Identification of Energy-Saving Factors from Hybrid Ventilation in Heritage Building

Michelle Celine Wiranata[1]*, Agus Dwi Hariyanto[1]
[1] Architecture, Petra Christian University, Surabaya, Indonesia

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Corresponding author:
Michelle Celine Wiranata
Architecture, Petra Christian University, Surabaya, Indonesia
Email:
b22250002@john.petra.ac.id

Abstract

Heritage buildings in tropical cities face challenges in balancing energy efficiency with conservation constraints. The aim of this study is to identify the energy-saving factor of the hybrid ventilation system (combining ceiling fans and air conditioning) in Locaahands Tunjungan Restaurant, a colonial heritage building in Surabaya. Field observations and literature-based predicted analysis were conducted to identify factors influencing energy savings, including fan mode, airflow rate, fan position, and AC inlet placement that was evaluated by Archimedes number, uniformity coefficients, turbulence intensity, and comfort indices from previous research. Results indicate that ceiling-fan-integrated air conditioning improves indoor air distribution, reduces reliance on additional AC units, and enhances thermal comfort while lowering energy demand. The downward fan mode at moderate speed provided optimal comfort in dining areas, maintaining air velocity within ASHRAE standards (0.1–0.8 m/s). This strategy allows adaptive reuse of heritage buildings without compromising their historical integrity, offering an energy-efficient alternative to conventional HVAC systems and contributing to urban heat island mitigation.

INTRODUCTION

The use of cooling devices (such as fans and air conditioners) as a thermal comfort solution in urban buildings is widely found in countries with high temperatures, particularly in tropical and subtropical climates (Lundgren-Kownacki et al., 2018). High temperatures in tropical countries such as Indonesia pose significant challenges, especially in large cities, due to the urban heat island (UHI) effect and represent an obstacle to sustainable development. The adverse impacts of UHI, aside from worsening urban microclimates, include heat-related deaths of hundreds of people during heatwaves and a 5–6% increase in energy consumption, which is accompanied by greater fossil fuel use and, consequently, global warming. Research in the United Kingdom indicates that energy consumption for cooling office buildings in rural areas is only 84% of that consumed by urban office buildings (Octaliana et al., 2024). Ariestadi's (2014) research further shows that in hot-humid tropical climates, buildings consume approximately 45–70% of their total energy for air conditioning systems. The increasing consumption for active cooling is particularly due to the relatively hot climatic condition year-round (Putra et al., 2022). Air conditioners (AC) becomes an immediate solution to create the desired thermal comfort as a result, which is the primary concern with the constant heat in tropical climate environments (Putra et al., 2022). It is also often promoted as a solution to ensure thermal comfort and prevent health risks during heatwaves, yet in reality, they also exacerbate the UHI effect (Lundgren-Kownacki et al., 2018).

UHI is primarily caused by land-use changes and the lack of green areas. In Surabaya, UHI hotspots are concentrated in the city center and, by 2011, had expanded eastward and westward (Sobirin & Fatimah, 2015). The city's average temperature has risen by 1.2°C in 2023 compared to the pre-industrial period of 1850–1900, reaching an average of 26–31°C, and is projected to continue increasing in the coming years (Muliawati, 2024). Mitigation efforts include introducing more greenery and implementing green roofs as part of sustainable urban development strategies (Limas et al., 2014), along with developing climate-responsive sustainable building standards (Guttridge-Hewitt, 2023). However, these strategies are difficult to implement in heritage buildings, where both structural and visual alterations are highly restricted.

Heritage buildings, depending on their location, reflect local cultural values in their architectural design (Couvelas, 2020). They are preserved to retain their historical value, and a commonly applied method is adaptive reuse, where the building is given a new, contemporary function without altering its original structure (Prihatmanti & Susan, 2017). In heritage zones such as Jalan Tunjungan, Surabaya, dense building development and limited greenery are common, and many adaptive reuse projects have added air conditioning systems. The preserved architectural style, largely colonial, is characterized by features such as shading facades and pitched roofs (Prijatna et al., 2022). These characteristics limit the possibility of adding elements like green roofs. At the same time, global warming has driven widespread reliance on air conditioning, which ironically contributes further to climate change.

Due to the high temperatures in hot-humid tropical climates such as Surabaya, the largest proportion of building energy consumption is typically dedicated to air conditioning systems (Saleh et al., 2022). Although AC use negatively impacts the environment, in conditions where its use remains unavoidable, it can be integrated with strategies for energy efficiency. One such method previously studied is the combination of fans and AC systems, referred to as ceiling-fan-integrated air conditioning (CFIAC). Previous research on this system includes studies by Atthajariyakul and Lertsatittanakorn (2008) in classrooms in Thailand, and by Chang et al. (2025) in office environments, as well as other experiments analyzing fan speed variations. Overall, the findings demonstrate that using fans in conjunction with AC improves both thermal comfort and building energy efficiency.

The efficiency of alternative hybrid ventilation systems in enhancing thermal comfort and energy performance has also been examined by various scholars. Building on these findings, this study explores the potential of hybrid ventilation as an energy-saving strategy for heritage buildings. The selected case study is Locaahands Tunjungan Restaurant, a heritage building that previously relied on passive ventilation but now employs a combination of AC and ceiling fans. Data on the number, placement, and types of AC units and fans in the restaurant were collected through direct field observation. These data were then analyzed against literature-based parameters of energy efficiency. The objective of this research is to identify the key factors influencing energy efficiency in the implementation of hybrid ventilation at Locaahands Tunjungan Restaurant.

LITERATURE REVIEW

Factors Influencing UHI on Jl. Tunjungan, Surabaya

Urban Heat Island (UHI) is a phenomenon in which the temperature in urban areas is higher compared to their surrounding regions (Radite Ranggi Ananta et al., 2024). The causes of increased UHI include changes in land use in major cities, where most green areas are replaced by asphalt, concrete, and other built structures due to urban population growth (Sobirin & Fatimah, 2015). The temperature rise caused by UHI can affect the environment and the quality of life of urban residents. Its negative impacts include increased energy consumption, higher air pollution and greenhouse gas emissions, adverse effects on human health and infrastructure functions, as well as deterioration of water quality (Biset, in Kurniati & Nitivattananon, 2016).

