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PREDICTING AIR FLOW DISTRIBUTION IN A NATURALLY VENTILATED ROOM

M.M. Eftekhari, L. D. Marjanovic[1], V. I. Hanby and A.D'Ovidio[2]

[1]Department of Civil & Building Engineering, Loughborough University, U.K.
[2]Departement of Engineering, University of Leicester, UK

ABSTRACT

The objective of this research is to predict the air flow distribution in a room that is naturally ventilated. The VENT simulation program is used to predict the spatial distribution of the air flow. The program calculates the thermal condition 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. Both buoyancy driven ventilation module, stack effect (based on the current mean internal temperature and the external dry bulb temperature) and the wind driven ventilation can be computed with the code. The predicted flow is then compared to the experimental data collected in a test room with and without heating. The test room is ventilated through adjustable louvers. The air pressures and velocities across the openings together with indoor air temperature and velocity at four locations and six different levels are measured. In general the measurements demonstrated considerable air movement inside the room and the air was entering the test room at bottom and leaving at the top louver. The VENT program was fed with the present measured data, namely the averaged external temperature and the mean pressure coefficients measured for the specific test. The predicted flow showed similar trend and the simulation results were in close agreement with the measured data when there was no heating in the room.

KEYWORDS

Natural ventilation, simulated and measured air flow distribution

INTRODUCTION

The distribution of fresh air and effectiveness of the depth of a room for single-sided natural ventilation has been assessed by Walker (1992). From the tracer gas measurements carried out in a room of 10 m deep it can be seen that the comfortable temperatures can be maintained with relatively modest design features to reduce solar gain and its effect. To model and test natural ventilation flow, Lane Serff and Smeed (1990) have constructed laboratory models from clear perspex, which allows the visualization of the flow. They used water as the working fluid and added salt to produce density differences. The different salt concentration represents different temperatures. Similar experiments for a displacement system has been carried out by Sandberg and Holmberg (1990) where water was used as operating fluid. Also recent experimental studies in a single-sided naturally ventilated portable cabin at Loughborough University, Eftekhari (1998), demonstrated considerable air movement inside the room. These studies show that experimental data for temperature profiles are necessary to evaluate the thermal comfort. These researches indicate that the increase in the temperature of the supply air stream as it progresses across the room is not easy to predict, Boutet (1987). It seems to vary with supply air flow rate, height of the supply air terminal, and the difference between supply air and room temperatures.

The objective of this paper is to predict the air flow distribution in a single-sided naturally ventilated test room over the winter period. The room is a portable cabin (Portakabin 1994) with a volume of 22.2 m^3 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 lowest level was at the same height as the bottom opening, at approximately 0.25 m above the floor.

The local outside air temperature, humidity, pressures and wind velocity and direction were measured. The experimental results for winter are presented. A simulation package (Ove Arup, 1996), VENT program was used to predict the air flow distribution for the above measurements.

EXPERIMENTAL AND SIMULATION TECHNIQUE

Experimental set up

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.

Over the winter period additional 2kW and 4 kW heaters were used. Due to the sheltered position of the test room there was no solar gain into the room. The tracer gas measurements for these new arrangements demonstrated that the air change per hour was now reduced to 1.3. Details of the U-values and the thermal capacity of the test room are described fully in another paper, Eftekhari (1998).

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 1.25m distance between the center 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.

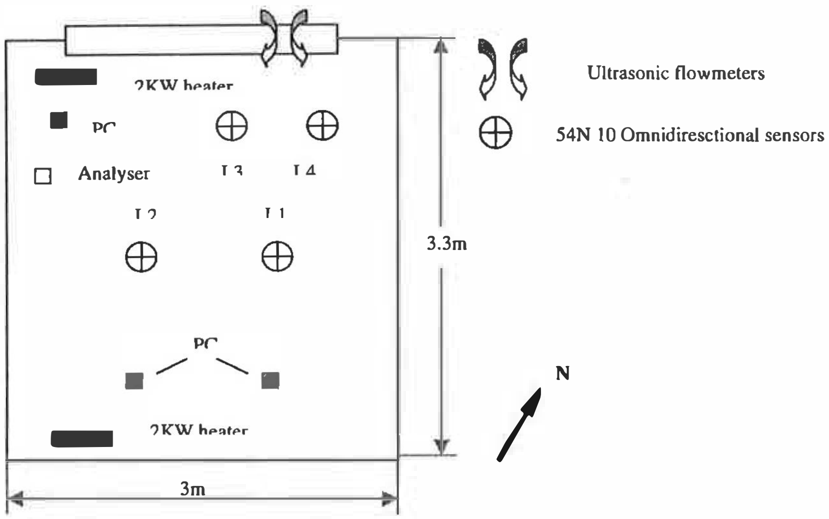

Figure 1 : The location of the sensors inside the test room and across the louver

Simulation Package

The VENT program is used to predict the temperature and velocity distribution inside the room. It calculates the bulk air movements within a building which are driven by buoyancy forces arising from temperature variations and wind pressures in a naturally ventilated building. The program calculates flow rates from specified wind speed, internal and external temperature.

