THERMAL COMFORT AND AIR FLOW MEASUREMENTS IN A SINGLE-SIDED NATURALLY VENTILATED ROOM

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ABSTRACT

The objective of this research is to investigate thermal comfort and air flow distribution inside a test room which is naturally ventilated. The test room is ventilated through adjustable louvers. The air pressures and velocities across the openings together with indoor air temperature and mean velocity at four locations and six different levels are measured. The collected data are used to predict thermal comfort parameters across the test room. Tests were carried out over the winter and summer time. The experimental results demonstrate that for both winter and summer the air was entering the test room at bottom and leaving at the top louver. The amount of air flow over the winter was increased as the heat input varied from 2 kW to 4 kW. The predicted thermal comfort indicated that the Percentage of People Dissatisfied (PPD) values for summer are significantly improved with a higher temperature difference between inside and outside and higher wind velocity.

INTRODUCTION

The link between natural ventilation and comfort levels has been studied in some recently reported work. 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 in a single-sided naturally ventilated portable cabin at Loughborough University [3] demonstrated that thermal comfort can be achieved for most days during summer.

The objective of this research was to investigate air flow and thermal comfort distribution in a single-sided naturally ventilated test room over the winter and summer. The room is a portable cabin [4] located in a sheltered area. The ventilation rate into the room was controlled by adjusting two sets of louvers. Inside the room the pressure, 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 local outside air temperature, humidity, pressure and wind velocity and direction were measured. The experimental results for winter and summer are presented. A simulation package developed by Ove Arup, Room [5] program was used to predict the PPD values [6] for the above measurements.

METHODS

An existing portable cabin of light mass is used as a test room for natural ventilation at Loughborough University, which is fitted with four sets of horizontal slats metal louvers. The adjustable louvers were fitted to ensure that a minimum ventilation of 8 l/sec/person was achieved inside the test room. The room was divided into four zones and for each zone the temperature and velocity stratification were measured.

During summer the internal heat loads inside the room were three computers, one analyser and two 58 W fluorescent luminaries. Over the winter period additional 2kW and 4 kW heaters were used. Due to the sheltered position of the test room there was no direct solar gain into the room. Details of the U-values and the thermal capacity of the test room are described fully in another paper [7].

Due to the sheltered nature of the test room, the external environmental weather conditions local to the test room were measured. Weather station sensors were mounted locally which measured the wind velocity, direction, outside air temperature, humidity and pressure. Inside the room, the air flow through the louver opening, mean air velocity and temperature inside the room were measured. The direction and air flow at the openings were measured using four ultrasonic air flow meters. The total pressure at top and bottom levels inside and outside across the louvers was recorded using low pressure differential transducers manufactured by Furness type FC044. The reference pressure for all pressure measurements was the static pressure inside the room taken at approximately 1m from the floor. During the experiments the size of the opening at the top and bottom was 0.07 m^2 and 0.12 m^2 respectively with a 1.25 m distance between the centre of the openings. Type 54N10 multichannel flow analyser was used for the measurements of the inside air temperature and velocity at four locations and six levels above the floor. The positioning of indoor sensors is shown in Figure 1.

