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Summary Thermal comfort in a naturally ventilated test room is investigated. The test room is a lightweight portable cabin located in a sheltered area at Loughborough University, UK. Thermal comfort simulations were carried out for various sizes of openings and glazing. Medium and high thermal mass were added to the test room and their effects on thermal comfort were investigated. The results suggested that thermal mass has significant effect on thermal comfort parameters. Adding a 200 mm thick layer of medium-density concrete to the walls improved the thermal comfort over the summer by 40%.

Natural ventilation: Impact of wall material and windows on thermal comfort

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1 Introduction

The distribution of fresh air and effective of room depth on single-sided natural ventilation have been assessed by Walker and White[1]. They demonstrated that comfortable temperatures can be maintained in deep offices. Eftekhari[2,3] conducted a series of air velocity and temperature measurements in an environmental chamber with single-sided natural ventilation. The measured and predicted thermal comfort analysis showed that thermal comfort can be achieved in small offices for most days during the summer.

The objective of this research was to investigate the impact of wall materials on thermal comfort for a naturally ventilated office. For this purpose, a computer program is used to calculate the thermal parameters defined by Fanger[4]. An existing portable cabin of volume 22.2 m^3 is used to represent a typical office. The predicted percentage of dissatisfied (PPD) and the predicted mean vote (PMV) parameters for different masses of the cabin were predicted. This information then will be used to modify the existing test room.

2 Simulation procedures

2.1 Simulation package

To assess thermal comfort inside the test room, a series of comfort analyses were carried out according to Fanger's theory[5]. A simulation program was used to predict the average comfort parameters PPD and PMV in the office. The simulation program is intended to assess detailed environmental conditions within a single space. The numerical model is based on an explicit finite-difference formula for unsteady heat flows within the building fabric. Internal radiation exchange between surfaces is assessed by a radiosity method. Long-wave radiant heat flows (those due to surface temperature differences) are handled separately from short-wave radiation.

Natural ventilation due to the stack effect is calculated within the program from open areas at high and low levels and the vertical separation between them. In general, the simulation program is useful in determining the environmental conditions in single spaces with a low level of servicing, such as naturally ventilated buildings[5].

The software uses a set of typical climatic conditions provided for the UK in the *CIBSE Guide*[6], which defines the minimum and maximum dry- and wet-bulb temperatures for each month of the year, the direct and diffuse radiation factors and cloud cover. The method adopted is to divide the weather in individual months into groups of days corresponding to ten equal intervals (band) for a given climatological parameter. Each band within each month is treated as a separate block of weather data when running the simulation program. The results obtained are weighted by the proportion of the month within each band[6]. The average PPD values for a naturally ventilated room using the default weather data, for a seated person in light office clothing performing light office activity, and for a total internal heat gain of 150 W were calculated.

2.2 Test room

An existing lightweight portable cabin is simulated. This is used as a test room for natural ventilation at Loughborough University, UK. The test room is of light mass so that a quick response to the effects of openings can be detected. Four sets of metal louvres are fitted in the room (see Figure 1). Each unit has overall dimensions 125 cm wide, 80 cm high and 20 cm deep, and contains five of 12 cm wide adjustable louvre blades. The louvres were fitted to the test room so that airflow can be measured for various sizes of opening at high and low levels.

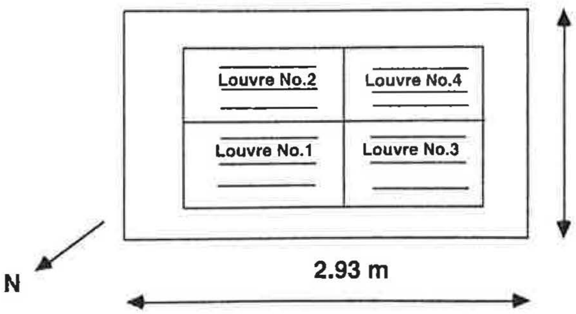

Figure 1 Schematic diagram of louvre arrangement in test room

After the louvres were installed the air infiltration into the test room was measured using tracer gas. Initially all the gaps and louvres were covered and SF_6 tracer gas was released into the room. After uniform readings at eight points inside the room were achieved, the covers were removed and the total leakage was calculated from the concentration decay.

