

**Investigation of a Novel Method of Using Wall Cavities to Preheat
Ventilation Air Using Both Solar Energy and Heat Recovery**

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ABSTRACT

This paper describes the analysis and practical testing of a novel method of pre-heating ventilation air for buildings by sucking the air from the cavity space in an external wall. The fresh air introduced into the building is pre-heated partly by recovery of the heat escaping through the inner leaf of the wall and partly by collection of some of the solar energy incident on the outer leaf of the wall. A classroom at Napier University in which the system was installed was monitored to assess the energy and comfort benefits. Consideration was also given to noise levels and the optimum control strategy. It is concluded that the "cavity-breather" method of pre-heating ventilation air is both energy-efficient and practical.

KEYWORDS

Active insulation, solar, ventilation, heat recovery, sick building syndrome.

INTRODUCTION

There is a need for the inhabitants of buildings to be supplied with fresh outside air for a number of reasons: the supply of oxygen, the dilution of CO₂ to biologically safe levels and the dilution of body odours to socially acceptable levels. In buildings lacking an air conditioning system this air is usually provided by a combination of open windows and Vent-Axia type window-mounted fans, both of which also supply noise - either outside traffic noise or mechanical operation noise - cause cold draughts in winter to those sitting nearby, and also in winter increase the load on the building's heat plant due to the need to warm the fresh but cold air. This paper looks at a method of supplying the required ventilation air to a room without the noise or cold draughts associated with these methods, while also reducing the heat load by pre-heating the air before it is introduced to the room.

Many institutional and public buildings in the UK - schools, universities, hospitals etc, Napier University's Merchiston site included - built from the mid 1960s to the present day are constructed on the principle of a steel and concrete frame supporting a two-leaf wall where the inner leaf provides all the thermal insulation and the outer leaf provides only weather protection. With this type of construction outside air is free to circulate through the wall cavity, meaning that this space provides little resistance to the escape of heat from the building. Air drawn by a fan from this cavity and supplied to the room would benefit from pre-heat both by the recovery of heat lost through the inner leaf of the wall and by collection of some of the solar energy incident on the outer leaf of the wall.

TEST SITE

The system was installed in classroom B68 at Napier University's Merchiston site, a room typical of many in the University in that in winter it often suffered from stuffiness and poor air quality with the windows shut, but was too cold and draughty with them open. The room was chosen because it was occupied by the same students each day,

allowing "before" and "after" opinions of the system's effectiveness to be gathered, and also because its outer wall faced almost directly due west, permitting the gathering of daytime data both with and without direct solar gain.

Figure 1 below shows a section through the outer wall of the classroom with the main components labelled and the position of the installed fan also shown. The room was heated by hot water flowing in the finned pipe creating a convective air flow upwards in the heating duct i.e. the space between the inner leaf and the wooden panel, and it was into this space that the air drawn from the wall cavity was blown.

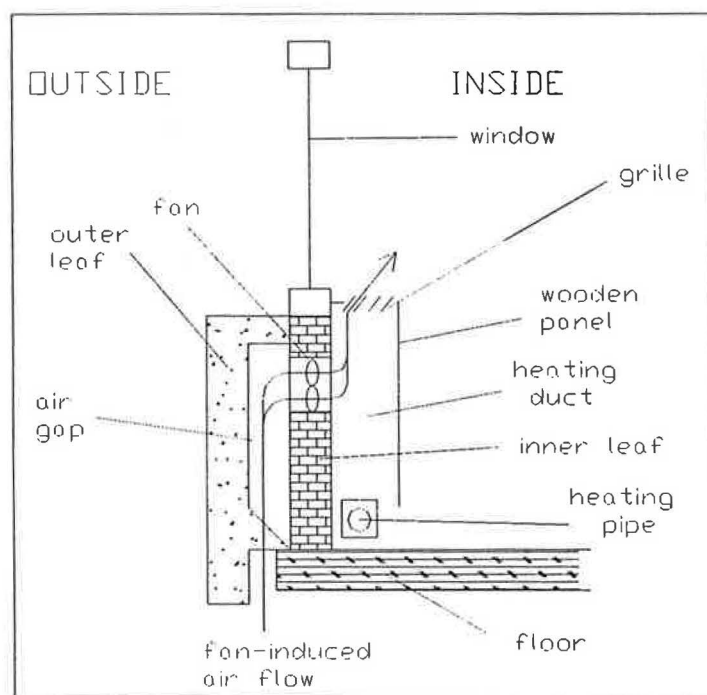


Figure 1: Section through test site wall

The classroom was never densely populated, usually containing a maximum of 20 people within its 200m³ volume. This density of occupation gave a fresh air requirement of 100 litres / second (Meyer B. 1983).

