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RESEARCH ARTICLE

# ASSESSMENT OF THERMAL COMFORT IN A NATURALLY VENTILATED MECHANICAL WORKSHOP BUILDING USING CFD METHOD

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## Abstract

In hot and humid climates thermal discomfort is a major problem to the occupants of many buildings especially when they are not equipped with an air-conditioning system. Thermal comfort is an essential requirement in most occupied spaces because it affects the productivity, health and thermal satisfaction of the occupants. Mechanical Workshops are considered as important buildings in Yemeni universities. They are places for the students and teachers to perform their researches and experiments activities. Most of the mechanical workshop buildings in countries with a hot and humid climate use a combination of natural ventilation and electrical fans that are commonly used to provide thermal comfort to the occupants. This paper presents a study on an assessment of the level of thermal comfort in the mechanical workshop building which is located in Faculty of engineering, university of Aden, Yemen using computational fluid dynamics (CFD) method. The CFD method was conducted to predict the thermal comfort inside the workshop building. The level of thermal comfort inside the workshop building was found to be well outside the comfort limits as specified by ASHRAE standards. Therefore, an alternative ventilation method is needed to improve the thermal comfort inside the Mechanical Workshop building.

**Keywords:** Mechanical workshop building, Natural ventilation, electrical fans, Thermal comfort, Hot and humid climate, computational fluid dynamics (CFD) method.

## 1. Introduction

The large space halls also known as high span spaces have been constructed in many places worldwide, including Yemen. Large space constructions such as workshop building, industrial buildings, aircraft hangars, sports halls, mosques, and stadiums are distinguished from other space constructions in terms of their energy consumption [1]. These spaces advance issues that are related to indoor air quality and thermal comfort [2-6]. A mechanical workshop building is considered as one type of large space building in Yemeni universities. It is a place of great importance for the students and teachers to perform their researches and experiments. Thermal comfort inside the mechanical workshops building is an important requirement because it affects the productivity, health and thermal satisfaction of the occupants [7]. The thermal comfort and indoor air quality in mechanical workshops building have not been widely studied [8]. There is a lack of in-depth study and analysis of thermal comfort and indoor air quality inside mechanical workshops building. Hence, there is a need to conduct such studies for the benefit of the occupants.

Thermal comfort is an essential requirement in most occupied spaces. According to ASHRAE Standard thermal comfort can be defined as “that condition of mind which expresses satisfaction with the thermal environment”. Thermal comfort is determined by evaluating six parameters [9]. Four of the parameters are related to the environment while the other two are related to the human. The environmental parameters are relative humidity (RH), air temperature, ($T_a$), air velocity ($V_a$) and mean radiant temperature ($T_{mrt}$), while the human parameters are clothing and activity levels. According to Markus [10], air temperature is the most important parameter that affects the indoor thermal environment.

There are several tools and methods that can be used to study and analyses thermal comfort in buildings. These include empirical models, analytical models, zonal models, multi-zone models, small-scale experimental models, full-scale experimental models, and computational fluid dynamics (CFD) models [6]. CFD is highly popular, accurate and widely employed in predicting ventilation performance and thermal comfort [6, 11]. A combination of CFD analysis and field measurement has been used in many studies to assess the thermal comfort and for CFD models validation [12, 13]. In this study, the evaluation of the thermal comfort inside the mechanical workshop building was performed by using CFD method.

The aim of this study is to assess the level of thermal comfort by predict the air temperature inside the mechanical workshop building located in faculty of engineering, university of Aden, Yemen using CFD method. The temperature predict from CFD method was compared to the corresponding limit as specified in the ASHRAE Standard.

