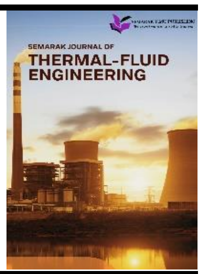
SEMARAK ILMU PUBLISHING

Semarak Journal of Thermal-Fluid Engineering

Journal homepage:
https://semarakilmu.com.my/journals/index.php/sjotfe/index
ISSN: 3030-6639



Temperature Distribution in a Cooled Room

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ARTICLE INFO

Article history:
Received 1 August 2024
Received in revised form 23 August 2024
Accepted 2 September 2024
Available online 30 September 2024

Keywords:
Air flow; temperature field; computational fluid dynamic; simulation; activity hall

ABSTRACT

A 3-dimensional numerical study was conducted to compare the computational and experimental results of airflow characteristics and temperature fields in the activity areas of Kolej Kediaman Tun Dr. Ismail (KKTDI) and Kolej Kediaman Tun Fatimah (KKTF), focusing solely on their indoor environmental conditions. Two methods were employed: experimental measurements and computational simulation using the Computational Fluid Dynamics (CFD) approaches. The validation process involved comparing the proposed simulation with previous experimental results, focusing on velocity and temperature results. The average relative error of the velocity was 12.59%, which was considered acceptable because it was less than 20%. This error was observed only at the KKTF, as no velocity was recorded at the KKTDI (0 m/s at all lines). The temperature simulation consistently showed 18°C across all lines. The experimental results for the KKTF ranged from 16.4°C to 17.8°C, whereas the KKTDI temperatures ranged from 27.8°C to 28.9°C. Comparing the simulation and experimental results, the KKTF results were similar, with differences ranging from 0.2°C to 1.6°C across the curves. However, the KKTDI exhibited significant differences, ranging from 9.2°C to 10.9°C across lines. This study successfully demonstrated the accuracy of the airflow characteristics and temperature field data obtained in the two active halls. The results provide valuable insights into the indoor environmental conditions of the KKTDI and KKTF, highlighting the importance of proper ventilation system design and equipment placement in managing heat accumulation. The results contribute to a better understanding of indoor environmental dynamics and can inform the future design and optimisation of similar spaces.

1. Introduction

An activity hall is frequently used for meetings and small events that require a flexible and efficient air distribution system. Designing rational air distribution systems that accurately predict indoor air distribution to meet user requirements is a significant challenge. Therefore, this study was conducted to investigate the airflow characteristics and temperature fields in two different activity halls with similar designs and spaces. The main objectives of this study were to analyze and compare the computational and experimental results of airflow characteristics and temperature fields in the

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https://doi.org/10.37934/sjotfe.2.1.1625

activity halls of KKTDI and KKTF. Additionally, this study simulated the air distribution using CFD with different variables and parameters to develop a more efficient air distribution system.

Research has shown that enhancing air-conditioning units can significantly improve their performance and energy efficiency [1,2]. Mohideen *et al.,* [3] found that incorporating window air conditioner units with wickless loss heat pipes (WLHP) can improve the unit's coefficient of performance by 18%–20%. Studies on the performance of air-cooled condensers in air-conditioning units have observed that an increase in ambient temperature negatively affects the performance coefficient due to a decrease in overall heat rejection [4,5]. A parametric study and optimisation of an air-conditioning system for a heat-loaded room indicated that the direction of the air supply from the air conditioners strongly affected the velocity field and temperature distribution in the room [6,7].

Rodriguez and Hinojosa [8] studied the airflow in an air-cooled, three-dimensional rectangular room, considering the turbulent flow and the radiative exchange between walls. Fulpagare *et al.,* [9] conducted experiments to investigate room airflow patterns and thermal comfort by examining rooms under four conditions: natural, only fan, only AC, and fan with AC. Prakash [10] used the CFD method to analyse thermal comfort and indoor airflow characteristics, developing new strategies to identify optimal window openings, improving low-temperature percentages by 50% [11]. Kato [12] performed CFD analysis on a network model of airflow and transport scenarios, whereas Nielsen predicted the flow and heat transfer in cavities [13]. They showed that the thermal wall jet from a radiator significantly influences the airflow patterns, temperature, and pollutant distribution in heated rooms [14]. Additionally, the ceiling average Nusselt number increases with Reynolds number and decreases with Grashoff number [15,16].

