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Transpired solar collector installations in Wales and England

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Abstract

Transpired Solar Collectors (TSCs) are a relatively new solar energy technology to the UK building-integrated renewable energy market. Since the first UK TSC was integrated with a profiling mill in County Durham in 2005, a further 19 commercial installations have ensued and have a combined absorber area totaling over 12,500 m^2. Wales and England are home to some architecturally and technically innovative TSC designs. These include one of the world's largest TSCs, a Cassette-Panel TSC array with special high-absorptivity selective coating and a TSC integrated with diurnal thermal storage. To accelerate the development of TSCs in Wales, the Welsh European Funding Office (WEFO) funded Sustainable Building Envelope Demonstration (SBED) project will monitor eight full-scale TSCs over two years to generate robust data on the feasibility of the technology.

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Keywords: Solar Air Heating, Transpired Solar Collector, TSC, Case Studies, Solar Ventiatlion Air Heating

1. Introduction

A transpired solar collector (TSC) is a solar thermal system which can be used to preheat the ventilation air supply to buildings using solar radiation as its energy source. Figure 1 illustrates the simple principle upon which it is based. External air is drawn into a plenum or cavity through thousands of evenly spaced perforations in a solar absorbing sheet. As the air passes over the front surface of the perforated sheet, heat is transferred from the sheet to the air. This heated air can then be distributed directly into the building as ventilation or ducted into the main heating system to reduce the fossil fuel load. The performance of a TSC is a complex balance of climatic conditions, size, absorptivity, building aspect, perforation pattern and air flow rates [1]. Although this technology has been used extensively in Canada and the USA since the early 1990s, it is a relatively new technology to the UK.

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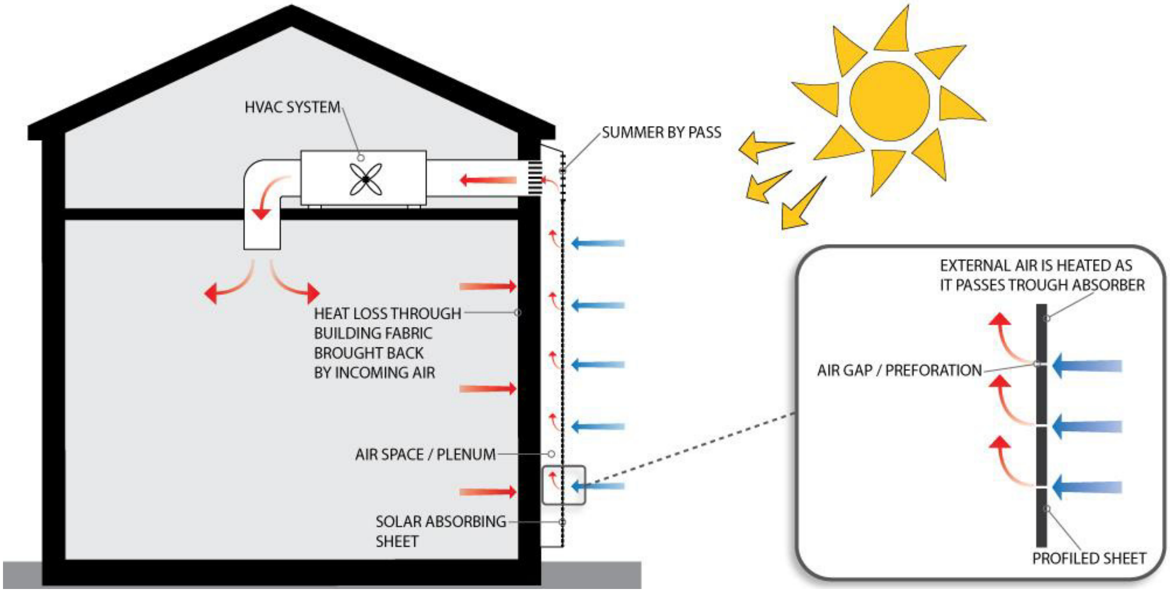

Fig. 1. Diagram illustrating the operating principles of transpired solar collector (based on source [2]).

