Renovation of Buildings using Steel Technologies (ROBUST)

RFCS Project RFSR-CT-2007-0043

WP 1.6 and 1.7

Field trials on a Transpired Solar Collector renovation system

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FIELD TRIALS ON AN OVER-CLADDING TRANSPIRED SOLAR COLLECTOR RENOVATION SYSTEM (WP1)

1 INTRODUCTION TO SOLAR AIR SYSTEMS

Solar Air Systems have been used for over 20 years in North America, but it is only in the last 3-5 years that their use has grown in Europe to meet the challenges of the ‘Energy Performance of Buildings’ Directive. In the steel sector, four systems have been developed:

- *Transpired Solar Collectors or SolarWall*®, now offered by CA Group in the UK (using a patent by Conserval in Canada);
- *EnergiPanel*, a composite panel system developed by Kingspan Insulated Panels;
- Ruukki system, a double skin system for roofs.
- VTT stand-alone solar air heating system

These systems heat air by passing ambient air under or through a solar heated metal sheet (usually steel). The heated air is actively brought into the building to provide ventilation space heating. Alternatively, the heated air is passed through a heat exchanger to heat water in a thermal store. In the summer, the warm air in the cavity can be expelled to avoid over-heating.

1.1 Transpired Solar Collectors

The development of Transpired Solar Collectors (TSCs) was based on perforated aluminium ribbed panels primarily in single storey buildings (Ref 1). However, the technology is now being applied to colour-coated flat steel panels in multi- storey buildings.

TSCs use micro-holes (around 1.5 mm diameter) punched into the outer sheet of metal. The air is heated as it is drawn through perforations in the solar heated metal sheet, as shown in Figure 1.

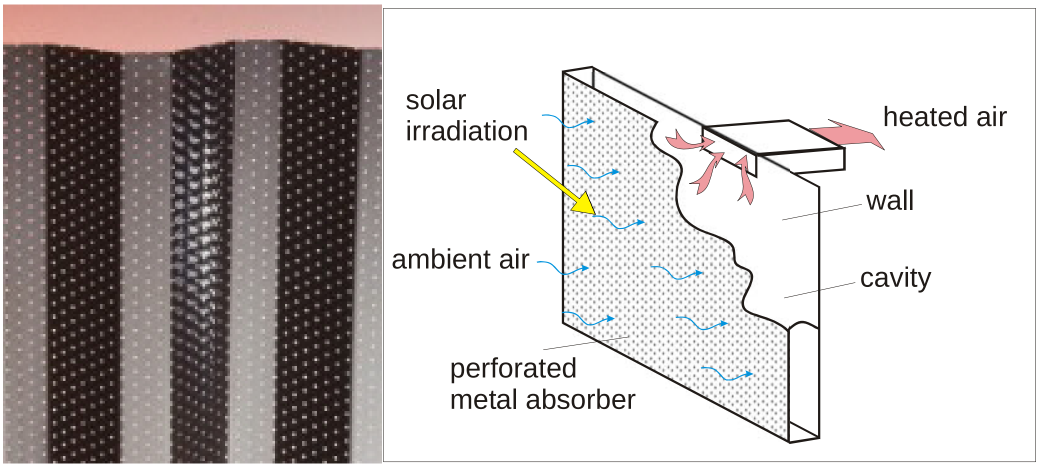


Figure 1 Illustration of *Transpired Solar Collector* concept

Theoretically, these systems also reduce the conductive heat loss through the façade as the cavity air is warmer than the external air and therefore the heat flux through the wall is reduced for a given U-value of the wall. Also, heat loss due to air leakage may be reduced, but this effect is unquantified as any air is brought back into the space.

The physical behaviour of TSCs is very complex and depends on:

- External ambient conditions, including solar radiance, local wind speed and turbulence, building orientation, etc.
- Internal conditions, including cavity temperature, heat loss through the internal wall, etc., flow rate through the cavity and perforations.
- Surface or boundary layer conditions, such as flat versus ribbed panels, perforation size and pattern, surface coating, colour and texture.

The efficiency of well designed TSCs at converting solar radiation into heat is typically between 50 % and 80 %. The highest efficiencies are achieved when the flow rates through the collector are high, although lower efficiency can be equally economical if high temperature rises are required. The effect of increasing air flow on the efficiency of the system for a given solar radiance is illustrated in Figure 2.

