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Transpired Solar Collectors – Results of a Field Trial

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Preface

This report summarises the findings from monitoring transpired solar collectors (TSCs) in a real live application, and addresses the issues associated with this technology.

Acknowledgments

This work was funded by the Building Research Levy.

I would also like to thank Lance Goodwin, architect and homeowner of the monitored home and his wife Sonya, for their support and contribution.

Note

This report is intended primarily for people interested in installing or monitoring the performance of TSCsr.

TRANSPIRED SOLAR COLLECTORS – RESULTS OF A FIELD TRIAL

BRANZ Study Report SR 167

Matthias Heinrich

Reference

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Abstract

Transpired solar collectors (TSCs) have been identified in the Zero and Low Energy House project (ZALEH) as one potential energy technology suitable for retrofit installations of existing buildings. Transpired collectors have the ability to provide background ventilation and solar heat through a simple low-tech approach which seems suitable for New Zealand building conditions. This report summarises the findings from monitoring six TSCs in a Wellington residence, and the experience gained in installing the system and monitoring equipment.

Keywords

Transpired solar collectors; air heating; space heating; cooling; indoor air quality; renewable energy

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1. INTRODUCTION

1.1 Previous research

Transpired solar collectors (TSCs) also known as "Solar Wall®" have a long history, but are not yet mainstream. The main development areas and markets are in the United States, Canada and Europe. Some research has also been conducted by the University of Auckland in recent years.

Depending on the source as much as 80% of the available solar radiation is converted to heat, which makes the technology ideal for sunny climates with long heating seasons. Research conducted by Auckland University, in conjunction with Dimond, suggests efficiencies of nearly 60% (Weerakoon 2004). Efficiencies and payback times are dependent on various factors. Climate and hours of sunshine are the two prime variables. Wind speed, size of perforation and size of air gap between the wall and the cladding, as well as the thickness of cladding, are other factors that need to be considered.

According to the US Department of Energy annual heating costs can be reduced by US$10–$30 per m^2 of collector wall, depending on the type of fuel used, by preheating intake air by as much as 30°C (DOE 2000). Almost no maintenance is required, as there are no liquids and no moving parts apart from the ventilation fan. DOE also claims that this technology is the most efficient solar air heating system available today. As a rule of thumb, 1 ft^2 of collector area will heat 4–10 ft^3 of air per minute (hence 1 m^2 of collector area will heat 1.22–3.05 m^3 of air per minute).

The Office of Power Technologies states a cost of US$65 per m^2 in new construction and US$108 in retrofit applications. The estimated payback period ranges from 3–12 years, depending on the climate; the type of displaced fuel; and the owners heating behaviour. The system lifetime is estimated to be 30 years (DOE 2000).

SolarWall® states efficiencies up to 75%, which was rated by both the US and Canadian governments. On a sunny day the air temperature in the SolarWall® can rise by 16–40°C. A typical installation can yield 500–700 Wh/m^2, which translates to energy savings of US$10-60 m^2 during the heating season. Paybacks typically range from 1–6 years and annual CO_2 savings are up to 1 tonne for each 5 m^2 of collector surface (SolarWall®).

Canadian-based RetScreen® International has tools available for calculating the efficiencies of TSC efficiencies in different climate zones. These are available to download free from their website (www.retscreen.net).

1.2 Technology description

A TSC is a space-heating system which consists of a dark-coloured metal cladding that is installed on the sun-facing side (north side in southern hemisphere) wall of a building a few centimetres off the wall's surface. The sun heats the metal cladding, which creates a layer of warm air in front and on the back of the sheet. When the ventilation fan behind the top of the wall is turned on, negative pressure in the cavity (between the building and the panel) is created. This effect draws outside air through the holes in the TSC, which transfers its thermal energy to the air. The warm air is then brought into the house by the fan and distributed via insulated ducts. This technology is ideally suited for sunny climates that have a long heating season. Figure 1 illustrates the principle.

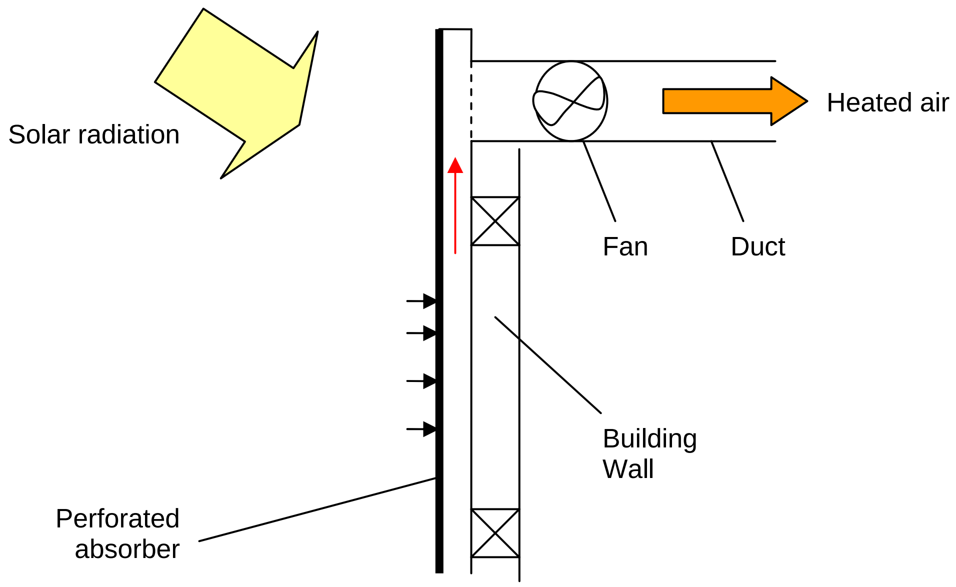

Figure 1. Diagram of components.

1.3 Benefits and advantages

Application of TSC includes:

- preheating ventilation air for:
  - schools and institutional buildings
  - industrial and maintenance buildings
  - apartment buildings
  - aircraft hangars
- process air heating
- crop drying.

The largest benefits of TSC include:

- improved air quality (by improved ventilation of fresh air)
- reduced condensation
- positive pressure on building reduces incoming drafts, increasing comfort
- the wall acts as insulation and reduces heat loss (since the heat lost through the building heats up the air behind the wall, which in turn gets drawn back into the house).
- low cost
- no maintenance
- high efficiency
- no moving parts (except fan)
- robust low-tech application
- can easily be retrofitted
- can be reversed for cooling.

2. THIS EXPERIMENT

2.1 Introduction

A Wellington architect incorporated six TSCs in the construction of his new home. During the construction period numerous wires, cables, sensors and other monitoring equipment were installed by BRANZ to monitor the performance of this technology. The collected data includes:

- solar radiation on collector surfaces
- several temperatures within the collectors
- external, preheated and room air temperatures
- air flow volume through collectors.

The installation started in November 2005 during the construction period.

2.2 The site

Figure 2 shows the orientation of the house and Figure 3 the elevation drawing.

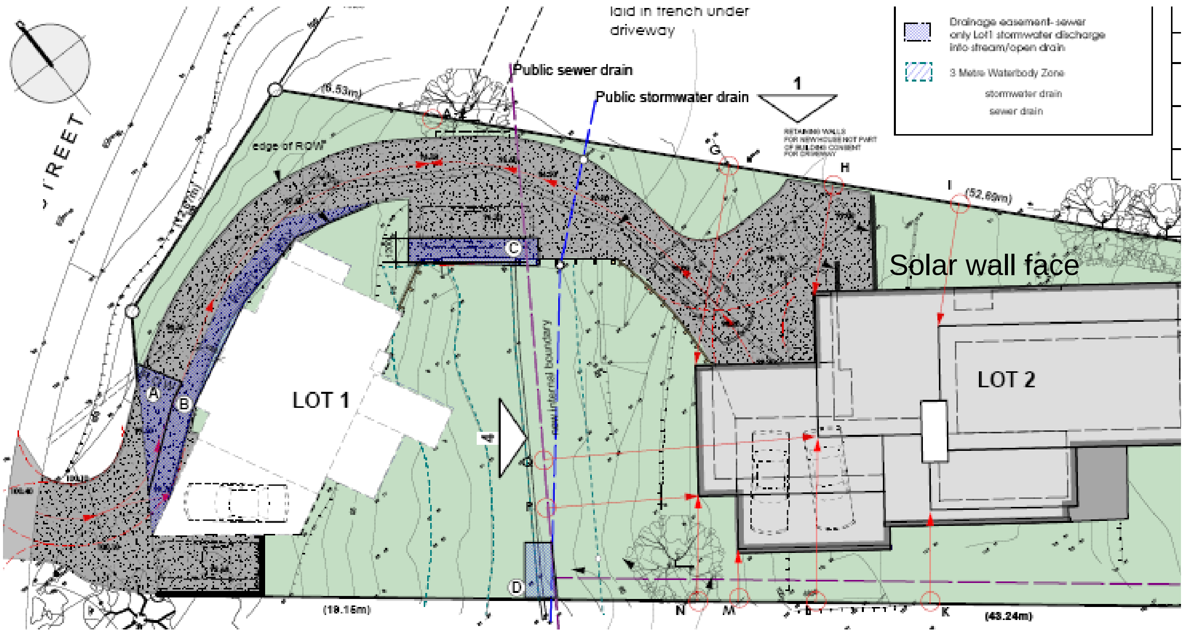

Figure 2. Plan view and orientation.

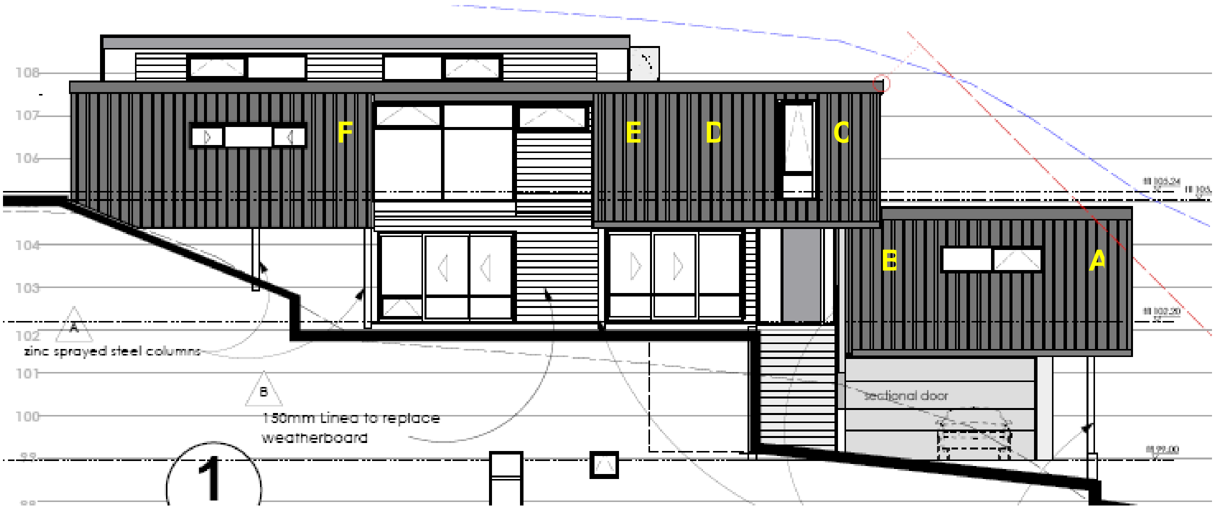

Figure 3. Elevation and location of TSC cladding.

2.3 Installed system

This section deals with the type of TSC and monitoring systems installed such as equipment, materials and controls.

2.3.1 Walls

Six TSCs with a 1% porosity (proportion of holes compared to total surface area) were installed on the north-facing side of a Wellington architect's residence. The black aluminium panels ranged in size from 3.7 m² to 6.4 m². The location and size of the panels can be seen in Figure 4 and Table 1.