## 2. Methodology

### *2.1 Description the Mechanical Workshop Building*

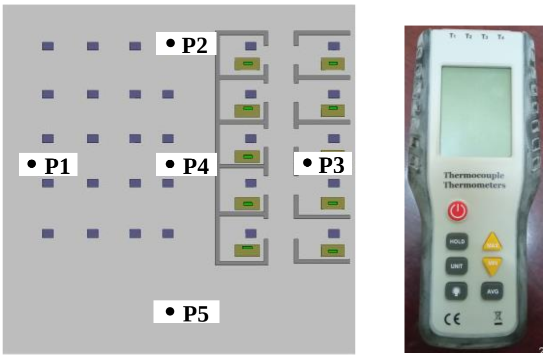
The mechanical workshop building was selected as a case of study for this research. The photo of the mechanical workshop building is shown in **Figure (1a).** It is one of the largest typical mechanical workshop building in faculty of engineering, university of Aden. It was built in 2007 and constructed based on rectangular shape with length, L = 13 m, width, W = 10 m and height, H = 6 m. The total built-up area of the hall building is 130 m$^2$. The hall building of mechanical workshop can be occupied by about 35 people. The walls of mechanical workshop building are built with three doors and eight windows. The mechanical workshop does not use air conditioning system. It rather uses natural ventilation for cooling purposes. The natural ventilation in the mechanical workshop is supported by 9 units of ceiling electrical fans as can be seen in **Figure (1b).**

### *2.2 Field Measurements*

The purpose of the field measurement is to obtain the values of parameters which influence the level of thermal comfort inside the workshop building. In this study, the evaluation of the thermal comfort inside the workshop building was performed by measuring the air temperature ,which is the most important factor that affects the indoor thermal comfort [10]. The air temperature was acquired at five chosen locations inside the building. These locations were indicated by points $P_1$ to $P_5$ as shown in **Figure (2a)**. The air temperature at these points was measured at the (1.1 m) height from the ground level. The chosen height level is based on [14]. The measurements were conducted from 08:00 AM to 06:00 PM with a 30-minutes interval in June, 2022. The instrument tools set-up was tested and calibrated before starting the measurements. Thermocouple Thermometers instruments is used for the measuring inside temperature with accuracy ± (0.4% + 0.5ºC) are shown in **Figure (2b).**


**(a)** **(b)**

**Fig. 1: (a)** A photo of the mechanical workshop building; **(b)** Internal view of the mechanical workshop building.




**(a)** **(b)**

**Fig. 2: (a)** Locations of data collection points (P1 to P5) inside the Mechanical Workshop, and **(b)** Thermocouple Thermometers Instruments used for the field measurement.

