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Investigating the Impact of Portable Humidifier on Coefficient of Performance (COP) and Power Consumption of Non-Inverter Split Unit Air Conditioner in Malaysian Climate

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Abstract: As global temperatures continue to rise, the demand for air conditioning (AC) has surged, especially in hot–humid climates where efficiency is a major concern. Although humidity strongly influences AC performance, the specific effects of portable humidifiers on non-inverter split-unit systems remain underexplored. This study investigates the influence of a portable ultrasonic humidifier on the Coefficient of Performance (COP) and power consumption of a 9,700 BTU/h R-32 split-unit AC under typical Malaysian indoor conditions. Experiments were conducted in a sealed room using three humidification rates (100, 200, and 300 mL/hr) at two setpoints (20°C and 24°C), with continuous monitoring of temperature, relative humidity, and operating current. Results showed that at 20°C, COP decreased by up to 7% (≈3% on average across humidification rates), accompanied by a 6% rise in operating current, indicating higher dehumidification loads and compressor workload. Conversely, at 24°C, COP improved by up to 7% (≈3% on average), with a 13% reduction in current, as humidification helped optimize the balance between sensible and latent cooling loads. These findings demonstrate that humidification alters AC performance differently depending on the operating setpoint, highlighting the dual role of added moisture as both an efficiency burden at lower temperatures and a potential efficiency enhancer at higher temperatures. The study concludes that COP variations are closely linked to dehumidification requirements and recommends the integration of humidity-sensitive control strategies and adaptive algorithms in AC systems to optimize performance, reduce energy consumption, and enhance indoor comfort in humid environments.

Keywords: Coefficient of Performance (COP); Humidification Effects; Portable Humidifier; Power Consumption; Split Unit Air Conditioner

1. Introduction

The demand for indoor thermal comfort has led to the widespread adoption of air conditioning (AC) systems, particularly in hot and humid climates[1–3]. In Malaysia, where temperatures frequently exceed 30°C and relative humidity surpasses 60%[4,5], AC systems play a vital role in maintaining comfortable indoor conditions[6,7]. However, high humidity levels pose significant challenges to AC efficiency[8,9]. In such conditions, AC units must work harder to remove excess moisture from the air, leading to higher energy consumption, prolonged operational time, and increased wear on system components[10,11]. The Coefficient of Performance (COP), a critical measure of AC efficiency, declines as humidity levels rise, increasing operational costs and carbon footprint due to higher electricity consumption[12–14].

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Ideally, an AC system should regulate both temperature and humidity efficiently to provide thermal comfort without excessive energy use. However, in tropical regions, maintaining this balance remains a challenge[15–17]. Humidity control should enhance AC performance, but in Malaysia's naturally humid environment, the growing trend of using portable humidifiers raises concerns about their unintended effects. Does the increasing use of portable humidifiers in Malaysia, despite its high humidity (RH > 60%), influence the performance of air conditioners in indoor environments? While humidifiers are commonly used for indoor air quality improvement[18–21], their impact on AC operation, particularly in non-inverter split-unit systems, remains unclear.

To address this gap, this study investigates the impact of a portable humidifier on the COP and power consumption of a non-inverter split-unit AC system. By analyzing varying humidification rates (100 ml/hr, 200 ml/hr, and 300 ml/hr) in a controlled environment, the study aims to quantify changes in indoor temperature, humidity, and AC efficiency.

The research employs experimental testing in a controlled bedroom environment, ensuring that observed variations in AC performance are due to humidification effects rather than external factors. The expected outcome is that higher humidification rates will reduce COP at lower temperature setpoints (20°C) due to increased dehumidification load, while at higher setpoints (24°C), humidification may improve COP by reducing excessive cooling demand.

This study provides valuable insights into the interplay between humidification and AC performance, contributing to energy-efficient residential cooling strategies. The findings will benefit HVAC designers, policymakers, and homeowners by offering guidance on balancing humidity control and energy consumption, ultimately leading to more sustainable and cost-effective indoor climate management in humid regions.

2. Methodology

The methodology of this study is designed to systematically evaluate the impact of a portable ultrasonic humidifier on the Coefficient of Performance (COP) and power consumption of a non-inverter split-unit air conditioner in a controlled indoor environment. The experimental approach ensures that variations in AC performance are directly attributed to changes in humidification rates, minimizing external influences and improving result accuracy.

This methodology is structured into four key sections to provide a clear and systematic analysis of the study parameters. Section 2.1: Experimental setup and procedure describe the test environment, air conditioning system specifications, and data acquisition process to ensure reliable and repeatable measurements. Section 2.2: Ultrasonic portable humidifier details the humidifier specifications, mist output levels, and operational parameters used in the study, highlighting its role in controlling room humidity conditions.

Section 2.3: Case studies outline the different test conditions, explaining how varying humidification rates affect temperature, humidity, COP, and energy consumption under controlled scenarios. Section 2.4: Formulation of the derived COP presents the theoretical approach and mathematical equations used to compute the AC system's performance under different humidity levels, linking experimental observations to analytical formulations.

This structured approach provides a comprehensive framework for analyzing the dynamic relationship between humidification, AC efficiency, and energy consumption. By ensuring a scientifically rigorous and practically applicable methodology, this study contributes valuable insights into humidity control strategies for energy-efficient air conditioning in tropical environments.

2.1. Experimental setup and procedure

The experimental study was conducted in a controlled indoor environment within a bedroom space measuring 10.05 m² with a ceiling height of 2.85 m, as shown in Figure 1. The room was equipped with a non-inverter single split-unit air conditioner with a rated power input of 1.3 kW and a cooling capacity of 9,700 BTU/hr. The system utilized R-32 refrigerant, which offers higher energy efficiency and lower global warming potential compared to conventional refrigerants[22,23].