Surabaya, the capital city of East Java Province, has the highest development intensity and the densest population in the province, making it the second-largest city in Indonesia after Jakarta. According to BMKG data, the highest average temperature in Surabaya in 2014 reached 36℃, while in 2024 it reached 36.5℃. On dense roads such as Jl. Tunjungan, temperatures can reach up to 41℃ (Rashid, 2020). Satellite imagery analysis from 1994, 2000, and 2011 shows that most of Surabaya's land cover is dominated by built-up areas (Limas et al., 2014). This dominance is attributed to the continuous increase in population over the years, leading to a decline in green areas, while water bodies accounted for the smallest proportion of land cover (0.34% in 2011). Areas with the highest UHI tend to concentrate in the city center with a spatial pattern extending north and south. Surabaya itself has an average temperature that is 1.4℃ higher than its surrounding regions. This temperature increase has resulted in more than 26 uncomfortable zones across the city (Noviyanti et al., 2016).

Improving Energy Efficiency through Building Ventilation

Global energy demand continues to rise, with the building sector responsible for a significant share of total consumption. Among building services, HVAC systems are major contributors to energy use; thus, enhancing ventilation systems is essential not only for improving building energy efficiency but also for providing healthier indoor environments and reducing health-related risks (Chenari et al., 2016). Energy-efficient ventilation can further reduce building-related greenhouse gas emissions and mitigate climate change impacts.

The effectiveness of ventilation depends on multiple factors, with each system offering distinct characteristics and benefits. Best practices rely on balancing advanced technologies, innovation, and sustainability (Niza et al., 2024). Today, ventilation requirements are largely regulated by standards related to Indoor Environmental Quality (IEQ). Improving indoor air quality benefits occupant health and comfort, while also proving economically advantageous by boosting productivity and lowering health-related costs. Integrating IEQ as a key pillar in renovation and retrofitting initiatives is therefore crucial.

Findings on ventilation methods to support energy efficiency, as reviewed by Chenari et al. (2016), include:

- Natural ventilation reduces HVAC energy demand but poses challenges in control, consistency, acoustics, security, and air conditioning.
- Hybrid ventilation decreases mechanical energy use while maintaining good air quality.
- Low utilization of ventilation spaces leads to considerable annual energy waste.

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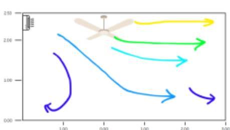
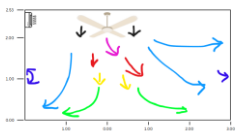
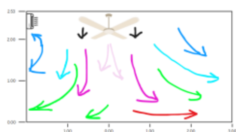
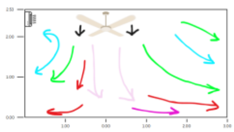
- Poorly designed ventilation systems may increase health problems depending on airflow rates and user health.
- Higher ventilation rates than minimum standards are recommended to support healthier and more productive indoor environments.

Hybrid Ceiling-Fan-Integrated Air Conditioning (CFIAC)

Ceiling-Fan-Integrated Air Conditioning (CFIAC) replaces conventional duct terminals and diffusers with nozzles that directly supply cool air around ceiling fans, which then mix and distribute it throughout the room (Luo et al., 2021). This creates a more uniform horizontal air temperature despite variations in air velocity. The fans enhance convective cooling by increasing airflow to occupants (Li et al., 2024). Both the AC and fans can operate jointly or separately depending on cooling needs. Fan rotation speed and direction strongly influence airflow: downward mode at high speed provides the strongest cooling, while upward mode generally produces lower velocities. At neutral or slightly warm conditions (28℃), downward fan operation achieves thermal comfort comparable to 26℃ when using AC alone. In cooler settings, upward airflow can reduce discomfort from overly cold supply air (Chen et al., 2020). With fans on, room temperature differences were reduced (0.2–0.4℃ across locations), non-uniformity decreased by 26%–43%, and cold spots were eliminated. Vertically, almost no temperature stratification occurred during fan operation.

CFIAC also improves indoor air quality by accelerating air exchange and enhancing heat dissipation (Li et al., 2024). Studies show that downward fans at 1.2 m/s and 122 rpm reduce central CO_2 concentration by 14%, and by 9%–6% when sources are located near room edges. In contrast, low fan speeds (0.6 m/s, 72 rpm) are ineffective, even increasing CO_2 levels. Faster airflow allows occupants to receive fresh air about four minutes sooner compared to no fan use. Heat dissipation efficiency depends on occupant distance from the fan: closer positions provide greater cooling, but even the farthest positions achieve up to 46% better heat release compared to AC-only conditions.

Table 1. Illustration of air flow rate and distribution directions in the room with different fan levels. (Source: Chen et al., 2020)

Wind -flow Illustration				
Airflow Rate	Fan Level 0	Fan Level 2 (1,2 m3/s)	Fan Level 4 (2,2 m3/s)	Fan Level 6 (3,3 m3/s)

An illustration of airflow direction and velocity with downward fans based on Chen et al. (2020) is presented in Table 1. From the experiment that was conducted by Chen, CFIAC was evaluated in a test room to find the distributions of air-speed, temperature, and calculated comfort level throughout the room. The room was installed with a ceiling fan of 1,5 m diameter, a wall mounted supply fan, and was set in the elevation of 2,5 m from floor surface. Air velocity was measured with omnidirectional anemometers (Sensor Inc., Gliwice, Poland), accurate to ±0.02 m/s (0.05–5 m/s), designed for low indoor airflows. Measurements were taken on vertical and horizontal grids at multiple heights (0.1–2.0 m), with dense sampling across planes to have a clearer flow result. The data then were analyzed using Archimedes number, uniformity coefficients, turbulence intensity, and comfort indices. From the result, it was found that different fan speeds result in varying indoor air velocities. The experimental setup positioned the fan at a height of 2 meters, 2 meters from the AC inlet, with the AC blowing air from the wall side toward the fan, and the test fan diameter was 1.55 m. Results indicated that lower fan speeds produced weaker and less dispersed airflow, causing greater indoor temperature variation and increasing the risk of air supply dumping beneath the AC and fan in activity zones. In contrast, higher fan speeds improved temperature distribution uniformity, particularly near the fan.

Overall, CFIAC reduces energy use while enhancing indoor thermal comfort. It lowers the need for multiple AC units and ducting by improving air distribution (Luo et al., 2021). Fans enhance AC cooling effects, allowing for higher thermostat settings and reducing both AC unit size and load (AC ≈ 1 kW/unit vs. fan ≈ 0.03 kW/unit). The uniform airflow also decreases the risk of overcooling compared to conventional AC systems, thereby creating more positive thermal comfort conditions (Chang et al., 2025). The benefits of CFIAC, as summarized in Table 2, directly address energy efficiency, indoor air quality, and thermal comfort.

