ARCHITECTURAL INTEGRATION OF TRANSPIRED SOLAR THERMAL FOR SPACE HEATING IN DOMESTIC AND NON-DOMESTIC BUILDING ENVELOPES

Hasan Alfarra; Vicki Stevenson; Phil Jones

Welsh School of Architecture, Cardiff University, Bute Building, King Edward VII Avenue, Cardiff, CF10 3NB, UK, email: alfarrah@cf.ac.uk

ABSTRACT

In response to climate change, energy poverty, and increasing prices of fossil fuel energy; building integrated renewable energy should find a quick and strong stream in design and construction fields. Solar thermal appears as a promising technology for domestic and non-domestic building envelopes, particularly for space heating which counts for 61% the total domestic energy consumption in countries with long cold seasons like UK. The integration of transpired solar collectors (TSC) technology however suffers lack of adoption in building envelopes despite its apparent technical competitiveness for using solar pre-heated external air for space heating since patented in the late-1980s. Architectural integration seems to play a major role in developing and encouraging the use of TSC in buildings. This paper therefore investigates the innovative possibilities of improving the architectural integration of TSC into building envelopes at both multi-functional and aesthetic levels.

An international web-based survey was distributed to architects, engineers, and other academic and professionals in design and construction fields with intensive focus on countries with long heating seasons and potential integrations of TSC such as Canada, USA, and UK and mainland Europe. The responses of 1,295 participants, the largest pool ever for previous comparative studies in this field, were analysed quantitatively and qualitatively. Unlike previous studies the outcomes were statistically examined using Pearson's Chi-square and Spearman's correlation Coefficient tests. Although respondents only had a moderate awareness of the TSC technology they were very interested in integrating solar energy into the built environment. Seven selective integration images of TSC and photovoltaic (PV), from existing projects in Canada, USA and Europe were rated by respondents in terms of multi-functional and aesthetic roles of integration. The barriers and limitations along with preferable integration schemes were investigated and discussed. Integration parameters such as function, type, and position of TSC which were found to be the most favoured by the participants were identified. The survey results provide valuable contributing information of architecturally integrating transpired solar thermal in the built environment. This contribution is necessary for researchers and professionals in design and construction fields.

Keywords: architectural integration, transpired solar, architect(s),

INTRODUCTION

The built environment is generally powered by conventional energy sources which contribute CO2 emissions and have an impact on climate change as well as consuming more than 40% of the total annual energy consumption worldwide [1]. Increasing energy demand and continuing fossil fuel dependency threatens global power sectors; as an example, the United Kingdom (UK) became a net energy importer in 2004 [2]. This leads to increasing energy prices and levels of energy poverty. It is necessary for further prosperity to ensure secure, equitable, affordable and sustainable supply of energy. Methods of meeting this demand through energy efficiency and renewable energy should be explored. Some renewable energy options have drawbacks such as occupying fertile land and being positioned where there are significant energy losses through distribution. Therefore, building-integrated renewable energy should find a quick and strong stream in design and construction fields.

Space heating in UK counts for 61% of the total domestic energy consumption [3]. Therefore, almost two-third of the energy savings in dwellings seems achievable through space heating. Furthermore, the operation control of many heating systems (boilers and heat emitters) in use in the UK is found to be inefficient [4, 5]. Novel efficient systems therefore are in a real demand for UK market as well as other countries with long heating seasons. These efficient systems are more likely to prosper if they appeal to architectural aesthetics, sustainability measures, and social parameters such as thermal comfort and energy saving.

