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Experimental Investigation of Attic Heat Gain Reduction and Indoor Illuminance Using a Light-Vent Pipe

Sopida Sungsoontorn[1], Dittha Nonthiworawong[2], Phadungsak Rattanadecho[3], Ratthasak Prommas[1*]

[1] Department of Mechanical Engineering, Faculty of Engineering, Rajamangala University of Technology Rattanakosin, Phutthamonthon, Nakhon Pathom 73170, Thailand
[2] Arch G Tech Co., Ltd. 770/25 Soi Patthanakarn 38, Patthanakarn Rd., Suanluang, Bangkok, Thailand
[3] Center of Excellence in Electromagnetic Energy Utilization in Engineering (CEEE), Department of Mechanical Engineering, Faculty of Engineering, Thammasat University (Rangsit Campus), Pathumthani 12120, Thailand

Corresponding Author Email: ratthasak.pro@rmutr.ac.th

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ABSTRACT

This research aims to investigate the potential of the light/ vent pipe, which is designed and integrated into the shed roof of the test house. The roof angle is 30 degrees. Two configurations of Light Vent Pipe (LVP) and Vent Pipe (VP) were manufactured by the aluminum sheet with silver surface treatment. Each pipe has 1.20 m of length and 15 cm in diameter. The LVP has a translucent flat cover with 15 cm of diameter. The results show that the LVP induced the natural airflow rate at about 1.8-5.4 m^3/h and corresponded to the number of air change between 1-4 Air Change per Hour (ACH). The heat gain through the ceiling of LVP was reduced by 5 W/m^2 at the percentage of heat gain reduction of 8-32%. The LVP provides indoor illuminance for about 50-150 Lx. The results showed reasonable agreements with experimental values of air velocity and corresponding to volume airflow rate ACH and heat gain reduction in the building.

1. INTRODUCTION

The energy crisis has become a crucial issue. The increase of energy demand in residential building was mainly associated with more ventilating and air-conditioning. During the last few decades, worldwide effort research on building has emphasized on energy efficiency with the improvement of indoor thermal comfort as essential benefits of appropriate design. The natural ventilation has received considerable attention for attic and room spaces, and also other components such as double skin façade and ventilated roof which is an effective attempt of using solar energy. Thailand is located between 5°37" and 20°27' Lat. N and between 97°22" and 105°37' Lat. E where the potential of solar energy level is high. The nationwide average solar radiation is approximately 17 MJ/m^2-day [1] which is suitable to apply in architectural applications. In the innovative building design; the ventilated and daylighting systems are popularly integrated to the building components, viz. ventilated roof (VR), ventilated roof with daylighting (VRD), and ventilated wall (VW) and ventilated wall with daylighting (VWD). Several studies on the performance of the VR, VRD, VW and VWD have been carried out and reported [2-8]. Weawsak et al. [3] reported the design of a bio-climatic roof (BCR) to reduce heat gain and provide indoor daylight. The BCR is composed of a combination of CPAC Monier concrete and transparent tiles on the outer side, while an air gap and the other side is a combination of gypsum with aluminum foil board and translucent panel. The BCR has two functions during daytime; I) decreasing heat gain by the induced natural ventilation and II) providing indirect daylight in the house. During night time, it plays an important role of a roof radiator to dissipate heat to the sky. Khedari et al. [7] investigated the performance of a Partially-Glazed Modified Trombe Wall (PG-MTW). PG-MTW is composed of a masonry wall which includes a transparent material, air gap, and a combination of aluminum foil gypsum board and acrylic panel. The performances of PG-MTW units were compared to a conventional Modified Trombe Wall (MTW). The results showed that the PG-MTW with glass block induced the highest air flow rate and daylight at about 60-80 m^3/h and 350-550 lux, respectively. Later, Ananacha et al. [8] proposed the daylighting and thermal performance of Thai Modern Façade Wall (TMFW). The TMF composes of two layers; I) the outer layer which has different materials (fiberglass cement and aluminum plate), and II) the inner layer which is a clear glass. The TMF-WF has three layers; the two first layers are similar to the TMF, while the third layer is an aluminum fin installed in front of the outer layer. There are opening air vents at the bottom (room side) and the top (ambient side). Experimental results showed that the average indoor illuminance of TMF-WF and TMF were higher than the illuminance standard by about 1,300 lux and 2,000 lux, respectively. In addition to those researchers, the roof tiles named ventilated roof tile (VRT) [9], and tile ventilator (TV) [10] were designed and manufactured at Rattanakosin College for Sustainable Energy and Environment, Rajamangala University of Technology Rattanakosin. The VRT composes of two layers with an air gap for an airflow through the middle section. The results indicated that the VRT provides high ventilation and reduction of ceiling heat gain. A TV has been designed appropriately to ventilate in the attic area. Two model houses were used to investigate the thermal performance of tile ventilator. The results perform that the tile ventilator is effective at reducing attic temperature and improving natural attic ventilation. From the review above, it can be concluded that the use of ventilated roof and ventilated wall to induce natural ventilation is a good potential. However, daylighting can transmit directly from the sun and reflected light from external surfaces; side lighting from the windows and top lighting from the roof, which increases the air-conditioning cooling load and consequently the energy consumptions. Nowadays, there is a technology in transmitting daylight into the building interior using the highly reflective material called the light pipe system. The modeling light pipe performances proposed by Jenkins and Muneer [11, 12] reports describing the method of predicting the luminous flux of light-pipe and also proposing methods calculating for overcast skies, and the illuminance resulting from the luminous flux. In 2000, Chirarattananon et al. [13] proposed the daylighting through a light pipe in the tropics. The result presented the development of a model based on a general configuration of a plenum in a test room and was compared to calculation results with results from physical measurements. Later, Chirarattananon et al. [14] presented the modeling, simulated the transmission of beams of sunlight, and diffused skylight both separately and together through the cylindrical light pipe. The program was used to generate some interesting results that included results from the simulation of the transmission of daylight through straight pipes, and bending pipes. A combination of the light pipe and stack ventilation with solar water heater had been studied in reference [15]. The light pipe in the experiment was a rectangular light pipe with cross section area 0.0625 m^2 and air duct cross-section area 0.023 m^2. This system performed both functions of providing cool natural ventilation air during nighttime, and transmitting daylight to the center of a large space in the building. However, enhancing of stack ventilation using a combination of solar roof collector and vertical stack had been reported by Yusoff et al. [16]. The results were presented and discussed in term of two performances as air temperature and air velocity. The findings indicated that the proposed strategy was able to enhance the stack ventilation in the semi-clear sky and overcast sky conditions. The classical air moving is the natural ventilation due to buoyancy force. The buoyancy force, which is also known as an air density gradient and the body force, is related to density. Buoyancy-driven single-side natural ventilation with large openings of the room [17], buoyant jet in natural ventilation of a model room [18], flowing characteristics of buoyancy-driven natural ventilation of in a full-scale building [19], and buoyancy driven flows by a heat source at different levels [20] were investigated [17], there was a study of the buoyancy-driven single-side natural ventilation with large openings of the room. The experimental data was used to validate the two models. The model showed that most energy was contained in the low-frequency region, and mean flow fields play an important role. Subudhi et al. [18] investigated the computational and numerical of flow characteristics of buoyancy-driven ventilation in a full-scale building. The study determined the basic flow field and temperature distribution in a building for the purpose of ventilation in a quiescent and steady-state environment. However, the buoyancy-driven can apply in several building components viz. roof, attic, and walls and so on. This paper introduces the light/ vent pipe (LVP) for heat gain reduction, natural ventilation enhancement, and the providing of indoor illuminance. The aims of this paper are to compare the LVP with the VP, and also compare with a reference house. Two configurations of LVP and VP are shown in section 2.