Table 2. Benefits of using CFIAC system based on multiple literatures.

Aspects	(Chen dkk., 2020)	(Luo dkk., 2021)	(Li dkk., 2024)	(Chang dkk.,2025)
Energy Efficiency				
Cooling distribution efficiency	The dominant air flow direction follows the airflow from the fan and distributes air more evenly throughout the room than a system with air conditioning alone, thereby reducing the number of AC units.	CFIAC reduces the number of AC units because it can improve the efficiency of air distribution and maintain a comfortable temperature even with a higher temperature setpoint, thereby reducing the cooling capacity usage of the main AC.	-	The fan helps lower the AC temperature so that the temperature from 25℃ can be increased to 27℃ and reduces energy consumption by 10%.
Heat-loss efficiency	-	CFIAC system eliminates the hot air layer around the body (boundary layer), thereby increasing the rate of heat convection away from the user's body.	The closer the user is to the fan, the more effective heat dissipation becomes. Even at the furthest point, heat dissipation effectiveness can reach up to 46% with high air velocity. The AC temperature can be set higher, reducing energy for AC performance.	-

Thermal comfort				
Room temperature adjustment	CFIAC can maintain indoor temperatures within the ASHRAE 55-2017 comfort standard of 26°C to 28°C.	The downward fan mode can cool the air temperature by 2°C from the set AC temperature. The upward fan mode can heat the room and reduce the risk of overcooling.	-	CFIAC can maintain indoor temperatures within a relatively stable human comfort range and feel cooler than the AC setpoint, from 25°C to 27°C.
Temperature variations	In general, the temperature difference is uniform for each fan condition (various fan modes and fan speeds), with an average difference of 0.2°C when the fan is in the center position, and 0.4°C when at the edge.	-	-	The fan in the CFIAC system distributes the temperature more evenly
Perceived temperature by user	The AC temperature in the CFIAC is 26°C, neutral to slightly cold. The AC temperature in the CFIAC is 28°C, neutral to slightly warm.	-	-	The CFIAC fan at low fan speed (air velocity ±0.3 m/s) provides the most thermally stable comfort with a PMV of -0.3, in accordance with the ASHRAE Standard 55 optimal standard.
Air flow	-	-	The airspeed in the downward mode is greater than in the upward mode. As the position gets closer to the fan, the airspeed increases.	-

According to literature sources, integrating a ceiling fan with an air conditioner can expand air distribution and temperature control in a room. The parameters that influence the energy efficiency of using hybrid ventilation include the fan mode, fan airflow rate, AC airflow rate, fan position, and inlet temperature.

Building Characteristics of Case Study

The research object is a building with a modern colonial architectural style located in the cultural heritage area of Surabaya, namely the Locaahands Restaurant (Figure 1). The Locaahands Restaurant building was originally the J.W.F. Sluyter Soerabaja Bookstore (Boekhandel J.W.F. Sluyter Amsterdam Filiaal Malang) and is one of Surabaya's cultural heritage buildings. Constructed in 1925, it features a modern colonial architectural style, one of the dominant styles characterizing the commercial buildings of Jalan Tunjungan (Romadhonita & Elviana, 2023). The building has undergone several functional transformations, including serving as Aneka Dharma Store, a car showroom, Bank Dagang Negara, Bank Bumi Daya, and later as the office of Yayasan Majelis Dzikir Surabaya "Nurussalam" Jawa Timur (Kusumo, as cited in Yuanditasari et al., 2024), before its façade was restored to the original design (Figure 3). In 2023, the building underwent adaptive reuse of its interior design, transforming it into a modern heritage-themed restaurant, Locaahands Tunjungan, with the addition of air conditioning.

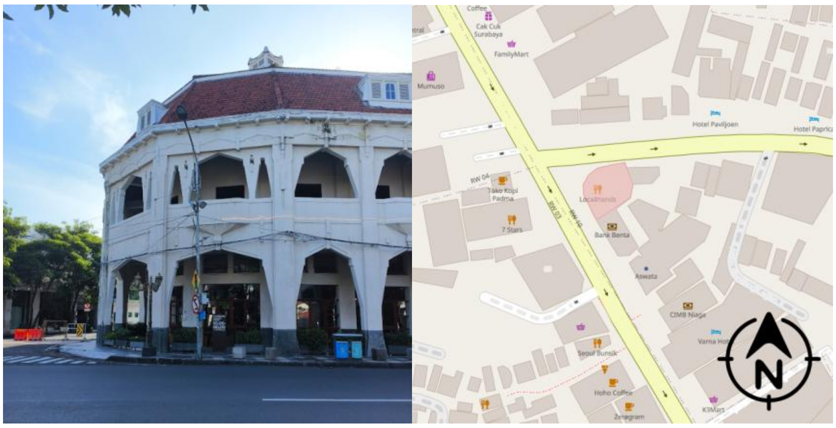


Fig. 1. Locaahands Tunjungan Restaurant.

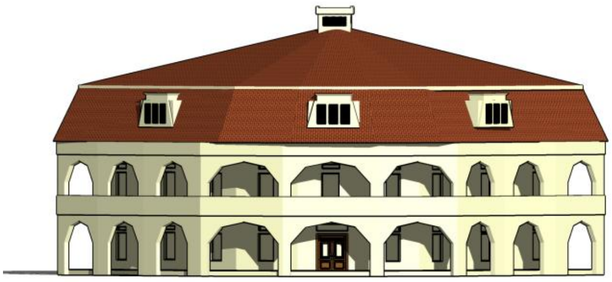


Fig. 2. Schematic facade of Locaahands Tunjungan.

Fig. 3. Locaahands Tunjungan's facade transformations.
(Source: Yuanditasari dkk., 2024)

The revitalization of the building through adaptive reuse retained its original structural components, including columns, walls, roof frames, and floors, as well as preserving nearly the entire original façade, as shown in Figure 2. Modifications were made by adding supporting infrastructure such as circulation pathways for electrical, mechanical, and utility installations. Based on direct observation, the building contains five VRV units and two ceiling fans (Figure 5).