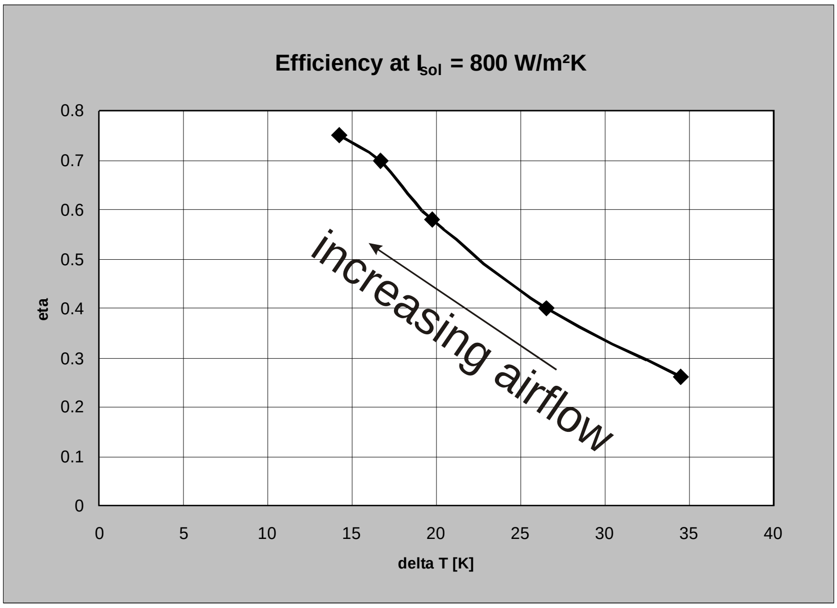


Figure 2 Efficiency of the *Transpired Solar Collector* concept for various flow rates and temperature differences

In the UK, experience of the use of TSCs is increasing. In 2006, 410m^2 of SolarWall$^®$ TSC was installed on the south façade of a factory building at CA Group's Roll Mill in Co. Durham, UK, and was independently monitored by BSRIA for 12 months to assess its performance. During its first year, SolarWall® generated 79,191 kWh (equivalent to 193 kWh/m^2 SolarWall® façade area) of renewable heat, which represented a 21% reduction in heating demand when compared to the previous year. In this building, the SolarWall$^®$ area was 22% of the building plan area.

In a recent project, Jaguar/Land Rover installed 270m^2 of SolarWall® at their Technical Training Academy at Leamington Spa, UK (Ref 2). The SolarWall® was positioned on the southern elevation at an inclination of about 70^o. The steel profiled cladding was manufactured using Corus Colorcoat Prisma$^®$ in the colour, Ariadne, which comes with a 25 year Confidex® Guarantee. The completed building is illustrated in Figure 3. This installation is predicted to save more than 80,000 kWh per year (296 kWh/ m^2 SolarWall® area). In a study by consultants Battle McCarthy, SolarWall® TSC was found to have the potential to contribute 50-70% of the building heating energy consumption for a modern enclosure designed to current Regulations.

In the UK climate, the benefits of these systems are less than in a colder climate with more solar radiance effects, such as Finland. Nevertheless, studies indicate that the benefits can be significant, generating around 250-500 kWh/m^2/year. Economic paybacks of 3 to 5 years are claimed.

Figure 3 Typical *SolarWall®* building in Leamington Spa , UK

1.2 *Energi Panel*

The Kingspan *Energi Panel* is based on a technique for manufacturing a composite panel with a void created in alternate ribs, as shown in Figure 4. Air is drawn in at the base of the wall, which means that it is less efficient than the perforated panel systems. Nevertheless, heating rates of 30 W/m^2/year are claimed, based on results of the first year of monitoring in Ireland.