2. Overview of transpired solar collectors in England and Wales

The first TSC installation to occur in the UK took place in 2005 at the profiling mill in Evenwood, County Durham, England and consisted of a 410m^2 TSC to the South East Façade [3]. This is one of 15 installations now active in England, with another 5 in Wales. The location of each is illustrated in Figure 2a. Although there are currently no commercially installed TSCs in Scotland or Northern Ireland, the total combined TSC absorber area in the UK exceeds 12,500 m^2. Table 1 lists details of these installations chronologically, and reveals a great variety in terms of size, location and building type. Figure 2b shows the variation of global horizontal irradiation with TSCs location.

a

b

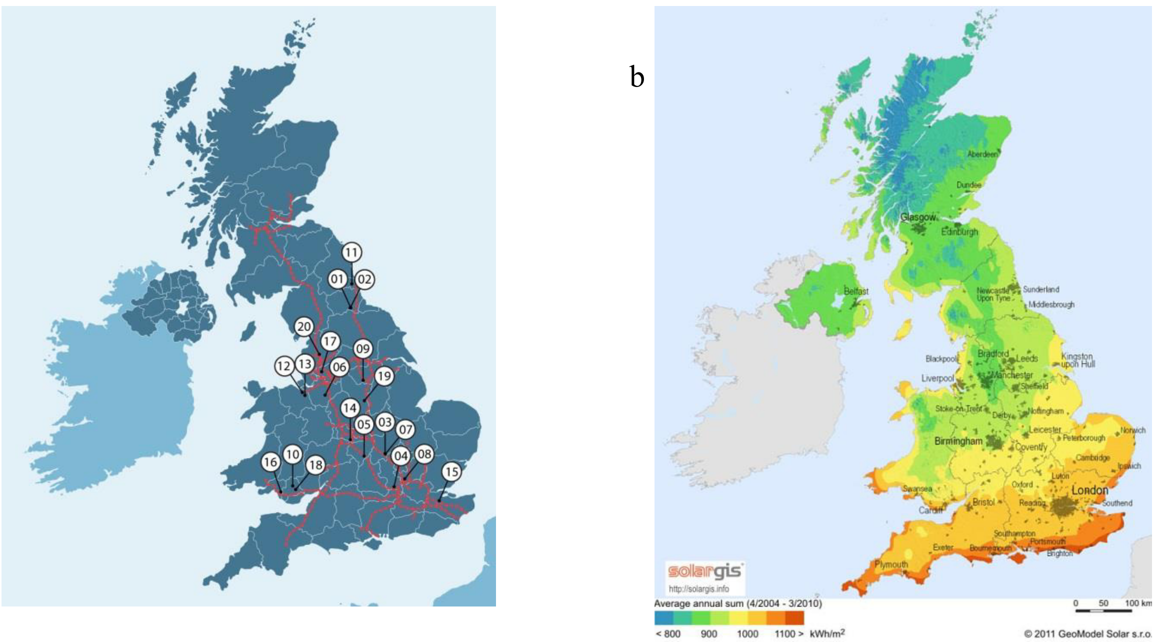

Fig. 2. Map illustrating (a) location of UK TSC installations; (b) global horizontal irradiation in the UK [4].

2.1. Orientation and inclination

Most of the TSC installations in the UK have an un-shaded orientation within 20 degrees of South. However, there are exceptions such as the Rhondda Cynon Taff (RCT) Homes dwelling in Aberdare which compensates for its imperfect orientation by splitting the TSC installation between the South West (Front) and South East (Side) façades. The orientation of this installation was selected so as to preclude a solution that was overly solar reliant and hard to replicate [5].

In the UK TSCs are generally installed vertically on the façade and to date roof mounted systems do not exist commercially. The only non-vertical example is the TSC at the Technical Training Academy of Jaguar Land Rover which is inclined on the façade at a 69° angle [6].

2.2. Size

TSCs are generally sized to match the fresh air requirement of the building. While the average area of installation in England and Wales is $596m^2$, the area of TSC collector ranges immensely. It extends from $9m^2$ of the Rhondda Cynon Taff (RCT) Homes dwelling in Aberdare up to $4334m^2$ at the Marks & Spencer distribution centre at Castle Donington, which is one of the largest TSCs in the world [7]. Figure 3 illustrates the increase in the annual operational collector area of TSC in the UK.

