An Experimental Field Study on the Energy Performance of Ventilation Chimneys in Small Buildings with Polycarbonate Roofing under Tropical Climate Conditions

Panuwat Suttimas[1], *Preeda Chantawong*[2], *Tika Bunnag*[3] and *Tantikorn Krajangsod*[4]
Energy Engineering Technology Department of Power Engineering Technology[1]
Industrial Technology College King Mongkut's University of Technology North Bangkok[2]
Industrial Technology College King Mongkut's University of Technology North Bangkok[3]
Engineering and Development Department Tobacco Authority of Thailand[4]
1518 Pracharat 1 Road, Wongsawang, Bangsue, Bangkok 10800, Thailand
Email : panuwatsut@gmail.com

Abstract

This study experimentally investigates the ventilation performance of a solar-driven thermal chimney in small-scale model houses with translucent polycarbonate roofing under tropical climatic conditions. Two identical model houses (volume: 4.275 m³) were constructed and compared, differing only in the number of ceiling ventilation openings (10 × 10 cm; one and two openings). The results show that sub-roof temperature increased rapidly under solar radiation, reaching peak values of 72–77 °C during midday. A temperature difference of approximately $\Delta T \approx 5$ °C was observed between the two configurations, demonstrating the influence of ventilation design on thermal behavior. The configuration with two ventilation openings reduced indoor heat accumulation more effectively. Buoyancy-driven airflow developed within the turbulent natural convection regime, enhancing heat transfer and supporting the solar chimney effect. The average heat flux was reduced from approximately 200 W/m² (House 1) to 180 W/m² (House 2), corresponding to an average efficiency of about 10%. These results indicate that increasing ventilation openings improves airflow stability and heat removal performance. In addition, the findings reveal that ventilation configuration plays a more significant role than roofing thickness in determining thermal performance. The high sub-roof temperature (>70 °C) also highlights the potential for future applications in thermal energy utilization.

Keywords: Polycarbonate, Ventilation Performance, Solar Chimney

Introduction

Natural ventilation is one of the key strategies for reducing energy consumption in buildings and improving occupants' thermal comfort, particularly in tropical climates where high temperatures and intense solar radiation persist throughout the year (Awbi, 2003). A fundamental mechanism of natural ventilation is the stack effect, which arises from differences in air density caused by temperature variations between indoor and outdoor environments, resulting in vertical airflow through buildings (Etheridge & Sandberg, 1996). Translucent roofing materials, such as clear polycarbonate sheets, are widely used in small buildings and semi-open structures due to their lightweight properties, high impact resistance, and high light transmittance. However, the transmission of solar radiation through such materials can significantly increase heat accumulation within the building, leading to high solar heat gain. This, in turn, elevates indoor air temperature and enhances buoyancy-driven airflow (Duffie & Beckman, 2013). As the air temperature beneath the roof increases, warm air rises and exits through ventilation openings, inducing cooler air to enter from below.

This mechanism is analogous to a solar chimney system, which utilizes solar energy as the driving force for natural ventilation (Kalogirou, 2006). Although numerous studies have investigated natural ventilation and solar chimney systems, most have focused on large-scale buildings or idealized configurations. In addition, many previous studies have been conducted under controlled laboratory conditions or through numerical simulations, which do not fully capture the dynamic and highly variable environmental conditions found in tropical climates. As a result, the applicability of these findings to real-world tropical environments remains uncertain. More importantly, a clear research gap exists due to the limited number of experimental studies conducted under real tropical conditions, particularly for small-scale buildings with polycarbonate roofing and transient thermal behavior. Experimental investigations of natural or hybrid ventilation systems in real tropical outdoor environments are still limited, especially for small-scale buildings (volume < 5 m^3), which exhibit rapid thermal response and transient characteristics. Furthermore, there is a lack of studies specifically addressing polycarbonate roofing systems, which have high solar transmittance and result in significantly greater heat accumulation compared to conventional roofing materials. In addition, the combined effects of heat flux, airflow balance, and transient ventilation performance over extended daytime periods have not been comprehensively investigated in previous experimental studies. Moreover, prior research has typically focused on either experimental investigations or numerical modeling independently, with limited integration of thermodynamic analysis, empirical modeling, and parametric evaluation. Such integration is essential for developing a more comprehensive understanding of ventilation performance under real operating conditions.

Therefore, this study aims to investigate the ventilation performance of a solar-driven thermal chimney in small-scale buildings equipped with transparent polycarbonate roofing under tropical climate conditions. In addition, an empirical model is developed to estimate airflow rates, and key parameters influencing ventilation performance—including heat flux and airflow balance—are systematically analyzed. The study also examines transient behavior over a 12-hour period, capturing the dynamic response of the system under real environmental conditions.