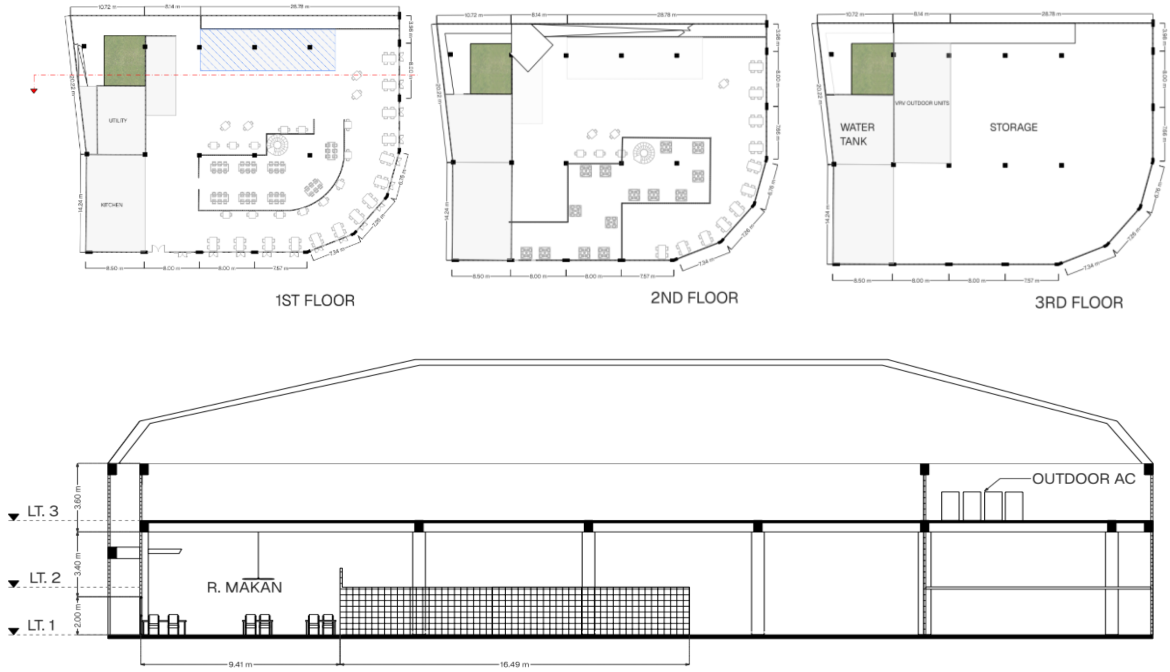


Fig. 4. Schematic floor plan & section.

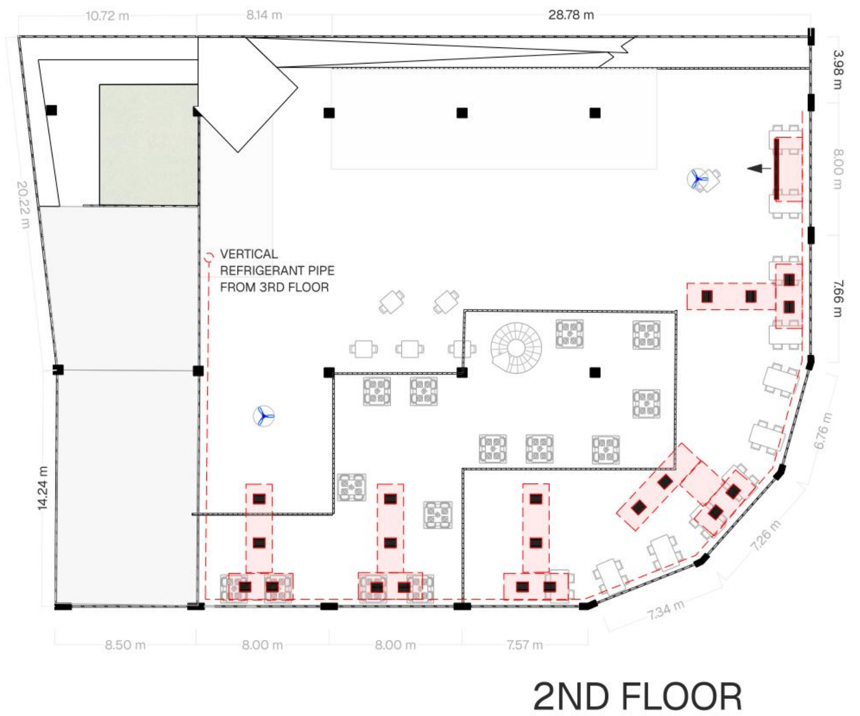


Fig. 5. VRV units and ceiling fans mapping.

METHODS

The research method was carried out through direct field observation of the heritage building, Locaahands Tunjungan Restaurant, to determine its ventilation system, including the quantity, kind, and positioning of both AC units and ceiling fans. The acquired data were then examined and compared to parameters defined in earlier research on hybrid ventilation, including fan mode, fan airflow rate, fan location, and AC inlet positioning, all of which influence energy efficiency. This study sought to determine how the use of hybrid ventilation can improve thermal comfort and energy efficiency while preserving the landmark building's structural integrity. Eventually, the factors found from analysis will be a guide to propose an architectural element design that enhances the ventilation system and reduces energy consumption. The design proposed in this topic will be in the form of a new shape of ceiling to boost cooling air distribution and energy integration with alternative energy sources such as solar panel with ceiling fan ventilation system. The research framework scheme can be summarized as follows (Fig. 6).

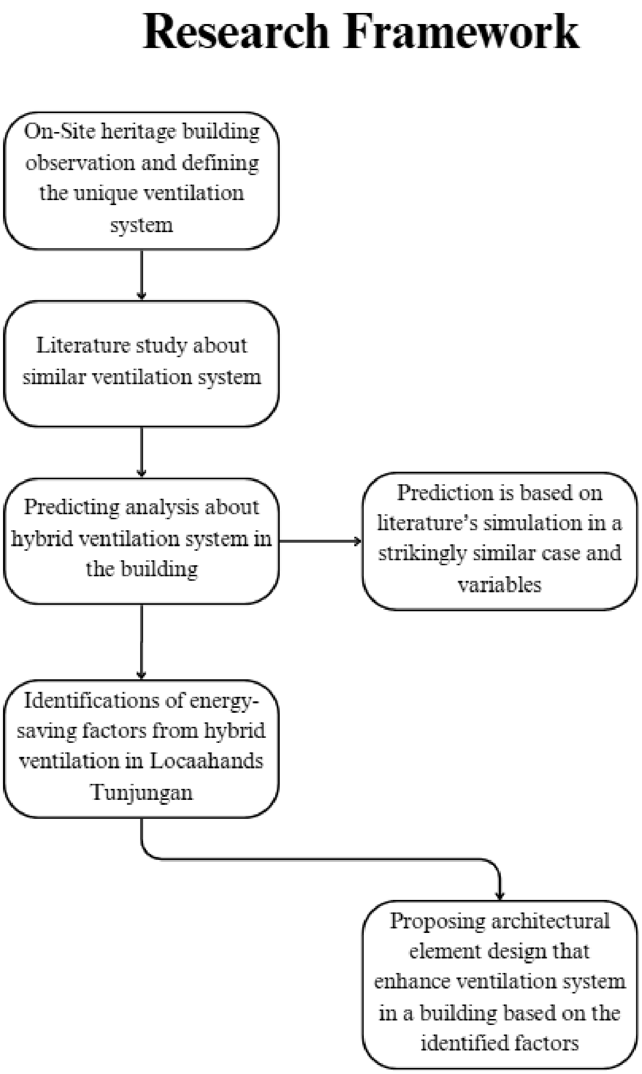


Fig. 6. Research framework.