2. VENT PIPES SYSTEM INVESTIGATION

The air pipes used in this work have been designed to consist of a vertical section, and the inclined section joined with 30 degrees of the elbow; the vertical and inclined sections have length 40 cm and 80 cm, respectively. Each pipe's diameter is 15 cm. As the natural ventilation is applied to the pipe, the flow rate through the pipe is satisfactory, and the means of improving is beneficial to the system. The air flow pipe is suggested to be modified using low-cost methods to improve convection heat transfer from the interior surface to air flow. The schematic of a vent pipe (VP) and a light/vent pipe (LVP) configurations that had been studied are shown in Figure 1. The VP and LVP were manufactured from the aluminum sheet with silver surface treatment (SILVER-PLUS with 98% super reflective factor according to DIN 5036).

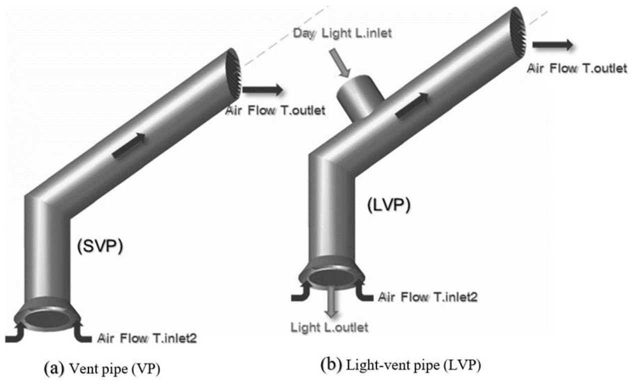


Figure 1. Two pipe configurations studied

The VP is heated by the absorbed thermal exchange between VP surface, and roof surface (attic side). A portion of this heat lost to the surrounding from the roof, and some heat lost to the inside of the pipe. The heat losing to the inside of the pipe heats up the air setting-up buoyancy force that induces air flow from the room space through the VP outgoing to the outdoor, while the LVP has a translucent flat cover on the roof, which transmitted daylight to the interior space.

