OPTIMUM VENTILATION AND AIR FLOW CONTROL IN BUILDINGS

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A Technique for Controlling Air Flow through Modified Trombe Walls

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Synopsis

This paper describes an experimental investigation into the operation of a modified Trombe wall. The construction has been altered to include a layer of insulation material; two alternative positions for this insulation layer have been considered and tested. Air flow from the top of the Trombe wall has also been enhanced by the inclusion of a low power axial flow fan which was controlled to function dependent on measured temperature in the wall cavity. The construction with exposed concrete facing into the air cavity has a slower response than that with exposed insulation facing the cavity. The concrete option also produces higher outlet temperatures, though the fan was found to operate for longer periods with the insulation option. The controller used could be developed for employment in more sophisticated control strategies.

1. Introduction

An important aspect of passive solar design, and one which has a great influence over the ultimate level of success and efficiency of such designs, is the control of air movement. This is particularly the case with 'indirect gain' and 'isolated gain' categories, which often rely on air flows to redistribute solar heat gain. This paper deals with the design and experimental investigation of a modified indirect gain Trombe wall in which the air flow is of particular importance (though the general principles are of relevance to a number of other passive design options). Several related studies have been carried out at the University of Sheffield [1,2], and form the background to the work described here. The enhanced design employs automatic control of air flow and is thus specifically relevant to the theme of the conference - 'optimum ventilation and air flow control in buildings'.

2. Trombe Walls

Trombe walls evolved from the mass wall form of passive design. In the basic mass wall design, a high thermal mass wall is positioned behind a southerly facing expanse of glazing. Solar radiation passes through the glazing and is absorbed on the outer surface of the wall. The 'greenhouse effect' helps retain the heat which has been absorbed. Depending upon the thickness and thermal properties of the wall, the heat which has been absorbed will be released some hours later from the interior surface of the wall. In domestic situations, the wall can be designed to introduce a time lag suitable to delay heat gain to the interior until the most profitable time of the day (in terms of heating needs), that is until the occupancy period of the early evening. Figure 1 shows the main features of the mass wall.

An advance on the basic mass wall was the introduction of air flow openings at bottom and top of wall, as developed by Trombe. The air which has been warmed by solar heat gain in the cavity between wall and glazing, rises due to buoyancy effects and enters the room interior, whilst cooler air is drawn into the bottom of the cavity. Figure 2 illustrates the basic concept of the Trombe wall. Whilst the basic form relies only on natural air flow, there is the opportunity for a more sophisticated control system to be employed. In combination with a controller, there is also the potential for the wall to be used in a passive cooling, as well as heating, mode.

When initially developed, the concept of the Trombe wall was that air flow through the wall cavity (between glazing and absorbing surface), allowed heat absorbed in the cavity to be delivered more quickly to the interior of the building. Such a modification has been found to be particularly useful in climates with variable solar radiation intensity (the UK climate being a case in point). In these circumstances, the ability to extract and deliver the heat to the interior using the air flow is considered a more effective means of utilising the energy absorbed on the outer surface of the wall, (by comparison with the mass wall approach of allowing heat to slowly permeate through the solid wall). If a steady supply of solar heat throughout a substantial portion of the day is unlikely to occur, then it seems to be more effective to extract the heat using the air flow and deliver it immediately to the interior.

If alternatively, the system is to be used in a cooling mode, then provision must be made for the warm air to be vented directly to the exterior rather than allowing it to enter the occupied interior space. This can be achieved by providing an alternative outlet at the top of the wall, however this outlet needs controlling or positioning in some way relevant to the prevailing conditions, perhaps using some sort of automatic controller. Once a controller is installed, however simple it may be, then there is less reason not to develop the system a stage further with even better control options. This reasoning was fundamental for the study described here.

3. Wall Construction

In this study, variations on the basic wall construction have also been introduced. The reason for this was to attempt to optimise heat absorption and also to increase the level of thermal insulation between the interior and exterior. This lack of insulation has often proved to be the weak link in the thermal design of passive solar designs: whilst the sun is shining, some beneficial positive heat balance can be produced, at other times the high thermal heat transfer allows heat loss at a higher than acceptable rate (U value of the order of 1.0 $Wm^{-2}K^{-1}$, compared to currently acceptable wall U values of the order of 0.3-0.4 $Wm^{-2}K^{-1}$).

If the argument advanced in section 2 is accepted, that is that the main mode of solar heat extraction will be by using the air flow, then the heat gain through the wall itself becomes less significant and the extra insulation more acceptable and beneficial. In making this choice, the Trombe wall has been converted to act more in the fashion of an isolated gain collector.

