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# Test Rig Design: Advancement and Experimental Approaches for Enhanced Thermal Comfort Study

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**ABSTRACT**

Indoor environmental quality, especially thermal comfort, is a crucial aspect of Heating, Ventilation, and Air Conditioning (HVAC) system performance. This study addresses the challenge of accurately capturing thermal dynamics in current test rig designs. The primary objective is to enhance the thermal test rig's design by implementing specific modifications and analysing their impact on the thermal behaviour of tested chambers. The research focuses on improvements in ducting design, design positioning and mixing boxes. An experimental approach is utilized to assess the modifications. The study aims to improve the rig's performance and ensure reliable replication of specified thermal conditions. The results demonstrate significant enhancements in the test rig's efficiency and provide valuable insights into the thermal dynamics within the chambers following the modifications.

## 1. Introduction

Indoor environmental quality, particularly thermal comfort, is a critical aspect of Heating, Ventilation, and Air Conditioning (HVAC) system performance. Sustaining occupant comfort and maximizing energy efficiency depend on accurately evaluating and controlling thermal conditions [10]. Nevertheless, the current generation of thermal test rigs for assessing indoor thermal conditions frequently fails to achieve the required levels of accuracy and dependability [3]. The existing thermal test rig, designed to evaluate indoor thermal conditions, struggles to meet desired standards effectively. This modification will be focused on the ducting design, positioning and mixing box size to enhance the rig's overall performance. By achieving precise and controlled thermal conditions, the redesigned test rig aims to meet the stringent standards required for HVAC system evaluations. The growing demand for HVAC systems, vital to building health, has raised concerns about their potential

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to spread microbial contamination and disease. With their substantial global energy consumption, researchers, industries, and policymakers are now prioritizing efforts to enhance the sustainability of HVAC systems. To guarantee that the experimental procedures comply with HVAC system regulations, the study takes a careful examination of the shortcomings of the existing system, the planning and execution of specific changes, and a comprehensive assessment of the performance of the upgraded rig. Individuals can significantly adapt to their environments, whether in air-conditioned or naturally ventilated buildings. He emphasized the importance of adaptive options for achieving better comfort ratings, which were supported by his development of adaptive comfort models and the adaptive comfort equation [2]. Optimizing energy efficiency reduces costs and enhances comfort by adapting HVAC controls to fluctuating thermal demands due to weather changes and occupancy patterns. This involves making real-time adjustments to heating, cooling, and ventilation systems to ensure sustainable and cost-effective operation [5].

Personalized HVAC control and thermal comfort can be improved through probabilistic thermal preference profiles, a low-cost thermal sensing network, and a Model Predictive Control (MPC) framework. They highlighted the potential of integrating personalized MPC with low-cost thermal sensing networks to optimize HVAC control and enhance thermal comfort in building management systems. Measurement site selection for instrument type and positioning, including methods for determining mean radiant temperature, is crucial for the long-term study of thermal comfort. Standardized guidelines for conducting field surveys in outdoor environments have been developed to better understand outdoor thermal comfort and subjective thermal perception [6]. In recent years, numerous studies have focused on enhancing various aspects of ventilation and air quality systems through advanced simulation techniques. For example, one research effort to improve aircraft cabin comfort developed six customized ventilation systems (PVSs) to enhance thermal comfort metrics, resulting in a significant 12% increase in relative humidity [1]. Research investigating damper adjustment techniques through CFD analysis of airflow distribution and resistance in HVAC ducts has identified shortcomings in traditional air balancing methods under non-fully developed flow conditions [4]. In the context of building ventilation, evaluations of cross-ventilation performance through simulations and experiments have shown that aligning the Window-to-Wall Ratio (WWR) of air ducts with that of windows significantly improves ventilation efficiency [9].

Additionally, optimizing airflow distribution using CFD simulations, compared with experimental data, has shown that the iris damper pattern outperforms both butterfly and radial patterns in achieving optimal temperature and airflow distribution. This makes the iris damper pattern ideal for enhancing thermal comfort in Variable Air Volume (VAV) systems [11]. Study also said that a well-designed ducting system is crucial for the efficiency of HVAC systems, ensuring smooth airflow, precise temperature control, and minimal energy loss. An effective ducting layout, appropriate sizing, and integration components such as ducts, dampers, and vents are essential for maintaining a comfortable indoor environment, reducing energy consumption, and enhancing overall system performance [12]. Using a data-based multiple regression model for air flow rate measurement in Variable Air Volume (VAV) systems can significantly improve accuracy by providing more precise and reliable data on air flow rates. This model leverages historical data and various input variables to predict air flow rates more accurately than traditional methods [7].