To ensure the stability of the indoor environment, the room was fully enclosed with two sealed windows (each

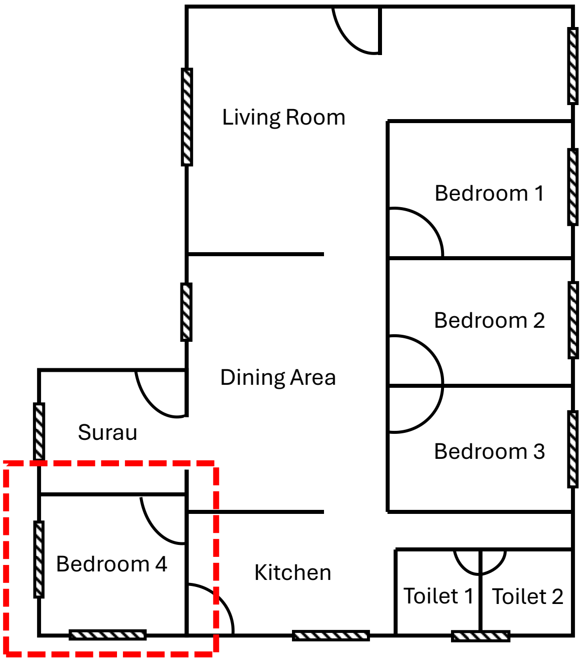

Fig. 1: Home layout plan

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measuring 2.0 m × 1.2 m) and a single-leaf timber door, minimizing heat loss and air infiltration. All potential leakage points were sealed using weather stripping and silicone sealants to prevent uncontrolled heat exchange with the surrounding environment.

The outdoor temperature was continuously monitored using an external sensor placed 1 meter outside the test room, recording ambient temperature fluctuations. The average outdoor temperature during testing was recorded at 32°C with a fluctuation range of ±1.5°C. This data was used to ensure that external climate conditions remained stable and did not influence the indoor environment.

A heat balance approach was maintained by ensuring that no additional heat sources (e.g., electronic devices or human presence) were present in the test room during data collection. The only heat contributions were from the air conditioner, humidifier, and minor thermal radiation from the walls, which were considered when analyzing the system's performance.

A high-precision temperature and humidity data logger was deployed to continuously monitor indoor environmental conditions. The logger had a temperature accuracy of ±0.3°C and a relative humidity (RH) accuracy of ±2%, with a measuring range of −30°C to 80°C for temperature and 0% to 100% for RH. It provided repeatability tolerances of ±1°C for temperature and ±1% for RH, with response times of 5.0 seconds for temperature and 8.0 seconds for RH, ensuring reliable and precise measurements.

For comprehensive data collection, the logger was configured with a temperature threshold of −20°C to 60°C and RH limits from 0% to 99.9%, logging data at 4-minute intervals throughout each test cycle. The placement of the data logger was carefully considered to minimize localized temperature variations. It was mounted at a height of 1.5 meters from the finished floor level (FFL) and positioned at the geometric center of the room, ensuring that the recorded values accurately represented average indoor climate conditions. Figure 2 illustrates the precise sensor placement and experimental layout as configured using manufacturer-provided software.

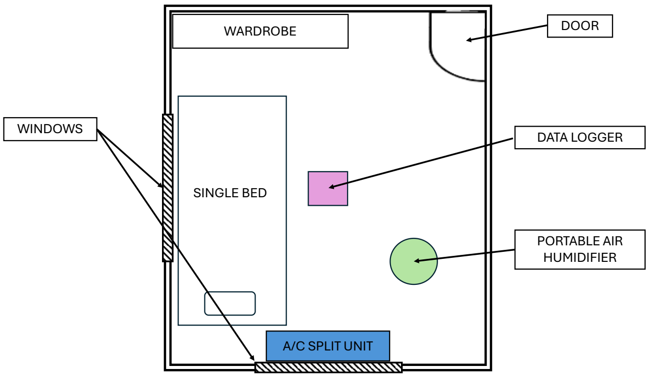

Fig. 2: Detail of studied space: Bedroom 4

This methodologically controlled setup ensured that:

Indoor conditions were not influenced by outdoor fluctuations, as external temperatures were monitored and room sealing measures prevented heat infiltration.

Heat balance was maintained by eliminating additional heat sources, ensuring that all variations in AC performance were solely due to humidifier operation and indoor air dynamics.

Data accuracy was prioritized by using precise logging equipment and strategic sensor placement to capture representative temperature and humidity variations.

By integrating environmental isolation, heat balance considerations, and continuous monitoring, this methodology ensures that experimental conditions remain stable and scientifically valid, allowing for a rigorous assessment of the humidifier's impact on AC performance.

2.2. Ultrasonic portable humidifier

The Deroma M808 8L ultrasonic portable humidifier, as shown in Figure 3, was selected for this study due to its precise humidity control, high mist dispersion efficiency, and compatibility with indoor air conditioning experiments. This humidifier operates using ultrasonic technology, which vaporizes water into fine mist particles without heat, ensuring minimal interference with room temperature.

It features three (3) adjustable mist levels (low, medium, and high) corresponding to output rates of 100 ml/hr, 200 ml/hr, and 300 ml/hr, respectively. These settings provide a controlled range of humidification levels, enabling systematic evaluation of how varying moisture levels influence AC efficiency and energy consumption. The humidifier also includes an intelligent constant humidity feature, allowing precise regulation of room humidity between 45% and 90% RH, which is essential for maintaining a stable experimental environment.

To ensure accurate and consistent humidity control, the humidifier underwent preliminary calibration tests before the actual experiment. A high-precision external hygrometer (±1% RH accuracy) was used to verify the

Fig. 3: Selected ultrasonic portable humidifier

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humidifier's mist output at each level. The humidifier was operated at each mist level (100 ml/hr, 200 ml/hr, and 300 ml/hr) for a 30-minute stabilization period, and the recorded RH values were compared against the target settings to confirm consistent moisture dispersion.

Since the humidifier’s mist dispersion capacity is rated for 42 m², significantly larger than the 10.05 m² experimental room, a pre-test was conducted to assess humidity uniformity. Three secondary humidity sensors were placed at different locations in the room to verify even RH distribution. If variations exceeded ±3% RH, the humidifier's position was adjusted until humidity was evenly dispersed across the room.

The humidifier was operated continuously throughout each test, using its constant humidity feature to maintain 70% RH within a tolerance of ±2%. The AC dehumidification effect was monitored, and manual adjustments were made if humidity fluctuations exceeded the set range. This ensured that indoor conditions remained stable without unexpected moisture accumulation or loss.

To quantify the energy demand of the humidifier, its power consumption was measured separately at each mist output level using a digital wattmeter. The recorded power usage for different humidification rates was as follows:

- Low (100 ml/hr): 18.2 W
- Medium (200 ml/hr): 23.7 W
- High (300 ml/hr): 29.5 W

These results indicate a direct correlation between mist output and power consumption, with higher humidification rates requiring more energy. This trend aligns with the increased ultrasonic oscillation frequency and water atomization intensity necessary to generate denser mist at higher settings.

