# EFFECTS OF WINDOW SIZE AND LOCATION AND WIND DIRECTION ON THERMAL COMFORT WITH SINGLE-SIDED NATURAL VENTILATION

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## ABSTRACT

An energy-efficient building is a major target in building research and design worldwide. Obviously, any portion of energy saved in this respect can be directed to consumer where energy may be badly needed. Building energy consumption can be reduced through manipulation of various systems such as mechanical air conditioning (a major building energy consumer), lighting, equipment, etc. In regions where energy is limited or scarce, one would have to resort to some natural ventilation system to achieve acceptable thermal comfort for occupants. The form of the building and wind direction determine its natural ventilation performance. This includes building's shape, number, location, size and form of openings (windows) , the ventilator's shape, etc.

In this paper, results of an investigation of natural ventilation criteria as affected by various factors such as window size WWR (window-to-wall ratio), window location and building orientation (wind direction) are considered. Wind tunnel measurements and finite-element-based computation were adopted to gain an understanding of such effects. A wind tunnel test facility was constructed at the Housing & Building Research Center (HBRC) and utilized to test several idealized building models. On the other hand, a CFD software package (ANSYS FLOTRAN) was applied to the problem. These techniques gave clear pictures of the situation inside the ventilated space with various opening sizes and locations and for several wind directions. With the flow structure inside the ventilated space, it is a simple task to evaluate a thermal comfort index ($\overline{PMV}$) for a given thermal load (internal heating, solar radiation, … etc.). Results indicate significant effects of WWR, window location and building orientation on such index. Therefore, it is concluded that building designers should not overlook such factors if the buildings is to be naturally ventilated.

## INTRODUCTION AND REVIEW

Low-energy architecture concentrated of various aspects of building energy consumption and attempts to reduce it one way or the other. A major aspect of energy consumption in building is that associated with the thermal comfort of occupants which can be achieved by several means. Mechanical systems such as ventilators, air conditioners, …etc. known as active cooling systems, consume large amount of energy that may not be available. Passive cooling systems may be an alternative. However, ventilation is an essential element in thermal comfort. Such ventilation may have to at least natural in case of scarecity of energy. Some research workers investigated natural ventilation as a method of achieving thermal comfort for occupants. Kolokortoni [4 ] investigated the suitability of night ventilation for cooling offices in moderate climates. To confirm the suitability of night ventilation cooling in office-type buildings, thermal simulations were carried out using the computer model APACHE, considering typical construction of office modules, occupancy pattern and other internal heat gains. A parametric analysis was carried out to examine the effect of a number of variables such as orientation and solar gain, internal gain and occupant pattern, hourly external temperatures and infiltration, day and night ventilation rate as well as single control strategies to avoid over cooling. The results recognized that simplified and pre-design tools either in the form of hard copy design curves or simple computer-based calculations will allow the wider uptake of this low energy cooling technique by design and building facilities managers. Murkami [2] carried out model experiments and numerical analysis during the design stage of a wholesale market building 180 x 540 x 28 m in size to make use of natural ventilation to save energy and also to be maintained free. The ventilation system and building shape best suited to natural ventilation were selected. The ventilation characteristics of indoor space were verified by the field tests. Three types of model experiments were conducted, a wind tunnel test using a small model (1/600 scale model) with four wind directions and two sets of openings. To investigate the details of the ventilator, a wind tunnel test experiment using a large model (1/100 scale model) was constructed. The third model experiments were constructed to investigate the stack effect using a 1/50-cutout scale model. A flow visualization of wind tunnel test was conducted using a large model (1/100 scale model) to investigate the distribution of air flow and how pollutants from the vehicles would be dispersed. Measured air change rates corresponded well to the values given by the wind tunnel tests. The results of the investigation were applied in planning process to achieve good ventilation performance. Panzhauser [3] presents the empirical and theoretical background of design supporting simulation model (LUFT) for predicting the air flow rates in naturally ventilated buildings based on technical literature. A simulation model was developed to predict the air flow rates and, thus the air change rates between indoor rooms and exterior environment. It was designed to assist the design in the task of dimensioning and control of natural ventilation systems. A number of parametric studies were performed to demonstrate the practical applicability of the simulations program for design purposes. The comparisons of simulation results and filed measurements showed an encouraging correlation. Coorme [1] carried out experiments to measure the indoor environmental parameters such as air change rate, air velocity, turbulence intensity and air temperature in a naturally ventilated office. Since, thermal sensation was in general dependent on the room air temperature and velocity, therefore the regression equation for thermal sensation (TS) at head level, foot level, and overall for the room against mean air temperature and velocity are defined. The results obtained that, to achieve a good indoor climate and air quality, it is necessary to supply fresh air either by opening windows or by installing a suitable vent for the introduction of fresh air. Models for evaluating thermal comfort sensation, air movement and air freshness have also been developed.