This research aims to provide a reliable testing infrastructure that ensures precise and reliable indoor thermal settings by addressing thermal control and stability requirements. The results of this study could greatly increase the dependability of thermal testing for HVAC applications, which will eventually help to improve indoor environmental quality and building systems' energy efficiency.

## 2. Methodology

### *2.1 Enhancement Design*

The design for a test rig chamber is intended to evaluate modifications made to the thermal behavior within the chamber. The setup features two rectangular enclosures connected by a series of pipes, forming a closed loop. These pipes likely facilitate the controlled flow of air or another fluid, enabling precise regulation and measurement of thermal changes within the chamber. The design emphasizes creating a controlled environment to monitor temperature and airflow distribution accurately. By examining the efficiency of the modifications under these controlled conditions, the test rig helps optimize the thermal performance and ensure consistent results. Figure 1 below shows the overall design that has been proposed for the experimental design.

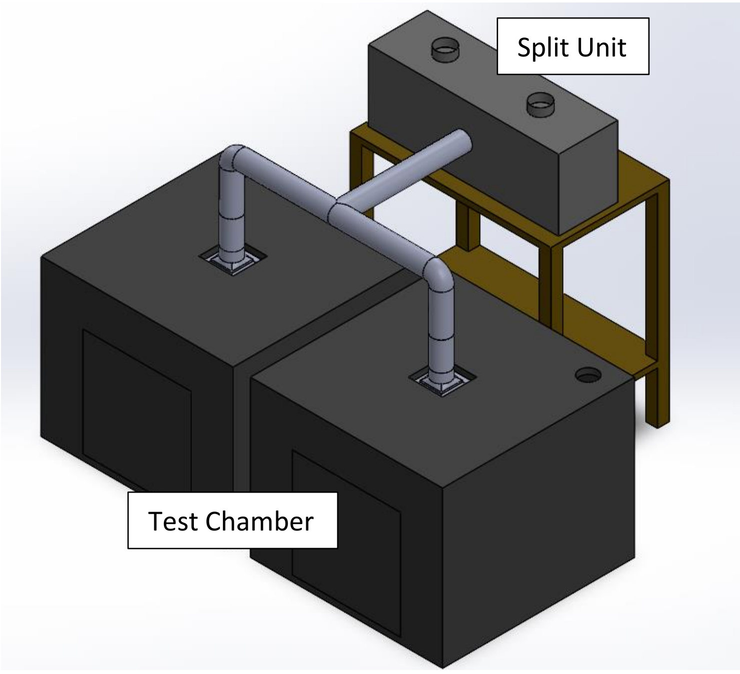


**Fig. 1.** Illustration of the test rig design for Air Conditioning (HVAC) system

The proposed redesign of the new test rig involves a strategic repositioning of the compressor, transitioning from its previous placement at the top of the rig to a more practical attachment on the wall. This adjustment aims to enhance accessibility and optimize the rig's overall layout for improved functionality. The main modification focused on is the ducting and mixing chamber. The modification lies in expanding the mixing box, necessitating the acquisition of new plywood to craft a larger box manually. The deliberate increase in size is designed to enhance the mixing chamber's efficiency and accommodate a higher volume of airflow. A meticulously crafted platform has been introduced for the mixing box to ensure a harmonious flow, aligning its height linearly with the compressor. This thoughtful integration contributes to the aesthetic and functional coherence of the entire system. Improved design also allows for more efficient airflow balancing, which lowers energy use and improves indoor air quality. From the observation made, a non-linear ducting design may also be the cause of its inefficient airflow. Furthermore, the design's direct ducting utilization minimizes potential airflow disparities, enhancing the system's overall efficiency. The separation of ducting entering both chambers in this configuration supports the uniform air distribution, reducing the likelihood of temperature differences between the two spaces.