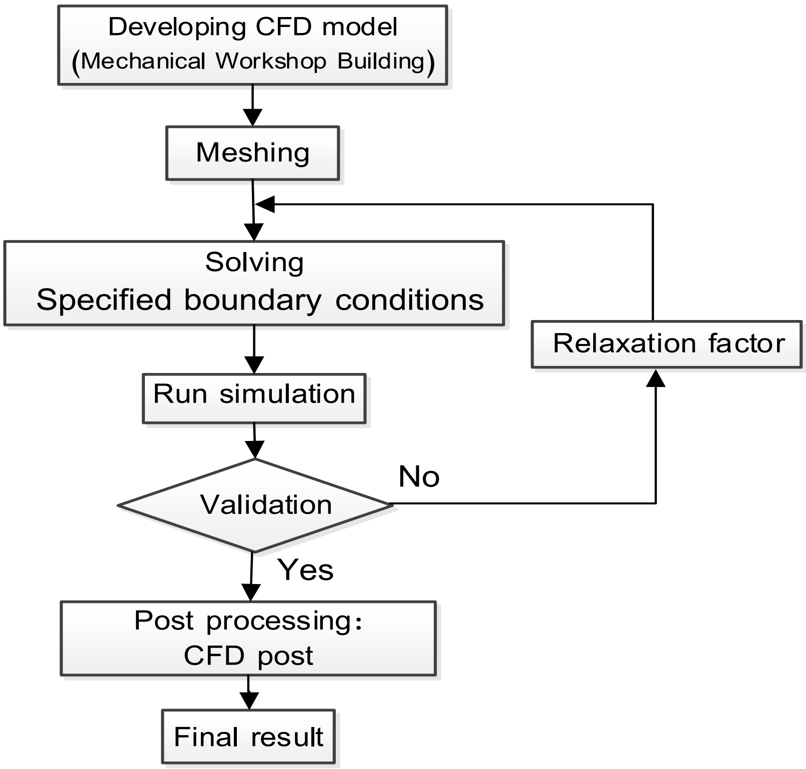



**Fig. 3:** A CFD procedure for analyzing thermal comfort in the Mechanical Workshop Building

### *2.3 CFD method*

A CFD simulation method is a useful tool that can be used to develop 3D model to predict the air temperature that are directly related to thermal comfort inside the mechanical workshop building. The CFD procedure for analyzing thermal comfort in the Mechanical Workshop Building is shown in **Figure (3)**. The CFD simulation procedure starts with the pre-processing stage by construction a 3D geometry of the building. After creating the geometry of the building, a mesh/grid was generated using meshing tools within the CFD (ANSYS Mesh-R17 software). When the mesh/grid generation was completed, the material characteristics and boundary conditions were set. The boundary conditions required for each object in the model including parameters such as temperature was also set. The next stage after the boundary condition is the solving process stage, which includes solution monitors to set the convergence criteria in terms of iterations in the scaled residuals and the solution is initialized and calculation is run. Finally, the results are obtained by post-processing stage. The results are visualized in the form of graphics, animations contours, vectors, path lines, streamline.

#### *2.3.1 Development of the CFD Model*

A simplified 3D model of the workshop building was constructed based on the actual dimensions of the mechanical workshop building. In this work, the fluent CFD software was used to create the model representing the various sections of the mechanical workshop building geometrically. **Figure (4)** shows the CFD model of the mechanical workshop building. The workshop building comprises several regions namely: the hall and welding rooms. The workshop building is not furnished with air-conditioning system. It rather uses natural ventilation for cooling purposes. The natural ventilation in the mechanical workshop is supported by 9 units of ceiling electrical fans. The occupants (Students) were taken into account in the computational domain. There are 35 occupants in the mechanical workshop. The average height, width and thickness of the people are 1.6 m, 0.40 m and 0.30 m, respectively ASHRAE standard [15].

#### *2.3.2 Boundary Conditions*

Boundary conditions are appropriate and important in terms of the accuracy of CFD calculations [11]. The boundary condition parameters were obtained from the actual field measurement. The field measurements data of June was chosen for the simulation purpose because it has the highest temperature among the other months. All boundary conditions prescribed on the CFD model are shown in **Table 1**.

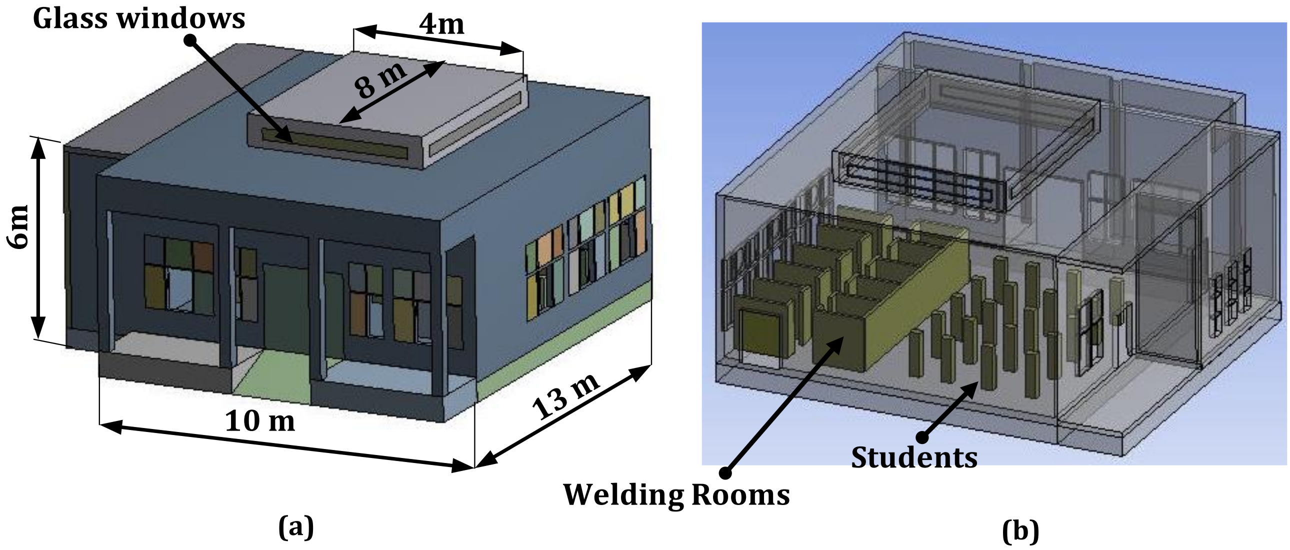



**Fig. 4**: **(a)** A CFD model of the Mechanical Workshop Building, **(b)** Internal view of the mechanical workshop building.