Integrating solar thermal systems in building envelopes differs according to the solar collector type, design, function and the economic feasibility. According to Zhai, Wang [6], the integration of solar thermal technologies with green buildings, for supplying space heating, is recently under rapid development. Transpired Solar Collectors (TSC) technology pre-heats the ambient outdoor air which is drawn into the building for space-heating. The TSC technology was patented in Canada in the late-1980s with the first application in 1990 [7-10]. The TSC consist of perforated solar absorbing sheet, ducting and fan. The perforated pane is placed approximately fifteen centimetres to building's external wall creating a plenum of air, and it is usually a dark colour to maximize the solar absorption. The fan is fixed in a cut-out through the building's exterior wall and connected to the duct work connection or HVAC (Heat, Ventilation, and Air-Conditioning) system. The fan draws fresh air into the plenum through the perforations in the outer pane by creating negative pressure [7, 8, 11]. The TSC proved in their early development to be a competitive technology with instantaneous thermal efficiencies that exceeded 70% and low capital costs. Those two factors constitute the basic potential of simple economic payback of almost two years for large installations [8, 12, 13]. The orientation of TSC is ideally south-facing although, orientation between east and west remain possible at lower solar gain [14]. The TSC can be integrated into the building envelope through wall or roof mounting; it can also be stand-alone. The TSC can be combined with photovoltaic panels as a hybrid system to produce space heating and electricity.

Although, TSC has proved competent for air preheating and performance, it is rarely integrated with building envelopes. Almost all the current applications are for non-domestic buildings [8] with little information about installations in the domestic sector. Furthermore, most of the existing solar thermal integrations in buildings have fairly poor architectural quality which discourages further take-up [15]. The quality of architectural integrated solar thermal is defined as the controlled and coherent interaction of solar thermal collectors in the building envelope. This interaction should simultaneously satisfy the multi-functional and aesthetic aspects of architectural form and space [15, 16]. The paper aims to investigate the socio-technical and socio-cultural parameters important to the legitimisation lobby (architects, researchers, authorities, building owner…etc.). It focuses on the optimum features of integrating TSC in domestic and non-domestic building envelopes to improve the architectural integration quality at both multi-functional and aesthetic levels.

METHOD

In order to analyse the perception of the legitimatisation lobby about integrating TSC, an international web-based survey was designed to investigate parameters like awareness, limitations, and recommendations of the technology and integration. Following a pilot study with selected experts in the field, the questionnaire was distributed to architects, engineers, and other academics and professionals in design and construction fields. The geographical focus was on countries with long heating seasons and potential integrations of TSC such as Canada, USA, and UK and mainland Europe. The responses of 1,295 participants were analysed quantitatively and qualitatively.

The quantitative data were investigated statistically to examine the significance of the results unlike similar previous studies in this field; a drawback which was acknowledged by Horvat, Dubois [17]. The survey data are non-parametric; therefore; there were two suitable statistical tests to address the data: 1. "Pearson's Chi-square test" which explores the significance of relationship and association between two categorical variables, and 2."Spearman's correlation coefficient" which determines the correlational strength and direction between variables [18, and 19]. The software used to carry these investigations is IBM SPSS 20 "Statistical Product and Service Solutions".

RESULTS

The respondents were 62.1% architects, 22.9% engineers, and 15% other professions distributed at different working fields and with various years of experience. The respondents were distributed on 73 countries; with 73% of them concentrated in USA, UK, and Canada.

Awareness: A key area to explore was the respondent's awareness of TSC (categorised as: expert, aware and unaware). Commercial brands of TSC were listed to ease recognition. It became apparent that 48.6% of the surveyed professionals were unaware of the technology. A further 49.7% were aware of the technology with 1.7% considering themselves to be expert. There was a significant association, according to Chi-Square statistical test, between awareness and respondents geographic region. The Canadian participants had the highest rate of awareness (71.0%) followed by 53.3% for Europe mainland excluding UK. The American respondents recorded 41.4% awareness.

Decision: The participants were asked to identify the stakeholder with most power to decide to use TSC in domestic buildings. Almost 74.2% of the participants identified the client, while 50% identified the architect. There is a statistically significant association of those architect respondents who selected client and architect as well as geographic regions association. For non-domestic buildings, 58.7% identified the client as having the most decision power, followed by the integrated design process "IDP" team (49.9%), then the architect (42.5%). Furthermore, 63.8% if the participants agreed that the architect had the lead in deciding the type of integration in building envelopes (i.e. wall-mounted…etc.) for both domestic and non-domestic buildings.