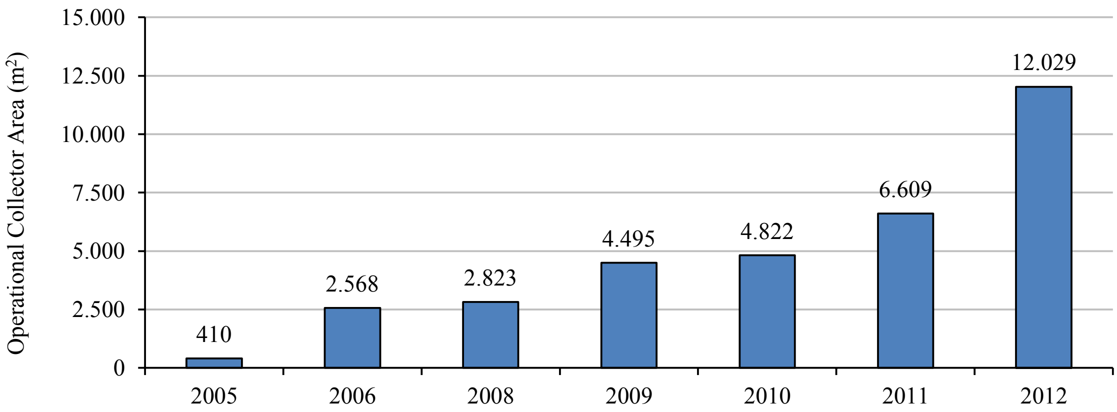

Fig. 3. Graph illustrating annual operational collector area of transpired solar collector in the UK

2.3. Colour

The colour of the collector is a good indicator of the absorber's ability to convert solar radiation to heat. As dark colours absorb more sunlight, black is the obvious choice in terms of solar thermal performance. Despite this, high solar thermal performance colours such as black & kronos have not yet been used in any TSC installations in the UK. Recently, a new range of steel coatings with improved solar absorption including light colours has been introduced. Although these are still less effective than darker colours, it is argued that the loss in performance associated with lighter colours can easily be compensated by utilising a larger collector area [8]. As TSCs are a relatively inexpensive technology and the extra area is generally readily available on the building envelope this provides a logical solution. Two separate European surveys, addressed predominately to architects, suggest that the availability of a range of collector colours is an important factor affecting the acceptance of solar energy technologies [9, 10]. The respondents of one of these surveys rated grey colours the highest [9]. This is consistent with the choice of colour made for TSC absorber in the UK. Despite the extended range available, grey is the dominant colour used throughout. At least eight different shades of grey have been used including alaska grey, zeus, grey aluminium, anthracite, slate grey, merlin grey, ariadne and pure grey. Only four other colours have been used. They include linden green, sargasso, chocolate brown and M&S green (see Table 1).

2.4. Type of metal cladding

Led by the availability within the façade metal cladding market, the TSC installations in the UK employ three different types of metal cladding. These are Profiled Metal Sheeting, Cassette Panels and Tongue and Groove Planks and examples of each is illustrated in Figure 4. As can be seen in Table 1 the vast majority of TSC installations in the UK utilise Profiled Metal Sheeting as the collector surface, although at least one example exists for each of the Cassette Panel and Tongue and Groove Plank options.

Fig. 4. Examples of the three different types of metal cladding available for transpired solar collectors.

2.5. Types of building

Early on in their development, TSC were used to provide low-temperature process heat for agricultural or industrial purposes i.e. crops and drying card board, textiles or paint. These are proven applications still used today however, there are no examples of TSC being used for this purpose in the UK. Another traditional application of TSCs is the heating of industrial or warehouse buildings with large wall areas. The majority of TSC installations taking place in the UK fall into this category. Less common applications of TSC in the UK include heating leisure facility, healthcare, commercial and residential buildings. Two TSCs have been installed on leisure facility buildings which include Firth Park Community Arts College and Deeside Leisure Centre. One TSC has been installed on a prototype healthcare building: the Willmott Dixon Healthcare Campus at the BRE Innovation Park. One has also been installed on the food hall at the Beaconsfield Motorway Service station. Finally one TSC has been installed on a residential dwelling: the RCT Homes dwelling in Aberdare. Industrial and warehouse/distribution buildings generally comprise of the largest collector areas, while other building type such as the residential and health care buildings are the smallest.