3. EXPERIMENTAL SET-UP AND DESCRIPTION

The small schematic houses were designed and built for the experiment as shown in Figure 2. They were located at Rajamangala University of Technology Rattanakosin, Salaya, Puthamonthon, Nakhonpathom, Thailand. The coordinates are 13°47'N, 100°17'E.

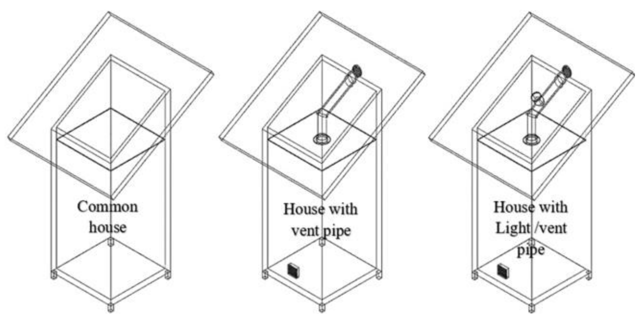


Figure 2. The schematic houses for the experiment

Each house has a square base of size 1.0 m x 1.0 m (1 m^2/

house), the height from floor to ceiling is 2.0 m. The roof is shed roof (3.4 m^2/ house) with 30 degrees of angle. The main structure was built from steel. The roof and wall were built of corrugated metal sheet, and the ceiling was made by gypsum boards. The reference house was thatched the normal corrugated metal sheet, while the test house was thatched the same material and also installed the light/ vent pipe for testing to reduce attic heat gain by natural ventilation and provide indoor illuminance. The ventilation pattern is the cross ventilation: the air first flows through the door into room space, and to inlet of the light/ vent pipe at the ceiling and exit at the overhang of the roof (Figure 3).

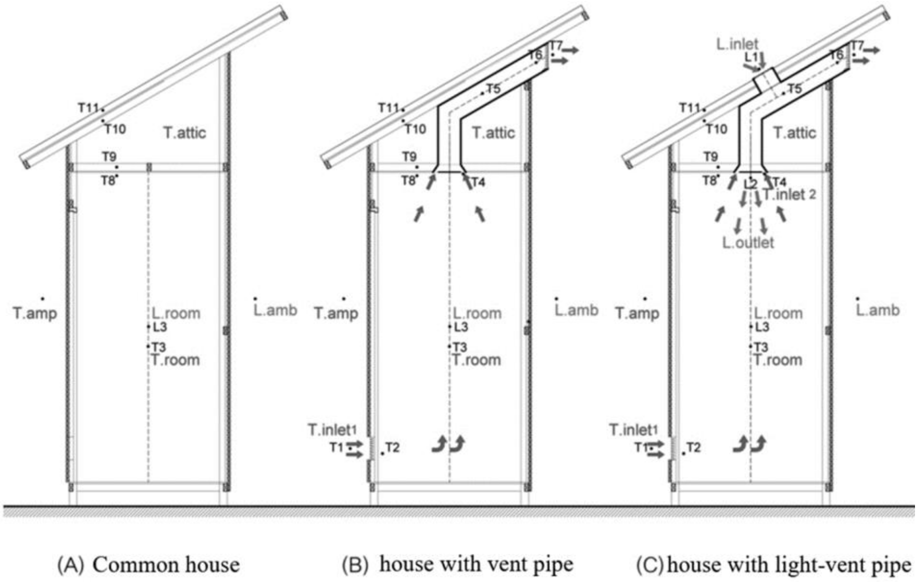


Figure 3. The houses used in the experiment

Thermocouples type K (range: 0-1250 ºC, accuracy ±0.5ºC), heat flux sensor (Omega HFs-3, range: 1-1400 W/m2) and a pyranometer (Kipp&Zonen), Model: CMP11, range: 310-2800 µm, uncertainty<2% were connected to a data logger (Hioki: Model 8422-52, accuracy ±0.8%). The illuminance was measured by using lux meter (Testo: Model 545, accuracy ±5%). The air velocity flow was measured by using hot wire anemometer (KIMO VT-100, range: 0-50 m/s, error ±0.5%). The data interval was recorded every 30 minutes from 6:00 a.m. to 6:00 p.m.

The houses have been installed the thermocouples to measure the temperatures at the roof, attic, ceiling, room as shown in Figure 3. Further thermocouples were used to measure the inlet and outlet air temperatures, and ambient temperature. Heat flux was measured at the ceiling (room side). Air velocity was measured at the center of the pipe. The indoor illuminance and outdoor illuminance were measured on the work plane and horizontal plane, respectively.

4. MATHEMATICAL MODEL OF THE VENT PIPE

The pipe with hot air accumulating in attic area performs as air to air heat exchanger, while the heated air flows up through the pipe by buoyancy force. The house where the pipe is located has one vent on the ceiling and one vent at the overhang of the roof. The mechanism of airflow and heat transfer in the pipe can be described by mathematical models as follows:

4.1 Air flow through the pipe and heat flow rate

Illustration the average air velocity through the VP and LVP depend on the temperature difference between the inlet and outlet airflow temperature, and inlet and outlet pressure losses and wall circular friction factor.

