IMPROVING INDOOR AIR QUALITY AND THERMAL COMFORT USING A TOTAL HEAT EXCHANGER VENTILATION SYSTEM FOR AN OFFICE BUILDING

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Abstract: Indoor air quality (IAQ) and thermal comfort affect occupant comfort and productivity. Thermal comfort supports productivity, while IAQ maintains occupant health. However, occupants are the main source of carbon dioxide, which is the main index for indoor pollutants in educational buildings due to many occupants gathering in one room. This study investigates the performance of applying a total heat exchanger (THX) for diluting carbon dioxide (CO_2). Besides, the thermal comfort of the occupants has been evaluated extensively as the THX also reduces the fresh air temperature. An office area with 14 graduate students seated in a meeting was investigated. Questionnaires and field measurements were conducted simultaneously. Time-varying IAQ (carbon dioxide concentration) was assessed using computational fluid dynamics. The numerical simulation program also contained User Defined Function (UDF) based predicted mean vote (PMV) algorithms to determine occupant thermal comfort. The results indicated that without using THX, the CO_2 concentration gradually rises until it reaches a maximum of 1400 ppm inside the room. This condition occurs because there is no air change between indoor and fresh air, mainly due to the lack of fresh air supply and reliance on split AC for circulation. With THX, the concentration could lower to below 1000 ppm. In addition, it also could make room temperature slightly lower, with the overall temperature average in this study being 24.5°C without THX and 24.1°C when THX is operated.

Keywords: *CFD, IAQ, Thermal Comfort, PMV, THX.*

1. Introduction

People depend on their environment, especially when most of their activities are indoors, with people spending approximately 90% of their time indoors. Many design and operational factors, such as thermal comfort and IAQ, affect how a building meets occupants' needs. Those environmental conditions can also significantly affect the occupant’s life, especially regarding health and productivity

[1]. A comfortable thermal environment and good air cleanliness can support their activities properly and even extend their lifespan. In comparison, bad environmental conditions lead to poor productivity and greatly affect the occupant's health. Therefore, good air quality is essential to maintain healthy environmental conditions within a building [2]. Thermal comfort is one of the keys to ensuring the productivity of the occupants within the room. However, the thermal comfort sensation for every person can be different even when all people gather simultaneously in the same conditioned room [3]. The thermal comfort perception is influenced by a combination of factors, including metabolism, clothing type, age, gender, and culture [4]. The level of thermal comfort and air quality should be controlled according to the standards to maintain a healthy environment and productivity. ASHRAE regulates the environmental conditions within a building, which is recommended for human life through its standards. Some ASHRAE standards related to environmental conditions include ASHRAE standard 55 [5] for thermal comfort and ASHRAE standard 62 [6] for ventilation and indoor air quality (IAQ). ASHRAE standard 55 mentions that six important parameters can determine thermal comfort: air temperature, air velocity, mean radiant temperature, relative humidity, human metabolism, and clothing insulation. While ASHRAE standard 62 mentions indoor pollutants that can affect occupants' life, one of the examples is carbon dioxide (CO_2). It is a non-toxic pollutant; therefore, it is sometimes overlooked. But when people are exposed to high CO_2 concentration, they can feel shortness of breath, headaches, confusion, and other discomforts. Furthermore, it can be easily produced indoors through the respiration of the occupants. So, in this study, the IAQ investigation will be focused on CO_2 as a pollutant.

IAQ is important for the health of the occupants. People are the main producers of CO_2, which is one of the indoor pollutants. Moreover, many people gather in one room in the educational purpose building. This kind of activity can lead to rapid accumulation of CO_2. Through the research, Azuma et al. [7] state that exhales of carbon dioxide can affect human health and psychomotor performance. When humans inhale CO_2 at 1000 ppm in the short term, it can affect cognitive performance, such as decision-making and problem-resolution. Moreover, it can affect the respiratory system when children inhale more than 1000 ppm. Even a low concentration of carbon dioxide is not healthy for the indoor environment, and they mention that 700 ppm of carbon dioxide can trigger sick building syndrome. Therefore, a good ventilation system is required to maintain the proper IAQ, whether natural or mechanical, within a building.

The investigation of IAQ has been done quite intensively; for example, Krawczyk and Wadolowska [8] investigated the indoor environment in educational buildings. One of the investigation's main focuses is CO_2 level. The concentration of CO_2 is used to determine IAQ. They reported that the CO_2 within the room exceeded 1000 ppm. Meanwhile, 1000 ppm of carbon dioxide is the recommended limit where a human can live indoors. It is recommended to increase the air change rates of the HVAC system to improve the air quality within the room. Telejko has done another investigation [9], investigating IAQ parameters such as temperature, relative humidity, and carbon dioxide levels in the computer laboratory in several high schools. The measurement revealed that the buildings have low IAQ. Two solutions were implemented during the study to improve IAQ. The air change rate enhanced the first solution by increasing the supply air volume from 90 m^3/h to 180 m^3/h. The increase in the outside airflow volume positively affected the indoor air's microbiological purity. Another solution involved air cleaning devices called radiant catalytic ionization (RCI). These devices use active air purification technology, which results in mold spore reduction achieved with RCI. Shi et al. [10] also investigated the indoor air environment on campus and the correlation between those parameters with time in a day. The indoor air parameters included temperature, humidity, and CO_2. Based on their investigation, a high number of people and low fresh air volume are the main reasons for the high CO_2 within a room, leading to poor IAQ. In this case, they mention that increasing the amount of natural ventilation and airflow can improve IAQ. Increasing the air change rate is an effective solution for decreasing carbon dioxide by diluting the high concentration with the fresh air with low concentration. However, introducing fresh air into the room without any special treatment will increase the room air temperature and finally affect the energy consumption of the HVAC system. It aligns with research done by Zhang et al. [11]. They investigated how natural ventilation can affect indoor air quality and the energy consumption of the air conditioning system. The results show that an increment in the fresh air volume will enhance the dilution of the indoor pollutant. Still, at the same time, it also increases the energy consumption of the air conditioning systems.

Fresh air temperature affects the increase in energy consumption of the HVAC system. In this case, the tropical and summer seasons in the subtropical climate with high ambient temperatures will significantly influence energy consumption. Energy recovery ventilation (ERV) or total heat exchanger (THX) is needed to reduce the fresh air temperature without consuming more power and lowering the effectiveness of the air dilution. It is proven by the research done by Laverge and Jannsens [12]. They compare energy recovery and natural ventilation effectiveness and efficiency in European climates. The result shows that it has an advantage over natural ventilation. Nasif et al. [13] conducted similar research in a hot and humid environment. They investigated the difference in energy consumption between the HVAC system coupled with THX and the conventional one. The result shows that the system with THX has lower energy consumption with up to 8% energy savings annually. Furthermore, THX can improve energy savings while maintaining the indoor temperature and indoor air quality in zero-energy buildings, as mentioned by Liu et al. [14]. They review several developments of energy conservation that can be applied in zero-energy buildings.