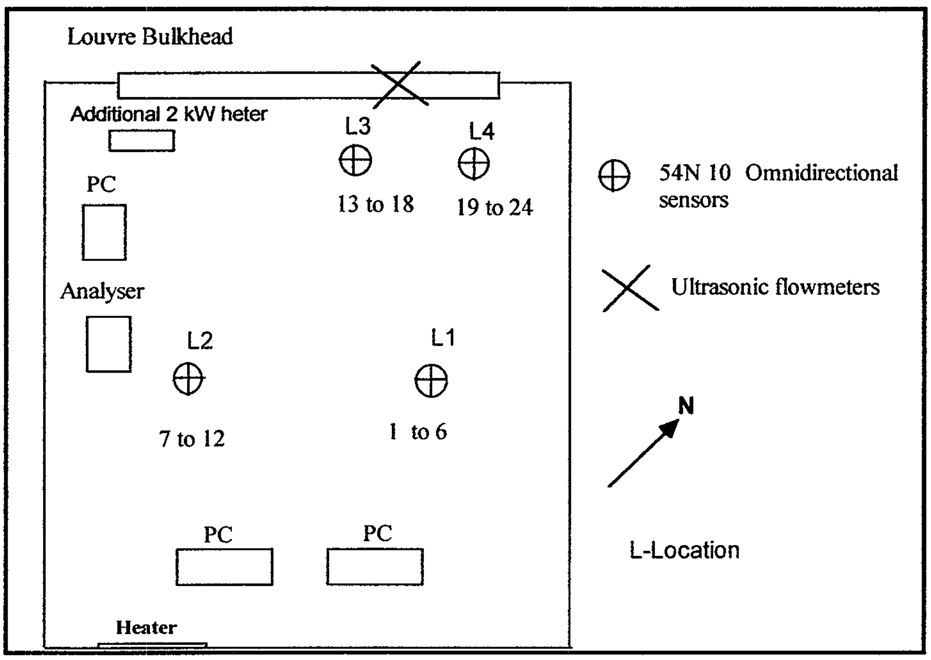

Figure 1. The location of the sensors inside the test room and across the louver

RESULTS

The results for two typical winter days are presented here. On 15 January, test 1, the heat load inside the room was 2kW and for test 2, 4 February 98 the heat load was increased to 4 kW. The local outside temperature wind speed and direction for both tests are shown in Figure 2. The average outside temperature for test 1 and test 2 was about 8.5°C and 7.9°C respectively. For both days the wind direction was windward (i.e. towards the louvred bulkhead) with an average of 2 m/s for test 1 and 1.4 m/s for test 2.

The temperature variations across the room at six different levels are shown in Figure 3. For both tests the temperature at lowest level is low and is increased with the distance from the floor and is the highest at head level. However the temperature difference between head and lowest level is more than 3 °C, which does not satisfy the thermal comfort requirements defined by ISO 7730. The air velocities measured at lowest levels were doubled as the heat load inside the room was increased to 4 kW.

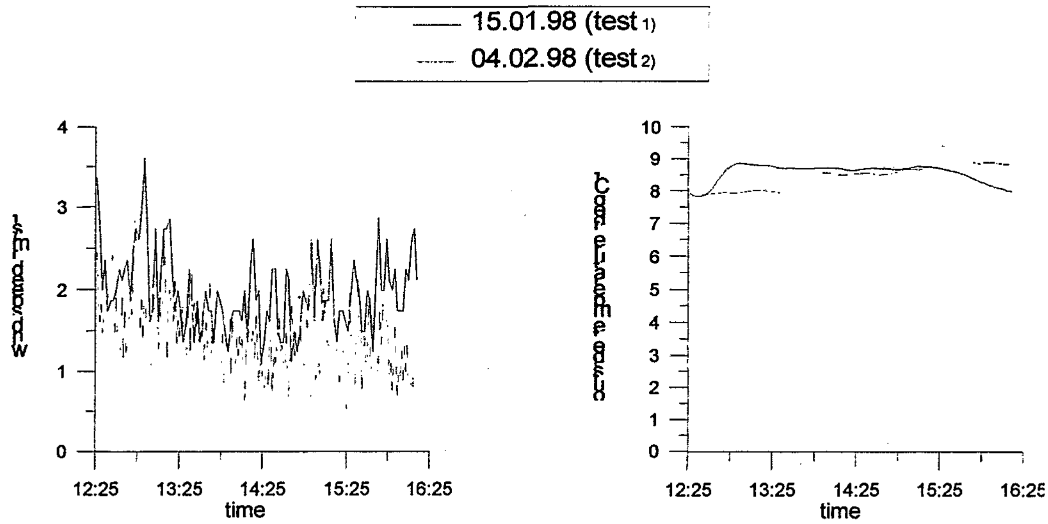

Figure 2. The outside condition for winter tests

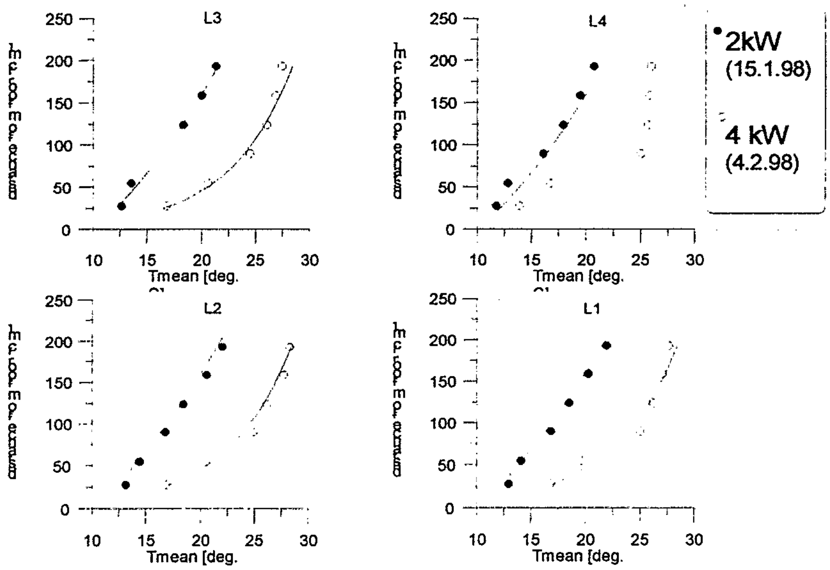

Figure 3. The temperature variations with height for winter tests

The results for two typical summer days are presented below. For test 3, 19 June 98, the outside temperature was 23.54 °C with an average wind speed of 1.12 m/s. Test 4 was carried out on 22 June 98, with an outside temperature of 18.4 and an average wind speed of 2.18