The recorded power data were then used to assess the humidifier’s relative impact on total energy consumption, particularly in comparison to AC power draw. Throughout the experiment, humidity levels and AC power usage were logged simultaneously to determine whether higher indoor humidity levels influenced AC efficiency. Specifically, the analysis focused on whether increased humidification forced the AC unit to work harder, thereby reducing its Coefficient of Performance (COP) due to a greater dehumidification load.

2.3. Case studies

To assess the impact of humidification rates on air conditioning efficiency, this study evaluated six (6) distinct case studies, as summarized in Table 1. These case studies were designed to examine how humidity levels interact with temperature setpoints to influence Coefficient of Performance (COP) and power consumption in a non-inverter split-unit air conditioning system.

The experiment was structured around two temperature setpoints, 20°C and 24°C, representing common residential cooling preferences in tropical climates. The humidifier was operated at three mist levels (low: 100 ml/hr, medium: 200 ml/hr, and high: 300 ml/hr) to assess how increased moisture levels affected cooling efficiency and energy demand. The choice of these humidification rates was based on realistic operational conditions found in indoor environments where humidifiers are used for air quality improvement.

Table 1: Case studies based on testing conditions

Case studies	AC temp (°C)	AC fan (m/s)	RH level (%)	Humidification rate (ml/hr)
1	20	1.8	70	100
2				200
3				300
4	24			100
5				200
6				300

Each case study maintained a fixed air velocity of 1.8 m/s, ensuring consistent airflow delivery throughout the tests. Cases 1 to 3 evaluated the effect of increasing humidification rates at a lower AC setpoint of 20°C, while Cases 4 to 6 replicated the same conditions at 24°C, allowing for a direct comparison of humidification effects at different cooling intensities. By keeping fan speed and humidity targets constant, the study was able to isolate the effects of humidification on system performance.

This structured approach allowed for a systematic evaluation of how increased moisture levels impact cooling efficiency, providing valuable insights into optimizing humidity control strategies for energy-efficient air conditioning operations in humid climates.

2.4. Formulation of the derived COP

The Coefficient of Performance (COP) of an air conditioning system is a critical measure of its cooling efficiency, defined as the ratio of cooling output to electrical energy input. This study derives an expression for optimal COP as a function of conditioned ambient temperature (T) and relative humidity (RH, denoted as φ). Understanding this relationship is essential for evaluating how humidity variations affect AC performance and developing strategies for energy-efficient cooling. The optimal COP under varying environmental conditions can be expressed as:

$$COP_{Optimal} = f(T, \varphi) \qquad (1)$$

Humidity directly influences heat exchange efficiency in air conditioning systems. As relative humidity (φ) increases, the latent cooling load increases due to the additional moisture in the air. This requires the AC system to remove more moisture, impacting thermal equilibrium and reducing effective cooling output. Through experimental observation and data analysis, it was found

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that the conditioned space temperature (T) varies inversely with the cube of relative humidity (φ):

$$T \propto \frac{1}{\varphi^3} \tag{2}$$

This cubic relationship arises because latent heat removal increases non-linearly with humidity, affecting the enthalpy balance within the conditioned space. Higher humidity reduces the sensible cooling effect, as a larger fraction of cooling energy is used for moisture condensation instead of temperature reduction. To express COP in terms of temperature and humidity, the inverse variation principle is applied:

$$T = COP \cdot \frac{1}{\varphi^3} \tag{3}$$

Rearrange for optimal COP, we obtain:

$$COP_{Optimal} = T \cdot \varphi^3 \tag{4}$$

This relation is derived empirically under Malaysian hot–humid conditions (20–28°C, RH 50–80%). Its validity may not extend outside this range, as compressor dynamics and coil saturation could alter the humidity–temperature dependency. Nonetheless, the equation provides a useful representation of the fundamental relationship between air temperature, humidity, and system efficiency, illustrating that higher humidity negatively impacts cooling performance by reducing sensible heat removal efficiency[24)].

To maintain steady-state testing conditions, the following fixed parameters were applied:

- Pre-set air conditioning temperatures: 20°C and 24°C
- AC cross-sectional area of air outlet: $A_{ac} = 0.1\ m^2$
- Air velocity from the blower: $V_{air} = 1.8\ m/s$

All other variables were adjusted based on the humidification rate variations, allowing a controlled assessment of how temperature and humidity affect COP and power consumption. This formulation provides a quantitative framework for predicting AC performance in humid environments. It highlights that:

Higher humidity significantly reduces effective cooling efficiency, requiring more energy-intensive dehumidification cycles.

AC units operating at lower temperatures experience greater efficiency losses in humid conditions due to increased latent cooling demand.

Energy savings can be achieved by optimizing humidity control rather than simply lowering temperature settings, improving overall system COP.

By integrating this COP formulation into HVAC system design and smart control algorithms, air conditioning efficiency can be optimized for tropical climates, leading to reduced energy consumption and improved indoor comfort.

3. Results and discussion

This part presents a comprehensive analysis of the experimental findings, highlighting the influence of humidification on air-conditioning (AC) performance, with a particular focus on temperature setpoints, relative humidity, Coefficient of Performance (COP), and power consumption trends. The results are systematically discussed to reveal the impact of varying humidification rates on both cooling efficiency and energy consumption, providing insights into the thermodynamic behavior of the system. Additionally, key performance comparisons between 20°C and 24°C setpoints are examined to illustrate how ambient conditions influence AC efficiency. Power consumption trends were analyzed using operating current as an indicator, assuming constant supply voltage and power factor. The observed current variations directly reflect changes in the AC system's workload and proportional energy demand. Although current alone does not quantify total energy usage, its trend serves as a reliable indicator of relative power consumption.

The discussion integrates quantitative analysis with theoretical interpretations, linking findings to latent and sensible cooling effects, and compares outcomes with existing literature to enhance the scientific validity of the results. Finally, the implications of these findings are discussed, emphasizing their relevance for energy-efficient HVAC system design and sustainable cooling strategies in humid climates.

