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Utilization of Air in crawl space with a Modified Trombe Wall for Natural Ventilation and Heat Protection

Maniporn Pichaisak and Sudaporn Chungloo*

Faculty of Architectural and Planning, Thammasat University, Thailand

* Corresponding Author. Tel: (662) 9869434 ext. 4012, Fax: (662) 9868067, E-mail: chungloo@tu.ac.th

Abstract: Typical house in Thailand possesses both cool air generated by cool earth surface in a crawl space and absorbed solar heat transferred through the building wall. To utilize these existing cool air and heat source, a modified Trombe wall was proposed to promote natural ventilation and heat protection using air flow driven by the differences of temperature. This research experimentally investigates the use of time-lag in heat transfer of high density external material in a modified Trombe wall in creating ventilation in the appropriate time, and proposes the use of cool air in the crawl space to reduce accumulated heat in the modified Trombe wall by natural convection. The results showed that a time-lag of 3 hours was recorded by using a high density external material in a modified Trombe wall, providing maximum ventilation to occur at 6.00 pm. Moreover, utilization of cool air in crawl space contributes to the reduction of heat transfer through the modified Trombe wall.

Keywords: Modified Trombe wall, Natural convection, Stack ventilation, Low-energy buildings, High mass buildings

1. INTRODUCTION

The typical houses in hot and humid climate are raised above the ground, leaving the shaded crawl space under the house's floor. The wind breeze under the crawl space exchanging heat with the moist earth surface is cooled by evaporation. Givoni [1] shows that the minimum temperature of air above the moist earth is similar to those of the minimum ambient temperature.

Nowadays, most people live in a building and need of air condition system to get rid of heat transferring from the building envelope, the lighting system, the electronic appliance, the infiltration of air and human. The heat transfer through the building envelope as the result of solar energy absorption of increases the wall and air temperatures, leads to thermal discomfort of people and increases the energy consumption of air conditioning system [2]. This research aims to utilize the existing heat sources to create natural ventilation and to reduce the heat transfer into building by using the modified Trombe wall.

Trombe wall is a kind of double wall that naturally promotes air flow in the air channel by using the buoyancy force. Consisting of the glazing as an external layer, the air gap and the masonry wall as an internal layer, the warm air in the air channel is created from the transmitted sunlight through the glazing and the absorbed heat in the masonry wall. This warmed air between the glazing and the absorber surface flows to the top opening by the buoyancy force [3]. In the cold climate, this system is used to warm up the space, called "passive solar heating" as shown in Fig. 1. Since the high temperature of outdoor air during the daytime in the hot climate, using the system for cooling is inadequate but the storage wall still provides a good thermal insulation. During the nighttime, the warm air flows out at the top opening of wall system, draws the cool ambient air into the space and removes heat from occupied room (see Fig. 2). The latter is called "passive solar cooling" which has been rarely studied [4].

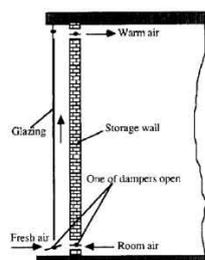


Fig. 1 passive solar heating.

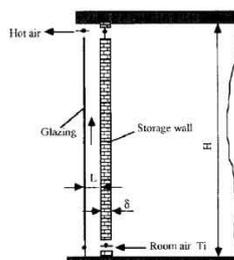


Fig. 2 passive solar cooling.

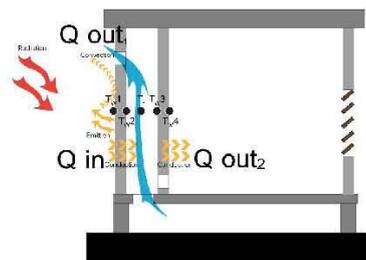


Fig. 3 modified Trombe wall system.

The Trombe wall researches in Thailand are those studies about the effect of channel width and internal layer material on the maximum ventilation. There are studies of channel width of 10, 11.5, 13 and 14 cm. with black-painted internal

concrete wall [5] and black-painted internal metallic wall [6] and study of channel width of 5, 10, 15, 20, 25 and 30 cm. with the lightweight concrete masonry wall [7]. The study of the modified Trombe wall (MTW) develops thermal resistance appropriate for the hot climate by changing the external layer from glazing to opaque wall. The purposes are to decrease the accumulated heat, room temperature and maximize ventilation with external black-painted masonry brick wall [8] and external lightweight concrete wall [9]. These researches show the ventilation for the daytime but the appropriate ventilation in residential houses in Thailand occurs in the nighttime.

In the decade of environmental and energy concerns, the use of passive systems have become more interesting. This research proposes a passive system called a modified Trombe wall that integrates the cool air from crawl space and hot air from air channel in the building envelope to promote a natural ventilation and heat protection.

The objective of this study is to investigate the use of time-lag in heat transfer of high density material in a modified Trombe wall in creating ventilation in the appropriate time. This study proposes the use of cool air in the crawl space to reduce accumulated heat in the modified Trombe wall by natural convection as shown in Fig. 3.