Integration Examples: Seven selective integration images of TSC and PV, from existing projects in Canada, USA and Europe were rated by respondents in terms of multi-functional and aesthetic roles of integration. All of those examples were from non-domestic buildings due to the lack of availability of domestic images. Integration was considered in terms of multi-functionality and in terms of aesthetics. The façade integration generally rated above roof integration in terms of multi-functions. In terms of aesthetics, rating of façade integration was further extremely in higher acceptance than roof integration. Figure 1 for instance represents the integration image which was ranked the highest for both multi-function and aesthetics. This project is for a governmental building in USA which included a façade integration of TSC along with dummy cladding in order to conceal the areas which did not have TSC panels. The building was rated on a Likert scale from -2 to +2, by 1,051 participants for multi-function and 1,058 for aesthetics. Where -2 represented a very poor integration and +2 represented a perfect integration. By investigating the relationship between multi-function and aesthetics using Spearman's Correlation, there was a strong direct relation between multi-function and aesthetics for architects versus medium correlation for the other professions.

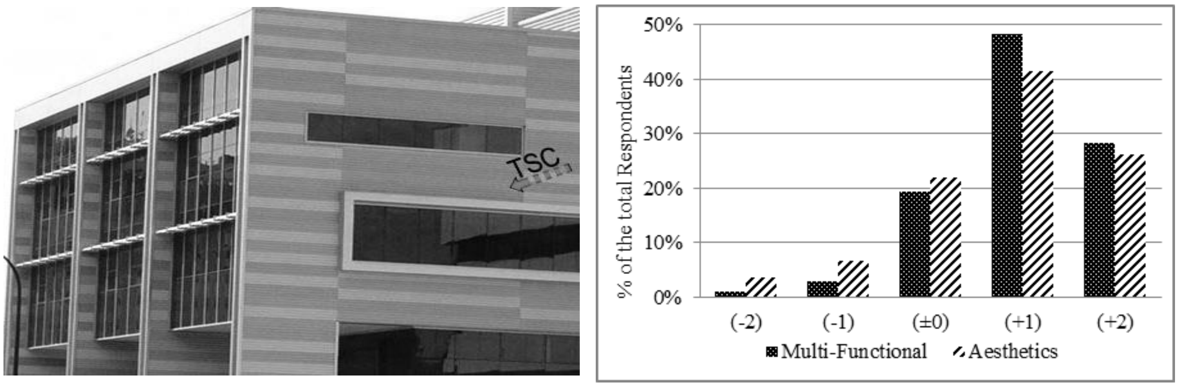
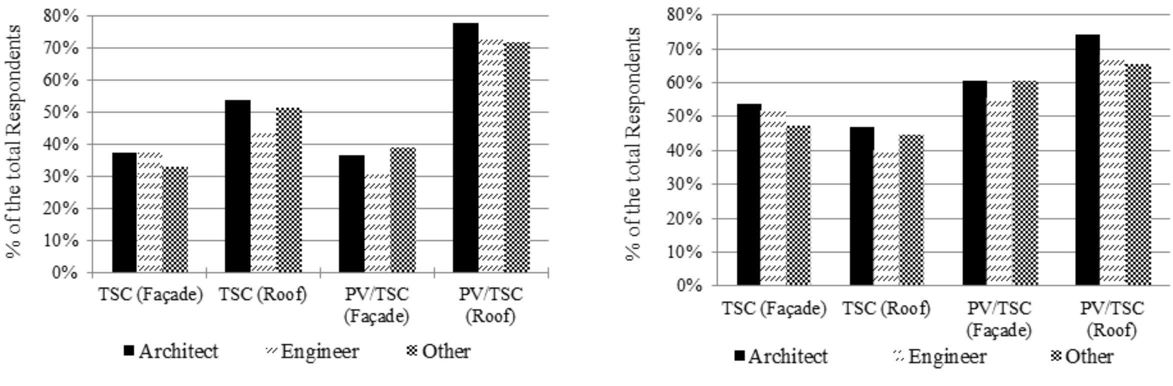


Figure 1: (a) Ann Arbor Municipal Building, USA. InSpire wall [20]. (b) Likert scale rating by total respondents for Multi-function and Aesthetics

Multi-function Integration: When questioned the priority of integrating TSC in building envelopes, the majority of votes (71.6%) were given to the multi-functional role of the technology to act as an architectural element in the building envelope as well as functions as an energy source, rather than as an isolated energy generating device or aesthetic feature. There was a significant association between professions and the selection of multi-function as the architects were found committed to prioritize the multi-functional role more than others. There was no association in selection with location, work field or experience.