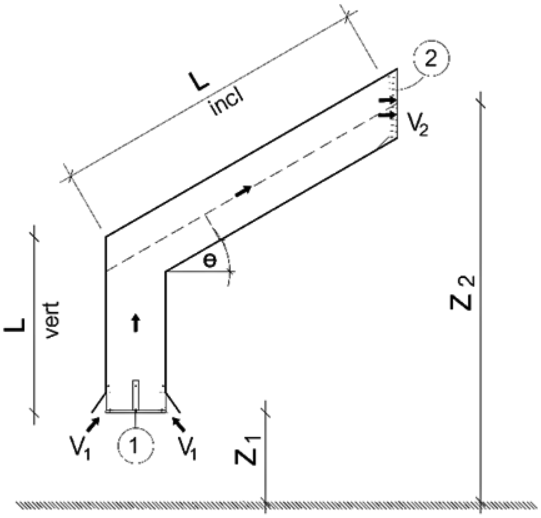


Figure 4. Section the inlet and outlet air flow model

In this study, the expression for the natural flow rate by buoyancy force for study system under steady state is derived by applying Bernoulli's equation from inlet to outlet of the VP and LVP as shown in Figure 4, The inlet and outlet air flow area is not equal the cross section area.

$$P_1 + \frac{\rho_1 v_1^2}{2} + \rho_1 g Z_1 = P_2 + \frac{\rho_2 v_2^2}{2} + \rho_2 g Z_2 + f\left.\frac{L}{D}\frac{\rho v^2}{2}\right|_{vert} + f\left.\frac{L}{D}\frac{\rho v^2}{2}\right|_{incl} + K_1\frac{\rho_1 v_1^2}{2} + K_{30}\frac{\rho v^2}{2} + K_2\frac{\rho_2 v_2^2}{2} \tag{1}$$

$$\dot{m} = \rho_1 A_1 v_1 = \rho_2 A_2 v_2 = \rho A_p v \tag{2}$$

And the simplified relationship between temperature and density are given by:

$$\rho_T = \rho\beta T \tag{3}$$

Rearrange and solve Eqns. (1), (2) and (3) obtain:

$$\beta g(L_{vert} + L_{incl} \cdot \sin\theta)(T_o - T_i) = \beta T_1(K_1 - 1)\frac{v^2}{2}\left(\frac{A_p}{A_1}\right)^2 + \beta T_2(K_2 + 1)\frac{v^2}{2}\left(\frac{A_p}{A_2}\right)^2 + K_{30}\frac{v^2}{2} + \left[f\frac{L}{D}\bigg|_{vert} + f\frac{L}{D}\bigg|_{incl}\right]\frac{v^2}{2} \tag{4}$$

The expression of the induced air velocity is obtained by rearranging Eq. (4) yields:

$$v^2 = \frac{2\beta g(L_{vert} + L_{incl} \cdot \sin\theta)(T_o - T_i)}{\left[\beta T_i(K_i - 1)\left(\frac{A_p}{A_i}\right)^2 + \beta T_o(K_o + 1)\left(\frac{A_p}{A_o}\right)^2 + K_{30} + \left[f\frac{L}{D}\bigg|_{vert} + f\frac{L}{D}\bigg|_{incl}\right]\right]} \tag{5}$$

Eq. (5) gives the magnitude of the velocity induced in the pipe and together with Eq. (2), the induced mass flow rate is given by Eq. (6)

$$\dot{m} = \left(\frac{2\beta g(L_{vert} + L_{incl} \cdot \sin\theta)(\rho A_p)^2(T_o - T_i)}{\left[\beta T_i(K_i - 1)\left(\frac{A_p}{A_i}\right)^2 + \beta T_o(K_o + 1)\left(\frac{A_p}{A_o}\right)^2 + K_{30} + \left[f\frac{L}{D}\bigg|_{vert} + f\frac{L}{D}\bigg|_{incl}\right]\right]}\right)^{\frac{1}{2}} \tag{6}$$

Heat flow rate due to ventilation of air between the interior of a test house and the outside is given by Eq. (7)

$$\dot{Q}_{vent} = \dot{m}C_p(T_o - T_i) = \left(\rho C_p \frac{NV}{3600}\right)(T_o - T_i) \tag{7}$$

where, f is friction coefficient (f=0.05 [21]), K_1, K_2 and K_{30} are inlet, outlet pressure losses and elbow pressure loss (K_1=K_2=3 and K_{30}=0.2, [22]), L_{vert} is the pipe length (vertical), L_{incl} is pipe length (inclined), D is the diameter of the circular pipe, Ai is internal surface area of the pipe, Ko is thermal expansion coefficient, Ti is inlet air flow temperature, To is outlet air flow temperature, *V* is average air velocity, m^o is the mass flow rate. Based on the experimental data; the inlet and outlet air flow temperature, and air velocity are used to calculate the mass flow rate in Eq. (6). These correlations will be calculated to compare the experimental data.