Literature Review

This study is grounded in fundamental engineering principles, including heat transfer, fluid dynamics, natural ventilation, and solar energy transfer in small-scale buildings with smooth, transparent polycarbonate roofing. These processes can be described using established theoretical frameworks in thermal engineering. Heat transfer within the roofing system and indoor air occurs via three primary modes: conduction, convection, and thermal radiation, which form the basis for energy balance analysis (Incropera et al., 2017). Conduction is the process of heat transfer through a material due to a temperature gradient and can be described by Fourier's law: $Q_{cond} = kA\frac{\Delta T}{L}$. Convection is the process of heat transfer between a solid surface and the surrounding fluid: $Q_{conv} = hA(T_s - T_{air})$. Thermal radiation is the transfer of energy through electromagnetic waves and can be described by the Stefan–Boltzmann law: $Q_{\mathrm{rad}} = \epsilon\sigma A(T_{\mathrm{s}}^4 - T_{\mathrm{sky}}^4)$. Solar energy is the primary driving source responsible for temperature rise in translucent roofing systems. The transmitted solar heat gain through the material can be expressed as (Duffie & Beckman, 2013): $Q_{solar} = \tau IA$. Natural ventilation driven by buoyancy forces is one of the most widely applied passive cooling strategies in buildings, particularly in warm climates (Awbi, 2003). The stack effect is generated by density differences between warm and cool air, which induce vertical airflow through openings (Etheridge & Sandberg, 1996). The airflow rate depends on temperature difference, opening size, and flow resistance. Previous studies have shown that ventilation performance is highly sensitive to opening configuration. Bansal et al. (1993) experimentally demonstrated that increasing opening areas enhances airflow rate and heat removal efficiency. Similarly, Gan (2018) reported that airflow in naturally ventilated spaces is strongly influenced by inlet–outlet balance and internal flow resistance. Translucent roofing materials such as polycarbonate have been widely studied due to their high solar transmittance and impact resistance. However, several studies have highlighted that such materials significantly increase solar heat gain within buildings. For instance, Santamouris et al. (2016) reported that lightweight and translucent building envelopes tend to exhibit rapid thermal response and high indoor temperature fluctuations under strong solar radiation. Similarly, Wong et al. (2007) found that solar radiation transmitted through transparent roofing can significantly increase sub-roof air temperature, often exceeding indoor temperature by more than 30–40 °C. Recent experimental studies in warm and tropical climates have confirmed these findings. Khedari et al. (2000) and Hirunlabh et al. (2001) showed that roof structures exposed to high solar radiation can generate substantial temperature gradients, which enhance natural ventilation but may also lead to excessive indoor heat gain if not properly ventilated.

Experimental investigations under tropical climates are essential due to highly variable solar radiation and ambient conditions. However, such studies remain relatively limited, particularly for small-scale structures. Khedari et al. (2000) experimentally studied ventilation and thermal performance in hot climates and reported that indoor temperature reduction strongly depends on ventilation effectiveness. Similarly, Ong (2003) investigated the thermal performance of roof-integrated ventilation systems and found that temperature differences between roof and indoor air can exceed 40 °C under peak solar conditions. More recent studies have emphasized the importance of transient analysis. For example, Santamouris et al. (2016) highlighted that buildings in hot climates exhibit strong time-dependent thermal behavior due to fluctuating solar radiation. These findings indicate that steady-state assumptions may not adequately represent real building performance.

Based on the aforementioned theoretical and experimental studies, it is evident that solar radiation significantly influences thermal behavior and ventilation performance in buildings with translucent roofing. In small-scale buildings, these effects become more pronounced due to low thermal mass and rapid temperature response. In this study, the experimental setup (Fig. 1) represents a small-scale building equipped with transparent polycarbonate roofing and reflective insulation. Under tropical conditions in Thailand, the sub-roof region experiences significantly higher temperatures, with differences exceeding 48–50 °C during daytime. This large temperature gradient enhances buoyancy-driven airflow and plays a critical role in natural ventilation performance. The study focuses on experimentally capturing the interaction between solar radiation, temperature distribution, airflow, and heat flux under real outdoor conditions, providing a more comprehensive understanding of thermal behavior in small-scale buildings compared to previous studies.