The sizing of the mixing box had to be significantly altered to improve the thermal test rig's ability to contain and regulate cold air before releasing it. The idea was to increase the air mixing capacity and improve temperature stratification and cold air trapping by enlarging the box's dimensions. This modification was made to increase the accuracy and consistency of the test rig's ability to simulate desired indoor thermal settings by allowing for a more steady and controlled air release. The improved box sizing improves the overall performance and dependability of the thermal testing infrastructure by addressing past inefficiencies in temperature control. Lastly, the platform idea is to reposition the compressor and the mixing box to increase its airflow capability. After determining the platform design, the design can be concluded that the height of the platform needs to be parallel with the compressor position, which is 190 cm from the floor. The material required to build this platform also needs to handle the mixing box weight, which is more than 10kg.

### *2.2 Functionality Test*

After modification is made, it is important to test the setup to test its efficiency. In this pivotal phase of our experimental progression, the primary objective focusing on the indoor temperature dynamics. During the fully open condition, where the damper is not applied, our target is to ensure that the indoor temperature falls within the specified range of 21 to 24 degrees Celsius. This range aligns with the requisite conditions for our thermal testing. The initial temperature for the indoor unit is set at 18 degrees Celsius, serving as the baseline for our observations. The effects of the ducting modifications will be methodically analysed during this functionality test, providing valuable insights into the efficiency and performance of our adapted test rig.

A systematic procedure for evaluating the performance of an air conditioning system by varying its blower speeds and recording indoor temperature changes. The process begins with turning on the AC and blower for an initial test run to ensure everything is functioning correctly. Once verified, a PicoLog device is connected to a thermocouple to measure temperature. The AC is then operated at its maximum blower speed for 30 minutes. If the AC runs smoothly, it is turned off for 30 minutes to rest. Following this, the AC is turned back on with the blower set to a speed of 1 meter per second, and the indoor temperature changes are recorded for 2 hours using the PicoLog. This step is repeated with different blower speeds to collect comprehensive data. The gathered data is then analysed, and the results are visualized through graphs to observe the AC's performance across various blower speeds. The procedure concludes after completing these steps.

### *2.3 Velocity Calibration*

Setting the flow velocity first is crucial for several reasons, primarily to ensure accurate and reliable data measurement. Establishing the flow velocity allows for the calibration of instruments and sensors accordingly, ensuring that measurements are taken within the appropriate range. This preliminary step helps optimize the sensitivity and resolution of the measurement equipment, minimizing errors and improving data precision. Additionally, setting the flow velocity first provides a stable baseline for the experimental conditions. It ensures consistency throughout the measurement process, as variations in flow velocity can significantly impact the thermal dynamics within the chambers. A controlled and consistent flow velocity enables a more accurate assessment of temperature changes and their correlation to air movement. Its helps in understanding the interaction between air velocity and thermal distribution. It allows for a detailed analysis of how different flow rates influence temperature gradients and cooling efficiency. By establishing a known flow velocity, researchers can systematically study the impact of various velocities on thermal performance, leading to more comprehensive and reliable conclusions.

**Table 1**
Velocity and Voltage Setup

| No | Velocity (m/s) | Voltage (V) | Flow Temp (°C) |
|---|---|---|---|
| 1 | 1.0 | 10 | 21.7 |
| 2 | 1.5 | 12 | 19.8 |
| 3 | 2.0 | 14 | 17.9 |
| 4 | 2.5 | 16 | 17.1 |
| 5 | 3.0 | 22 | 16.9 |

## 3. Results

### *3.1 Performance Evaluation*

The three main modifications made to a system to improve its performance which is firstly, the ducting was changed from a nonlinear flow to an improved design that provides a more linear flow. This enhancement boosts airflow efficiency, minimizes turbulence, and ensures uniform air distribution. Secondly, the size of the mixing box was increased from its original dimensions. This modification allows for better mixing of air, resulting in more consistent temperature control. Lastly, the positioning of the mixing box was altered. Originally placed directly above the rig, it was repositioned onto a platform that allows for better adjustment of both the mixing box and compressor. This change improves airflow dynamics and provides easier access for maintenance.