Figure 4. Photo of house showing the TSCs.

Wall	Area (m^2)	Max air flow (l/s)	Duct length (m)	Supplied room	Fan specs	Power input fan (W)
A	6.4	60	6.5	Downstairs open plan	TD-500/150	68
B	4.5	45	7	Downstairs bedroom	TD-500/150	68
C	4	50	2	Upstairs bedroom	KS 130/2E	40
D	4.6	101	5.5	Upstairs living room	TD-500/150	68
E	4.6	30	9*	Downstairs bedrooms	TD-500/150	68
F	4	43	1.5	Kitchen/dining	KS 130/2E	40

*of which 5 m have a vertical downward airflow

Table 1. Panel details.

2.3.1.1 Cross-section

The cross-section of the panels was chosen to be metric, rather than corrugated, for architectural reasons. The metric cross-section has the disadvantage of shading when the sun has reached a particular angle. However, the amount of direct solar radiation on the panel should be the same (Figure 5 illustrates this). The effects of shading were not covered in this experiment, since all the walls had the same cross-section.

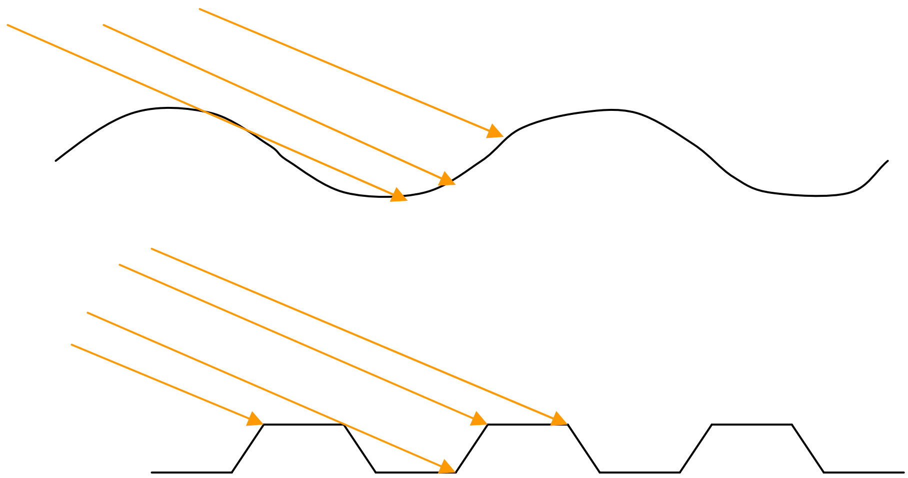

Figure 5. Difference between corrugated and metric profiles.

In the following drawings (Figure 6 and Figure 7), the TSC is referred to as a perforated rain screen. This was fixed on 20 mm battens at 250 c/c, which were fixed to a 9 mm sheet of Titan board (see Section 3.3.1.2). The wall insulation was R2.8 fibreglass segments (4.0 in ceiling and 1.8 in enclosed floors).

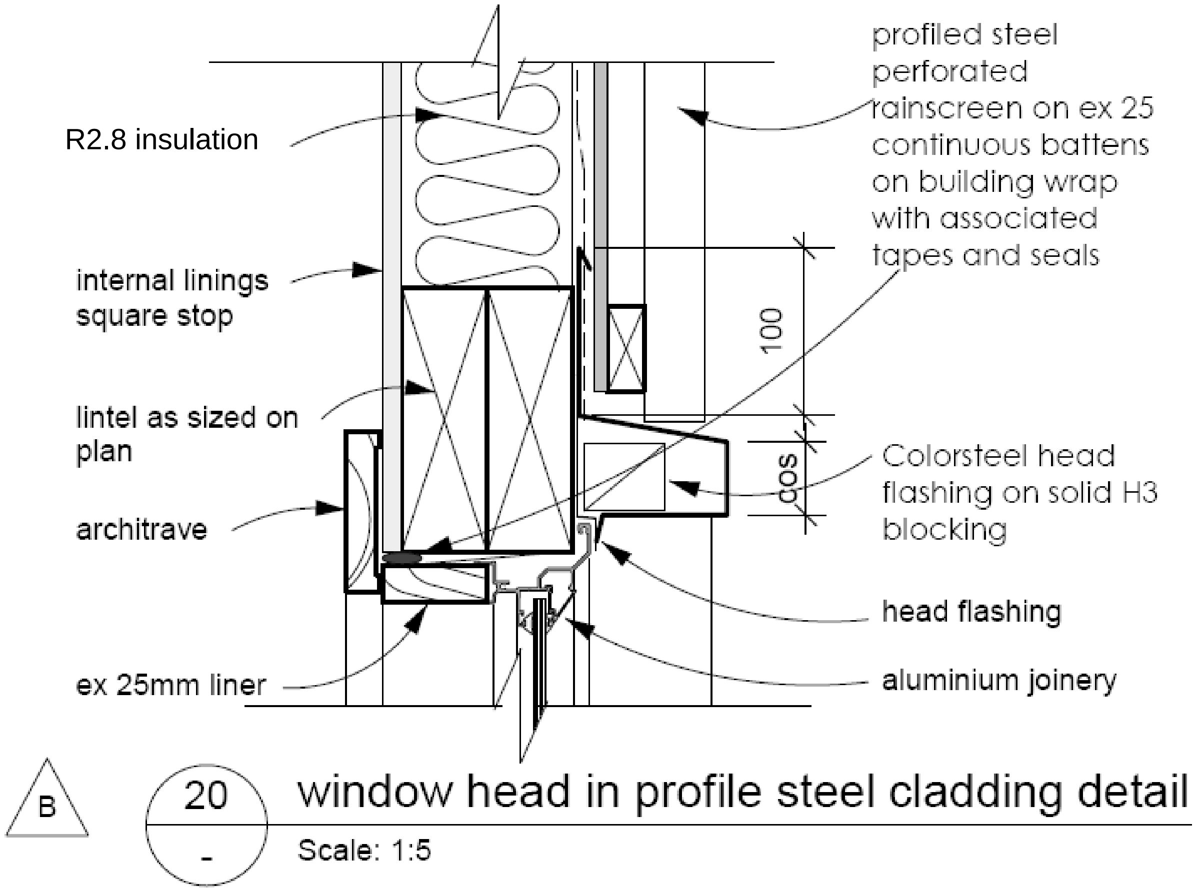

Figure 6. Cross-section details.

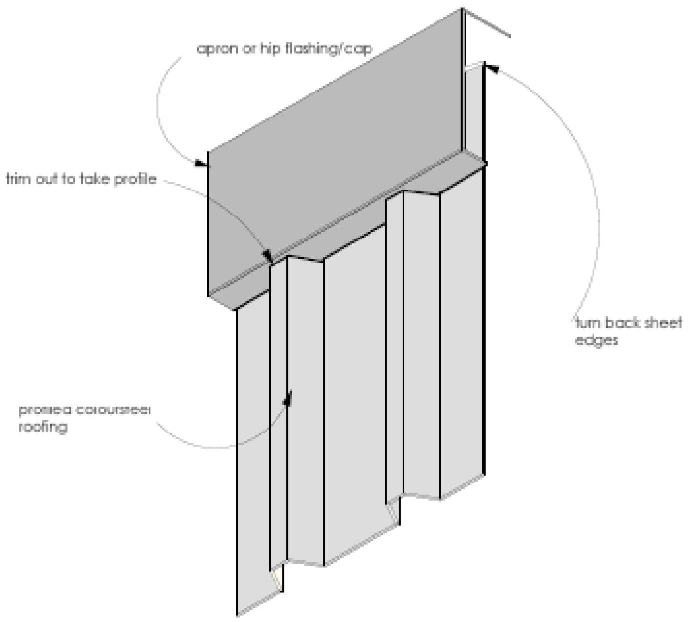

Figure 7. Metric profile.

2.3.1.2 Material choices

The reason for choosing aluminium in favour of iron was mainly durability, even though this material has a higher embodied energy. The material for the exterior face of the framing (behind aluminium panel) was chosen by the architect to be 9 mm Titan board (compressed sheeting) in favour of 12 mm plywood and 7.5 mm Hardiflex (fibre cement). The reason for the Titan board was the high temperatures expected in the air gap between the exterior facing and the TSC, which could have caused expansion in the other materials (especially in the plywood).

2.3.2 Fans

There were two different types of fans installed. Walls A, B, D and E are operated by a variable speed fan TD500/150 from Fantech. Walls C and F are operated by an on/off fan. The reason for choosing variable speed fans initially was to have greater control over the energy transfer into the room, and provide slower airflows and air circulation at times where the TSC produces little heat or the heating demand is low. See also Section 2.4.2 on fan speed.

2.3.3 Controls

The systems were operated using a separate controller system for each TSC. Depending on the nature of the fans (on/off or variable speed) different controllers were required. These controllers worked on a series of algorithms. Many separate components were required to get the walls running. Figure 8 shows the miscellaneous parts. Appendix A shows a detailed drawing of the exact wiring.

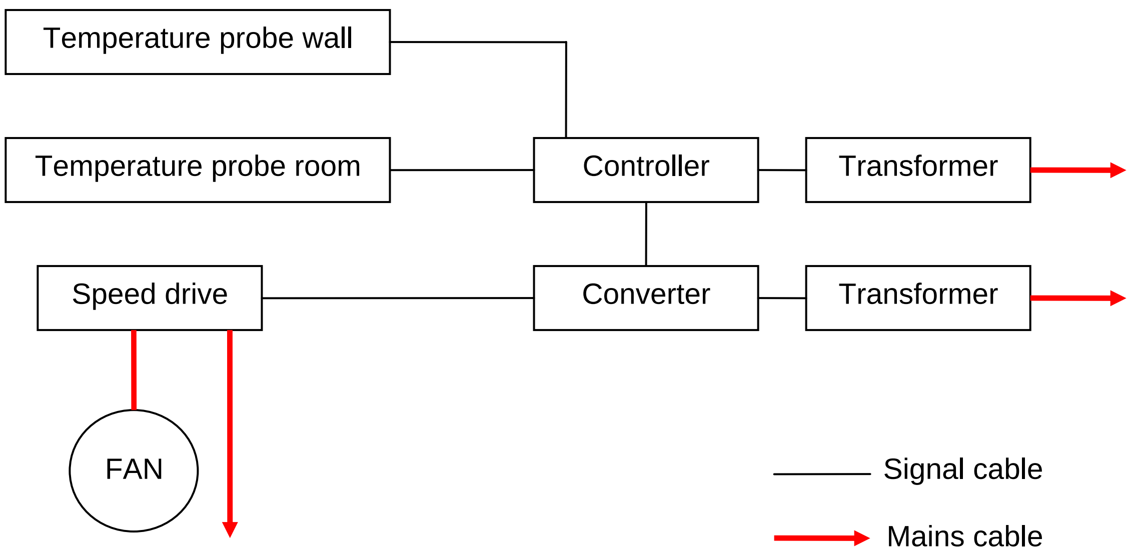

Figure 8. Component interaction.

Required items for controlling fan:

- **Controller IR32 D** – acts as the brain of the system and controls it
- **0/10 V (4–20mA) converter** – changes digital signal into a voltage
- **2 x 3 VA transformers 240/24 V** – reduce mains voltage to suit component input temperature

- 2 x **temperature probes** (one in room and one in the TSC) – give an indication of the two temperatures, which are required for the controller to operate
- **4 x amp 1ph fan speed driver module** – acts like a relay.

