22 3:54 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Social Barriers	Node	2014-01-22 4:05 AM	2014-01-22 4:06 AM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Social Barriers\Acceptance by consumer	Node	2012-04-25 11:36 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Social Barriers\Cultural Differences	Node	2012-02-20 6:39 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Social Barriers\Expectations	Node	2012-04-30 10:22 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Social Barriers\Fear or reluctant to New technologies. Individual - Negative	Node	2014-01-22 3:52 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Social Barriers\Lack of familiarity either by client or design team	Node	2012-04-30 9:22 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Social Barriers\Lobby Group Failures	Node	2012-04-27 10:40 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Social Barriers\People Management	Node	2012-02-20 5:02 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Technical Berriers	Node	2014-01-22 4:04 AM	2014-01-22 4:04 AM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Technical Berriers\Disposal of unsustainable material	Node	2014-01-22 3:56 AM	2014-01-22 3:56 AM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Technical Berriers\Low Architectural value	Node	2014-01-22 3:52 AM	2014-01-22 3:52 AM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Technical Berriers\one responsible lead contractor	Node	2014-01-22 3:57 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Barriers\Technical Berriers\unproven technology	Node	2014-01-22 3:56 AM	2014-03-13 12:53 PM

Ch6 Reports\\Project Summary Report (10/15)
2014-03-13 13:39

Hierarchical Name	Item Type	Created On	Modified On
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers	Node	2012-02-10 12:14 PM	2014-01-26 8:34 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Economic Enablers	Node	2014-01-22 4:28 AM	2014-01-22 4:28 AM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Economic Enablers\Cost Competitiveness	Node	2012-04-25 7:32 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Enterpruneurial Enablers	Node	2014-01-22 4:17 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Enterpruneurial Enablers\Demand Pull	Node	2012-02-22 9:45 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Enterpruneurial Enablers\Demonstration, Prototype - Attractive, Succesful and Accessable	Node	2012-01-25 7:35 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Enterpruneurial Enablers\Firms Collaborating	Node	2012-04-30 6:24 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Enterpruneurial Enablers\Local supplier	Node	2014-01-22 3:48 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Enterpruneurial Enablers\New dimension of development (expansion)	Node	2014-01-28 8:43 PM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Enterpruneurial Enablers\Skilled Staff (Entrepreneurship)	Node	2012-02-03 5:58 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Environmenta Enablers (Health requirements i.e. fresh air)	Node	2014-01-22 4:21 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Institutional Enablers	Node	2014-01-22 4:18 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Institutional Enablers\Expectation Management	Node	2012-04-30 6:57 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Institutional Enablers\Government Incentives	Node	2012-04-25 11:37 AM	2014-03-13 12:53 PM

Ch6 Reports\\Project Summary Report (11/15)
2014-03-13 13:39

Hierarchical Name	Item Type	Created On	Modified On
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Institutional Enablers\Government Incentives\ecoENERGY	Node	2014-01-30 11:34 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Institutional Enablers\Government Incentives\Fee-In Tarif	Node	2014-01-28 6:14 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Institutional Enablers\Government Incentives\Grants and Obligations	Node	2014-01-28 6:14 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Institutional Enablers\Government Incentives\Green Deal	Node	2014-01-28 6:14 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Institutional Enablers\Government Incentives\Renewable Heat Incentives	Node	2014-01-30 11:34 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Institutional Enablers\Government Incentives\Renewable Heat Premium Payment	Node	2014-01-30 11:48 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Institutional Enablers\Govt Fund & investments	Node	2014-01-22 4:23 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Institutional Enablers\Govt Plans	Node	2012-04-25 6:00 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Institutional Enablers\New Codes & Standards	Node	2014-01-22 4:18 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Institutional Enablers\Research and development	Node	2014-01-22 4:24 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Institutional Enablers\Technological Learning. Trainning to Workers and End Users	Node	2014-01-22 3:46 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Social Enablers	Node	2014-01-22 4:24 AM	2014-03-13 12:53 PM

Ch6 Reports\\Project Summary Report (12/15)
2014-03-13 13:39

Hierarchical Name	Item Type	Created On	Modified On
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Social Enablers\Costumer's satisfation	Node	2014-01-27 12:47 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Social Enablers\Information and awareness campaigns	Node	2014-01-22 4:26 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Social Enablers\Moral and ethical considerations	Node	2014-01-22 4:25 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Technical Enablers	Node	2014-01-22 4:19 AM	2014-01-22 4:19 AM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Technical Enablers\Hybrid Design	Node	2014-01-22 3:49 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Technical Enablers\Incremental Improvements	Node	2012-04-30 7:11 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Technical Enablers\Penetration of Renewables	Node	2012-04-26 10:02 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Analysis\TSIS evolving\Enablers\Technical Enablers\pre-engineered modules	Node	2014-01-26 11:20 PM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Conclusion Remarks	Node	2014-01-28 6:31 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Good Quotes	Node	2011-08-16 7:55 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Infrastructure and Supply Chain	Node	2011-08-10 9:45 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Intro. to Analysis	Node	2014-01-27 1:20 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Notes 4 discussion	Node	2014-01-30 8:35 PM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Objectives	Node	2014-01-28 8:13 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Policy Drivers	Node	2011-08-12 11:06 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Policy Drivers\Boost Employment	Node	2011-08-12 11:07 AM	2014-03-13 12:53 PM