The majority of TSCs in the UK have been integrated into new buildings. However, there are many examples of installations being carried out as part of an existing building refurbishment. These include Deeside Leisure Centre, RCT Homes dwelling, TWI Technology Centre, Sustainable Building Envelope Centre, Willmott Dixon Healthcare Campus, Jaguar Land Rover Material Planning & Logistics Centre as well as the first UK TSC installation at the CA Group Mill Building (A).

Table 1. Transpired solar collectors in Wales and England [3, 5-7, 11-14].

Reference	Project	Location	Year	Absorber projected area (m^2)	Colour	Form of TSC absorber
1	CA Group Mill Building A (Renovation)*	Evenwood, County Durham	2005	410	Merlin Grey	Profiled Steel Sheet
2	CA Group Mill Building B (New Build) *	Evenwood, County Durham	2006	1211	Merlin Grey	Profiled Steel Sheet
3	Sainsbury's Distribution Centre*	Pineham Park, Northampton	2006	947	Alaska Grey	Profiled Steel Sheet
4	Beaconsfield Motorway Services*	Beaconsfield, Buckinghamshire	2008	255	Merlin Grey	Profiled Steel Sheet
5	Jaguar Land Rover Material Planning & Logistics Centre*	Leamington Spa, Warwickshire	2009	268	Ariadne	Profiled Steel Sheet
6	Premier Park 33*	Winsford, Cheshire	2009	580	Sargasso	Profiled Steel Sheet
7	Royal Mail*	Swan Valley, Northampton	2009	800	Zeus	Profiled Steel Sheet
8	Willmott Dixon Healthcare Campus (Full Scale Showcase) *	Bre Innovation Park, Watford	2009	24	Grey Aluminium	Profiled Steel Sheet
9	Firth Park Community Arts College*	Sheffield, South Yorkshire	2010	218	Anthracite	Profiled Steel Sheet
10	RCT Homes Dwelling	Cwmbach, Aberdare	2010	9	Chocolate Brown	Steel Plank
11	Chartek International Paints*	Felling , Gateshead	2010	100	Merlin Grey	Profiled Steel Sheet
12a	Sustainable Building Envelope Centre (SBEC)	Deeside, Flintshire	2011	62(sum of 3 units)	High Absorptivity Linden Green	Steel Cassette Panel
12b	Sustainable Building Envelope Centre (SBEC)	Deeside, Flintshire	2011	200	Anthracite	Profiled Sheet Sheet
13	Deeside Leisure Centre	West Queensferry, Deeside	2011	260	Slate Grey	Profiled Steel Sheet
14	Jaguar Land Rover Deck 92	Solihull, West Midlands	2011	565	Slate Grey	Profiled Steel Sheet
15	Royal Mail*	Strood, Kent	2011	700	Pure Grey & Anthracite	Profiled Steel Sheet
16	TWI Technology Centre	Port Talbot, Neath Port Talbot	2012	486	Slate Grey	Profiled Steel Sheet
17	Armstrong Point Business Park*	Wigan, Greater Manchester	2012	390(sum of 9 units)	Sargasso & Anthracite	Profiled Steel Sheet
18	SSE	Treforest, Rhondda Cynon Taf	2012	210	Anthracite	Profiled Steel Sheet
19	Marks & Spencer*	Castle Donington, Leicestershire	2012	4334	Alaska Grey,Anthracite Grey and M&S Green	Profiled Steel Sheet
20	Royal Mail*	Chorley, Lancashire	2013	495	Anthracite	Profiled Steel Sheet

*Personal communication with A. Brewster of CA Group Limited specific to the SolarWall® Transpired Solar Collector supplied by CA Building Products. SolarWall® is a registered trademark of Conserval Engineering Inc.

3. Architecturally and technically innovative TSC designs

Corrugated iron cladding (also known colloquially as wrinkled tin) was first patented in 1829 by Henry Robinson Palmer of the London Dock and Harbour Company [15]. It was used extensively for industrial and agricultural buildings in the UK but was gradually replaced by mild steel from the 1890's. It is thought that this association of profiled steel with industrial buildings may limit penetration of the TSC technology in non-industrial buildings.