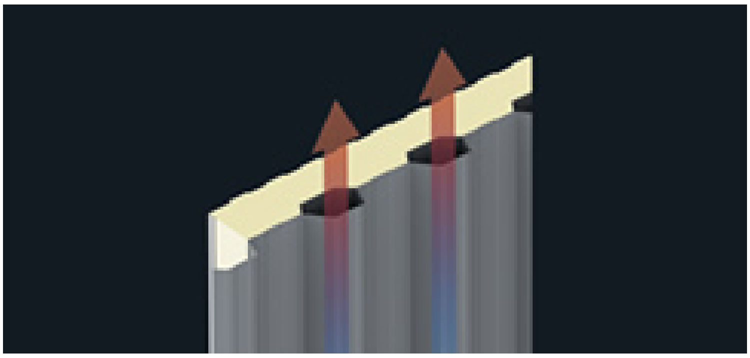


Figure 4 Kingspan *Energie wall* concept

1.3 Ruukki double skin roof system

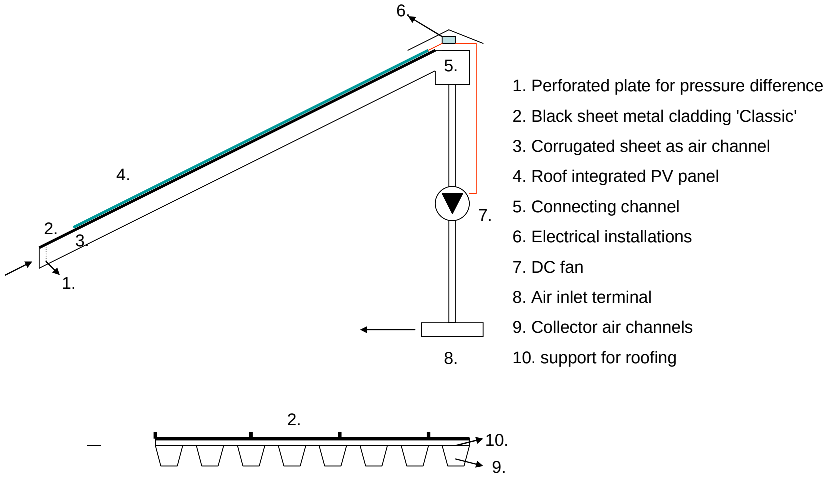
The *Ruukki* system was used in a demonstration house in Tuusuula near Helsinki built in 2000. It is a double skin or ‘built-up’ system, using a black external sheet above a conventional internal water-tight roof. Air is drawn in from eaves to ridge and is heated by contact with the back of the dark external sheet. The warmed air is passed to a heat exchanger (in this case located in the basement of the building). The demonstration building was monitored over the first year of its occupation and is shown in Figure 5

Figure 5 Ruukki demonstration building in Tuusuula, Finland

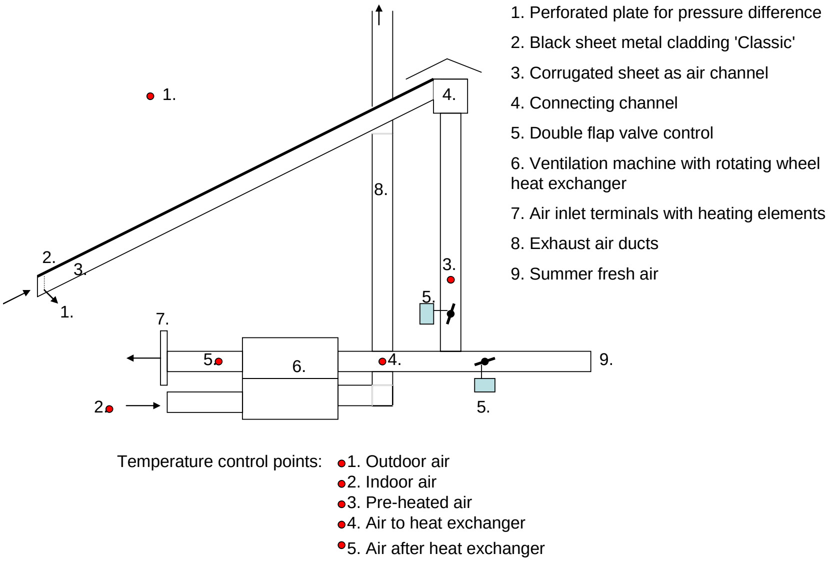
1.4 VTT roof stand-alone solar air heating system

The principle of the stand-alone solar air system is shown in Figure 6. It comprises a roof integrated air collector, roof integrated PV system, fan, and heating duct work and it provides supplementary heating for houses, warehouses and other industrial buildings.

The system was tested at a VTT's test house in Finland (see Figure 7) which is 2.4 m wide and 7 m long. The test roof is made of corrugated roof profile and a collector. The corrugated steel structure serves as the air channel of 0.038 m^2/m area. The collector is a standing seam sheet steel cladding with black surface. The PV system is directly integrated into the cladding. The prototype system used a PV laminate of 0.394 m × 5.486 m with rated power and operating voltage 128 W and 24 V correspondingly. The PV array output power is directly used to run a ventilation fan. A maximum air flow of 120 - 150 litres/s is used for ventilation.



(a) Solar air collector



(b) Solar air ventilation system

Figure 6 Principle of a roof solar air system

VTT's test roof. The roof slope is approximately 30°, facing south

Corrugated steel as air channel system.

Figure 7 Test roof for stand-alone solar air heating system

In the Finnish climate, summer houses are usable for 3 to 5 months during spring and autumn. The result of the test showed that the system can deliver 1000-1500 kWh of heat into a typical house.

An extension of this system is a solar integrated ventilation heating system, which comprises a roof integrated air collector, mechanical ventilation system with heat recovery, double flap valve control system controlled by temperature measurements, and air duct heaters at air inlet terminals.

The integrated solar air system can contribute 2000 – 2500 kWh to a detached house's heating energy demand. The energy saving potential depends on indoor temperature and ventilation rate. Especially during spring, all the heat collected from the roof cannot be utilised due to over-heating of the indoor air. The performance is improved if heat storage can used as a part of the solar air system.