Figure 1

Mass Wall Design

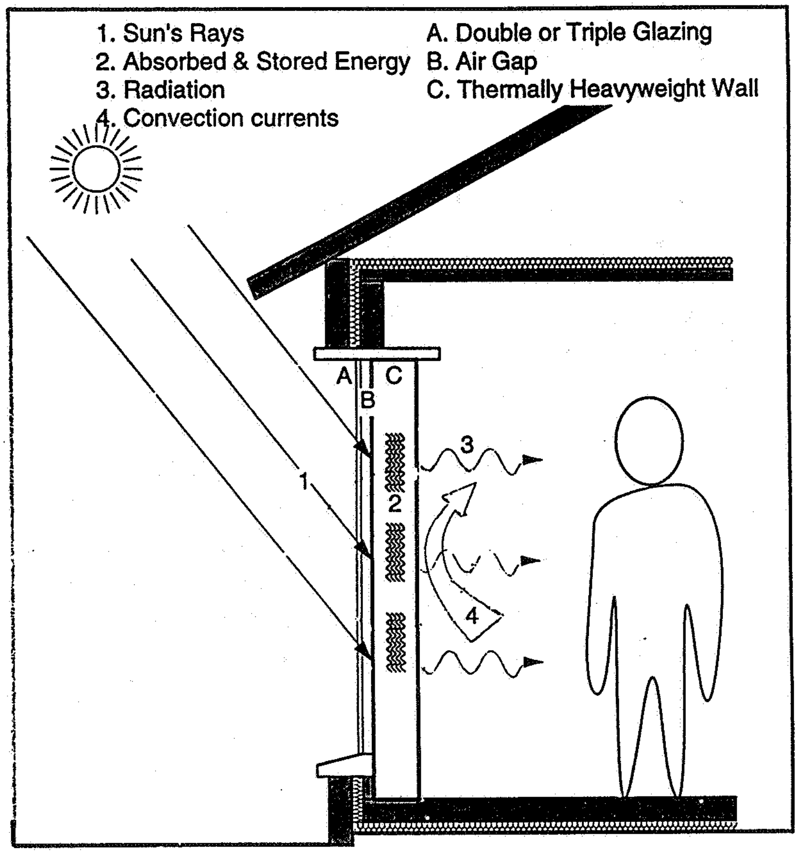
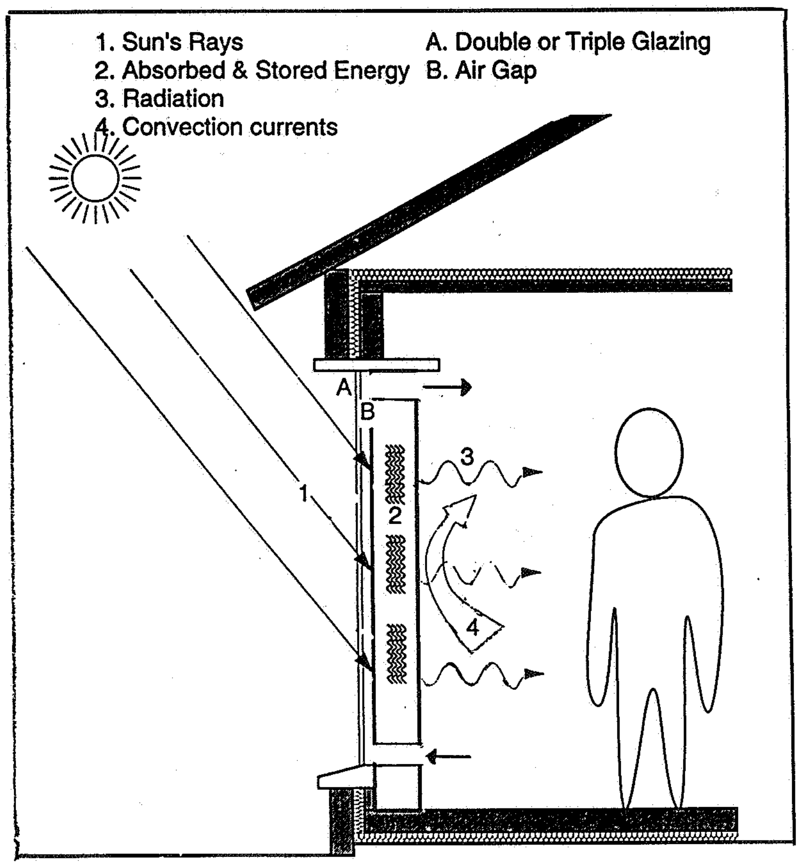


Figure 2

Trombe Wall Design



Two forms of wall construction were used for comparison in the tests performed. Each was of the same nominal U value (0.6 $Wm^{-2}K^{-1}$ approximately), however in one case the insulation layer was placed facing into the air flow cavity, whilst in the second it was placed facing into the room interior. The alternative face was concrete blockwork. Around the sides and above and below each construction, the wall was well insulated to reduce edge effects.