In this study, we analyzed the airflow characteristics and temperature distributions within two activity halls with similar designs and spatial configurations. We began by collecting temperature data from both halls to understand the baseline conditions and used CFD to simulate the air distribution, which allowed us to compare the results and identify differences in airflow patterns and temperature fields. To deepen the analysis, additional CFD simulations were conducted by adjusting various variables and parameters to observe their impacts on air distribution within buildings.

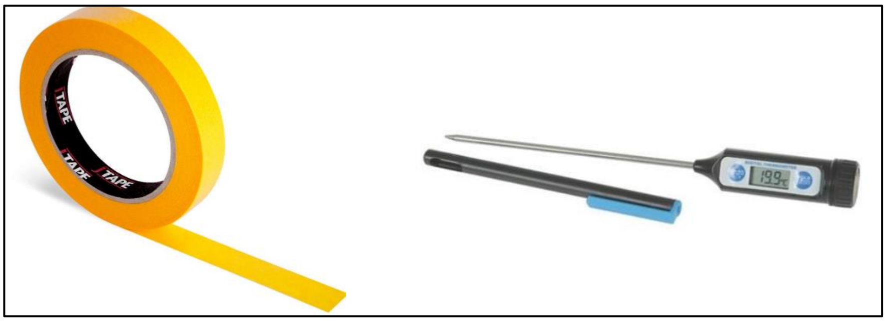
2. Methodology

This study employed two methods: an experimental approach and computational simulation using the ANSYS FLUENT software. The methodology outlines the implementation of each method to achieve the research objectives.

2.1 Experimental Method

This study focuses on investigating the airflow characteristics and temperature fields. Temperature readings inside the activity halls of KKTDI and KKTF were obtained every two hours starting at 8:00 a.m. to 10:00 p.m. Furthermore, the results are compared with the simulation results. Figure 1 illustrates the tools used to obtain the experimental data: (a) measuring tape, (b) anemometer, (c) tape, and (d) digital thermometer.

(a) (b)



(c) (d)

Fig. 1. The tools were used to obtain the experimental data (a) Measurements Tapes (b) Anemometer (c) Tape (d) Digital thermometer

2.2 Numerical Method

ANSYS software was used for finite element analysis to address structural issues [17,18]. The application of CFD analysis to fluid dynamics problems is becoming increasingly common. For visualisation purposes, ANSYS FLUENT can solve CFD applications related to airflow characteristics and temperature fields in the activity halls of KKTDI and KKTF.

2.2.1 Geometries of the KKTDI and KKTF activity halls

The activity halls of KKTDI and KKTF were modelled using SOLIDWORKS software, with a parameter view of the halls shown in Figure 2. In this project, the model was built in SolidWorks, transferred to the design modeller, and saved in the IGS format, which is compatible with ANSYS. This format is illustrated in Figure 3.