**Table 1:** Boundary conditions used in CFD model

| Section | | Types of Boundary Condition | Value of Parameters |
|---|---|---|---|
| Right door and window | | Inlet Air | Velocity = 0.2 m/s, Temperature = 32°C |
| Left door and Back windows | | Outlet air | Pressure= 0 |
| Wall | Roof | Temperature | Temperature = 41°C |
| | Front | | Temperature = 33°C |
| | Back | | Temperature = 33 °C |
| | Right | | Temperature = 33°C |
| | Left | | Temperature = 32°C |
| | Floor | | Temperature = 32°C |

## 3. Results and Discussion

### *3.1 Results and Discussion of Field Measurements*

In this study, the evaluation of the thermal comfort inside the workshop building was performed by measuring the air temperature, which is the most important factor that affects the indoor thermal comfort. **Figure 5** shows the variation of the air temperature at five selected locations inside the mechanical workshop building from 8:00 a.m. to 6:00 pm in June. It can be seen that the air temperature for at all locations has similar trends, in which increasing and experienced decreasing in the similar period. As shown in the figure the air temperature in the south region of the mechanical workshop hall (location $P_3$) is the highest while the air temperature in the other areas (locations $P_1$, $P_2$, $P_4$ and $P_5$) is the lowest. This is because the people and welding operations that occupy the mechanical workshop hall release heat from their body to the surrounding air. Additionally, the figure clearly shows that the highest air temperature at 1.40 p.m. was about 36.3°C, at location $P_3$, while the lowest air temperature at this time was 32.6°C, at location $P_1$. It can be observed that for all the locations, the measured air temperature inside the workshop building is higher and ranging from 29.6°C to 36.3°C which exceeded the acceptable thermal comfort range that recommended in the ASHRAE standard [15]. This indicates that the air temperature value in all points inside the mechanical workshop building varies means that the thermal comfort level is not equally distributed. An addition the condition inside the mechanical workshop hall is not quite thermally comfortable to the occupants.

