Energy Efficient Buildings :Investigation of Thermal Comfort

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ABSTARCT

The construction of energy efficient buildings is a major interest of building research centers around the world, since any saving in energy here can be directed to industrial purposes. The effort was therefore concentrated upon reduction of building energy, which is consumed by various systems such as air conditioning, being the major consumer of the energy supplied to a building. Other but small consumers include lighting, pumps, and appliances. Hence, as a building designer succeeds to reduce the energy needed for an air conditioning system or to replace the later by some natural ventilation arrangement that carries the heating load, the building is then energy efficient. In the present work the possibility of heat removal through natural ventilation is examined for various wind directions (0, 45, 90, and 135°) and window configurations and combinations. The investigation was carried out in a wind-tunnel test facility which was designed, built and tested at the Housing and Building Research Center (**HBRC**), Guirguis [1]. The tunnel floor was provided with rotatable disc on which the model was mounted and set at any required angle (α) relative to wind direction. The present suction-type wind-tunnel test facility has a working section 1.0 m wide, 1.0 m high and 2.0 m long, serving the purpose of testing building models of size that permitted the observation of phenomena with reasonable accuracy. The duct was provided with a standard-profile intake. Turbulence-generating grids were constructed and mounted some distance ahead of the test model to obtain turbulent "shear-like" ABL (Atmospheric Boundary Layer) profile. A simplified parallelopiped-shaped building model was constructed from 5-mm thick Plexiglass sheet and its floor was provided with heating elements (for thermal measurements). However, for effective natural ventilation, the design of building openings (windows, wind shafts, balconies, … etc) must consider the structure of prevailing wind and its characteristics (speed, direction, turbulence, … etc). Because data for optimum design of openings for acceptable comfort (temp., humidity, contamination, and air motion) is not adequate, it would be important to provide such data through systematic testing in a research study that considers all possible variables. In the present work, the effect of wind direction and window size and arrangement on two thermal comfort indices (predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD)) was investigated in an attempt to determine the optimum building angle façade angle relative to wind direction. The PMV and PPD values were derived from measurements and plotted for each wind speed. The experimental study demonstrated that wind condition has significant effect on temperature distributions on internal surfaces as well as in interior space of a typical building and consequently on the thermal comfort indices.

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INTRODUCTION

Previous works on provision of thermal comfort in buildings through natural ventilation may be grouped into four categories: (i) experimental in-door investigations (wind tunnel tests), (ii) experimental out-door investigations (field tests), (iii) theoretical investigations (mainly by CFD techniques), and (iv) combined investigations. For experimental in-door investigations, Chand [2] discusses wind tunnel studies on the effect of the mean speed profile of the on-blowing wind on the rate of airflow through cross-ventilated enclosures. The tunnel he used is an open-circuit suction type about 14 m long, with an open working section about 2.4 m wide, 1.8 m high and 4.5 m long, surrounded by a test chamber 4.8 m wide, 3.3 m high and 6 m long. The investigation was carried out on a 1/30 scale model of a room 4.2 x 3.6 x 3 m high, which was provided with identical windows, each covering about 15 percent of floor area, in the center of the two long walls. The sill height of the windows was kept at 0.9 m, whereas the height was 1.6 m. The ratio between average wind velocity through the windows of a cross-ventilated building to free outdoor velocity at window level decreased with an increase in the value of the power-law exponent defining the speed profile of the on-blowing wind. The speed of wind flow through window can be expressed as a fraction of the free wind-speed at window level, without introducing significant errors in the results due to a variation in the type of terrain. For experimental out-door investigations, Subarto [3] proposed a new experimental technique for investigating the natural ventilation potential of new building designs. The proposed low-cost alternative test method comprises a small-scale model and outdoor testing in the natural wind. The validity of this test method was examined by comparing results from this method to wind tunnel and full-scale tests for a residential scale building. The test building was the Florida Solar Energy Center (FSEC) passive cooling laboratory (PCL). An accurate 1:25 scale clear plastic model of the PCL built and was used to conduct outdoor tests. Quantitative results show that there is an excellent agreement between the scale model value and the full scale for the ratio of internal to external wind speed. For theoretical investigations, Holz [4] carried out an investigation on a 31-story office building. Using a building energy performance simulation program “DOE-2” the building energy performance for three energy conservation measures was predicted. The output from DOE-2 was used to determine the consequence on thermal comfort. Parametric runs were performed to examine the effects of incremental changes in the cooling set point, lighting density and window’s shading coefficients. Several sensitivity studies were conducted in order to validate the comfort calculations. Six primary factors were identified that most affect the comfort indices, PPD and PMV. The study on clothing was one of the important factors in thermal comfort. The next factor that was tested was the metabolic rate. It was varied from 57 to 95 W/m^2 steps 6 W/m^2, simulating a quiet seated person on the low end and a person walking about on the high end. The ranging was representative of the types of activities that normally take place in an office setting. Runs for the remaining four factors (humidity, air velocity, air temperature, and mean radiant temperature) were also carried out under various conditions. The main conclusion here was that comfort is much less sensitive to humidity and air velocity than to air temperature and mean radiant temperature

