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Summary The airflow distribution inside a naturally ventilated lightweight test room is investigated. The room is situated in a relatively sheltered location and is ventilated through adjustable louvres. Indoor air temperature and velocity are measured at four locations and at six different levels for various sizes of opening. The outside local temperature, wind velocity and direction are also monitored. The collected data are used to predict thermal comfort parameters across the test room. The experimental results demonstrate that a displacement mode of ventilation is maintained in the space when the wind comes from behind the test room. When the wind impinges on the louvre bulkhead the displacement flow into the room is reduced. Predicted mean votes (PMV) for thermal comfort indicate that values in the afternoon are significantly improved with a higher internal air velocity.

Natural ventilation: Airflow measurements in a lightweight test room

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1 Introduction

There is currently a growing worldwide interest in low-energy building design. An important aspect of this is the goal of maximising the effectiveness of the environmental control provided by the building envelope and minimising the use of mechanical plant, especially in cooling systems. Much attention has been focused on taking advantage of natural ventilation. However, since it is driven by forces which are primarily of a stochastic nature, there is need to evaluate and control the resulting airflow in order to maintain comfortable conditions.

The link between natural ventilation and comfort levels has been studied recently. Matthews[1,2] used a flow network model which took account of both wind and buoyancy forces. It was found that the changes in air temperature along the flow path were not easy to predict and that empirical room air temperature profiles were necessary for the evaluation of thermal comfort. Also, recent experimental studies at Loughborough University[3] demonstrated that thermal comfort can be achieved for most days during summer in a single-sided naturally ventilated office.

The objective of this research was to investigate airflow and temperature distribution for a single-sided naturally ventilated test room. The room is a portable cabin[4] with a volume of 22.2 m^3 located in a sheltered area. The ventilation rate into the room was controlled by adjusting four sets of louvres. The local outside air temperature, humidity, pressure, wind velocity and wind direction were measured. Inside the room the velocity and direction of the inflow air across the high- and low-level openings and temperature and velocity distribution at four locations and six levels across the room were recorded. The experimental results for wind velocities to the face of the louvres and from the behind of the test room are presented. A simulation package developed by Ove Arup, the Room[5] program, was used to determine the PMV values[6] for these two dominant wind directions.

2 Experimental technique

2.1 Test room

The test room for natural ventilation at Loughborough University is a portable cabin of light mass. It is fitted with four sets of horizontal metal slat louvres (Figure 1). Each unit had the overall dimensions of 125 cm wide, 80 cm high and 20 cm deep, and contained five 12 cm wide adjustable louvre blades. Relative to the internal dimensions the louvres covered just over 60% of the bulkhead area with a capability, when fully open, of providing an aperture equivalent to approximately 28% of the bulkhead area. The adjustable louvres were fitted to ensure that significant ventilation entered the test room.

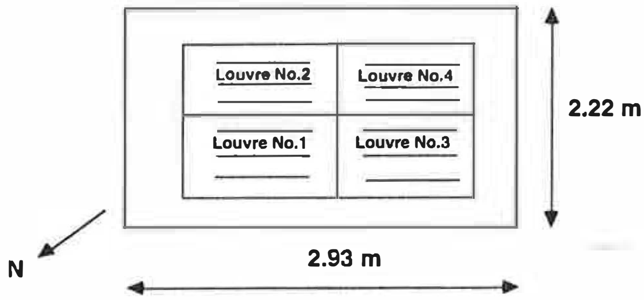

Figure 1 Schematic diagram of louvre arrangement in test room

In order accurately to regulate the degree of opening of the louvre blades while controlling each louvre unit or bank individually to any configuration, a motor actuator was required for each unit. The motors were driven by a 24 V DC supply with a positioning signal ranging from 0–10 V. The motors provided a return signal to indicate their position ranging from 2–10 V. In the experimental configuration 2 V represented fully open and 10 volts fully closed. The system also incorporated a voltmeter reading 0–10 V that could be switched between the motors to measure the return signal, thus allowing the motor to be positioned accurately and consistently.

The internal heat loads inside the room were three computers, one analyser and two 58 W fluorescent luminaires. Due to the sheltered position of the test room there was no solar gain into it. Initially there was a large air infiltration of 8 ac h^{-1} into the room. To reduce the infiltration the door and louvre gaps were completely sealed off. The tracer gas measurements for this new configuration demonstrated that the air change rate was now reduced to 1.3 ac h^{-1}. Details of the U-values and the thermal capacity of the test room are given fully elsewhere[7].