INSTALLED EQUIPMENT

The fan installed was a mains-driven Vent-Axia T - series TX7WL model set to run at its lowest of 3 speed settings and giving an air delivery rate of 93 litres / second. Under normal circumstances it was to be switched on and off as required by a Vent-Axia Air Quality Sensor which would operate the fan when the air quality fell below a preset level. Outside air, fan-delivered air and room air temperatures were each recorded at 2-minute intervals using thermocouples connected to a Squirrel data logger. Incident solar irradiance was also recorded at 2-minute intervals, using a Kipp & Zonen solarimeter connected to the same data logger.

PREDICTED SYSTEM PERFORMANCE

Recovered Heat Pre-Heat

Heat escaping through the inner leaf can be considered to follow one of 3 paths, as shown in figure 2 on the following page:

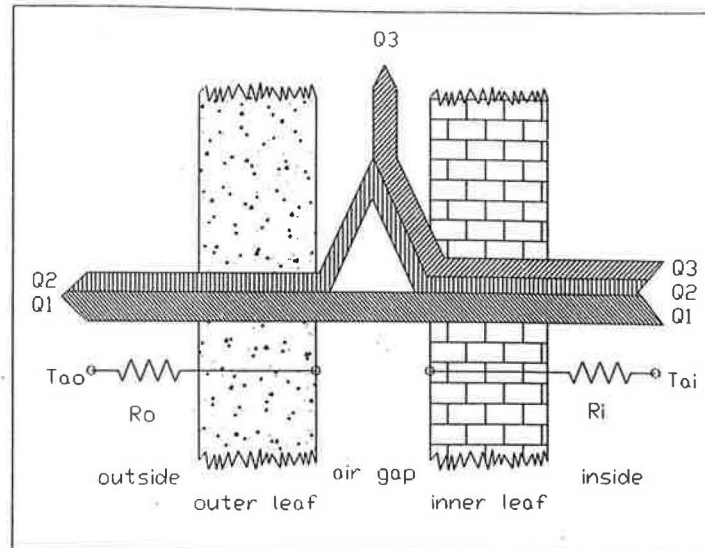


Figure 2 : Heat Loss Through Wall (Not to Scale)

| | |
|------------------------------------------|-----|
| Radiated across the air gap and lost | Q1, |
| Convected across the air gap and lost | Q2, |
| Convected into the air gap and recovered | Q3. |

It can be shown using steady state thermal resistance analysis that the value of Q3 can be found from

$$Q3 = \frac{T_{ai} - T_{ao}}{R_i + R_o + \frac{1}{\left(\frac{2mC}{A}\right)}} \quad (1)$$

where m and C are the mass flow rate and specific heat capacity of the air, and A is the exposed surface area.

Assuming typical values for R_i and R_o of 0.8 and 0.17 $\text{m}^2 \text{K} / \text{W}$ respectively (CIBSE Guide A, 1988) and assuming that the air is drawn uniformly from a wall area of 7.5m^2 i.e. from an area within 2m to either side of the fan, and taking $T_{ao} = 0^\circ\text{C}$ and $T_{ai} = 35^\circ\text{C}$ (the temperature in the heating duct, not the temperature in the room), the following results are found:

| | |
|---------------------------------|----------------------------------|
| Recovered heat : | $Q3 = 34 \text{ W} / \text{m}^2$ |
| Air pre-heat (recovered heat) : | $T_d = 2.1^\circ\text{C}$ |

This gives an indication of the expected air pre-heat solely from recovery of heat lost through the fabric of the building.

