Performance of a 120 m^2 solar air heater for a commercial building in Victoria

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Abstract

The operation of two 60 m^2 solar air heaters serving a large studio teaching space has been monitored for a twelve month period. The solar contribution of the heaters was found to be less than 5%, and in some instances the heaters actually contributed to the space heating load. A validated mathematical model of the studio and it's heating, ventilation and air conditioning system was used to investigate performance improvement strategies. It was found a different control strategy and recommissioned control sensors would substantially improve the solar air heater performance.

1. INTRODUCTION

In 1999, a study commissioned by the Australian Greenhouse Office found that the greenhouse gas emissions from the commercial buildings sector were expected to increase by nearly twofold from 32 Mt of CO_2 per annum to 63 Mt of CO_2 between the years of 1990 and 2010 under the BAU scenario. The specific operational energy applications responsible for the majority of these greenhouse gas emissions were cooling (28%), air handling (22%), lighting (21%) and heating (13%) (AGO, 1999). Solar air heating offers the potential to reduce the emissions associated with heating. Large scale systems have been installed on various commercial buildings in various northern hemisphere countries (Hastings & Morck, 2000). A solar air heating system is normally designed to contribute up to 50% of heat to the space and complement a conventional fossil-fuelled space heater, but the solar contribution can practically range between 25% and 90% (Duffie & Beckman, 1991).

This paper reports the performance of a large solar air heater (SAH) installed on a university building in southern Victoria. The paper begins with a description of the building and the solar air heating system. The methodology used to assess the performance of the solar heating system is described, followed by the results. A validated mathematical model was used to investigate performance improvement strategies. Discussion and conclusions drawn from these results are finally presented.

2. BUILDING AND HVAC DESCRIPTION

The building is an old wool store on the Geelong waterfront that has been refurbished and converted to a teaching and administration space (Figure 1). It accommodates the Deakin University's School of Architecture and Building. The SAHs are part of a heating ventilation and air conditioning (HVAC) system that serves a large open teaching and studio space called the A+B Studio. This studio is at the southern end of the building on the upper level. It has a mainly western aspect with a smaller southerly aspect. The floor area of the Studio is approximately 1,000 m^2, with the roof over six metres above floor level. There is no ceiling and the floor is polished timber. The walls are the original double brick with a new additional brick skin on the outside. The roof is the original asbestos cement sheet, with aluminium foil underneath and new fibreglass insulation and steel sheeting above.

Figure 1 Deakin University's Woolstore Campus Building

The HVAC system serving the A+B Studio is a mixed mode system (Figure 2). Fifteen manually openable windows and five motorised ventilation openings in the roof provide natural ventilation. Mechanical ventilation is a displacement system supplied by six constant volume fan coil units (FCUs) each with hot water heating and chilled water cooling coils. The six FCUs are located in pairs on three platforms at a high level within the space and each serve separately controlled zones within the one large open space. Each air-handling unit has an economiser mode.