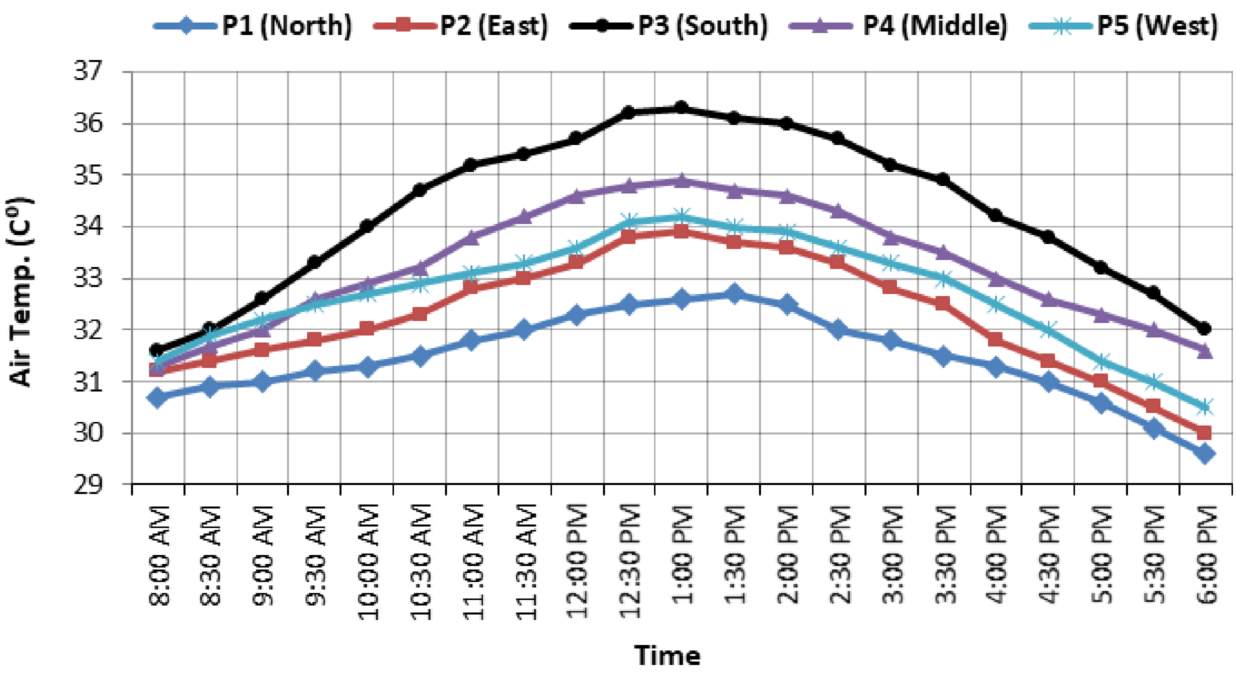



**Fig. 5:** Variation of air temperature inside the mechanical workshop building.

### *3.2 Results and Discussion of CFD Simulation*

The CFD simulation results for air temperature are presented in the form of contour plots on three cross-sections plans A-A, B-B and C-C, as shown in **Figure 6.** It can be seen that the air temperature distribution inside the mechanical workshop building is not uniform and ranging from 32.02°C to 41°C on the section plane A-A, 32.14°C to 41°C on the section plane B-B, and 32°C to 38.92°C on the section plane C-C. As shown in the figure the temperature on the roof experienced the highest temperature about to 41 ⁰C. It was found that the lower temperature near the floor, which is to 32 ⁰C. It can also be observed that the temperature in the roof of the mechanical workshop building is the highest, and it gradually decreases away from the roof to the inside mechanical workshop building, as shown in the section planes A-A and B-B. This is because the solar radiation intensity is very high in the roof. Additionally, the figure clearly shows that the air temperature around the occupants is the highest and it gradually decreases away from the middle of the mechanical workshop building, as shown in the section planes C- C. This is because the occupants occupy the hall release heat from their body to the surrounding air through breathing and respirations. It is also observed from the figure that for all the section plane, the air temperature inside the workshop building is higher and ranging from 32°C to 41°C. These temperatures are higher than the level of thermal comfort specified by the ASHRAE standard [15], and this finding agrees quite well with the temperatures obtained from the actual field measurements.

### *3.3 CFD Model Validation*

Validation of a CFD program is necessary to ensure the accuracy of obtained results. Validation is defined as the "uncertainty assessment of a computational simulation by comparison with field measurements" [16]. In this study, the validation of the CFD simulation was done by comparing its results with the corresponding data from actual field measurement of the air temperature obtained at five different locations inside the mechanical workshop building.

**Table 2 and Figure 7** show the comparison of measured and predicted data of air temperature for five different locations namely north ($P_1$), east ($P_2$), south ($P_3$), middle ($P_4$) and west ($P_5$). It was found that the numerical predictions were obtained generally in fair agreement with the field measurement. The deviation between the predicted and measured air temperatures was in the range 1.5% to 1.6 %. A ±5 % difference between predicted and field measurement can be accepted [17, 18]. This result can be considered very good comparing its results with the actual field measurement. The CFD simulation has shown a good capability of predicting the air temperature accurately inside the mechanical workshop building.

