Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Exploring the Effect of Indoor Thermal Comfort using Iris Dampers: A Justification Study

Nur'Amirah Busu[1,2], Norasikin Mat Isa[1,2,*], Azian Hariri[2], Mohamed Hussein[3], David Shina Adebayo[4]

[1] Energy Technologies Research Group (EnRG), Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia
[2] Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia
[3] Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[4] School of Engineering and Technology, College of Engineering and Physical Sciences, Aston University, Aston Triangle, Birmingham B4 7ET, United Kingdom

ARTICLE INFO

Article history:
Received 13 May 2024
Received in revised form 20 August 2024
Accepted 2 September 2024
Available online 30 September 2024

Keywords:
Iris damper; thermal comfort; temperature distribution; HVAC; VAV system

ABSTRACT

This study explores the impact of fixed damper openings on indoor thermal comfort in a lab-scaled chamber. Experiments with maximum, medium, and minimum iris damper openings were conducted under various occupancy conditions. Results show that the maximum opening maintained temperatures close to the ideal 24°C with minimal fluctuations. In contrast, medium and minimum openings resulted in higher temperature variability and less efficient air distribution. Statistical analysis highlighted significant differences in temperature stability among the different damper settings. The maximum opening ensured a stable temperature range, while the minimum opening caused noticeable temperature stratification and discomfort, especially with more occupants. The findings indicate that fixed damper openings are inadequate for maintaining consistent thermal comfort due to their lack of adaptability. This underscores the need for advanced control systems that can dynamically adjust damper positions to ensure optimal indoor temperature regulation and improve energy efficiency.

1. Introduction

Central air conditioning systems play a significant role in regulating the indoor thermal environment, providing cooling or heating as needed to maintain a comfortable temperature range, typically between 23°C and 26°C, and controlling humidity levels within a comfortable range, generally between 40-60%.

Centralized air conditioning systems often face several issues that significantly impact thermal comfort. Inadequate temperature control can lead to inconsistent and uncomfortable temperatures throughout the building, causing discomfort for occupants [1-4]. Poor air distribution may result in stagnant or insufficient airflow in certain areas, leading to temperature stratification and further discomfort [2]. Additionally, inaccurate thermostat settings, humidity imbalances, and inadequate

---

[*] *Corresponding author.*
E-mail address: sikin@uthm.edu.my

https://doi.org/10.37934/arfmts.121.2.111

ventilation can exacerbate these problems [5,6]. Energy inefficiency is another concern, affecting thermal comfort and increasing operational costs [7-9]. The lack of individual control over the temperature settings can leave some occupants dissatisfied. Maintenance issues and inherent system design limitations can further hinder the performance and effectiveness of centralized air conditioning systems, making it challenging to achieve optimal thermal comfort [10-12]. The bibliographic analysis of current research trends in HVAC systems in Figure 1 reveals that energy efficiency and thermal comfort receive the most attention, indicating that this topic is a prominent research area and remains highly relevant for further exploration. This paper will focus on indoor thermal comfort study areas in central air conditioning systems.

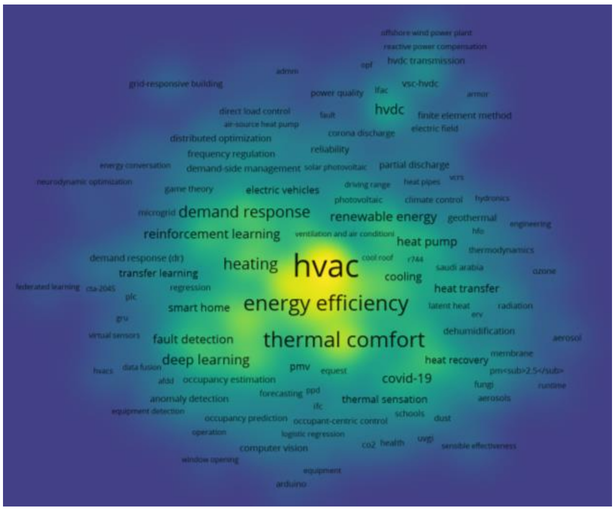

Fig. 1. Bibliographic analysis in the HVAC field

Generally, indoor thermal comfort refers to the condition in which building occupants feel satisfied with the thermal environment inside. It is a subjective state of mind that varies from person to person. The extent of temperature rise within indoor spaces resulting from human activity and capacity can fluctuate depending on various factors. A recent study by Yao *et al.,* [13] investigated the relationship between thermal sensation and student performance in a classroom, resulting in good academic performance when the classroom environment is cooler. Abbasi *et al.,* [14] stated that the human body's response to heat is contingent on its capacity to dissipate heat, and research indicates that an increase of 1°C can lead to a decrease in performance by 2%.