RESULTS AND DISCUSSION

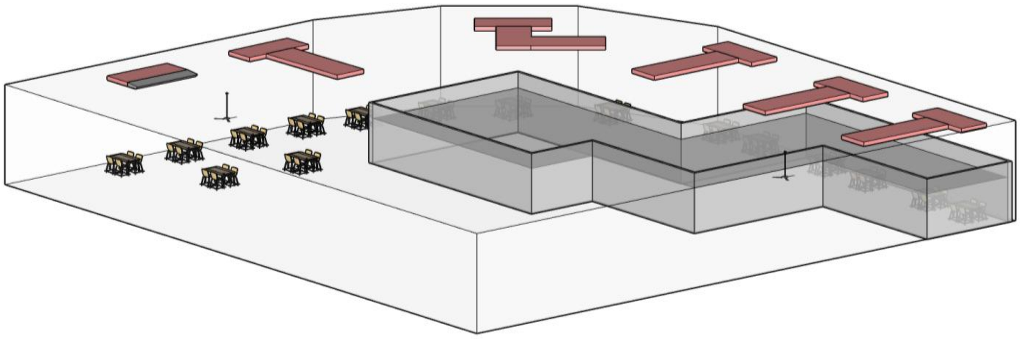


Fig. 7. AC units and fans position in axonometry in 3D.

The case study analysis of Locaahands Restaurant examines the mixed-mode ventilation elements, including AC units and ceiling fans, as positioned in Figure 7. The purpose of the study is to identify the factors influencing energy efficiency resulting from the implementation of hybrid ventilation at Locaahands Tunjungan. Based on the literature review, hybrid ventilation systems can enhance energy efficiency while improving thermal comfort and indoor air quality. These factors are assessed through direct field observations, with the collected data compared against parameters derived from the literature. The objective of the observation is to evaluate efficient ventilation principles that may be further developed to propose alternative ventilation systems that are more energy-saving and capable of mitigating the UHI effect in heritage buildings.

Data regarding the case study object were obtained through direct field observation, though limitations existed in the data collection process. Considering the available data and the research focus, indicators from previous similar literature sources were analyzed and filtered to align with the observed conditions. The key indicators examined include fan mode, fan airflow rate, fan position, and the position of AC air inlets, all assessed against thermal comfort and energy efficiency parameters.

Ceiling Fan & AC Specifications

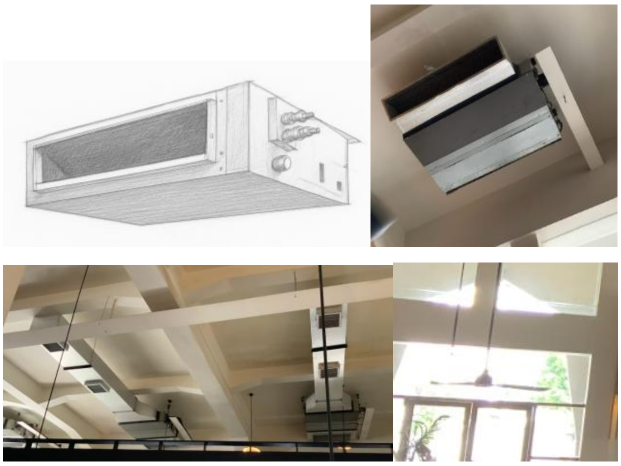


Fig. 8. HVAC and fans units in restaurant.

Based on field observations (Fig. 8) and image searches using Google Lens, the cooling system units at Locaahands Restaurant consist of:

- 1 unit Daikin Middle Static Pressure Ceiling Mounted Duct (without extended ducting, 1 diffuser
- 4 units Daikin Middle Static Pressure Ceiling Mounted Duct (with ducting, 3 diffuser points)
- 2 units (estimated) Valerio 56" Modern Ceiling Fans
- 4 Daikin VRV RXMQ8AY1 8HP outdoor units

The air conditioning system used at Locaahands Restaurant is a VRV system, with the outdoor units located on the roof (exposed, third floor). The indoor AC units are ceiling-mounted at approximately 5.8 meters above the dining floor level, positioned along the northern and southern edges of the building. The VRV system circulates refrigerant cooled by the outdoor unit through piping to the indoor units, which then return the refrigerant to the outdoor units for re-cooling. Of the five AC points, four units use a single indoor unit extended with ducting to three diffuser outlets.

The identification of the AC model was based on the type of outdoor unit found during field observation, along with matching dimensions, form, and specifications, in order to determine the closest possible unit type. According to restaurant staff, the AC set point is maintained at 25℃ with a high airflow rate. Specifications of the AC units are presented in Table 3.

Table 3. VRV unit specifications.
(Source: daikin.co.id)

HVAC Unit Type	Dimension (HxWxD) mm	*Airflow Rate* (H/M/L) m3/s	*Power Consumption* (kW)
Middle Static Pressure Ceiling Mounted Duct FXDQ63SPV14	245x1.550x800	1.377/1.183/988	0,222

Searching for a suitable ceiling fan type is by examining potential physical appearance of the fan based on on-site observation. The obtained most similar specifications is from Valerio ceiling fan:

Table 4. Ceiling fan specifications.
(Source: ola-outdoor-living.com)

Ceiling Fan Type	Dimension (mm)	Airflow Rate (1/2/3/4/5/6) m3/s	Power Consumption (watt/h)	Cooling Capacity (Btu/h)
Valerio 56" Modern Ceiling Fan	1440	1,24/1,77/2,27/2,68/3,00/3,38	35	54.600

Airflow rate that are used are Level 1, Level 3, and Level 6 (Table 4) because of the similar airflow rate 1,2 m3/s, 2,2 m3/s and 3,38 m3/s according to reference from Chen’s experiment and simulation so we can predict the impact of the air-flow accordingly (2020).