## EXPERIMENTAL MODEL

A test model was constructed for the purpose of the present work. The model took the form of a cube of 200 mm on a side, with the possibility of front wall replacement for change of window size and location. Also, the model was provided with heating elements embedded in its base, giving a heating capacity of 1025 W/m$^2$ of floor area. The model was mounted on a revolving table for various orientations relative to wind direction.

The inner surfaces of the model are provided with thermocouples for the measurement of temperatures and the evaluation of the mean radiant temperature ($T_{mrt}$) to be used in the determination of thermal comfort index (PMV).

**RESULTS**

Fig.(1) gives computed flow patterns (shown here as velocity contours) inside the space of the model for three typical opening sizes (WWR= 0.15, 0.20, and 0.25 of the front façade) and two wind directions ($\alpha$=0$^o$ and $\alpha$= 45$^o$) for two opening locations (at the center of the front wall and off-center of the front wall). At $\alpha$ =0, as size is increased more air would be infiltrated into the space for the two locations. One should always remember that the final judgment on thermal comfort is based on the value of PMV (Predicted Mean Vote).

Figure (2) shows comparison between experimentally- and CFD-obtained $\overline{PMV}$ (normalized PMV) inside the ventilated space for various wind direction and different wind speeds for three different values of window-to-wall ratios (WWR= 15%, 20%, and 25%). In one case the opening was center-located whereas in the other case, it was located off center (to the left of an occupant facing the opening). It may be noticed that for the case of a "center" location and at all wind speeds, the influence of wind direction (building orientation) may be considered negligible. However, with a left-located opening there is some significant effect on $\overline{PMV}$ for all WWR. For wind speeds up to ~17 km/hr, a centrally-located opening of WWR=0.25 gives better ventilation than the smaller opening of WWR=0.15. Also, values of WWR=0.15 and WWR=0.2 give almost the same ventilation level at low speeds. Moreover, at a wind speed ~17 km/hr, the effect of WWR on $\overline{PMV}$ appears negligible for an off-center opening. This means that economically a small opening is better located off center. Further, at low speed (~17 km/hr) there is a noticeable effect of WWR as indicated by the rise in $\overline{PMV}$ level as the opening size is increased. The effect of wind speed is clear in raising the level of $\overline{PMV}$ from ~0.45 (Fig.(2-a) to ~0.55 (Fig.(2-b). As wind speed rises to ~28 km/hr, in the case of center-located Fig.(2-c) there is little or even negligible difference in effect between WWR=0.15 and WWR=0.25, in which case, an architect should select a smaller opening. Moreover, the improvement in $\overline{PMV}$ with WWR=0.15 when wind speed rises from ~17 km/hr to ~28 km/hr may be observed. Surprisingly, with an opening of WWR=0.2, the rise in wind speed from ~17 km/hr to ~28 km/hr gives a negative effect, $\overline{PMV}$ level dropping from ~0.55 to below 0.4. but for the case of an off-center-located opening a WWR=0.25 shows a $\overline{PMV}$ level that is adversely affected by wind speed ($\overline{PMV}$ dropping from ~ 0.6 to ~ 0.45).