Thus, indoor thermal comfort is essential for individuals' well-being, productivity, and overall satisfaction, particularly in buildings with central air conditioning systems. Furthermore, maintaining thermal comfort in workplace environments is critical as it directly impacts workers' morale, performance, concentration, and productivity [15]. Prolonged exposure to thermal discomfort can lead to fatigue, reduced productivity, and increased worker complaints and absenteeism [16].

Mu *et al.,* [17,18] proposed a feed-forward control method to predict the VAV damper opening and fan frequency by demand flow rate to enhance thermal comfort. Similarly, Cao *et al.,* [19] proposed implementing PID control in a VAV system to manipulate the inlet airflow in a zone based on the step response of the room temperature. Besides that, Rastegar-Moghadam *et al.,* [20] propose using the zonal method for thermal modelling in office rooms with VAV systems, emphasizing its simplicity and accuracy for year-round thermal control. This method is a foundation for developing effective control strategies but does not directly address energy efficiency or personalized comfort. Shi *et al.,* [21] introduce a model-based optimal control strategy for multi-zone VAV systems, optimizing fan frequencies and damper openings to balance indoor temperature and room pressure, enhancing comfort and energy efficiency. This approach is more comprehensive than the zonal method, addressing the complexities of concurrent temperature and pressure control. Previously, Zhang *et al.,* [22] focused on personalized thermal control using a model predictive control (MPC) framework and low-cost local sensing, achieving significant energy savings and higher occupant satisfaction by tailoring conditions to individual preferences. Compared to the other two, Zhang *et al.,* [22] approach is the most advanced in customization and energy efficiency.

A notable research gap exists in the literature, as prior studies predominantly concentrated on manipulating dampers within VAV systems, a practice potentially disrupting overall system performance. As a novel approach, this study proposes an analysis of diffuser dampers to address thermal comfort issues without necessitating adjustments to the original settings of the VAV system. An initial study was conducted by Busu *et al.,* [23-25] to integrate the step-based thermal control method with an iris damper pattern into the inlet air diffuser's damper to maintain the indoor temperature range between 23.5°C to 24.5°C, assuming that an indoor temperature of 24°C is ideal for thermal comfort.

This paper aims to justify the development of an integrated iris damper and step-based thermal control system. The study observes explicitly the effects of using a fixed opening damper on indoor thermal performance. It demonstrates that relying on a fixed damper with manual adjustment fails to maintain consistent indoor thermal comfort throughout the day. By examining real-time indoor temperature distribution with an iris damper without a control system, the study reveals the inadequacies of the fixed opening method. The results underscore the necessity of a step-based control approach to enhance indoor thermal performance and ensure stable thermal comfort.

2. Methodology

An experimental study was conducted to observe the effect of a fixed opening damper on indoor thermal performance in real time. The study aimed to establish cause-and-effect relationships, explore hypotheses, validate theories, and provide evidence-based insights by manipulating independent variables and measuring their effects on dependent variables. The experiment utilized a lab-scaled chamber with dimensions of 5ft x 5ft x 4ft. The chamber featured a single inlet with a square diffuser and an iris damper, as shown in Figure 2. To measure the indoor temperature, type-K thermocouples were installed at five selected points (Figure 3), and a PicoLog TC-08 data logger was used to read the temperature sensors (Figure 4). Channels 1 through 5 were connected to collect real-time temperature data.

Experiments were conducted with three iris damper opening types: maximum, medium, and minimum. The choice of aperture sizes allows for examining how varying airflow affects temperature distribution and thermal comfort. These variations help to identify the limitations of a fixed damper opening and highlight the potential benefits of a step-based thermal control system.