In order to simulate temperature distribution across the cabin, cabin had to be fictitiously divided in 27 rooms of equal size and 0.8m^3 volume as simulation program VENT is based on one zone model. Predicted room temperatures were chosen to be the temperature in the middle of each zone. In the program, the option with some fixed temperature was selected. Four temperatures at low level in the room were chosen to be fixed and set to have the same values as the measured temperatures. In order to predict air movement inside the cabin, each fictitious room was connected through the crack and hole type opening.

RESULTS

The results for two typical winter days are presented here. On 4th February, test 1, the heat load was 4 kW and for the test 2, 13th February 98 there was no heating inside the room. The measured 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 7.9°C and 15.3°C respectively. For both days the wind direction was windward with an average of 1.4 m/s for test 1 and 1.79 m/s for test 2.

The pressure difference and the direction of the flow across the louvers, indicated that air is entering at bottom louver and leaving at the top for both tests. For test 2 the amount of air flow is increased as the heat input is 4 kW.

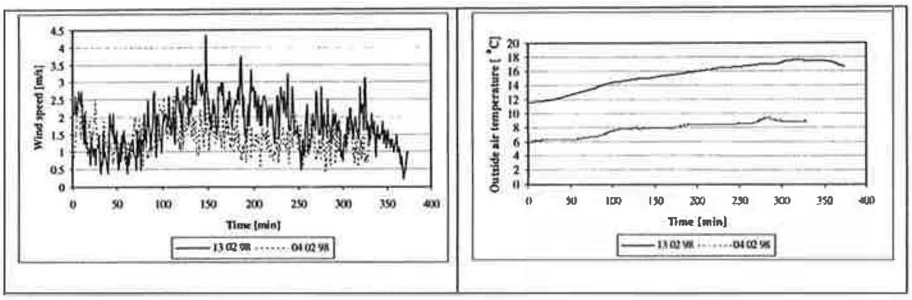

Figure 2 : The outside condition for tests 1 and 2

The simulated and experimental temperature variations across the room at six different levels are shown in Figure 3. For both tests the measured 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.
For the test 1, simulated results show rather good agreement with measured data. But for the test 2 with additional heating in the test room, the difference between simulated and measured temperatures at high level was about 3 °C.

The VENT program was used to predict the air flow distribution between each room. The predicted flow distribution for the test 2 is shown in Figure 4. The air velocity between each room is shown in Table1. The predicted air flow demonstrated that air is flowing into the room from the bottom louvre and leaving at top.