Predicted Air Movement Study

Chen et al. (2020) analyzed indoor airflow resulting from the addition of a fan near the AC inlet. The results showed that in tropical climates, fans are more suitable when operated in the downward mode, as this helps cool the indoor temperature. The airflow direction within the room predominantly follows the fan's rotation (Figure 9)

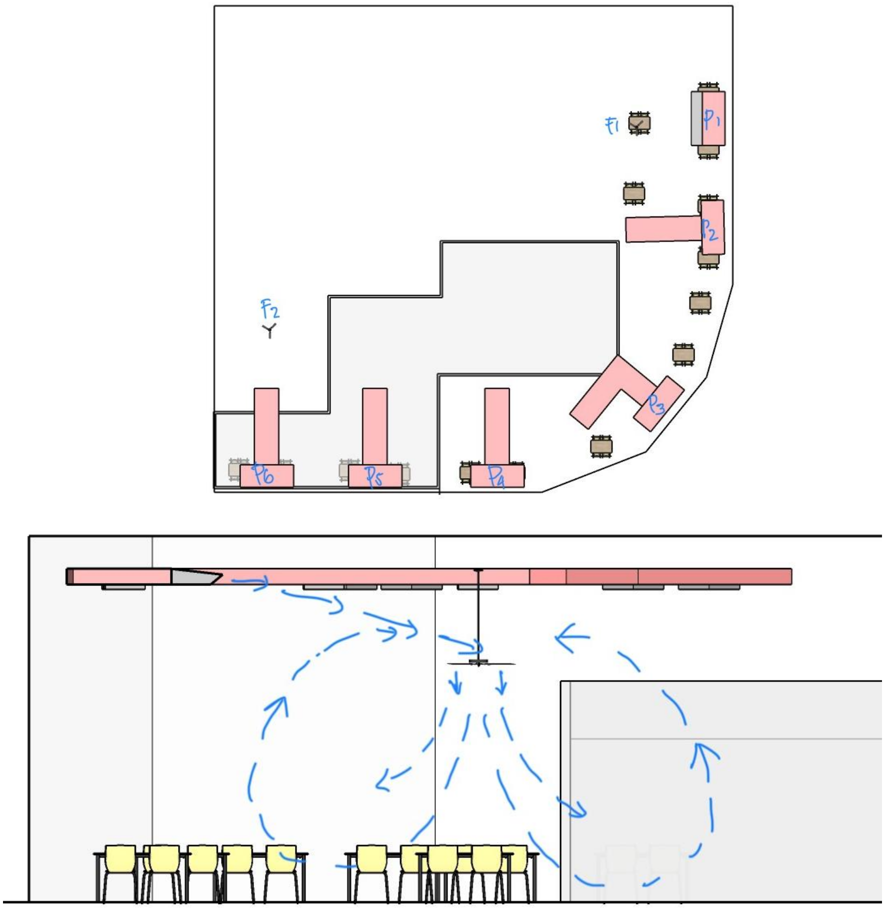


Fig. 9. Air-flow circulation from downward fan mode.

The units observed for hybrid ventilation at Locaahands Restaurant are P1 and F1. The fan is positioned at a height of 2.9 meters above the floor, while the AC unit is installed at 4.5 meters with an extension directing the cool air flow toward the fan. The airflow direction derived from literature guidelines was applied to a sectional model of Locaahands Restaurant to predict the resulting air circulation.

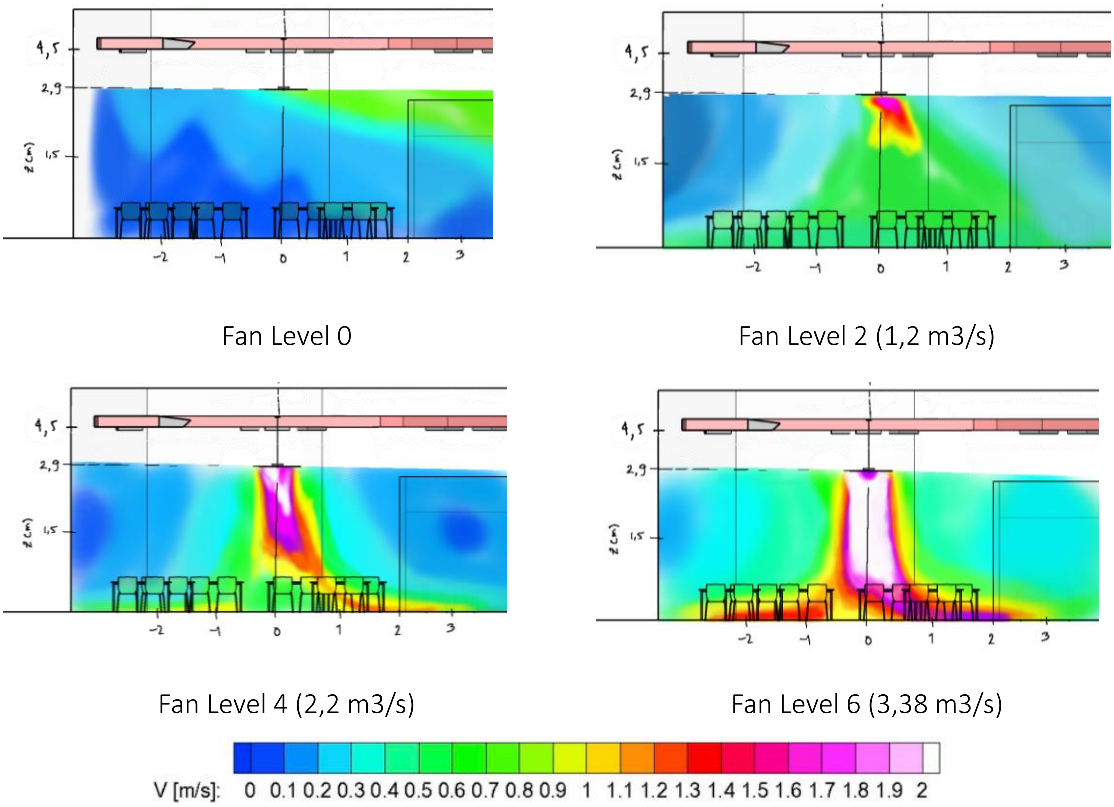


Fig. 10. Air velocity predicted inside the restaurant on different fan speeds.