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An example of combined experimental and theoretical investigations is the work published by Rene [5], in which, the validity was established of DOE-2 for parametric analysis of cooling strategies by comparing the results with room air temperature measurements in a low-mass and a high-mass building at different unoccupied and non-air conditioned thermal configurations. The two buildings were identical with a floor area of 27 m^2. The results showed that the DOE-2 gives accurate calculation of the basic heat transfer process in such cases and recommended an additional measurement to support the validity of DOE-2.

TEST MODEL AND INSTRUMENTATION

The present building model was constructed from Plexiglas sheet 5-mm thickness and with dimensions of 48 cm x 40-cm x10 cm height. The model had double walls where thermocouples were fixed on the inner surface of the internal wall and the pressure tappings on the outer surface of the external wall. Only thermocouples were fixed on the inner surface of the roof with no pressure tappings fixed on the exterior surface of the roof. In order to investigate thermal comfort indices, predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD), in the space of the model, thermocouples were fixed at heights corresponding to standard levels (0.6,1.1 and 1.8 m from the floor). The floor was provided with the heating elements. In order to complete the picture of thermal analysis, thermocouples were fixed to the upper surface of the formica sheet (on tunnel floor) at different points (see Figure 1-a). In order to investigate the effect of wind direction on the thermal comfort indices, the model was heated by a 150 volt supply to produce a heat flux of 800 W/m^2, intended to be removed by the natural ventilation with different wind speeds of 3.8, 4.8 and 7.5 m/s corresponding to low, medium, and high winds. The range of wind direction was $\alpha=0^o$, 45^o, 90^o and , 135^o (see Figure 1-b). The recording equipment was a data logger, OMEGA OM-272, 32 channel for measuring the temperatures inside the model at 32 locations at the same time. Because the number of temperature points was greater than 32 a transfer card was used to transfer from one set of points to another. A voltage regulator with a range 0-220 AC volt and a maximum power of 5 kW was used for the adjustment of voltage input to the heating element.

RESULTS AND DISCUSSION

Figure 2 shows the PMV_H of the heated environment (inside the model) with no ventilation (wind speed=0) indicating a constant value independent of model orientation. In this case, PMV_H attains a value greater than 3 , meaning that all people are dissatisfied under these conditions. Also the PPD_H of the heated environment (inside the model) with no ventilation (wind speed=0) indicating a constant value independent of model orientation. In this case, PPD_H attains a value equal 100, meaning that all people are dissatisfied under these conditions. When the fan was switched on, following heater being switched off, the PMV_C (with ventilation) values fall to below 3 and the effects of wind speed and directions are clear in this case (Figure 3). Also, When the fan was switched on, following heater being switched off, the PPD_C (with ventilation) values fall to below 100 and the effects of wind speed and directions are clear in this case (Figure 3).In Figure 4 the PMV_C and PPD_C values were normalized as

$$\mathbf{PMV_N=(PMV_H-PMV_C)/PMV_H} \quad \mathbf{(1)}$$

$$\mathbf{PPD_N=PMV_C/PMV_H} \quad \mathbf{(2)}$$

showing that PMV_N values with rear windows closed are greater than with all windows opened. This may be interpreted in terms of fact that circulation of air inside the model is expectedly greater when rear windows are closed, allowing more heat dissipation. Moreover, as wind speed increases, the PMV_N values increase in general (i.e. better comfort). At high wind speed (7.5 m/s), the level of comfort has significantly increases in both cases. Showing that PPD_N values with rear windows closed are smaller than with all windows opened, which means the most of people will satisfied under these conditions. Moreover, as wind speed increases, the PPD_N values decreases in general (i.e. better comfort). At high wind speed (7.5 m/s), the level of comfort has significantly increases in both cases.

CONCLUSIONS

- Wind speed and directions have significant effects on the thermal comfort.
- Higher PMV value occurs at angle 0^o (wind facing).
- Orientation of a building by 45^o relative to wind is not advisable.
- Identical PMV values occur for the two cases at $\alpha=90^o$, wind speed being 7.5 m/s, 4.8 m/s and 3.8 m/s.
- Identical PMV values occur for the two cases at $\alpha=45^o$, wind speed being 7.5 m/s.
- Higher PPD value occurs at angle 0^o (wind facing).

