NUEJ
NARESUAN UNIVERSITY
ENGINEERING JOURNAL

Thermal Characteristics of the Hybrid Ventilation Using Solar Chimney and Earth Tube Heat Exchanger

Waraporn Rattanongphisat[1*], and Piphat Imkong[2]

[1] Energy Technologies Building Laboratory, Department of Physics, Faculty of Science, Naresuan University
[2]Department of Physics, Faculty of Science, Naresuan University
[*]Corresponding author : warapornr@nu.ac.th

Abstract

This paper presents an experimental finding on the thermal characteristic of the hybrid ventilation by combining a Solar Chimney, SC, Earth Tube Heat Exchanger, ETHE, and small fan. A buoyancy driven natural ventilation causes an air flow inside the chimney. The latter is the pipe system buried underground, the ground operated as a heat sink. The combination of two effects would enhance the ventilation performance in which an indoor temperature could be reduced further than using just one. In this research, the square chimney made of steel plates with the outlet area of 0.09 m^2 and an underground pipe system made of PVC pipe diameter of 7.62 cm (3 inch) were assembled in the small demonstration house with the volume of 0.512 m^3. The thermal characteristic of the chimney and earth tube heat exchanger was investigated by an outdoor test on the two identical houses, the reference and the hybrid ventilating houses. Air flow velocity, temperature and solar radiation were measured and be used in the analysis. It was found that the stack effect could provide natural ventilation according to the airflow velocity measurement; however, the better result can be achieved when the force flow due to the use of a small fan, 4.5 W, was adopted to increase the air velocity through the ETHE thus greater indoor temperature reduction can be achieved. The hybrid ventilation system proposes good thermal characteristic under the current study criteria evident by the indoor temperature reduction of 3.6ºC which is higher than other configuration by 33%. This technique is considered a prominent part of the building application.

Keywords: Hybrid ventilation, Forced flow, Solar chimney, Earth tube, Heat exchanger

1. INTRODUCTION

Statistically analysis has pointed out that building sector share about one-fourth of energy consumption of the whole country as reported by Energy Policy and Planning Office, Thailand. The Heating Ventilation and Air Conditioning system, HVAC, is the most energy consuming in buildings it shared nearly half of the total building energy consumption. Several techniques has been proposed for solving the issue that can divide into two aspects as finding more efficient cooling technology or employing passive cooling as much as possible. Natural ventilation is one of passive cooling techniques providing human comfort. Its benefits are zero energy utilization and clean. However, the high ambient temperature in summer could cause inefficient ventilation due to the small temperature difference between outdoor and indoor air. An enhance performance can be achieved by using more than one technique such a hybrid ventilation. The passive cooling and low energy forced flow can be used to pre-cool the space. A solar chimney has been available for a century and still be effectively used nowadays. A buoyancy driven natural ventilation causes the air flow inside the chimney according to the convection heat transfer. Lower temperature air has high density thus sinking to the bottom while the higher temperature air has low density so floating on the top; therefore, the circulation of air has started. In addition, the ground temperature at some depth remains invariant which is lower than ambient air temperature in summer. Thus it can be used as a heat sink to receive a dumped heat that extract from the building space. This methodology could be employed to reduce indoor air temperature by inducing colder air into the house space at the same time ventilated the hotter air to the environment.