Ch6 Reports\\Project Summary Report (13/15)
2014-03-13 13:39

Hierarchical Name	Item Type	Created On	Modified On
Nodes\\Tree Nodes\\Policy Drivers\CO2 reduction	Node	2011-08-12 11:07 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Policy Drivers\develope regulatory framework	Node	2014-01-26 10:03 PM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Policy Drivers\Economic Regeneration	Node	2011-08-24 6:25 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Policy Drivers\Education & Training for Appropriate Skills	Node	2012-02-20 6:43 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Policy Drivers\Energy Security	Node	2011-08-12 11:08 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Policy Drivers\Free Market v Protectionism	Node	2012-02-20 5:51 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Policy Drivers\Green Clustering	Node	2012-04-24 7:29 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Policy Drivers\incentives	Node	2014-01-26 10:01 PM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Policy Drivers\Link solar to Industry	Node	2011-08-24 6:23 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Policy Drivers\mix of policy processes	Node	2012-01-28 9:28 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Policy Drivers\Policy Learning	Node	2014-01-28 7:56 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Policy Drivers\State Support via Contracting	Node	2012-02-10 11:56 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Policy Drivers\Sustainability	Node	2012-04-24 6:20 AM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\R&D	Node	2011-07-18 3:58 PM	2014-03-13 12:53 PM
Nodes\\Tree Nodes\\Recommendations	Node	2014-01-30 11:42 PM	2014-03-13 12:53 PM
Relationships			
Relationships\\Entrepr Activs (+Influ) Guide of Search-Expects	Relationship	2011-07-28 4:39 AM	2014-03-13 12:53 PM
Relationships\\Entrepr Activs (+Influ) Legit-Lobby	Relationship	2011-07-28 5:18 AM	2014-03-13 12:53 PM
Relationships\\Entrepr Activs (-Influ) Guide of Search-Expects	Relationship	2011-08-15 4:25 PM	2014-03-13 12:53 PM

Ch6 Reports\\Project Summary Report (14/15)
2014-03-13 13:39

Hierarchical Name	Item Type	Created On	Modified On
Relationships\\Entrepr Activs (-Influ) Legit-Lobby	Relationship	2011-08-15 4:26 PM	2014-03-13 12:53 PM
Relationships\\Guide of Search-Expects (+Influ) Knowl Creation	Relationship	2011-07-28 4:40 AM	2014-03-13 12:53 PM
Relationships\\Guide of Search-Expects (-Influ) Knowl Creation	Relationship	2011-08-15 4:27 PM	2014-03-13 12:53 PM
Relationships\\Knowl Creation (+Influ) Entrepr Activs	Relationship	2011-08-02 10:35 AM	2014-03-13 12:53 PM
Relationships\\Knowl Creation (+Influ) Knowl Diff v Nets	Relationship	2011-07-28 4:42 AM	2014-03-13 12:53 PM
Relationships\\Knowl Creation (-Influ) Entrepr Activs	Relationship	2011-08-15 4:32 PM	2014-03-13 12:53 PM
Relationships\\Knowl Creation (-Influ) Knowl Diff v Nets	Relationship	2011-08-15 4:29 PM	2014-03-13 12:53 PM
Relationships\\Knowl Diff v Nets (+Influ) Entrepr Activs	Relationship	2011-07-28 4:48 AM	2014-03-13 12:53 PM
Relationships\\Knowl Diff v Nets (-Influ) Entrepr Activs	Relationship	2011-08-15 4:33 PM	2014-03-13 12:53 PM
Relationships\\Legit-Lobby (+Influ) Knowl Diff v Nets	Relationship	2011-07-28 6:37 AM	2014-03-13 12:53 PM
Relationships\\Legit-Lobby (+Influ) Mark Form	Relationship	2011-07-28 4:46 AM	2014-03-13 12:53 PM
Relationships\\Legit-Lobby (+Influ) Res Alloc-Mobilize	Relationship	2011-07-28 4:43 AM	2014-03-13 12:53 PM
Relationships\\Legit-Lobby (-Influ) Knowl Diff v Nets	Relationship	2011-08-15 4:38 PM	2014-03-13 12:53 PM
Relationships\\Legit-Lobby (-Influ) Mark Form	Relationship	2011-08-15 4:36 PM	2014-03-13 12:53 PM
Relationships\\Legit-Lobby (-Influ) Res Alloc-Mobilize	Relationship	2011-08-15 4:35 PM	2014-03-13 12:53 PM
Relationships\\Mark Form (+Influ) Entrepr Activs	Relationship	2011-07-28 5:21 AM	2014-03-13 12:53 PM
Relationships\\Mark Form (-Influ) Entrepr Activs	Relationship	2011-08-15 4:39 PM	2014-03-13 12:53 PM
Relationships\\Res Alloc-Mobilize (+Influ) Knowl Creation	Relationship	2011-07-28 4:47 AM	2014-03-13 12:53 PM
Relationships\\Res Alloc-Mobilize (-Influ) Knowl Creation	Relationship	2011-08-15 4:42 PM	2014-03-13 12:53 PM

Ch6: Reports\\Project Summary Report (15/15)
2014-03-13 12:06

Hierarchical Name	Item Type	Created On	Modified On
Reports			
Reports\\Coding Summary By Node Report	Report		
Reports\\Coding Summary By Source Report	Report		
Reports\\Node Classification Summary Report	Report		
Reports\\Node Structure Report	Report		
Reports\\Node Summary Report	Report		
Reports\\Project Summary Report	Report		
Reports\\Source Classification Summary Report	Report		
Reports\\Source Summary Report	Report		

Ch6 Reports\\Project Summary Report

End

APPENDIX H ||

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