Integration Scheme: For domestic buildings, all professions preferred roof installations for TSC and then hybrid PV/TSC installations. For non-domestic buildings, there was more acceptance of TSC façade installations, but roof installations were still the most preferred for PV/TSC hybrids (Fig. 2). There was no significant association within professions, location groups, or experience which means that all respondents were in agreement with the selections.



a) Domestic building envelope *b) Non-domestic building envelope*

Figure 2: Recommended constructive integration schemes of TSC for Domestic and Non-domestic building envelopes

DISCUSSION

Although the majority of responses are from architects approximately one third of the response is from engineers and others which reduces the architectural bias in comparison to some previous surveys like Farkas and Horvat [21] and Horvat, Dubois [17], while being a similar mix to Probst and Roecker [15].

The high awareness of Canadian participants was to some extent expected as the TSC technology was patented in Canada. Canada furthermore is the home country of the chief four TSC providers. The low rate of awareness in USA was quite surprising nevertheless, it could be attributable to the fact that space heating is in lower need in the southern part of USA. This notice was in some way reflected in respondents' comments from States in the southern part of USA such as Arizona, New Mexico, and South Carolina. The participants from those hot-dry and hot-humid States [22] were almost quarter of the total USA respondents with overall awareness of about 30%.

Of the respondents who see the client as the most important stakeholder in decision making, the majority were architects who are likely to have a good picture of the client's role as the architect is usually the principle dealer with clients. On the other hand, there might be some bias in selecting architect as a decision maker by architect respondents. However, the effect size is statistically small and furthermore, the other respondents achieve balance level which leads to gain reliability confidence in the results.

The most highly rated aesthetic integration example (illustrated in Fig 1) is likely to be highly rated due to the unity and coherence of integration within the building envelope, and the use of dummy panels. On the contrary, very few participants (8.2%) supported the use of dummy panels when they were directly asked their opinion on using dummy panels to achieve unity of building façades. This truly reflects that good integration is acceptable despite possible conflict with existing opinions or beliefs at some extents.

Similarly, the roof integration scheme of TSC/PV was most favoured for both domestic and non-domestic building envelopes (illustrated in Fig 2) in spite the fact that the example of TSC/PV roof integration was rated the lowest out of the examples. Furthermore, this could be explained by the concept of integration being favoured but the example question was not a good presentation of the concept. The visualisation of the concept might moreover supress the theoretical belief. This leads to adopting a concept in theory but neglecting it on the visualisation stage. Another possible interpretation is that the roof integration could be preferred because it can be easily hidden especially when roofs are mostly not used spaces therefore, there will be no complication for the façade design. Façade integration however is found more acceptable for non-domestic buildings than domestic where roof integration is more preferred.

CONCLUSION

An international survey with a significant response of 1,295 built environment professionals was statistically analysed.

The legitimatisation lobby relating to the built environment (architects, engineers, academics, authority…etc.) in countries including Canada, USA, and Europe mainland were surveyed to investigate their perceptions and recommendations about transpired solar thermal for space heating. The participants were equally divided in term of previous awareness of TSC despite its availability since the late-1980s and laboratory proven competence. Even fewer respondents had knowledge of the working principles of the TSC technology.

The clients of the buildings were found to be the most important stakeholder for decision making in choosing to use TSC. The architects almost agreed certain guidelines of integrating solar thermal in building envelopes for both domestic and non-domestic building envelopes; these guidelines included: types; positions; and function. For domestic buildings, the position of integration outweighed the function. There was a strong preference for TSC to be integrated on the roof rather than the façade. A stronger preference was for the type of hybrid PV/TSCs to be installed on the roof (Fig. 2a). For non-domestic buildings, the preference was different as the type and function of integration was given the priority. There was a stronger preference for hybrid PV/TSCs rather than only TSC to be installed either on the roof or façade; however, there was more support for TSC façade integration (Fig. 2b) than domestic buildings.