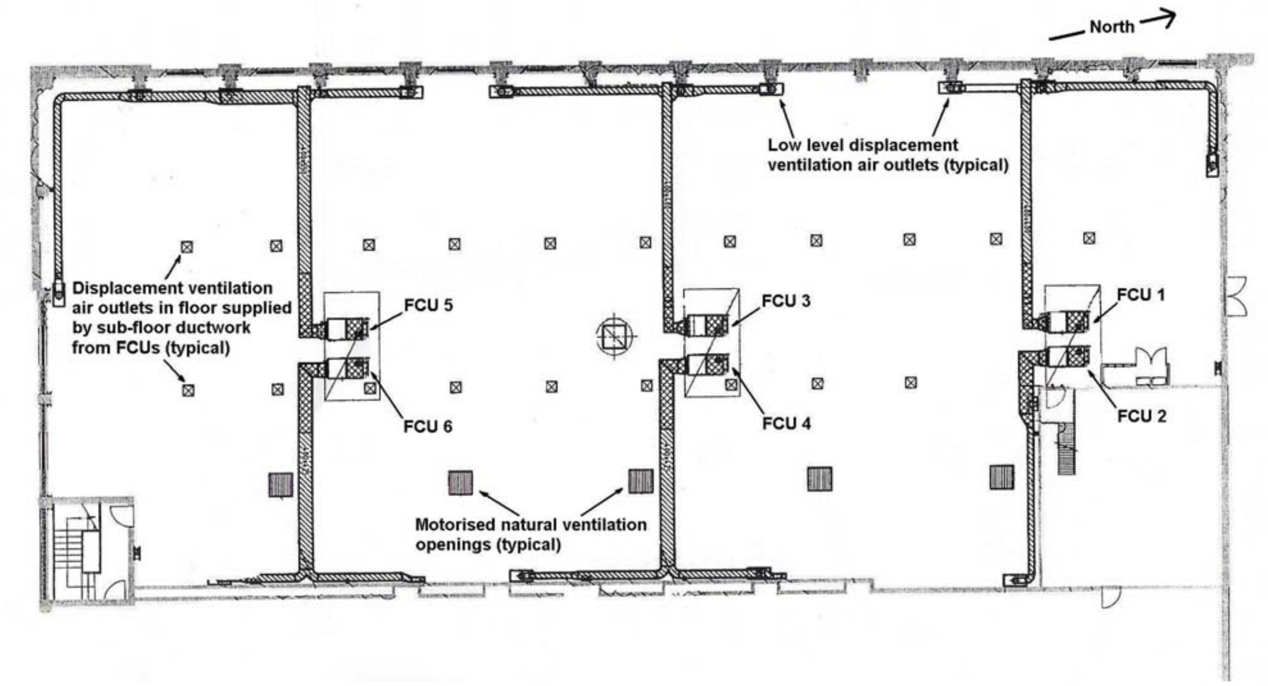


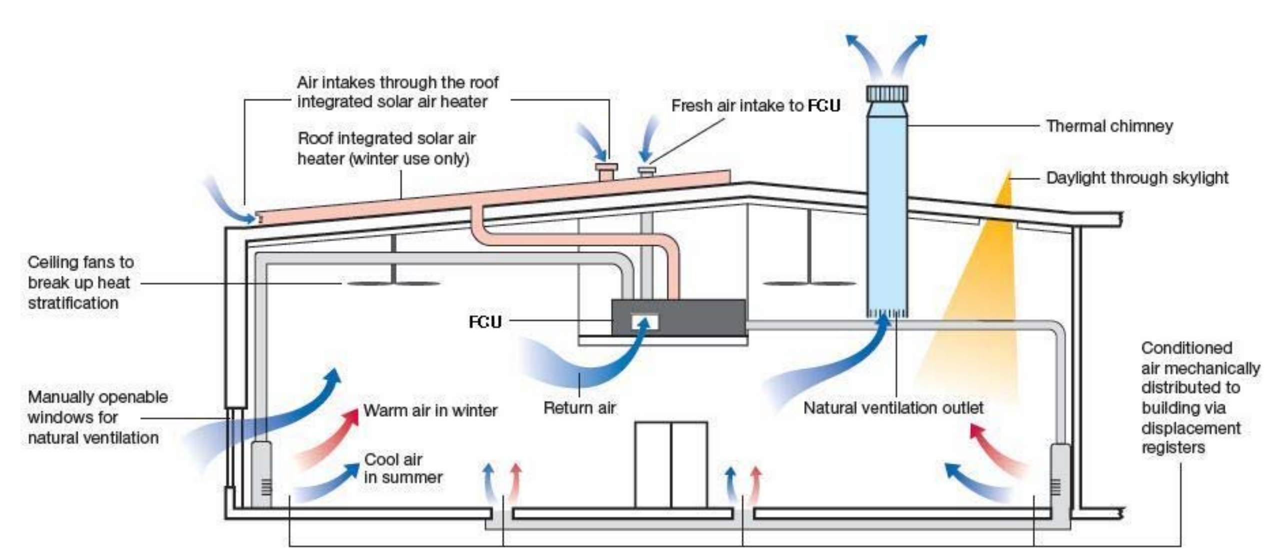
Figure 2 Layout of the HVAC Scheme used in A+B Studio

Manual switches are provided for each FCU enabling building users to select 'Air Conditioning' or 'Natural Ventilation'. The switch for each unit is located adjacent to the thermostat on the external wall within the zone it serves. The switches are not centrally located. If 'Air Conditioning' is selected, the FCU, including the heating and cooling coils and the SAH, is controlled automatically by direct digital control (DDC) via the Building Management System (BMS). If 'Natural Ventilation' is selected, the FCU switches off, the associated motorised natural ventilation opening in the roof opens, and building users are required to manually open the windows. It is possible, and common, for some FCUs to be operating in 'Air Conditioning' mode and others to be operating in 'Natural Ventilation' mode at the same time.