Parameters affected to the performance of a solar chimney with the glass covered under outdoor test were solar intensity and air gap distance [1]. Unquestionably, the higher solar radiation offers the greater chimney performance. The air velocity of between 0.25 and 0.39 m/s for the air gap of 0.1 and 0.3 m respectively were found at the solar radiation of 650 W/m^2. Similar model of solar chimney with dimension of 1x1x1 m^3 was tested and found that the solar chimney could provide air flow rate between 50 and 150 m^3/h corresponded to 2-5.6 air changes per hour for a room size of 27 m^3 [2]. Among the air gap between 0.1 m and 0.3 m, the greater air gap provided higher air change rate in all range of height from 0.85 to 0.95 m. A glazed solar chimney wall as the size of window as 0.74 m high and 0.5 m wide can induce airflow rate up to 0.28 m^3/s into an air gap of 10 cm for a small testing house of 2 m high and the area of 1.96 m^2 [3]. An indoor air velocity between 0.07 and 0.14 m/s was observed as well as the room temperature lower than the outer glass for 3 ºC can be accomplished at the highest temperature period of the day for this natural ventilated house. The comparison of using moist air and dry air as a working medium in a vertical solar chimney was studied by numerical method [4]. A model of solar chimney was designed on the ratio of height to width at 14:1. It was reported that the ventilated air flow velocity in the case of using humid air as a working medium for the relative humidity between 30% and 80% was 15.4% and 26.2 % lower than dry air while the temperature was higher than the use of dry air. This suggested that using dry air in the solar chimney offered higher performance. Another study was shown that occupant in the space may provide enough heat to drive the buoyancy flow for a natural ventilation and possibly reach the comfortable temperature of 21 - 25 ºC [5].

In addition, an earth to air heat exchanger operates by using the soil inertia depended on the amount of heat transfer between the soil and air in the pipe [6]. Thus it could be called an earth tube heat exchanger in this aspect. In certain depth, the soil temperature is less fluctuate and lower than the surface temperature which can be used as heat sink in summer or in the country with high ambient temperature throughout the year. The system can be integrated with the mechanical ventilation such a Heating, Ventilation and Air Conditioning system (HVAC). The pipe materials are steel [7], aluminum [8] and plastic such as PE and PVC [9]. Passive cooling system combined earth to air heat exchanger, solar chimney and solar collector was reported its high potential of cooling capacity to cover nearly all of the summer design cooling load [10]. The experiment was done in the research test facility in the US. It was also found that the indoor air temperature of the one-story building with 3 m high could be maintained in standard thermal comfort. A research on the climate of Thailand affected to the heat transport in soil was found that the soil temperature would not vary when the depth is deeper than 0.75 m onward [11]. In other words, the use of soil as a heat sink can be done at the depth of more than 0.75 m as to avoid the soil temperature variation.

Accordingly, a square chimney is selected due to the simplicity of structure and potential utilization. This prototype is similar to the chimney with an air gap mentioned in the literature. In this research, the chimney and PVC pipe system buried underground is constructed for an investigation of the hybrid ventilation characteristic that apply on the demonstrated small house. The variation of temperature performs the thermal characteristics of the system in which the two identical houses, one is with solar chimney and earth tube heat exchanger while another is the house alone, were compared to identify its thermal characteristic.

2. EXPERIMENTAL DESCRIPTION

A vertical solar chimney made of steel plate of 1.5 mm thickness with the dimension of 0.3 m wide, 0.3 m long and 1.5 m high as shown in Table1. The chimney was painted in black on the outer surface to absorb heat to providing the air temperature difference between outside and inside that can cause a stack effect for ventilation. The solar chimney is attached to the outer wall of the demonstration house on one side in which the open channel is at the bottom of the house to allow the air flow through the chimney as shown in Fig1. Another important part, an earth tube made of PVC pipe with 7.62 cm (3 inch) diameter for the total length of 10 meters buried at 1.1 meters underground, as shown in Fig.2, has the outlet inside the house as illustrated in Fig.1. K-type thermocouples with ±0.4 of reading were connected to the data logger and they were placed along the inside chimney duct and the demonstration house for temperature measurement included inlet, flow channel, outlet, ambient, and indoor temperature as illustrated in Fig.1. Although, the more temperature sensors inside the houses would give more detail of indoor temperature, the identical of two demonstrated houses with the same number of temperature sensor and located position provide enough information for the current research. The earth tube and ground temperature are also measured by K-type thermocouples at various position as shown in Fig.2 while an air velocity is measured by hot wire anemometer with ±0.03 m/s accuracy (Testo 425 hot wire anemometer).

To avoid the error of velocity measurement caused by natural wind outside the chimney, the air flow measurement was taken at about 5 cm below the flow channel exit near the inside wall surface and center. The solar radiation was measured by Pyranometer Kipp & Zonen CM3.