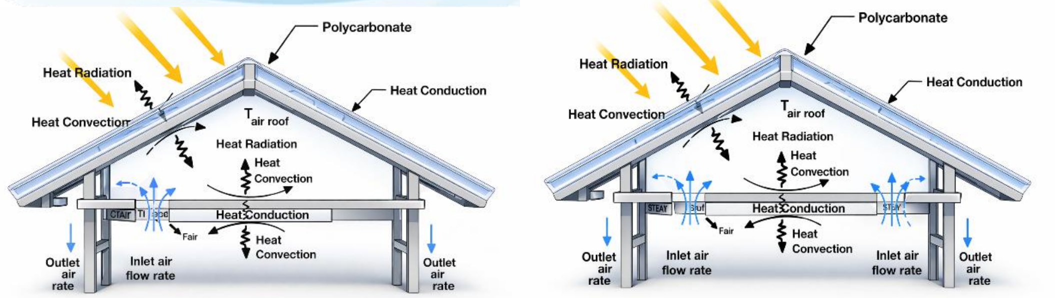

Figure 1 Schematic of natural heat transfers through the roof into the experimental house, illustrating configurations with one and two ventilation grille openings. (Incropera et al., 2017, Preeda Chantawong , 2009)

Research Methodology

Two identical experimental houses were constructed and tested in a residential area in Phattharin Village, Khu Bang Luang, Lat Lum Kaeo, Pathum Thani, Thailand (as shown in Figure 2).

Figure 2 Photograph of the experimental house (House 1) used for data collection in the evaluation of the system's thermal performance.

The study investigates the performance of solar chimney ventilation and compares its effectiveness in reducing heat gain in small-scale model houses with an internal volume of 4.275 m³ under natural climatic conditions. Each model house had dimensions of 1.5 × 1.5 × 1.9 m, corresponding to the same internal volume. Two configurations were examined. The first configuration was equipped with a single ventilation grille opening (10 × 10 cm, 0.01 m²), while the second configuration had two identical openings. Thermal insulation consisting of 10 mm thick cross-linked closed-cell polyethylene was installed above the ceiling, which was constructed from SCG Smartboard panels (flat edge, cement finish; 120 × 240 × 0.6 cm). The roof structure was designed as a gable roof, with the sub-roof space divided into two layers.

The outer layer consisted of a 2 mm thick translucent polycarbonate sheet, while the inner layer was formed by the Smartboard ceiling. The detailed specifications of the experimental setup are summarized in the table below.

Table 1 Table presents the key parameters and experimental configurations of the two test houses.

Category	**Parameter**	**House 1**	**House 2**	**Unit**
Building Geometry	Length × Width × Height	1.5 × 1.5 × 1.9	1.5 × 1.5 × 1.9	m
	Building volume	4.275	4.275	m^3
	Roof type	Gable roof (double layer)	Gable roof (double layer)	-
	Roof area (solar exposure)	4.275	4.275	m^3
	Roof angle	38.66°	38.66°	degrees
Roof Material	Outer layer	Polycarbonate (clear)	Polycarbonate (clear)	-
	Thickness (outer)	2	2	mm
	Inner layer	Smart board	Smart board	-
	Thickness (inner)	6	6	mm
Insulation	Type	Cross-linked PE	Cross-linked PE	-
	Thickness	10	10	mm
Ventilation System	Vent opening size	10	10	cm
	Vent area per opening	0.01	0.01	m^2
	Number of vents	1	2	-
	Total vent area	0.01	0.02	m^2
	Solar radiation	Pyranometer ML-020V	Pyranometer ML-020V	W/m^2
	Temperature	Thermocouple type K	Thermocouple type K	°C
	Air velocity	Testo 425	Testo 425	m/s
	Heat flux	EKO MF-180	EKO MF-180	W/m^2
Data Acquisition	Data logger	HIOKI 8400-20	Same	-
	Sampling interval	10	10	min
	Measurement period	07:10–20:10	Same	hr.
Environmental Conditions	Climate	Tropical (Thailand)	Same	-
	Max solar radiation	~1000	~1000	W/m^2

The effect of rooftop slope and material properties has been explicitly defined and incorporated into the analysis. The gable roof used in this study has a slope angle of approximately 38.66°, which directly influences both solar radiation exposure and buoyancy-driven airflow within the roof cavity. This inclination enhances the vertical component of airflow, thereby strengthening the stack effect and promoting more efficient heat removal from the sub-roof region.