Initially the air change rate was measured at 8 ac h^{-1}. This was mainly due to the gaps between the louvres' blades and to the gap around the door. To eliminate this large infiltration, the door and louvre gaps were completely sealed off. The tracer gas measurement for this new configuration is shown in Figure 2. This demonstrated that the air change rate per hour was reduced to 1.3 ac h^{-1}. This value was then used in the simulation program.

There are two windows in addition to louvres inside the test room which were closed at all times. Only single-sided natural ventilation through the louvres was considered. The internal heat loads inside the room were three computers, one analyser and two 58 W fluorescent luminaires.

2.3 Simulated test room: Standard portable cabin

The simulated room was a standard 'off-the-shelf' portable cabin. The external walls are of composite construction. The external skin is of plastisol-coated galvanised steel sheet, there are timber studs and a peripheral frame, a galvanised steel bottom rail and an internal lining of 0.6 mm thick polyester-coated steel. The 85 mm cavity between the external skin and the internal lining is filled with injected, rigid polyurethane insulation. The thermal conductivity coefficient λ measured for the external wall is 0.45 W $m^{-2}K^{-1}$(7). The floor comprises 18 mm thick moisture-resistant wood chipboard fixed to the steel joists and covered by carpet. A profiled steel underdrawing is fixed to the underside of the steel joists. Thermal insulation is provided by injected rigid polyurethane insulation. The U-value for the floor is 0.34 Wm^{-2} K^{-1}.

The roof is of composite construction with an external profiled skin of plastisol-coated galvanised steel sheet, rigid polyurethane/plywood composite inserts, a softwood peripheral frame, and a ceiling of polyester-coated steel. The 110 mm cavity thickness is filled with rigid polyurethane insulation. The U-value supplied by the manufacturer is 0.32 W m^{-2} K^{-1}.

2.4 Combination of louvres

Simulations were carried out for five damper positions as shown in Table 1. Louvres 1 and 3 were placed at low level and louvres 2 and 4 were high-level openings. For each case the simulation software was used to predict room conditions and hence PPD values.

3 Simulation results

3.1 Lightweight test room

The predicted comfort results for the standard portable cabin and cases 1, 3, and 5 are shown in Figure 3. It can be seen that for the months of April, May and October the best ventilation strategy is to close the louvres. This is mainly due to the lack of any heating input, and the average PMV value was about –2.0. However, for the months of June, July, August and September maximum opening will provide better comfort