2. Methodology

2.1. System Description

Offices typically have predictable occupancy patterns, with people spending extended periods indoors. Given people's time in office environments, the societal impact of improving IAQ and thermal comfort in offices is substantial. It can lead to better health outcomes for occupants and improved productivity. The investigated office is illustrated in Figure 1, and it is located on the first floor of the engineering building at the university in central Taiwan. Its dimensions are 14 m in length, 10 m in width, and 4.5 m in height. Its function is for the graduate student office, occupying around 10 to 20 people in normal use. Regarding the AC system, there are three wall-mounted split ACs, one 1.5 RT (4.2 kW) and two 2 RT (7.3 kW). Four external windows face north. In addition, 6 ceiling fans were installed to improve the temperature and velocity distribution.

Determining the best location for the supply air diffuser is essential to ensure good airflow effectiveness and avoid dead zones with stagnating airflow and higher loaded particle concentration. The experiment of this office is to install a THX to improve the IAQ in the environment, record the change in CO_2 concentration before and after the use of the THX, and especially measure the IAQ during multi-person meetings. The THX has a round duct with two supply air diffusers, as the fresh air is arranged above the meeting area. Another exhaust grille is also installed not far from that area. The diffuser and grille have a diameter of 0.16 m. According to ASHRAE Standard 62.1, the ventilation rate procedure recommends that the minimum external air volume of the office space is 15 CFM/person. With a total of 14 graduate students, the minimum external air volume is 210 CFM. In this study, the THX that is used has a specification of an air volume of about 350 CMH which is equal to 210 CFM. THX dimensions are 881 × 615 mm with fan blades for air intake and air exchange of 240 mm. It has a washable, non-woven filter with gravimetric collection efficiency above 82%. The AC and THX specifications are shown in Table 1. In addition, offices often consume a significant amount of energy for AC systems. Implementing an efficient THX ventilation system can contribute to energy savings.

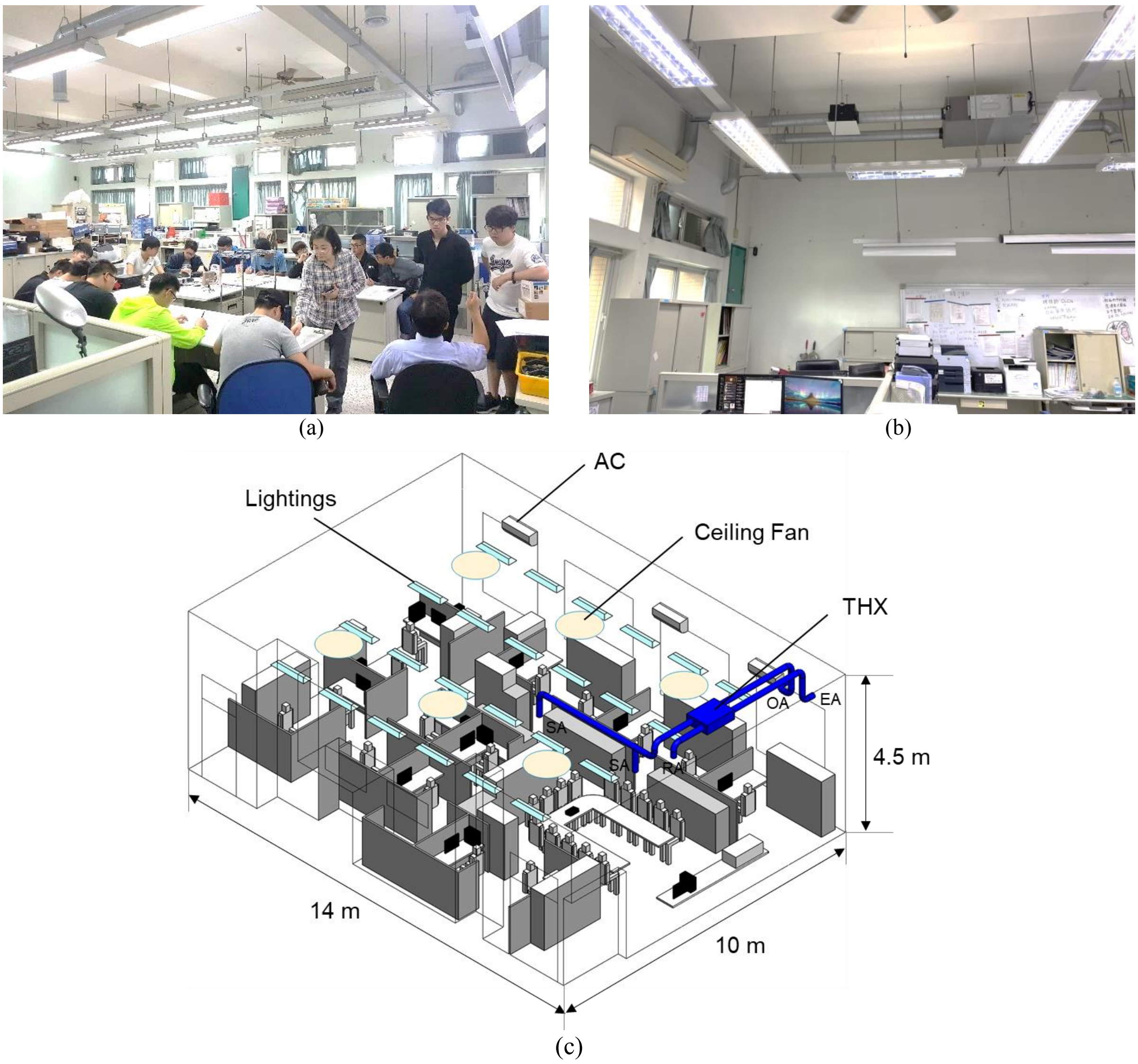


Figure 1. System Description, (a) snapshot during questionnaire survey, (b) THX, (c) Geometry.

Table 1. The specification of the AC and THX System.