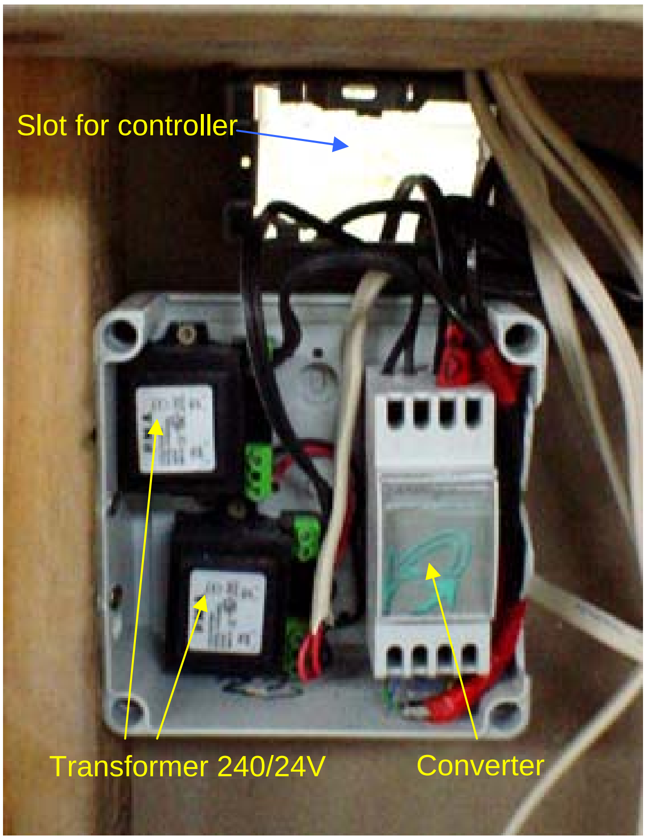

Figure 9. Components for controlling system.

A series of algorithms, programmed into the controller, were responsible for the operation of the system. This worked on the principle of having a set point, which could be changed within the controller. This set point specified a certain wall temperature at which the fans would start to operate. The general settings were as follows: if wall temp > room temp and wall temp > set point, then activate fan, or stop fan when room temp > x). The set point could be changed by the operator, but was mainly kept at 20°C.

Figure 9 and Figure 10 show parts of these components which were installed at the location of the controls within the interior walls of the house. After the gypsum board was installed, the only visible part was the operation panel of the controller, which acted as a form of thermostat.

Figure 10. Controller.

2.4 Monitoring

This section gives an overview of equipment and wiring required to monitor the collector performance.

A data acquisition system was placed in a central position of the house where all the wires came together (Figure 11). The Agilent 34980A was fitted with two data cards, each capable of recording 40 channels (80 channels altogether). The cables and thermocouples had to be wired into the two cards (Figure 12) and specified via a configuration program. This included the distinction between thermocouple and cable, which would output temperatures or voltages respectively. A list of channels and their purposes can be found in Appendix B.

Figure 11. Where the monitoring wires come together – logging cupboard during construction.

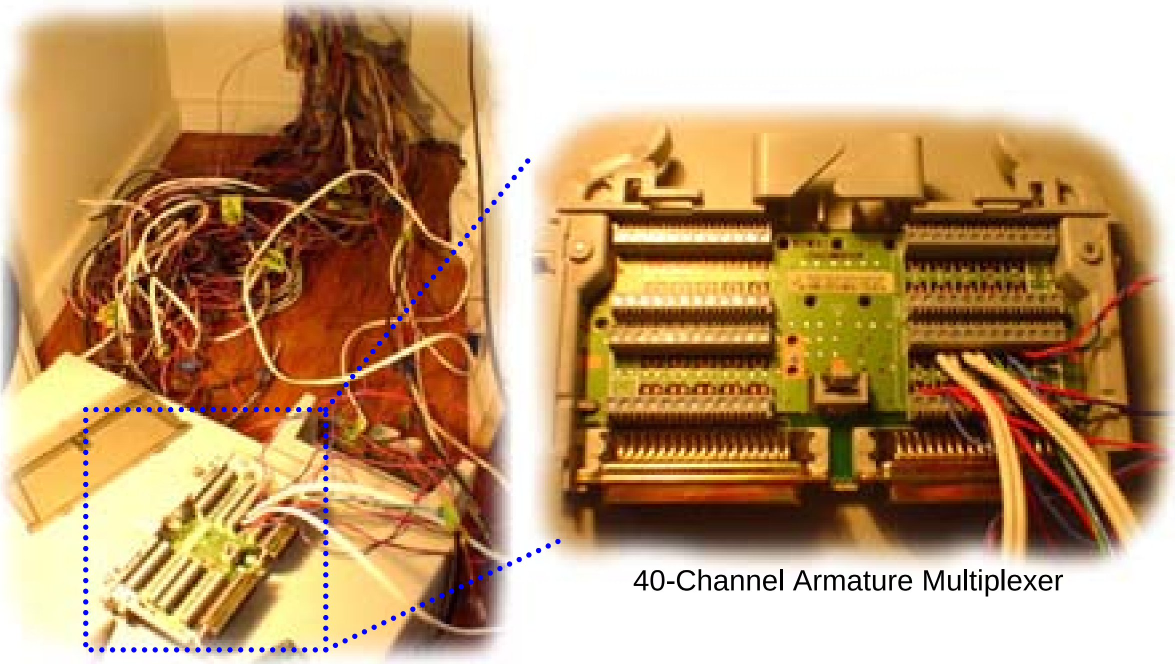

Figure 12. Wiring of data cards for Agilent logger.

The storage capacity of the logger was 500,000 readings. After this the data needed to be downloaded via a laptop. The main recording interval was set to 3 minutes, giving 13 days of measurements before the next download. This interval was chosen to capture the variable speed of the fans, and also because a higher resolution results in more accurate data. A higher resolution was not chosen as this would have resulted in more data and a reduced storage capacity, which would have meant more frequent downloads. Table 2 shows the maximum storage capacity for the various intervals.

Interval (min)	Readings (per hour)	(per day)	Storage (# of days)
1	4800	115200	4.3
2	2400	57600	8.7
3	1600	38400	13.0
4	1200	28800	17.4
5	960	23040	21.7
6	800	19200	26.0
8	600	14400	34.7
10	480	11520	43.4
12	400	9600	52.1
15	320	7680	65.1

Table 2. Storage capacity of Agilent.

The data was then imported into a master file to be analysed.

2.4.1 Temperatures

The various temperatures were measured using type-T thermocouple wire, which was coated with heat shrink at the ends, but still allowed air to get to the tip. The other end was directly wired into the terminal of the Agilent card. Reference temperatures for the thermocouples were supplied by an inbuilt temperature sensor in the Agilent logger.

2.4.1.1 Wall temperatures

Each TSC had five to six thermocouple wires fixed to the battens supporting it, to measure the temperature at certain points within the air cavity and to see the temperature variation within the panel. Figure 13 shows how these wires were fixed and their position. Various positions behind the wall were chosen.

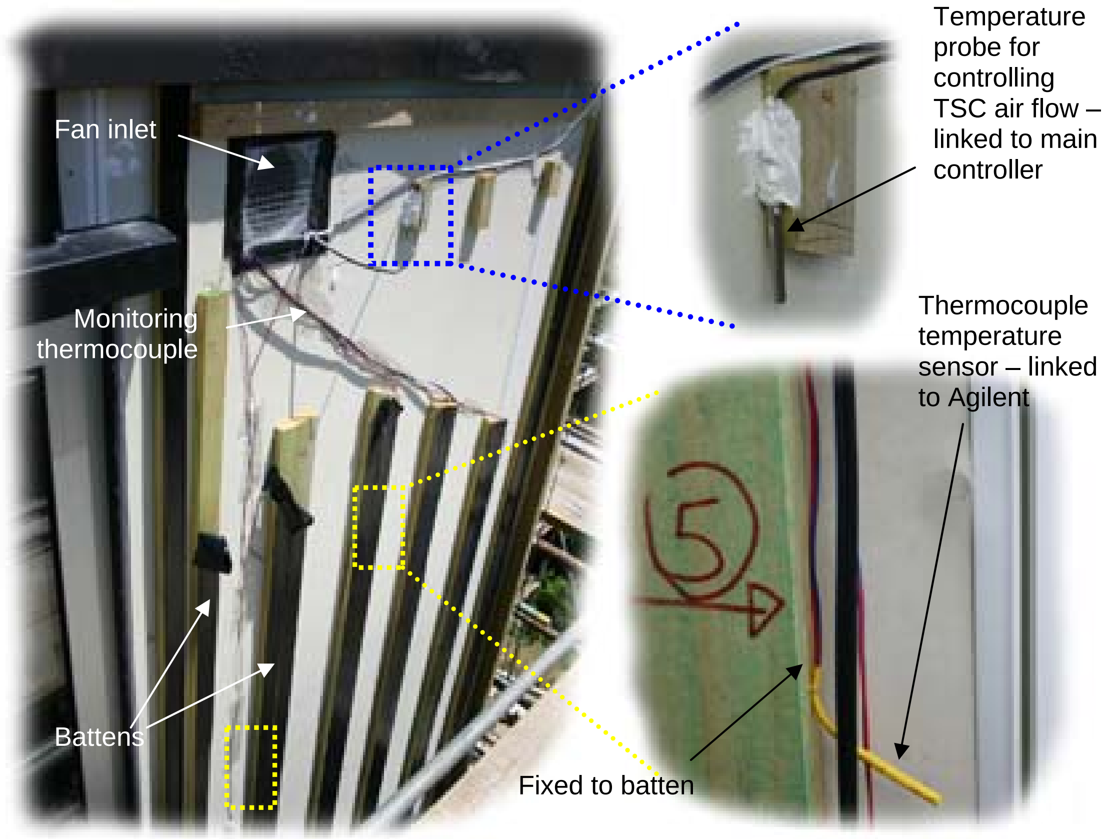

Figure 13. Monitoring and control sensors behind TSC panel.

2.4.1.2 Duct temperatures

The air temperatures in the ducts must be measured to calculate the energy transferred into the house. A specially designed probe was built, which would penetrate the duct and measure the air temperature in the centre (Figure 14). A thermocouple wire was slid into the probe, so its tip was exposed to the air flow. The probe was located between the fan and the inlet of the room, but at least 2 m or as far away as possible from the fan.

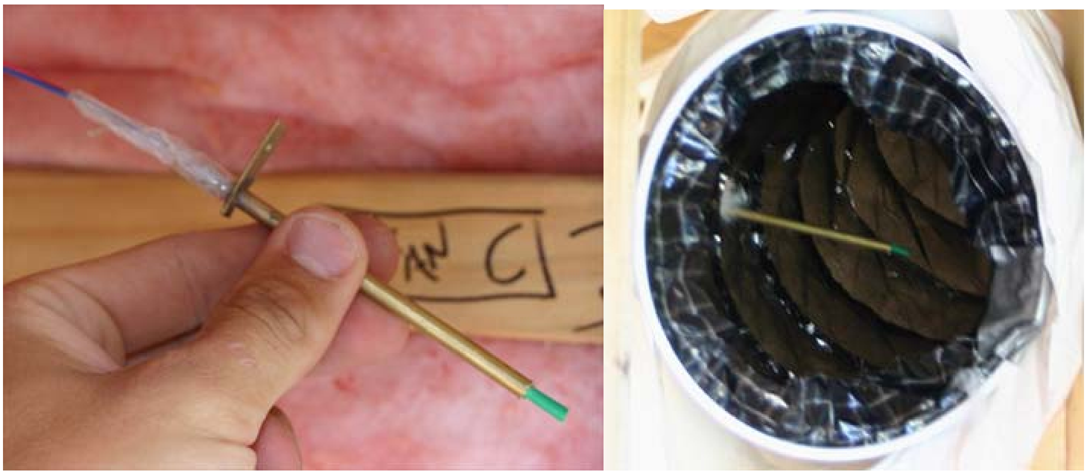

Figure 14. Temperature probe in duct.

