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Numerical Investigation of Thermal Comfort and Air Quality for a Single-Sided Naturally Ventilated Office Room

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Abstract

The aim of the present paper is to investigate the effect of parameters on thermal comfort in an office room with single-sided natural ventilation. A three-dimensional numerical model was implemented to predict temperature and velocity distribution indoors using ANSYS Airpak software. The temperature and velocity distributions obtained are coupled with thermal comfort indices (PMV, PPD) and local discomfort indices (DR, PD) to evaluate occupant thermal sensation. Results show an outside temperature of 18°C–20°C is best for establishing comfort for all occupants, with PMV between -0.4 and 0.6, consistent with ISO 7730 criteria. As temperature increases, the mean age of air increases, but thermal discomfort due to draught (DR) decreases. Increasing wind velocity and opening dimensions decreases PMV and PPD, approaching the permissible comfort range. Mean age of air decreases as wind velocity and opening dimensions increase, reaching a minimum at 7 m/s, while DR remains constant with changing wind velocity. According to the results, installing two openings has a better performance in establishing thermal comfort conditions than installing a single opening.

Keywords:

Single-sided Natural ventilation, Thermal comfort, Air conditioning, Energy in the building.

1. Introduction

Buildings are recognized as major energy consumers, primarily for heating, cooling, and air conditioning [1], making energy efficiency a top priority in regulations due to limited resources and environmental degradation. While non-renewable resources may suffice for decades, increased demand leads to significant environmental consequences like climate change, global warming, ozone depletion, and acid rain. Thus, utilizing renewable energy and protecting environmental health is a duty towards future generations [2].

Thermal comfort conditions, typically achieved through HVAC systems, account for over two-thirds of building energy use in developed countries. Therefore, optimizing energy consumption while ensuring occupant thermal comfort is essential, especially in office spaces where thermal satisfaction impacts productivity. Evaluating thermal comfort is complex, influenced by physical environmental parameters and human physiological and psychological factors [1].

In response to high energy consumption, energy-efficient mechanisms like passive heating and cooling strategies have been prioritized. Natural ventilation, a passive cooling mechanism with optimal energy consumption, effectively provides fresh air and favorable indoor conditions [3]. Its low operational costs, low energy consumption, improvement of indoor air quality, and provision of thermal comfort make it a significant alternative to mechanical ventilation systems. Given that people spend many hours indoors, proper ventilation is crucial. Air exchange occurs via natural or mechanical ventilation. Mechanical ventilation has drawbacks like energy consumption, environmental pollution, and high maintenance costs. Natural ventilation eliminates these concerns, leading to its increased discussion in modern building design due to its energy, economic, and environmental advantages [4].

In recent years, numerous numerical and experimental studies have been conducted on natural ventilation, mostly focusing on ventilation rates, the accuracy of simple analytical models, air velocity, and types of openings. In the present study, the considered model is first simulated numerically in three dimensions using ANSYS Airpak software to obtain temperature distribution, air velocity, and airflow patterns within the computational space. Then, to assess indoor air quality, the mean age of air parameter is calculated near each occupant, aiming to evaluate not only thermal comfort conditions but also the air exchange rate and quality for individuals in the room equipped with single-sided natural ventilation.

2. Methodology

Natural ventilation is classified into four categories based on opening configuration: single-sided ventilation, cross ventilation, ventilation using the stack effect, and combined ventilation. Cross ventilation is more efficient than single-sided ventilation but has limitations that hinder its easy application. For example, the location and orientation of openings, often constrained by urban planning laws where only one side of a house faces the exterior, pose challenges for designers and engineers in implementing cross ventilation. Consequently, its use is often limited in urban buildings. Thus, single-sided natural ventilation becomes a practical choice [5].

In the present study, ANSYS Airpak software has been used to simulate fluid flow, heat transfer, and analyze the thermal comfort of occupants. An office room at the University of Mohaghegh Ardabili, typical of faculty rooms where single-sided natural ventilation is commonly applicable, has been modeled as the office room in the Airpak software. As shown in Figure 1, the room dimensions are 4.5 m length × 3 m width × 3 m height. Two openings are considered on one of the room's walls, each with dimensions of 0.75 m × 0.65 m, arranged vertically with a spacing of 0.05 m between them. Within the considered office room, three seated individuals are considered, two of whom are sitting and working with computers. The height and weight of each person are assumed 175 cm and 64 kg, respectively. The metabolic rate and clothing insulation for each occupant are considered to be 1.2 met and 0.7 clo, respectively [6]. Four ceiling-mounted lamps, each with dimensions of 0.2 m × 0.15 m × 1 m and a heat output of 181 W, two computers with a heat output of 190 W each, and two bookshelves without any heat load are also included in the model.