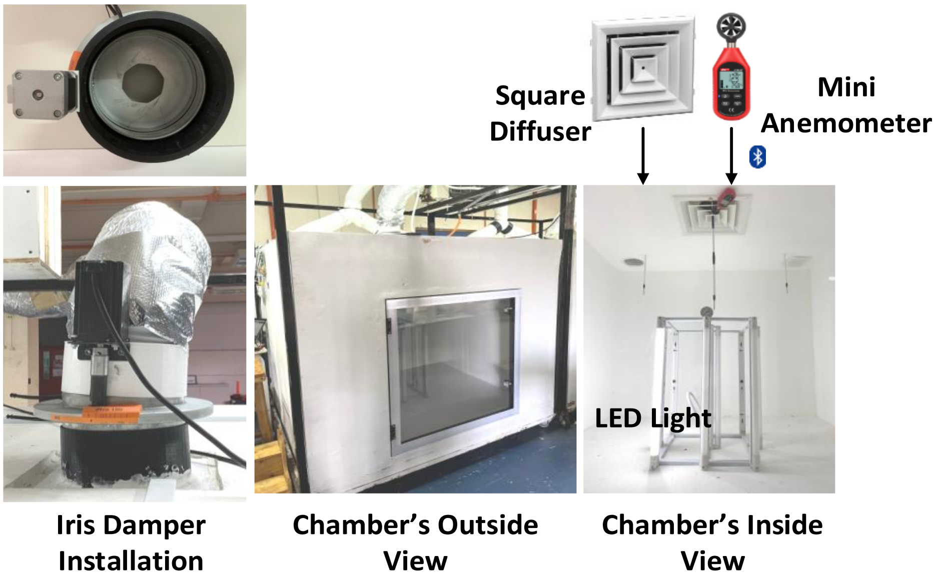

Fig. 2. The lab-scaled chamber

Fig. 3. The installation of the square diffuser and thermocouple type-K in the chamber

Fig. 4. PicoLog TC-08 used to log real-time temperature data from thermocouple

Each opening type was tested under four different occupancy conditions: no occupant, one person, two persons, and three persons. The experimental conditions were carefully chosen to reflect real-world situations as accurately as possible within a lab-scaled setup. The occupancy levels (no occupant, one person, two persons, and three persons) were selected to simulate typical small room scenarios where the number of occupants can vary throughout the day. These levels help to understand the impact of human presence and activity on indoor thermal performance. Detailed experimental conditions are presented in Table 1.

Each condition was run for one hour, with an initial stabilization period of one hour to achieve a steady indoor temperature. At every one-hour interval, a heat initiator generating 50 watts was activated to simulate occupant presence, ranging from one person to three persons. The heat generation was scaled to 1:2 from the 100 watts typically associated with a resting person, approximated using a 100-watt LED bulb as a baseline for heat release. Although this approximation does not fully capture the complexity of human thermodynamics, it provides a reasonable and consistent measure for experimental purposes.

Table 1
Occupancy conditions in experimental study

Opening Type	Aperture Diameter (mm)	Occupancy Level			
		No Occupant	1 Person	2 Persons	3 Persons
Maximum	150	/	/	/	/
Medium	115	/	/	/	/
Minimum	80	/	/	/	/

Real-time temperature distribution data for each condition were recorded and interpreted through graphical representation using OriginPro software for data analysis. Several statistical methods and data analysis techniques were employed to ensure a comprehensive evaluation. Descriptive statistics, including mean, median, and standard deviation, were calculated to summarize the central tendency and dispersion of the temperature data. Additionally, time series analysis plotted temperature data to observe trends and fluctuations throughout the experimental period.

Therefore, incorporating different occupancy levels and heat generation values, the structured approach ensures that the experimental conditions closely mirror real-world scenarios. This comprehensive evaluation offers valuable insights into the performance of fixed-opening dampers. It emphasizes the need for advanced control systems, proposed by Busu *et al.,* [25] to maintain consistent indoor thermal comfort. These methods highlighted the effects of fixed damper openings on indoor temperature distribution, providing a thorough understanding of thermal performance under various conditions.

3. Results on Indoor Temperature Distributions

This section presents the results of the experimental study based on the different iris damper opening types. Generally, a larger opening area allows for greater airflow, resulting in more efficient air distribution and better temperature mixing within the chamber. Conversely, reducing the iris damper opening area restricts airflow, lowering air exchange rates and limiting temperature mixing. This restriction can cause airflow to concentrate in specific areas, resulting in uneven temperature distribution within the chamber. As the damper opening area decreases, temperature stratification and the occurrence of hot or cold spots become more likely.

Figure 5 illustrates the temperature distribution with a maximum damper opening. Initially, the temperature drops significantly from around 28°C to below the ideal temperature of 24°C within the first 60 minutes with no occupants, stabilizing at a mean temperature of 21.28°C with a standard deviation of 0.467°C. The fluctuations in temperature are relatively minor during this period. As the number of occupants increases from one to three persons, the average temperature rises slightly but remains close to the ideal temperature. Specifically, with one person, the mean temperature is 21.18°C (SD = 0.426°C); with two persons, it is 21.87°C (SD = 0.229°C); and with three persons, it is

22.73°C (SD = 0.457°C). The maximum damper opening allows for optimal airflow and efficient temperature mixing, which helps maintain thermal comfort despite the increasing heat load from additional occupants.