2.2 Instrumentation and data acquisition

Due to the sheltered nature of the test room, the external environmental weather conditions local to the test room were measured. Weather sensors were mounted locally to measure the wind velocity, wind direction, outside air temperature, humidity and pressure. Inside the room, the airflow through the louvre opening, the airflow and temperature across the room were measured. The direction and airflow at the openings were measured using two ultrasonic airflow meters. During the experimental tests the flowmeters designated ultra1 and ultra2 were located in the cell adjacent to the top and bottom openings respectively. During the experiments the areas of the openings at the top and bottom were the same at 0.15 m². The distance between the centre of the openings was 1.25 m. A type 54N10 multichannel flow analyser was used to measure the inside air temperature and velocity at four locations and six levels above the floor. The positioning of indoor sensors is shown in Figure 2.

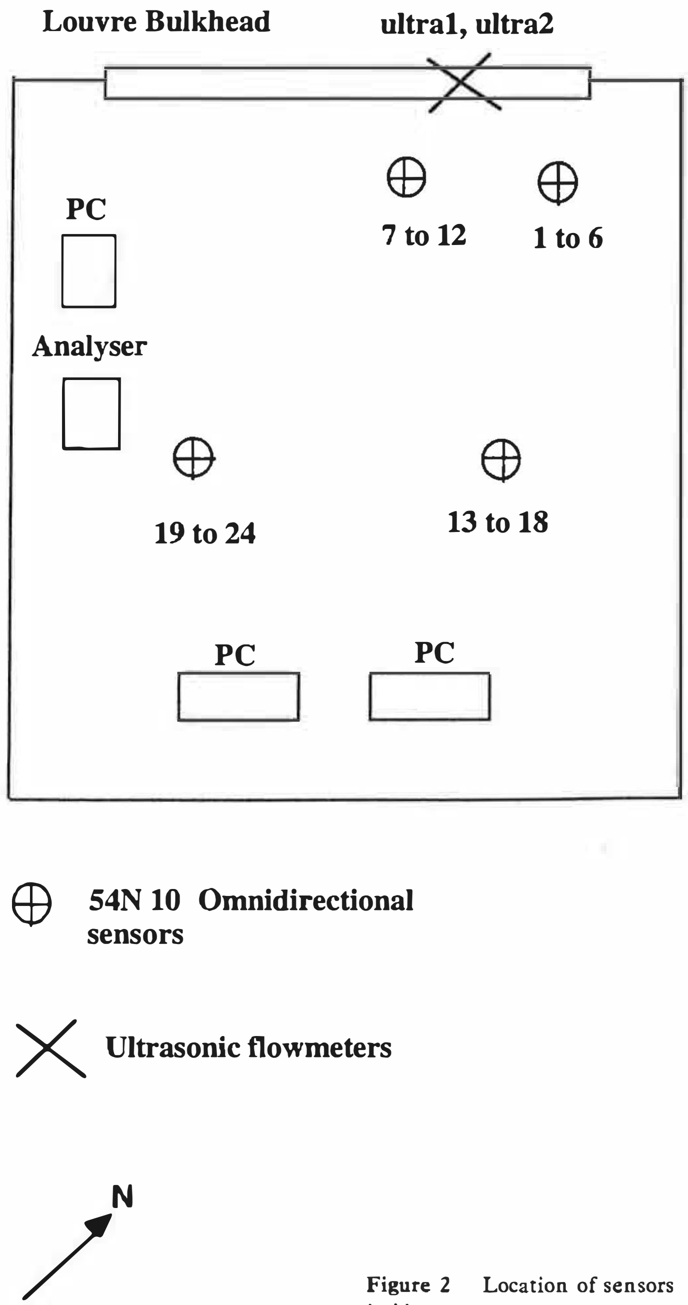

Figure 2 Location of sensors inside test room

3 Experimental results

The results for two different outside wind direction and velocity of 64° N, 2.17 m s⁻¹ and 257° N, 2.22 m s⁻¹ are presented here. Figure 3 shows the outside wind velocity, and velocity variations at upper and lower openings for the wind direction of 64° N (wind blowing from behind of the cabin). The ultrasonic flowmeter located at the bottom opening follows the outside velocity fluctuations, and registered a mean value of 0.4 m s⁻¹. The other flowmeter placed at the high-level opening registered a mean value of 0.05 m s⁻¹. The horizontal components registered by the flowmeters indicated that flow through the higher opening tended to be outward whereas that through the lower opening was inward.