2 FIELD TRIALS ON A TRANSPIRED SOLAR COLLECTOR RENOVATION SYSTEM

The application of the Transpired Solar Collector (TSC) concept to over-cladding of existing concrete or masonry buildings is new and could potentially reduce the heating costs of a building significantly when combined with external insulation. This application was investigated in the RFCS project ROBUST. In this project, an existing 1960s concrete panel building at the Wheatley campus of Oxford Brookes University was over-clad using steel cassette panels manufactured in lengths of up to 2.9 m and widths of 0.9 m. The south facing façade was over-clad on the lower two levels and this was extended onto the east facing faces. Figure 8 shows the original tower block and details of the wall construction. The metallic panels were manufactured from Corus *Prisma* colour-coated steel with up to 2,500 perforations per m^2 and a target air flow rate of 120 litres/second.

2.1 Installation of over-cladding

The manufacture and installation of the large cassette over-cladding panels was carried out at Oxford Brookes University in July and August 2009.

The lower two storeys of the 16 storey tower block were over-clad on the south face and also partially on the east face. The original south facing wall is shown in Figure 8. The wall construction by Bison dates from 1962 and consists of storey-high precast concrete panels in a double skin construction (75 mm external leaf, 25 mm insulation, 150 mm internal leaf. The window panels of the original building projected 80mm outside the flat panels between the windows. The whole building is supported on a podium level at second floor, from which the installation work was carried out.

The calculated U-value of the original façade was 1.2 W/m^2K, and the renovation strategy is designed to reduce the U-value of the over-clad wall to 0.25 W/m^2K, whilst generating ‘free’ heating using the TSC concept. The energy that is generated can amount to 30% of the operational energy of the building, depending on climatic conditions.

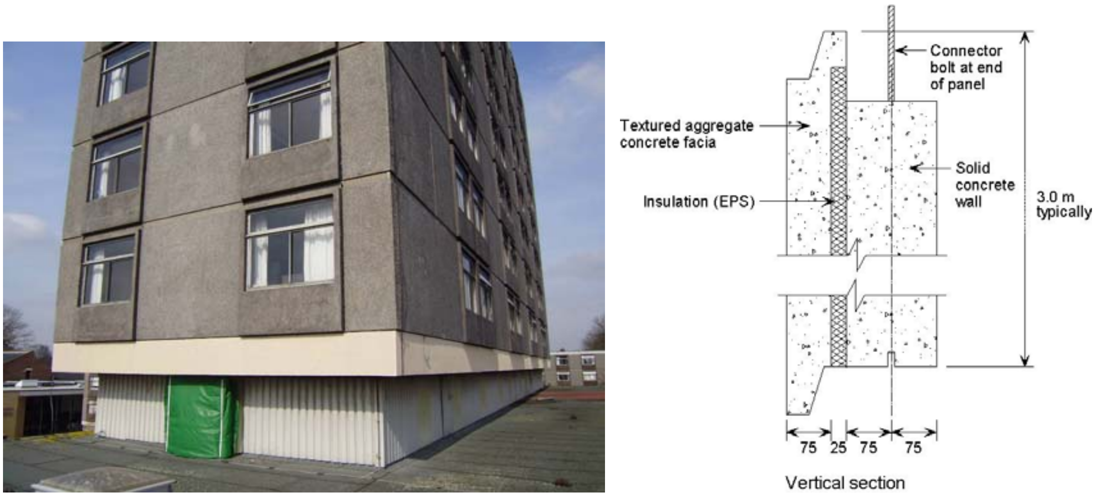


Figure 8 Original tower block before over-cladding and its details

The cassette panels were manufactured by the CA Group in Durham, UK from Corus’ Merlin Grey 1.2 mm thick colour-coated steel. The panels were typically 2.9 m wide × 0.9 m high, and consisted of an edge return of 30 mm and stiffening ribs bonded to the rear face at 1 m spacing. Some cassette panels were perforated to demonstrate the application of the TSC concept using flat panels

The supporting cold formed steel rails were placed along the vertical edges of the panels and were manufactured in 200 mm wide × 2 mm thick 'top hat' sections. The layout of the support rails is presented in Figure 9.