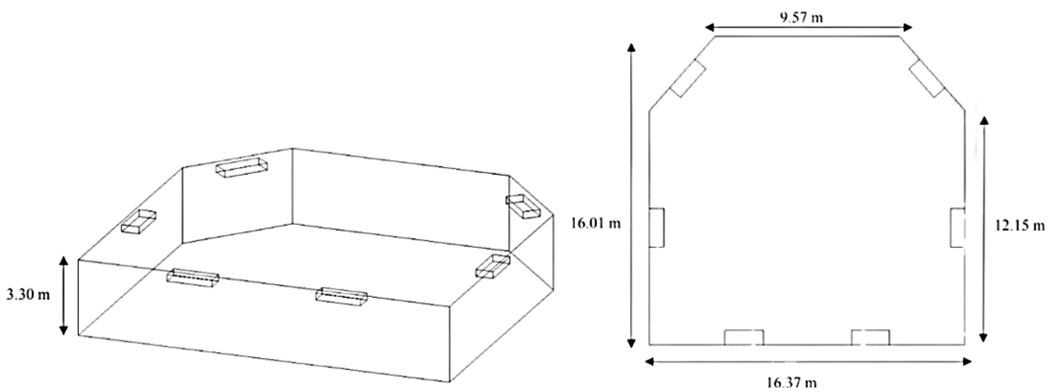


Fig. 2. Overall sizes of the KKTDI and KKTF halls

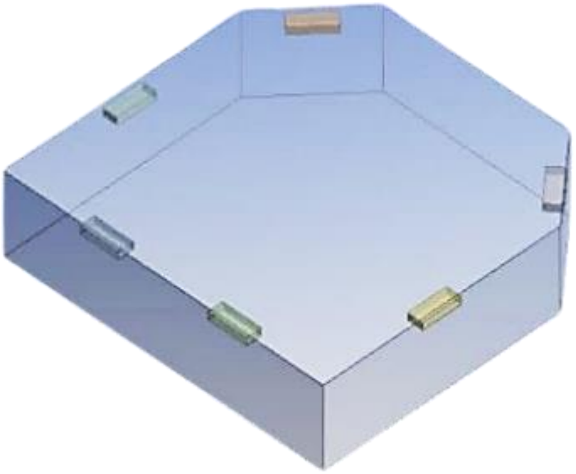


Fig. 3. Geometry in design modeler

2.3 Meshing

The meshing process discretizes the computational domain into numerous cells or elements [19]. This process generates mathematical equations related to the fluid flow model, thereby enhancing the numerical analysis and evaluation [20]. The accuracy of the entire model depends on the mesh quality. A high-quality mesh resulted in a more accurate flow solution. Figure 4 shows an overview of the meshed product. The model was subjected to a Grid Independence Test (GIT) to determine the appropriate element size for the geometry. Because of the GIT, the meshed model had a maximum skewness of 1.0 and a computational grid consisting of 128,129 nodes and 104,696 elements.

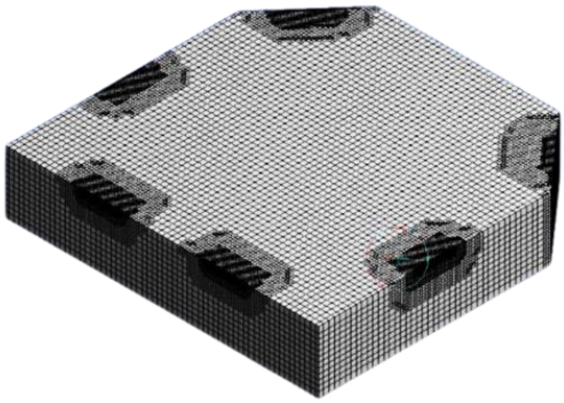
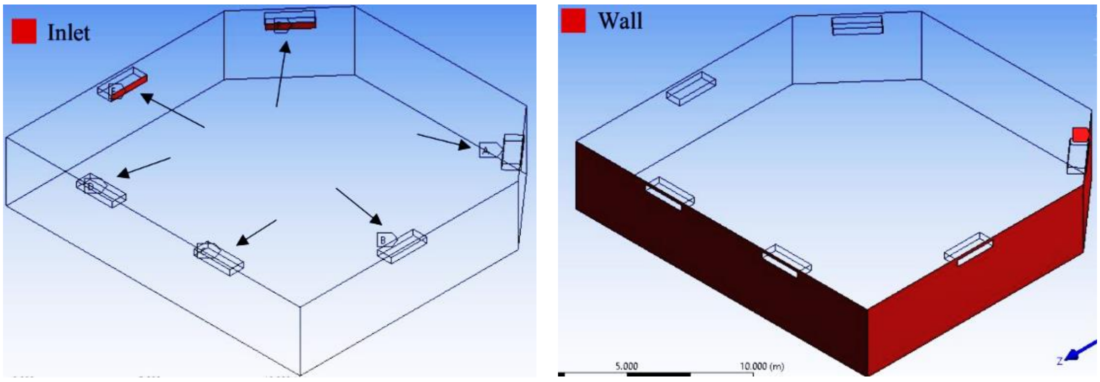


Fig. 4. Overview of the mesh product

2.4 Boundary Conditions

Boundary conditions were employed to define the specific boundaries of the flow variables within the model. The flow solution is influenced by the selected parameters, and the precise configuration of these parameters is crucial. Inappropriate boundary conditions can lead to inaccurate results. Therefore, suitable boundary conditions were specified for each part of the proposed model.