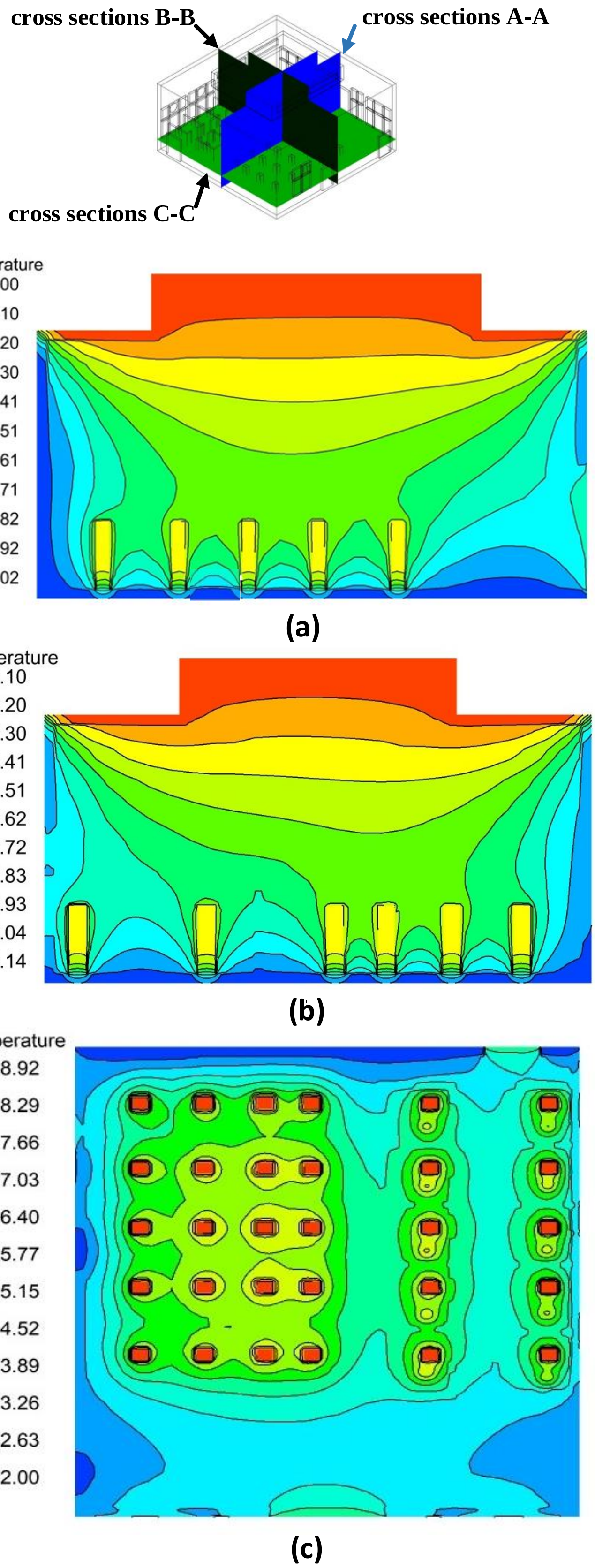



**Fig. 6:** Air temperature distribution **(a)** In cross section A-A **(b)** In cross section B-B, and **(c)** In cross section C-C

**Table 2:** The percentage of the deviation between predicted and measured air temperature at the different locations inside the Mechanical Workshop Building.

| Temperature | $P_1$ (North) | $P_2$ (East) | $P_3$ (South) | $P_4$ (Middle) | $P_5$ (West) |
|---|---|---|---|---|---|
| Measurement | 32.6 | 33.9 | 36.3 | 34.9 | 34.2 |
| Predicted | 32.1 | 33.4 | 35.7 | 34.4 | 33.7 |
| Percentage % | 1.5 | 1.5 | 1.6 | 1.5 | 1.5 |