### *3.2 Average Indoor Temperature vs Velocity*

The graph in Figure 2 below illustrates the average indoor temperature in Chamber A at different air velocities (1 m/s, 1.5 m/s, 2 m/s, 2.5 m/s, and 3 m/s), measured under three different conditions (T1 in orange, T2 in green, and T3 in purple). It shows a clear trend of decreasing temperatures as air velocity increases, indicating a cooling effect with higher air velocities. This pattern is consistently observed across all three temperature measurements, suggesting that increased air velocity helps lower the average indoor temperature in Chamber A. At a velocity of 1 m/s, the temperatures are approximately 24.65°C for T1, 24.59°C for T2, and 24.80°C for T3, with T3 being slightly higher. As the velocity increases to 1.5 m/s, the temperatures decrease slightly to around 24.20°C for T1, 24.17°C for T2, and 24.49°C for T3, showing a more noticeable difference with T3 remaining higher. At 2 m/s, the temperatures drop further to approximately 23.75°C for T1, 23.96°C for T2, and 24.16°C for T3. This trend continues at 2.5 m/s, with temperatures around 23.37°C for T1, 23.72°C for T2, and 24.24°C for T3. Finally, at 3 m/s, the temperatures are the lowest recorded: about 23.20°C for T1, 23.29°C for T2, and 23.55°C for T3. Overall, the graph shows that increasing air velocity leads to a decrease in the average indoor temperature, with T3 consistently recording slightly higher temperatures than T1 and T2, indicating a less effective cooling condition.

Figure 3 below depicts the average indoor temperature for Chamber B across the same air velocities (1 m/s, 1.5 m/s, 2 m/s, 2.5 m/s, and 3 m/s) under three conditions (T1 in orange, T2 in green, and T3 in purple). At a velocity of 1 m/s, the temperatures are around 24.66°C for T1, 24.85°C for T2, and 25.07°C for T3, with T3 being the highest. As the velocity increases to 1.5 m/s, the temperatures slightly decrease to about 24.52°C for T1, 24.78°C for T2, and 24.87°C for T3. At 2 m/s, the temperatures are approximately 24.37°C for T1, 24.46°C for T2, and 24.75°C for T3, indicating a further slight decrease. At 2.5 m/s, the temperatures drop more significantly to around 23.78°C for T1, 23.94°C for T2, and 24.18°C for T3. Finally, at 3 m/s, the temperatures are the lowest: about 23.25°C for T1, 23.42°C for T2, and 23.43°C for T3. The overall trend in Figure 3 is like that in Figure 2, with increasing air velocity leading to a decrease in the average indoor temperature. T3 consistently shows slightly higher temperatures than T1 and T2, suggesting it is less effective in cooling compared to the other two conditions. The differences between T1 and T2 are minimal, indicating similar cooling efficiency for these conditions.