The temperature distributions across the room at the heights of upper and lower openings for all four locations are shown in Figures 4 and 5 respectively. The temperatures are very close together, and follow the outside temperature variation with a maximum temperature difference of 6 °C overnight. However the temperatures at the height of lower opening and the two locations near to the louvres follow the outside temperature very closely (see Figure 5). The temperature distribution at the other two locations in the centre of the room follows the same pattern but with a maximum temperature difference of 4°C.

The outside wind velocity, velocity variations at the upper and lower openings for a mean wind direction of 257° N are shown in Figure 6. The velocities registered by the two ultrasonic flowmeters are very similar, with an average value of 0.1 m s⁻¹. This is mainly due to the direction of the wind as it impinges on the louvre bulkhead. The results indicate that the flow into the room is restricted and that air velocities are much lower than in the first case, mainly due to the direction of the wind. Temperatures at high and low levels are very close together and follow the outside temperature (see Figures 7 and 8).

The collected experimental data were analysed for turbulence intensity. There is no identifiable correlation in turbulence intensity between the driving force (wind) and the driven (measured vent rate) down to the lowest sampling time of four minutes. However, it is apparent that the frequency of pulsation of the vent rate matches that of the wind at the trial sampling rate of two minutes (see Figures 4, 5, 7 and 8).

The ROOM program developed by Ove Arup was used to calculate thermal comfort parameters inside the room for the two different wind directions. The PMVs for a naturally ventilated room, a seated person in light office clothing engaged in light office activity, a total internal heat gain of 150 W, and internal velocities of 0.1 m s⁻¹ and 0.4 m s⁻¹ were calculated. Initially the software was checked for the sensitivity of PMV values to air velocity. It was found that for a velocity range of 0.1–0.4 m s⁻¹ the PMV value for each hour in the afternoon was reduced approximately by 0.1 for an increase of 0.1 m s⁻¹ in internal velocity for the same internal conditions. Figure 9 shows the PMV distributions at 15.00 h for wind blowing from behind the cabin and for wind impinging on the louvre bulkhead (air velocities of 0.4 m s⁻¹ and 0.1 m s⁻¹ respectively). The average PMV value for the latter case is 0.9, and 0.5 for the wind from behind the cabin. The PMV results shown in Table 1 indicated that thermal comfort is improves significantly in the afternoon, with wind blowing from behind the cabin (64° N) resulting in a higher internal air velocity.