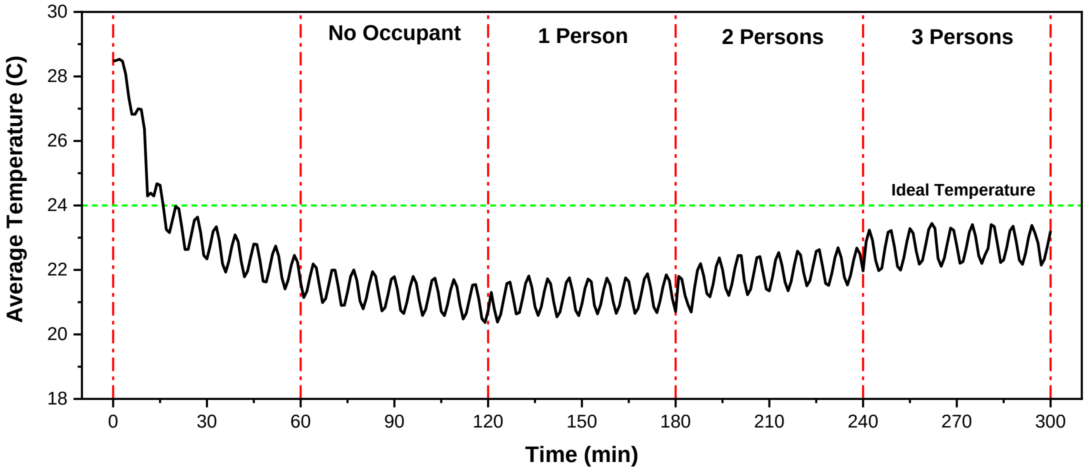

Fig. 5. Real-time temperature distribution during a maximum opening area of the iris damper with different occupancy conditions

Meanwhile, Figure 6 shows the temperature distribution with a medium damper opening. The temperature initially drops from around 28°C to approximately 24°C within the first 60 minutes with no occupants, showing some fluctuations with a mean temperature of 23.87°C and a standard deviation of 0.171°C. As the occupancy level increases, the temperature begins to rise gradually. With one person, the mean temperature is 24.47°C (SD = 0.273°C); with two persons, it is 25.25°C (SD = 0.251°C); and with three persons, it is 25.74°C (SD = 0.321°C). The fluctuations become more pronounced than the maximum opening, indicating less efficient air distribution. When three occupants are in the chamber, the temperature exceeds the ideal 24°C ideal temperature. This suggests that the medium damper opening is less effective in maintaining thermal comfort under higher occupancy levels.

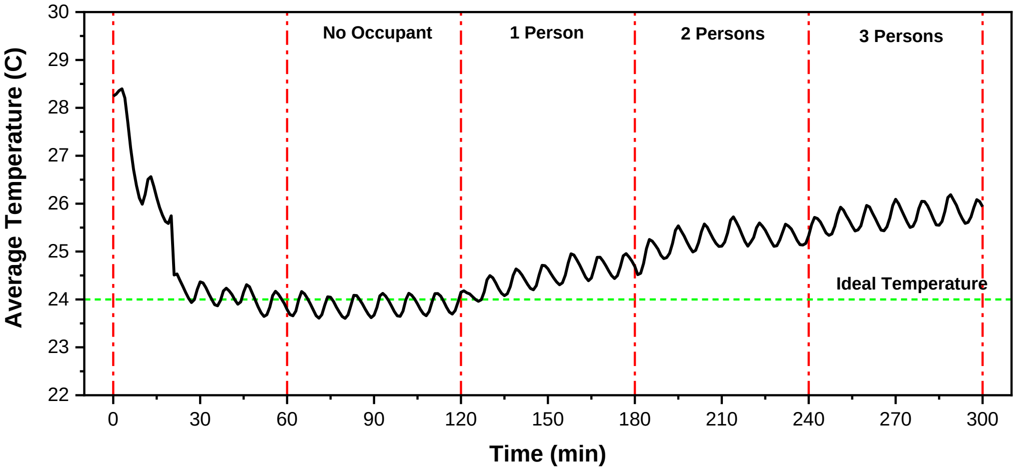

Fig. 6. Real-time temperature distribution during medium opening area of iris damper with different occupancy conditions