The velocity inlet boundary condition was used to determine the scalar properties and velocity flow at the inlet wall boundaries. In this study, velocity inlets were positioned at the front surfaces of six air conditioners. The side wall is treated as a symmetry boundary condition, which is commonly applied to lateral walls to reduce the computational time and cost associated with fluid flow problems caused by the flow field and symmetry of the geometry. Figure 5 illustrates the velocity inlet and wall boundary conditions. Table 1 lists the boundary conditions used in this simulation.



(a) (b)

Fig. 5. Boundary conditions (a) Velocity inlet (b) Wall

Table 1
Boundary conditions

Zone	Type
Inlet	Velocity magnitude = 1.317 m/s Temperature = 289 K
Wall	Wall (symmetry in 2D cases)

3. Results

3.1 Experimental Results

This section presents and discusses the main findings from the KKTDI and KKTF activity halls using an experimental approach. The results focused on airflow characteristics in terms of velocity and temperature fields. Figure 6 shows a schematic of the activity hall.

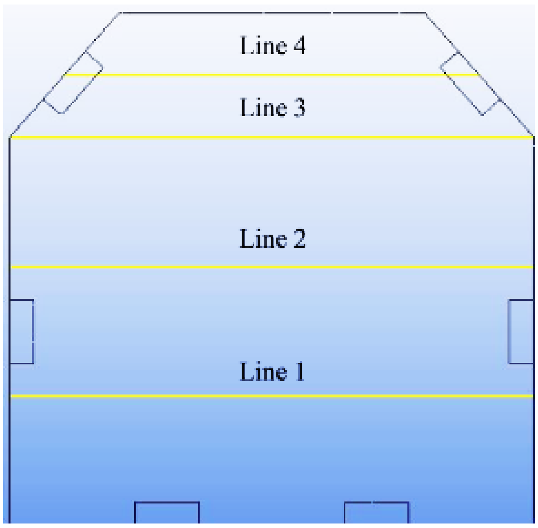


Fig. 6. Schematic of the activity hall

3.1.1 Evaluation of airflow characteristics in activity halls (velocity)

The velocity measurements near the walls were approximately zero; therefore, only the nodes in the center were considered. The values for these four lines are listed in Table 2. In the KKTDI model, the air velocity was zero at all nodes, whereas in the KKTF model, it was zero on line 4. The highest velocity recorded in the KKTF was 0.167 m/s. Figure 7 illustrates the air velocity decline across the lines, starting from Line 1.

Table 2
Experimental velocity result

No line	Velocity (m/s)	
	KKTF	KKTDI
1	0.167	0
2	0.133	0
3	0.067	0
4	0	0

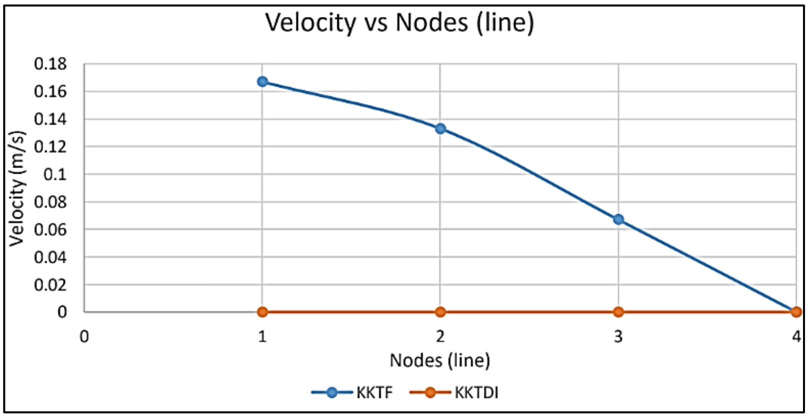


Fig. 7. Experimental velocity result

3.1.2 Evaluation of temperature field in the activity areas

The temperature readings at KKTF and KKTDI were notably different: KKTF was freezing, and KKTDI was hot. The highest temperature recorded at KKTDI was 28.9°C, while the lowest temperature recorded at KKTF was 16.4°C. Table 3 lists the experimental temperature results. Figure 8 shows that the temperature differences across the lines for KKTF and KKTDI were minimal and acceptable.