Item	Specification	Power Consumption	Power Supply	Quantity
AC TECO MS63F1	7.3 kW 2 RT 6300 (kcal/h)	2,317 W	1φ220V 60Hz	2
AC TECO	4.2 kW	1,313 W	1φ220V 60Hz	1

MS36F1	1.5RT 3550 (kcal/h)			
THX - Alaska VH-6338SC2	350 CMH	230 W	1φ220V 60Hz	1

2.2. Measurement and Questionnaire Survey

On-site, in-depth measurements were also taken of the characteristics of the indoor environment, including temperature, air velocity, humidity, and CO_2 concentration with and without THX. Equipment used for field measurements, operating range, and accuracy levels are detailed in Table 2. In order to investigate the connection between the number of participants, the levels of CO_2, and the level of thermal comfort with and without THX, meetings with multiple people and questionnaires are being held. On a shelf that is 1.2 meters high, the testing apparatus is stored in its designated location. During the inspection, measurements, and recordings are also carried out to establish data references for comparing the indoor and outdoor environmental parameters.

The content of the questionnaire design also refers to the questionnaire in the appendix of ASHRAE Standard 55 based on the six parameters of thermal comfort theory that affect thermal comfort. The on-site questionnaire survey was used for the respondents to obtain their comfort feeling status answered by the respondents, and the subjective comfort indicators were aggregated and quantified. A total of 14 male graduate students aged around 22-24 were filling out the questionnaire survey. The results were then summarized using statistical analysis based on the recovered samples. At the same time, both the questionnaire survey and the measurement of the parameters of the indoor physical environment were carried out. The sample of the questionnaire survey based on ASHRAE standard 55 is listed in Table 3.

Table 2. Apparatus for field measurement.

Model	Parameter	Operating Range	Accuracy
JNC IAQ-S v1.09	CO_2 Temperature RH	CO_2:0~10,000 ppm T: -40~100℃ RH: 0~100%	$CO_{2:}$ ±70ppm ±3% T: ±0.4℃ RH: ±3%
Delta OHM HD 32.3	Black-globe temperature	-10~+100℃	± 0.3℃
	Temperature	-40~+100℃	± 0.3℃
	Humidity	0~100% RH	± 2.0%
	Velocity	0.1~5 m/s	± 0.2 m/s (0~1 m/s) ± 0.3 m/s (1~5 m/s)
ALNOR EBT-721	Velocity	0.0125~12.5 m/s	± 3%

Table 3. Point-in-Time Questionnaire Survey.

Point-in-Time Survey	Description
Basic information	Gender, age, date, time, seasonal condition
Comfort perception	Cold, cool, slightly cool, neutral, slightly warm, warm, hot
Satisfied perception	Very dissatisfied, dissatisfied, slightly dissatisfied, neutral, slightly satisfied, satisfied, very satisfied
Desired Changes in	Temperature (cooler, without change, warmer)

Environmental Comfort	Airflow (less air movement, no change, more air movement)
Clothing insulation (clo)	Which ensemble best matches what they wear (underwear, footwear, trousers, coveralls, dress, skirts, sweaters, suits, jackets)
Activity level	Sleeping, seating, standing, walking, running
Workspace Location	Which floor level? Which area? (north, south, etc.) Near the window or wall within 5 meters?
Air Quality Perception	Stuffiness, dustiness, odors, ventilation, and satisfaction
Physical Characteristics of The Interviewee	Describe any aspects related to the thermal environment of the nearby workspace

2.3. CFD Simulation

Figure 1c illustrates the geometry of the investigated office, which was created based on the actual size and layout of the room. The simulation was performed by using the Ansys Fluent software version 2020 R2. ANSYS Fluent offers a total solution for CFD problems. Starting from 3D geometric modeling, meshing, assigning mathematical models, and post-processing. One of the advantages of the ANSYS Fluent software is the presence of the user-defined function (UDF). UDF are lines of a program written in C language that can be dynamically loaded inside the ANSYS Fluent solver. UDF allows the implementation of new user models and extensive customizations, which can significantly enhance the ANSYS Fluent capabilities. The PMV equations, used to determine the level of thermal comfort, are incorporated into the simulation through UDF. PMV shows the level of comfort or discomfort of the human body to the thermal environment and is expressed as 7 scale (3, 2, 1, 0, -1, -2, -3). The PMV value can be determined using equation (1) as follows ISO 7730 [15].

$$\begin{aligned} \mathrm{PMV} = {} & [0.303 \cdot \exp(-0.036 \cdot \mathrm{M}) + 0.028] \cdot \\ & (\mathrm{M}-\mathrm{W}) - 3.05 \cdot 10^{-3} \cdot [5733 - 6.99(\mathrm{M}-\mathrm{W}) - \mathrm{P_a}] - 0.42 \cdot [(\mathrm{M}-\mathrm{W}) - 58.15] \\ & -1.7 \cdot 10^{-5} \cdot \mathrm{M} \cdot (5867 - \mathrm{P_a}) - 0.0014 \cdot \mathrm{M} \cdot (34 - \mathrm{t_a}) \\ & -3.96 \cdot 10^{-8} \cdot \mathrm{f_{cl}} \cdot [(\mathrm{t_{cl}} + 273)^4 - (\mathrm{t_r} + 273)^4] - \mathrm{f_{cl}} \cdot \mathrm{h_c} \cdot (\mathrm{t_{cl}} - \mathrm{t_a}) \end{aligned} \tag{1}$$

$$\begin{aligned} \mathrm{t_{cl}} = {} & 35.7 - 0.028 \cdot (\mathrm{M}-\mathrm{W}) - \mathrm{I_{cl}} \cdot \{3.96 \cdot 10^{-8} \cdot \mathrm{f_{cl}} \cdot [(\mathrm{t_{cl}} + 273)^4 - (\mathrm{t_r} + 273)^4 + \mathrm{f_{cl}} \cdot \mathrm{h_c} \\ & \cdot (\mathrm{t_{cl}} - \mathrm{t_a})\} \end{aligned} \tag{2}$$

$$\mathrm{h_c} = \begin{cases} 2.38 \cdot (\mathrm{t_{cl}} - \mathrm{t_a})^{0.25}, & \text{for } 2.38 \cdot (\mathrm{t_{cl}} - \mathrm{t_a})^{0.25} > 12.1 \cdot \sqrt{\mathrm{v_{ar}}} \\ 12.1 \cdot \sqrt{\mathrm{v_{ar}}}, & \text{for } 2.38 \cdot (\mathrm{t_{cl}} - \mathrm{t_a})^{0.25} < 12.1 \cdot \sqrt{\mathrm{v_{ar}}} \end{cases} \tag{3}$$

$$\mathrm{f_{cl}} = \begin{cases} 1.00 + 1.29 \cdot \mathrm{I_{cl}}, & \text{for } \mathrm{I_{cl}} \le 0.078\ \mathrm{m^2 k/W} \\ 1.05 + 0.645 \cdot \mathrm{I_{cl}}, & \text{for } \mathrm{I_{cl}} > 0.078\ \mathrm{m^2 k/W} \end{cases} \tag{4}$$