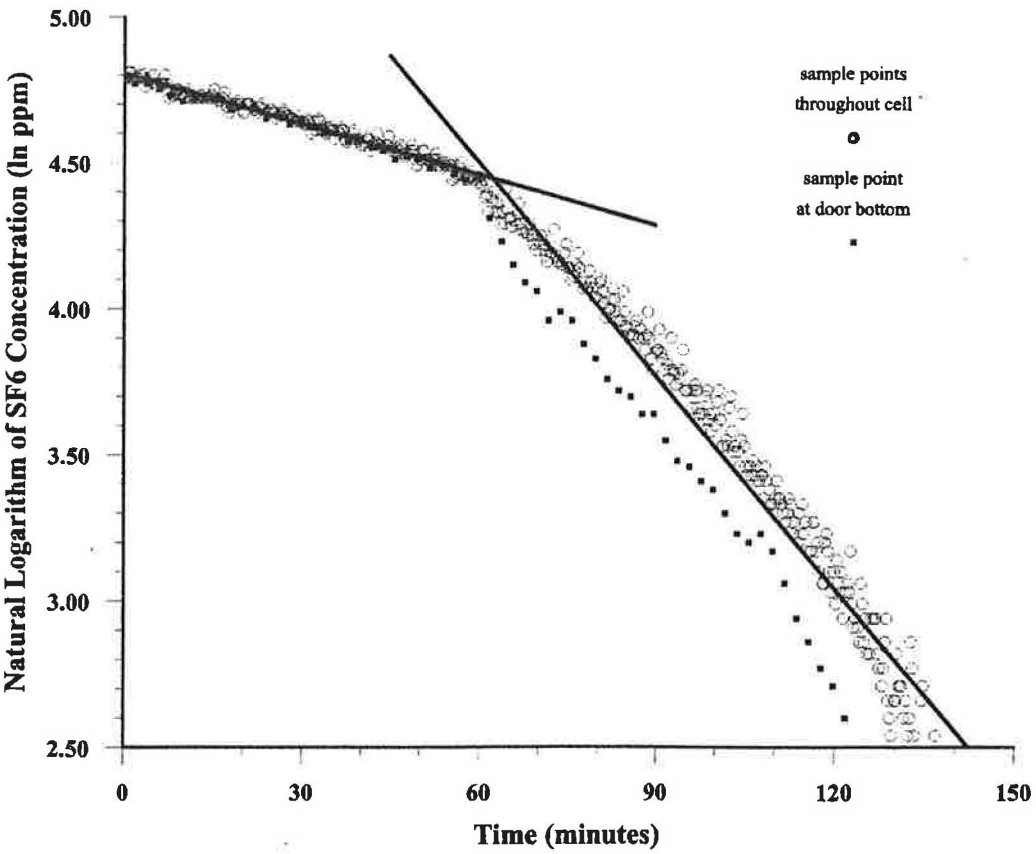

Figure 2 Tracer gas measurement for well sealed lightweight test room

Table 1 Simulated opening size of louvres

Case no.	Louvre positions	Low-level area (m^2)	High-level area (m^2)	Space between openings (m)
1	Closed	0	0	1.5
2	Louvres 1 and 2 at mid-position	0.4	0.4	0.8
3	Louvres 1 and 2 fully open	0.805	0.805	0.1
4	All louvres at mid-position	0.805	0.805	0.8
5	All louvres fully open	1.61	1.61	0.1

inside the room. Despite maximum opening the PPD values for the months of July and August were very high at about 80% and 58% respectively.

3.2 *Medium thermal capacity test room*

In this case a 200 mm thick layer of medium-density concrete block was added to the walls. Simulations were carried out for the same cases as before and the results are shown in Figure 4. A louvre control strategy similar to the above was observed. However for the months of June and September the PPD values were reduced by as much as 50%, and for July and August the PPD values were reduced by 40%. For April, May and October, with the louvres closed, the PPD values were increased by 25%. The main reason for this increase is the thermal capacity of the building, as it takes longer to heat the room as shown in Figure 5. It can be seen that the response of the lightweight room is much faster than that of the medium-weight building.

3.3 *High thermal capacity test room*

The mass additional to the original lightweight walls consisted of a layer of medium concrete block 200 mm thick, an 85 mm thick cavity filled with rigid polyurethane insulation, and a layer of inner brick 100 mm thick. Also a 110 mm thick cavity filled with rigid polyurethane insulation was added to the ceiling.

The results, shown in Figure 6, demonstrate the same control strategy as before but with even lower PPD values than given above for the summer months. The effect of glazing on thermal comfort was investigated by comparing the performance of two types of glazing in the super-insulated test room: single 6 mm float glass and Luxg 6 mm low emissivity (low-*E*) glazing. For the months of April, May and October and for case 1, the Low-*E* glazing resulted in 30% lower PPD values than for single glazing. This resulted from the low-*E* glass acting like a greenhouse and storing heat inside the room. However for the other four months 25% higher PPD values were predicted. (See Figure 7.) For the other four cases of louvre opening, there was no significant difference.