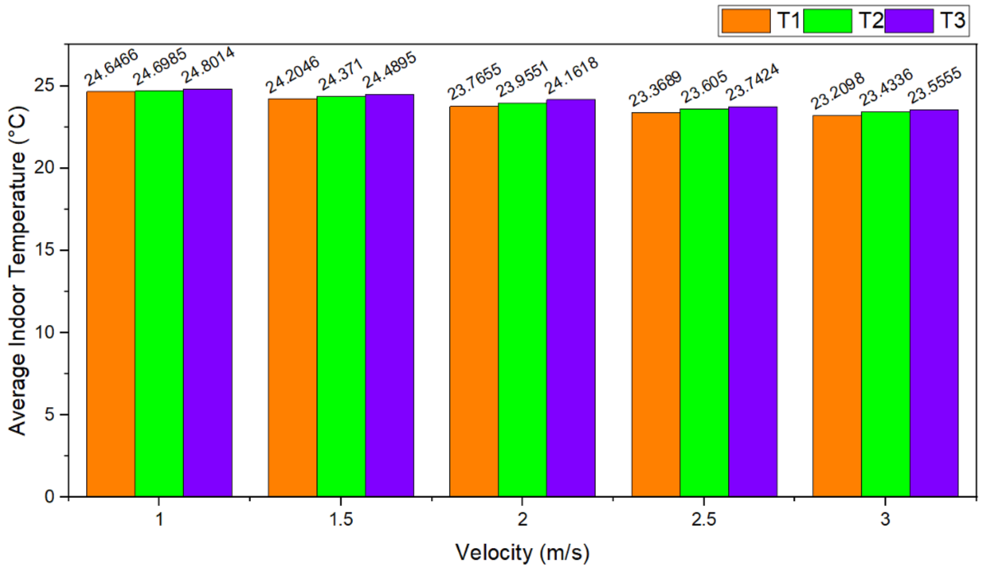


**Fig. 2**. Average Indoor Temperature for Chamber A

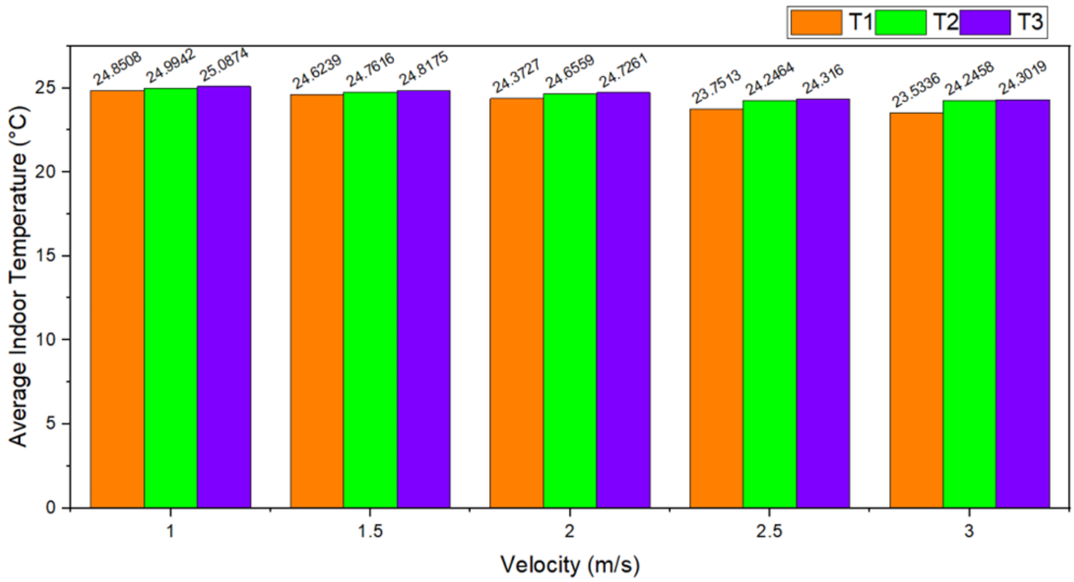


**Fig. 3.** Average Indoor Temperature for Chamber B

In both chambers, a consistent trend is observed: as air velocity increases from 1 m/s to 3 m/s, the average indoor temperature decreases, indicating a significant cooling effect. The findings highlight the importance of optimizing air velocity to enhance thermal management in HVAC systems, with the potential to improve indoor environmental conditions. The consistent decrease in temperatures across both chambers and all conditions underscores the reliability of the data and supports the conclusion that air velocities contribute to better cooling performance.

*3.2 Average Indoor Temperature vs Velocity*

The graphs in Figures 4 and figure 5 illustrate the average temperature over time for Chambers A and B at minimum and maximum blower velocities (1 m/s and 3 m/s respectively).