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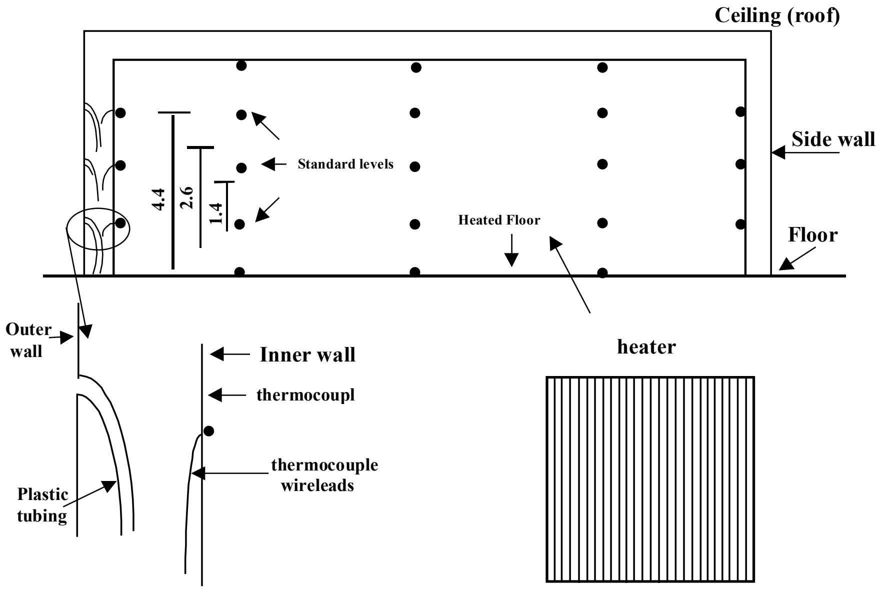

Figure 1-a Building Model and Measuring Points at Different Levels.

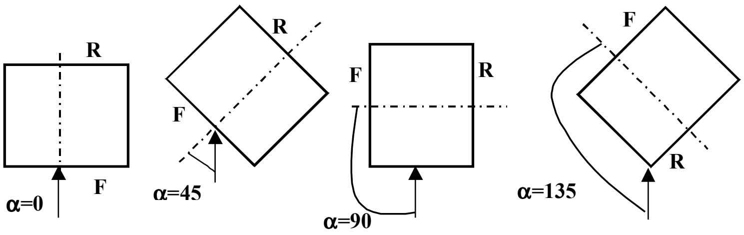

Figure 1-b Wind Direction Relative to Building Model Centerline.

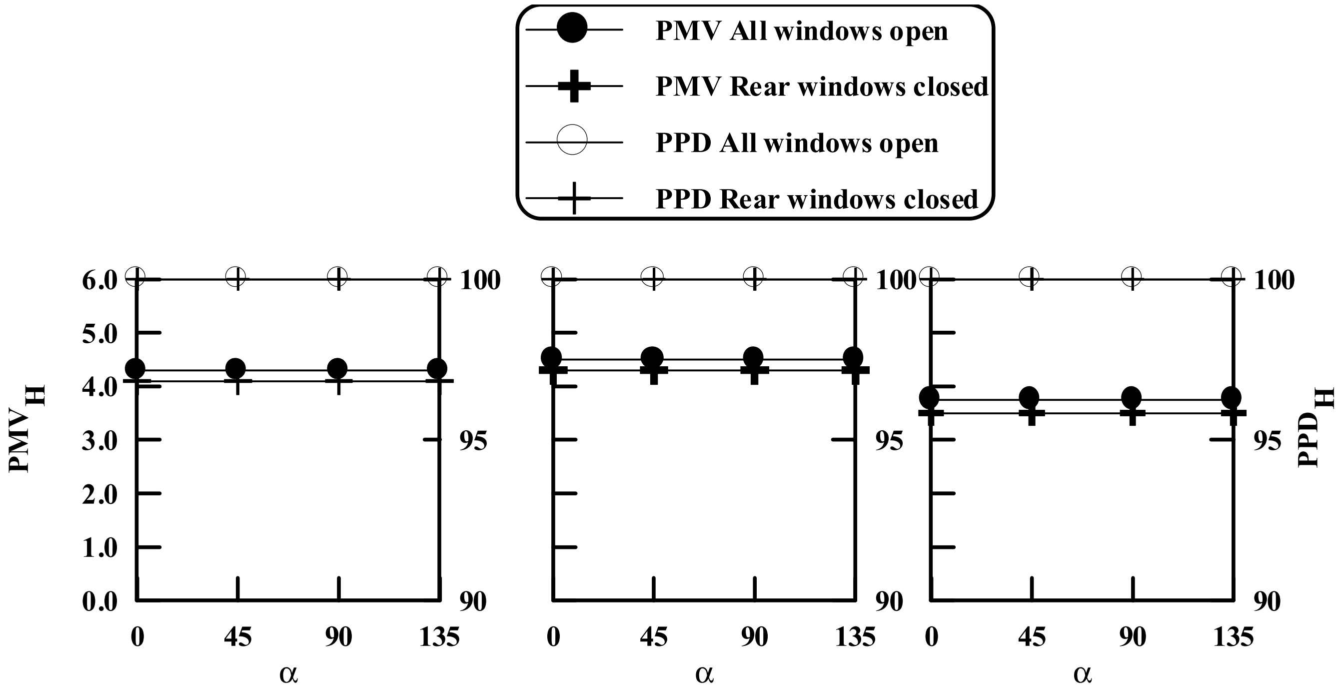

Figure 2 Heated Environment, No Ventilation.