Lastly, Figure 7 depicts the temperature distribution with a minimum damper opening. Initially, the temperature drops from nearly 30°C to around 25°C within the first 60 minutes with no occupants. Still, the fluctuations are more pronounced than the other two settings, with a mean temperature of 24.99°C and a standard deviation of 0.334°C. As the occupancy level increases, the temperature steadily rises, reaching and exceeding 27°C with three occupants. With one person, the mean temperature is 25.05°C (SD = 0.295°C); with two persons, it is 25.79°C (SD = 0.329°C); and with three persons, it is 26.64°C (SD = 0.327°C). The minimum damper opening restricts airflow, leading to inefficient temperature mixing and pronounced temperature stratification. This results in a less comfortable thermal environment, especially under higher occupancy conditions. Table 2 presents each condition's descriptive statistical data, including the mean and standard deviation.

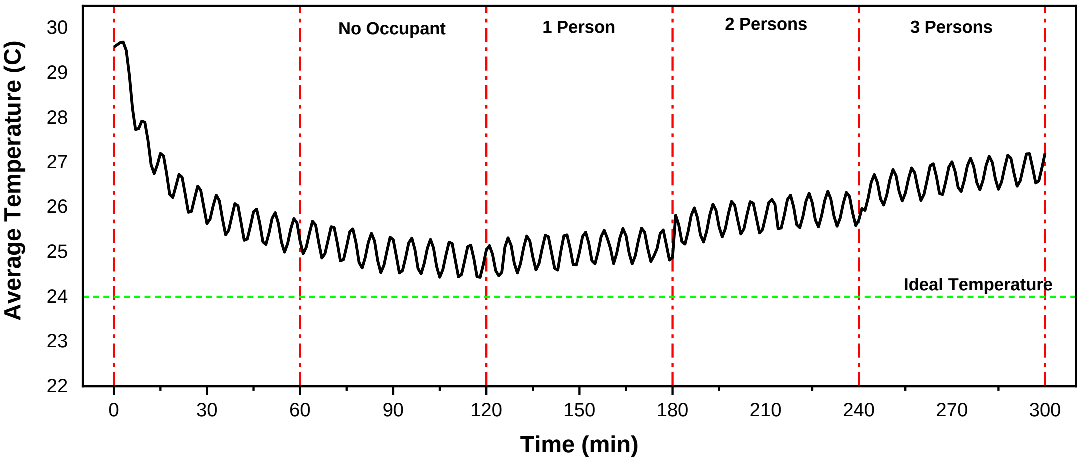

Fig. 7. Real-time temperature distribution during a minimum opening area of iris damper with different occupancy conditions

Table 2
Statistical data analysis on indoor temperature distribution

Occupancy Condition	Opening Type	Indoor Temperature	
		Mean (°C)	Standard Deviation (°C)
No Occupant	Maximum	21.28	0.467
	Medium	23.87	0.171
	Minimum	24.99	0.334
1 Person	Maximum	21.18	0.426
	Medium	24.47	0.273
	Minimum	25.05	0.295
2 Persons	Maximum	21.87	0.506
	Medium	25.25	0.251
	Minimum	25.79	0.329
3 Persons	Maximum	22.73	0.457
	Medium	25.74	0.220
	Minimum	26.64	0.327

Across all three graphs, it is evident that the ability to maintain an ideal indoor temperature diminishes as the damper opening size decreases. The maximum damper opening provides the best temperature control, keeping the environment close to the ideal temperature even with increasing occupancy. The medium damper opening shows moderate control but struggles to maintain thermal comfort as the heat load increases. The minimum damper opening is the least effective, leading to significant temperature rises and fluctuations, indicating poor air distribution and mixing.

In conclusion, these observations highlight the critical role of damper opening size in maintaining indoor thermal comfort. Larger damper openings facilitate better air distribution and temperature control, while smaller openings result in inadequate airflow and increased temperature stratification, significantly as occupancy levels rise. This underscores the necessity for a dynamic and responsive damper control system to ensure consistent indoor thermal comfort across varying conditions. The data support these findings, with mean temperatures and standard deviations reflecting the varying effectiveness of each damper opening size under different occupancy conditions.

4. Box Plot Comparison of Indoor Temperature Variability Across Damper Settings

The box plot in Figure 8 compares indoor temperature performance under different damper openings—maximum, medium, and minimum—providing valuable insights into how each setting influences temperature distribution and stability within the chamber.