In addition, the polycarbonate roofing material plays a critical role due to its high solar transmittance, low thermal mass, and small thickness (2 mm). These properties allow rapid heat accumulation beneath the roof, leading to elevated sub-roof temperatures (>70 °C) and increased temperature gradients ($\Delta T > 40$ °C). The combined effect of roof slope and material properties results in intensified natural convection, which significantly improves ventilation performance. The first configuration was equipped with a single ventilation grille opening of 10 × 10 cm (0.01 m^2), while the second configuration had two identical openings. Thermal insulation in the form of 10 mm. thick cross-linked closed-cell polyethylene was installed above the ceiling, which consisted of SCG Smartboard panels (flat edge, cement finish) with dimensions of 120 × 240 × 0.6 cm. The roof structure was designed as a gable roof, with the sub-roof space divided into two layers. The outer roof layer consisted of a 2 mm. Thick transparent polycarbonate sheet, allowing increased natural light transmission. The inner roof layer was constructed from a flat Smartboard panel with a thickness of approximately 6 mm. The structural frame of the house was made of black steel square tubes (2 × 2 inches, 3 mm. thickness), with joints connected by welding. The walls were constructed from SCG Smartboard panels (flat edge, cement finish) with dimensions of 120 × 240 × 0.6 cm. The floor was made of Viva Board panels (cement finish) with dimensions of 120 × 240 × 1.0 cm. The roof structure was designed as a gable configuration, with the sub-roof space divided into two layers. The outer layer consists of a 2 mm thick transparent polycarbonate sheet to enhance natural daylight transmission, while the inner layer is constructed from a flat Smartboard panel with a thickness of approximately 6 mm. This study experimentally evaluates and compares the ventilation performance of a solar chimney system in reducing heat gain within small-scale model houses. The analysis focuses on variations in ambient temperature and solar radiation intensity, measured using a pyranometer (Model ML-020V, sensitivity: 7.2 $\mu V/W/m^2$; measurement range: 0–2000 W/m^2). In addition, temperatures were monitored inside the model houses, at the ceiling level, and at the roof surfaces of both configurations. House 1 was equipped with a smooth, transparent solid polycarbonate roof integrated with a single ventilation grille opening (10 × 10 cm, 0.01 m^2). In contrast, House 2 featured the same roofing configuration but with two identical ventilation grille openings. The temperature variations within the roof cavity and across both configurations were analyzed to assess the impact of ventilation opening quantity on thermal performance. Temperature measurements were conducted using Type K thermocouples (range: 0–1250 °C, accuracy: ±0.5 °C). Air velocity inside and outside the model houses was measured using a Testo 425 (range: 0–20 m/s, accuracy: ±5%). Heat flux through the roof was measured using a heat flow meter (EKO Instruments, Model MF-180, temperature range: −30 °C to 120 °C, accuracy: ±2%) for both model houses. All data were recorded using a data logger (HIOKI, Model 8400-20, accuracy: ±0.8%). Measurements were taken at 10-minute intervals from 07:10 to 20:10, for a total duration of 13 hours. The methodology for validating the measurement data has been clearly established to ensure accuracy and reliability. All sensors, including thermocouples, anemometers, and pyranometers, were calibrated prior to the experiments according to manufacturer specifications. Measurement uncertainty was assessed based on instrument accuracy, resulting in an overall uncertainty range of approximately ±2–5%.

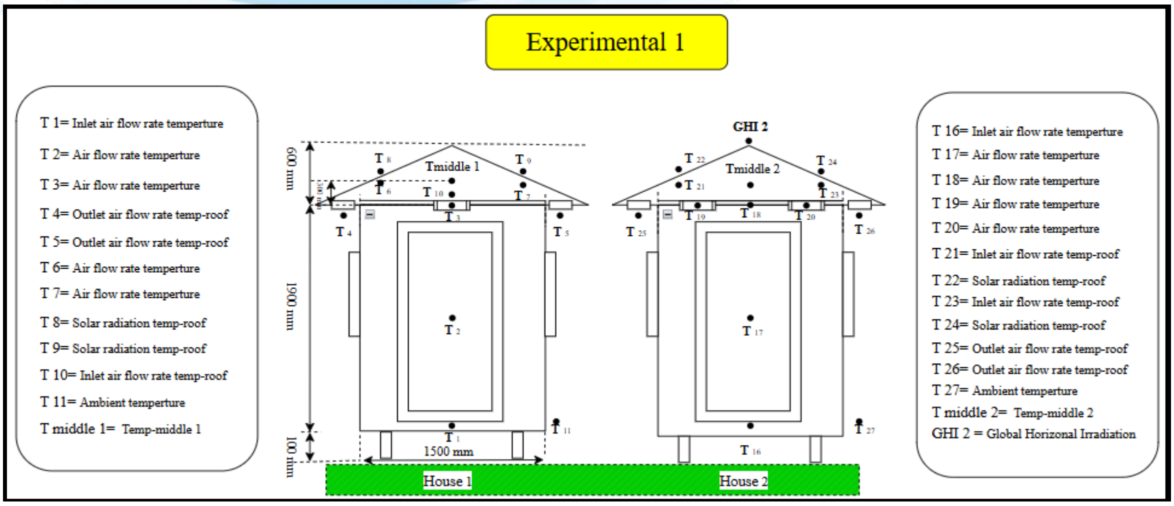

Figure 3 Schematic showing the locations of measurement instruments installed for evaluating the thermal performance of the system.

Result

The comparative results of indoor temperatures indicate that House 1, with only a single ventilation opening, provides insufficient ventilation for effective heat dissipation in a polycarbonate roofing system. As illustrated in Figs. 4 and 5, the sub-roof temperature in House 2 reached approximately 75–78 °C, while the indoor temperature remained significantly lower at approximately 30–32 °C. This increased temperature gradient enhances buoyancy-driven airflow, thereby improving ventilation performance. The results demonstrate that the ventilation configuration in House 2 is more effective in reducing heat gain and enhancing the overall thermal performance of the building.