3. SOLAR AIR HEATING SYSTEM

There are two SAHs serving the A+B Studio (Figure 3). They are integrated with the roof structure. The inclination and orientation of the collectors are 5º from the horizontal and 288º (i.e. 720 W of N) respectively. Each SAH is 60m^2 and works in conjunction with a pair of FCUs. Two of the six FCUs are not connected to a SAH. The arrangement is schematically shown in Figure 4. The SAHs were fabricated on site during the installation of the new roof. They are sheet metal boxes 12.5 m long, 4.6 m wide and 0.2 m deep. Outdoor air enters from both ends and is drawn through a hole in the centre, when conditions are suitable, to the FCUs below. There are no baffles within the SAH directing the passage of air. The glazing of the SAH is clear acrylic sheet and the roof, which forms the bottom of the SAH, is painted black. Air is exhausted from the studio via chimneys fitted with rotary ventilators.

Figure 3 Solar air heaters on roof of A & B Studio



(source: Sustainability Victoria, 2006)

Figure 4 Schematic representation of solar air heating system

Solar preheat is only installed on FCUs 3 to 6. A SAH is common for FCUs 3 & 4, and another for FCUs 5 & 6. Solar preheat is initiated if both zones (FCUs) require heating and the solar panel temperature is greater than the average zone temperature by 1ºC. The solar preheat and the return air dampers are used initially to achieve supply air set point, ranges between 21ºC to 35ºC in heating mode. The supply air set-point is determined by how far the zone temperature is from set point using proportional and integral control. If the set-point is not reached the hot water valve is opened.

4. DATA SOURCES

The data from five sources was used to evaluate the performance of the solar air heating system

1. *Thermistors:* An array of 16 thermistors were calibrated and positioned in a cross-sectional arrangement across the A+B Studio (Figure 5). Readings are recorded by a data logger (dataTaker DT600) and displayed in real time on a computer with LabVIEW software. The data is averaged over a 15-minute period and data collection commenced in August 2004.

2. *Energy Meters:* Two ultrasonic heat meters (Siemens Sonogyr - Sonoheat 2WR5) were installed in the chilled water and heating hot water pipes to the FCUs. The meters record the cooling and heating energy supplied to the A+B Studio. The meters were manually read periodically and are also monitored by the Building Management System (BMS).

3. *Trend Logs:* Trend logs were set up on the Building Management System (BMS) to log the 33 parameters shown in Table 1. The data are averaged over a 15-minute period and data collection commenced in February 2006.

4. *Weather:* A permanent weather station was established on the roof of the A+B Waterfront Building in 2001. Nine climate parameters (Table 2) are measured and recorded. The data are averaged over a one-minute period and data collection commenced in February 2001.

5. *Commissioning:* The HVAC systems were commissioned in 2001. The systems were tested and adjusted, and their performance was measured and recorded in the Operating and Maintenance Manuals. The measurements were National Environmental Balancing Bureau (NEBB) certified. The commissioned supply and outdoor air quantities for each FCU were used in the performance assessment and analysis (Table 3).