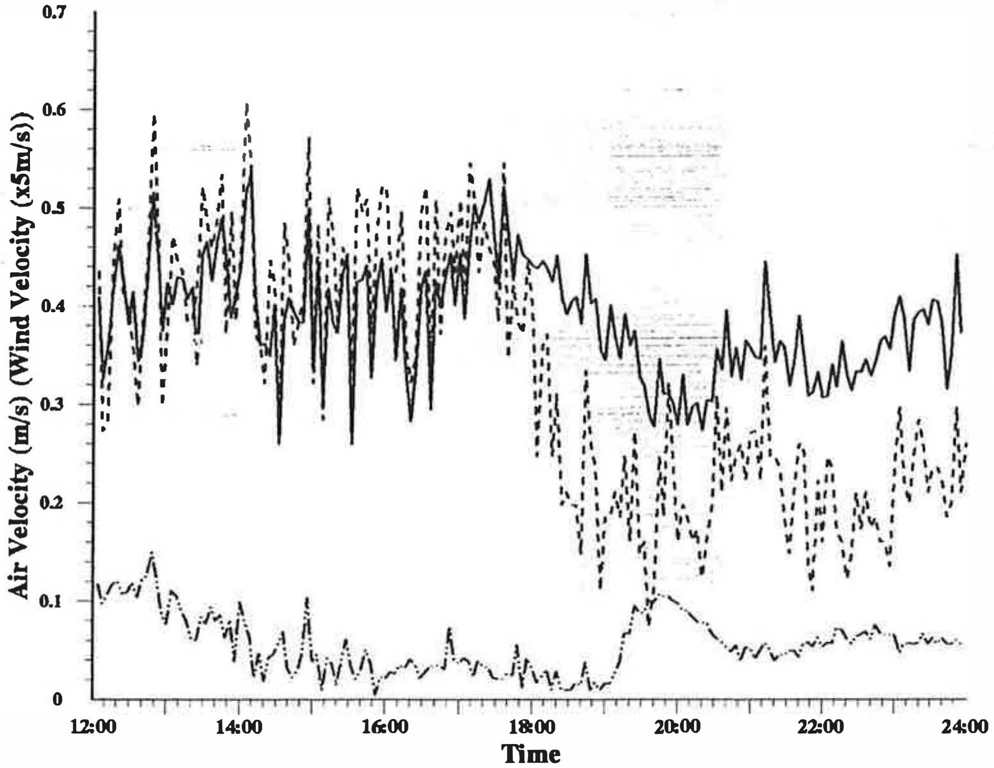

Figure 3 Velocity of wind blowing from behind the test room (64° N), and air velocities at lower and upper opening levels (— — — wind velocity; —·—·— upper opening; —— lower opening)

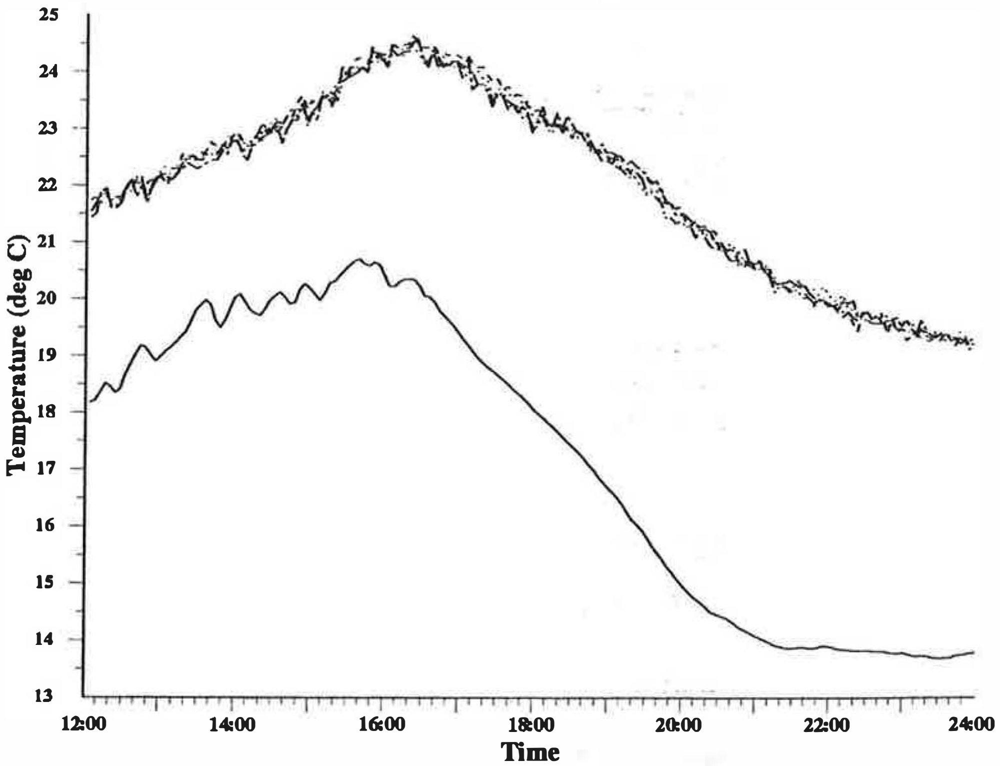

Figure 4 Temperature variations at heights of upper opening across the room for wind direction 64° N (—— external; —·—·— channel 1; — · — · — · — channel 7; – – – – – – channel 13; · · · · · · channel 19)

Table 1 PMV values for the two different wind directions

Wind direction	Time (h) 09.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00
64°N	–1.5	–1.3	–0.9	–0.4	0	0.3	0.5	0.6	0.6
257°N	–0.8	–0.7	–0.3	0.1	0.5	0.8	0.9	1.0	0.9

4 Conclusions

In general the measurements demonstrated air movement inside the room. Sensors further into the room away from the louvres showed less airflow and variation in temperature, whereas sensors closer to the openings recorded more air movement particularly at low levels. The velocity at low levels was significantly affected by the direction of the wind. For a wind direction facing the louvres the air velocity was

