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Investigating the application of small scale transpired solar collectors as air preheaters for residential buildings

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Abstract
This paper presents the performance of a transpired solar collector (TSC) used as a preheater for an air to air heat pump, installed in a demonstration house in Wales, UK. The TSC is activated when there is a demand for both heating and ventilation. The system is designed to be aesthetically pleasing, affordable, and can be installed on south facades/roofs in new and retrofit buildings. A TSC has been monitored for one year at a demonstration house and data normalised using historic weather data. Results show the system contributed 15% of the heating and hot water demand (1360kWh) in one year. In 2017 UK figures this translates into £100 to £200 savings per year compared to a conventional heating source. The total cost of the TSC technology for a mature market is projected to be less than £1600 for the installed area which indicates that the payback could be less than 8 years.

1. Introduction

A large number of solar collector technologies are available [1], however not all are considered suitable for building integration. Besides the necessity of technical and structural effectiveness, solar thermal technologies have to meet design criteria as well [2]. The technology demonstrated is a renewable thermal system that preheats fresh air subject to solar energy availability. It is an unglazed system with high building integration potential for all types of buildings [3, 4].

This paper presents the fundamental performance figures of the TSC technology and relevant literature together with a case study demonstrating the application of a TSC on a new build demonstration house [5]. A south-facing 17m^2 vertical TSC has been installed as a preheater for an air to air space heating and hot water heat pump (Figure 1). Built as part of the Cardiff University-led Low Carbon Research Institute (LCRI), the SOLCER House was funded by the European Regional Development Fund through WEFO, with support from the EPSRC Buildings as Power Stations project led by SPECIFIC. Monitoring information is briefly presented and monthly heat delivery results are illustrated. Moreover, a cost analysis based on UK trends and projected figures is discussed. The study also reviews the uncertainties of the results and examines some the positive and negative aspects associated with the future application of TSCs with heat pumps.

Figure 1 Solcer House, Bridgend, Wales (latitude 52^0). Left: The TSC is located across the external area of the upper floor (dark grey/black). Right: Detail of the metal cladding/ perforation

2. Background and related work

TSCs have been applied to large scale industrial units with a number of successful examples across UK [3]. This study explores the use of TSCs installed and monitored at a small scale in combination with a domestic scale heating system with the anticipation that this will help to reduce heating costs. The demonstration house case study is located in an area of relatively high cloud coverage and low annual global horizontal irradiation (1000kWh/m^2)[6]. The vertical installation is more efficient for low solar altitudes (<45^0) occurring in the morning, in the afternoon and during heating season (October to April).

The 100m^2 floor area demonstration house has been designed to maximize energy efficiency and is therefore highly insulated and air tight. There is significant heating demand during spring, winter and autumn with a maximum design mechanical ventilation demand of 200m^3/hr served by a GENVEX Combi 185 heat air to air pump with heat recovery. Air to air heat pumps are a potential solution to increased need for mechanical ventilation, however, their performance is highly dependent on outside air temperature, and preheating would therefore reduce electricity costs [7].

Figure 2 presents the operational principle of the technology at the demonstration house. A fan is used to draw fresh external air through evenly spaced micro perforations in the surface of the TSC. The air in the cavity is heated predominantly by the solar absorbing front sheet, then by the perforations surrounding area and finally by the cavity itself. The heated air can be directly distributed via a mechanical ventilation system or fed into an air heating system (e.g. heat pump). During the heating season the transpired collector provides heat and during the summer months it can be bypassed if the maximum temperature is exceeded. The fresh air coming from the TSC passes through a heat recovery unit which transfers the heat from the house to the incoming cooler air.