m/s. For both days the wind direction was windward. The differential pressure and the component of velocity in the direction perpendicular to the louver (indicated by "v") at the two levels showed that air was entering the room from the bottom louver and leaving at the top opening (see Figure 4). For the test 3 there were some local eddies suggests again downward air flow. The temperature distribution across the room in all locations demonstrated that the temperature difference between head and lowest level are less than 3 °C. Similar mean velocity distributions as winter time were recorded where air velocity was high at lowest level. For test 3 the average velocity was about 10% higher than test 4 for all locations.

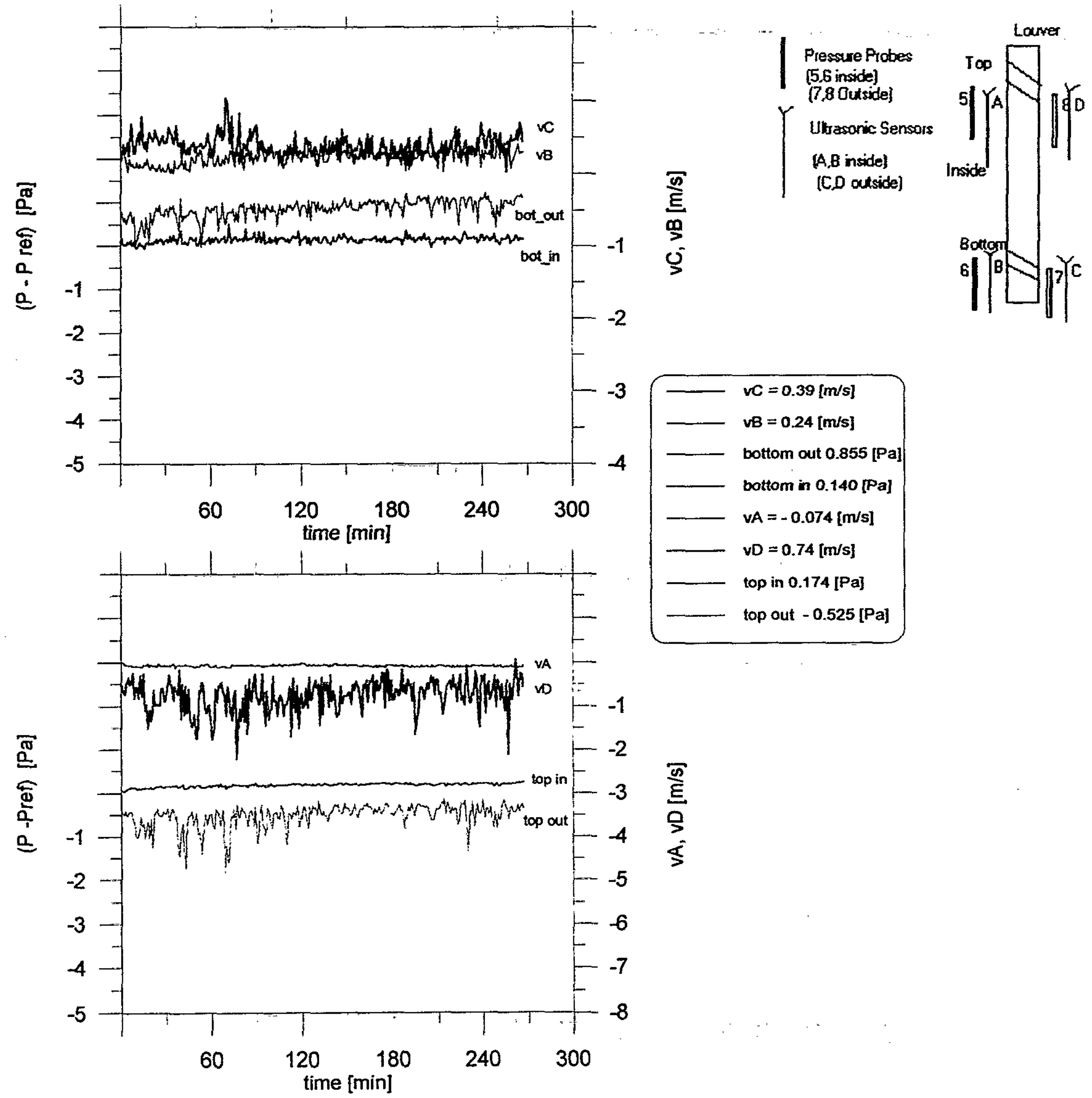

Figure 4. Variation of Pressure and v-component of ultrasonics at the openings for tests 3 & 4