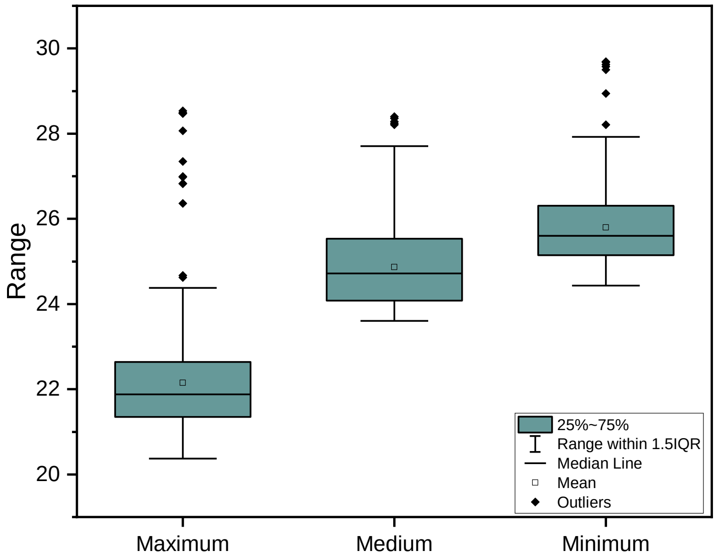

Fig. 8. Box plot comparison of indoor temperature distribution under different damper opening conditions

The box plot for the maximum damper opening demonstrates the most consistent temperature distribution, with the median temperature and the interquartile range (IQR) indicating a tightly clustered data set. The lower and upper quartiles are relatively close, suggesting that most temperature readings are within a narrow range. Several outliers above 26°C indicate occasional temperature spikes, but these are not frequent. The maximum damper opening achieves the lowest median temperature and the least variability, reflecting effective air mixing and temperature control.

Meanwhile, the box plot for the medium damper opening shows a wider IQR than the maximum opening, indicating more variability in the temperature distribution. The median temperature exceeds the maximum opening, suggesting less efficient cooling. Additionally, there are more outliers and a higher range of temperatures extending up to 28°C. This variability indicates less effective air distribution and more pronounced temperature fluctuations within the chamber. The medium damper opening provides moderate control but struggles to maintain a stable temperature, especially under varying occupancy conditions.

The box plot for the minimum damper opening reveals the highest median temperature and the widest IQR, indicating the most significant variability in temperature distribution. The range of temperatures is also broader, with numerous outliers extending above 27°C. This setting results in the least effective air mixing and the most pronounced temperature stratification, leading to considerable fluctuations and hot spots within the chamber. The minimum damper opening restricts airflow significantly, causing inefficient temperature control and more significant thermal discomfort.

Comparing the three box plots, it is evident that the maximum damper opening provides the best performance in maintaining a stable and comfortable indoor temperature. The lower median temperature and reduced variability highlight its effectiveness in promoting efficient air distribution and temperature mixing. The medium damper opening, while somewhat effective, shows increased variability and higher temperatures, indicating moderate performance. The minimum damper opening performs the worst, with the highest median temperature, the most significant variability, and the most outliers, reflecting poor air distribution and inadequate temperature control.

In conclusion, the box plot analysis underscores the importance of damper opening size in maintaining indoor thermal comfort. Larger damper openings facilitate better air distribution and more consistent temperature control, while smaller openings lead to increased temperature variability and reduced thermal comfort. This analysis further supports the need for dynamic and responsive damper control systems to ensure optimal indoor temperature regulation across varying conditions.

5. Conclusions

The experimental analysis and statistical evaluation highlight the significant impact of damper opening sizes on indoor temperature distribution and thermal comfort. The results demonstrate that the maximum damper opening provides the best temperature control with the lowest variability. In contrast, the medium and minimum damper openings show increased temperature fluctuations and higher mean temperatures, leading to less effective thermal regulation.

Overall, the study clearly demonstrates that fixed damper openings are inadequate for sustaining thermal comfort across different occupancy levels. The inability to dynamically adjust to changing thermal loads results in significant temperature variability and discomfort. These findings emphasize the critical need for exploring and implementing advanced control systems. Such systems would enable real-time adjustments of damper positions, ensuring consistent and optimal indoor temperature regulation. By integrating responsive control mechanisms, it is possible to achieve enhanced thermal comfort and energy efficiency, addressing the limitations observed with fixed damper openings.