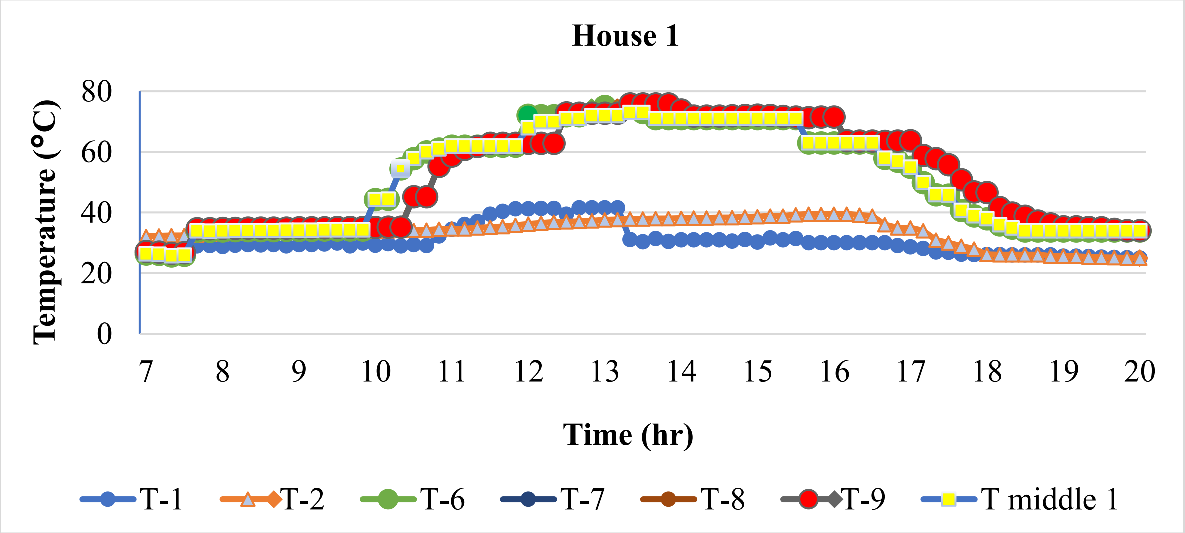

Figure 4 Temperature profile showing natural heat transfer between the sub-roof space and the indoor environment of the experimental house with one ventilation grille opening.

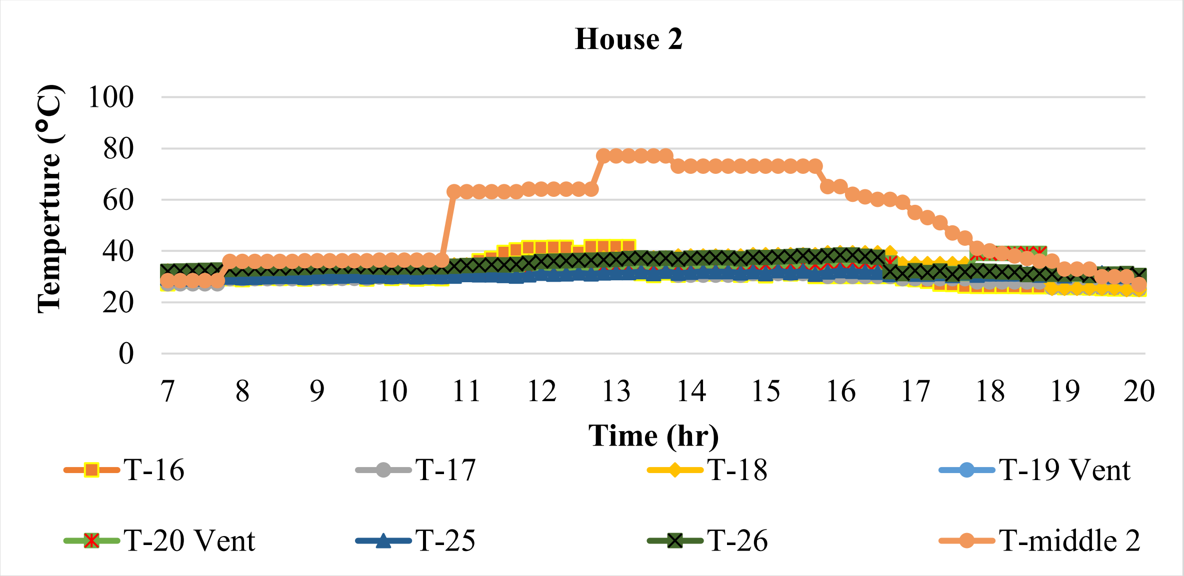

Figure 5 Temperature profile showing natural heat transfer between the sub-roof space and the indoor environment of the experimental house with two ventilation grille openings.