ACKNOWLEDGEMENTS

The authors would like to thank the respondents to the survey and the pilot study for their participation, time, efforts, and information. The authors also would not forget to express acknowledgement to anyone who helped in guiding this research to success.

REFERENCES

1. Shi, L. and M.Y.L. Chew, A review on sustainable design of renewable energy systems. Renewable and Sustainable Energy Reviews, 2012. 16(1): p. 192-207.
2. DECC, UK Energy Sector Indicators 2011, 2011, Department of Energy and Climate Change Business Plan Quarterly Data Summary.
3. DECC. Energy consumption in the United Kingdom 2011 [cited 2012 28 February]; Available from: http://www.decc.gov.uk/en/content/cms/statistics/publications/ecuk/ecuk.aspx.
4. Liao, Z., M. Swainson, and A.L. Dexter, On the control of heating systems in the UK. Building and Environment, 2005. 40(3): p. 343-351.
5. BRECSU, Energy consumption guide 81: Benchmarking tool for industrial building—heating and internal lighting, 2002, Building Research Energy Conservation Support Unit.
6. Zhai, X.Q., et al., Experience on integration of solar thermal technologies with green buildings Renewable Energy, 2008. 33(0): p. 1904-1910.
7. McLaren, B., S.A. Parker, and C. Christensen, Transpired Collectors (Solar Preheaters for Outdoor Ventilation Air), in Federal Energy Management Program, Federal Technology Alert, B. McLaren, S.A. Parker, and C. Christensen, Editors. 1998, US. Department of Energy.
8. Hall, R., et al., Transpired solar collectors for ventilation air heating. Proceedings of the ICE - Energy, 2011. 164(3): p. 101-110.
9. Hollick, J.C., Solar cogeneration panels. Renewable Energy, 1998. 15(1–4): p. 195-200.
10. Kutscher, C.F. Transpired solar collector systems: a major advance in solar heating. in Proceedings of the 19th World Energy Engineering Congress. 1996. Atlanta, GA.
11. Brown, D.S., An Evaluation of solar air heating at United states air force instalations, in Department of Systems and Engineering Management2009, Air Force Institute of Technology, Air University.
12. Brunger, A.P., C.F. Kutscher, and J. Kokko, Low Cost, High Performance Solar Air-heating Systems Using Perforated Absorbers, 1999, International Energy Agency: Paris.
13. Brewster, A., Using the sun's energy. Building Engineer, 2010. 85(6).
14. CA-Group. SolarWall®: Transpired Solar Collector (TSC). n.d [cited 2012 15 January]; Available from: http://www.cagroupltd.co.uk/pages/cabp/products/cabp_solarwall.php.
15. Probst, M.C.M. and C. Roecker, Architectural Integration and Design of Solar Thermal Systems. 2011, Italy: Taylor & Francis Group Ltd.
16. Krippner, R. and T. Herzog. Architectural Aspects of Solar Tecniques: Studies on the Integration of Solar Energy Systems into the Building Skin. in Eurosun 2000, 3rd ISES-Europe Solar Congress. 2000. Copenhagen, Denmark.
17. Horvat, M., et al., International survey about digital tools used by architects for solar design, in Task 41 - Solar Energy and Architecture. Subtask B - Methods and Tools for Solar Design2011, International Energy Agency Solar Heating and Cooling Programme.
18. Pallant, J., SPSS survival manual. 4th ed. 2010, New York: Allen & Unwin Book Publishers, australia.
19. Field, A., Discovering statistics using SPSS. 3rd ed. 2009, California: Sage Publication Lts.
20. Atas, Ann Arbor Municipal Building, 2010, ATAS International, Inc.
21. Farkas, K. and M. Horvat, Building Integration of Solar Thermal and Photovoltaics – Barriers, Needs and Strategies, in IEA SHC Task 41: Solar Energy and Architecture. Subtask A: Criteria for Architectural Integration2012, International Energy Agency Solar Heating and Cooling Programme.
22. Ramirez, D. Natural Remodeling with Kelly Lerner: Considering Your Home's Climate. 2008 [cited 2013 12-Apr]; Available from: http://ecohomeresource.com/2008/08/natural-remodeling-10-weeks-wi.html.