Here are the variables and their values: M stands for metabolic rate (W/m^2), W for effective mechanical power (W/m^2), I_{cl} for clothing insulation (m^2. K/W), f_{cl} for clothing surface area factor, t_a for air temperature, t_r for mean radiant temperature, P_a for water vapor partial pressure (Pa), h_c for convective heat transfer coefficient (W/m^2. K), t_{cl} for clothing surface temperature (°C), v_{ar} for relative air velocity (m/s). Through iteration, the values of t_{cl}, h_c, and f_{cl} can be determined by utilizing the subsequent equations (2), (3), and (4).

This method employs the k-ε turbulence model with a standard wall function for near-wall treatment. The species transport is also activated to solve the CO_2 mass fraction problem. The pressure-based solver is used in this simulation, with the Semi-Implicit Method for Pressure-linked Linked Equations (SIMPLE) method applied to the solver. The SIMPLE method is known for its stability and robustness in solving pressure correction equations. It helps achieve convergence in iterative solvers, ensuring the simulation reaches a solution that accurately represents the flow field.

Boundary conditions are essential for defining fluid flow behavior at the boundaries of the simulated domain. These conditions are based on site measurements to ensure the simulation accurately represents the studied physical system. In the first simulation, a transient method is used in this simulation. The CO_2 concentration inside the room within three hours will be analyzed in this study based on field measurement data. Two methods are used in the simulation to assess the office's environmental factors. In the second simulation, a steady-state method is utilized to evaluate the temperature of the occupant, the air velocity, and the level of thermal comfort. The simulation's boundary conditions are detailed in Table 4, which presents the results of the simulation's execution. When calculating the boundary conditions of the THX and the AC supply mass fraction, the UDF function is called upon to do the heavy lifting. For this investigation, human respiration is defined as the air that has been completely exhaled. Wang et al. [16] figured out how to measure the volume of air exhaled due to respiration.

Table 4. Parameter setup for boundary condition.

Parameter	Type	Value
AC - Supply air	Velocity Inlet	2.5 m/s, 18°C
AC - Return air	Pressure Outlet	0 Pa, 25°C
THX – Supply	Velocity Inlet	2.7 m/s, 26.8°C
THX – Return	Pressure Outlet	0 Pa, 28.2°C
Ceiling Fan	Fan	0.2 m/s, 0.3 Pa
Human Respiration	Velocity Inlet	0.1875 m/s 38,000 ppm
Human	Heat flux	70 W/m^2
CPU	Heat flux	20 W/m^2
Monitor	Heat flux	20 W/m^2
Projector	Heat flux	180 W/m^2
Lamp	Heat flux	180 W/m^2
Relative humidity	UDF Function	50%
Mean radiant temperature	UDF Function	Equal to the air temperature
Occupant’s clothing	UDF Function	0.57 clo
Metabolic rate	UDF Function	1.2 met

3. Results and Discussion

3.1. Measurement and Questionnaire Results

There are two conditions with AC turning off and turning on. In the first condition, the weather was cool, and the outdoor temperature was about 20°C, so the AC was turned off. The weather was relatively sunny in the second condition, and the outdoor temperature was about 25.7°C, so the AC was turned on. Figure 2a shows the indoor temperature and humidity changes during the two conditions. When there is no AC, even though many people are inside and no windows are open, the temperature is still high at around 28°C. However, when there is air conditioning, the temperature inside is about 26°C. The multi-person meeting typically has 14 participants, and variations in CO_2 concentration are observed and recorded. Figure 2b demonstrates that the CO_2 concentration in the environment is significantly impacted by the beginning and end of the meeting. The CO_2 concentration gradually rises when the THX system is turned off because the relationship between the meeting and the number of participants starts in the morning, especially after 16:00. The CO_2 concentration rose rapidly, reaching the highest point of 1,416 ppm at about 19:00, which exceeded the IAQ standard by 1,000 ppm. Then, the number of people in the room decreased at the end of the meeting. However, the CO_2 concentration was still higher than in the beginning. The influence factor of the number of people is included as a reference, indicating the need for THX's existence.

(a)

(b)

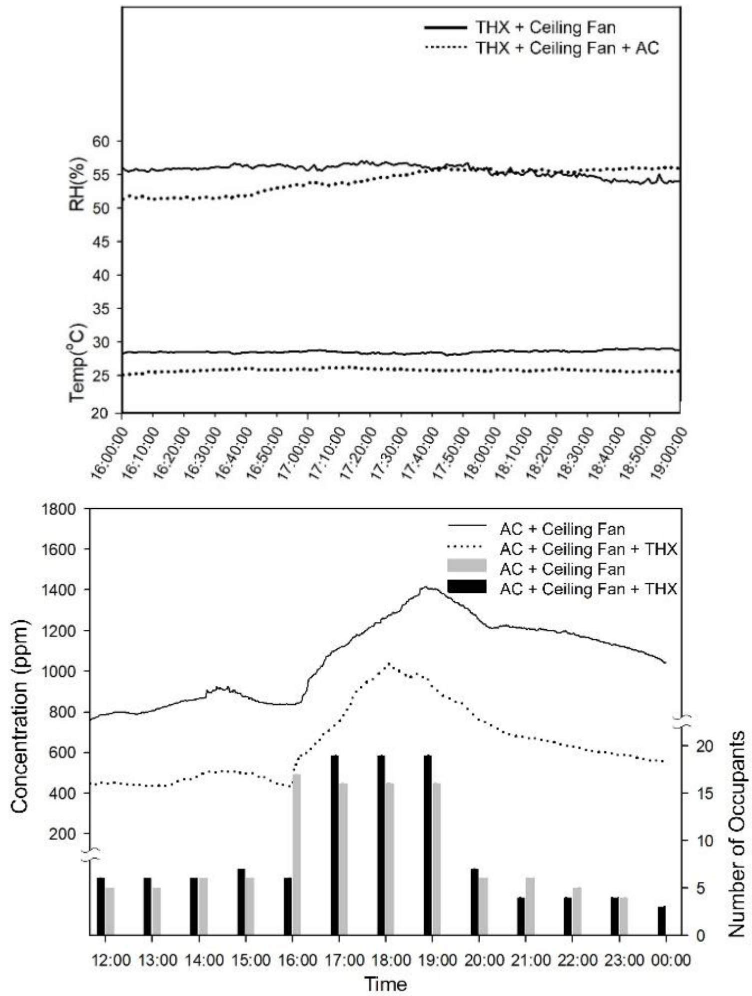
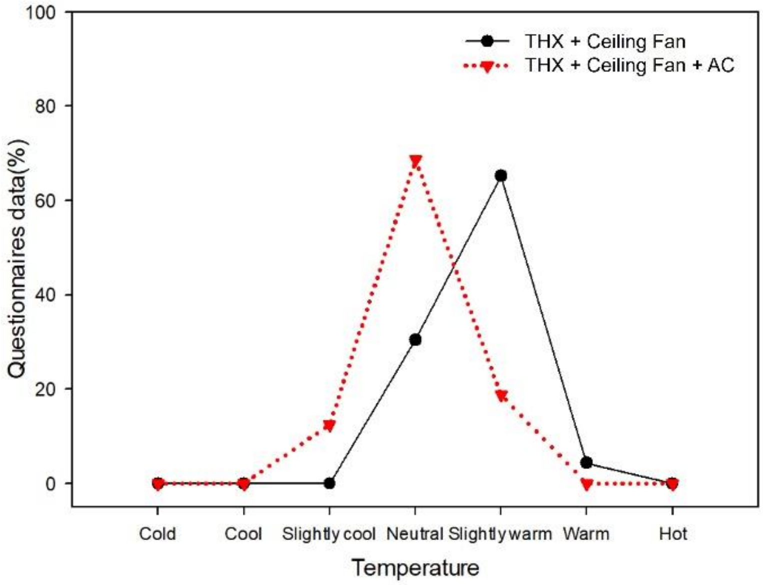