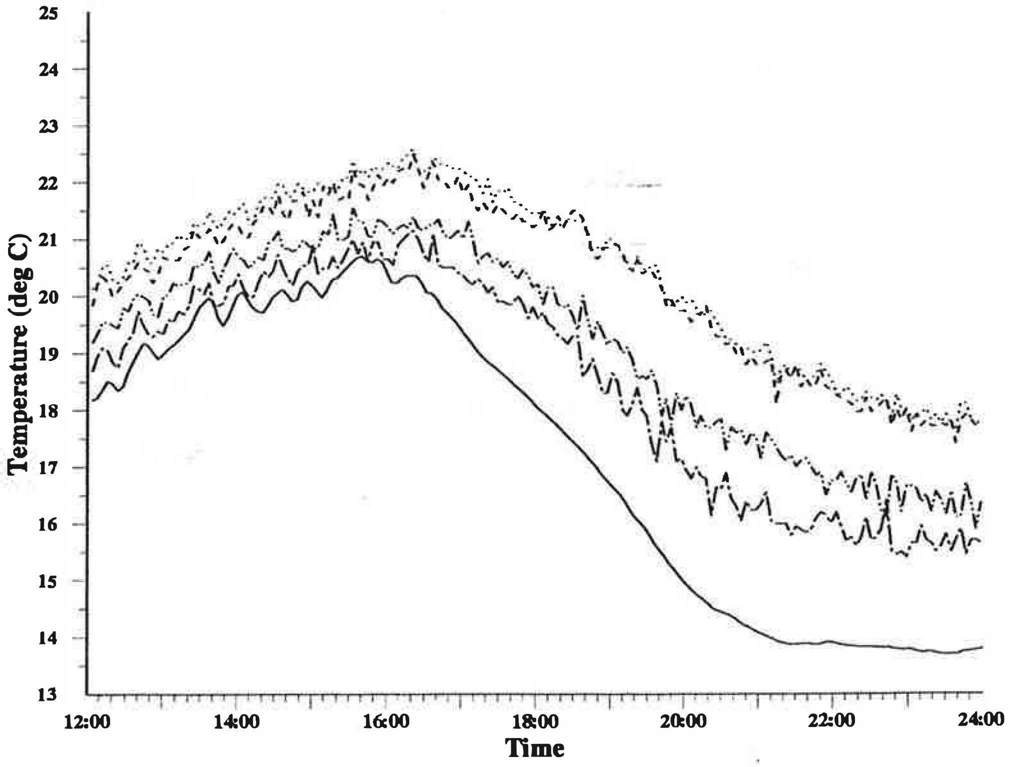

Figure 5 Temperature variations at heights of lower opening across the room for wind direction 64° N (—— external; —·—·— channel 5; — - — - — - channel 11; – – – – – – channel 17; · · · · · · channel 23)