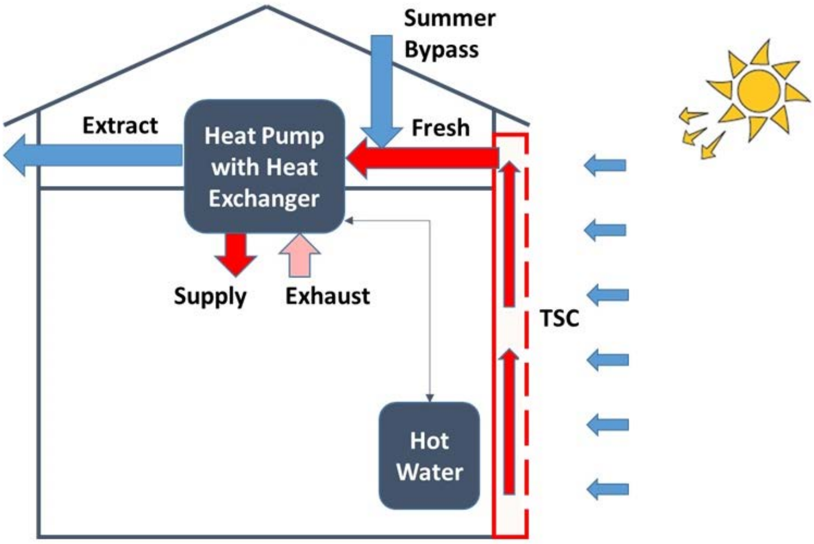

Figure 2 TSC with a heat exchanger and heat pump

Previous research in UK has found that TSC can contribute approximately 20% of the building's heating demand with a payback of between 2 and 10 years [8]. The National Renewable Energy Laboratory in US indicates a payback range of 3 to 12 years with a lifespan of 30+ years and claim an installation cost of approximately $\$65/m^2$ for new construction and $\$110\ m^2$ for retrofit applications [9]. Data collection from UK commercial sites indicate that the system can deliver from 200 to 300kWh/m^2/year for a volume flow rate between 50 and 150m^3/hr/m^2TSC [10]. Similarly, TATA Steel UK claim that TSC delivers 250 kWh/m^2/year which could contribute up to 50% of space heating requirements depending on building usage and configuration [11]. Solarwall Limited and BSRIA Limited report similar savings for commercial buildings in UK with a lifespan of 40 years [12].

3. Methodology

The monitoring methodology at the demonstration house was based on Perisoglou and Dixon study of TSCs [13]. The heat delivery (Q_{del}) of the TSC is calculated using the fundamental equation for fluid heat transfer.

$$Q_{del} = \dot{m}\ C_p\ T_{rise} \qquad \text{(equation 1)}$$

where $\dot{m}$ is the mass flow rate, C_p is the specific heat of air and T_{rise} is the difference between the ambient air temperature and the air temperature just after the collector.
Temperature sensors were positioned before and after every potential temperature change: outside ambient, in the TSC cavity, at the TSC supply

duct, before and after the heat exchanger, after the heat pump and after an electric top-up heater in the ducting. Extra thin, calibrated PT100 class A (4 wires) temperature sensors were used. Also, multipoint, high accuracy, low differential pressure probes were placed in the duct to calculate the mass flow rate. The logging time interval was set to 5 min to record transient conditions.

4. Results and Discussion

Figure 3 presents the monthly heat delivery of the TSC which indicates that the solar absorption of the vertical collector is maximised at the low solar angles prevalent in winter and delivers circa 3kWh/day. During the shoulder months (from September to November and from March to May), the higher solar irradiation increases heat delivery to circa 5kWh/day. Heating demand is reduced during the summer; however, the TSC preheated air is still passed to the heat pump condenser where the heat pump heats water in an integrated storage tank, for domestic use. The collector is bypassed during the summer when the external ambient temperature is higher than 24^{0}C.

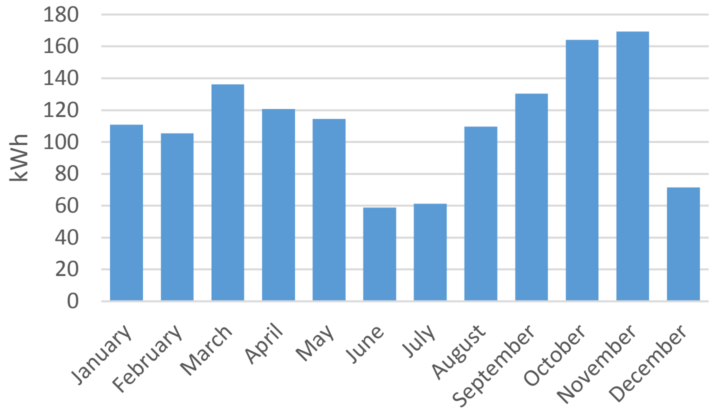

Figure 3 Monthly total TSC heat delivery

The total heat delivery from the TSC is approximately 1360kWh/year. This means that each of the 17m^2 of the TSC delivers approximately 80kWh/year which is significantly lower than the published figures [10]. The main reason behind this is that the system was sized for a very low flow rate (12m^3/hour/m^{2}TSC) and maximum temperature rise. There were also architectural integration considerations. The presence of the heat exchanger could also occasionally reduce the benefit of the TSC; when the TSC delivers above room temperature, the heat exchanger should be bypassed.
The TSC delivers approximately 15% of the house's total heat and hot water demand. The contribution is much higher during daylight hours and for the shoulder months. Figure 4 illustrates the heat delivery of each system component to the house for the typical month of October 2016.