3.1. Temperature and relative humidity dynamics over a 3-day period

Data was collected systematically over a 3-day period, with average temperature and relative humidity (RH) trends presented in Figure 4. The recorded temperatures showed a minimum of 28.2°C at 09:31 hours and a maximum range between 34.2°C and 35.3°C from 14:31 to 15:11 hours, corresponding to the peak solar radiation period. During these peak temperature hours, relative humidity reached its lowest value, aligning with the principle that warm air holds more moisture, reducing RH as temperature rises.

The average temperature stabilized at 32°C, with mean relative humidity at 68%, demonstrating a daily cyclical pattern typical of indoor thermal dynamics in controlled spaces. The standard deviation for temperature was ±1.1°C, while for relative humidity, it was ±2.3%, indicating moderate variability due to heat gain and air circulation effects.

The analysis highlights a distinct inverse relationship between temperature and RH, consistent with psychrometric principles. As temperature rises, the air's moisture-holding capacity increases, causing relative

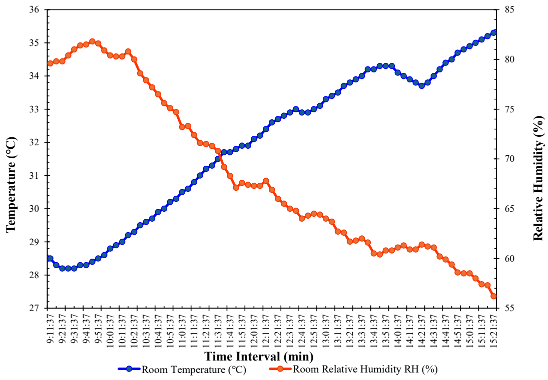

Fig. 4: Temperature and relative humidity behavior without any psychrometric process

humidity to decrease. Conversely, when temperature falls, the air becomes saturated more quickly, resulting in a rise in relative humidity.

This relationship is further supported by psychrometric chart behavior, where air nearing dew point temperatures exhibits a steeper RH increase at lower temperatures. The observed temperature-RH dynamics align with findings from Zhmakin (2023), which emphasizes the inverse temperature-humidity relationship in tropical and semi-closed indoor environments[25)]. Additionally, Feng et al. (2018) report similar patterns of humidity depression during peak temperature periods, further validating these results[20)].

From an air conditioning (AC) performance perspective, these temperature and RH variations are crucial. Higher temperature periods (with lower RH) reduce dehumidification loads but increase sensible cooling demand, which impacts the COP differently based on the AC setpoint temperature. Lower temperature periods (with higher RH) place a greater latent load on the AC system, as it must remove moisture from the air, resulting in higher energy consumption for dehumidification.

These dynamics highlight the importance of humidity control strategies when operating AC systems, particularly with humidifiers, as explored in subsequent sections.

3.2. Air conditioning at 20°C ad 24°C without humidifier application

The performance of the air conditioning system without a humidifier was evaluated at two temperature setpoints (20°C and 24°C), with results summarized in Figure 5 to Figure 10. The temperature and relative humidity (RH) trends were consistent across three experimental repetitions, confirming the system's repeatability and stability.

As illustrated in Figure 5 to Figure 7, at a 20°C temperature setting, the room temperature dropped from 32°C to a steady 24°C within 40 minutes, achieving a cooling rate of approximately 0.2°C per minute. Concurrently, relative humidity (RH) decreased from 72% to 66%, marking a 6% reduction in moisture levels. The system maintained this temperature with minimal fluctuation, demonstrating effective temperature regulation. Across repetition experiments, the results were consistent, with temperature stabilization observed between 39 to 41 minutes, and RH varying within a narrow range of ±0.5%, indicating high system reliability.

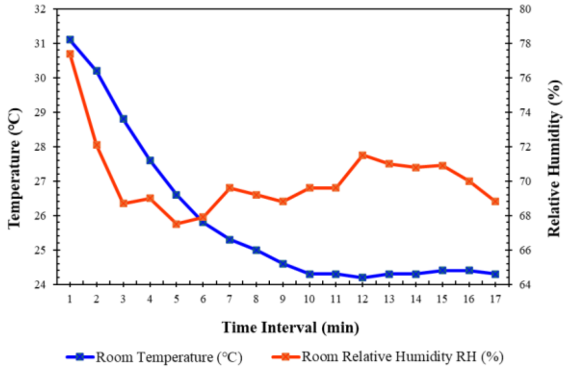

Fig. 5: Temperature and relative humidity behavior for cooling and dehumidifying process at 20°C (Experiment 1)

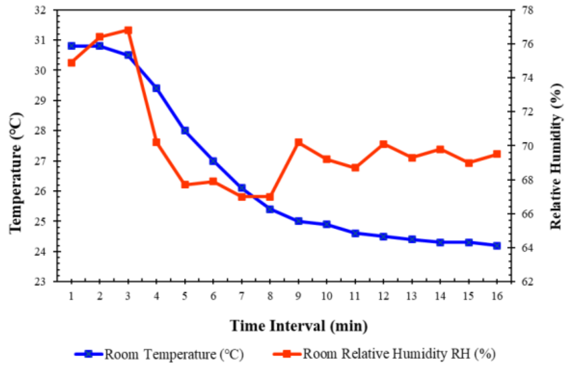

Fig. 6: Temperature and relative humidity behavior for cooling and dehumidifying process at 20°C (Experiment 2)

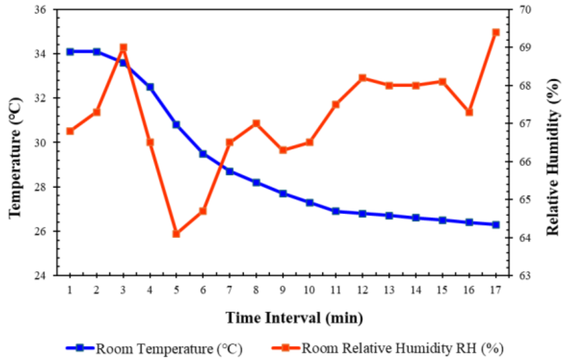

Fig. 7: Temperature and relative humidity behavior for cooling and dehumidifying process at 20°C (Experiment 3)

At the 24°C setpoint, as shown in Figure 8 to Figure 10, the initial room temperature of 28°C dropped to the target 24°C within 32 minutes, a cooling rate of approximately 0.25°C per minute, which was faster than at 20°C due to a smaller temperature differential. During this period, relative humidity decreased from 69% to 64%, a 5%