4.2 Heat transfer in the pipe

The problem of calculating the internal heat transfer coefficient of the pipe is reduced when the pipe surface temperature is assumed constant surface. The temperature of the air entering the pipe measured at the ceiling (Ti), the air received heat around the pipe, and the heated air flows up through the pipe by buoyancy force outgoing to the ambient as the outlet air temperature (To) as show in Figure 5. This exchange is air to air exchanger. The equations for heat exchangers applied to the pipe can be expressed as [23] by Eqns. (8), (9) and (10).

$$\dot{m}C_p(T_o - T_i) = h_i A_p \Delta T_{LM} \tag{8}$$

$$A_p = \pi d_i L \tag{9}$$

and

$$\Delta T_{LM} = \frac{T_i - T_o}{\ln\left(\frac{T_s - T_o}{T_s - T_i}\right)} \tag{10}$$

where, is the internal heat transfer coefficient, is the internal surface area of the pipe, is the log means temperature difference (LMTD) and is the pipe surface temperature. Since in this experiment LVP and VP push an accumulating heat in the attic out by transmit through the pipe surface and to the air flow.

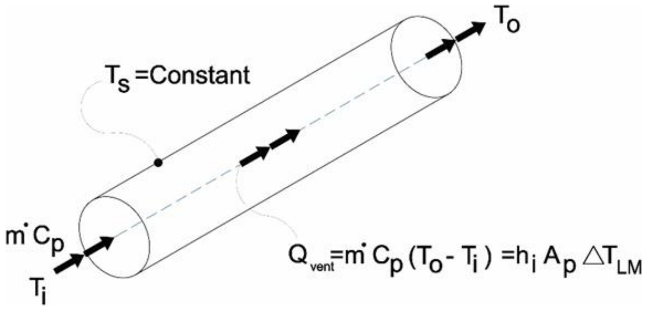


Figure 5. Transmit through the pipe surface and to the air flow model

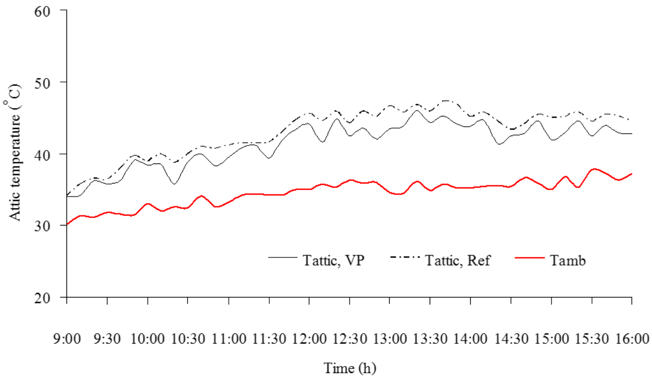
Therefore, an evaluation of internal convective heat transfer coefficient can be evaluated from energy balance. However, it can be seen that the mass flow rate (M=ρAV) changes according to the change in temperature of air that flows through LVP and VP. Finally the method is used for evaluating internal convective heat transfer coefficient to observe heat transfer ability by LVP and VP.

5. RESULTS AND DISCUSSION

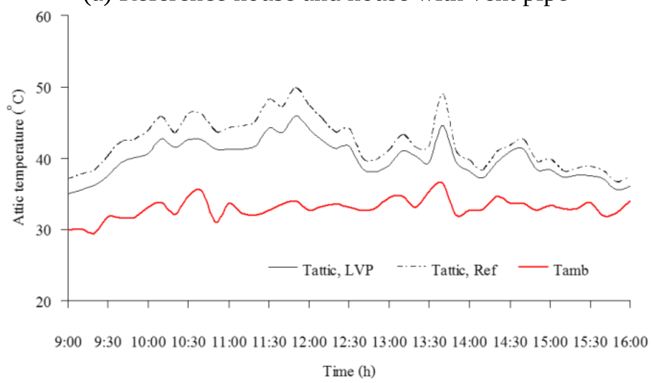
In order to evaluate the performance of the light/ vent pipe (LVP); the results are illustrated in term of temperature, ventilation, luminous flux, etc. Measurements were made of the ambient conditions such as solar radiation, ambient temperature, and wind velocity. The results are presented in two parts: the first is preliminary study between the reference house and house with vent pipe (VP), and reference house and house with light/ vent pipe (LVP). Moreover, the second is to study between a house with VP and house with LVP. During the day of testing (February 2017), there was a clear sky, the solar radiation was high, and wind velocity was very low.

5.1 Preliminary study

The preliminary study was set and carried out in order to investigate the reducing of heat accumulating in attic space using the VP and LVP compared with a reference house. The attic temperature involves to the reduction of heat transferring through the ceiling, and also induced natural air flow through the pipes. Figure 6 shows the attic temperature of the experimental houses; (a) reference house and house with VP, and (b) reference house and house with LVP.