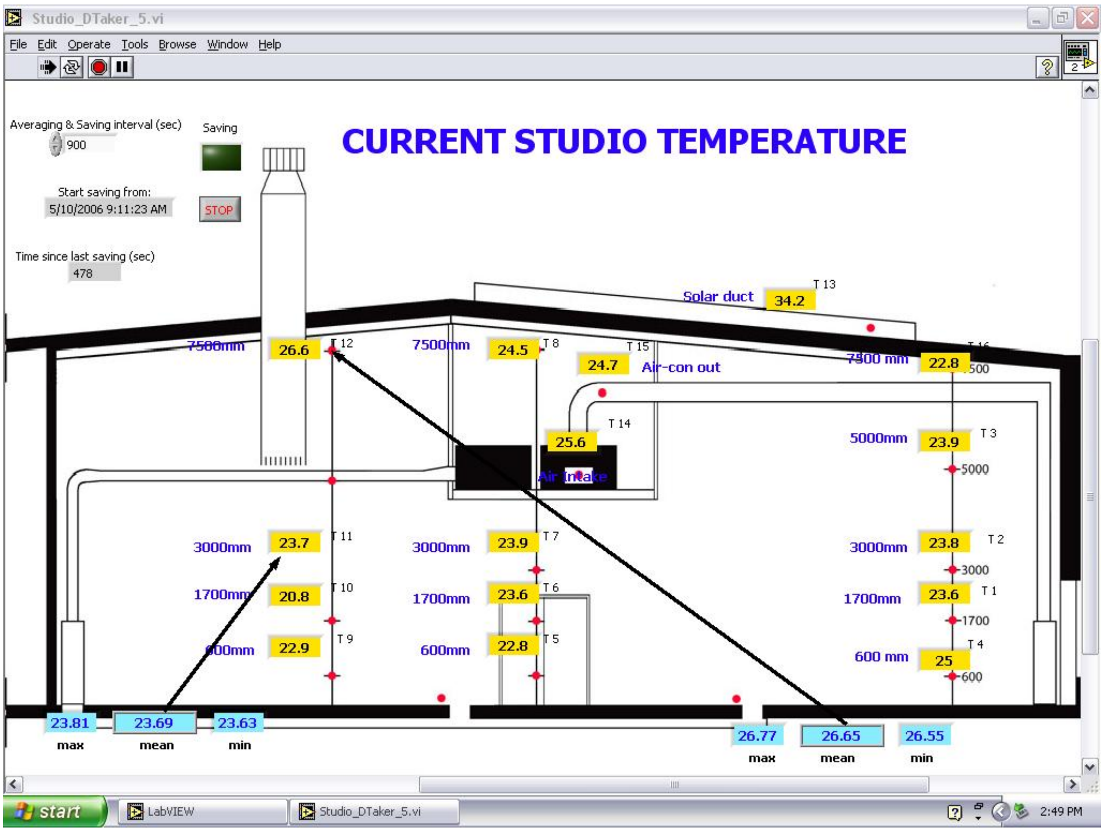


Figure 5 LabVIEW front panel display of thermistor readings in the A+B Studio

Table 1 Schedule of fan coil unit BMS points that were trend logged

Parameter	No. of points	Measurement
Room thermostat temperature	6	ºC
Supply air temperature	6	ºC
Return air temperature	3	ºC
Fan status	6	On / Off
Control mode	6	1. Shut down, 2. On, 3. Natural Ventilation Only, 4. Warm-up, 5 Night Purge, 6. Fire
Solar air heater damper position	2	% open
Solar air heater temperature	2	ºC
Outdoor air temperature	1	ºC

Table 2 Climatic parameters measured by the Deakin Waterfront Campus weather station

• Direct normal radiation	• Wind speed	• Relative humidity
• Global horizontal radiation	• Wind direction	• Precipitation
• Diffuse horizontal radiation	• Temperature	• Atmospheric Pressure

Table 3 Schedule of designed and commissioned fan coil unit air quantities

Designed/Commissioned	FCU 1	FCU 2	FCU 3	FCU 4	FCU 5	FCU 6
	Des/Com	*Des/Com*	*Des/Com*	*Des/Com*	*Des/Com*	*Des/Com*
Supply Air (L/s)	750/806	620/639	750/765	940/1040	1,050/1,313	790/638
Outdoor Air (L/s)	300/285	250/274	300/232	375/59*	415/426	310/60*