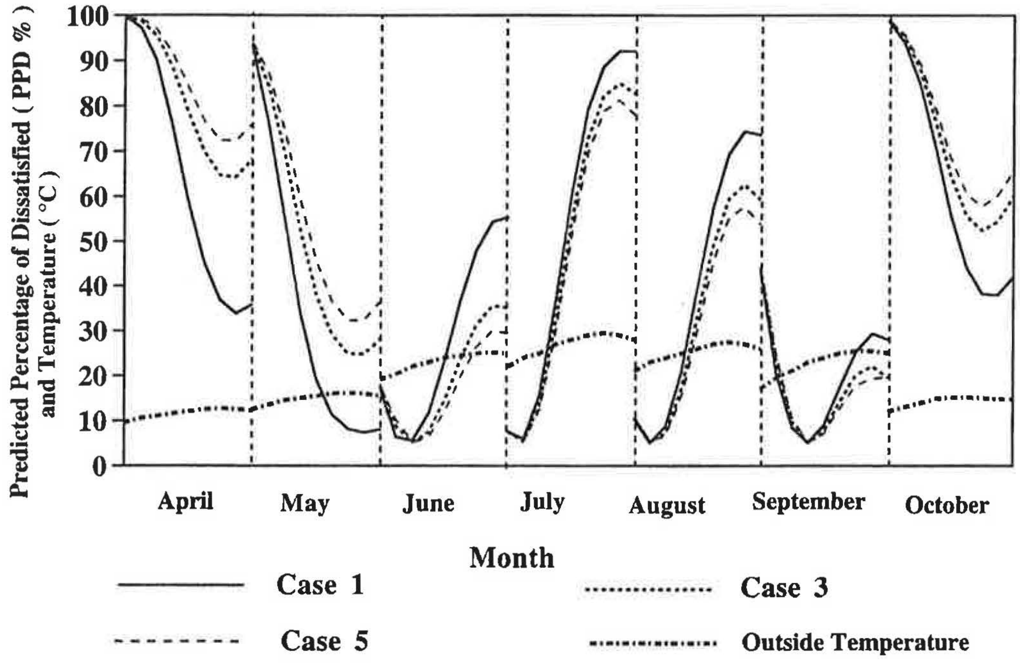

Figure 3 PPD values for lightweight test room with three different louvre positions