Table 1 Chimney, demonstration houses and PVC pipe dimension

Detail	Values	Unit
Chimney:		
Height	1.5	m
Inlet	0.09	m^2
Outlet	0.09	m^2
Length of delivery duct	0.14	m
Demonstration house space:		
Height	0.8	m
Wide	0.8	m
Length	0.8	m
PVC pipe:		
Internal diameter	0.0762	m
Thickness	0.00252	m

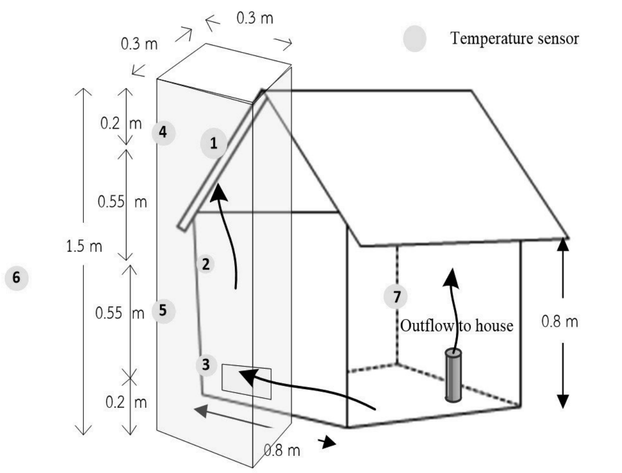

Figure 1 Schematic diagram of experimental setup for the solar chimney with deliver duct in house space

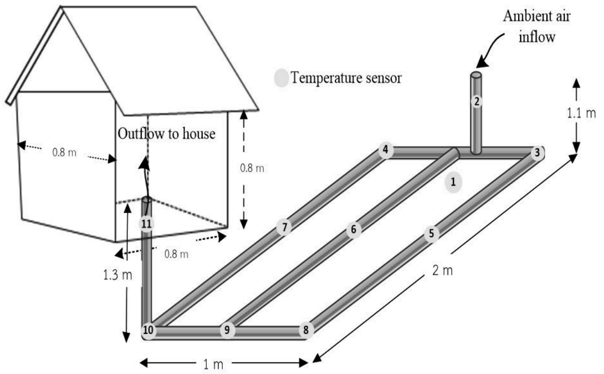

Figure 2 The earth tube of 10 meter long buried underground at 1.1 meter depth and installed thermocouple for temperature measurement

The three ventilating configurations are investigated as follows; by earth tube heat exchanger (ETHE), by solar chimney with earth tube heat exchanger (SC and ETHE), and by solar chimney with earth tube heat exchanger and fan (Hybrid). The outdoor testing was conducted on the field besides the Department of Physics building.

3. RESULTS AND DISCUSSION

Two identical demonstration houses are well insulated. One is used as a reference house while another is a ventilating house with the solar chimney and earth tube heat exchanger. The experimental tests were carried out between 8:30 and 16:00 from 18 to 28 November 2016. Indoor temperature varies throughout the day which depends on the solar radiation. Sunlight incidence on the house caused the transfer of heat through the wall and roof. The heat loss was preventing by installing insulation on the wall and roof, the space temperature slightly rise during the day could cause uncomfortable to live in the building. However, the solar chimney function when the sunlight has caused a deviation of air temperature inside the chimney from the room air temperature as well as inducing a cooler air from the earth tube heat exchanger. With this method, the space temperature of the house with the solar chimney and earth tube heat exchanger would be lowered and providing more comfortable temperature for living in the house.

3.1 Thermal characteristic of house with ETHE

On the test of the effect of earth tube heat exchanger, it can be seen that space temperature of the house is fluctuated during the day related to the solar radiation and reach the peak in the afternoon at 13:30 pm on the test day. The thermal characteristic of earth tube heat exchanger to the house space temperature can be shown in Fig.3. Evidently, the house space temperature of the house with the ETHE is lower than the reference house by the maximum temperature reduction of 1.6ºC. This has shown that the heat transfer between inlet ambient air of the ETHE and the soil provide the cooler air temperature at the outlet of the ETHE. This cold air can be used to deliver to the house for the conditioned space as a natural ventilation system.