2. METHODOLOGY

2.1 Experimental setup

The experiment composes of 2 experimental models: 1) the utilization of air in crawl space with a high density material of the modified Trombe wall to promote a heat protection (heat protection wall system) and 2) a study of modified Trombe wall with high density material to promote a natural ventilation (ventilation wall system) in the nighttime.

Experiment #1 studies the effect of solar heat radiation and time-lag on the airflow rate and wall surface temperature. The adjustable halogen light bulb simulating the solar heat creates the air temperature differences via increasing of wall surface temperature and inducing the air from the crawl space to reduce the accumulated heat in the wall. This halogen bulbs simulates the solar heat in the summer equinox and winter equinox days. Table 1 shows variables involved in experiment #1.

Table 1 Variables in experiment #1

Independent variable	Solar heat radiation and time-lag of high density material
Dependent variable	Air flow, Wall surface temperature
Controlled variable	Crawl space air temperature(26°C), model geometry, external factor

Experiment #2 studies the effect of heat transfer and time-lag of high density material and the room heat flux on the air velocity and airflow rate. This experiment includes the occupied room in the daytime (8.00-18.00), the occupied room in the nighttime (18.00-22.00) and the unoccupied room. Table 2 shows variables of experiment #2.

Table 2 Variables in experiment #2

Independent variable	Time-lag of high density material, room heat flux
Dependent variable	Air velocity, air flow rate
Controlled variable	Solar heat radiation, model geometry, external factor

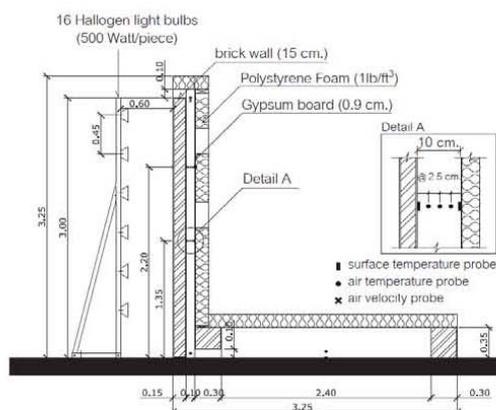


Fig. 4 Experiment 1 model.

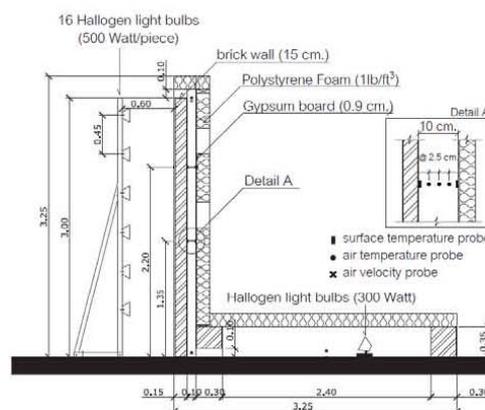


Fig. 5 Experiment 2 model.

2.2 Experimental model and Data collection

The experimental model, the modified Trombe wall of 1 meter width and 3.1 meter height, consists of brick wall (external wall) of 15 cm. thickness, air gab of 10 cm. thickness and gypsum board (internal wall) of 0.9 cm. thickness. The other side of wall is protected from heat transfer by installing a high density polystyrene foam. The solar heat radiation is simulated in a controlled room by using an adjustable of 16 halogen light bulbs of 0-500 Watt. The air temperature, surface temperature and the air velocity was collected by 17 thermocouples and anemometer. Figs. 4-5 show both of experimental model and the location of measuring sensors.

3. RESULT AND DISCUSSION

3.1 Study of heat protection wall system

The study of using low air temperature in crawl space together with a high density material in modified Trombe wall to reduce the accumulated heat by the natural convection is shown in experimental #1. The experimental results show that the high density materials, brick wall of modified Trombe wall, reduces the maximum surface temperature of 7.50 °C and delays the heat transfer to the air gab for 3 hours. It is shown in Fig. 6, the alteration of air and surface temperature from experiment #1.

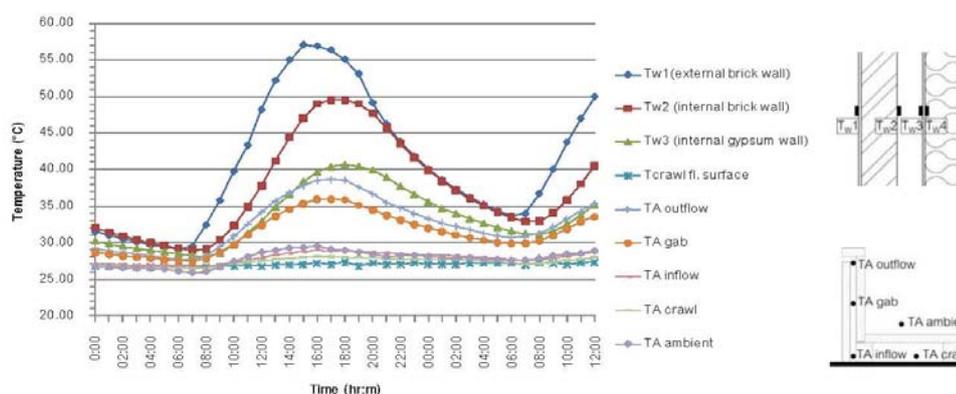


Fig. 6 Surface and air temperatures influenced by solar radiation.