Solar Pre-Heat

Of the heat generated on the outer surface of the wall, some is lost to the outside air while the rest passes through the outer wall, whence it again follows one of three routes: either radiated or convected across the air gap and

then passed into the building, or convected into the air gap and captured by the passing air, then blown into the room by the fan. This is shown in figure 3 below:

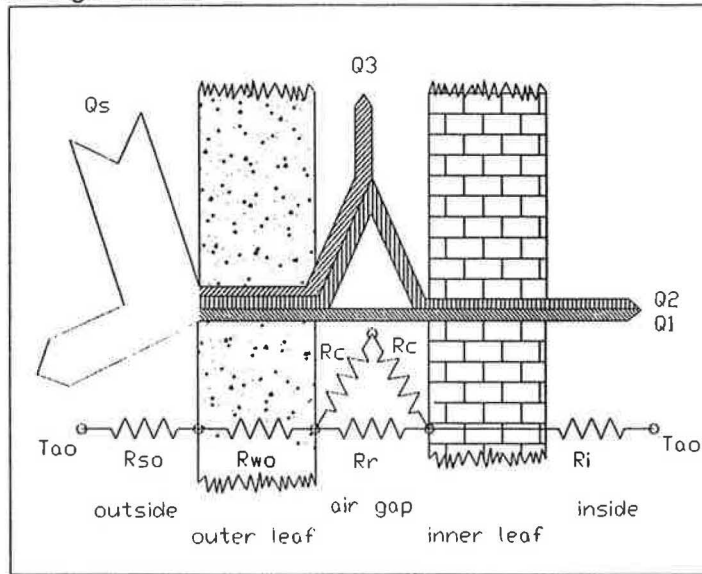


Figure 3 : Solar Heat Gain (Not to Scale)

The 24 hour-average heat absorbed by the outer surface of the wall can be found from

$$Q_s = I \alpha \tag{2}$$

and, assuming that $Q_1 = Q_2 = 0$ due to the relatively high value of R_i compared with R_c , then the amount of solar heat delivered to the room can be found from

$$Q_3 = I \alpha \left(\frac{R_{so}}{R_{so} + R_v} \right) \tag{3}$$

where

$$R_v = R_{wo} + \frac{1}{\frac{1}{R_c} + \frac{1}{R_r + R_c}} + \frac{1}{2mC/A} \tag{4}$$

Again taking typical values for the resistances $R_c = 0.2$, $R_r = 0.2$ and $R_{so} = 0.1 \text{ m}^2 \text{ K / W}$ (CIBSE Guide A, 1988) and the measured surface absorptivity $\alpha = 0.65$, and taking I as the average measured solar irradiance for the day, the following expected 24 hour average values are found:

| | |
|-----------------------|------------------------------------|
| Solar heat : | $Q_3 = 27 \text{ W / m}^2$ |
| Air pre-heat (solar): | $T_d = 1.7 \text{ }^\circ\text{C}$ |

Combined Preheat

With both recovered and solar components active in pre-heating the ventilation air, an average temperature lift of 3.8K was anticipated, based on the assumptions made and the solar irradiance measured on the outer wall throughout the day 19th March 1994.

ACTUAL SYSTEM PERFORMANCE

Although the system was designed to run intermittently as required throughout the day, in order to analyse the energy effects of the system it was run continually over a 48 hour period (19th and 20th of March 1994). The results of 19th March are summarised in figure 4 below.