Therefore, future research and development should focus on designing and deploying intelligent damper control systems that can adapt to varying conditions, ensuring a stable and comfortable indoor environment for occupants. This approach will improve thermal comfort and contribute to more efficient energy usage in HVAC systems.

Acknowledgement

The authors would like to thank Universiti Tun Hussein Onn Malaysia (UTHM) for the full support of the research work. This work was financially supported by the TIER 1 Grant Scheme Vot No. Q394.

References

[1] Ganesh, Ghogare Abhijeet, Shobha Lata Sinha, Tikendra Nath Verma, and Satish Kumar Dewangan. "Investigation of indoor environment quality and factors affecting human comfort: A critical review." *Building and Environment* 204 (2021): 108146. https://doi.org/10.1016/j.buildenv.2021.108146

[2] Derks, M. T. H., A. K. Mishra, M. G. L. C. Loomans, and H. S. M. Kort. "Understanding thermal comfort perception of nurses in a hospital ward work environment." *Building and Environment* 140 (2018): 119-127. https://doi.org/10.1016/j.buildenv.2018.05.039

[3] Kaushik, Amit, Mohammed Arif, Prasad Tumula, and Obas John Ebohon. "Effect of thermal comfort on occupant productivity in office buildings: Response surface analysis." *Building and Environment* 180 (2020): 107021. https://doi.org/10.1016/j.buildenv.2020.107021

[4] Kim, Jungsoo, Federico Tartarini, Thomas Parkinson, Paul Cooper, and Richard De Dear. "Thermal comfort in a mixed-mode building: Are occupants more adaptive?." *Energy and Buildings* 203 (2019): 109436. https://doi.org/10.1016/j.enbuild.2019.109436

[5] Jamaludin, Nazhatulzalkis, Nurul Izma Mohammed, Mohd Faris Khamidi, and Suriani Ngah Abdul Wahab. "Thermal comfort of residential building in Malaysia at different micro-climates." *Procedia-Social and Behavioral Sciences* 170 (2015): 613-623. https://doi.org/10.1016/j.sbspro.2015.01.063

[6] Hussin, Norasikin, Siti Shareeda Mohd Nasir, Nor Azirah Mohd Fohimi, Rohidatun Mahmod, Yusli Yaakob, and Dzullijah Ibrahim. "Analysis of Thermal Comfort and Energy Consumption for Educational Building." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 10, no. 1 (2022): 1-9.

[7] Irfan, Muhammad, and Faizir Ramlie. "Analysis of parameters which affects prediction of energy consumption in buildings using Partial Least Square (PLS) approach." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 25, no. 1 (2021): 61-68. https://doi.org/10.37934/araset.25.1.6168

[8] Johnson, Zwalnan Selfa, Abakar Yousif Abdalla, Shanmugam Anandan, Chan Andy Tak-Yee, and Su Yuehong. "A Numerical Evaluation of the Effect of Building Thermal Load on the Overall Performance Characteristic of a Grid-Coupled PV/T Energy System." *Journal of Advanced Research in Numerical Heat Transfer* 4, no. 1 (2021): 32-43.

[9] Fahmy, M., M. Morsy, H. Abd Elshakour, and A. M. Belal. "Effect of thermal insulation on building thermal comfort and energy consumption in Egypt." *Journal of Advanced Research in Applied Mechanics* 43, no. 1 (2018): 8-19.

[10] Taheri, Saman, Amirhossein Ahmadi, Behnam Mohammadi-Ivatloo, and Somayeh Asadi. "Fault detection diagnostic for HVAC systems via deep learning algorithms." *Energy and Buildings* 250 (2021): 111275. https://doi.org/10.1016/j.enbuild.2021.111275

[11] Ab Ghani, Ahmad Fuad, Mohd Azhar Shah Rizam, Jeefferie Abd Razak, Mohd Syaiful Rizal Abdul Hamid, Raja Nor Firdaus Kashfi Raja Othman, and Rahifa Ranom. "Analytical Hierarchy Process and Failure Mode and Effect Analysis on HVAC Semi-Hermetic Compressor Maintenance Strategy." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 32, no. 3 (2023): 256-272. https://doi.org/10.37934/araset.32.3.256272

[12] Bam, Ramnath V. Prabhu, Rajesh S. Prabhu Gaonkar, and Clint Pazhayidam George. "A machine learning framework for detection and severity estimation of faults for chillers and air handling units in HVAC systems." *Energy and Buildings* 313 (2024): 114235. https://doi.org/10.1016/j.enbuild.2024.114235