Simple, medium density concrete blocks, commonly available in the UK were used as supplied, with insulation (expanded polystyrene foam) attached to one surface. Unfortunately the absorptivity of each surface varied - the polystyrene being bright white, the concrete blockwork being fairly dark grey. despite this anomaly, the project continued with the blocks as they were supplied since the aim was to devise a simple system which required minimal specialist components.

4. Air Flow Enhancement

In a plain Trombe wall, natural buoyancy effects cause some air flow in the wall cavity, but it is largely uncontrolled. The heat gain to the air occurs from the solar absorption on the wall surface (and to a lesser extent from the interior surface of the glazing), the heat transfer is by natural convention. The attachment of a fan to the outlet from the wall permits control of flow, both time periods and flow rate. The heat transfer will be by forced convection from the interior cavity surfaces, and thus more effective for heat extraction. The air flow can also be controlled so as to deliver the heat either to the interior when this would be beneficial, or to the exterior when overheating would be likely.

Air flow from the modified wall design was enhanced and controlled using a low power (2.2W) axial flow fan attached to the top outlet of the wall section. The airflow generated by the fans was in the range 12 to 14 litres per second.

5. Experimental Investigation

In order to investigate the performance of the two designs a series of experiments were carried out. The two versions of the modified wall were used in a number of flow configurations - closed air flow loop; open without fan induced air flow; and with fan controlled flow. The results reported here deal with the last of these options. More details of the alternatives are available in Craigen[3].

Figure 3 shows the two test set-ups, the upper diagram is of the exposed concrete facing into the air gap, the lower is of insulation facing into the air gap. The position of fans, measurement points and solarimeter are all shown. the two wall configurations were positioned adjacent to each other in the south facing wall of the Arts Tower building at the University of Sheffield.

A data logger took measurements over a variety of weather conditions ranging from November 1995 to July 1996.