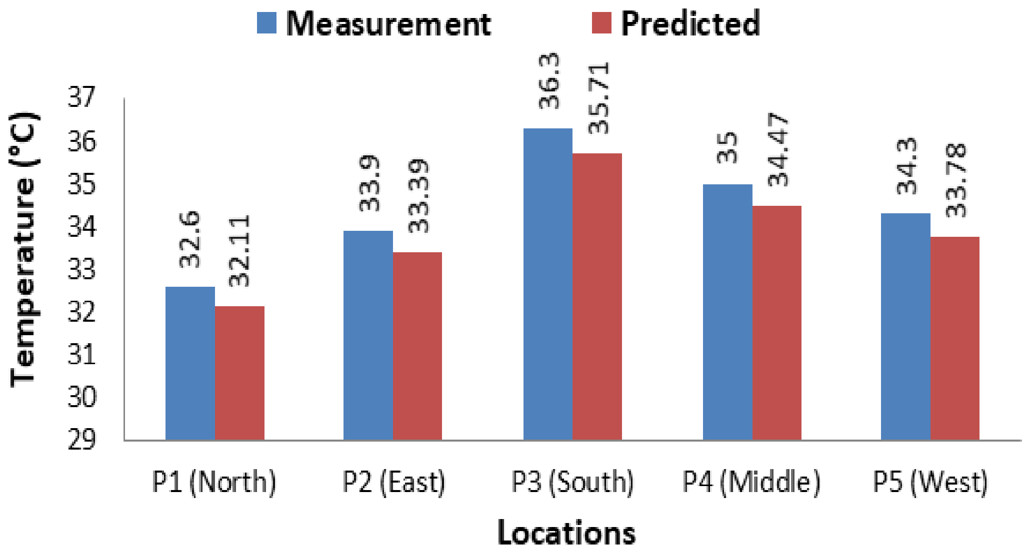



**Fig. 7**: The percentage of the deviation between predicted and measured air temperature at the different locations inside the Mechanical Workshop Building.

## Conclusion

This study has presented the results of a field measurement and CFD simulations aimed to assessment the effects of natural ventilation and electrical fans on the thermal comfort level of the mechanical workshop building located in faculty of engineering, university of Aden, Yemen. Actual field measurements on the air temperature show that the thermal comfort in the mechanical workshop building is well outside the recommended limits specified by ASHRAE Standard comfort range. The CFD simulations were conducted on a simplified model of the workshop building to predict the air temperature inside the workshop building. The CFD simulation results conformed to thermal comfort data obtained from the actual field measurements. The level of thermal comfort inside the workshop building was found to be well outside the comfort limits as specified by ASHRAE standards. These findings suggest that the natural ventilation and electrical used in the mechanical workshop building are not capable of providing adequate thermal comfort for occupants. The work demonstrates the CFD software that has great capability to predict thermal comfort inside the workshop building and can be used to identify a suitable ventilation system to improve the thermal comfort inside the mechanical workshop building.

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## References

[1] H. M. Kamar, N. Kamsah, F. Ghaleb, and M. I. Alhamid, "Enhancement of thermal comfort in a large space building," *Alexandria Engineering Journal*, vol. 58, no. 1, pp. 49-65, 2019.

[2] P. Heiselberg, S. Murakami, and C.-A. Roulet, "Ventilation of large spaces in buildings," *Final Report IEA Annex*, vol. 26, 1998.

[3] M. S. Al-Homoud, A. A. Abdou, and I. M. Budaiwi, "Assessment of monitored energy use and thermal comfort conditions in mosques in hot-humid climates," *Energy and Buildings*, vol. 41, no. 6, pp. 607-614, 2009, doi: 10.1016/j.enbuild.2008.12.005.

[4] P. Rajagopalan and M. B. Luther, "Thermal and ventilation performance of a naturally ventilated sports hall within an aquatic centre," *Energy and Buildings*, vol. 58, pp. 111-122, 2013, doi: 10.1016/j.enbuild.2012.11.022.

[5] T. T. Xu *et al.*, "Performance of thermal distribution systems in large commercial buildings," *Energy and buildings*, vol. 34, no. 3, pp. 215-226, 2002.

[6] Q. Chen, "Ventilation performance prediction for buildings: A method overview and recent applications," *Building and Environment*, vol. 44, no. 4, pp. 848-858, 2009, doi: 10.1016/j.buildenv.2008.05.025.

[7] L.-R. Jia, J. Han, X. Chen, Q.-Y. Li, C.-C. Lee, and Y.-H. Fung, "Interaction between thermal comfort, indoor air quality and ventilation energy consumption of educational buildings: A comprehensive review," *Buildings*, vol. 11, no. 12, p. 591, 2021.

[8] G. A. Ganesh, S. L. Sinha, T. N. Verma, and S. K. Dewangan, "Investigation of indoor environment quality and factors affecting human comfort: A critical review," *Building and Environment*, vol. 204, p. 108146, 2021.