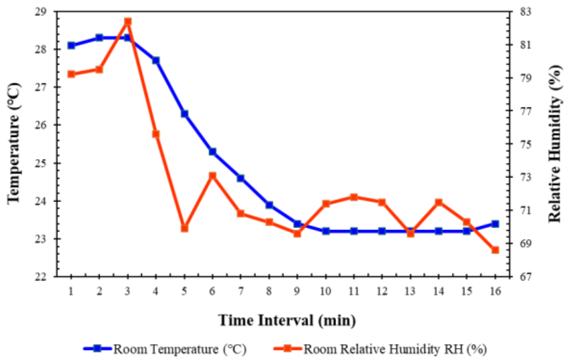

Fig. 8: Temperature and relative humidity behavior for cooling and dehumidifying process at 24°C (Experiment 1)

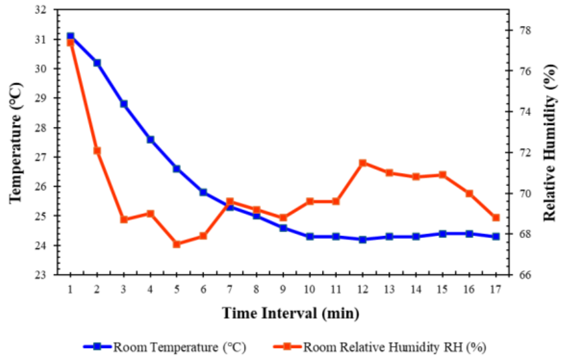

Fig. 9: Temperature and relative humidity behavior for cooling and dehumidifying process at 24°C (Experiment 2)

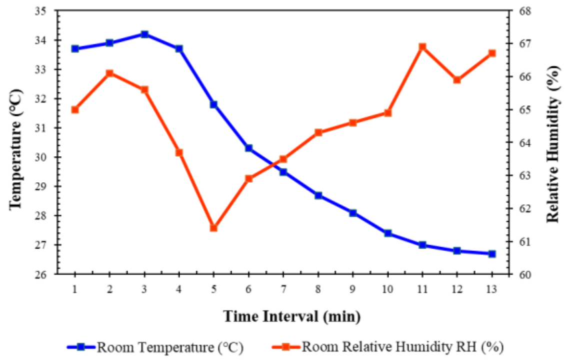

Fig. 10: Temperature and relative humidity behavior for cooling and dehumidifying process at 24°C (Experiment 3)

reduction, though slight fluctuations of ±0.7% were observed, likely due to cycling of the compressor and reduced latent cooling load at a higher temperature setpoint.

The comparison between 20°C and 24°C setpoints highlights notable differences in performance. First, the 24°C setting achieved the target temperature 8 minutes faster than the 20°C setting, demonstrating higher cooling efficiency due to the lower temperature differential. Second, the 20°C setting reduced RH by a greater margin (6% vs. 5%), reflecting a higher latent heat removal rate, which is typical when operating at lower temperatures, where the evaporator coil temperature is below the dew point, resulting in more condensation and moisture removal. Third, temperature stabilization was smoother at 20°C, while minor RH fluctuations occurred at 24°C, suggesting that the AC system cycled more frequently to maintain the higher setpoint, impacting humidity consistency.

Across three repetitions for each temperature setting, results remained consistent, with only minor variations. At 20°C, the temperature stabilization varied between 39 to 41 minutes, and RH fluctuations were within ±0.5%. At 24°C, the temperature stabilization occurred between 31 to 33 minutes, with RH variations of ±0.7%, indicating slightly less humidity control stability.

These results align with statements from Rhee, Olesen, and Kim (2017), which reported that lower temperature settings increase latent cooling loads, resulting in greater RH reduction but longer stabilization times[26]. Similarly, ASHRAE recommends a temperature range of 23°C to 26°C for cooling in humid climates, with 24°C being a common midpoint for balancing thermal comfort and energy efficiency, consistent with the faster cooling rates observed in this study[27].

The observed trends have important implications for energy efficiency and COP performance:

For lower temperature setpoints (20°C): More effective dehumidification but with a longer cooling time, leading to increased energy consumption and lower COP.

For higher temperature setpoints (24°C): Faster cooling with less dehumidification, which may result in higher COP but less humidity control, especially in humid climates.

This highlights the importance of balancing temperature setpoints and humidity control to achieve optimal energy efficiency, a topic explored further in the next sections, where the impact of humidification on COP performance is analyzed.

3.3. Air conditioning at 20°C and 24°C with humidifier application

The effects of humidification on air conditioning performance were evaluated by recording temperature and relative humidity trends while operating the humidifier for 1 hour after the room temperature had stabilized. The humidity level was set to 70%, with three humidification rates (100 ml/hr, 200 ml/hr, and 300 ml/hr) tested under two air conditioning setpoints: 20°C and 24°C.

For the performance at 20°C setpoint, at a 100 ml/hr humidification rate, the initial temperature was 25.3°C, with relative humidity at 68%. After 60 minutes, the temperature increased to 26.2°C, a 0.9°C rise, while RH reached 70%. This indicates that low humidification rates had a minor effect on temperature, with only a 2% RH increase as depicted in Figure 11.

At 200 ml/hr, the initial temperature was 24.3°C with RH at 71%. After 60 minutes, RH stabilized at 73%, while temperature remained constant at 24°C, suggesting that the

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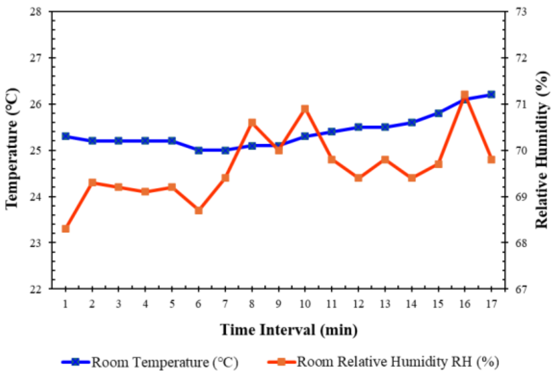

Fig. 11: Temperature and relative humidity behavior for cooling and dehumidifying process at 20°C with 100 ml/hr of humidification rate