Table 3
Experimental temperature results

No line	Temperature (°C)	
	KKTF	KKTDI
1	16.5	27.8
2	16.4	28.2
3	17.0	28.9
4	17.8	28.9

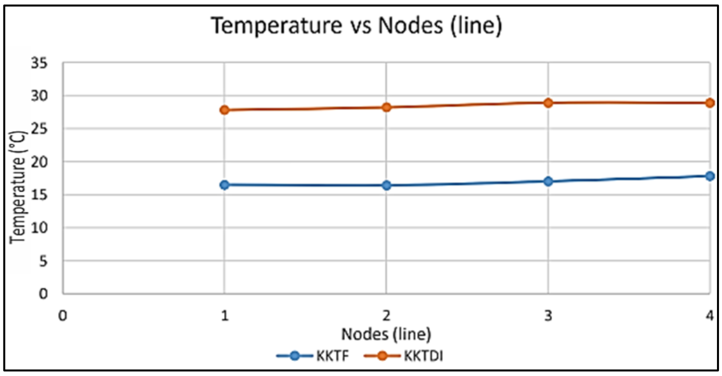


Fig. 8. Experimental temperature results

3.2 Computational Simulation Results

3.2.1 Evaluation of airflow characteristics in activity halls (velocity)

The velocity values obtained from the CFD simulations are listed in Table 4. The highest velocity was at line 1, measuring 0.125 m/s, whereas the lowest was at line 4, measuring 0.00139 m/s. Figure 9 shows the simulated velocity results.

Table 4
Simulation velocity result

No line	Velocity (m/s)
1	0.12542
2	0.10971
3	0.07232
4	0.001399

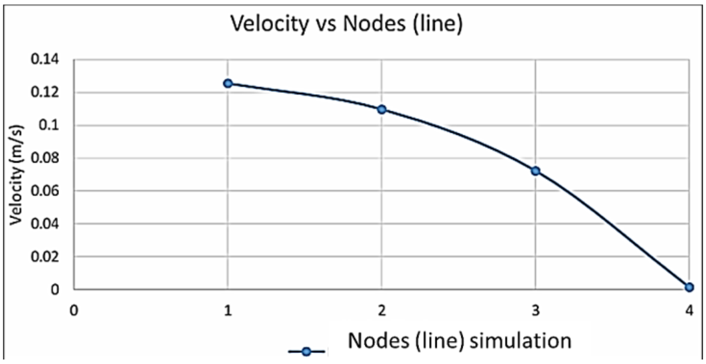


Fig. 9. Simulation velocity result

3.2.2 Evaluation of temperature field in the activity hall

Table 5 presents the experimental results for Tun Fatimah and Tun Dr. Ismail residential colleges. The highest temperature occurred at line 1, with 17.8°C (TF) and 28.9°C (TDI). The lowest temperature for TF was in line 3, at 16.4°C, while for TDI, it was in line 4, at 27.8°C. Figure 10 indicates that the temperature at the TF was similar to the experimental temperature, with differences of only 0.2°C (line 1), 1°C (line 2), 1.6°C (line 3), and 1.5°C (line 4). In contrast, the temperature at the TDI showed significant differences of 10.9°C at lines 1 and 2, 10.2°C (line 3), and 9.2°C (line 4).