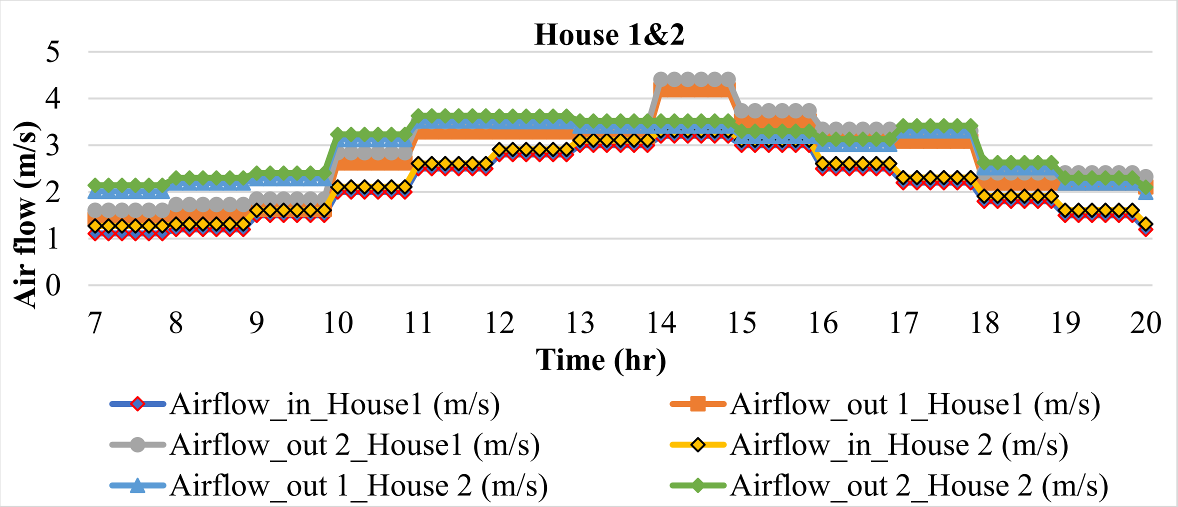

Figure 6 Comparison of air velocity variations between the experimental houses (House 1 and House 2).

As shown in Figure 6, the measured airflow indicates that the outlet air velocity is consistently higher than the inlet air velocity, particularly during the peak temperature period (13:00–15:00), when velocities reached up to 4.5 m/s. This behavior confirms the presence of strong buoyancy-driven flow. However, the imbalance between inlet and outlet airflow suggests a system limitation due to insufficient inlet area, which reduces overall ventilation efficiency.

The mismatch between inlet and outlet openings is a critical factor limiting natural ventilation performance. In contrast, the airflow measurements for House 2 show a more balanced flow pattern compared to House 1, with inlet and outlet air velocities being nearly equal. Although the maximum airflow rate is slightly lower, the system demonstrates greater stability and higher overall performance due to reduced flow resistance and improved ventilation design. This indicates that balanced airflow is more critical than achieving high peak velocities for effective natural ventilation. A ventilation system with a balanced configuration between inlet and outlet airflow provides better cooling performance than a system with high air velocity but poor flow balance.

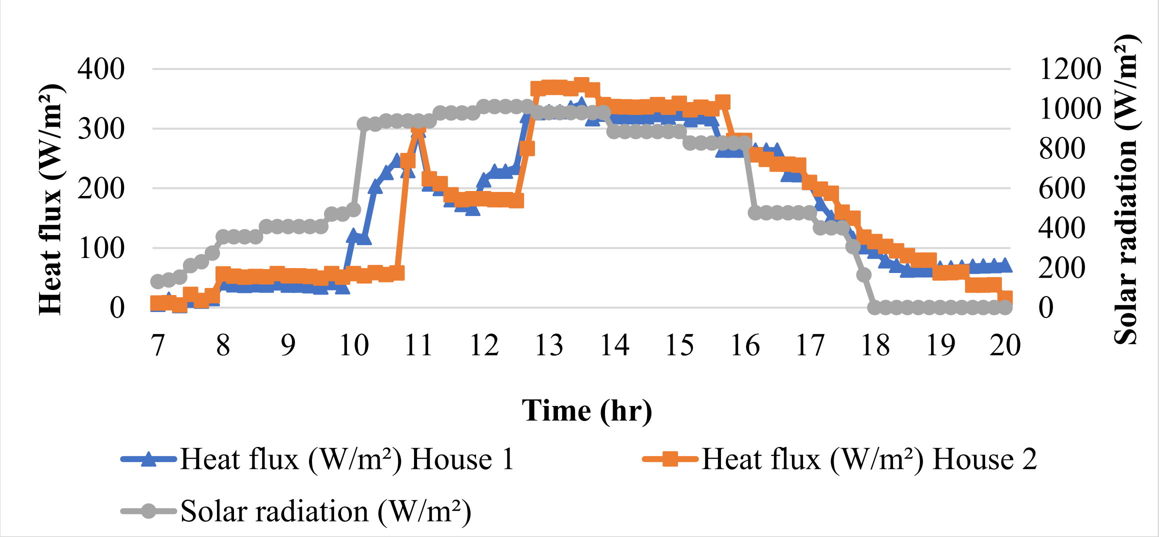

Figure 7 Variation of ambient temperature, comparison of heat flux through the roof between the two model houses, and solar radiation intensity.