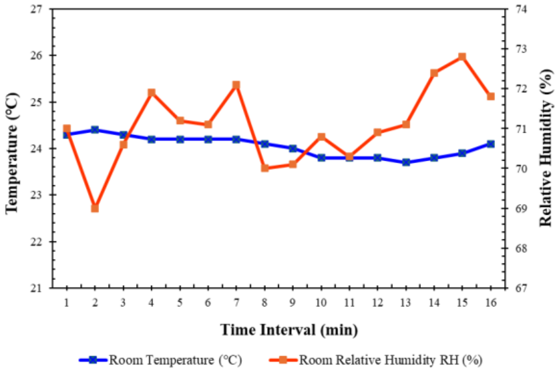

Fig. 12: Temperature and relative humidity behavior for cooling and dehumidifying process at 20°C with 200 ml/hr of humidification rate

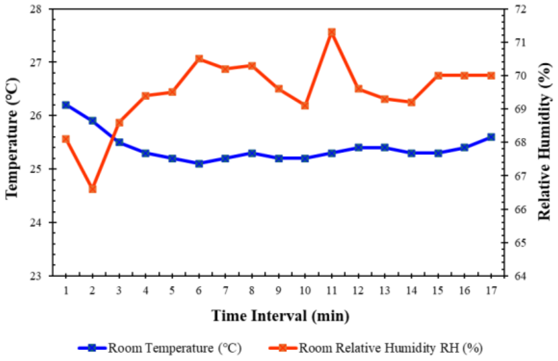

Fig. 13: Temperature and relative humidity behavior for cooling and dehumidifying process at 20°C with 300 ml/hr of humidification rate

AC system effectively counteracted moisture-driven temperature variations as depicted in Figure 12.

At the highest humidification rate (300 ml/hr), the initial temperature was 26.2°C with RH at 68%. After 30 minutes, the temperature dropped to 25.1°C, with RH increasing to 71%. This 1.1°C temperature drop demonstrates that higher humidification rates can effectively lower ambient temperatures as depicted in Figure 13. This cooling effect is likely due to the evaporation of water, which absorbs heat from the surrounding air. However, it is important to note that once the air reaches higher humidity levels, further evaporative cooling becomes less effective, as the air's capacity to hold additional moisture diminishes. This observation aligns with the principles of psychrometrics and statements by Tejero-González and Franco-Salas (2021), who emphasized the importance of humidity control in optimizing thermal comfort and cooling efficiency in indoor environments[28].

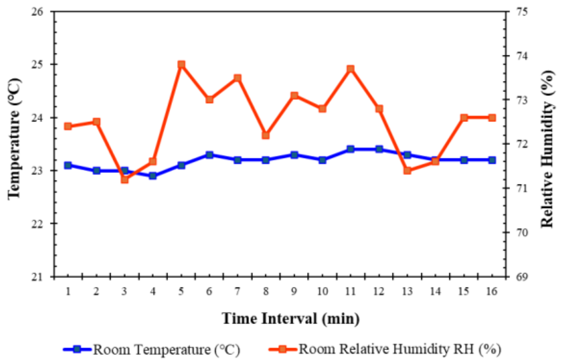

Fig. 14: Temperature and relative humidity behavior for cooling and dehumidifying process at 24°C with 100 ml/hr of humidification rate

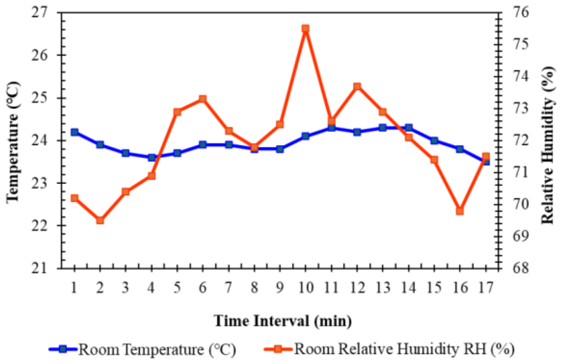

Fig. 15: Temperature and relative humidity behavior for cooling and dehumidifying process at 24°C with 200 ml/hr of humidification rate

For the performance at 24°C setpoint, at 100 ml/hr, the initial RH was 72% with a temperature of 23.1°C. Over 60 minutes, the temperature remained at 23.2°C, while RH increased by only 2%, indicating that low humidification rates minimally influenced the room's thermal balance as depicted in Figure 14.

At 200 ml/hr, the initial RH was 70%, and temperature was 24.2°C. After 40 minutes, RH reached 76%, while the temperature slightly decreased to 24.1°C, with the lowest recorded temperature at 23.5°C after one hour as depicted in Figure 15. This suggests that higher humidity levels may have a slight cooling effect due to increased latent heat absorption.

At 300 ml/hr, the initial temperature was 26.8°C with RH at 67%. After 30 minutes, RH increased to 70%, and temperature dropped to 26.5°C. By the 50-minute mark,

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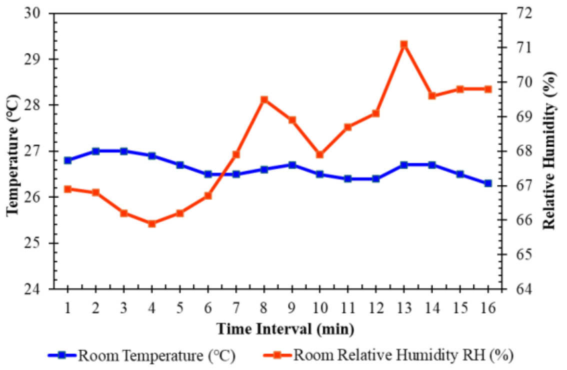

Fig. 16: Temperature and relative humidity behavior for cooling and dehumidifying process at 24°C with 300 ml/hr of humidification rate

RH reached 71%, with a recorded temperature of 26.7°C. The lowest temperature recorded was 26.3°C, reinforcing the trend that higher humidification rates contribute to a mild cooling effect as depicted in Figure 16.

These results highlight a key thermodynamic relationship: Lower humidification rates (100 ml/hr) had minimal effects on temperature, suggesting that the AC dehumidification cycle effectively maintained room conditions.

Higher humidification rates (300 ml/hr) resulted in measurable temperature reductions, likely due to increased latent heat exchange between moisture droplets and air.

According to psychrometric principles, humid air has a higher heat capacity, meaning it absorbs and retains heat more efficiently than dry air. This can lead to localized cooling effects, as observed in previous studies on evaporative cooling mechanisms[29–33].