2.4.1.3 Room temperatures

The room temperatures were measured at critical points using thermocouples for monitoring purposes and another probe, similar to the one within the TSCs air cavity, was required for controlling the fan. These were placed next to each other and in the same thermal zone as the fan outlets.

2.4.1.4 Outside temperatures

Three thermocouple wires were installed at various points around the house. These sensors were placed at unexposed places away from direct sunlight to ensure accurate readings.

2.4.2 Fan speed

The fan speed of the variable fans was measured by using the 0–10 V signal from the controller. A 0 V signal showed that the fan was off and a 10 V signal that it was running at full speed. Using an airflow calibration hood these voltages could be transformed into the actual airflows. The ability of the fans to be variable speed was found not to be necessary, since the volumes of the rooms were too large and the response time of the system (sensors, temperature changes) too slow, to require a fraction of flows. Figure 15 shows the fan speed of the two different types of fans over time. Voltage is directly proportional to fan speed.

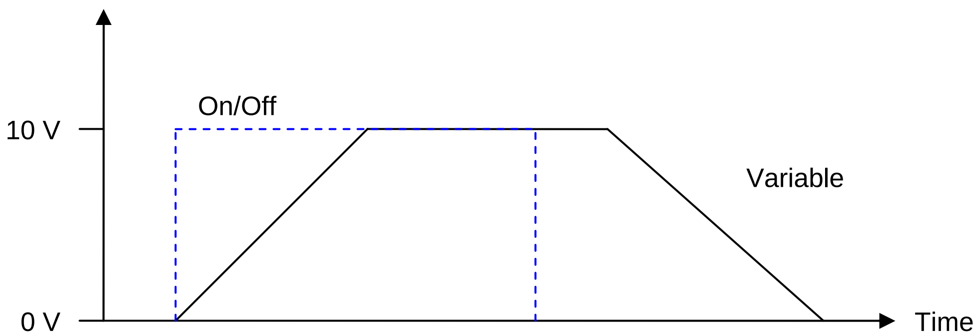

Figure 15. Fan operation.

The controllers of the fixed speed fan simply send a short pulse signal to the relay near the fan, which activates the power to the fan (Figure 16). This is a very short signal and the probability of the signal being captured by the Agilent is near zero. To identify whether the fan is turned on or idle another approach had to be used. As the controllers work on a series of logical equations it was possible to identify the times of operation by looking at the various temperature sensors. (i.e. if wall temp > room temp and wall temp > set point, then activate fan, or stop fan when room temp > x).

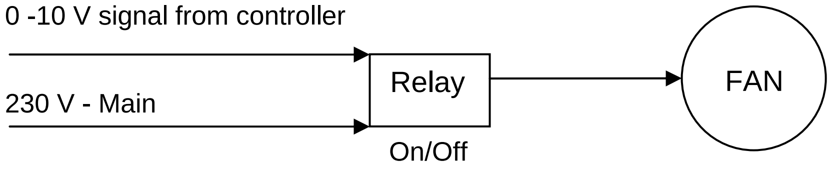

Figure 16. Connections of relay and fan.

2.4.3 Solar radiation

At either side of each TSC panel small low-cost solar cells measured the amount of solar radiation (Figure 17). The cells produced a small voltage, depending on the amount of radiation. The cells were calibrated using a pyranometer, which measured the radiation in W/m^2. Figure 18 shows the calibration curve for the solar cells.

Figure 17. Installation of PV cell and surface of cladding.

The problem with the calibration of the PV cells was that the calibration curve shows exponential growth towards the larger end of the radiation flow. This means that a small change in voltage transfers to a high change in radiation. As this section is the most important (time of operation), a source of error was introduced. In spite of the limitation the PV cells gave an approximate feedback on the available sunlight. This feedback was acceptable, since many readings have been taken, which produced a representable trend line.

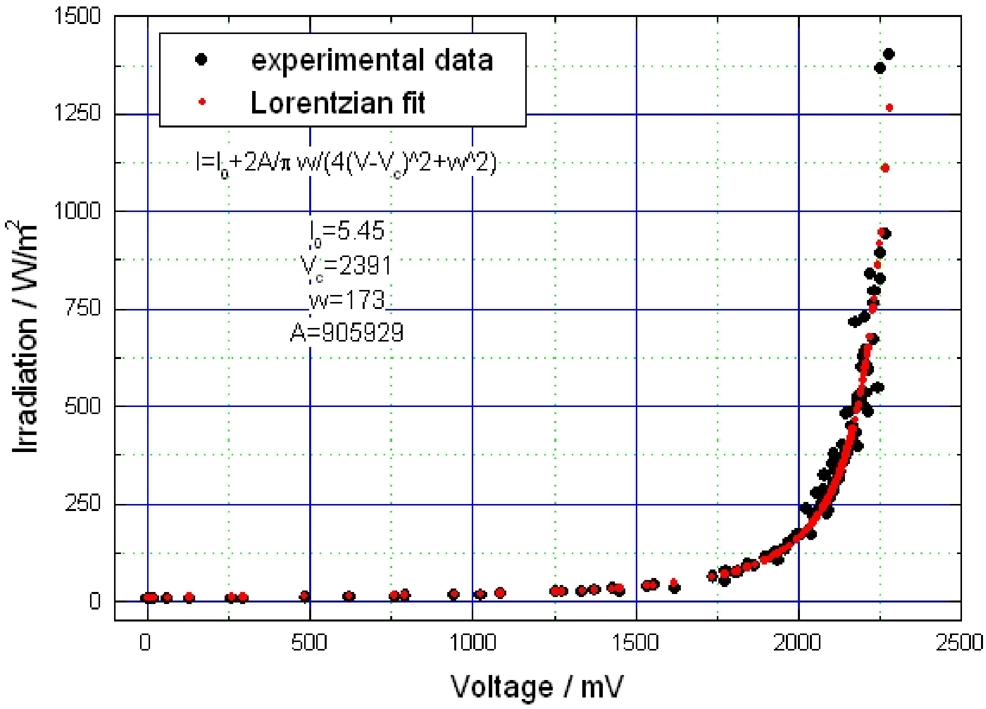

Figure 18. PV cell calibration curve.

PV cell data showed that Panel F, which was shaded by a tree, received limited amount of solar radiation.

3. ISSUES, RECOMMENDATIONS AND EXPERIENCE GAINED

This section outlines the experience which was gained in installing the TSCs, the controls, the monitoring equipment and the operation of the walls.

3.1 Issues for TSC operation

This section addresses important points for consideration for someone installing a TSC.

3.1.1 Installation of components

A large amount of cables and thermocouple wires were laid throughout the house, to ensure both the operation of the controller and the fan, as well as to provide the necessary information to the data logger. This installation turned out to be very time-consuming, since large distances had to be bridged by multiple wires to link the relevant components.

Due to the design of the building, a large number of holes had to be drilled through the floor joists, which had a relatively small spacing. Cables from the ground floor also had to be brought to the first floor where the data logger was located. Overall more than one km of wires and thermocouple wires have been laid. The positioning of the cables and their operation was a crucial part of the whole project, since one faulty wire could compromise the whole operation of a particular wall. Once the internal lining was put up, it would not be possible to access these components without major complications and costs.

3.1.2 Documentation

Very good documentation was needed to keep track of all the components and all the changes to the original set-up that have been made over time. A few hundred digital pictures were taken over the duration of the installation and beyond. Detailed installation check-lists were set up to ensure each cable was laid and each component was connected properly. Quality assurance included going through the components and checking wires and connections. The main priority was to get the wall running followed by the actual monitoring.

3.1.3 Probe placement

The placement of the temperature probes (sensors), both in the wall and the room, are essential to an effective performance of the whole system as these two variables are the main variables the control algorithm is based on. For example, if wall temperature is two degrees above the set point and greater than the room temperature, the fan is switched on.

The room temperature probe should be placed to represent the average temperatures. It should also be placed away from electrical appliances that produce heat, windows, fan outlets, and similar sources that could influence the temperature measurement. This was the case for some room sensors, which were not placed at the optimum position due to architectural and design decisions. One sensor, for instance, was close to the floor and next to a window which was in direct sunlight for parts of the day. Another sensor was placed under the bed, which caused a delay in both switching the fan on and off. Design changes (i.e. shifting of fan outlets after the sensor has been placed) are an example of this.

3.1.4 Duct length and positioning

Ideally the duct length should be kept as short as possible to deliver the largest amount of energy to a room. Some of the ducts were over 9 m in length and delivering warm air to downstairs rooms through a vertical duct length of 5 m. This reduced the efficiency and the airflows. Hence it is advisable to install the TSC close to the point of operation to avoid unnecessary losses. The warm air will still be in the house if it is insulated correctly, but not necessarily where it is wanted.

3.1.5 Vents

The installed vents have not been ideal for the application. They cannot be closed off and unwanted heat loss and drafts occur. The ideal vent would close off automatically when the fan is not supplying air. This could be placed in the duct itself.

3.1.6 Controls

Based on feedback from the occupants, the ideal control of the wall would include a manual type of dimmer switch, which would allow the user to control the fan speed and resulting air flow themselves without having to use the algorithms of the controllers. These algorithms would be too complicated to be effectively used by an inexperienced or average consumer, as too many variables can be entered. It is advisable to keep the system as simple as possible.

3.1.7 Number of components

A high risk to the reliable operation of the system was introduced by the large number of crucial components that were required for each wall and fan unit. Each separate wall system required a high number of components and cables. When trying to find a fault it was sometimes necessary to go through each of the connections and intersections with a volt meter to find the problem. Again, it is best to keep the system as simple as possible, with the minimum number of parts to eliminate sources of error and potential problems.

3.1.8 Access

Access holes were left, to access the fan and the components of the controls for potential future maintenance without having to open the lining. Access to the sensors within the panels and the wires within the walls was restricted.

3.2 Monitoring issues during operation

This section outlines the challenges in monitoring the TSCs.

3.2.1 Data logging equipment

One challenge was that if a power cut occurred, the stored data in the Agilent logger would be lost. This happened on one occasion. Even once the power comes back on, the Agilent would not start recording again and the stored data would be lost. This could have been overcome by installing a desktop computer connected to the logger, which would have reset the logger after the power came on again. This would have been more expensive and additional programming would have been required. As downloads were conducted fortnightly anyway a separate PC was considered unnecessary.

After the power cut some of the recording channels produced faulty readings. After the logger was reset, however, the faulty readings disappeared. Because of these faulty readings a large amount of time was needed to go through all the lines of data and identify the problems. This is especially a problem when a critical channel (e.g. fan operation or temperature) gives a faulty reading, as the data for this period becomes almost useless as the energy transfer cannot be calculated.

The Agilent logger itself is fairly noisy when in operation. This is predominantly noticeable at night-time when there is no background noise. For this reason the cupboard in which the logger was situated was fitted with sound insulation (this measure eliminated the noises).

3.2.2 Seasonal

The start of the initial monitoring period was delayed due to some complications with the set-up of the TSC, its controls and components. It was originally intended to commence by the beginning of June in order to capture part of the winter period, which should have been the period were the TSC works most effectively and brings the greatest benefits. The delay caused the start date to be shifted to the end of August.

4. ANALYSIS AND RESULTS

This section outlines the results that were measured and the findings made throughout the monitoring process.

4.1 Wall and duct temperatures

The importance of the wall and duct temperatures is that the energy transfer into the building is based on these variables. The higher the temperature in the panel and duct, the more energy can be delivered. However, “unwanted” energy and heat can also be delivered and cause overheating.

4.1.1 Maximum temperatures

The following graph (Figure 19) shows the daily profile of the maximum temperatures reached in each of the TSCs (all days). The maximum temperature reached was 41.5 ºC in Wall C. As a general trend, there is a sharp rise in temperature in Walls C, D, E from around 07:00 (shortly after sunrise) until 11:00 and immediate feedback from the wall is received.