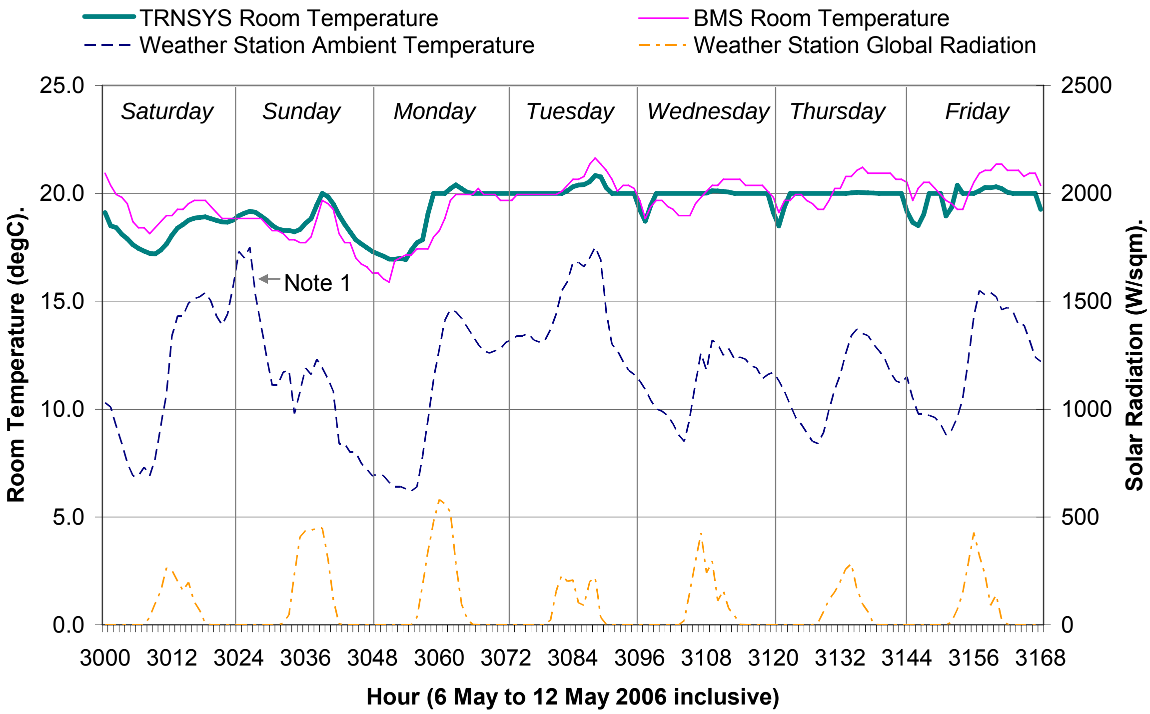
* These commissioning results are substantially less than the design values.

Within the five data sets used in the analysis, there were significant gaps. These gaps and other occasional missing data were re-compiled from available data from other data sets (e.g. missing ambient air temperature data from BMS trend logs was substituted with Weather Station data) or estimated from other known parameters (eg missing return air temperature data from BMS trend logs was calculated by averaging room thermostat temperatures). Thermistor, energy meter and weather data was reasonably consistent and reliable. Trend log data from the BMS was inconsistent with some of logs, in particular return air temperature, frequently missing data.

5. PERFORMANCE ASSESSMENT METHODOLOGY

The heating energy supplied by the gas fired central plant was calculated using the energy meter readings. The energy supplied by the SAH was calculated using the BMS trend log data. A mathematical model of the A+B Studio, its HVAC and SAHs, was also developed using TRNSYS software (SEL, 2005).

A TRNSYS weather file was prepared with the measured data from the weather station, and a fan status input file was prepared from the BMS trend logs. The A+B Studio and HVAC model output was validated against measured space conditions using both BMS trend log and thermistor data (Figure 6). There was, however, insufficient data from the very limited periods of SAH operation to fully validate the SAH model, especially with regard the modelled outlet temperature predictions, although SAH heating energy contributions determined by the model were generally consistent with heating energy contributions calculated from BMS trend log data.



Note1: Increase in night ambient temperature corressponds to a change in wind direction.

Figure 6 Comparison of measured and predicted studio air temperatures

The model was used to estimate auxiliary heating energy from the central gas fired boiler and also solar energy contribution from the SAHs under the following conditions:

- Actual operation (i.e. as recorded by the BMS, between March 2006 and August 2006).
- Theoretical operation (i.e. as designed with the SAH operating on the full / modulating fan supply air quantity and fan coils units operating only when required).
- Improved operation (i.e. assuming modifications are made to the solar air heater (SAH) and air-handling plant). The following modifications were modelled:
  - (1) SAH operates with minimum outdoor air (i.e. the minimum rate required for occupant health)
  - (2) As in (1) but with baffles installed in the SAH
  - (3) As in (2) but with new selective absorber added to SAH for the air to pass below.
  - (4) As in (3) but inclined at 45° toward north.

The key collector parameters for each of the above modifications were calculated theoretically using methodologies in Duffie & Beckman (1991), Holman (1981), Parker (1980) and Peck & Proctor (1983). These parameters are presented in Table 4.