Figure 2. Measurement results: (a) temperature and relative humidity, (b) CO_2 concentration.

The results of the questionnaire survey evaluation based on ASHRAE Standard 55 thermal comfort are displayed in Figure 3. In the first scenario, without air conditioning, respondents found themselves in a moderately warm environment with a light breeze. This setting aimed to simulate conditions without active temperature control systems. In contrast, the second scenario included air conditioning, which kept the room at a comfortable temperature while providing mild airflow. The data shows a clear trend toward the second scenario among respondents, indicating a collective preference for the comforts provided by air conditioning. The second scenario, which includes a comfortable temperature and mild airflow, meets the requirements of ASHRAE Standard 55. This standard considers various factors, including air temperature, radiant temperature, and air velocity, all of which influence the overall perception of thermal comfort. The survey results highlight the importance of keeping indoor temperatures within the recommended comfort range in order to meet occupant perceptions. It suggests that respondents prioritize both temperature control and optimal air circulation.

(a)



(b)

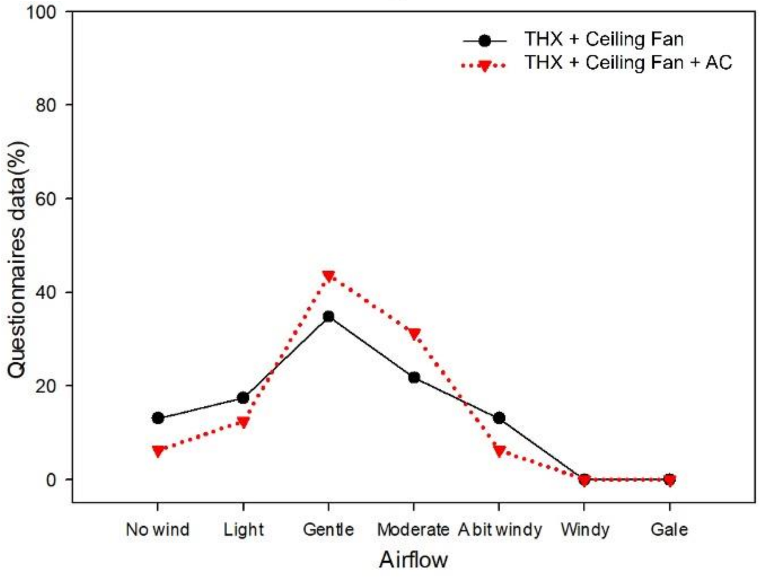
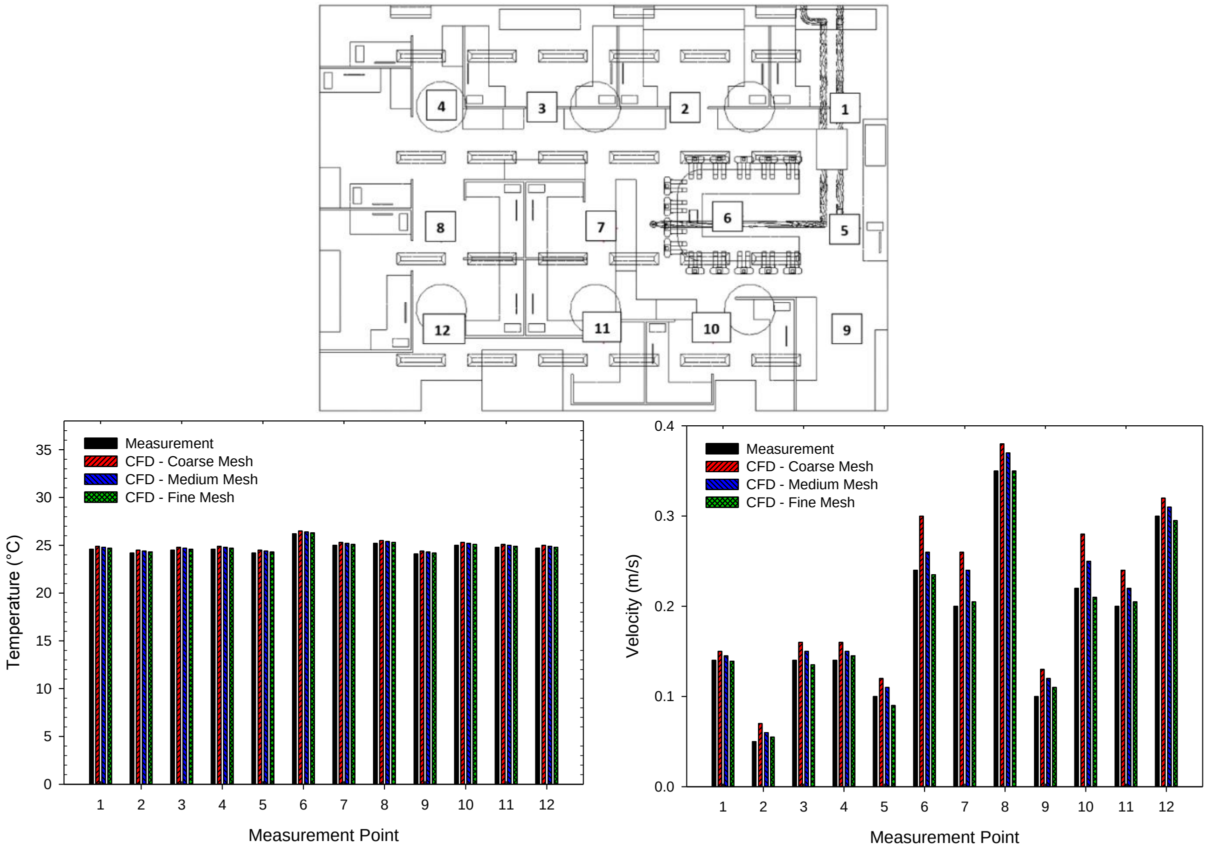