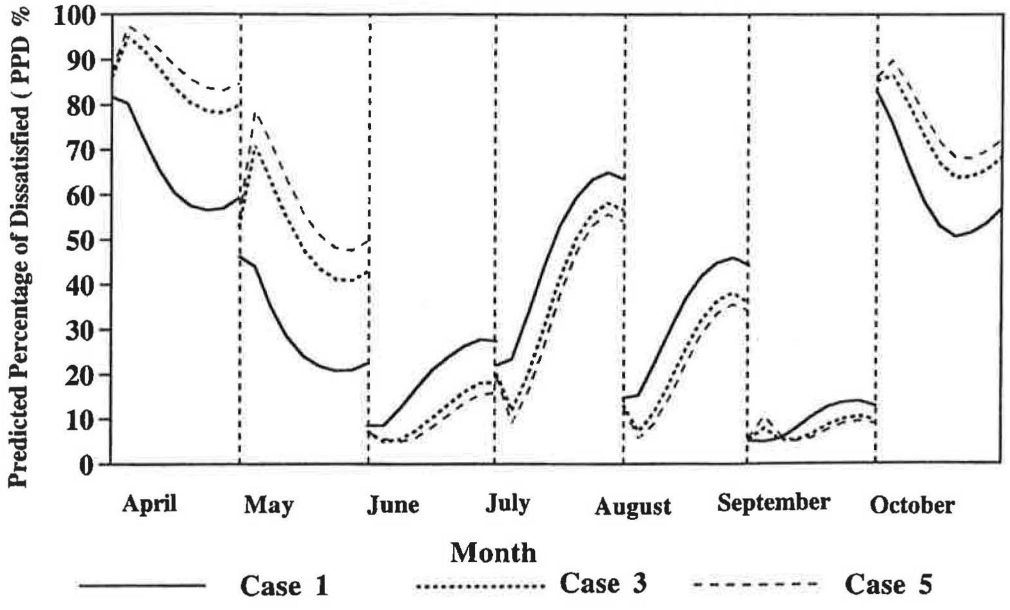

Figure 4 PPD values for medium thermal capacity test room

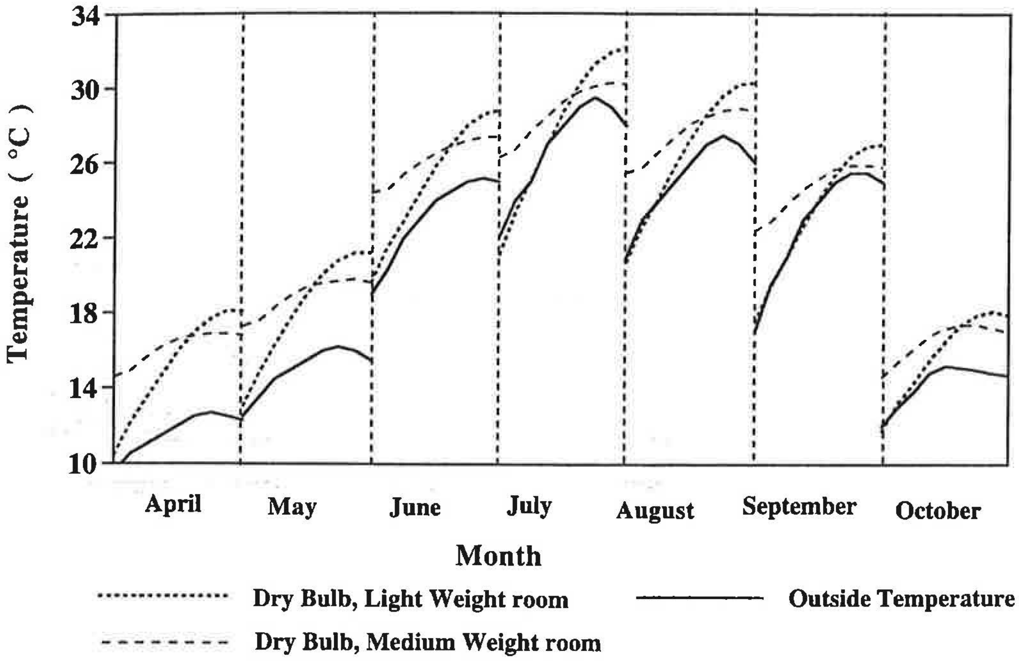

Figure 5 Dry-bulb temperatures for low- and medium-weight test rooms

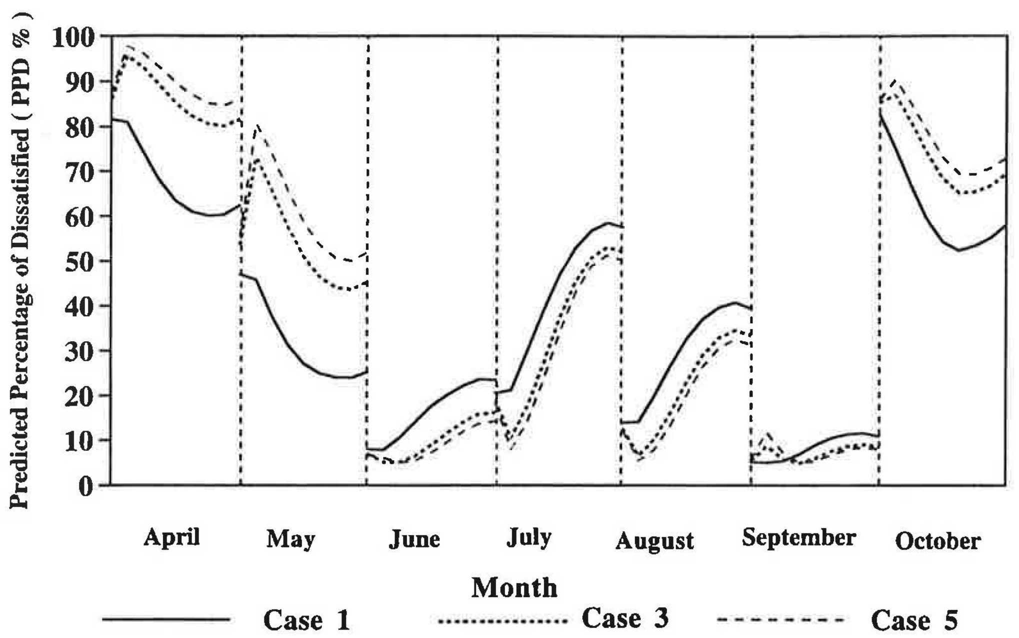

Figure 6 PPD values for high thermal capacity test room

4 Conclusions

Thermal comfort simulations were carried for a naturally ventilated lightweight test room. The results showed that to achieve thermal comfort the control strategy for the months of April, May and October is to close the louvres (case 1); for the months of June, July, August and September it is to have the maximum opening (case 5).

Additional mass was added to the test room and simulations were carried out for medium and high thermal capacities. Similar control strategies were predicted for the two cases. PPD values improved by 20% and 25% respectively.