[9] T. Mamani, R. F. Herrera, F. Muñoz-La Rivera, and E. Atencio, "Variables that affect thermal comfort and its measuring instruments: A systematic review," *Sustainability*, vol. 14, no. 3, p. 1773, 2022.

[10] T. A. Markus and E. N. Morris, *Buildings, climate, and energy*. Pitman Pub., 1980.

[11] M. Hurnik, M. Blaszczok, and Z. Popiolek, "Air Distribution Measurement In A Room With A Sidewall Jet: A 3d Benchmark Test For Cfd Validation," *Building and Environment*, 2015.

[12] X. Tian and Z. Lin, "Predicting personalized thermal comfort in stratified micro-environments using turbulent jet theories and data-driven models," *Building and Environment*, vol. 230, p. 110009, 2023.

[13] G. M. Stavrakakis, D. A. Katsaprakakis, and K. Braimakis, "A Computational Fluid Dynamics Modelling Approach for the Numerical Verification of the Bioclimatic Design of a Public Urban Area in Greece," *Sustainability*, vol. 15, no. 15, p. 11642, 2023.

[14] E. Malyavina and S. Landyrev, "Checking the parameters of the internal environment by calculated simulation of measurements with a ball thermometer," in *E3S Web of Conferences*, 2023, vol. 376: EDP Sciences.

[15] A. Standard, "Standard 55-2013 (2013) Thermal environmental conditions for human occupancy," *American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA, USA.*

[16] Y. Tominaga, L. L. Wang, Z. J. Zhai, and T. Stathopoulos, "Accuracy of CFD simulations in urban aerodynamics and microclimate: Progress and challenges," *Building and Environment*, p. 110723, 2023.

[17] A. Aryal, P. Chaiwiwatworakul, S. Chirarattananon, and W. Wongsuwan, "Subjective assessment of thermal comfort by radiant cooling in a tropical hot humid climate," *Energy and Buildings*, vol. 254, p. 111601, 2022.

[18] S. Hussain, *Nnumerical investigations of the indoor thermal environment in atria and of the buoyancy-driven ventilation in a simple atrium building*. Queen's University (Canada), 2012.

مقالة بحثية

# تقييم الراحة الحرارية داخل مبنى الورشة الميكانيكية ذو تهوية طبيعية باستخدام طريقة ديناميكيات الموائع الحسابية (CFD)

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## المُلخّص

في المناخات الحارة والرطبة، يعد الانزعاج الحراري مشكلة رئيسية لشاغلي العديد من المباني خاصةً عندما لا تكون مجهزة بنظام تكييف الهواء. تُعَد الراحة الحرارية مطلبًا أساسيًا في معظم الأماكن المشغولة، لتأثيرها على الإنتاجية والصحة والرضا الحراري للأفراد. تُعَد الورش الميكانيكية من المباني المهمة في الجامعات اليمنية. كونها مكان للطلاب والأساتذة لإجراء أنشطة أبحاثهم وتجاربهم العلمية. تستخدم معظم مباني الورش الميكانيكية في البلدان ذات المناخ الحار والرطب مزيجًا من التهوية الطبيعية والمراوح ألكهربائية التي تستخدم بشكل شائع كوسيلة لتوفير الراحة الحرارية للأفراد. يعرض هذا المقال نتائج دراسة عن تقييم مستوى الراحة الحرارية في مبنى الورشة الميكانيكية الواقع في كلية الهندسة، جامعة عدن، اليمن باستخدام طريقة ديناميكيات الموائع الحسابية .(CFD) تم استخدام طريقة CFD للتنبؤ بالراحة الحرارية داخل مبنى الورشة. ووجد أن مستوى الراحة الحرارية داخل مبنى الورشة خارج حدود الراحة كما هو محدد بواسطة معايير ASHRAE Standard. لذلك، هناك حاجة إلى طريقة تهوية بديلة لتحسين الراحة الحرارية داخل مبنى الورشة الميكانيكية.

**الكلمات المفتاحية:** مبنى الورشة الميكانيكية، التهوية الطبيعية، المروحة ألكهربائية، الراحة الحرارية، المناخ الحار والرطب، طريقة ديناميكيات السوائل الحسابية (CFD).

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