Wall B and Wall F have a slower temperature rise due to the fact that they remain shaded for a substantial amount of time. This is especially so for Wall F, which was originally shaded by a tree, which is now removed. Wall B is shaded by the building itself until about 11:00. At 12:00 there is a slight temperature drop in the panels. This might be due to the fact that the sun is at its highest point, which reduces the amount of radiation striking the panel. During night-time, the panel temperatures reach air temperature.

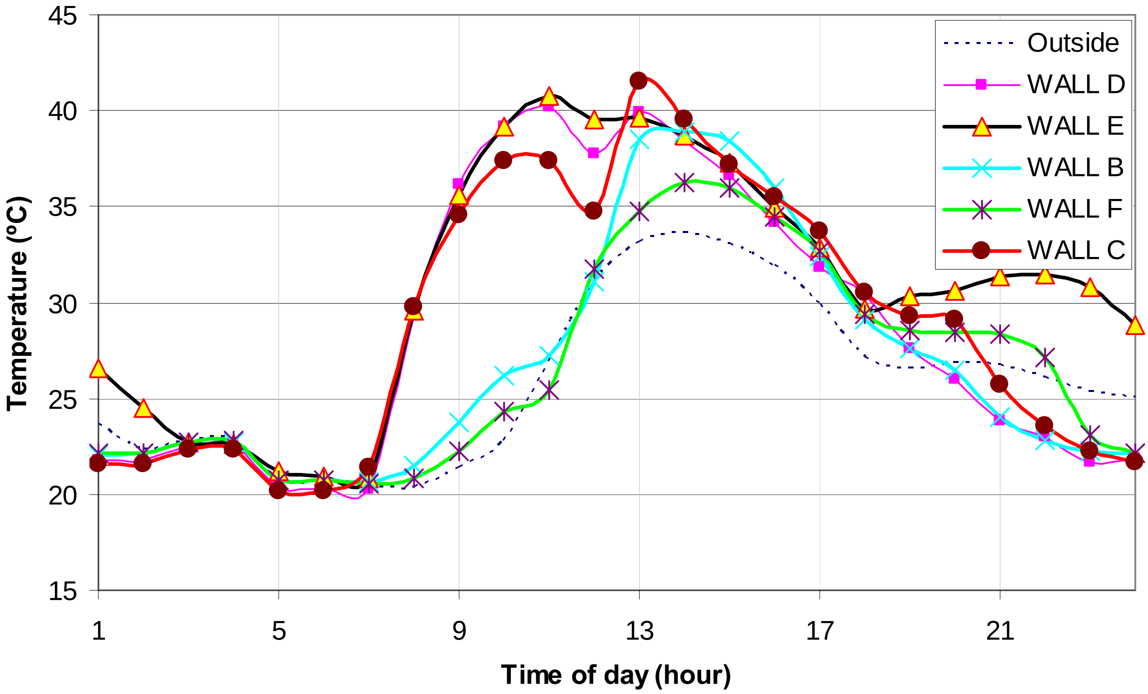

Figure 19. Daily profile of maximum wall temperatures.

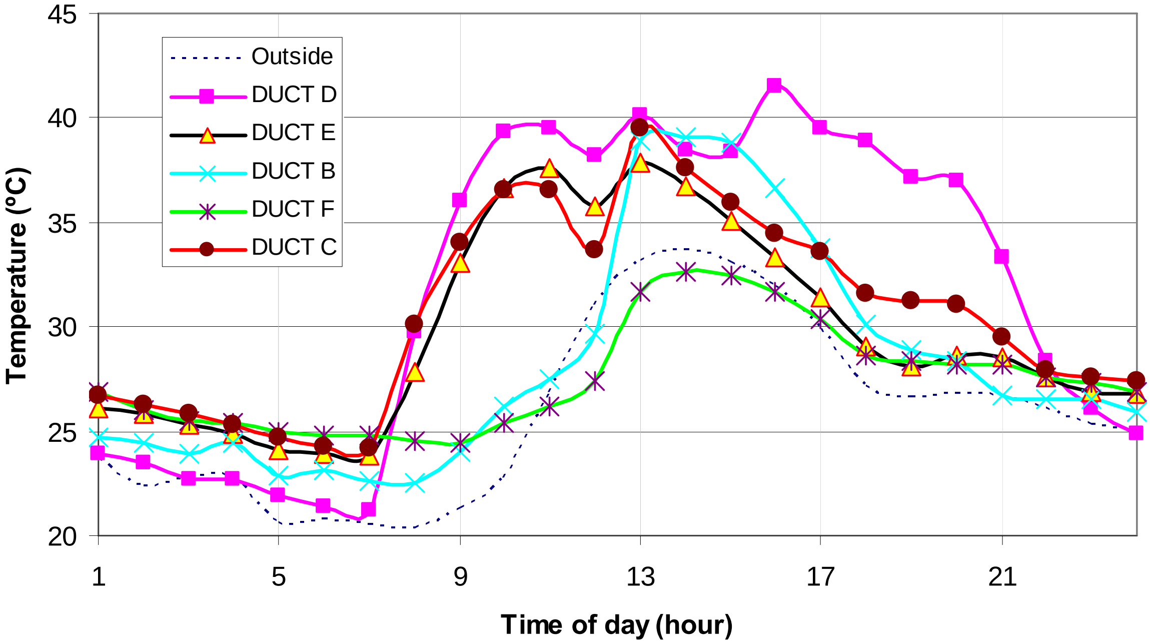

Figure 20. Daily profile of maximum duct temperatures.

Wall	Δ T (°C)	ΔT 2°C and above (% of time)
B	11.8	4%
C	19.6	17%
D	21.9	25%
E	22.3	25%
F	6.1	5%

Table 3. Maximum temperature differences.

The maximum temperature differences between the panel and the outside air temperature are given in Table 3. The highest difference was in Walls E and D, with a temperature variation of 22.3°C and 21.9°C respectively. Wall F, which remained shaded for most parts of the day, reached a maximum delta value of only 6.1°C.

When looking at the cumulative frequency, the temperature difference is above 2°C for only 5% of the time for Wall F. Delta T is above 2°C for 25% (above 7°C for 10%) of the time for Walls D and E. For Wall B, delta T is above 2°C for only 4% of the time and for Wall C its 17%. The energy input or amount of heating in Walls D and E are virtually identical, although the energy outputs into the house vary considerably.

4.1.1 Average temperatures

The average daily wall temperature profile is shown in Figure 21. Soon after the sun rises at about 06:00 there is a temperature rise in all of the panels except Panel F, which is shaded by a tree. Walls D and E show a similar profile in wall temperatures as they are the same size, and right next to each other. However, they do not produce the same energy output. This is further explained in the following section. The peak for Walls C, D and E is reached at about 11:00. The temperature then slowly declines until it reaches outside air temperature. During the night-time the temperatures in the panels are close to the outside air temperature.

Wall B follows a similar pattern, but it is generally 2ºC warmer than the other walls. This might be due to the fact that it receives more sun in the afternoon, and at these times the heat is not required in the house so the duct is warmer.

The temperature in Wall F peaks at around 14:00 and hardly goes 2ºC (only 4% of the time) above the air temperature. This is not enough to transfer significant heat from this wall into the building.

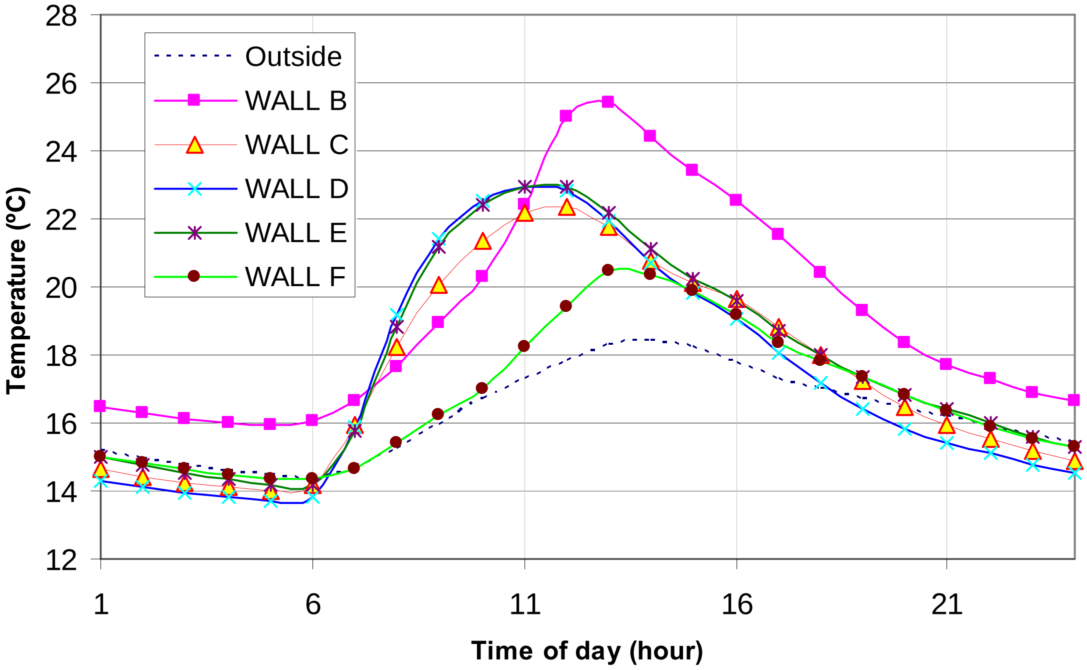

Figure 21. Daily profile of average wall temperatures.

The daily profile of the average duct temperature (Figure 22) shows a similar pattern as the previous graph. The exception is that these temperatures do not drop to the outside air temperature at any time.

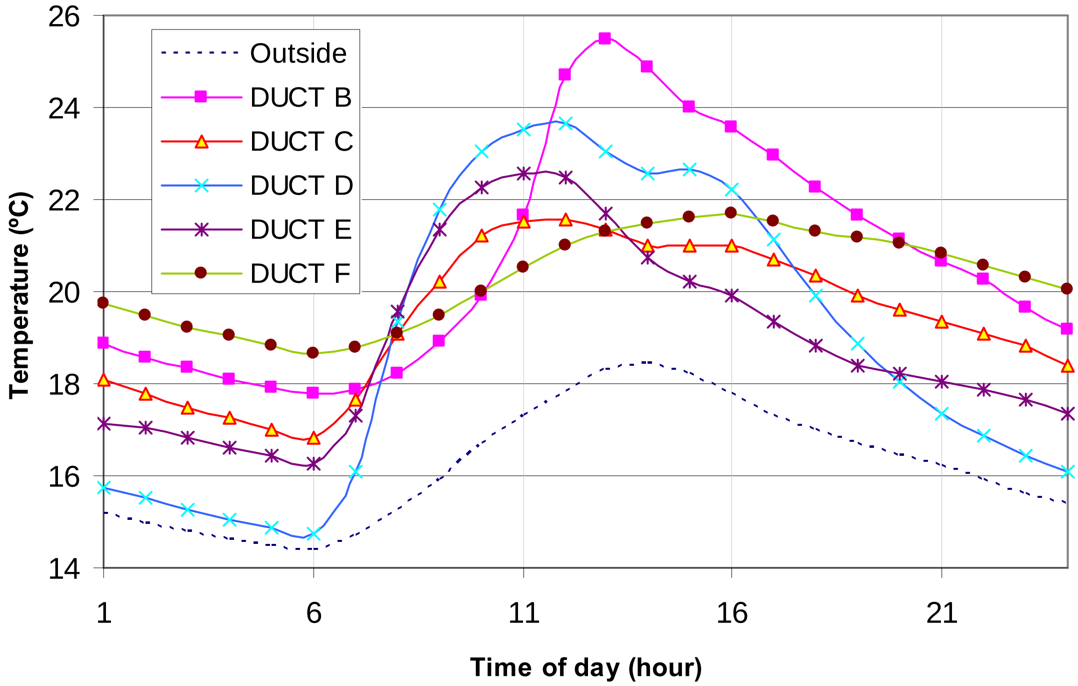

Figure 22. Daily profile of average duct temperatures.