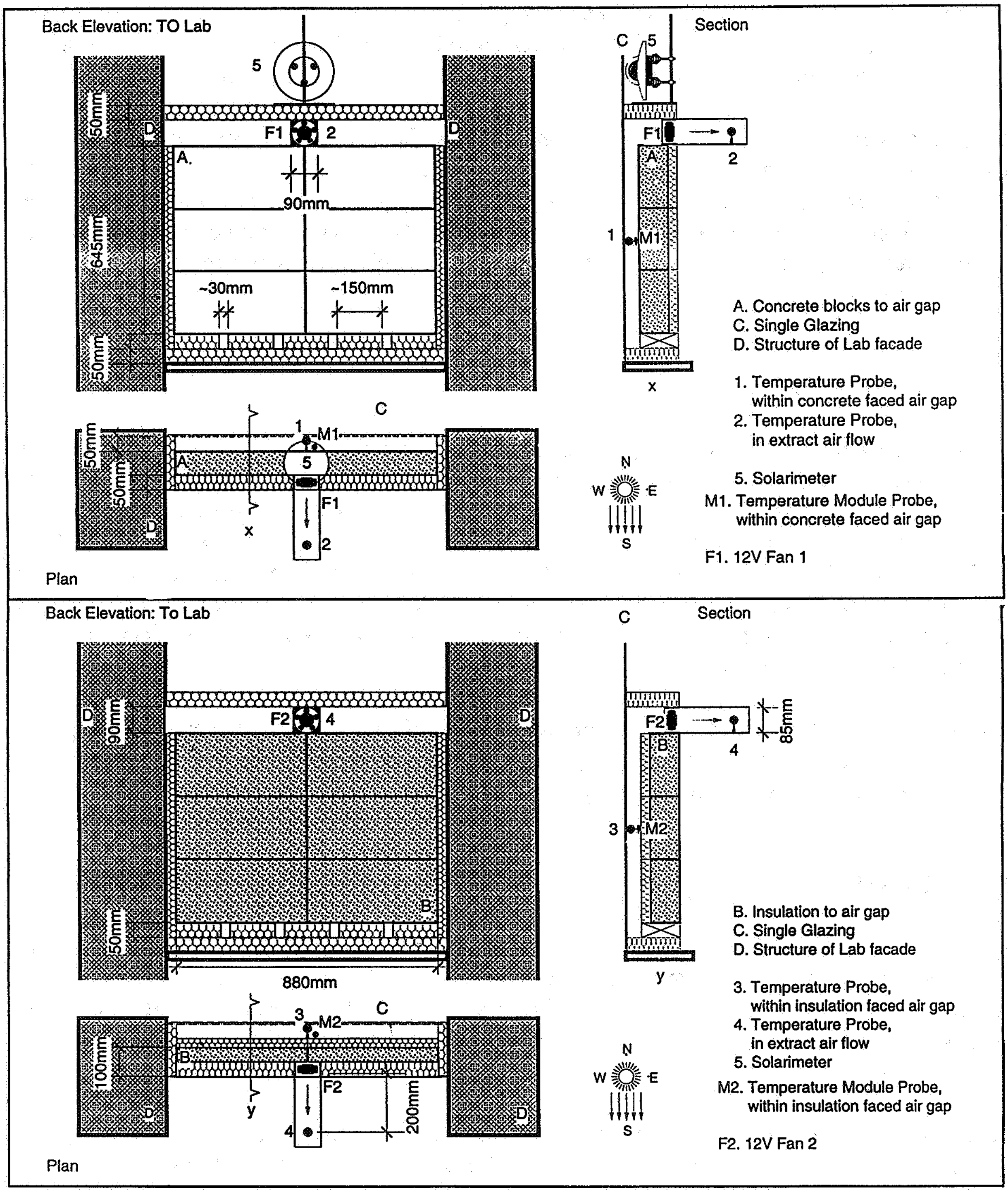


Figure 3 Experimental Arrangement
(Top: Concrete surface to air gap; Bottom: Insulation surface to air gap)

6. Control of Air Flow

A purpose designed controller was constructed using only easily available and relatively cheap components. Temperature sensors within the wall fed information to the controller which then decided to switch fans off or on. The switching point at which the fans operated occurred when the temperature measured within the wall air cavity exceeded 30°C, though any other value could have been used. There were two reasons for choosing this temperature. Firstly, the temperature of the air at the outlet needed to be above internal air temperature to derive any benefit, 30°C seemed a reasonable value to choose under these circumstances. Secondly, arising from initial tests on the walls, it had been noted that the temperature measured in the air cavity was above the air temperature due to radiant effects on the sensor which could not easily be eliminated.

7. Analysis

A range of comparative analyses were undertaken. In general it was found that the insulation to air gap construction produced a more rapid rise in temperature closely in phase with solar radiation intensity. The construction with concrete facing into the air gap exhibited a 1-2 hour delay in resulting temperature rise, however the maximum temperature was significantly higher. The switching sensor in the insulation to air gap wall appeared to be more affected by solar radiation intensity causing the fan to be switched on for longer periods, yet the temperature at the wall outlet was lower, and in some cases would have provided little useful heat gain.

Figure 4 illustrates comparative results for a typical day. The top diagram relates to the concrete facing into the air gap, and the bottom shows the insulation facing into the air gap.

Peak temperature rise (air temperature at outlet compared to room temperature) was 7.4°C. At the air flow rate in use this would deliver a heat transfer rate of abut 108W. The area of the absorbing surface was $0.57m^2$ and the solar radiation intensity $730Wm^{-2}$; this would indicate an available solar heat input rate of 416W and thus an operating efficiency of (108/416), that is about 26%.