Table 4 Calculated solar air heater modification performance with 700W/m^2 incident radiation

Modification	**m**	**F_R**	**$\tau\alpha_e$**	**U_L**
Full OA	1,690	0.60	0.82	7.6
Min OA	670	0.41	0.82	6.8
Min OA & Baffles	670	0.59	0.82	8.8
Min OA, Baffles & new absorber	670	0.60	0.82	7.9
Min OA, Baffles, new absorber & 45°	670	0.60	0.82	7.7

Where: m = flow rate (L/s)
F_R = collector heat removal factor
$\tau\alpha_e$ = effective transmittance-absorptance product
U_L = collector overall heat loss coefficient (W/m^{2}C)
T_a = ambient temperature (C)
T_o = collector outlet temperature (C)
Q_u = collector useful heat gain (W/m^2)
η = collector efficiency

6. RESULTS

The energy consumption both calculated, using actual measured operating data, and predicted, using TRNSYS modelled data, for the 6 month period between March and August 2006, is presented in Table 5 and shown graphically in Figure 7. The actual solar heater contribution, in the 'existing' condition, can be seen to be less than 5%.

Table 5 Solar heating contribution for existing and modified SAH design & operation

Solar Air Heater Scheme	Fan Coil Unit Hours of Operation^		Solar Air Heater Hours of Operation*		Total Heat	Solar Heat Contribution	
	Hours	*%Total*	*Hours*	*%Total*	*MJ*	*MJ*	*%Total*
Measured							
0) Actual - 100%OA	2,810	64%	119	2.7%	141,583	4,780	3.4%
Modelled							
0) Actual - 100%OA	2,798	63%	37	0.8%	140,778	4,714	3.3%
1) As designed - 100%OA	1,320	30%	38	0.8%	91,091	5,943	6.5%
2) As designed - Min OA	1,320	30%	783	17.7%	89,562	36,083	40.3%
3) As (2) with baffles	1,320	30%	737	16.7%	92,678	43,271	46.7%
4) As (3) with new absorber	1,320	30%	737	16.7%	92,809	43,519	46.9%
5) As (4) with 45º inclination	1,320	30%	665	15.1%	102,190	56,897	55.7%

^ Average operating hours of FCU3 / FCU4 and FCU5 / FCU6.
* Average operating hours of both SAHs.