(a) Reference house and house with vent pipe



(b) Reference house and house with light/vent pipe

Figure 6. Hourly variation of attic temperature

It had been observed that the attic temperature of VP and LVP were lower than the reference house; and also the average attic temperatures difference of (a) and (b) were calculated by measured data as about 1.61°C and 2.51°C, respectively. According to both cases of experiments, it was found that the surfaces of VP and LVP had received heat from the attic space, while the air in the VP and LVP had been heated and driven air by buoyancy force. This behaviour is thermal exchanged air which is similar to air heat exchanger. Solar radiation from the clear sky had increased sky light transmitted through the LVP that assists producing the natural ventilation rate through the LVP, which is to be described next.

5.2 The results of VP and LVP

As previously results, in order to test the potential of VP and LVP to induce air flow through the pipes, ceiling heat gain reduction and indoor illuminance. We first show the results of measurement of the attic, inlet, and outlet air flow temperatures, and also air velocity through the pipes. Then we will illustrate the indoor illuminance through the LVP. This section is presented on a comparison between the house with VP and the house with LVP under identically ambient conditions.

5.2.1 Experiment with temperature

Experiments were conducted during daytime to record the temperatures at different positions. Three significant points were selected, which were inlet and outlet of VP and LVP, and attic of the houses. The data of these points were shown in Figures 7 and 8. The x and y axis's of the graph depicts the hourly measured results and temperatures, respectively. Despite the similar air temperature profiles in Figure 7, it was found that the inlet air flow temperature of VP was nearly closed to the inlet air flow temperature of LVP throughout the day. There are two periods of the air flow temperature patterns: 9:00-13:00 and 13:00-15:00. The distinctive patterns of the temperatures of the inlet and outlet air flow between 13:00-15:00 in Figure 5. required a detailed examination. For more understanding, Figure 7 assists to explain the situation. Period 1: 9:00-13:00; start record at 9:00, the air in the VP and LVP received heat from the attic space and flowed through the pipes by buoyancy force, and air temperatures had increased together with the ambient temperature. It can be seen that the temperature difference between outlet and inlet air flow temperatures of LVP is higher than the VP. The reason is that LVP received a higher amount of heat, and LVP also received some sky light via a translucent flat cover on the roof. Meanwhile, Figure 7 compares the attic temperature of VP and LVP; it is apparent that the attic temperature of VP is higher than that the LVP. The highest attic temperature achieved by VP is 49°C at 12:30, whereas 47.5°C is achieved by LVP at the same time.

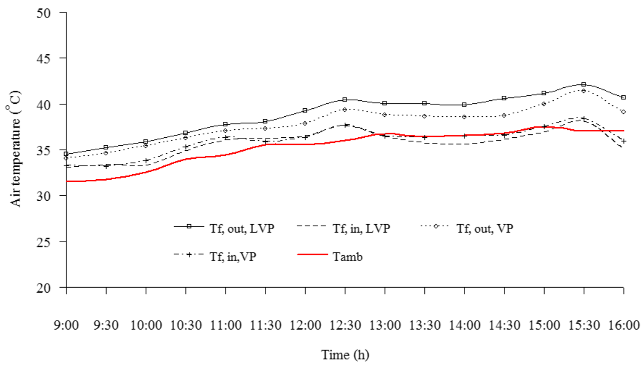


Figure 7. Hourly variations of inlet and outlet air flow temperature

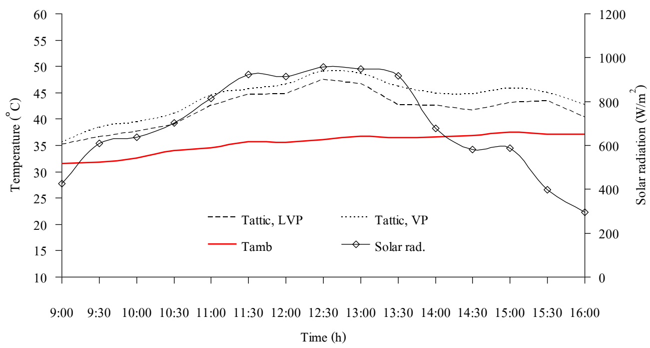


Figure 8. Hourly variations of attic temperature and solar radiation

Period 2: 13:00-15:00; Figure 6 together with Figure 7 illustrate and explain the situation at the start of this period. The solar radiation had started decreasing; it is apparent that the air temperature decreased, as well as attic temperatures. Meanwhile, the inlet air flow temperature of VP and LVP decreased to nearby the ambient temperature. For this reason, the LVP can transfer more amount of heat than the VP.

5.2.2 Airflow rate of VP and LVP

The air velocity was analyzed by comparing the performance of VP and LVP in the same ambient condition.