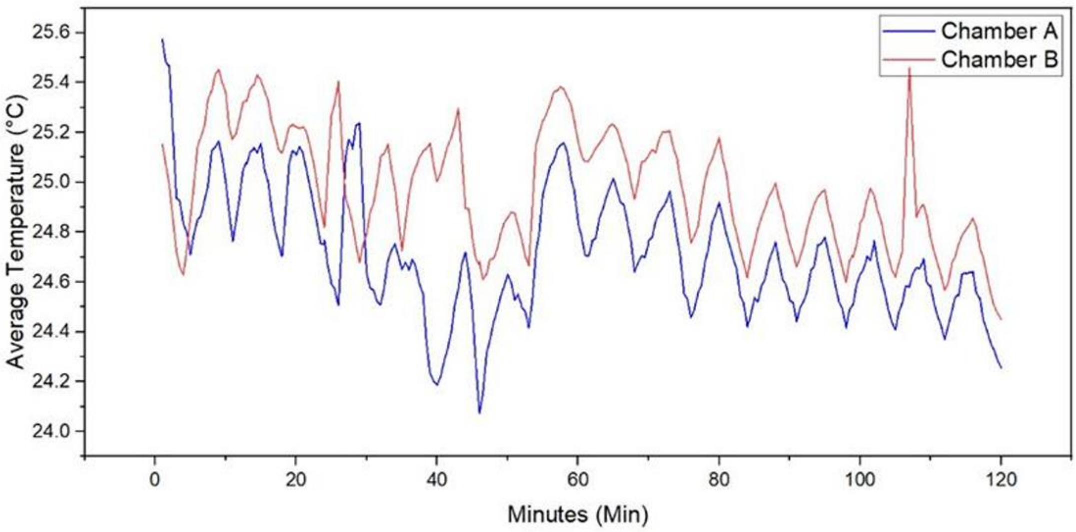


**Fig. 4.** Average Temperature vs Time for 1m/s Blower Velocity

Figure 4 presents the average temperature over time for two chambers, labelled Chamber A and Chamber B, when subjected to a blower velocity of 1 m/s. The graph spans a period of 120 minutes, with the X-axis representing time in minutes and the Y-axis showing the average temperature in degrees Celsius (°C), ranging from 24.0°C to 25.6°C. At the beginning of the experiment, both chambers start with temperatures around 24.6°C for Chamber B and slightly lower for Chamber A. As time progresses, both chambers exhibit fluctuating temperature patterns. The blue line, representing Chamber A, and the red line, representing Chamber B, show a series of peaks and valleys indicating periodic fluctuations in temperature. These fluctuations suggest that the temperature within each chamber is not stable and undergoes continuous changes.

Chamber B consistently maintains a higher average temperature compared to Chamber A throughout the experiment. This difference in temperature is evident from the outset and persists for the entire 120 minutes. The fluctuations in Chamber B are more pronounced, with the red line showing higher peaks and deeper valleys compared to the blue line of Chamber A. This indicates a higher level of volatility in Chamber B's temperature control at the 1 m/s blower velocity. Around the 100-minute mark, there is a significant spike in Chamber B's temperature, reaching approximately 25.4°C, the highest temperature recorded in the experiment. This spike suggests a momentary increase in temperature that is not observed in Chamber A, which maintains a more consistent fluctuation pattern without such pronounced spikes. The overall trend indicates that Chamber B's temperature is not only higher but also more erratic compared to Chamber A. The periodic nature of the temperature fluctuations in both chambers' points to a cyclic pattern possibly influenced by the blower's operation at this velocity. However, the amplitude and frequency of these fluctuations differ between the two chambers. Chamber A, with the blue line, shows a relatively smoother and more regular pattern, whereas Chamber B, with the red line, displays more variability and higher amplitude changes.

Overall, Chamber B experiences higher and more volatile temperatures compared to Chamber A. The fluctuations in both chambers suggest instability in maintaining a constant temperature, with Chamber B showing particularly pronounced variability. The significant spike in Chamber B around the 100-minute mark highlights a momentary disruption in temperature control, emphasizing the challenges of maintaining stable conditions at this lower blower velocity.