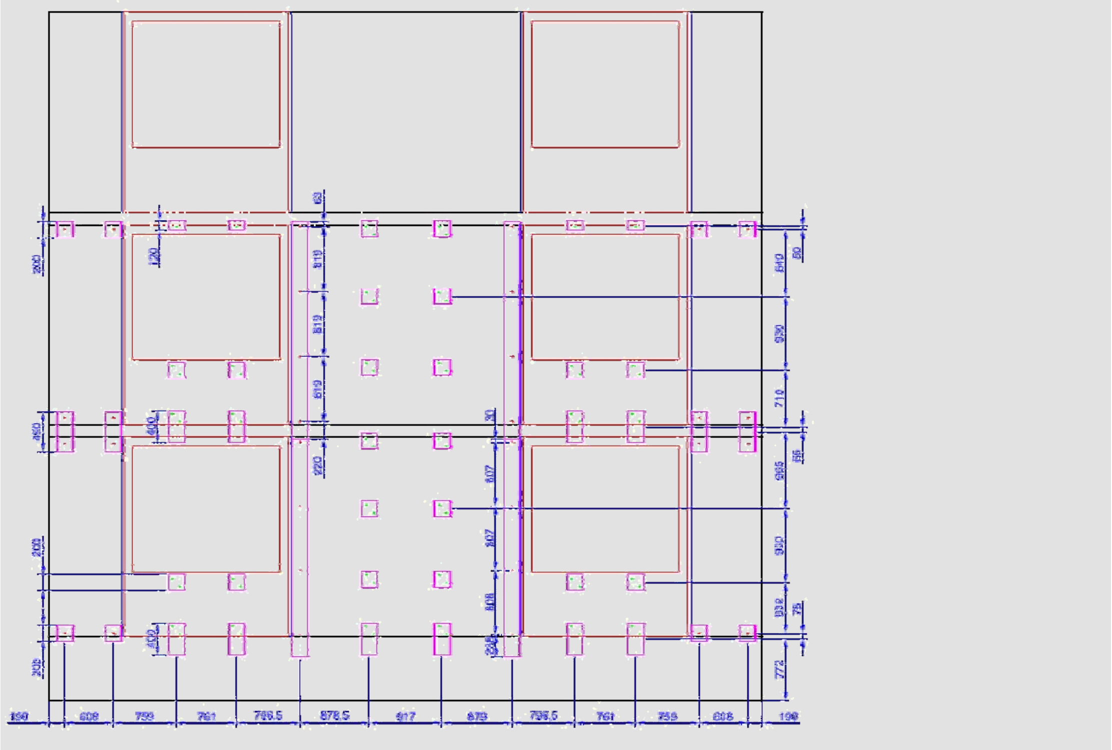


Figure 9 **Details of support locations to the over-cladding panels**

The rails were connected through to the inner leaf of the precast concrete wall by 120 mm long chemical anchors using 8 mm diameter stainless steel rods. The distance between the outer face of the over-clad panel and the external face of the original façade was 140 mm. The existing windows were not replaced. Two cassette panel configurations on the south facing wall were installed:

- the lower storey height was insulated by 80 mm thick closed cell insulation board attached to the existing façade between the windows. A 30 mm cavity was created at the back of the over-cladding panels
- the upper storey height was un-insulated in order to compare the performance with the insulated panel tests.

On the east facing wall, the entire over-clad area was insulated. In both storey heights on the south facade, only two of the central panels were perforated. The density of perforations in these two panels was approximately 0.22% of the total panel area (i.e. 10.4 m^2).The periphery of the panels was sealed to prevent unwanted air ingress.

Two 150 mm diameter holes were drilled through the existing façade which allowed air to be drawn into the building through the perforated panels. Extract fans with a flow rate of up to 120 litres/sec were attached to the inside face of the existing wall and the air speed through the flexible ducting could be measured internally.

The panels were joined along their horizontal edges using the clip detail shown in Figure 10 and were fixed on their top edge to the top hat sections. This required the panels to be lifted into position from the inside of the scaffolding. The typical weight of a panel was less than 20kg.

Figure 10 Horizontal joint detail between the panels showing the top hat section behind

Flashings or closure pieces were then installed around the periphery of the over-clad area, around the windows and on the corners. Final finishing of corner flashings was carried out using a moveable ‘basket’. The completed façade is shown in Figure 11.

Figure 11 Completed over-clad façade (19 August 2009)

2.2 Monitoring and results

A total of 42 gauges was installed as the construction progressed, and their locations are shown in Figure 12. The insulated panels are indicated in yellow. The rooms were heated to simulate normal occupied conditions. A weather station was also placed on the podium level, as shown in Figure 13.

Data was recorded at 15 second intervals and downloaded regularly. Tests have been carried out at various flow rates to compare the generated energy with predictions for various climatic conditions. A weather station adjacent to the south façade recorded external conditions and solar radiance on the podium level (4 additional data records).

A record of typical October day is given in Figure 14, which shows the temperatures of the steel cladding, external and internal wall, the incoming air and cavity temperatures.