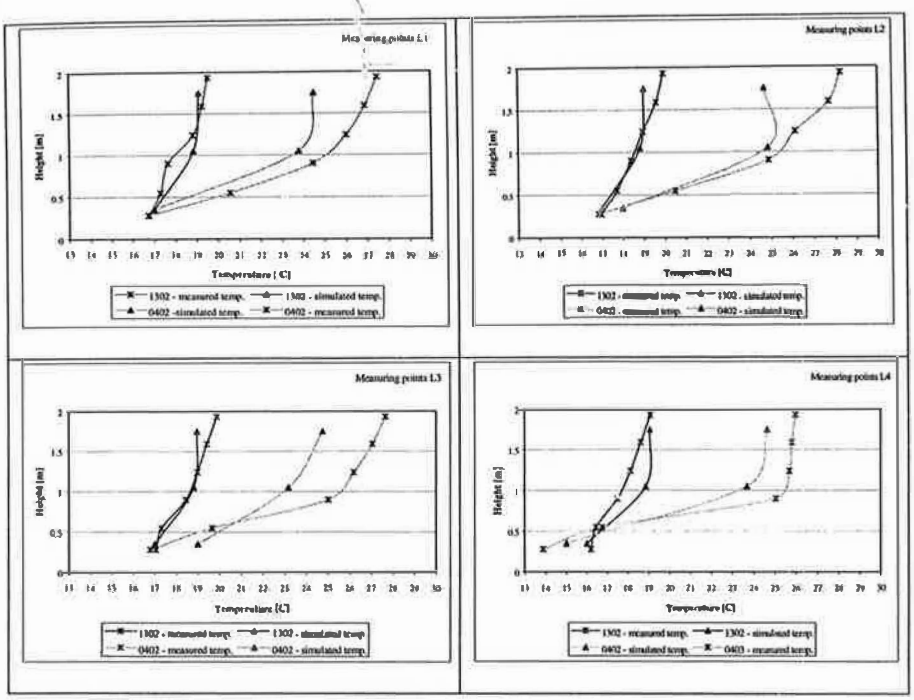

Figure 3 : The simulated and experimental temperature variations with height

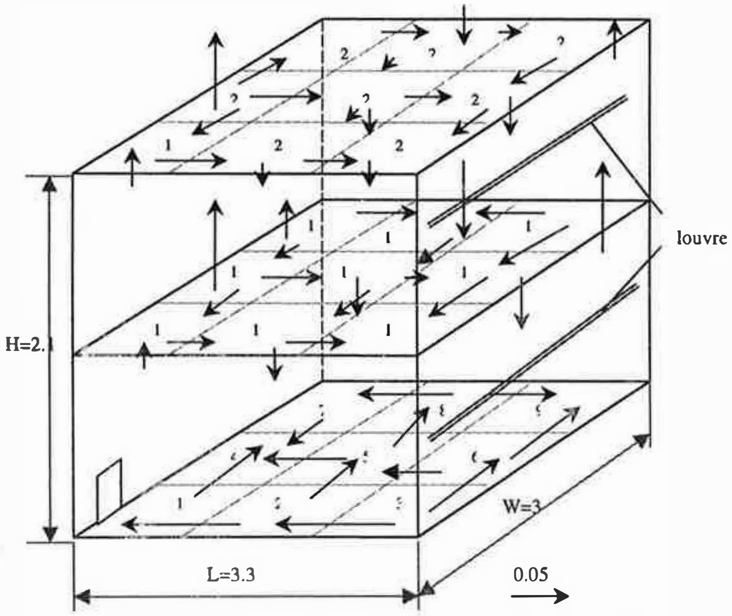

Figure 4 : The predicted air flow pattern for the test 2

TABLE 1
PREDICTED AIR VELOCITY BETWEEN EACH ROOM

Room	3-2	3-6	3-12	2-1	2-5	2-11	1-4	1-10	6-5	6-9	6-15
Vel (m/s).	*0.094*	*0.089*	*0.072*	*0.097*	*0.044*	*0.033*	*0.068*	*0.014*	*0.054*	*0.092*	*0.037*
Room	5-4	5-8	5-14	4-7	4-13	9-8	9-18	8-7	8-17	7-16	
Vel (m/s).	*0.11*	*0.037*	*0.031*	*0.029*	*0.138*	*0.064*	*0.105*	*0.099*	*0.078*	*0.043*	
Room	12-15	12-11	12-21	11-10	11-14	11-20	10-13	10-19	15-18	15-14	
Vel (m/s).	*0.053*	*0.043*	*0.007*	*0.049*	*0.032*	*0.006*	*0.04*	*0.011*	*0.065*	*0.009*	
Room	15-24	14-17	14-13	14-23	13-22	18-17	18-27	17-16	17-26	16-25	
Vel (m/s).	*0.023*	*0.02*	*0.054*	*0.011*	*0.084*	*0.061*	*0.021*	*0.052*	*0.02*	*0.001*	
Room	21-20	21-24	20-19	20-23	19-22	24-23	23-26	22-25	27-26		
Vel .(m/s)	*0.05*	*0.036*	*0.05*	*0.009*	*0.03*	*0.036*	*0.005*	*0.038*	*0.007*		

CONCLUSIONS

The experimental measurements demonstrated considerable air movement inside the test room. 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. For test 2, the difference between low and high level temperatures was less than 3 °C and for test 1, with additional heating this was increased to 10 °C. For test 2 with no heating the simulated temperatures followed the experimental results very closely for all four locations (see Figure 3). For test 1 the simulated pattern was the same as the experimental one but with lower temperature at the top level. This indicates that the simulation program is not sensitive to the heating condition. The predicted and measured air flow patterns indicated that the air was entering the room at the bottom level and leaving at the top louvre. 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.

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