Table 5
Simulation velocity result

No line	Tun Fatimah (℃)	Tun Dr Ismail (℃)	Simulation (℃)
1	17.8	28.9	18.0
2	17.0	28.9	18.0
3	16.4	28.2	18.0
4	16.5	27.8	18.0

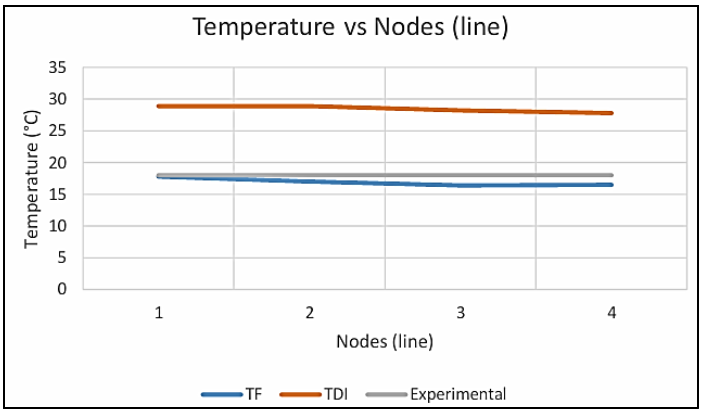


Fig. 10. Simulation temperature results

3.2.3 Air flow characteristics in the activity hall

Figure 11 illustrates the velocity contour and streamline obtained by post-processing. The velocity reached its maximum value of 2.135 m/s at several locations, including above line 1, between lines 2 and 3, and near air conditioners 4 and 3. However, the vorticity between lines 3 and 4 is greater than that at other locations. Overall, the center of the hall exhibited higher air conditioner velocities than the walls, approaching 0 m/s. This situation is consistent with the velocity profile, indicating that the center of the hall is cooler than the other regions.

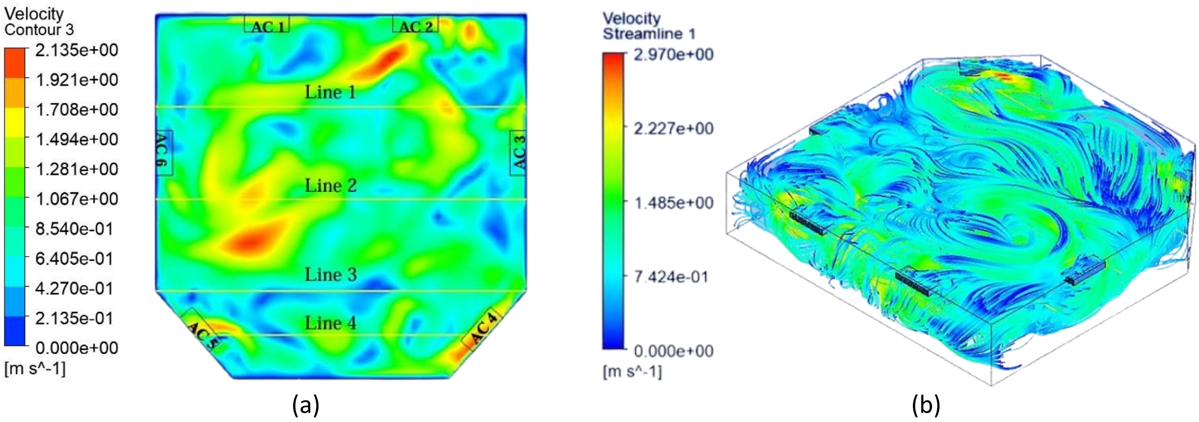


Fig. 11. Postprocessor process: (a) Velocity contour (b) Streamline

3.3 Verification Process

To verify the accuracy of the current simulation, a comparison with previous experimental studies is necessary. Table 6 lists the simulation and experimental velocity results. Figure 12 shows that the shape of the simulation graph is similar to that of the experimental graph, with an average relative error of 12.59%. This error is within the acceptable range (below 20 %). Therefore, the reliability of the current simulation was confirmed as genuine and valid.