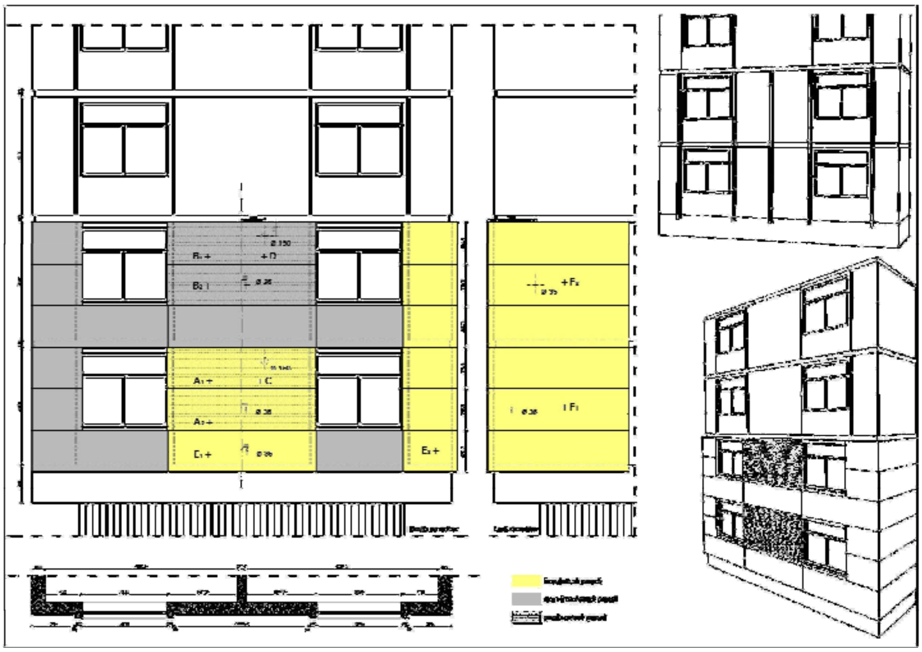


Figure 12 Location of monitoring points

Figure 13 Weather station as viewed from the monitored facade

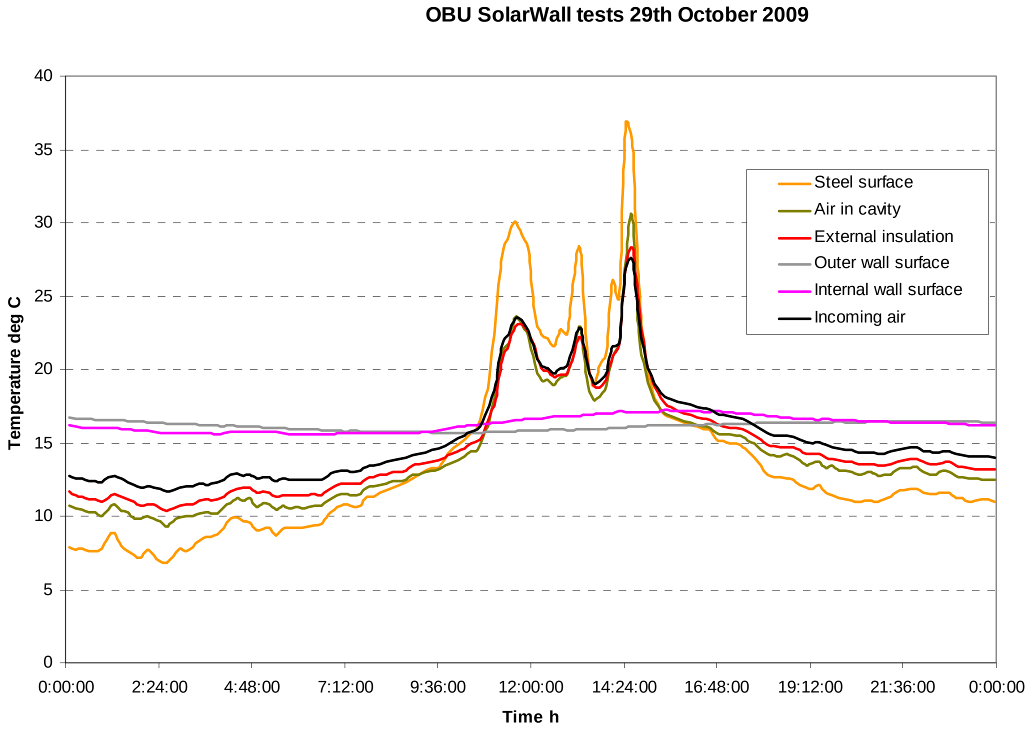


Figure 14 Test results for one monitoring position (29 October 2009)

The results for a typical day in February are presented in Figure 15. The solar radiance measurements on the horizontal plane are also shown. These results are extended over the week, which shows that the solar radiance was reasonably consistent for 4 of the 7 days.