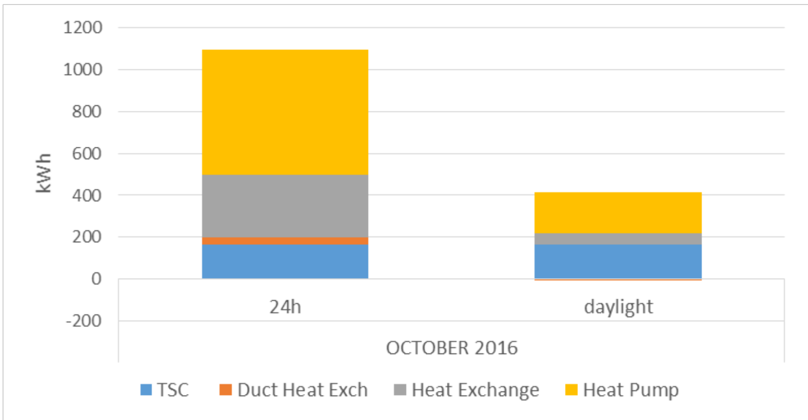

Figure 4 Heat delivery break down for October 2016 total (24h) and during daylight

The heating demand *during daylight hours* is served by the TSC (40%), the heat exchanger (12%) and the heat pump (48%). The significant contribution of the TSC is partially reduced by the heat exchanger when high temperature rises occur during the day. Over a 24 hour period, 15% of the demand is covered by the TSC, 27% by the heat exchanger, 55% by the heat pump and approximately 3% by heat recovery via the ductwork in the loft.

When considering cost of the technology, it must be recognised that the market prices cited [9] apply to a mature market for large commercial/industrial applications. Small residential installations are more expensive due to one-off design requirements such as aesthetic considerations such as colour and profile customisation and logistics costs. Moreover, the integration to a heat pump and the summer bypass outlet may require some extra system components, such as ducting and finishing, dampers, sensors and control adjustments. An extra heat exchanger bypass with controls may also be required to allow high TSC temperature rise. The cost in new buildings is significantly lower than for retrofit, as alterations are considered in the design stage and ducting is designed to facilitate south wall/roof inlet and bypass. Considering the NREL cost projections [9], a 17m^2 collector could cost less than £1000 assuming for substantial market demand. Taking into account that the TSC feeds a heat pump manufactured with TSC control compatibility and summer bypass is essential, an extra cost of £600 for the controls has to be added. The total cost of £1600 for the TSC can be matched in 8 to 16 years for a 1360kWh/yr heat delivery; this payback period is based on 2017 UK figures and assumes £200/yr savings compared to an electric heater or £100/yr compared to a heat pump.

If maximization of temperature rise is the priority, then the flow has to be as low as possible; however, if it is too low then the heat transfer mechanism will not work efficiently. The maximum mechanical ventilation demand for the study (200m^3/h) requires each m^2 of installed TSC to deliver 12m^3/hr/m$^2_{TSC}$; whereas the lowest volume flow rates used in the literature are in the range of 50m^3/hr/m$^2_{TSC}$ [10-12]. This indicates that a much smaller

TSC could have been used and dummy panels could be substituted to serve the architectural integration of the system without a significant decrease in heat delivery. However, a future study could verify this suggestion.

5. Conclusions

This paper presents some of the benefits and the limitations of small scale application of TSC. Mechanical ventilation demand and heating during daylight hours make the technology ideal for air preheating and a good match with air to air heat pumps. The UK case study presented, indicates that 15% of the total heating demand is delivered by the TSC. Heat exchangers may need bypass controls to optimise performance in high solar days. The TSC could also reduce hot water costs especially if sophisticated weather responsive scheduling is applied which could be part of a future investigation A limitation is that the UK TSC market is relatively immature; however, heat pump manufacturers and construction industry is now aware of the TSC technology and cost reduction for small installations is a realistic target.

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