As shown in Figure 7, both solar radiation and heat flux for the two houses increase clearly with increasing solar radiation, with peak values occurring between 11:30 and 13:30. This indicates that solar radiation is the primary driving force of heat transfer. During the morning period (07:00–10:00), heat accumulation remains low, and heat transfer is in its initial stage. The maximum heat flux reached approximately 330 W/m² for House 1 and 370 W/m² for House 2. The higher heat flux observed in House 2 is attributed to its more effective heat removal through improved ventilation performance. As shown in the table below.

Table 2 Table presents summary of key experimental results.

Category	**Parameter**	**House 1**	**House 2**	**Key Finding**
Temperature (Fig. 4–5)	Sub-roof temperature	70–75 °C	75–78 °C	Higher ΔT observed in House 2
	Indoor temperature	35–40 °C	30–32 °C	Lower indoor temperature in House 2
	Temperature difference (ΔT)	~30–35 °C	> 40 °C	Greater buoyancy driving force
	Temperature reduction	-	8–12 °C	Improved cooling performance
Airflow (Fig. 6)	Inlet air velocity	Low	Balanced	Insufficient inlet airflow in House 1
	Outlet air velocity	High (up to 4.5 m/s)	Comparable to inlet	Flow imbalance in House 1

	Flow pattern	Unbalanced	Balanced	More stable airflow in House 2
	Ventilation performance	Moderate	High	Flow balance is more critical than velocity
Heat Flux (Fig. 7)	Peak heat flux	~330 W/m²	~370 W/m²	Higher heat removal in House 2
	Morning heat flux	<100 W/m²	<100 W/m²	Low heat accumulation
	Peak time	11:30–13:30	11:30–13:30	Strong correlation with solar radiation
	Heat transfer behavior	Heat accumulation	Efficient heat removal	Enhanced convective heat transfer
Overall Performance	Cooling performance	Moderate	High	House 2 performs better
	Airflow balance	Poor	Good	Key factors affecting performance
	Heat removal efficiency	Low	High	Improved ventilation effectiveness
	Thermal stability	Fluctuating	Stable	More consistent performance

Discussion and conclusions

The experimental results indicate that polycarbonate roofing plays a significant role in heat accumulation and airflow behavior within the test structure. The rapid increase in sub-roof temperature under direct solar radiation induces natural convection and enhances stack-driven ventilation within the system. The measured sub-roof temperature (T middle) increased from approximately 26–28 °C in the morning to peak values of about 72 °C (House 1) and 77 °C (House 2) during 12:00–14:00, corresponding to the period of maximum solar radiation in Pathum Thani. The observed maximum temperature difference between the two configurations was approximately $\Delta T \approx 5$ °C, reflecting differences in ventilation performance between the roof systems. These results are consistent with previous experimental studies on translucent and lightweight roofing systems. For example, Wong et al. (2007) and Santamouris et al. (2016) reported that solar radiation transmitted through lightweight or transparent roofs can significantly increase sub-roof temperatures, often exceeding indoor temperature by more than 30–40 °C. Similarly, Khedari et al. (2000) observed that roof spaces in tropical climates can reach high temperatures under strong solar radiation, leading to enhanced buoyancy-driven airflow. In this study, House 2 exhibited slightly higher sub-roof temperature, which indicates greater heat accumulation within the roof cavity. This behavior is attributed to limitations in ventilation opening configuration, which reduce the effectiveness of natural convective heat transfer. A similar observation was reported by Gan (2018), who demonstrated that ventilation performance is strongly influenced by opening size and airflow resistance, and that insufficient or improperly balanced openings can limit heat removal despite strong buoyancy forces. In addition, the increase in sub-roof temperature showed a direct correlation with solar radiation, which generated buoyancy forces within the roof cavity. The resulting airflow behavior can be explained by the solar chimney effect, a well-established mechanism for heat removal in buildings (Kalogirou, 2006). This finding is consistent with Ong (2003), who reported that solar-induced temperature differences are the primary driving force for airflow in roof-based ventilation systems. From the heat transfer analysis, the heat reduction efficiency can be defined as: $\eta = \frac{q_{H1}-q_{H2}}{q_{H1}} \times 100$. The average heat flux values were approximately 200 W/m² (House 1) and 180 W/m² (House 2), yielding an average efficiency (η avg) of about 10%. This result is comparable to previous experimental studies. For instance, Li et al. (2021) reported that ventilation-enhanced systems can reduce heat transfer by approximately 5–10%, depending on airflow conditions and system configuration. The present study confirms that similar levels of performance can be achieved under real tropical outdoor conditions. Furthermore, the thermal behavior observed in this study corresponds to the turbulent natural convection regime, indicating strong convective activity within the sub-roof cavity and effective heat transfer from the building structure. This agrees with classical heat transfer theory (Incropera et al., 2017), which states that high temperature gradients promote turbulent convection and increase heat transfer rates. In the late afternoon (after 17:00), the sub-roof temperature decreased rapidly due to the reduction in solar radiation intensity and ambient temperature. Consequently, the temperature difference between indoor and outdoor environments diminished, leading to a reduction in buoyancy forces and airflow. This transient behavior is consistent with findings by Santamouris et al. (2016), who emphasized that thermal performance in buildings under hot climates is strongly time-dependent and influenced by solar radiation variability. In conclusion, the findings of this study are in good agreement with previous research while providing additional experimental validation under real tropical conditions. A polycarbonate roofing system with appropriately designed ventilation openings can function as an effective passive cooling strategy, with strong potential to reduce indoor temperature and enhance natural ventilation performance.