As shown in Fig.(2) the agreement in trend between computation and experiment is good in all cases.

## CONCLUSIONS

1- The combined effects of external conditions and opening size, location on the ventilation characteristics of a typical space are generally remarkable.

2- The increase in size of a centrally-located front wall opening results in more air infiltration (ventilation air) at all wind directions.

3- When the front-wall opening is shifted off-center, the amount of ventilation air decreases.
4- Single-sided ventilation systems are effective with moderate-to-high wind speeds.
5- CFD can successfully replace experimental tools in determining the ventilation characteristics, thus saving much effort and cost.

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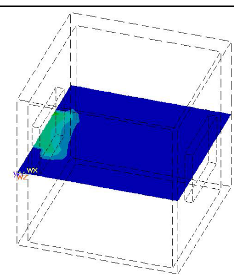
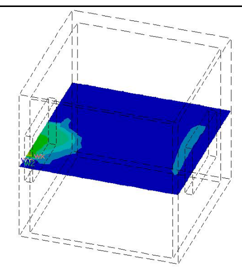
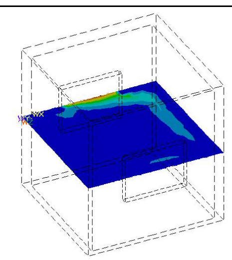
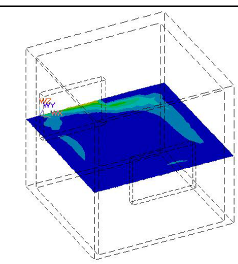
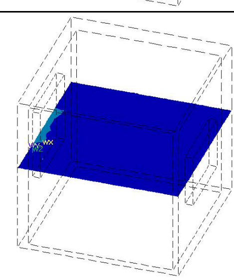
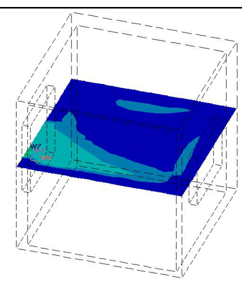
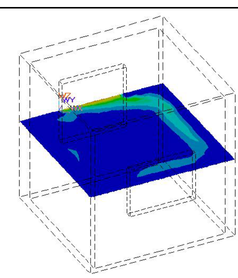
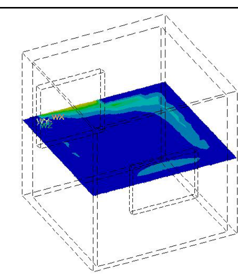
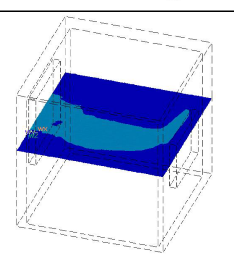
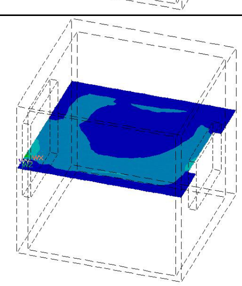
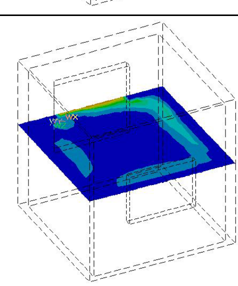
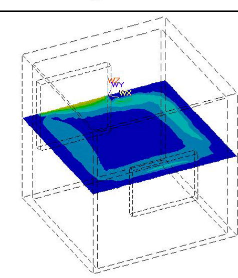
| α / WWR | 0° | | 45° | |
|---|---|---|---|---|
| | Center | Left | Center | Left |
| 15% |  |  |  |  |
| 20% |  |  |  |  |
| 25% |  |  |  |  |

Fig.(1): Computed (ANSYS-obtained) Flow Patterns in a Single-sided Ventilation System (effect of size of at various wind directions).