Figure 3. Questionnaire results, (a) temperature, (b) airflow.

3.2. Validation

There are three different numbers of mesh in this simulation model. The result of each mesh will be compared with the field measurement results to assess the level of accuracy. The compromised mesh between the accuracy and the simulation time will be chosen for further examination. In this study, three different mesh sizes were taken into consideration, with the number of elements for each mesh being 5,750,221 for coarse mesh, 10,653,761 for medium mesh, and 13,024,003 for fine mesh. The outcomes of each mesh were then verified using the field measurement results.

Figure 4 shows the velocity and temperature validation results of the twelve sampling points. It shows that the fine mesh is close to the field measurements result. The accuracy difference between every mesh is quite close to the temperature results (Figure 4a). But in the velocity result, the difference is quite large (Figure 4b). The fine mesh has the most precise result, with an average error of 2.1%. In comparison, the medium mesh has an average error of 2.8%, and the coarse mesh has the lowest accuracy with an average error of 4.5%. It reveals that the fine mesh has better accuracy than others. Therefore, the fine mesh is selected based on these findings for further investigation.



(a) (b)

Figure 4. Validation between measurement and simulation, (a) temperature, (b) air velocity.

3.3. Simulation Results

The simulation's velocity vector results are shown in Figures 5a and 5b, respectively, without and with THX superimposed on them. The overall velocity distribution is very similar in both cases in terms of the magnitude of the velocity and the direction in which it is distributed. Something unusual can be seen in the area around the conference table. This condition presents itself as a direct result of the air stream's influence on the THX supply. The airflow from the THX supply causes the airflow from the AC supply to be forced downward. It manipulates the flow of air from the AC supply to change direction. As a result, this condition compels the airflow from the AC supply to circulate for more time, impacting the cooling process. A couple of vortices can be seen on the upper side of the room as an unintended consequence of the THX supply. However, because this circumstance does not produce a flow directly from the AC supply to the return, the situation in the room is not significantly impacted by it. It is possible that the level of thermal comfort that each experience will be comparable, given that the average velocity throughout the room is very similar.

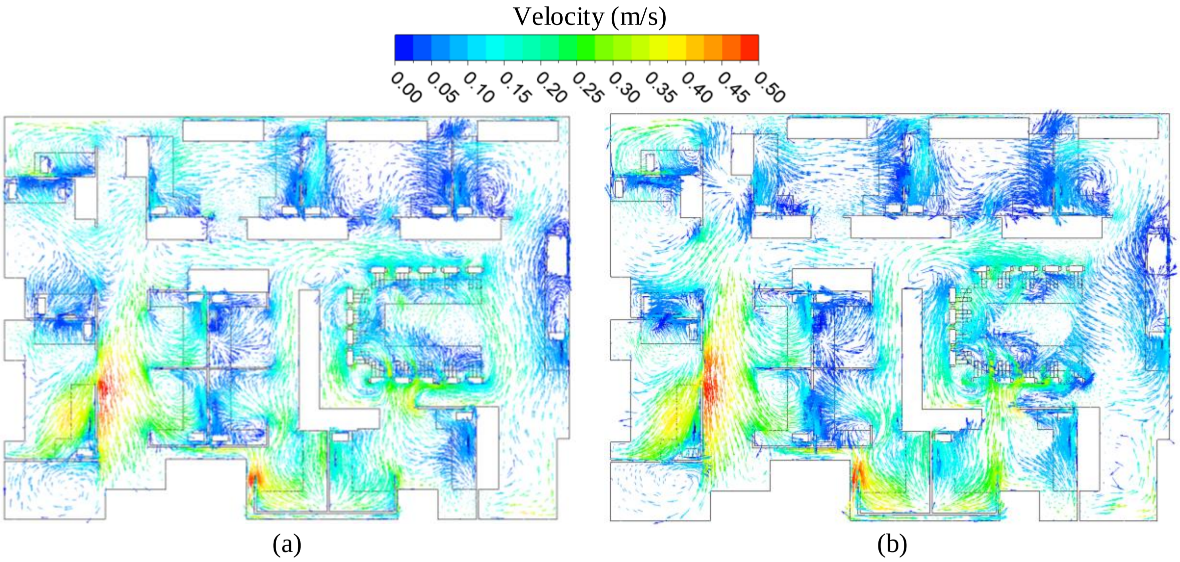


Figure 5. Velocity profile under different conditions, (a) without THX, (b) with THX.

The use of THX and its impact on IAQ, particularly CO_2 concentrations and thermal comfort, is subjected to computational analysis. There are two different parts of the results that are up for discussion. The first one is a transient method simulation result, and it will discuss the CO_2 removal to maintain the IAQ while using THX. In the second part of this conversation, we will investigate the surrounding conditions to determine whether or not the application of THX affects the level of thermal comfort provided by the steady-state method simulation. Figure 6a shows the CO_2 concentration variation from time to time between the simulation without and with THX. Both simulations have the same initial condition of the carbon dioxide concentration at 800 ppm. The black line indicates the simulation without the THX, which reveals that CO_2 concentration increases with time. The maximum concentration reaches 1400 ppm, above the regulation of 1000 ppm. This condition occurs because there is no air change between indoor and fresh air, mainly due to the lack of fresh air supply and reliance on split AC for circulation. With THX, the CO_2 concentration could reach nearly 800 ppm. The introduction of a THX is a key intervention. THX systems facilitate the exchange of indoor and outdoor air, bringing fresh air while simultaneously conditioning it. This helps dilute indoor pollutants, including CO_2 and provides a healthier breathing environment for occupants. This suggests that introducing fresh air through the THX effectively mitigated the buildup of CO_2. The CO_2 concentration contour within the office is shown in Figures 6b and 6c. The air quality in the room is very well maintained even though the total supply air diffuser from THX is only installed on the top of the meeting table. The simulation results with and without THX are profoundly different, and it is clear to see why. As a result, making use of THX can significantly help maintain indoor air quality (IAQ).