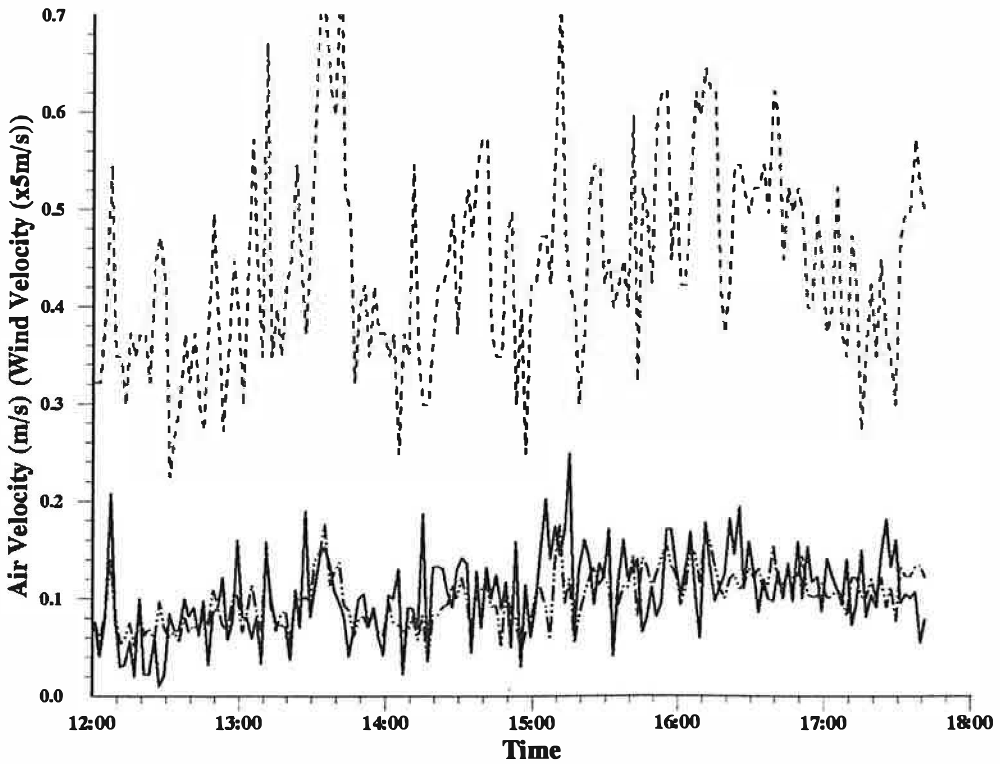

Figure 6 Wind velocity impinging on the face of the louvres (257° N), and air velocities at lower and upper opening levels (– – – wind velocity; —· —·— upper opening; —— lower opening)

0.1 m s^{-1}, and for a wind direction from behind the test room the velocity was measured as 0.4 m s^{-1}. However the air velocity at low level followed the outside wind velocity and was greater than the velocity at the higher opening. Flow through the higher opening tended to be outward, whereas through the lower opening the trend was inward flow. The internal temperature in all cases was higher than that outside, due to the internal heat gains, which would suggest the main reason for the warmer air leaving the room at the higher opening. The experimental results demonstrated that a displacement mode of ventilation is maintained in the space when the wind either comes from behind the test room or impinges directly on the louvre bulkhead. Thermal comfort simulations demonstrated that a wind direction from behind the test room resulted in a higher internal air velocity which improved the average PMV values in the afternoom by 40%.

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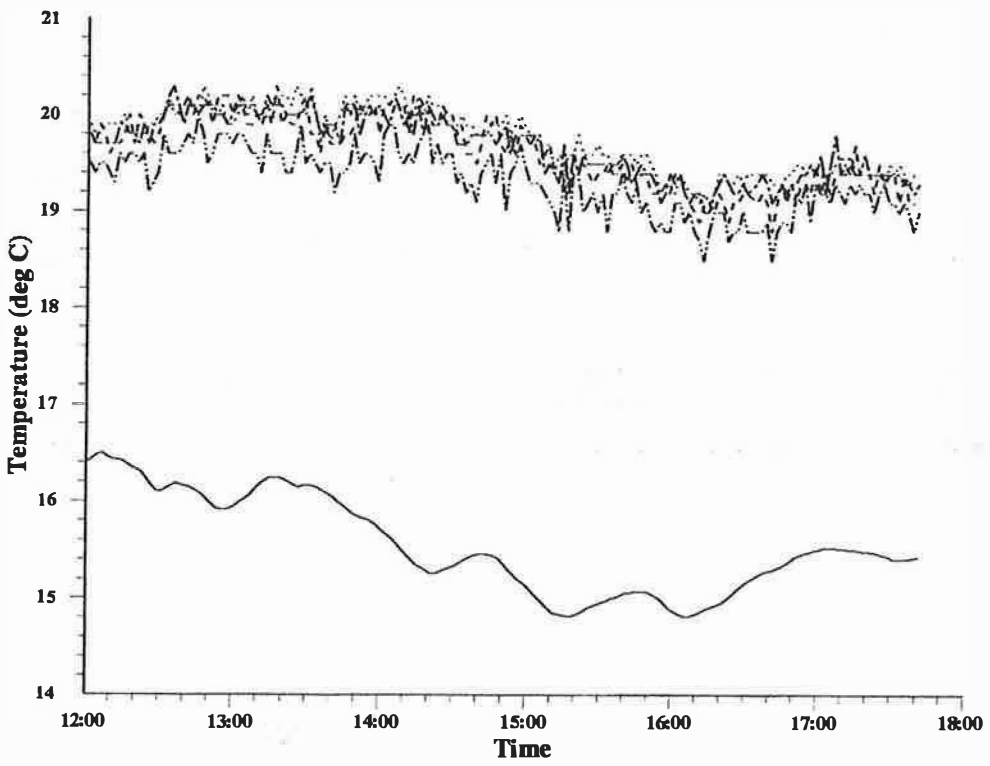

Figure 7 Temperature variations at heights of upper and lower openings across the room for wind direction 257° N (—— external; — — —— — channel 1; — · — · — · — channel 7; – – – – – – channel 13; · · · · · · channel 19)