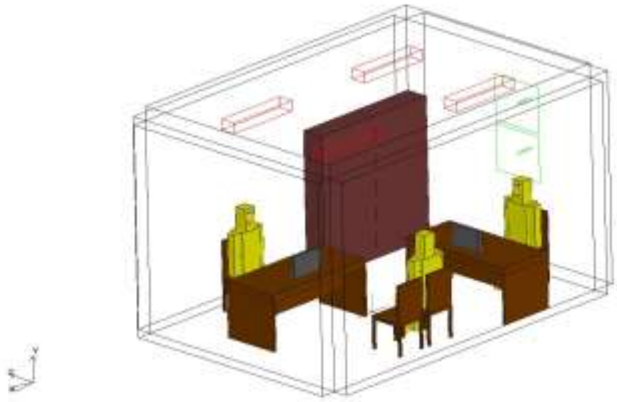

Figure 1. Isometric view of the office room

Fanger's comfort equation, derived from his experiments, led to the development of the PMV-PPD model, which is now widely used for designing and evaluating thermal comfort. In Fanger's model, two main indices are defined: one is the PMV[1], which estimates the average vote of a large group of people regarding the thermal environment, and the other is the PPD[2], which estimates the percentage of people dissatisfied with the thermal conditions. Furthermore, even when occupants generally feel an acceptable level of overall thermal comfort, they might experience unwanted local sensations of cold or warmth in specific parts of their body. This local thermal discomfort can manifest as DR[3] or PD[4] as a function of the vertical air temperature difference [7]. The acceptable ranges for the four mentioned indices are presented in accordance with Table 1.

Table 1. The desired thermal environment for a space [7].

	ACCEPTABLE RANGE
PMV	$\lvert PMV \rvert < 0.7$
PPD	PPD < 15%
DR	DR < 30%
PD	PD < 10%

[1] Predicted Mean Vote

[2] Predicted Percentage of Dissatisfied

[3] Draught Rating

[4] Percentage of Dissatisfied

In addition, one of the indicators for evaluating air quality is the mean age of air. In fact, the mean age of air indicates how many seconds it takes for the air around individuals to be replaced. This indicator has a significant impact on people's satisfaction with the surrounding environment and plays an important role in their performance.

Thermal comfort indices and mean age of air are calculated at a distance of 0.1 meters from each occupant and at three heights of 0.1, 0.6, and 1.1 meters above the floor, corresponding to the ankle, abdomen, and chest areas, respectively [8]. The effects of temperature, wind speed, opening dimensions, and opening placement are then investigated.

3. Results and Discussion

The experimental data from Jiang et al. [9] was used to validate the present study. For numerical validation, the horizontal velocity distribution (U) along a vertical line located at six points within the computational domain was utilized. As an example, Figure 2 shows the results of the numerical solution from the present study compared with the experimental data from Jiang et al. [9] along the vertical line located in the middle of the office room. The results of the numerical solution show good agreement with the experimental data.

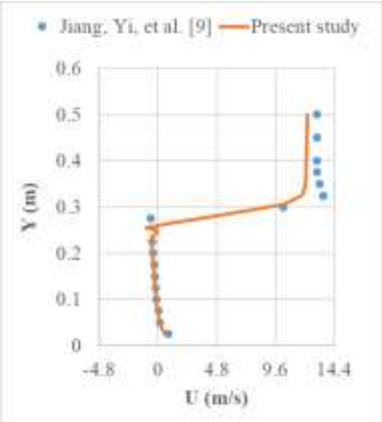

Figure 2. Comparison of the results of the present study with experimental data

This study investigates the effects of outdoor climatic conditions and geometric parameters on thermal comfort and indoor air quality in a sample office room with single-sided natural ventilation. Outdoor temperature and wind speed were defined as the environmental variables, while opening size, number, and position were considered as geometric parameters.

Outdoor temperatures ranging from 18°C to 26°C and seven wind speeds between 1 and 7 m/s were examined. Three opening-to-wall ratios were evaluated: 5%, 10%, and 15%. In addition, three opening configurations were analyzed: a single opening at a higher elevation, two openings, and a single opening at a lower elevation.

Figure 3 illustrates the variation of PMV against temperature for the third occupant. The acceptable PMV range is between -0.7 and 0.7. Within the outdoor temperature range between 18°C and 20°C, the thermal comfort indices are in the permissible thermal comfort range. At outdoor temperature of 22°C and above, the PMV reaches one, indicating that the occupant perceives the environment as hot. Additionally, at a height of 0.6 meters, the PMV value is marginally higher than the other two heights.

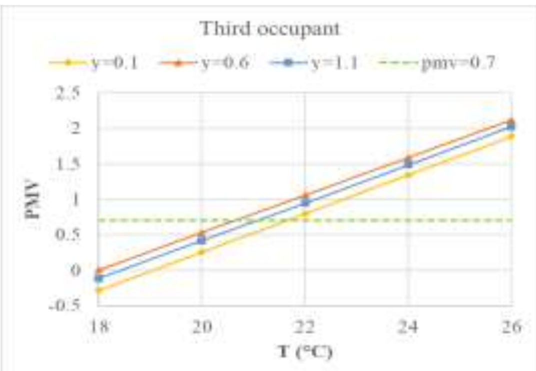

Figure 3. PMV of the third occupant varies with temperature

4. Conclusions

In this study, an office room with single-sided natural ventilation was numerically simulated using ANSYS Airpak. The effects of outdoor temperature, wind speed, and the dimensions, number, and positioning of openings on thermal comfort indices and indoor air quality were examined.

The results indicate that outdoor temperatures between 18°C and 20°C provide optimal thermal comfort conditions. Within this range, PMV and PPD values for all occupants remain within the permissible limits. As outdoor temperature increases, the mean age of air increases for all occupants, while DR decreases for the second and third occupants and remains constant for the first.

As wind speed increases, the thermal comfort indices approach the permissible range. The mean age of air decreases with increasing wind speed, while DR remains constant for all three occupants and stays within the permissible thermal comfort range.

Larger opening dimensions enhance thermal comfort performance, as PMV and PPD approach the permissible range and the mean age of air decreases. The use of two openings yields better thermal comfort conditions compared to a single opening; however, when only one opening is employed, positioning it at a higher elevation is recommended.

5. References

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