The VP and LVP are heated by heat accumulate in the attic area, and the stored heat in their fabric is utilized to induce ventilation. The pipe heated surface of both VP and LVP produces the natural ventilation that withdraws air from the room and extracts it to the ambient at the outlet area. As a consequence, outdoor air enters the room via the door opening area which makes the number of air change through the room. Applying Eqns. (5)-(7) for calculation of air velocity and volume airflow rate through the VP and LVP.

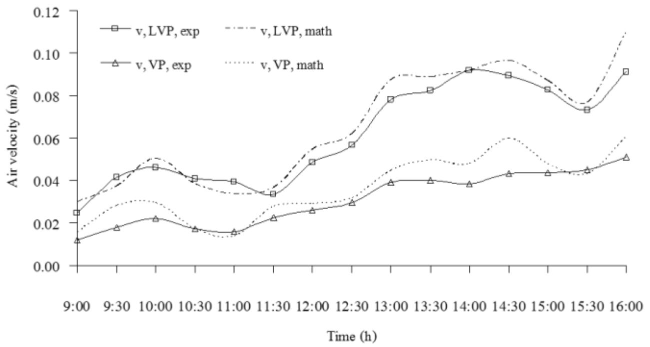


Figure 9. Comparison between experimental and calculation air velocity

Figures 9 and 10 show comparisons between the measured and calculation of air velocity and volume of airflow rate through the VP and LVP in the same ambient condition. Obviously, the measured air velocity inside the LVP is much higher than that of VP. Meanwhile both of measured and calculation data show the similar trends. However, the measured data agrees reasonably well with the calculations. As expected that the volume air flow rates had fluctuated according to air velocity, then an observation shows that during 13:00-16:00 the volume air flow rate of LVP is about twice that of VP. Furthermore, the number of air change of VP and LVP were compared. Applying Eq. (7); for calculation of the number of air change by VP and LVP. It was found that the number of air change of VP and LVP were ranged 0.5-2.1 and 1-4, respectively, indicating the good performance of LVP as no moving part was used.

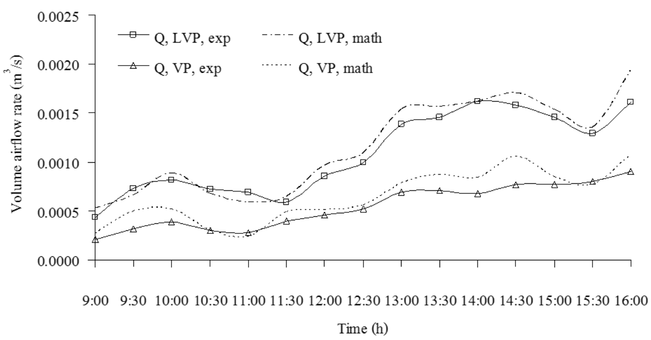


Figure 10. Comparison between experimental and calculation volume airflow rate

5.2.3 Daylighting through the LVP

The measured illuminance for an experiment was conducted on a day in February 2017. The sky was clear whereas solar radiation was high. The amount of outdoor illuminance on a horizontal plane was about 93 kLx around noon as shown in Figure 11. The amount of daylight contribution from the ceiling of LVP on the work plane (75 cm from a floor) is ranged from 60 to 190 Lx.

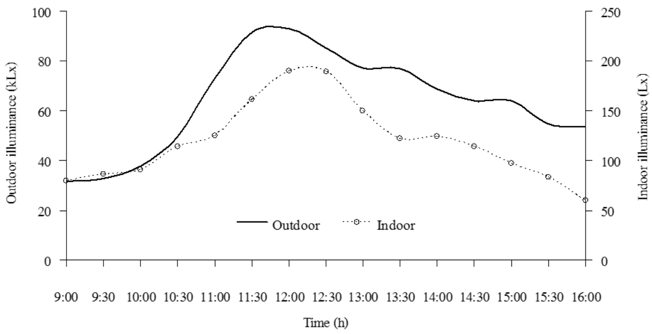


Figure 11. Hourly variation of outdoor and indoor illuminance

During 9:00-12:00, the indoor illuminance increased continuously till 12:00, while from 12:00 to the evening it continuously decreased. It was apparent that the measured indoor illuminance is less than the standard indoor illuminance value (300 Lx for working plane) recommended by the Illuminance Engineering Society [24]. However, it satisfies the recommended value for illuminance level for a place that requires about 50-150 Lx illuminance [3]. Figure 12 shows the photographs of indoor illuminance on the maximum and minimum indoor illuminance. As in Figure 10, the minimum and maximum indoor illuminances are 190 Lx (left) and 60 Lx (right), respectively.