These findings have important implications for AC efficiency:

At lower temperature setpoints (20°C), humidification increases the dehumidification load, which can reduce the AC's COP due to higher latent heat removal requirements.

At higher temperature setpoints (24°C), humidification contributes to slight cooling effects, potentially reducing sensible cooling demand and improving efficiency in humid climates.

Energy-efficient cooling strategies should balance temperature and humidity control, rather than solely reducing temperature to achieve comfort.

These insights reinforce the importance of humidity management in air conditioning systems, particularly in tropical climates, where both sensible and latent heat loads play a crucial role in overall system performance.

3.4. Impact of relative humidity level on COP

This study analyzed the effects of relative humidity on the Coefficient of Performance (COP) of the air-conditioning system at two temperature setpoints: 20°C and 24°C. Using the derived COP equation (Equation 4), COP values were calculated from recorded temperature and humidity data. The results indicate opposing trends at different temperature settings, highlighting the interplay between cooling and dehumidification loads.

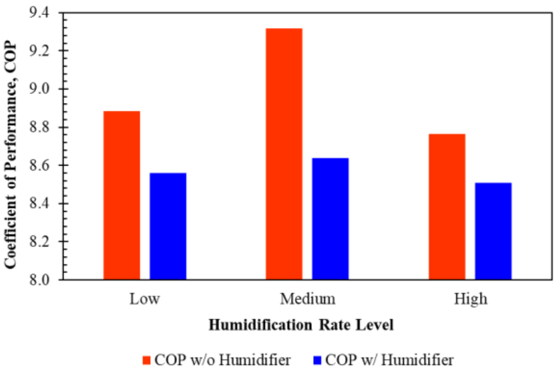

Fig. 17: COP of air conditioning for 20°C

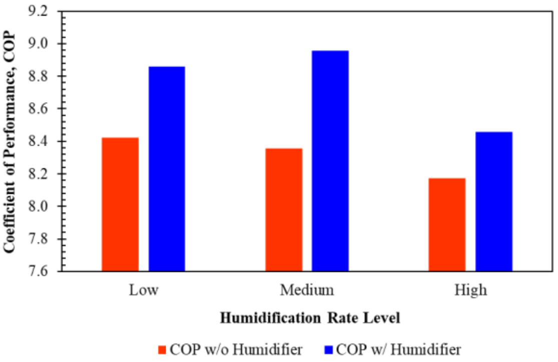

Fig. 18: COP of air conditioning for 24°C

As illustrated in Figure 17, at a 20°C setting, increasing humidification rates led to a decline in COP:

- Low humidification (100 ml/hr): COP dropped from 8.9 to 8.6 (4% decrease).
- Medium humidification (200 ml/hr): COP fell from 9.3 to 8.6 (7% decrease).
- High humidification (300 ml/hr): COP declined from 8.8 to 8.5 (3% decrease).

This negative correlation between humidity and COP at 20°C is attributed to increased latent cooling demand. When a humidifier introduces additional moisture, the AC system must work harder to both cool the air and remove excess humidity. The evaporator coil condenses more water vapor, which slows down the cooling process, requiring the compressor to operate at a higher capacity for longer durations. This leads to greater energy consumption for the same cooling output, thus reducing the COP.

This behavior aligns with findings from Woods et al. (2022), who reported that higher indoor humidity at lower setpoints increases compressor cycling and dehumidification loads, leading to efficiency losses[34]. Similarly, Dhamodharan et al. (2024) observed that air conditioners operating at lower temperatures suffer from performance degradation due to excessive moisture removal requirements[35].

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In contrast, as illustrated in Figure 18, at a 24°C setpoint, increasing humidity improved the COP:

- Low humidification (100 ml/hr): COP increased from 8.4 to 8.9 (5% improvement).
- Medium humidification (200 ml/hr): COP rose from 8.4 to 9.0 (7% improvement).
- High humidification (300 ml/hr): COP climbed from 8.2 to 8.5 (3% improvement).

This trend suggests that at higher temperatures, humidification has a positive effect on AC efficiency. The primary reason is that at higher temperature settings, cooling demand dominates over dehumidification demand. Since the AC system removes less moisture at 24°C compared to 20°C, the additional humidity does not significantly impact latent heat removal. Instead, higher humidity levels improve convective heat transfer within the conditioned space, reducing compressor workload and allowing the system to operate more efficiently.

These findings are supported by Ahmed et al. (2025), who demonstrated that at moderate temperature setpoints, humidity levels near 70% can enhance AC efficiency by optimizing the balance between latent and sensible cooling loads36). Similarly, Ma et al. (2024) found that higher setpoint temperatures reduce dehumidification strain on AC systems, resulting in improved COP37).

This inverse behavior can also be explained by the thermodynamic interplay between sensible and latent cooling loads. At lower temperatures (20°C), the AC system prioritizes latent heat removal (moisture extraction). Additional humidity increases dehumidification demand, increasing compressor workload and lowering COP. More energy is used for condensation rather than cooling, reducing efficiency.

At higher temperatures (24°C), the AC system prioritizes sensible cooling (temperature reduction). Higher humidity levels do not significantly increase latent load, allowing the system to focus on efficient temperature regulation. Moisture retains more heat, promoting better heat transfer and reducing compressor cycling, improving COP.

These findings emphasize the importance of humidity control in air conditioning system optimization:

At lower temperature settings (20°C): Avoid high humidity levels, as they increase dehumidification loads, reducing efficiency.

At higher temperature settings (24°C): Humidity levels around 70% may enhance efficiency, reducing compressor cycling and energy consumption.

Energy-efficient cooling strategies: AC systems with smart humidity control algorithms can adapt humidity removal processes based on the setpoint temperature, leading to significant energy savings.

By incorporating humidity-dependent control mechanisms, air conditioning systems can dynamically adjust cooling and dehumidification loads to maximize COP, making them more sustainable and cost-effective in humid climates.

3.5. Power consumption

This section examines the impact of integrating portable humidifiers on the power consumption of an air conditioning (AC) system, particularly at high humidification rates for both 20°C and 24°C setpoints. The analysis is based on recorded operating currents, providing insights into how moisture levels influence system workload and energy efficiency.

As illustrated in Figure 19, at a 20°C setting, the AC system exhibited a stable operating current during cooling and dehumidification without the humidifier. However, when additional moisture was introduced, the operating current increased from 3.1A to 3.3A over one hour, representing a 6% increase (0.2A rise).