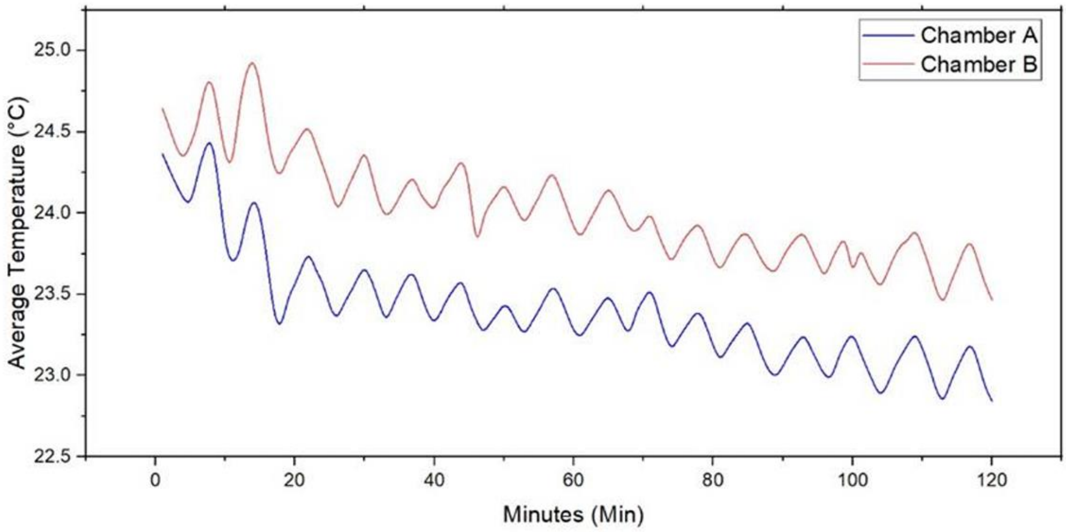


**Fig. 5.** Average Temperature vs Time for 3m/s Blower Velocity

Figure 5 illustrates the average temperature over time for the same two chambers, Chamber A and Chamber B, but with an increased blower velocity of 3 m/s. The graph covers the same 120-minute period, with the X-axis representing time in minutes and the Y-axis indicating the average temperature in degrees Celsius (°C), ranging from 22.5°C to 25.0°C. Initially, both chambers start with temperatures around 24.7°C for Chamber B and slightly lower for Chamber A. As the experiment progresses, both chambers again exhibit fluctuating temperature patterns. However, in this graph, the fluctuations are more regular and less volatile compared to Figure 4. The blue line represents Chamber A, and the red line represents Chamber B. Chamber B maintains a higher average temperature throughout the experiment, similar to the observations in Figure 4.

The temperature fluctuations in this graph are smoother and more consistent. Both chambers show a clear pattern of periodic fluctuations, but the amplitude and frequency are more stable. This indicates that the higher blower velocity of 3 m/s contributes to more controlled and predictable temperature changes. The overall temperature range is lower, between 23.0°C and 24.7°C, suggesting better temperature management at this increased blower velocity. A notable observation is the slight downward trend in temperatures over time, particularly in Chamber A. By the end of the 120-minute period, the average temperature in Chamber A drops below 23.5°C. Chamber B also shows a slight decrease in temperature but maintains a higher average temperature compared to Chamber A. This trend suggests that the increased blower velocity helps in reducing the overall temperature in both chambers. The regularity and lower amplitude of temperature fluctuations in this graph indicate improved stability and control. Unlike in Figure 4, there are no significant spikes in temperature, and the variations are more predictable. This improved stability is likely due to the higher blower velocity, which enhances the circulation and distribution of air within the chambers, leading to more uniform temperature conditions.

The increasing of the blower velocity to 3 m/s results in more stable and controlled temperature fluctuations in both chambers. Chamber B consistently maintains a higher average temperature, but the overall volatility is reduced compared to the 1 m/s blower velocity scenario. The slight downward trend in temperatures suggests improved cooling efficiency, particularly in Chamber A. The enhanced stability and predictability of temperature changes highlight the benefits of a higher blower velocity in maintaining controlled environmental conditions within the chambers.

## 4. Conclusions

In conclusion, the study achieved its objectives by implementing targeted modifications that improved the thermal test rig's efficiency and provided valuable insights into the thermal dynamics within the chambers. These enhancements increased the accuracy of thermal measurements and contributed to the overall effectiveness of HVAC systems in maintaining desirable indoor environmental conditions. Analysis of the provided graphs clearly indicates that the advancements made led to a significant reduction in average indoor temperatures in both Chamber A and Chamber B. The experimental approach adopted in this study enabled a thorough evaluation of the thermal dynamics within the chambers, confirming that the enhanced design resulted in significant improvements in thermal performance. The data obtained serves as robust evidence of the effectiveness of the modifications, contributing to the field of thermal management in controlled environments. This research underscores the importance of experimental validation in optimizing system designs and provides a foundation for further studies and practical applications in optimizing thermal systems. The successful achievement of the research objectives demonstrates the potential for these design enhancements to be applied in similar contexts, leading to broader advancements in thermal management technologies.

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