Table 6
Simulation velocity result

No line	Experimental velocity (m/s)	Simulation velocity (m/s)	Relative error (%)
1	0.167	0.12542	24.89
2	0.133	0.10971	17.51
3	0.067	0.07232	7.94
4	0	0.001399	-
Average relative error (%)			12.59

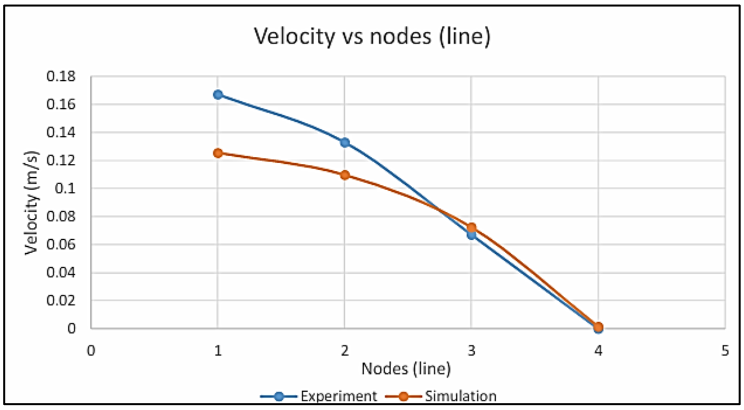


Fig. 12. The velocity contour and streamline obtained in post-processor process

4. Conclusions

This study successfully achieved its main objectives by analysing and comparing the airflow characteristics and temperatures in the activity halls of KKTDI and KKTF. The first objective was to examine the parameters of computational simulations and experimental measurements. The results show that the highest and lowest velocity values in the simulation were 0.12542m/s, and 0.00139 m/s, respectively. In contrast, the KKTF experiment recorded velocity differences of 0.167m/s, and 0 m/s, with an average velocity difference of 12.59%. For temperature, the simulation recorded the highest value of 18°C, while the KKTF experiment ranged from 16.4°C to 17.8°C, and the KKTDI experiment displayed a temperature range of 27.8°C to 28.9°C. The average temperature differences were 5.97% and 57.23% for KKTF and KKTDI, respectively. These findings demonstrate that the experimental results closely match the simulation data, thereby confirming the accuracy of the airflow and temperature field measurements at both activity halls. Therefore, this study successfully validated the computational models and achieved their objectives.

Acknowledgement
This research was supported by the Ministry of Higher Education (MOHE) through the Fundamental Research Grant Scheme (FRGS) (FRGS/1/2022/TK10/UTHM/03/5).

References

[1] Yang, Zixu, Chenqiu Du, Hansong Xiao, Baizhan Li, Wenxing Shi, and Baolong Wang. "A novel integrated index for simultaneous evaluation of the thermal comfort and energy efficiency of air-conditioning systems." *Journal of Building Engineering* 57 (2022): 104885. https://doi.org/10.1016/j.jobe.2022.104885

[2] Han, Zongwei, Xiaoqing Sun, Haotian Wei, Qiang Ji, and Da Xue. "Energy saving analysis of evaporative cooling composite air conditioning system for data centers." *Applied Thermal Engineering* 186 (2021): 116506. https://doi.org/10.1016/j.applthermaleng.2020.116506

[3] Tharves, Mohideen Sheik Ismail, and Nagachari Nethaji. "Experimental studies on improvement of coefficient of performance of window air conditioning unit." *Thermal Science* 21, no. 3 (2017): 1349-1358. https://doi.org/10.2298/TSCI141215139T

[4] Khalifa, Abdul Hadi N., Johain J. Fataj, and Ali K. Shaker. "Performance study on a window type air conditioner condenser using alternative refrigerant R407C." *Engineering Journal* 21, no. 1 (2017): 235-243. https://doi.org/10.4186/ej.2017.21.1.235

[5] Cataldo, Filippo, and John R. Thome. "Experimental evaluation of the thermal performances of a thermosyphon cooling system rejecting heat by natural and forced convection." *Applied Thermal Engineering* 127 (2017): 1404-1415. https://doi.org/10.1016/j.applthermaleng.2017.08.166

[6] Cataldo, Filippo, and John R. Thome. "Experimental evaluation of the thermal performances of a thermosyphon cooling system rejecting heat by natural and forced convection." *Applied Thermal Engineering* 127 (2017): 1404-1415.