This increase in power consumption is attributed to the higher dehumidification demand imposed on the AC system. At lower temperatures (20°C), the AC prioritizes latent heat removal, meaning it must continuously condense and remove excess moisture from the air. The evaporator coils reach lower temperatures, increasing condensation and compressor workload, leading to higher energy consumption.

This behavior aligns with findings by Ahmed et al. (2025), who reported that higher humidity levels at low AC setpoints increase compressor cycling due to higher latent loads, causing efficiency losses36). Similarly, Yuan et al. (2021) observed that in humid conditions, lower AC setpoints lead to increased dehumidification cycles, consuming more power38).

Conversely, at a 24°C setting, the AC system exhibited an opposite trend as illustrated in Figure 20. The operating current decreased from 3.2A to 2.8A over one hour, representing a 13% reduction (0.4A drop).

This suggests that higher humidity at 24°C improved system efficiency, likely due to a thermodynamic balance between cooling and moisture retention. At higher temperatures, the sensible cooling load dominates over latent cooling, meaning that the air retains more moisture without significantly increasing condensation demands. This reduces compressor strain, allowing the system to maintain the preset temperature with lower energy input.

This finding is supported by Liang et al. (2018), who demonstrated that at moderate temperature setpoints, higher humidity can reduce compressor cycling, leading to improved power efficiency39). Additionally, Wang et al. (2025) found that when dehumidification loads are reduced, AC systems operate at lower energy intensities, enhancing overall efficiency40).

This inverse behavior can also be explained by the fundamental relationship between humidity and cooling system performance. At 20°C (lower temperature setting), the AC system prioritizes latent cooling (moisture removal). Higher humidity increases condensation loads,

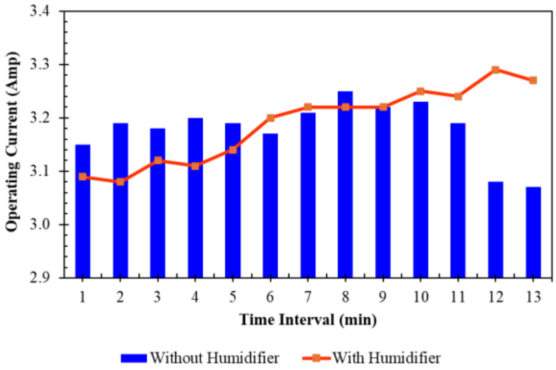

Fig. 19: Operating current of air conditioning for 20°C

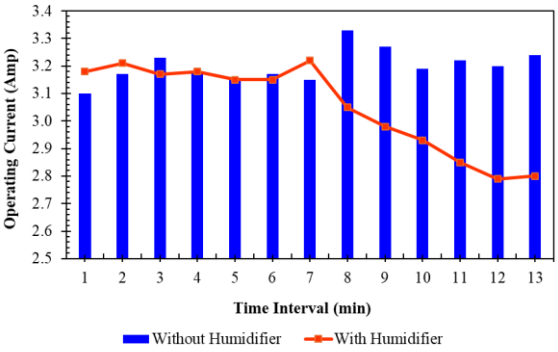

Fig. 20: Operating current of air conditioning for 24°C

causing the compressor to work harder, raising power consumption. More energy is used for phase change (water vapor to liquid) rather than cooling, reducing efficiency.

At 24°C (higher temperature setting), the AC system prioritizes sensible cooling (temperature reduction). Higher humidity does not significantly increase latent loads, allowing the system to maintain efficiency. Increased moisture retains more heat, improving convective heat transfer and reducing compressor workload.

These findings emphasize the importance of humidity control in AC energy efficiency:

Lower Temperature Settings (20°C): Avoid high humidity levels, as they increase dehumidification demand, leading to higher energy consumption.

Higher Temperature Settings (24°C): Humidity levels around 70% may reduce power consumption, improving energy efficiency.

Smart AC Control Strategies: Modern AC systems with adaptive humidity sensing can optimize compressor operation based on setpoint temperature and relative humidity, minimizing energy use.

By integrating humidity-sensitive control mechanisms, air conditioning systems can intelligently adjust cooling and dehumidification loads, leading to reduced electricity consumption and improved long-term sustainability.

4. Conclusion

This study demonstrated that using a portable ultrasonic humidifier in an air-conditioned room significantly influences cooling performance, humidity dynamics, and energy efficiency. The results revealed that increased moisture levels slightly reduced room temperature but altered cooling efficiency differently depending on the AC setpoint. At 20°C, the Coefficient of Performance (COP) decreased by up to 7% under medium humidification, reflecting the higher dehumidification load that forced the system to work harder and increased power consumption. Conversely, at 24°C, COP improved by up to 7%, suggesting that humidification at higher temperature setpoints may enhance efficiency by optimizing the balance between latent and sensible cooling. When averaged across all humidification conditions, the COP variation was more modest (≈3%), which explains the smaller values reported in some sections of the analysis. The study also confirmed that COP is directly linked to power consumption, where lower efficiency results in higher energy demand and costs. These findings highlight the importance of integrating humidity-sensitive control strategies into HVAC systems to improve energy efficiency. Future research should explore adaptive humidity regulation algorithms and smart AC setpoint adjustments to further optimize performance in humid environments, thereby reducing overall electricity consumption in air-conditioned spaces.

CRediT authorship contribution statement

B P Muhamad: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft.
M F H Rani: Conceptualization, Methodology, Validation, Writing – review & editing, Supervision, Project administration.
S A Smith: Data curation, Writing – review & editing.
N M Ghazali: Validation.
W K Yinn: Visualization, Validation, Software, Data curation.
Z M Razlan: Conceptualization, Methodology, Validation.
A B Shahriman: Funding acquisition, Validation.
N S Kamarrudin: Resources, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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ideas and contributions to the research.

Nomenclature

AC	Air conditioner (–)
ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers (–)
COP	Coefficient of Performance (–)
FFL	Finished floor level (–)
HVAC	Heating, Ventilation and Air-Conditioning (–)
RH	Relative humidity (%)
T	Temperature (°C)
temp	Temperature (°C)
Greek symbols	
f	Function (–)
φ	Relative humidity (%)
Subscripts	
A_{ac}	AC cross-sectional area of air outlet (m^2)
V_{air}	Air velocity from the blower (m/s)

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