Building integrated solar thermal systems have been designed and developed around the world for over half a century. The importance of their aesthetics has long since been emphasized; however, it is noted that the architectural quality of these integrations is generally poor [16-19]. As previously discussed, the vast majority of TSC installations in the UK have taken place on industrial buildings. Although it is evident that the quality of architectural integration is not exceedingly successful, it is in general, appropriate to the building type. Despite this there are some excellent examples of successful architectural integration such as the Sustainable Building Envelope Centre in Flintshire, North Wales.

Despite the late introduction of TSC technology to the UK, it is home to some technically innovative TSC designs. These include one of the world's largest TSCs, a Cassette-Panel TSC array with special high-absorptivity selective coating, a residential building and a TSC integrated with diurnal thermal storage.

3.1. Sustainable Building Envelope Centre

Sustainable Building Envelope Centre (SBEC) was one of the first buildings to incorporate TSCs for renewable heat in Wales and was shortlisted for the innovation category of the 2013 Construction Excellence Awards (CEW). SBEC is the first commercial installation in the UK to use Cassette Panels as the TSC absorber. The high absorptivity Linden Green coating was developed specifically for this project. SBEC is innovative in its approach to demonstrating TSC integration with technologies including air source heat pump, radiant ceilings, phase change materials and under floor heating. The building was divided into different sections to allow this range of technologies to be tested. A direct feed from the TSC is provided into the meeting room which has phase change materials embedded in the composite floor slab to provide thermal buffering. The TSC also provides a pre-heated air supply to an air source heat pump which feeds warmed water through pipes embedded in the concrete floor. The supply can be switched to cold water to absorb thermal gains during the day and be purged at night to prevent overheating. Warmed water from the air source heat pump can also be fed through the radiant ceiling system.

The architectural integration of this installation was carefully considered. The position and dimension of TSC at SBEC is coherent with the architectural composition of the whole building. The TSC has been designed as a multifunctional constructional element and fulfills several functions including sun shading, facade cladding and solar collector absorption. The TSC sections are cleverly integrated into the façade by incorporating the use of non-active elements (dummies). The size and shape of the cassette panels are compatible with the composition grid of the building and with the various dimensions of the other façade elements.

3.2. Marks & Spencer Distribution Centre at Castle Donington

The 4,334m² TSC on south façade of the Marks & Spencer Distribution Centre at Castle Donington is one of the largest TSC in the world. This new 80,000 m^2 distribution centre has been rated Excellent by BREEAM and recognised with an A rated EPC certification [7]. The installation required careful consideration of the architectural integration which resulted in careful detailing of the profiled sheeting especially around the adjoining loading bays and window sections. The TSC design used three shades of profiled steel (Alaska Grey, Anthracite Grey and M&S Green) to facilitate its integration into the building grid.

3.3. TWI Port Talbot, Neath Port Talbot/ transpired solar collector with diurnal heat storage

TWI building in Port Talbot (South Wales) is an industrial building which has been retrofitted with a TSC for ventilation air heating and a TSC with diurnal heat storage. The combined system has the potential to provide 100% of the heating demand of a thermally efficient industrial building. Figure 5 shows a simplified schematic of the prototype TSC with diurnal storage. As in a TSC for ventilation air heating, the outside air is heated as it travels through the solar heated perforated collector. The heat from the air is then transferred to water via an air to water heat exchanger. This heated water is then passed through a heat pump and into a water tank for short term heat storage. When there is a demand for heat, heat is extracted from the tank and is delivered to the internal space via the building's heating system.