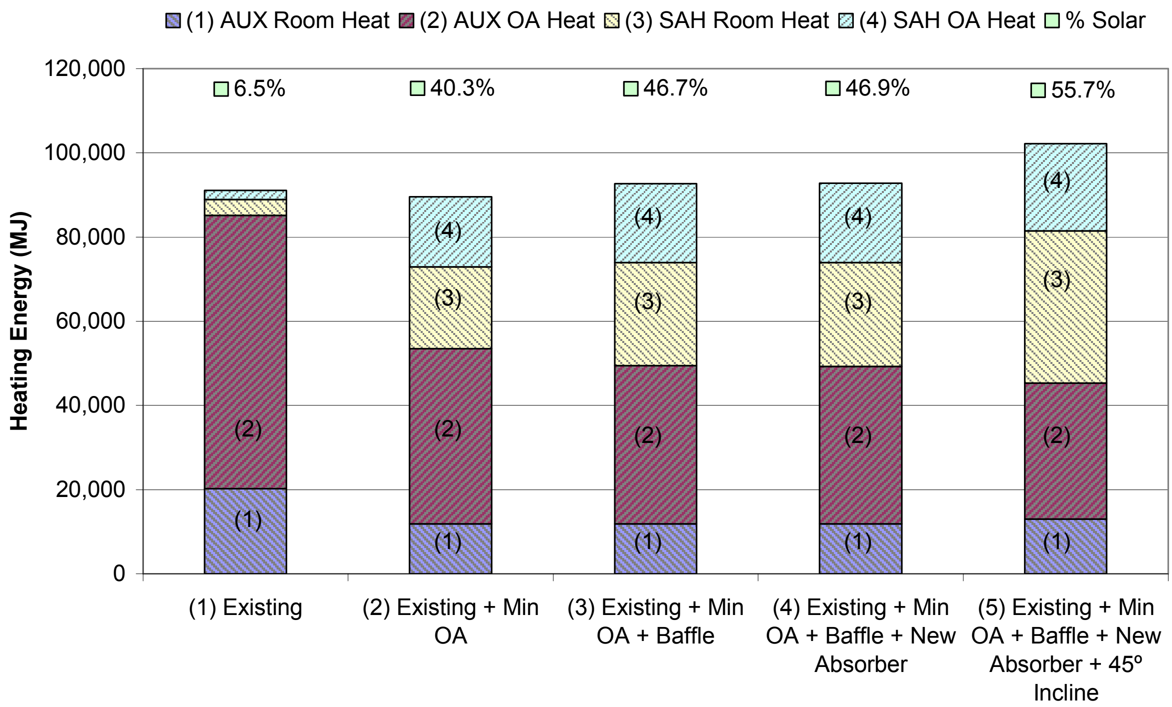


Figure 7 Heat use for existing & modified SAH design & operation during March to August 2006

7. DISCUSSION

The A+B Studio has a relatively high outdoor air requirement and associated heating demand, making it a suitable application for solar air heating.

Integrating the construction of the SAH with the A+B roof structure has reduced the installation cost of the SAH, but has limited opportunities for optimal solar and thermal performance.

In assessing the data from actual operation, it was found that the HVAC operated for extended periods of time, sometimes almost continuously. This is presumed to be an operational error. One FCU (FCU5) was found to operate only about 10% of the time, while the others were found to run for 50% of the time.

Since the FCUs have mixed mode operation, and can be operated by building users in either heating or natural ventilation mode independently of other units, one unit can be heating while an adjacent unit can be in natural ventilation mode with its roof vent open, which was frequently the case. This problem is exacerbated by the manual control switches not being centrally located.

The dampers of one of the natural ventilation shafts were permanently open during the evaluation period. The remaining four were not well sealed. These openings tended to draw conditioned air from an adjoining conditioned space rather than outside.

The readings of the two BMS sensors measuring the air temperature in each of the SAHs were very different. Typically there was 10 - 20 ºC temperature difference between the readings of the two sensors despite the two SAHs being of identical design. Consequently one heater operated more frequently and provided an unrealistically higher solar 'contribution' to the heating load (one SAH operated for only 9 hours while the other operated for 228 hours during the evaluation period). In reality, the high reading sensor was probably activating the solar heater inappropriately, introducing cool air and increasing the heating load, rather than reducing it. The location and calibration of the control sensors is critical to the operation of the SAHs. They should be shaded from, or insensitive to, radiant heat sources, particularly the sun.

The designed and commissioned control strategy severely limits the opportunity of the SAHs to operate. The temperature in the SAH measured by the BMS was only above room set point temperature for approximately 2% of the operating time. However, operating the SAH at the minimum required outdoor air quantity results in the SAH always providing a useful heat contribution whenever there is a requirement for heating of ventilation air. Changing the control strategy in this way would enable a solar contribution of up to 40% to be possible.

Operating the SAH at the minimum required outdoor air quantity does reduce the flow, heat transfer (FR) and efficiency, but these can be improved by installing baffles in the SAH. This has the effect of increasing air velocity, the heat transfer co-efficient and heat removal factors (FR). Making these physical changes to the construction of the heater could enable a solar contribution of up to 45%.

Installing a new selective absorber above the existing one, and thus creating a duct for the air to pass through, reduces the overall heat loss (UL) by creating a stagnant air gap between the new absorber and the existing cover. However, because of the relatively low inlet and collector air temperatures, this had only marginal benefit toward increasing the solar contribution.

If the SAH was constructed with an inclination of 45º and orientated north, which is not a practical modification of the the current arrangement, a solar contribution of up to 55% could be possible with a 30% increase in the SAH ouput compared to the horizontal orientation.

8. CONCLUSIONS

The SAH installed at the A+B Studio has the potential to reduce space heating loads by 50%. However, because of inadequate design, control strategy and commissioning, the SAH is only making a 5% contribution to the total heating load.

In some circumstances, because of faulty control sensors, the SAH is possibly increasing the room heat load by introducing large quantities of cool air.

Operating the SAH, as designed, with the full fan supply air quantity when the SAH temperature is greater than the room temperature set point, provides only limited periods of opportunity for a useful solar heat contribution. Operating the SAH with the minimum required outdoor air, whenever there is a requirement for heating, provides a greater opportunity for a useful solar heat contribution.

The solar heater could be simply and inexpensively re-commissioned to achieve substantially improved performance. The performance could be further improved by the installation of baffles and a new absorber within the SAH.

9. REFERENCES

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