[7] Dogan, Ahmet, Nurullah Kayaci, Baris Burak Kanbur, and Hakan Demir. "Experimental investigation of mean radiant temperature trends for a ground source heat pump-integrated radiant wall and ceiling heating system." *Buildings* 13, no. 10 (2023): 2420. https://doi.org/10.3390/buildings13102420

[8] Rodríguez, Norma A., and Jesus F. Hinojosa. "Numerical study of airflow and heat transfer in an air-cooled room with different inlet positions." *Journal of Building Physics* 37, no. 3 (2014): 246-268. https://doi.org/10.1177/1744259112462106

[9] Fulpagare, Yogesh, and Neeraj Agrawal. "Experimental investigation on room air flow pattern & thermal comfort quantification." *International Journal of Engineering Sciences & Emerging Technologies* 6, no. 1 (2013): 120-132.

[10] Prakash, D., and P. Ravikumar. "Analysis of thermal comfort and indoor air flow characteristics for a residential building room under generalized window opening position at the adjacent walls." *International Journal of Sustainable Built Environment* 4, no. 1 (2015): 42-57. https://doi.org/10.1016/j.ijsbe.2015.02.003

[11] Liu, Yiqiao, Wen Tong Chong, Yat Huang Yau, Li Chang, Tong Cui, Haowei Yu, Ying Cui, and Song Pan. "Rethinking the limitations of research on occupants' window-opening behavior: A review." *Energy and Buildings* 277 (2022): 112552. https://doi.org/10.1016/j.enbuild.2022.112552

[12] Kato, Shinsuke. "Review of airflow and transport analysis in building using CFD and network model." *Japan Architectural Review* 1, no. 3 (2018): 299-309. https://doi.org/10.1002/2475-8876.12051

[13] Nielsen, Peter V. "Flow in air conditioned rooms: Model experiments and numerical solution of the flow equations." (1974).

[14] Lu, Weizhen, Andrew T. Howarth, and Alan P. Jeary. "Prediction of airflow and temperature field in a room with convective heat source." *Building and Environment* 32, no. 6 (1997): 541-550. https://doi.org/10.1016/S0360-1323(97)00014-0

[15] Al-Sanea, Sami A., M. F. Zedan, and M. B. Al-Harbi. "Heat transfer characteristics in air-conditioned rooms using mixing air-distribution system under mixed convection conditions." *International journal of thermal sciences* 59 (2012): 247-259. https://doi.org/10.1016/j.ijthermalsci.2012.04.023

[16] Nordin, N., S. M. Seri, I. Taib, A. N. Mohammed, M. K. Abdullah, and A. Sapit. "Secondary flow vortices and flow separation of 2-D turning diffuser via particle image velocimetry." In *IOP Conference Series: Materials Science and Engineering*, vol. 226, no. 1, p. 012149. IOP Publishing, 2017. https://doi.org/10.1088/1757-899X/226/1/012149

[17] Zhang, Ran, Xiaodong Xu, Ke Liu, Lingyu Kong, Wei Wang, and Thomas Wortmann. "Airflow modelling for building design: A designers' review." *Renewable and Sustainable Energy Reviews* 197 (2024): 114380. https://doi.org/10.1016/j.rser.2024.114380

[18] Al-Bana, Ahmed S., Shady Zahran, Mohamed M. Ahmed, and Karem M. Al-Sayaad. "Performance analysis and validation of different meshing techniques used for computational fluid dynamics simulation." In *2022 International Telecommunications Conference (ITC-Egypt)*, pp. 1-5. IEEE, 2022. https://doi.org/10.1109/ITC-Egypt55520.2022.9855763

[19] Stromberg, Henrik, Valentin Mayer-Eichberger, and Armin Lohrengel. "Combinatorial Methods in Grid Based Meshing." In *International Meshing Roundtable*, pp. 253-269. Cham: Springer Nature Switzerland, 2023. https://doi.org/10.1007/978-3-031-40594-5_12

[20] Baker, Nazar, Ger Kelly, and Paul D. O'Sullivan. "A grid convergence index study of mesh style effect on the accuracy of the numerical results for an indoor airflow profile." *International Journal of Ventilation* 19, no. 4 (2020): 300-314. https://doi.org/10.1080/14733315.2019.1667558