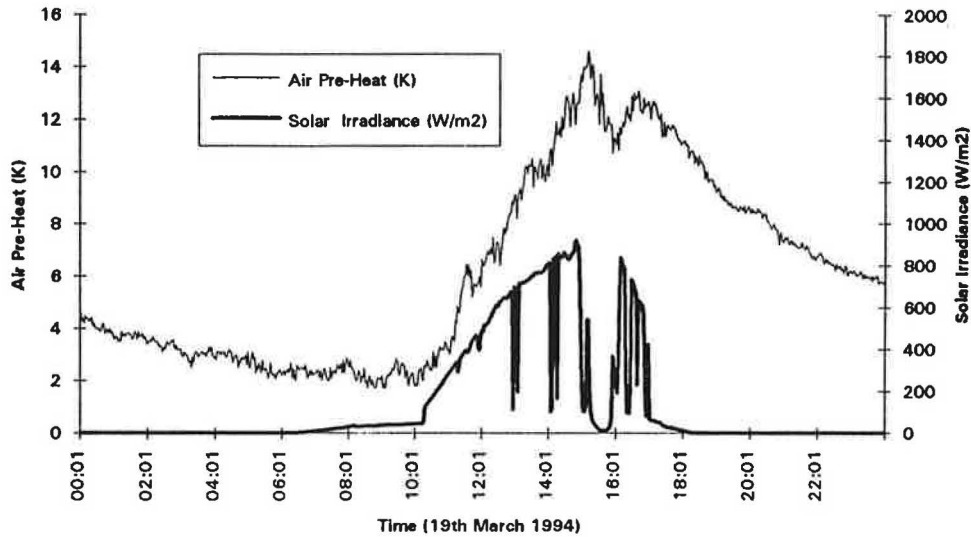


Figure 4 : Incident Solar Irradiance and Air Pre-Heat

The air pre-heat can be seen to fall steadily from 4K at midnight to 2K at 10.00am as the drawn air removes solar heat stored in the wall from the previous day and finally relies solely on the recovered heat to give the predicted 2K pre-heat. As the sun comes round onto the wall later in the day and the incident solar power increases the pre-heat also increases quite dramatically. Of particular interest is the sudden drop in incident solar power from 900 W / m^2 to almost zero at 3.00pm, with a subsequent drop in pre-heat about 15 minutes later, showing clearly the time required for the heat to traverse the outer leaf. An impressive 14K of pre-heat can be seen at 3.00pm when the sun was shining strongly onto the outer wall.

The 24 hour-average ventilation air pre-heat based solely on the effect of the solar irradiance was found to be 4.2K, significantly more than the predicted value. The most likely explanation is that the delivered ventilation air was being drawn from a much wider area than the estimated 7.5 m^2 .

Table 1 below shows peak and 24 hour average coefficients of performance.

| | Air Pre-Heat (K) | Heat Saving (W) | Fan Power (W) | Coefficient of Performance |
|-----------------|---------------------|--------------------|------------------|-------------------------------|
| Peak | 14 | 1700 | 50 | 34 |
| 24 hour-average | 6.2 | 750 | 50 | 15 |
| No Solar | 2.1 | 250 | 50 | 5 |

Table 1 : Peak and 24 hour average performances

With the system running either intermittently as required or continually, the occupants of the test room claimed to notice improved air quality and with no draughts and very low and unobtrusive noise levels. Noise levels measured in the test room showed 38 dB(A) background, with 44 dB(A) measured at a distance of 1m from the fan when running. This increase in noise level was unnoticeable when the room was occupied and used under normal conditions, and also compares favourably with a window-mounted fan where an increase from 47 dB(A) to 56 dB(A) was measured for a similar air flow rate.

There was no recorded drop in room temperature at either head or foot height when the system was running when compared with a set of control measurements taken with the system disconnected.

ECONOMICS

It is very difficult, if not impossible, to determine a payback period for the installed ventilation system for two reasons: firstly, since the system is designed primarily to improve indoor air quality it would be necessary to place a monetary value on this improvement and include this value in the payback calculation. Secondly, since the system is envisaged as running only when the room is occupied, the reduction to the building's heat load would depend on a relationship between the occupancy of the room and the amount of sunlight falling on its west-facing wall, both of which are difficult to predict. However, as an example, the savings for 19th March 1994 are presented.

| | | |
|---------------------------------------------------------------------------|---|----------|
| Average 24 hour pre-heat | - | 6.2 K |
| Net 24 hour heat saving due to pre-heat | - | 16.6 kWh |
| Net 24 hour financial saving due to pre-heat (for gas at £0.025 / kWh) | - | £0.42 |
| Cost of fan and controller | - | £250 |
| Simple payback period | - | 600 days |

It should be noted that this simple payback period is for the whole system, however the installation of the system is no more complex or costly than for a window-mounted fan, so the extra cost of installation is negligible, giving energy savings from the day the system is installed.

CONCLUSIONS

Significant levels of air pre-heat, up to a peak of 14K on the test day, were recorded, with a 24 hour average pre-heat of 6.2K. Due to the low power of the fan (50W) these preheats give system coefficients of performance of 34 and 15 respectively. Even with no solar input over a period of several days a pre-heat of 2K was anticipated, giving a COP of 5. On a single day with the fan running continually a saving of 16.6 kWh, or £0.42 at Napier University gas rates, was seen due to the air pre-heat. Occupants of the test room claimed that air quality was improved, while there were no draughts or fall in air temperature and that fan noise was completely unnoticeable under all but the quietest conditions.

The system is highly energy efficient, unobtrusive, and quiet in operation, whilst its design permits installation in many buildings throughout the UK, where it can be considered as an equal-cost alternative to a window-mounted fan.

REFERENCES

- Chartered Institute of Building Services Engineers (1988), CIBSE Guide A, CIBSE, London, Section 3
Meyer B. (1983) Indoor Air Quality, Addison-Wesley, Massachusetts, page 5