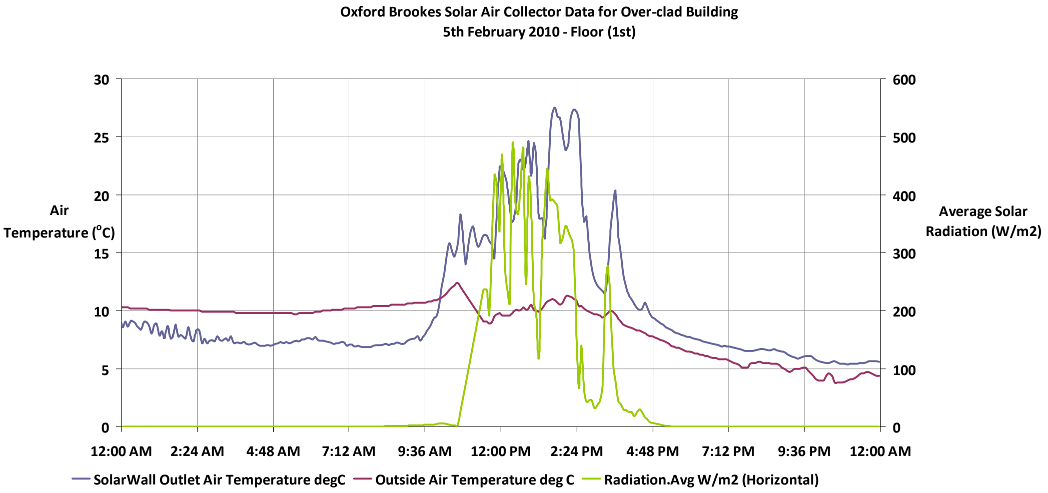


Figure 15 Test results for air temperature and solar radiance (5 Feb 2010)

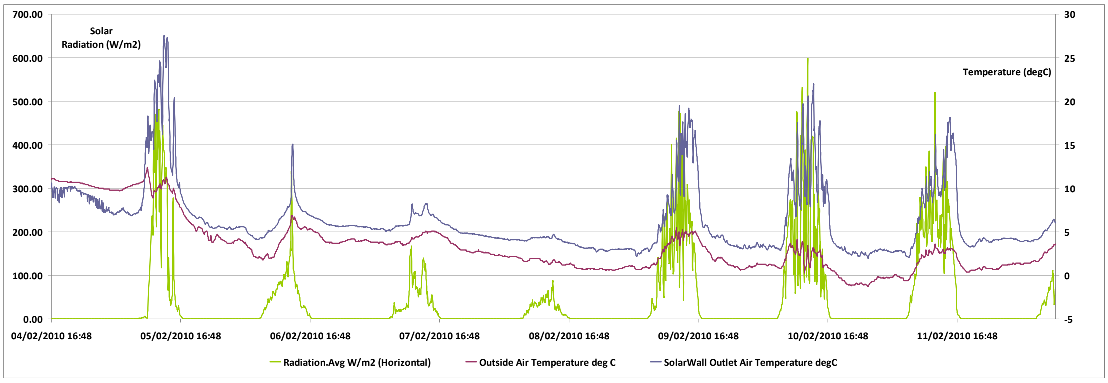


Figure 16 Test results (week February 2010)

2.3 Assessment of Transpired Solar Collector results

Consider the results obtained in a typical October day for a south-facing TSC panel as illustrated in Figure 14. The measured heating period was from 11 am until 4 pm. The external steel temperature reaches up to 37°C although the average during the heating period is 25°C. The incoming air (into the room) is on average 21°C during the heating period. The peak incoming air temperatures are about 6°C lower than the external temperature of the steel surface. During the non-heating periods, the temperature of the steel surface is 3 to 9°C lower than the room air, but the incoming air is 2 to 5°C warmer than the steel surface, showing the performance is also influenced by the heat loss through the existing façade.

Typical data for the autumn/ winter period are:

• Temperature difference between incoming and the internal air	10°C average
• Heating period (11 am to 4 pm approx.)	5 hours
• Air-flow rate (approximate)	60 litres/sec
• Area of TSC panels (per floor)	5.3 m^2

Heat generated by the Transpired Solar Collector

The calculated energy generated per hour was 0.72 kW. Over a 5 hour period per day, this is equivalent to a heating energy of 3.6 kWh. Assume that 150 days per year have this level of solar radiance, this is equivalent to an annual energy input of 540 kWh.

Assume this heating energy is distributed over a building width of 5 m and length of 10 m. The equivalent saving in heating energy, $Q_{nef} = 540/(5 \times 10) \approx 11$ kWh/m^2 floor area. This is equivalent to about 20% of the heating demand of the overclad building. The heating energy provided by the TSC is approximately 136 W/m^2.

The fan energy is rated at 0.1 kW at full flow rate of 120 litres/sec, and so the energy required to operate the fan over 5 years at half this maximum flow rate is about 0.25 kWh per day. This is equivalent to about 7% of the heating energy that is created.