Fans increase air velocity in proportion to their rotational speed. Figure 10 illustrates the airflow pattern, showing that areas near the floor and ankles experience higher air velocity due to surface contact with the floor. The closer the point to the fan, the higher the air velocity (Chen et al., 2021).

Study of CFIAC on Thermal Comfort

Standards for thermal comfort can be referred to ASHRAE Standard 55, which defines comfort as a combination of several factors, including air temperature, humidity, air velocity, radiant temperature, physical activity, and clothing. The standard aims to ensure that more than 80% of occupants feel comfortable with the indoor environmental conditions. For eating activity, ASHRAE-55 specifies a stable air velocity of around 0.15 m/s—approximately 0.3 m/s for operative temperatures below 22.5°C and up to 0.8 m/s for operative temperatures above 25.5°C (Gwok, 1998).

As the observation conducted in Locaahands were not followed by thorough temperature studies, the user's perception of the airflow and comfort was taken by interview to the visitors. The employee were also being interviewed to ask what system they use in the restaurant, and how they adjust the temperature of AC and fan speed of the ceiling fan. The results were described in Table 5.

Table 5. Observations regarding thermal comfort aspects.

Thermal Comfort	Observation
Adjusting room temperature	The VRV air conditioning system and the types of fan speeds (ceiling fan) can be controlled using the AC remote and the fan remote
Temperature variations	Although the AC inlet position is only at the edge of the room, the temperature difference inside the room is fairly uniform with visitors not feeling that much difference in temperature except in an area with more boundary at the centre of the restaurant. It’s to be expected because the ceiling fan rotates cool air downward to distribute it throughout the room.
Perceived temperature by users	The temperature felt at the desk position becomes cooler as it gets closer to the fan. The air temperature below the fan feels cooler the closer visitors are to the fan.

Air velocity at Fan Level 2, as shown in Figure 9, indicates an airflow prediction in the dining area ranging between 0.1–0.8 m/s according to literature and flows experimented by Chen et al. (2021), which aligns with comfort standards for dining spaces. When the fan operates at Level 4, air velocity at points more than 3 meters below the fan increases up to 1.3 m/s around the ankle area, and becomes even higher at Level 6. In response to this condition, the placement of chairs and tables at Locaahands Restaurant is appropriate, since the zones with such airflow correspond to circulation areas.

Meanwhile, the AC units P2–P5 are designated to provide ventilation in the dining area. The resulting circulation follows a fan-off condition (Level 0 illustration in Figure 9). The risk of air supply dumping, based on airflow direction from Chen et al. (2020), occurs near the dining zone adjacent to glass windows. However, daytime temperature is also influenced by heat transfer from the preserved façade of Locaahands Restaurant. The glass façade, partially shaded, contributes to heat transfer at the air supply dumping point, which helps mitigate the risk of overcooling (Luo et al., 2020).

Study of the CFIAC System on Energy Efficiency

In the condition where fans are not used, the area near the bar and kitchen lacks AC units for cooling (Figure 11). The AC units are only installed along the northern and western walls, likely due to the arrangement of refrigerant piping placed along the building’s perimeter. If the AC units were positioned in the center of the room, the ducting and refrigerant pipes would cover the exposed structural elements, which are a distinctive feature of the heritage building formerly known as J.W.F. Sluyter Soerabaja Bookstore.

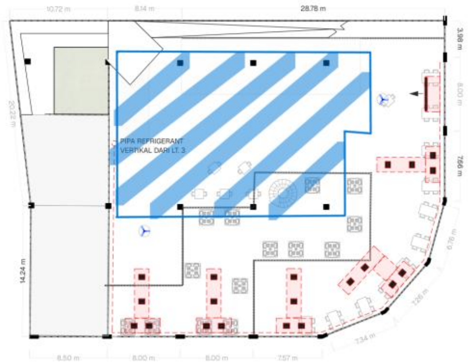


Fig. 11. Marked area (blue) without AC unit.

Table 6. Observations regarding energy efficiency aspects.

Energy Efficiency	Observation
Cooling distribution efficiency	The ceiling fan mode downward Level 2 and above helps distribute air from the AC point to the surrounding area.
Heat-loss efficiency	Heat release in the bar area is improved because it is close to the fan position. Therefore, the placement position is appropriate as it is near the dense area and generates heat.

The placement of fans can influence air velocity; therefore, the function of the space surrounding the fans needs to be carefully considered. Considering the span of the restaurant and decision to place AC diffuser only at the half surrounding of the restaurant, it's to be expected that the centre (near bar area) would've been less cool than its surroundings. However, the addition of fan F1 near the AC diffuser extends the distribution of AC ventilation to cover the bar area. Following the airflow prediction of previous literature study, air velocity within the stable range (0.1–0.8 m/s) is found in the dining area, while higher air velocity, as illustrated in Figure 9, occurs in the circulation area in front of the bar. The direction of airflow distribution and the resulting air velocity align well with the spatial zoning type, as the dining area experiences a more comfortable air speed. The application of a hybrid ventilation system allows adequate airflow distribution to areas with less ventilation, making it more balanced without the need to add additional AC units, thereby saving and optimizing energy use.

DESIGN PROPOSAL

Building utilities are supporting components designed to achieve comfort, health, safety, ease of communication, and mobility within buildings (F., 2010). Utility systems in buildings generally include plumbing and sanitation, fire prevention, ventilation/air circulation, lighting/illumination, telephone, and others. All utility systems must meet adequate safety and comfort standards, provide affordable and continuous service, and allow for easy repair and maintenance. Locating utility networks within the building core can facilitate service accessibility, particularly for systems requiring piping and ducting networks such as ventilation (Yuliarso, 2021).

The application of a hybrid ventilation system, based on the study, can help improve indoor air distribution and reduce the number of AC units required. This system is beneficial in minimizing the length of AC ducting and reducing branching, thereby improving the efficiency of the AC system. However, the placement of fans within the room must take into account the function of the space in order to achieve user thermal comfort, as well as the noise generated by the fans. Factors affecting air distribution can also be integrated into ceiling design to enhance the efficiency of airflow. Based on airflow direction from the study results, the most suitable ceiling design is one that allows air circulation to expand more widely, as illustrated in Figure 12. Additionally, incorporating sound absorbers in the ceiling should be considered to minimize noise generated by the fans. The outcome is a ceiling design that supports hybrid ventilation systems by providing space for positioning and directing AC inlets, reducing fan noise, and allowing air circulation to follow an effective path in line with the airflow generated by ceiling fans.