(a) Left: 190 Lx at 12:00 (b) Right: 60 Lx at 16:00

Figure 12. The illuminance at the ceiling

5.2.4 Internal heat transfer in the pipe

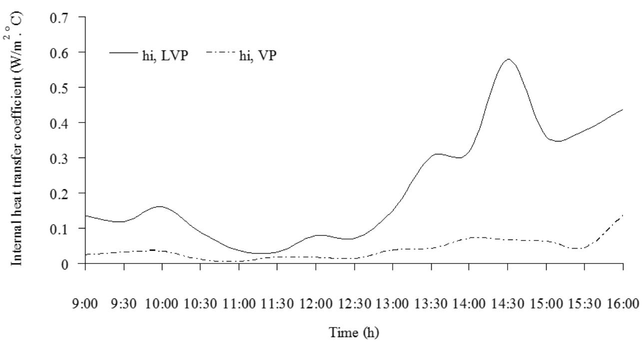


Figure 13. Hourly variation of internal heat transfer coefficient

Based on the experimental data, applying the Eqns. (8) to (10) were used to calculate the internal heat transfer coefficient of LVP and VP. The internal heat transfer coefficient of LVP and VP were ranged between 0.03-0.58 W/m^2-°C and 0.005-0.1 W/m^2-°C, respectively. Figure 13 together with Figure 10 assist illustrate the situation. Obviously, the internal heat transfer coefficient changes with the volume airflow rate. Apparently, the internal heat transfer coefficient of LVP is higher than the VP throughout the day, which the ranges were between 0.03-0.58 of LVP and 0.005-0.1 of VP.

5.2.5 Heat gain reduction

The heat gain has been measured at the ceiling (room side). As expected, the heat gain through the ceiling of LVP is lower than the VP because the LVP can extract heat from the attic better than the VP by natural ventilation through the pipes.

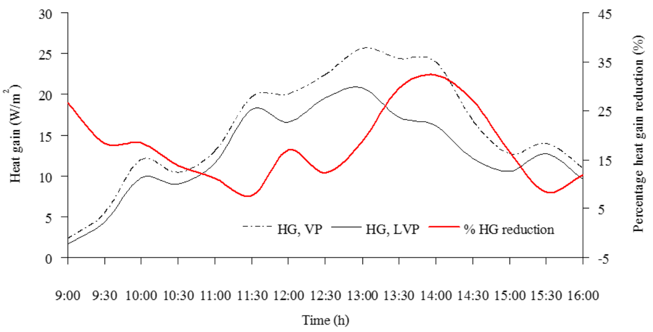


Figure 14. Hourly variation of heat gain and percentage heat gain reduction

The maximum heat gain of LVP and VP are about 20.60 W/m^2 and 25.60 W/m^2, respectively. The maximum heat gain reduction is about 7 W/m^2. The heat gain as shown in Figure 14, which can be used for calculating the percentage heat gain reduction [25], it is apparent that the LVP can reduce heat gain, as illustrated in term of percentage, about 8-32%.

6. CONCLUSIONS

Since LVP have a light pipe that light can pass through and make inlet air has a higher temperature than VP, the air density tends to be lower and the buoyancy force is higher than VP. Therefore, air velocity of LVP is also higher than VP which makes the convective heat transfer coefficient of LVP higher than VP. The LVP and VP had been investigated to evaluate their performances. The maximum temperature differences between the inlet and outlet temperature are 5.6°C. The highest heat gain reduction rate of LVP is about 7 W/m^2 when compared to a VP. Meanwhile, the percentage of heat gain reduction which was calculated from the experimental data that shows that the reduction rate was 8 to 32%. In fact, apart from environmental and energy-saving benefits, the LVP can provide two important functions: the number of air change in the room corresponding to the induced natural ventilation rate, and sufficient day lighting without overheating. The LVP induced a higher natural ventilation rate than the VP at about 0.0002 m^3/s (0.6 m^3/hr). In addition, the internal heat transfer coefficient of LVP and VP were evaluated based on the experimental results, and they were varied with the volume airflow rate [26-39]. Finally, this combination concept could be applied to the other roof configurations and also modern buildings.

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NOMENCLATURE

A_1	Inlet area of channel (m^2)
A_2	Outlet area of channel (m^2)
A_p	Cross section area of the pipe (m^2)
C_p	Specific heat at pressure constant (J/kg. °C)
F	Friction factor
G	Acceleration due gravity (m^2/s)
K_1	Inlet pressure loss coefficient
K_2	Outlet pressure loss coefficient
K_{30}	Elbow pressure loss coefficient
$\dot{m}$	Air mass flow rate (kg/s)
N	Number of air change (1/hr)
P_1	Pressure at inlet of the pipe (Pa)
P_2	Pressure at outlet of the pipe (Pa)
Q	Volume flow rate (m^3/s)
v	Velocity through the cross-section area (m/s)
v_1	Velocity at inlet of channel (m/s)
v_2	Velocity at outlet of channel (m/s)

Greek symbols

θ	Tilt angle (degree)
ρ_1	Density of air at inlet of the pipe (kg/m^3)
ρ_2	Density of air at outlet of the pipe (kg/m^3)
ρ_T	Density of air at any temperature (kg/m^3)
β	Thermal expansion coefficient of air (1/K)