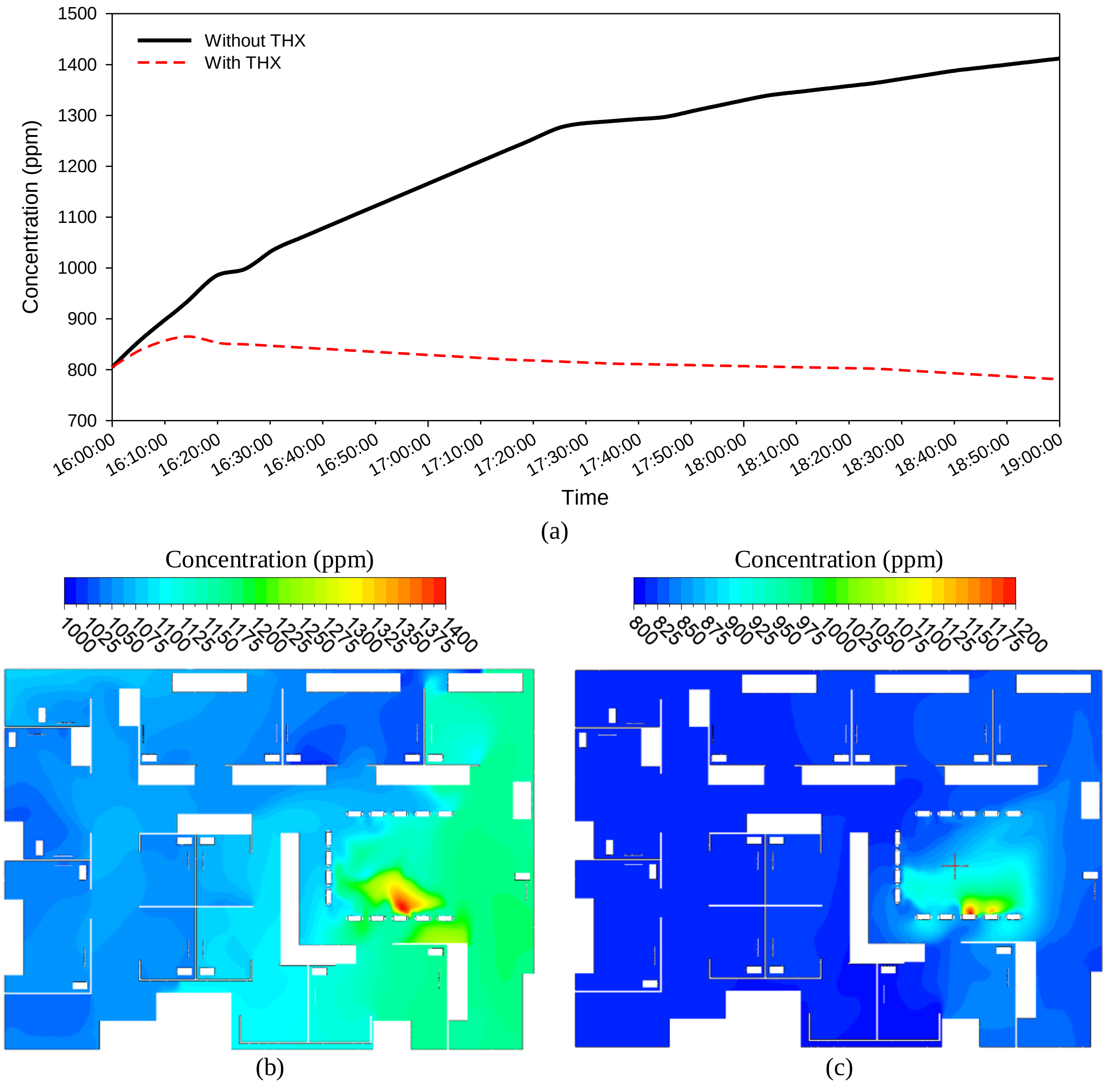


Figure 6. Concentration profile under different conditions, (a) changes of CO_2 concentration, (b) without THX, (c) with THX.

Figure 7a shows the temperature distribution of the simulation without THX, while Figure 7b shows the result of the simulation with THX. Both figures show quite similar results in the temperature inside the office, but some points are different. In the area near the meeting table, the temperature is higher than the other points, reaching around 25°C because of the heat dissipation from the human body. In addition, the temperature near the human area (point 6) is slightly lower in the simulation with THX than without. This situation occurs because of the air stream effect from the THX supply that pushes the AC supply air stream downward. The air stream from the AC supply, which has a low temperature, can cool down the meeting area better. Besides, the THX supply also has a lower temperature than the human body. This situation also enhances the heat dissipation process apart from the cooling process from the AC supply. These conditions could also affect the thermal comfort level of the occupants. According to points 2, 3, 4, 8, 11, and 12, it can be seen that the color is more blue with THX than without THX. For example, in point 12, the temperature is 23.6°C when the THX is operated, and without THX, it is around 24°C. The overall temperature average of 12 measurement points is 24.5°C without THX and 24.1°C when THX is operated.