[13] Yao, Chong Zi, Mohamad Nor Azhari Nor Azli, Azian Hariri, Amir Abdullah Muhamad Damanhuri, and Mohd Syafiq Syazwan Mustafa. "Preliminary study on student's performance and thermal comfort in classroom." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 101, no. 1 (2023): 59-72. https://doi.org/10.37934/arfmts.101.1.5972

[14] Abbasi, Ali Mohammad, Majid Motamedzade, Mohsen Aliabadi, Rostam Golmohammadi, and Leili Tapak. "The impact of indoor air temperature on the executive functions of human brain and the physiological responses of body." *Health Promotion Perspectives* 9, no. 1 (2019): 55. https://doi.org/10.15171/hpp.2019.07

[15] Lan, Li, Zhiwei Lian, and Li Pan. "The effects of air temperature on office workers' well-being, workload and productivity-evaluated with subjective ratings." *Applied Ergonomics* 42, no. 1 (2010): 29-36. https://doi.org/10.1016/j.apergo.2010.04.003

[16] Voordt, Theo Van Der, and Per Anker Jensen. "The impact of healthy workplaces on employee satisfaction, productivity and costs." *Journal of Corporate Real Estate* 25, no. 1 (2023): 29-49. https://doi.org/10.1108/JCRE-03-2021-0012

[17] Mu, Yuanpeng, Jili Zhang, Zhixian Ma, and Mingsheng Liu. "A novel air flowrate control method based on terminal damper opening prediction in multi-zone VAV system." *Energy* 263 (2023): 126031. https://doi.org/10.1016/j.energy.2022.126031

[18] Mu, Yuanpeng, Mingsheng Liu, Zhixian Ma, and Jili Zhang. "Resistance characteristic analysis based study on a novel damper torque airflow sensor for VAV terminals." *Building and Environment* 175 (2020): 106813. https://doi.org/10.1016/j.buildenv.2020.106813

[19] Cao, Shuanghua, Weichao Zhao, and Anxiong Zhu. "Research on intervention PID control of VAV terminal based on LabVIEW." *Case Studies in Thermal Engineering* 45 (2023): 103002. https://doi.org/10.1016/j.csite.2023.103002

[20] Rastegar-Moghadam, Mahdi, Yadollah Farzaneh, and Seyed Mohammad Yasoubi. "Thermal modeling of an office environment with variable volume air condition system using zonal method for control system applications." *Energy Efficiency* 17, no. 4 (2024): 28. https://doi.org/10.1007/s12053-024-10196-y

[21] Shi, Shanrui, Shohei Miyata, Yasunori Akashi, Masashi Momota, Takao Sawachi, and Yuan Gao. "Model-based optimal control strategy for multizone VAV air-conditioning systems for neutralizing room pressure and minimizing

fan energy consumption." *Building and Environment* 256 (2024): 111464. https://doi.org/10.1016/j.buildenv.2024.111464

[22] Zhang, Hejia, Athanasios Tzempelikos, Xiaoqi Liu, Seungjae Lee, Francesca Cappelletti, and Andrea Gasparella. "The impact of personal preference-based thermal control on energy use and thermal comfort: Field implementation." *Energy and Buildings* 284 (2023): 112848. https://doi.org/10.1016/j.enbuild.2023.112848

[23] Busu, Nur'Amirah, Norasikin Mat Isa, Azian Hariri, and Mohamed Hussein. "Air Damper Effect on Temperature and Airflow Distribution in Enhancing Thermal Comfort Performance." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 100, no. 1 (2022): 152-164. https://doi.org/10.37934/arfmts.100.1.152164

[24] Busu, Nur'Amirah, Norasikin Mat Isa, Azian Hariri, and Mohamed Hussein. "The Comparison of P, PI and PID Strategy Performance as Temperature Controller in Active Iris Damper for Centralized Air Conditioning System." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 102, no. 2 (2023): 143-154. https://doi.org/10.37934/arfmts.102.2.143154

[25] Busu, Nur'Amirah, Norasikin Mat Isa, Azian Hariri, and Mohamed Hussein. "Revolutionizing Indoor Thermal Comfort: Iris Damper Integration with Step-based Control in Central Air Conditioning System." In *2024 2nd International Conference on Mechatronics, Control and Robotics (ICMCR)*, pp. 62-66. IEEE, 2024. https://doi.org/10.1109/ICMCR60777.2024.10482191