The effects on thermal comfort parameters of using 6 mm single float glass and Luxg 6 mm new-low-*E* glazing were also investigated. The results showed that thermal performance using low-*E* glass and with the louvres closed (case 1) for April, May and October improved by 25%. For the same case the PPD values for June, July, August and September were increased by 20%. However for the other cases there was no difference and as for these four months the proposed control strategy is maximum opening, the use of low-*E* glass is recommended.

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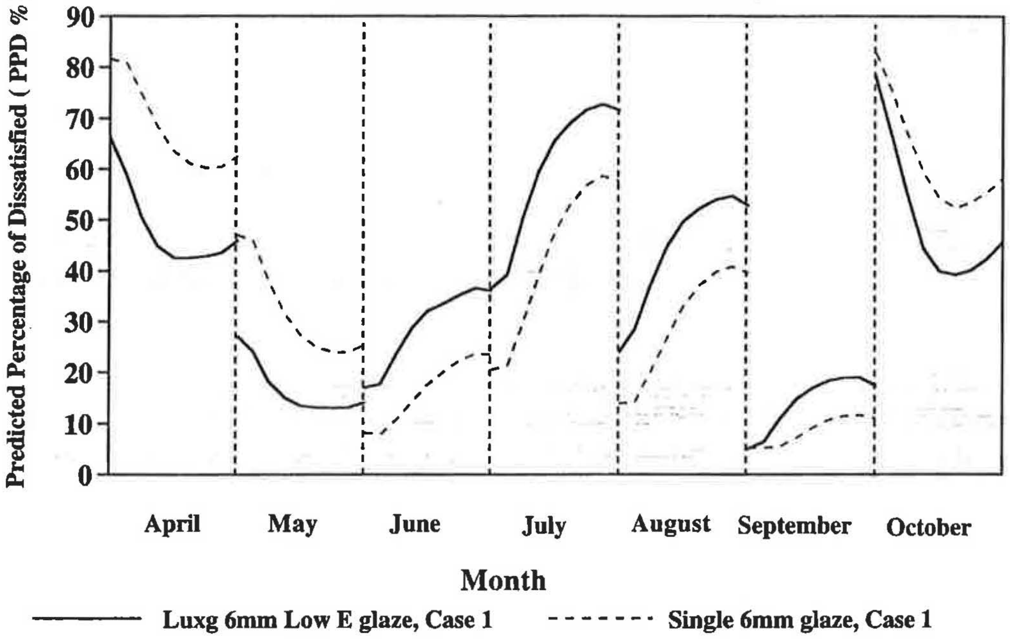

Figure 7 Effect of Low-*E* glazing on PPD values