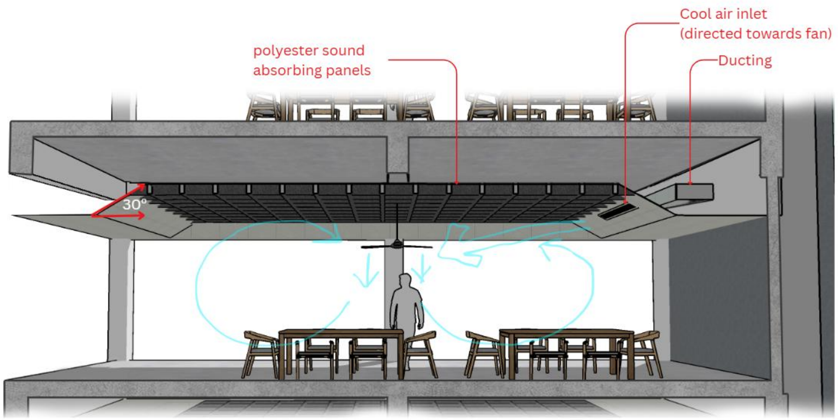


Fig. 12. Ceiling shape to enhance air distribution with hybrid ventilation system.

To improve energy efficiency, fans can be powered by alternative energy sources such as solar panels, as illustrated in Figure 13. Solar panels have the potential to be applied in high-rise buildings, particularly semi-transparent solar panels used as façades (Pramono et al., 2020). Based on the literature, the energy required to operate a ceiling fan is approximately 35 watts per hour. Meanwhile, according to Solar Authority (2024), a 300 WP solar panel can generate 300 watts per hour. Thus, a single 300 WP solar panel (or smaller panels in multiples thereof) can power at least eight ceiling fans.

The hybrid ventilation and ceiling system can be implemented as a strategy to reduce ducting requirements and the number of AC units, both in heritage buildings (as supported by literature findings) and in high-rise buildings. This is particularly relevant because high-rise buildings consume significant amounts of energy for HVAC. According to the study, the application of hybrid cooling systems can also enhance air distribution across a wide area, covering a radius of more than 4 meters around each fan. Therefore, the system can be adapted to both small and large spaces with flexibility in the positioning, number, and size of fans. This is advantageous for high-rise buildings with flexible spaces created through partitions, such as office buildings. Nevertheless, it can also be applied to other building functions, since indoor comfort achieved through air distribution can be easily adjusted using a remote control.

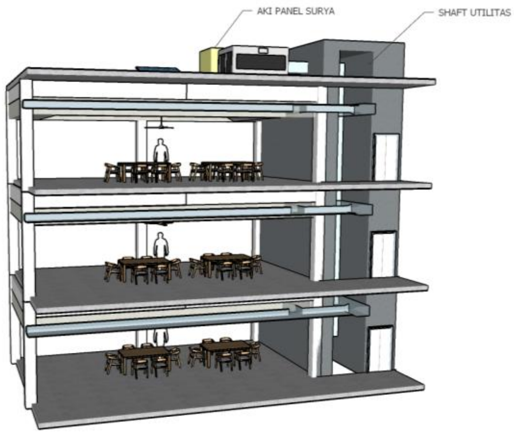


Fig. 13. Diagram of hybrid ventilation and solar panel.

CONCLUSION

Buildings in humid tropical climates such as Indonesia generally consume the largest portion of energy for air-conditioning systems, which also contribute to the intensification of the urban heat island (UHI). One solution to mitigate UHI in dense urban areas is through integrating greenery into buildings. However, this approach is difficult to apply to certain buildings, such as heritage structures, whose physical form must be preserved as part of their cultural value. To reduce energy consumption in such buildings—such as Locaahands Restaurant, which still relies on air conditioning as the primary cooling system—a hybrid ventilation system can serve as an effective energy-saving strategy.

The integration of ceiling fans with the air-conditioning (AC) system enables a more even distribution of cooled air throughout the space, thus optimizing AC energy use without compromising thermal comfort. Factors influencing air distribution include the type and dimensions of the fan, fan airflow rate, fan position and user activity location, floor material, as well as the type and placement of AC inlets. Considering the new function of the heritage building as a restaurant, indoor air distribution becomes more efficient with fan usage, particularly in high-activity zones such as near the bar and kitchen, even in areas without direct AC inlets.

From a thermal comfort perspective, a hybrid ventilation system with ceiling fans operating at Level 2 in downward mode is the most efficient for dining areas, as it achieves air velocity between 0.1–0.8 m/s at a fan height of 2.9 m above the floor and AC inlets positioned at 4.5 m. Since the AC units are mounted at ceiling level with edge-wall inlets, the cool air discharge can be directed toward the fans. The downward mode of ceiling fans circulates indoor air in a rotational flow, allowing cool air intercepted by the fans to spread more evenly throughout the space, following the airflow pattern. A higher fan airflow rate increases indoor air velocity, which helps equalize room temperature and minimize temperature variation. However, excessive airflow may increase air velocity near the fan, particularly closer to its base. Therefore, fan speed should be adjusted according to the functional zoning of the interior. Another influencing factor is fan height, as it determines air velocity distribution: the closer to the tables, the higher the air velocity, with air movement decreasing before intensifying again when reflected by solid (non-porous) floor surfaces compared to permeable ones.

The effectiveness of this system in heritage buildings—where structural modifications are limited—offers an energy-efficient cooling alternative without compromising historical value. Principles of ventilation aimed at enhancing the efficiency of AC systems include increasing air velocity and improving air distribution, both of which reduce the number of AC units required and lessen system workload, thereby lowering overall energy consumption. In the context of heritage buildings, ceiling fans also minimize the spatial requirements for HVAC utility systems in the ceiling, allowing the original structure to remain exposed for aesthetic purposes while showcasing its historical character. As a result, AC units can be positioned along the periphery rather than at the center of the heritage space. This reduces the number of AC units required, lowering electricity demand for HVAC systems and thereby reducing CO_2 emissions that contribute to UHI.

This study focuses on the influence of fan airflow rate, fan positioning, and AC inlet placement on the functional performance of a heritage building adapted as a restaurant. External factors affecting ventilation, based on observation, include heat transfer values of wall materials. Due to data limitations, the study evaluates only observational findings supported by literature review. Beyond thermal comfort and energy efficiency, there is potential for future research on indoor air quality and external factors influencing the implementation of hybrid ventilation in heritage buildings to achieve higher energy efficiency, which is not covered within the scope of this study.

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