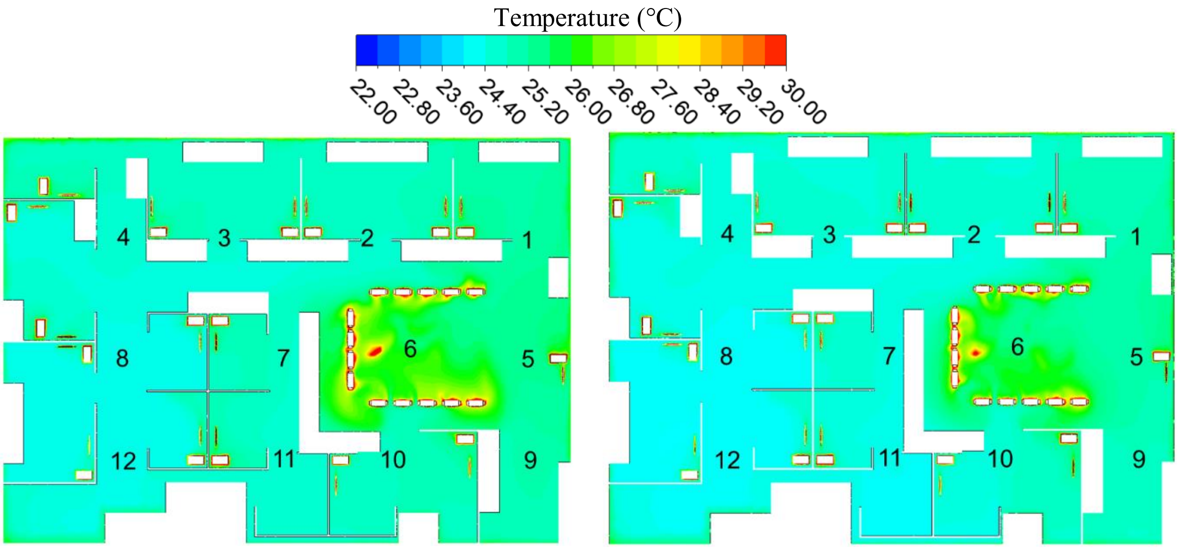
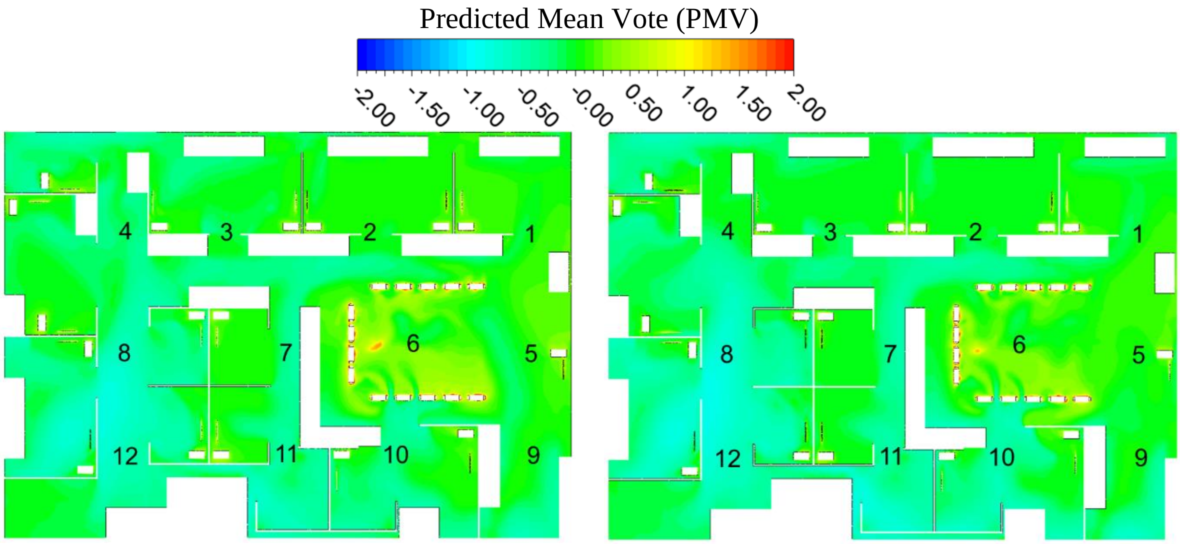


Figure 7. Temperature profile under different conditions, (a) without THX, (b) with THX.

Figure 8a shows the PMV contour of the simulation without THX, and Figure 8b shows the PMV contour of the simulation with THX. Both data sets exhibit average PMV values ranging from 0 to -1 that are almost identical to one another, except for the meeting area. Both scenarios have an average PMV value between 0 and 1 in the area designated for meetings. Compared to the simulation that included a THX, the one that did not include one exhibited a slightly broader perception of warmth. This circumstance arises as a consequence of the effect that the airflow from the THX supply has, which in turn influences the direction in which the airflow from the AC supply goes and the cooling process that it enacts. On the other hand, there is not much difference in the thermal comfort level between simulations with and without THX. As a consequence of this, utilizing the THX has only a marginal impact on the average temperature found inside the office. Overall, the PMV results when THX is operated are slightly lower than without THX, as indicated in Table 5.



(a) (b)

Figure 8. PMV profile under different conditions, (a) without THX, (b) with THX.

Table 5. Temperature and PMV results using THX and without THX.

Measurement Point	1	2	3	4	5	6	7	8	9	10	11	12
No THX (°C)	24.8	24.4	24.3	24.4	25.2	25.6	24.4	23.6	24.6	24.5	24.3	24.0
THX (°C)	24.5	24.1	24.0	24.0	24.6	24.4	24.3	23.5	24.4	24.2	24.0	23.6
No THX (PMV)	0.15	0.20	0.15	0.10	0.15	0.20	0.00	-0.5	0.00	-0.2	-0.2	-0.5
THX (PMV)	0.10	0.10	0.00	0.00	0.10	0.15	-0.2	-0.7	-0.2	-0.5	-0.3	-0.7

4. Conclusion

The primary focuses of this research are an investigation into the thermal comfort of office space as well as the enhancement of IAQ concerning CO_2 concentration. The study was carried out in great detail by using simulation and experimentation. The results revealed that due to the absence of a fresh air supply and the usage of split AC for circulation, the maximum concentration reaches 1400 ppm, which is higher than the standard of 1000 ppm. The utilization of THX was able to bring the levels of CO_2 down to approximately 800 ppm, as indicated by the findings. Consequently, it was discovered that using THX significantly contributed to maintaining IAQ. According to research on thermal comfort performance, implementing THX does not result in a material improvement in thermal performance within the workplace. Consequently, the IAQ and the thermal comfort levels of the occupant can be satisfactorily achieved by implementing a THX ventilation system.

While the THX ventilation system effectively lowered CO2 levels, future research could focus on improving its design and operation to improve overall thermal comfort. Additionally, the study emphasizes the importance of fresh air supply in maintaining IAQ. Future research could focus on sustainable and energy-efficient methods for maintaining continuous fresh air circulation within buildings. Furthermore, the study could focus on developing intelligent systems that dynamically adjust ventilation and air conditioning in response to real-time occupancy, weather conditions, and air quality measurements. Such advancements may result in more energy-efficient solutions prioritizing occupant well-being and environmental sustainability.

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