4.2 Average daily kWh

The following Table 4 shows details of each of the walls, including a summary of their energy and maximum observed power output. These were calculated using the following formulas:

$$Power = Flow \times specific\_heat\_of\_air \times \Delta T$$

$$Flow = density(\rho) \times volumetric\_flow\_rate(V)$$

$$\Delta T = T_{Duct} - T_{inside}$$

Wall	Area (m^2)	Capacity air flow (l/s)	Duct length (m)	Energy (kWh/day) Max	Energy (kWh/day) Average	Energy (kWh/day/ m2) Max	Energy (kWh/day/ m2) Average	Max power (W/m2)
A	6.4	60	6.5	N/A	N/A	N/A	N/A	N/A
B	4.5	45	7	1.60	0.52	0.36	0.12	175.36
C	4	50	2	3.95	0.94	0.99	0.23	281.48
D	4.6	101	5.5	11.66	1.96	2.53	0.43	537.21
E	4.6	30	9*	2.77	0.44	0.60	0.10	147.55
F	4	43	1.5	0	0	0	0	0

*of which 5 m is vertical (warm air pumped downstairs)

Table 4. Summary of energy and power output.

The greatest energy outputs are achieved by Wall D. Figure 23 shows the power output of three walls over a two-day period (the area under the graph representing the actual energy transferred). Wall D has the largest power output per m^2 and also achieves the highest energy transfers into the building. Wall D is 3.6 times more efficient than Wall E, twice as efficient as Wall C and three times more efficient than Wall B.

Wall D and E are next to each other with virtually identical systems, the only difference being the duct length. The warm air from duct E has to be pumped over 9 m, of which 5 m is downstairs. This reduces the heat transfer dramatically at the destination point. However, if the house is well insulated, the heat which is lost over the length of the duct, heats other parts of the house. It is still advisable to keep the duct length as short as possible, to ensure the maximum possible efficiency.

Fan sizing plays an important role in the amount of energy delivered. Wall E would have required a more powerful fan to obtain a higher energy output and to get the heat over a larger distance.

As Wall C has a less powerful fan than Walls D and E, the energy transfer into the room is also reduced. As mentioned before, Wall F has no energy output as it is shaded for most parts of the day and the temperature in the panel does not go high enough to deliver this energy to the room. When data analysis was completed, the owner stated that wall F was sometimes used for cooling during the night, by manually controlling the fan. This is achieved by lowering the set point in the controller. This change can not be captured by the monitoring equipment, since the change is made manually. Hence the energy output has the form of cooling energy.

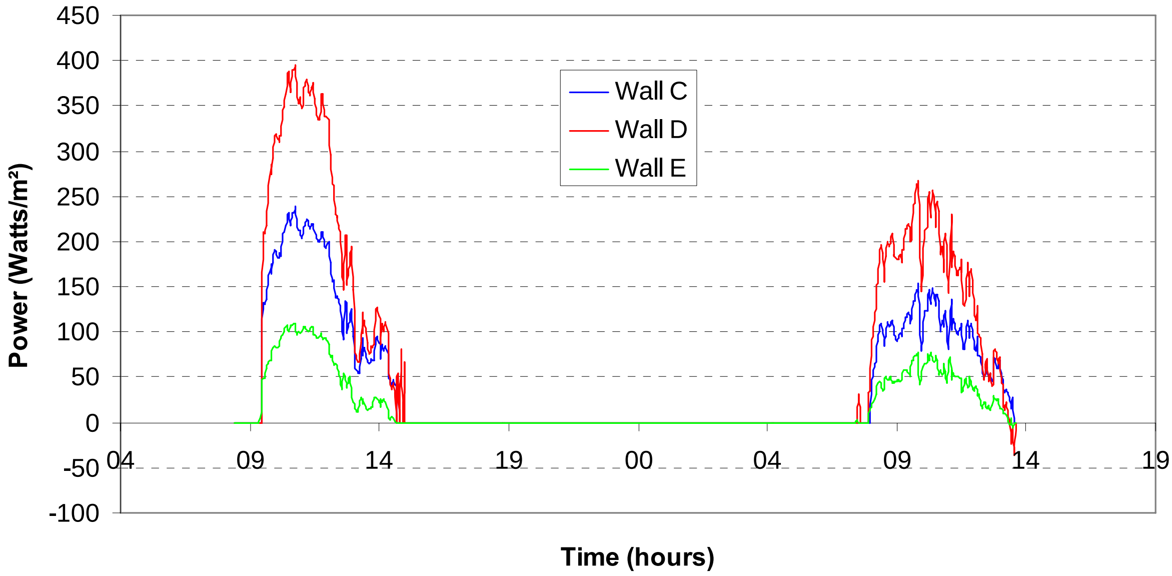

Figure 23. Two-day fan output profile.

Figure 24 shows an example of a maximum power output which was achieved. Over this period 9.26 kWh of energy was delivered into the house by Wall D and 2.58 kWh by Wall E.

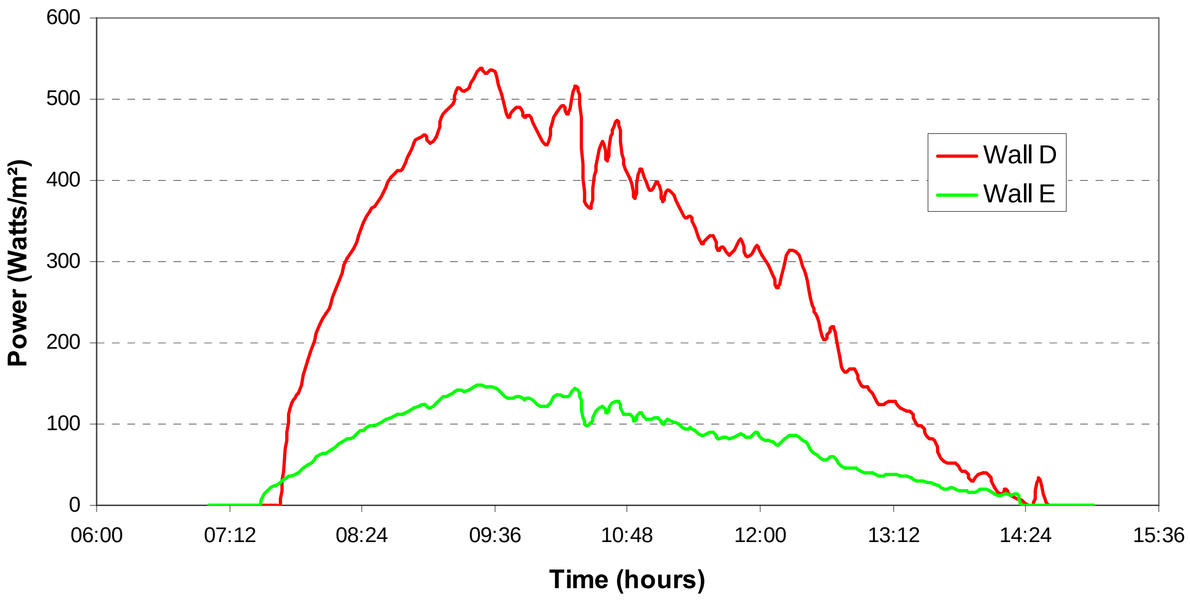

Figure 24. Example maximum power output.

4.2.1 Energy consumption of components

The majority of energy required in the system, is for running the fans. Table 5 outlines the average and maximum running times of the different fans and the associated energy consumptions.

Wall	Fan power (kW)	Run time (hours)		Energy Consumption (kWh/day)	
		Max	Average	Max	Average
A	0.068	-	-	-	-
B	0.068	11	4.5	0.748	0.306
C	0.04	6.9	2	0.276	0.08
D	0.068	9.5	3.5	0.646	0.238
E	0.068	9.5	3.5	0.646	0.238
F	0.04	0	0	0	0

Table 5: Fan consumption data

As the fan power is quite large, the switch on/switch off logic within the controls needs to be more carefully designed, to minimise the energy use by the components and maximise the energy gain from the TSC. This could be achieved by raising the temperature difference (wall/room), to draw in the same amount of energy, but in a shorter amount of time (higher temperature air drawn in more quickly) and hence reducing the operating times of the fans and the energy required to run them.

However, due to the air tight design of new buildings there is the likelihood that the occupants would run the fans even without a TSC for air quality reasons, and this consumption would then not be part of the energy balance.

4.3 Radiation and wall temperature

As a general trend, solar radiation is directly proportional to the wall temperature. The following diagrams (Figure 25 – Figure 28) show this positive correlation.

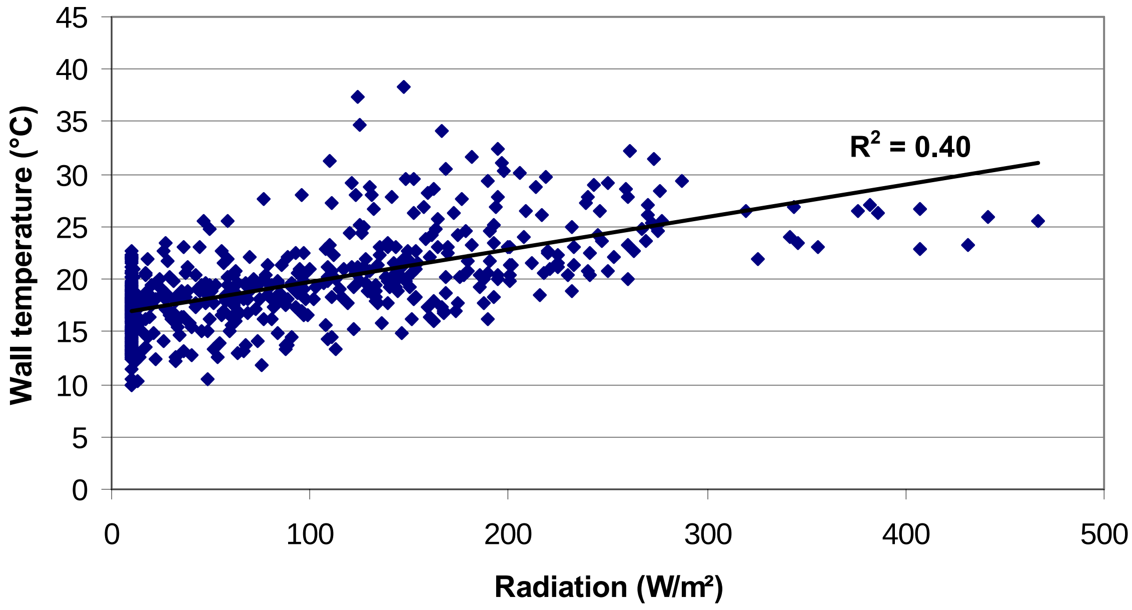

Figure 25. Average hourly solar radiation and air temperatures of Wall B.