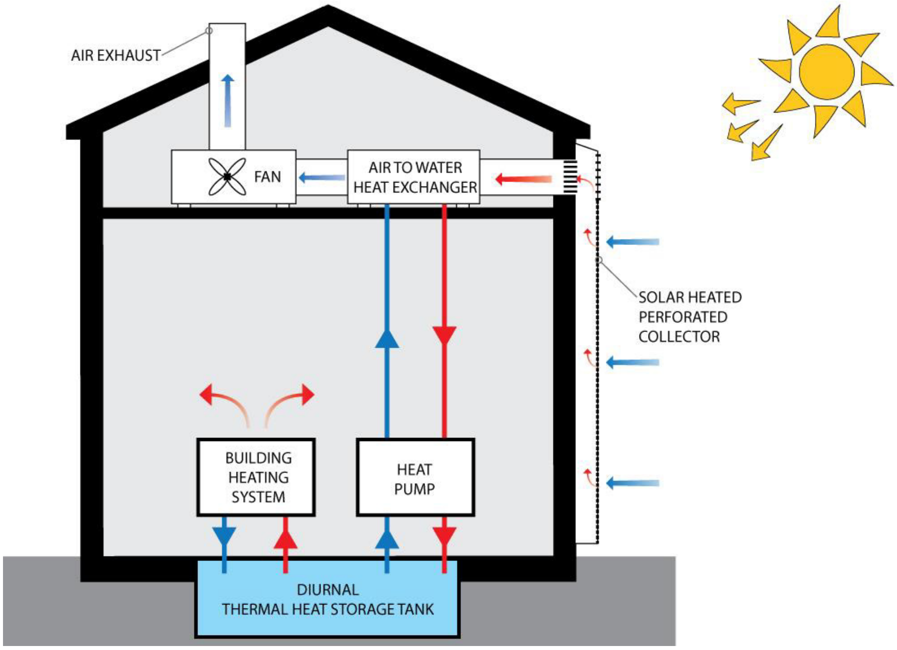

Fig. 5. Illustration of transpired solar collector with diurnal heat storage

3.4. RCT Homes dwelling, Aberdare

TSCs have previously been installed on residential buildings including the 335m^2 installation on a 24 story apartment building in Canada [20]; however, their installation on individual residential dwellings is not common. RCT Homes dwelling in Cwmbach, Aberdare is the only residential example of a TSC in the UK and is integrated with an air source heat pump. The TSC installation formed part of the Technology Strategy Board (TSB) Retrofit for the Future competition. This was an initiative to retrofit UK social housing stock in order to meet future targets in reduction of CO_2 emissions and energy use. The approximate area of TSC was 9m^2 (with half to the Front façade and half to the Side façade). To improve the architectural integration, the 1.6m high metal cladding strip is continued around the front, side and rear facade as well as around the adjoining property. It is acknowledged that by integrating the TSC into the cladding, a better architectural impact has been achieved in comparison with other non-integrated solar collector alternatives [5].

The performance of the TSC cannot be fully assessed without monitoring data. However, an interview conducted with the tenants twelve months post occupancy revealed that they were satisfied with the system. They confirmed that their utility bills were lower since they had moved into this property, that the house was never cold and that they were in general pleased with the system. However, they stated that they sometimes found it too hot (even in cold weather) and explained that they were told not to tamper with the controls unless really necessary and therefore they refrained from changing them at all.

Housing in the UK accounts for 27% of carbon emissions and more than 80% of the houses we will be living in by 2050 have already been built [21]. Furthermore when we consider the UK's target of an 80% reduction in carbon emissions by 2050, we can see how imperative it is to improve the performance of our existing housing stock. Accordingly, this refurbishment demonstrates an opportunity to use TSC to help meet the future targets in reduction of CO_2 emissions and energy use in the UK's existing housing stock.

4. Monitoring

There are a limited number of TSC installations around the world which have been monitored utilising a comprehensive and traceable methodology [22-26]. Those which do are generally located in the US and Canada where, the climate and weather patterns are considerably different from the UK. While cities such as Manchester, England and Edmonton, Canada for example share similar latitudes, their climate differs significantly. Based on the average annual climate values between 1973 and 2000, the annual average minimum temperature in Manchester is 6.2^{o}C while in Edmonton it is -4^{o}C [27]. In brief, Edmonton receives colder winters, more annual solar radiation and more snow; however, it receives significantly less annual precipitation. As a result TSC technology in the UK has to respond to different climate conditions and heating demands. Thus performance cannot be verified by previous monitoring of traditional applications of this technology elsewhere.