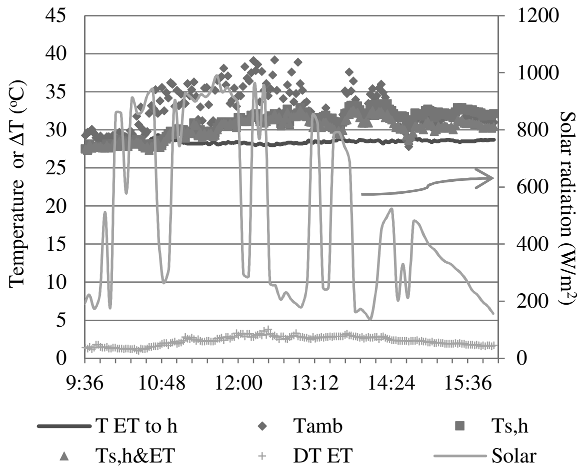

Figure 3 Ambient (amb), house space (s,h), house space with ETHE (s,h&ET), and outlet air of ETHE to the house (ET to h) temperature, ETHE temperature difference (ET) and solar radiation

3.2 Thermal characteristic of house with SC and ETHE

The effect of earth tube heat exchanger to cool the house space was seen by the air temperature reduction. Next experiment is carried out by combining the solar chimney and earth tube heat exchanger to investigate the performance of the two for natural ventilation. During the day, the solar radiation is fluctuated and climbed up to the maximum of 825 W/m^2 at 13:30 pm while the average is about 362 W/m^2. The incidence of sunlight on the outer surface of the solar chimney has been absorbed by the steel sheet then transfer to the air at the flow channel of the chimney. These has caused the deviation of air temperature in the flow channel from the space air temperature at the same time the buoyant ventilation would induce the low air temperature from the earth tube heat exchanger. The temperature difference of supply air, ambient air, at the inlet and deliver air to space at the outlet of the earth tube heat exchanger is from 1.7 ºC to 9.5 ºC. As well as, the temperature difference along the height of the chimney duct of 1 ºC up to 10 ºC was observed. It can be seen from the graph that, if the temperature difference of the chimney column indicated the magnitude of the chimney effect, the temperature difference depends directly on the solar radiation and a time lag due to the heat transfer from the chimney wall to the air in the flow channel. As can be seen in the Fig.4, the value is high during 12:30 to 13:00. Although, the solar radiation decrease at 13:00 the temperature difference reach the top then slightly decrease when the solar radiation goes up to the peak at 825 W/m^2. The time lag is about 28 minute.

In addition, an exit air velocity depends on the solar radiation as well as relates to the effect of chimney and earth tube heat exchanger. The average air flow velocity, on the cross section area, is from 0.5 to 1.2 m/s as can be seen in Fig.5. The maximum air flow velocity varies from 0.8 to 1.6 m/s. This system configuration offers higher velocity than the previous one which is only ETHE employed. As a result, the space temperature of the house with the combined SC and ETHE has lower than the reference house by 2.4 ºC.

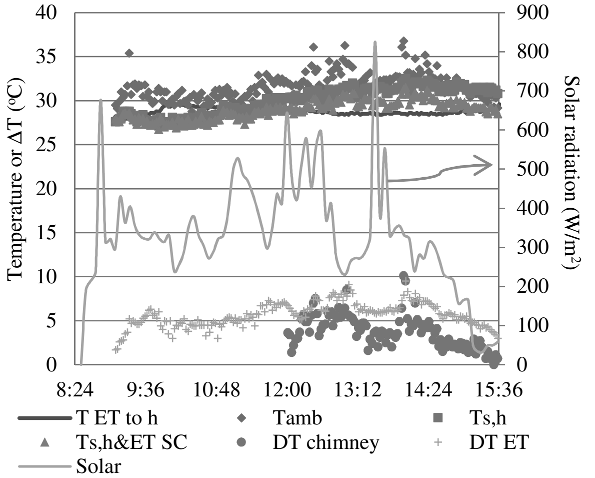

Figure 4 Ambient (amb), house space (s,h), house space with ETHE (s,h&ET SC) temperature, and outlet air temperature of ETHE to the house (ET to h), ETHE temperature difference (ET) and solar radiation: For SC and ETHE scheme