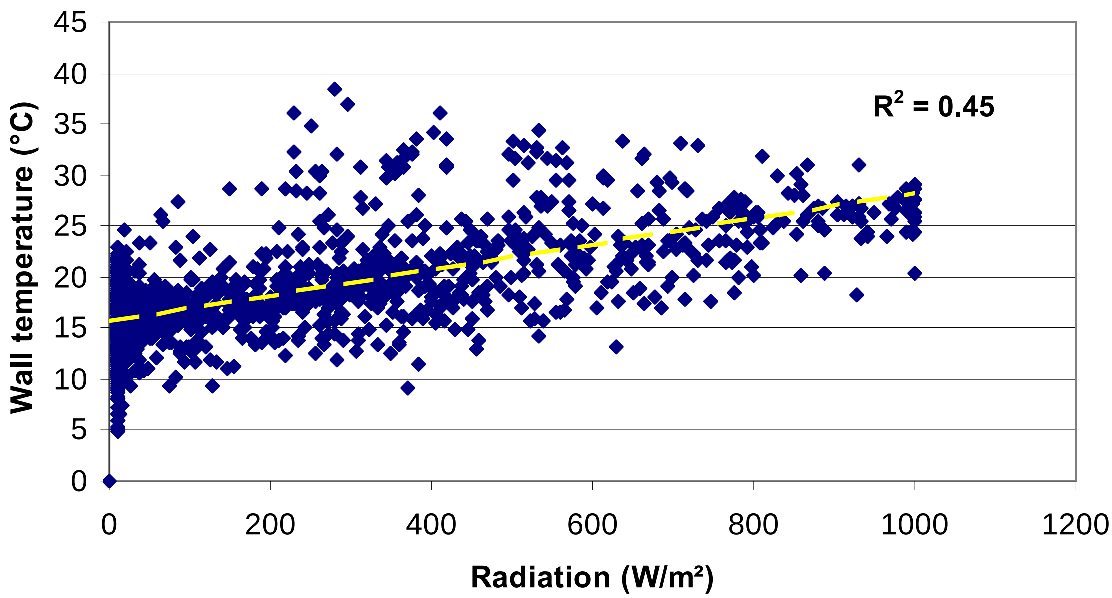

Figure 26. Average hourly solar radiation and air temperatures of Wall C.

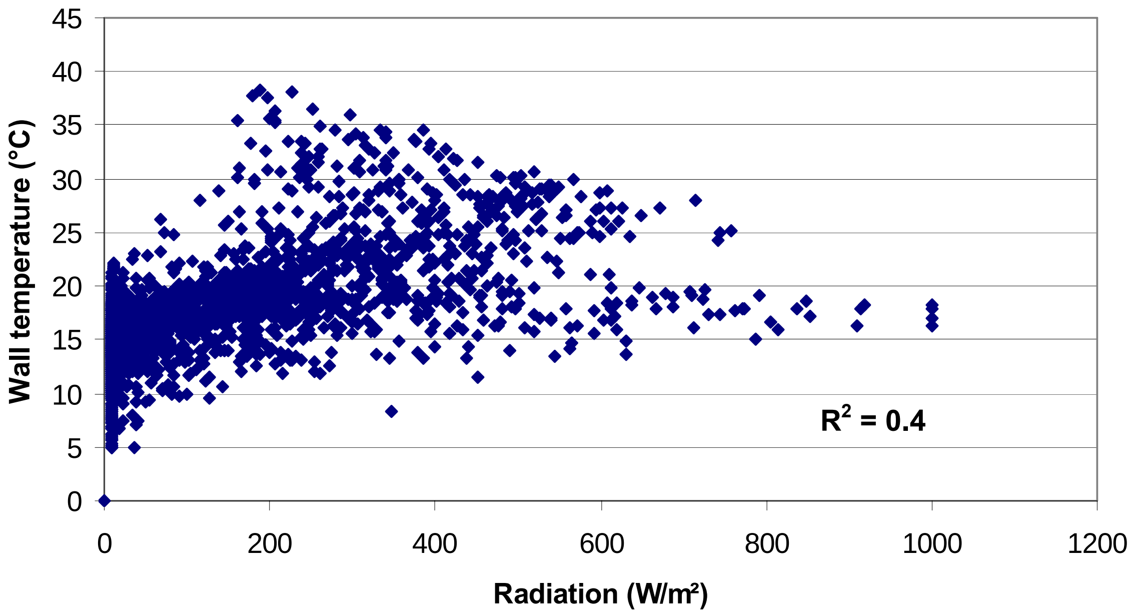

Figure 27. Average hourly solar radiation and air temperatures of Wall D.

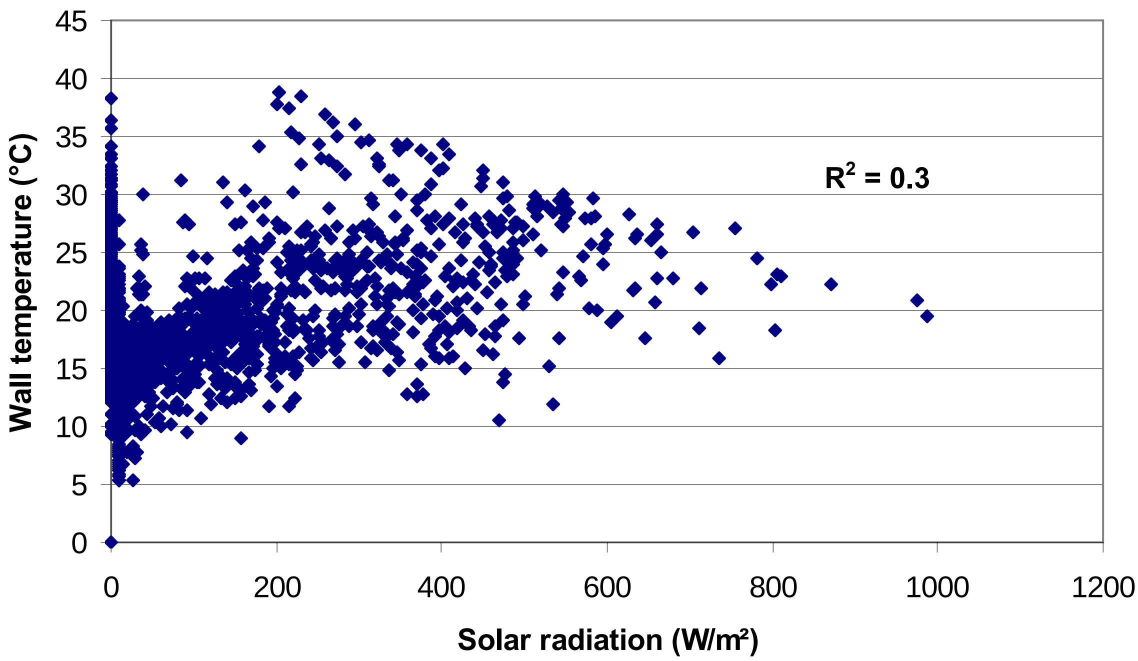

Figure 28. Average hourly solar radiation and air temperatures of Wall E.

Not all points on the graph follow the trend lines. This could be due to the fact that some of the PV cells are shaded by the metric cross-section of the wall, but the actual radiation striking the wall is much higher. Also when heat is drawn off from the wall, its temperature is reduced, with the radiation still being the same. When a cloud covers the sun during the time a reading is taken, the temperature in the wall will not be reduced, but the radiation reading will be less at this particular moment.

The graphs suggest that Walls D and E obtain a higher amount of solar radiation as the trend lines tend to be steeper. As parts of Wall B are shaded, a lower amount of direct solar radiation is striking its surface. This would also explain the reduced energy output. By taking the maximum solar radiation and the maximum power output from each wall, the approximate efficiencies can be calculated. These are represented in the following table.

	Max power (W/m^2)		
Wall	**Output**	**Input (from graphs)**	**Efficiency (%)**
A	N/A	N/A	N/A
B	175.36	475	37
C	281.48	1000	28
D	537.21	1000	54
E	147.55	1000	15
F*	0	N/A	N/A

*After analysis was completed, wall used for cooling during the night-time (manually)

Table 6. Efficiency of walls.

As can be seen from the table, the highest efficiency is reached by Wall D with 54%. This comes close to the findings of Auckland University researcher (Weerakoon), who suggested efficiencies of 60%. Wall E, which is virtually identical to Wall D, only has an efficiency of 15%. This is due to the long ducts, which have to deliver the heat downstairs. A larger fan or two fans in series might resolve this problem.

4.4 Temperature within wall

Figure 29 shows the average temperature variation within Wall D. Overall five sensors were measuring the temperature within each of the walls to see if there would be variations. The temperature within the wall was virtually identical at each of the points. However, when the fan was in operation the temperature near the top of the panel dropped slightly (0.5ºC maximum). This difference was, however, not great and had no influence on the energy transferred. The advantage of having more sensors in the wall was that if one sensor was not operational, you still had other data you could rely on. This was especially the case after the power cut when some wall sensors gave faulty readings. The data for the other walls shows similar results.

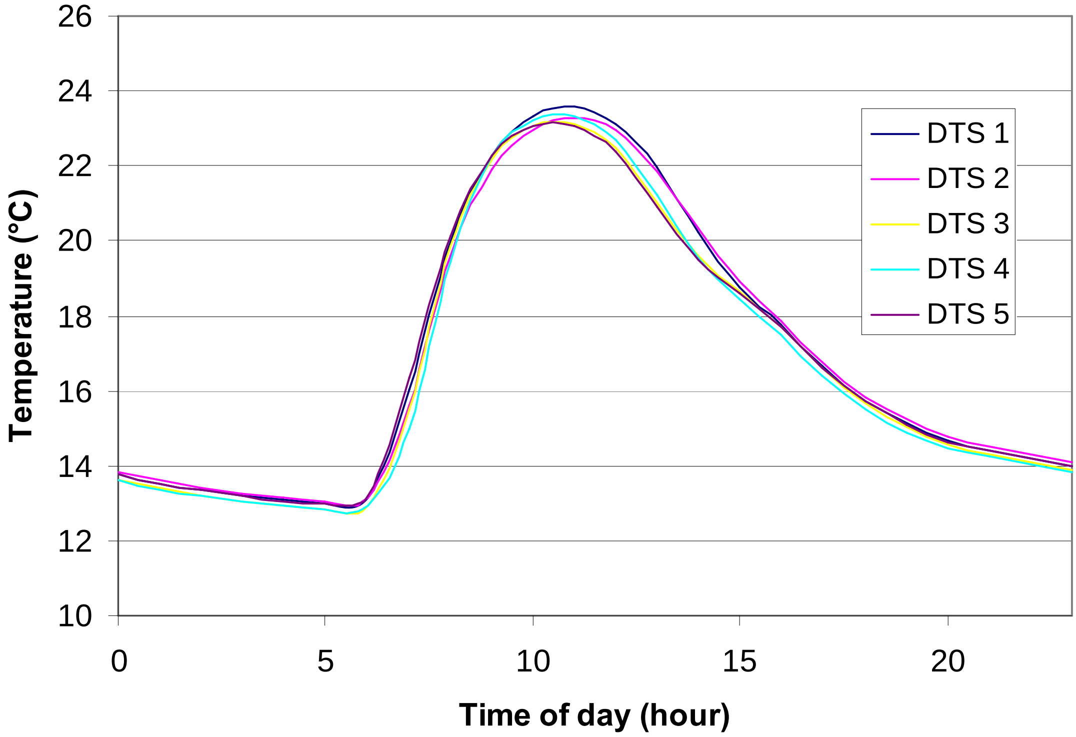

Figure 29. Temperature distribution in Wall D.

5. CONCLUSIONS

5.1 Duct length

Duct length was found to be a very critical factor. As duct length increased the airflow decreased, which reduced the amount of energy transfer. In particular, trying to deliver energy to a downstairs room was found to be unfavourable. A more powerful fan would have been required or two fans installed in series for Wall E. This, however, could have cooled down the air within the duct and hence have a negative impact on the efficiency.

5.2 Shading

Shading reduced the efficiency dramatically in some cases. Wall F, which was shaded for most parts of the day, had no useful energy output. It is advisable to keep shading to a minimum, to ensure maximum efficiency. However after data analysis was completed, the owner stated that wall F was used for cooling during night time, by manually reducing the set point of the controller. This is a major finding, as wall F can provide air-conditioning when the room temperatures are too high.