Weather scenarios used to predict the annual performance of TSCs

Typical weather conditions over the year may be grouped as shown in Table 1 and used to predict the total benefit of TSCs in terms of reduced annual heating demand for a typical residential building.

Table 1 *Typical weather scenarios used to predict energy savings due TSCs*

Condition	Room Temp θ_{room} °C	Cavity Temp θ_{cavity} °C	External Temp θ_{ext} °C	TSC Active
Bright cold day	20	20	5	Yes
Dull cold day	20	5	5	No
Bright spring day	20	15	10	Yes
Dull spring day	20	12	10	No
Warm summer morning	20	25	15	Yes
Warm summer day	25	35	20	No
Night time	15	-5 to 15 ie some heat loss due to radiation	0 to 15 depends on season	No

These typical temperature scenarios may be used to calculate the:

- Energy generated by TSC due to solar radiance.
- Saving in energy loss due to air leakage and conduction through the existing façade.
- Fan energy when TSC is in operation.

The night time cooling of the cavity due to radiant effects on the metal surface may be neglected. Similarly, in hot summer conditions, the heated air may be expelled rather than brought into the room.

3 REFERENCES

1. Hollick, J., *Perforated unglazed collectors*, in *Solar Air Systems: A Design Handbook*, O. Morck and R. Hastings, Editors. 2000, James & James (Science Publishers) Ltd: London.

2. Hart, D. *Jaguar Land Rover Academy to save 19 tonnes of CO2 per annum with SolarWall*. 2007 [cited 2009 13th May]; Available from: http://www.cagroupltd.co.uk/canews/building-products/jaguar-land-rover-to-save-19-tons-of-co2-per-annum-with-solarwall.

APPENDIX: Estimate of Heat Generated by *Transpired Solar Collector*

The following data was used in the calculation of the heat generated by the Transpired Solar Collector (TSC) in this renovation application

Temperature difference between incoming air and the internal air	**10°C average**
Heating period (11 am to 4 pm approx.)	5 hours
Air-flow rate (approximate)	60 litres/sec
Area of TSC panels (per floor)	5.3 m^2
Density of air	1.2 kg/m^3
Specific heat of air	1.0 kJ/kg

Heat generated by TSC:

$Q = 10 \times 60 \times 10^{-3} \times 1.2 \times 1.0 \quad = \quad 0.72$ kJ/sec = 0.72 kW

Over a 5 hour period per day, this equivalent to a heating energy of:

$Q_{day} = 0.72 \times 5 \quad = \quad 3.6$ kWh

Assume that 150 days per year have this level of solar radiance:

$Q_{annual} = 150 \times 3.6 \quad = \quad 540$ kWh

Assume this heating energy is distributed over a building width of 5 m and length of 10 m. Equivalent saving in heating energy:

$Q_{nef} = 540/(5 \times 10) \approx 11$ kWh/m^2 floor area

This is equivalent to about 10% of the heating demand of the overclad building.

Heating energy provided by TSC*:*

$Q_{peak} = 0.72 \times 10^3/5.3 \approx 136$ W/m^2

Fan Energy

The fan energy is rated at 0.1 kW at full flow rate of 120 litres/sec, and so the energy required to operate the fan over 5 years at half this maximum flow rate is about 0.25 kWh per day. This is equivalent to about 7% of the heating energy that is created.

Heat loss through the existing façade:

Assume the existing building has a relatively leaky façade (say 20 m^3/m^2/hr @ 50 Pa). This is equivalent to an air leakage of approximately 1 m^3/m^2/hr.

Assume the temperature difference between the room air and the cavity air behind the TSC panel is an average of 10°C (allowing for some times when solar radiance is low).

Heat loss saved by reducing air leakage over 5.3 m^2 per panel:

$Q = 1.2 \times 5.3 \times 10 / 3600 = 0.02$ kJ/sec = 0.02 kW

This reduction in air leakage is obtained when the fan is operational ie for 5 hours per day and is equivalent to 0.1 kWh over the day. This is approximately 3% of the heating energy delivered by TSC.

Similarly, the temperature increase in the cavity will reduce the conductive heat loss through the façade. Assume a U value of the over-clad façade of 0.25 W/m^2 K and an average increase in the temperature of the cavity of 10°C relative to external conditions over the operational period. This is equivalent to a saving in conductive energy loss of:

$Q_c = 0.25 \times 10 \times 5.3 \times 5 \text{ x } 10^{-3} = 0.07$ kWh

This is equivalent to about 2% of the heating energy delivered by TSC. It follows that the total reduction in heat loss is equivalent to about 7% of the heating energy created which may be added to establish the total effect of the TSC.