3.3 Thermal characteristic of house with hybrid ventilation system by SC, ETHE and fan

The hybrid ventilation has combined the solar chimney effect and earth tube heat exchanger with stimulate by small electric fan, 4.5 W. It is a 4 blades electric fan with 3 ranges of speed in which the first speed has been experimented (measured air velocity of 2.3 m/s at the pipe inlet). It is found that the temperature difference between supply ambient air at the inlet and deliver air to space at the outlet of the earth tube heat exchanger ranges from 2.7 ºC to 8.3 ºC. As well as, the temperature difference along the height of the chimney duct of 0.5 ºC up to 14 ºC is observed as shown in Fig.6. That is about 28% greater than the combined SC and ETHE system for the upper limit. In addition, this has increased the ventilation flow. The maximum temperature difference of 3.6 ºC between the two houses has been found. This is about 33% higher than the other schemes.

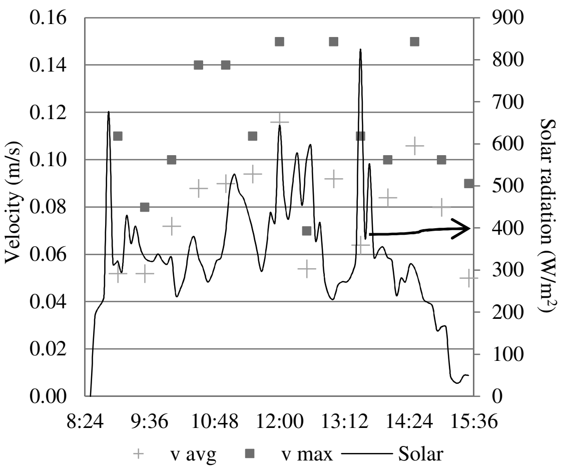

Figure 5 Average and maximum air velocity of the natural ventilation system and solar radiation

It can also be found that the air flow velocity of this hybrid ventilation is higher than other configurations. The maximum air flow velocity is found at 0.26 m/s as can be seen in Fig.7. That is about 42% greater than another two earlier configurations. Hence, this technique can be expanded to the larger scale for the application in buildings.

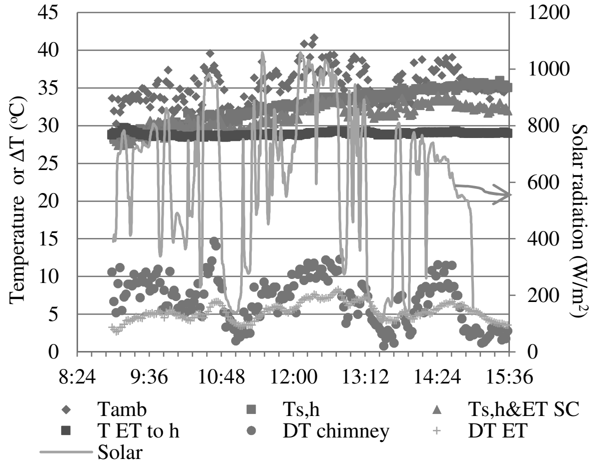

Figure 6 Ambient (amb), house space (s,h), house space with ETHE and SC (s,h&ET SC), and outlet air of ETHE to the house (ET to h) temperature, SC (chimney) and ETHE (ET) temperature difference and solar radiation : For SC, ETHE and fan scheme