The ROOM program developed by Ove Arup was used to calculate thermal comfort parameters inside the room for winter and summer tests. Full details of the simulation program are found in the Room User Manual [5]. The program calculates the thermal and comfort conditions within a single space, for a typical day in a selected month, under dynamic thermal loading. The numerical model used is based on an explicit finite difference formulation for unsteady heat flows within the building fabric.

The predicted average PPD values for a naturally ventilated room, a seated person with light office wear and light office activity, a total internal heat gain of 150 W, and internal velocities of 0.1 m/s for summer and 0.05 m/s for winter were calculated. For winter tests the appropriate heat gains were simulated (see Table 1).

Table 1 Summary of the simulated tests

Date	Mean wind speed (m/s)	Mean outside temperature (°C)	Mean pressure coefficient difference	T_{in} - T_{out} (°C)	Heat load (kW)
15.01.98 - Test 1	1.99	8.5	-0.704	12.5	2.0
04.02.98 - Test 2	1.40	7.9	-1.173	13.2	4.0
19.06.98 - Test 3	1.12	23.5	-1.096	1.9	-
22.06.98 - Test 4	2.18	18.4	-0.776	6.1	-

The winter comfort results are shown in Figure 5. For test 1, the PPD at 9 a.m. was about 100% as there was no heating on overnight. Gradually during the day PPD was reduced to 40%. For test 2, after 2 hours the PPD was reduced from 100% to 10% and after middy remained constant at 5%. Overall the thermal comfort is improved with the increase of the heat load, due to large temperature difference between inside and outside (T_{in} - T_{out}).

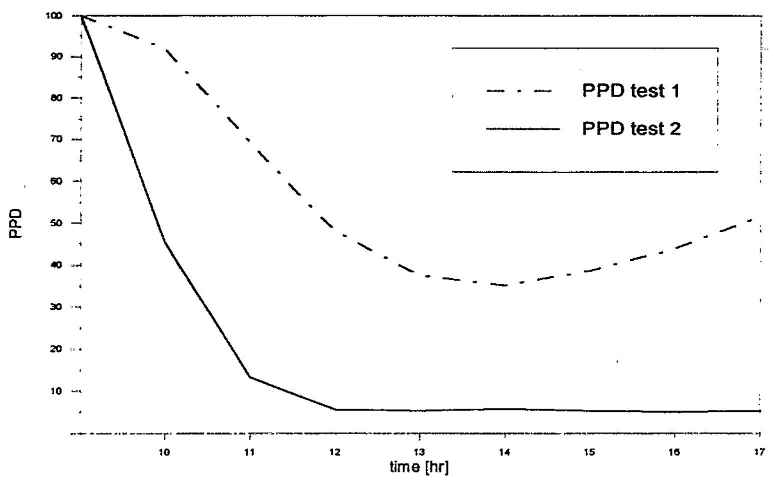

Figure 5. Variation of thermal comfort parameter for winter tests

During summer conditions for test 3, the steady state value of PPD was about 20% and for test 4 the steady value was about 15%. This improvement of thermal comfort is mainly due to the higher temperature difference (T_{in} - T_{out}) and also increased indoor air movement resulted from higher wind velocity (see Table 1).

DISCUSSION

In general the measurements demonstrated considerable air movement inside the room. The indoor airflow appeared to be driven by both induced air motion through the openings and buoyant air motion caused by the temperature stratification inside the room.

For both winter and summer conditions 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 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 data collected for winter tests measuring temperature stratification at four different locations across the room could all be expressed in form of an exponential equation. For summer tests the data could be fitted by a linear curve, with a temperature difference between lowest level and head of less than 3 °C. During winter the overall comfort was very poor and there was significant temperature difference between lowest and head levels. However thermal comfort simulations demonstrated that for winter the PPD values were improved by 40% for higher internal heat gain of 4 kW. During summer thermal comfort was improved by 5% for higher wind velocity and higher temperature difference between inside and outside.

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