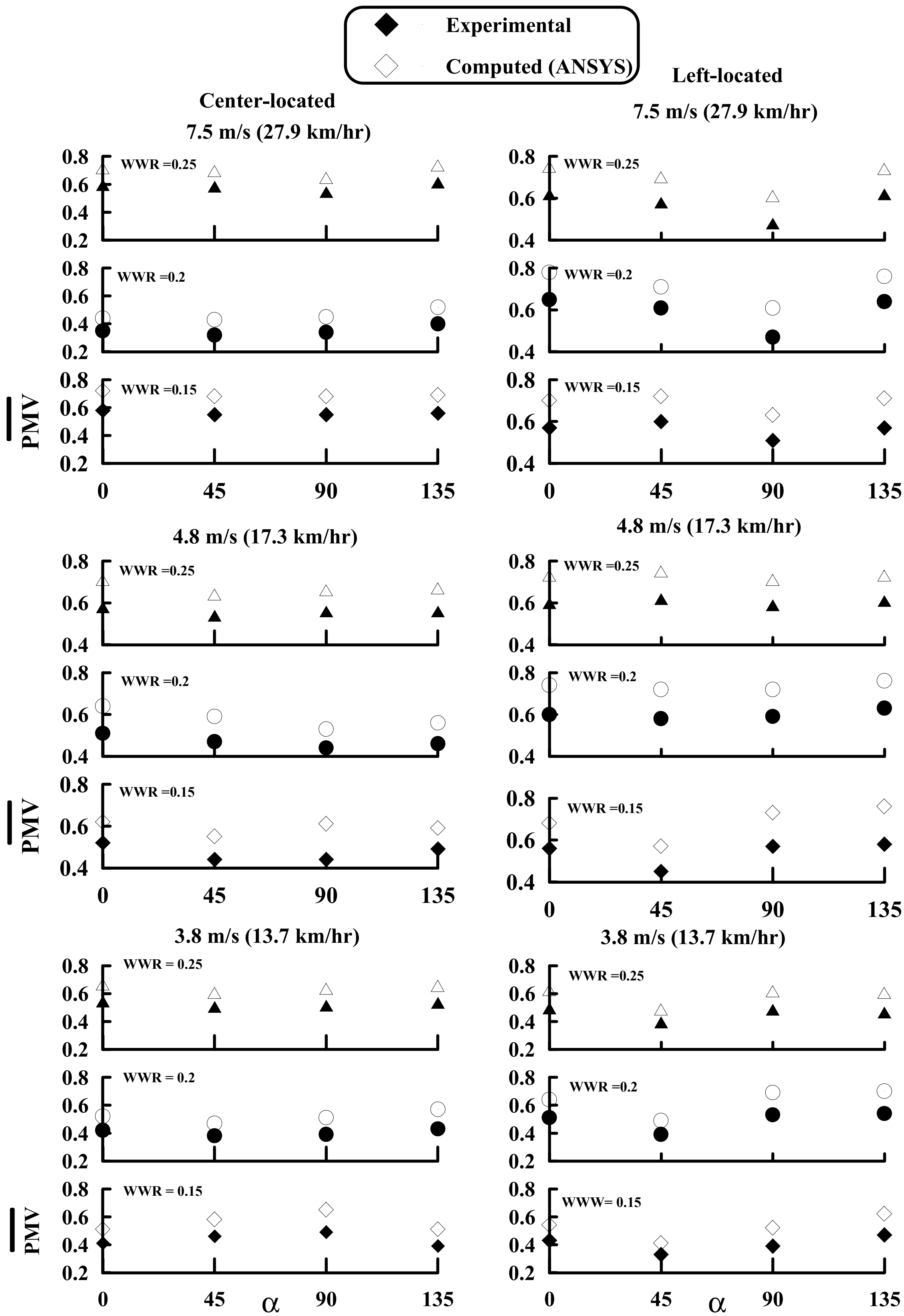



Fig.(2): Comparison Between Experimental and Computed $\overline{\text{PMV}}$ at different Wind Speeds and Directions (single-sided ventilation)