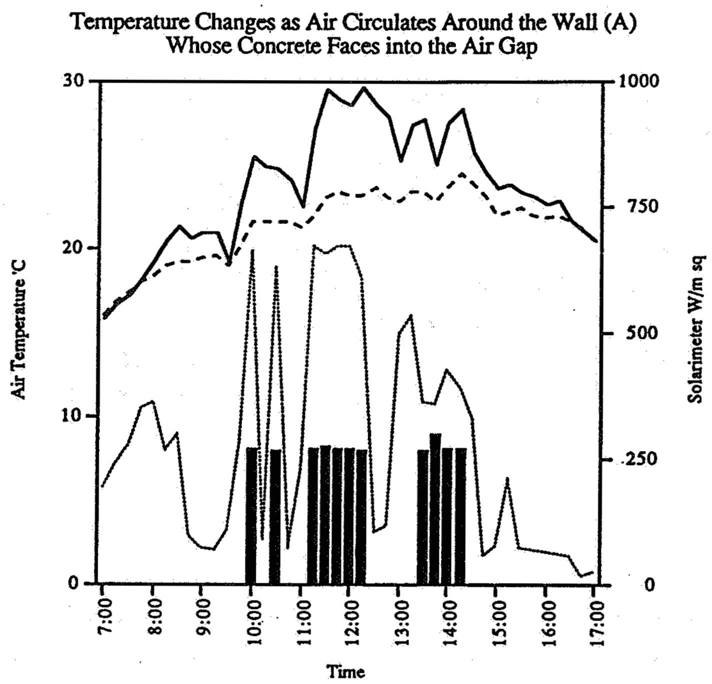
8. Control Strategy

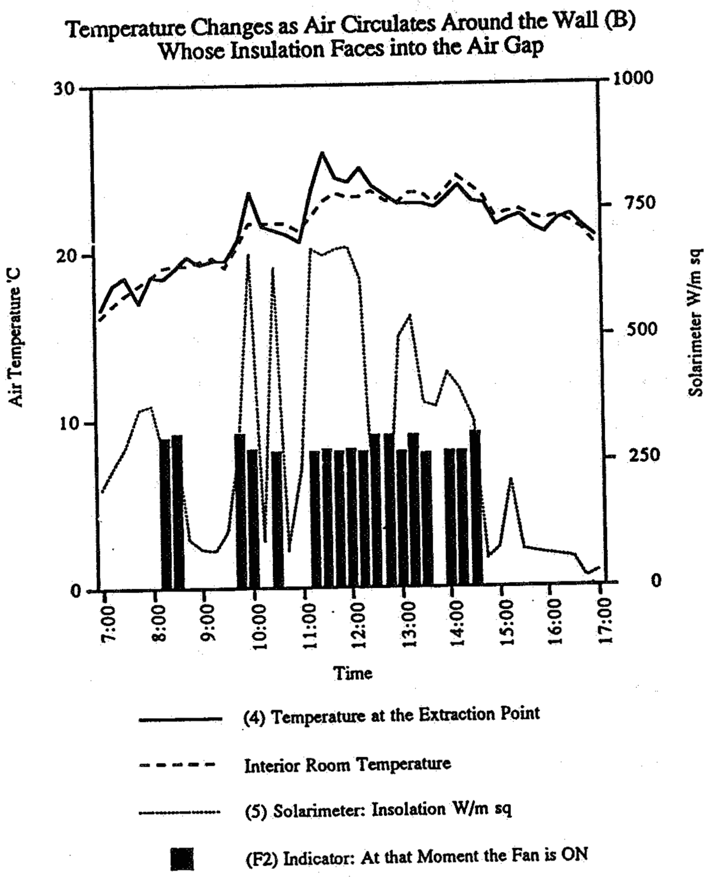
A relatively simple control strategy was employed in the system as tested, however a more sophisticated option would be quite feasible using a timed programmer to optimise heat extraction from the wall depending upon occupancy period and intended distribution (that is whether main function is as a heater or cooling mechanism).

Provision has also already been made within the controller to switch the fan not only in accordance with the temperature measured in the air cavity but also with reference to the room conditions.

Figure 4

Typical test results showing comparison of each wall type





9. Implications for Ventilation Design

A number of studies of passive solar design which have been carried out in recent years fail to demonstrate the expected benefits in terms of energy use reduction. One reason for this may be the over-reliance on natural energy and air flows. Work carried out at the University of Sheffield has shown that improvements in comfort and some reduction in energy use are possible if 'hybrid', or moderately controlled design options are employed. A level of control also engenders a more accepting response by residents.

On the basis of the work described in this and other papers it is suggested that controlled air flow is the key to successful functioning of passive solar design options. This has many implications for building ventilation design. The flow paths and the level of control to be applied must be considered at the sketch design stage. In particular the variations between winter heating and summer cooling operation must be included. The positioning of ventilation openings may have to be adjusted to match the overal 'system' requirements in order to optimise performance.

Of course, research is still necessary to improve designers' knowledge of the strategies, and the study described here has produced anumber of questions which deserve more attention.

The most critical aspect of successful design is the combining of commonly available components in relatively simple, yet robust, solutions which can be easily understood. It is hoped that this work makes some contribution to that goal.

References

1. A.C.Pitts and J.Patronis,
   "Environmental Control in Passive Solar Environments"
   Proceedings of C.I.B.S.E. National Conference p4473-475, Manchester, May 1993
2. A.C.Pitts
   "Photovoltaic Powered Fan-assisted Ventilation for Buildings in Hot Climates"
   Proc. International Symposium - Passive Cooling of Buildings, Athens, June 1995.
3. S. Craigen
   "Automated extraction of heat energy from solar storage wall"
   B.A. Dissertation, University of Sheffield, June 1996