5.3 Air quality issues

According to the occupiers of the building, there is no condensation on the windows or aluminium window frames. The relative humidity was not measured in this experiment. This agrees with the claims made by manufacturers (Section 1)

5.4 Temperature within the wall

The temperature within the panel does not vary considerably according to where the sensor is placed. When the fan is activated, the temperature near the intake drops slightly. It is not necessary to install more than two temperature sensors in the wall. The reason for having two sensors would be to have an additional back-up in case one of them gives faulty readings. The centre of the panel would be the ideal place for one of the temperature sensors.

5.5 Energy consumption of components

The components using the largest share of energy are the fans, especially if they are running for several hours. The variable speed fans in the house run on 68 Watts at maximum capacity (always run at maximum) and the smaller single speed fans at 40 Watts. To overcome this problem, the switch on/switch off logic within the controls needs to be more carefully designed, to minimise the energy use by the components and maximise the energy gain from the TSC. This could be achieved by raising the temperature difference (wall/room), to draw in the same amount of energy, but in a shorter amount of time (higher temperature air drawn in more quickly) and hence reducing the operating times of the fans and the energy required to run them. Larger and more powerful fans, which are run at slower speeds, could overcome this problem. However, the size of fan and ducting must be carefully designed, to ensure optimum operation and air transfer.

5.6 Lessons

The main problem was that the timeframe between the decision to monitor and the installation of the sensors was too short to have a detailed plan. High risks were identified at the start of the project and a lot of potential challenges identified. Due to ongoing construction, all the wires (about 1000 m in total) and sensors had to be installed within a few weeks. If one wire was installed in the wrong place, or missing, the whole functionality of the system could have been jeopardised. The interior and exterior walls were then sealed and there was no way of laying additional wires.

By changing the original design of the controls, new sources of potential risks were introduced since a lot of components and connections were required for a functional product. One faulty connection or switched polarity could cause failure of the whole system. This was seen in the end, when we had to return to the site to fix faults in the components of the wall system and the connections between them. Faulty components and connections within the set-up were the main cause for the delay. It is advisable to keep the system as simple as possible, with the minimum number of components. According to the owner, a manual dial for controlling the speed of the fan would be the best solution, rather than a more complex control system.

5.7 Seasonal variations

As there were problems with getting the system to function during the winter period, the home had to be heated with gas and two heat pumps. This will give a comparison when looking at the energy bills for the 2006 and 2007 winter season. The TSCs are expected to have a higher efficiency during the winter period. Although the project has finished, data is still being collected.

5.8 Future

In new systems it would be desirable that the whole control system should be contracted out to only one contractor who installs all the components, to reduce the likelihood of potential problems. In hindsight it was good that all six walls were monitored, because it was valuable to compare between them as different factors have an influence on the performance and different learning's and findings were made from each of the walls. Overall the owners where satisfied with the benefits they obtained from their system so far.

6. REFERENCES

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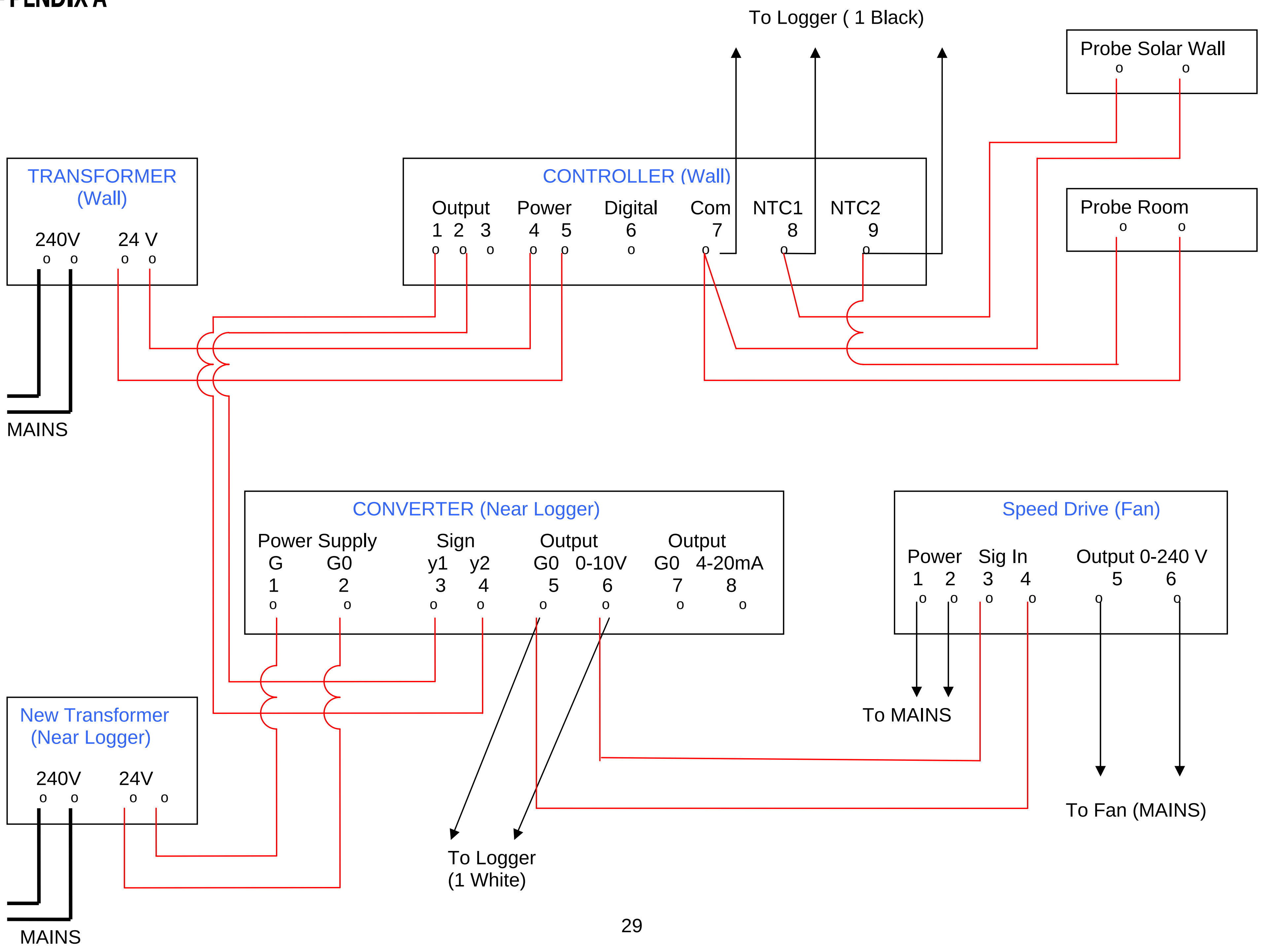
7. APPENDIX A



To Logger (1 Black)
Probe Solar Wall
TRANSFORMER (Wall)
240V
24 V
CONTROLLER (Wall)
Output
1 2 3
Power
4 5
Digital
6
Com
7
NTC1
8
NTC2
9
Probe Room
MAINS
CONVERTER (Near Logger)
Power Supply
G G0
1 2
Sign
y1 y2
3 4
Output
G0 0-10V
5 6
Output
G0 4-20mA
7 8
Speed Drive (Fan)
Power
1 2
Sig In
3 4
Output 0-240 V
5 6
To MAINS
New Transformer (Near Logger)
240V
24V
To Fan (MAINS)
To Logger (1 White)
MAINS

8. APPENDIX B

List of monitoring cables.

Wire labeling

Wall	Type	Purpose	No.
A	T	S	1

Label	Wall	Wire Type	Purpose	Length	Msmt	Done
ATS1	A	Thermocouple 1	Sensor		Temp	
ATS2		Thermocouple 2	Sensor		Temp	
ATS3		Thermocouple 3	Sensor		Temp	
ATS4		Thermocouple 4	Sensor		Temp	
ATS5		Thermocouple 5	Sensor		Temp	
ATS6		Thermocouple 6	Sensor		Temp	
ATD1		Thermocouple 7	Duct Temp		Temp	
APV1		Copper (2 wires)	Pv Cells 1		Voltage	
APV2		Copper (2 wires)	Pv Cells 2		Voltage	
AFC1		Copper (4 wires)	Fan		Thermistor Fan logic	
AFC2		Copper (2 wires)	Fan speed		Speed measurement	
BTS1	B	Thermocouple 1	Sensor			
BTS2		Thermocouple 2	Sensor			
BTS3		Thermocouple 3	Sensor			
BTS4		Thermocouple 4	Sensor			
BTS5		Thermocouple 5	Sensor			
BTS6		Thermocouple 6	Sensor			
BTD1		Thermocouple 7	Duct Temp			
BPV1		Copper (2 wires)	Pv Cells 1			
BPV2		Copper (2 wires)	Pv Cells 2			
BFC1		Copper (4 wires)	Fan			
BFC2		Copper (2 wires)	Fan speed			
GTS1	B1	Thermocouple 1	Sensor			
GTS2		Thermocouple 2	Sensor			
GTS3		Thermocouple 3	Sensor			
GTS4		Thermocouple 4	Sensor			
GTS5		Thermocouple 5	Sensor			
GTS6		Thermocouple 6	Sensor			
GTD1		Thermocouple 7	Duct Temp			
GPV1		Copper (2 wires)	Pv Cells 1			
GPV2		Copper (2 wires)	Pv Cells 2			
GFC1		Copper (4 wires)	Fan			
GFC2		Copper (2 wires)	Fan speed			
CTS1	C	Thermocouple 1	Sensor			
CTS2		Thermocouple 2	Sensor			
CTS3		Thermocouple 3	Sensor			
CTS4		Thermocouple 4	Sensor			
CTS5		Thermocouple 5	Sensor			
CTS6		Thermocouple 6	Sensor			
CTD1		Thermocouple 7	Duct Temp			
CPV1		Copper (2 wires)	Pv Cells 1			
CPV2		Copper (2 wires)	Pv Cells 2			
CFC1		Copper (4 wires)	Fan			
CFC2		Copper (2 wires)	Fan speed			
DTS1	D	Thermocouple 1	Sensor			

Wire labeling

Wall	Type	Purpose	No.
A	T	S	1

Label	Wall	Wire Type	Purpose	Length	Msmt	Done
DTS2		Thermocouple 2	Sensor			
DTS3		Thermocouple 3	Sensor			
DTS4		Thermocouple 4	Sensor			
DTS5		Thermocouple 5	Sensor			
DTS6		Thermocouple 6	Sensor			
DTD1		Thermocouple 7	Duct Temp			
DPV1		Copper (2 wires)	Pv Cells 1			
DPV2		Copper (2 wires)	Pv Cells 2			
DFC1		Copper (4 wires)	Fan			
DFC2		Copper (2 wires)	Fan speed			
ETS1	E	Thermocouple 1	Sensor			
ETS2		Thermocouple 2	Sensor			
ETS3		Thermocouple 3	Sensor			
ETS4		Thermocouple 4	Sensor			
ETS5		Thermocouple 5	Sensor			
ETS6		Thermocouple 6	Sensor			
ETD1		Thermocouple 7	Duct Temp			
EPV1		Copper (2 wires)	Pv Cells 1			
EPV2		Copper (2 wires)	Pv Cells 2			
EFC1		Copper (4 wires)	Fan			
EFC2		Copper (2 wires)	Fan speed			
FTS1	F	Thermocouple 1	Sensor			
FTS2		Thermocouple 2	Sensor			
FTS3		Thermocouple 3	Sensor			
FTS4		Thermocouple 4	Sensor			
FTS5		Thermocouple 5	Sensor			
FTS6		Thermocouple 6	Sensor			
FTD1		Thermocouple 7	Duct Temp			
FPV1		Copper (2 wires)	Pv Cells 1			
FPV2		Copper (2 wires)	Pv Cells 2			
FFC1		Copper (4 wires)	Fan			
FFC2		Copper (2 wires)	Fan speed			