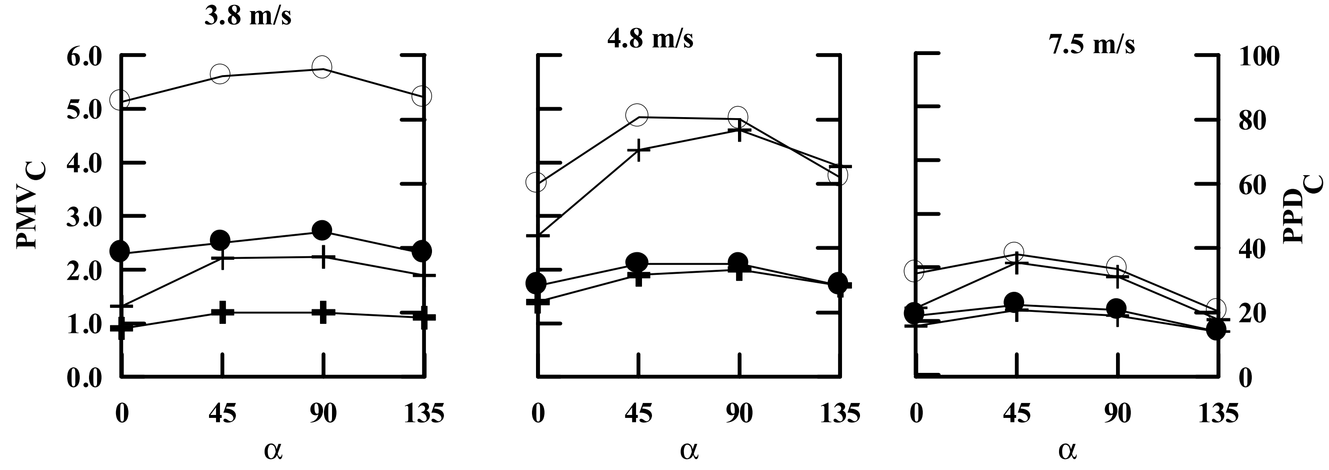

Figure 3 Variation of PMV and PPD for a Ventilated Environment with Wind Speed & Direction.

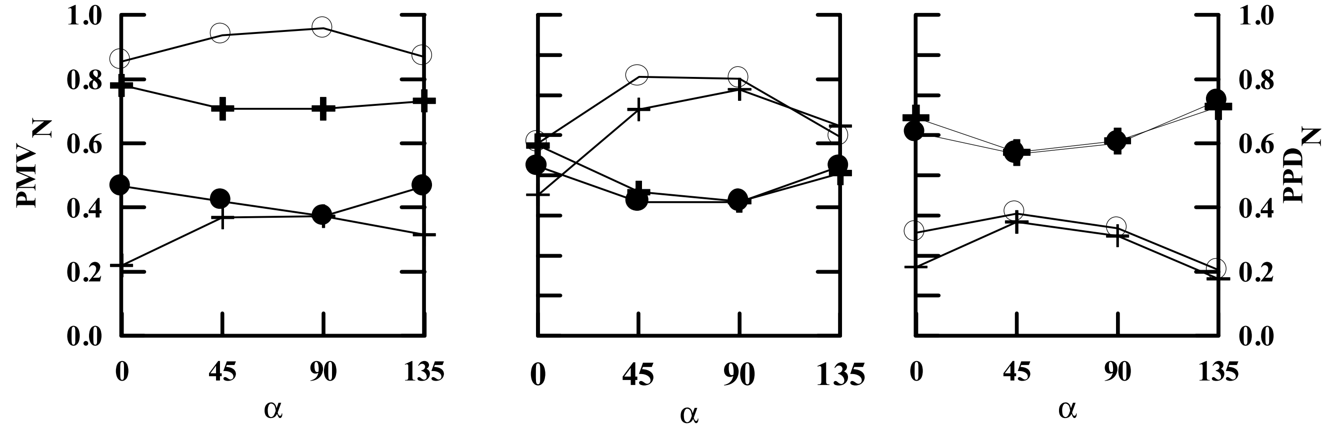

Figure 4 : Variation of Normalized PMV and Normalized PPD with Wind Speed and Direction.