Suggestion

Based on the experimental results and heat transfer analysis beneath the polycarbonate roof, several recommendations for design improvement and future research can be proposed. First, increasing the ventilation opening area beneath the roof is recommended. The results clearly demonstrate that ventilation plays a critical role in reducing heat accumulation in the sub-roof space. Therefore, enlarging ventilation openings at the ceiling level or along the roof ridge can significantly enhance natural ventilation performance.

Second, the implementation of a solar chimney ventilation system is suggested. Such a system can enhance buoyancy forces and improve airflow rates within the building, leading to more effective heat removal. Finally, the selection of roofing materials with high solar reflectivity should be considered. Although polycarbonate roofing allows excellent natural daylight penetration, it also leads to significant heat accumulation. Therefore, the use of reflective materials or coatings to reduce solar heat gain is recommended.

Acknowledgements

The author would like to express sincere appreciation to the advisor and all faculty members for their invaluable guidance, insightful comments, and continuous academic support throughout the duration of this research.

References

ASHRAE. (2021). ASHRAE handbook—Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Awbi, H. B. (2003). Ventilation of buildings. Routledge.https://doi.org/10.4324/9780203472673

Bejan, A. (2013). Convection heat transfer (4th ed.). Wiley.

Bansal, N. K., Mathur, R., & Bhandari, M. S. (1993). Solar chimney for enhanced stack ventilation. *Building and Environment, 28*(3), 373–377.

Chanwong, P., Isarangkun Na Ayudhaya, B., & Uengkul, Y. (2012). Natural ventilation of houses by a roof autoclaved aerated concrete solar chimney under hot humid climate of Bangkok. KKU Science Journal, 40(1), 83–94.

Duffie, J. A., & Beckman, W. A. (2013). Solar engineering of thermal processes (4th ed.). Wiley.

Etheridge, D., & Sandberg, M. (1996). Building ventilation: Theory and measurement. John Wiley & Sons.

Gan, G. (2018). Evaluation of buoyancy-driven natural ventilation in buildings. *Energy and Buildings, 169*, 1–13.

Gan, G. (2010). Natural ventilation in buildings. Energy and Buildings, 42(2), 221–227.https://doi.org/10.1016/j.enbuild.2009.09.002

Hirunlabh, J., Wachirapuwadon, S., Pratinthong, N., & Khedari, J. (2001). New configurations of solar chimney roof in building ventilation. *Solar Energy, 70*(4), 349–358.

Incropera, F. P., DeWitt, D. P., Bergman, T. L., & Lavine, A. S. (2017). Fundamentals of heat and mass transfer (7th ed.). Wiley.

Kalogirou, S. A. (2006). Solar thermal collectors and applications. Progress in Energy and Combustion Science, 30(3), 231–295.https://doi.org/10.1016/j.pecs.2005.08.001

Khedari, J., Hirunlabh, J., & Bunnag, T. (2000). Experimental study of ventilation and thermal performance in tropical housing. *Energy and Buildings, 32*(1), 67–75.

Ong, K. S. (2003). A mathematical model of a solar chimney. *Renewable Energy, 28*(7), 1047–1060.

Santamouris, M., Kolokotsa, D., & Synnefa, A. (2016). Passive cooling technologies for buildings. *Energy and Buildings, 128*, 102–113.

Wong, N. H., Tan, A. Y. K., Tan, P. Y., & Wong, N. C. (2007). Thermal evaluation of vertical greenery systems. *Building and Environment, 42*(2), 836–848.