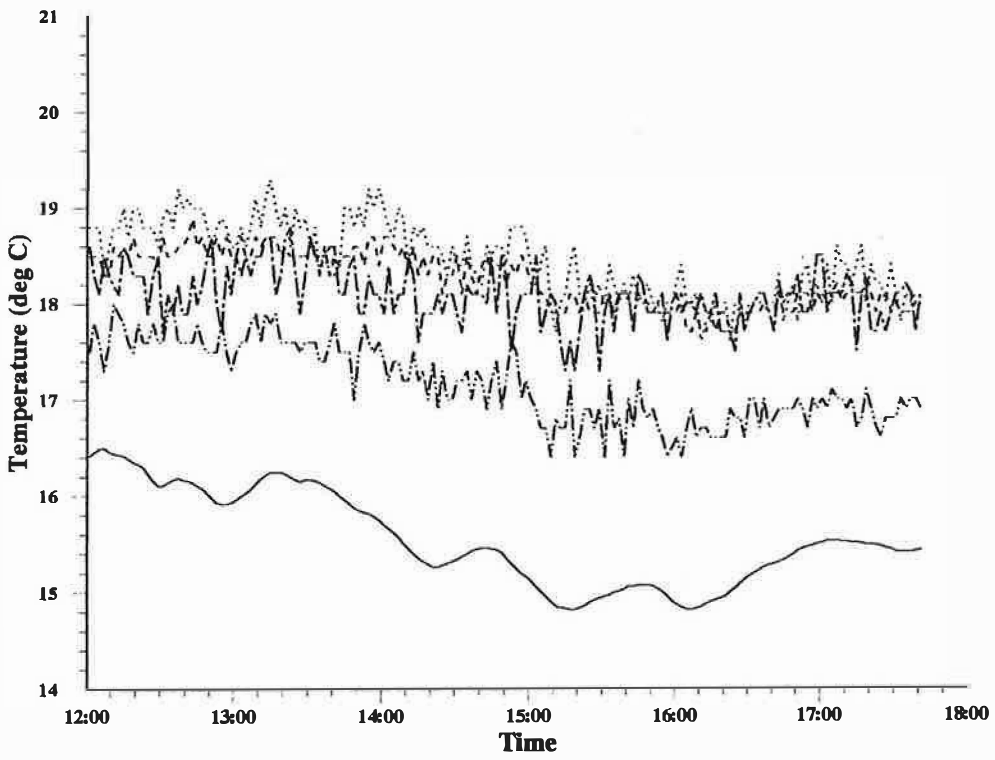

Figure 8 Temperature variations at heights of upper and lower openings across the room for wind direction 257° N (—— external; — — — — — channel 5; — · — · — · — channel 11; – – – – – – channel 17; · · · · · · channel 23)

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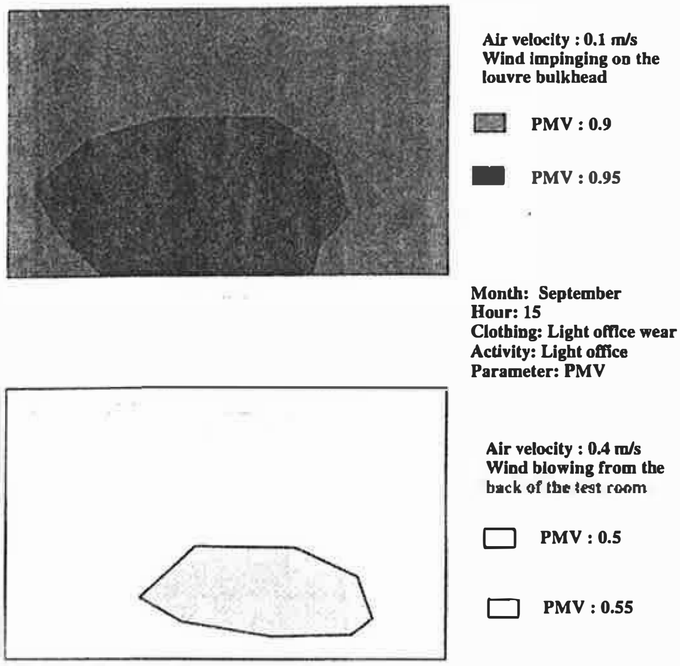

Figure 9 PMV distribution at 15.00 h for wind direction 64° N and 257° N