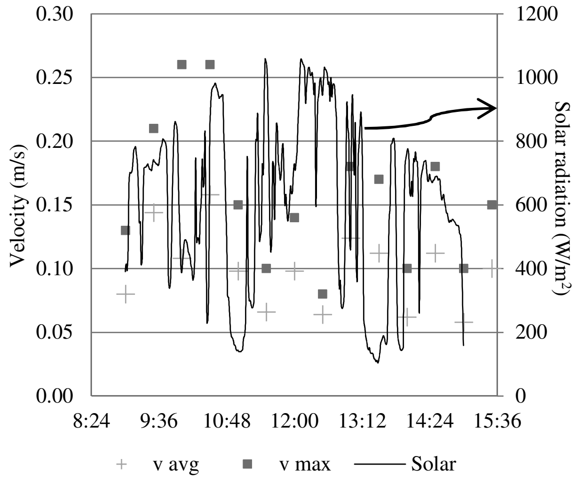

Figure 7 Average and maximum air velocity of the hybrid ventilation system and solar radiation

4. CONCLUSION

The chimney and earth tube heat exchanger with forced flow by a small fan is the hybrid ventilation system that has been investigated by the outdoor tests and compared with a reference house. Air flow velocity, temperature and solar radiation were measured and analyzed for the system characteristic. It was found that the stack effect could provide natural ventilation according to the value of airflow velocity. Higher ventilation and indoor temperature reduction can be achieved when the force flow due to the use of a small fan was installed to increase the air velocity through the earth tube heat exchanger. The hybrid ventilation system proposes more indoor air ventilation and temperature reduction of 3.6ºC. The research brings the beneficial of soil thermal inertia to be used as a heat sink. The use of the SC and ETHE system on demonstrated house could reduce the indoor temperature between 2.4 ºC and 3.6ºC which proved its potential. Further study can be done by design and install the larger scale on a single story building. This can be considered as an alternate low energy ventilation unit for buildings.

5. ACKNOWLEDGMENT

The first author would like to acknowledge Naresuan University for the research funding support.

6. REFERENCES

[1] Ong, K.S. & Chow, C.C. (2003). Performance of a solar chimney. *Solar Energy*, 74, 1–17

[2] Mathur, J. Bansal, N.K. Mathur, S. Jain, M. & Anupma. (2006). Experimental investigations on solar chimney for room ventilation. *Solar Energy*, 80, 927–935

[3] Chantawong, P. Hirunlabh, J. Zeghmati, B. Khedari, J. Teekasap, S. Win, M. M. (2006). Investigation on thermal performance of glazed solar chimney walls. *Solar Energy*, 80, 288–297

[4] Sudprasert, S. Chinsorranant, C. Rattanadecho, P. (2016). Numerical study of vertical solar chimneys with moist air in a hot and humid climate. *International Journal of Heat and Mass Transfer*, 102 , 645–656

[5] Chenvidyakarna, T. Woodsa, A. (2005). Multiple steady states in stack ventilation.. *Building and Environment*, 40, 399–410

[6] Peretti, C. Zarrella, A. Carli, M.D. Zecchin, R. (2013). The design and environmental evaluation of earth-to-air heat exchangers (EAHE). A literature review. Renewable and Sustainable Energy Reviews, 28, 107–116

[7] Badescu, V. (2007). Simple and accurate model for the ground heat exchanger of a passive house. *Renewable Energy*, 32, 845–855

[8] Santamouris, M. Mihalakakou, G. Balaras, CA. Argiriou A. Asimakopoulos, D. Vallindras, M. (1996). Use of buried pipes for energy conservation in cooling of agricultural greenhouses. *Solar Energy*. 55(2), 111–124

[9] Kopecky, P. (2008). Hygro-thermal performance of earth to air heat exchangers numerical model, analytical and experimental validation, measurements in- situ, design. Phd dissertation. The Czech Technical University in Prague

[10] Li, H. Yu, Y. Niu, F. Shafik, M. Chen, B. (2014). Performance of a coupled cooling system with earth-to-air heat exchanger and solar chimney, *Renewable Energy*, 62, 468-477

[11] Waewsak, J. Klompong, N. Kongkul, K. (2015). 3-D numerical modeling of heat transport phenomena in soil under climatic conditions of southern Thailand *Walailak Journal of Science and Technology*, 12, 703-720