In the UK, the only published document to discuss a monitoring process for TSC installation on a building in use has been conducted by the Building Services Research and Information Association (BSRIA) [3]. BSRIA monitored the performance of the TSC at the profiling mill in Evenwood, County Durham. Monitoring was carried out over a twelve month period (April 2006 to March 2007). The study found that during this period the heat collected by the TSC and delivered to the building ventilation system amounted to 21% of the total heating energy requirement of the building (79,191 kWh out of 375,104 kWh). The study also showed that the greatest benefit was achieved in the month of December when the weather was clear and air temperature and sun angles low. BSRIA also reported that the TSC, together with other energy saving features of the system (partly attributed to de-stratification) reduced the demand for gas fired heating so that the gas bill was reduced by 51% in comparison to the previous year despite cooler weather [3]. Installations such as the CA Group Mill, SBEC and Deeside Leisure Centre have been monitored over 12 or more months. However with the exception of the CA Group Mill this monitoring has been generally carried out by the collector manufacturer and therefore there is a lack of independently tested and verified data by which to evaluate the real life performance of the technology within the UK climate. The absence of independent evaluation of the TSC performance in the UK is self-evident and both market and public perception is cautious.

As more sophisticated and complex systems are developed, monitoring involves a comprehensive understanding of the control system which plays a dominant role on the performance. Energy delivered is the main indicator and is usually calculated on a monthly base. This indicator is not always equal to the building energy savings as there is an additional benefit in terms of air quality due to the high levels of fresh air brought into the building. Comparing such a system against a high recirculation system such as typical HVAC would be an unfair comparison. Furthermore, supplementary benefits such as air de-stratification and heat recapture savings should also be monitored and evaluated as an additional contribution to the energy saved.

5. The Sustainable Building Envelope Demonstration project

The Sustainable Building Envelope Demonstration (SBED) project is funded with £1.8 million from the European Regional Development Fund through the Welsh Government and matched by an industrial partner. The project was secured by the Welsh School of Architecture, Cardiff University and is delivered in partnership with Tata Steel. The principle aim of this project is to design, model, test, prototype and monitor low carbon building systems incorporating TSCs in eight 'buildings in use' in Wales. The full process of design, installation & operation, will be independently monitored along with investigation of public perception. This will allow dissemination of best practice in terms of installation, integration and maintenance along with data on the real life performance of the technology.

The SBED installations will include new build and retrofit as well as vertical and inclined installations on a variety of building types. Table 2 gives an overview of the proposed demonstration types and their expected size. Several building owners have submitted their buildings for consideration in the project. Four demonstration buildings (two each for industrial and institutional buildings) have been selected and preparation is underway. It is envisaged that the combined TSC area of this project will total over 2780m^2, which will significantly contribute to CO_2 reductions for the building users. Based on energy prediction methodology [28, 29] this should generate approximately 0.3GWh of renewable energy per year.

Table 2. Proposed Sustainable Building Envelope Demonstration TSC installations across Wales.

Building type	Number to be selected	Expected TSC area	Number submitted	Number selected
Residential	2	40m^2 each	2	-
Commercial (office/retail)	2	200m^2 each	11	-
Industrial /process	2	1000m^2 each	7	2
Institutional (school / hospital)	2	150m^2 each	10	2

6. Conclusion

Although there is evidence that Transpired Solar Collectors have been successfully implemented in the USA and Canada, they are a relatively recent technology in the UK where differences in climate and architectural heritage prevail. Despite their late introduction to the UK at least 20 installations are now active, giving a combined absorber area totalling over 12,500 m^2. Although there are examples of commercial and even residential buildings, installations have been more common on industrial buildings. There are examples of both technically and architecturally innovative TSC designs. Although anecdotal information indicates that the TSC installations have been successful, energy figures cannot be verified as there is a lack of independently tested monitoring data available to assess the efficacy of the installations. The Sustainable Building Envelope Demonstration (SBED) project aims to design, model, test, prototype and monitor low carbon building systems incorporating TSCs in eight ‘buildings in use’ in Wales. This project will fulfil the need for independently tested and verified data which will provide a real life performance evaluation of TSC technology within the UK climate. This project will also contribute significantly to promoting best practice in the TSC market and it is envisaged that it will significantly accelerate the development of TSCs in Wales.

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