The temperature of air in the air gap changes relatively to internal wall surface (internal brick wall and internal gypsum wall) and is always lower than the surface temperature. The thermal energy transferred from surface by the air is written as Eq. (1).

$$Q_{\text{convection}} = h_c (T_{w2 \text{ or } w3} - T_{A_{\text{gap}}}), \quad (1)$$

where h_c is the convection coefficient at internal surface, $T_{w2, w3}$ is the internal surface temperature and $T_{A_{\text{gap}}}$ is the air temperature in the air gap.

The results show that the cool air in crawl space decreases the inflow air temperature (T_{inflow}) before it is raised by the heat from internal brick wall surface. As the air temperature in the air gab increase, the outflow air temperature increase, enhancing the temperature differences in modified Trombe wall that induce the natural air flow according to Eq. (2).

$$v_f = C_D \sqrt{\frac{gH(T_{\text{outflow}} - T_{\text{inflow}})}{T_{\text{outflow}} + T_{\text{inflow}}}}, \quad (2)$$

where v_f is a velocity of fluid (m/s), C_D is the discharge coefficient, g is an acceleration of gravity (m/s^2), H is wall height (m.) and $T_{\text{outflow}}, T_{\text{inflow}}$ are air temperature at the opening. The experimental results of wall surface temperature, air temperature, air in crawl space temperature and the air velocity show in Fig. 7.

According to the diagram of energy flow in Fig. 3, the cumulative heat energy (Q_{in}) in wall is always ventilated (Q_{out}) because the average temperature in modified Trombe wall system is always higher than the crawl space temperature. Therefore the proposed system shows reducing of heat transferring into the room (Q_{out2}) all of the daytime. The reduction of surface temperature in the modified Trombe wall with ventilation is compared with those without ventilation in Fig. 8. The conclusions of temperature differences of this reduction are shown in Fig. 9.

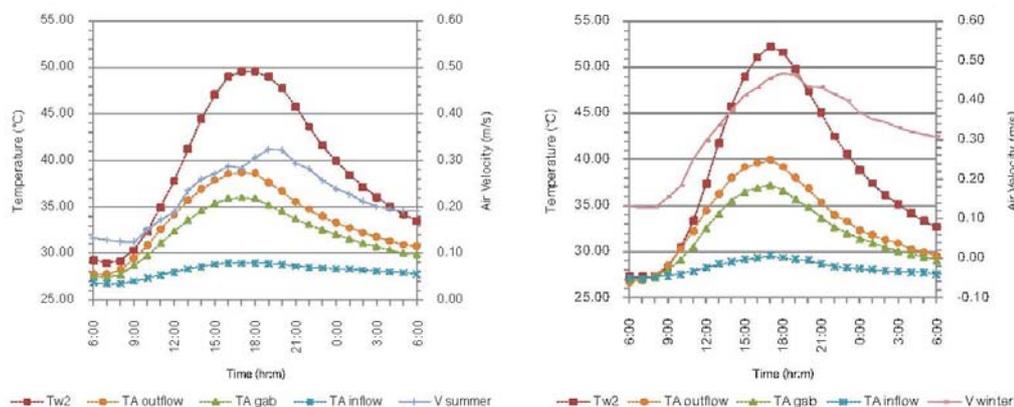


Fig. 7 Experimental results of surface temperature, air temperature and air velocity in experiment #1.

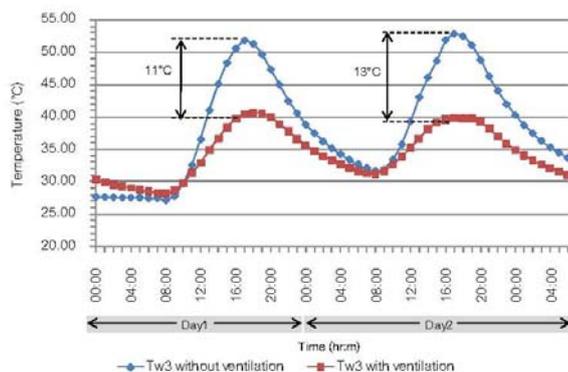


Fig. 8 Comparison of internal gypsum surface temperature(T_{w3}).

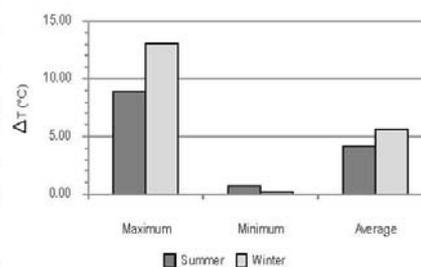


Fig. 9 The differences of surface temperature.

3.2 Study of ventilation wall system

The results of experimental #2 show that the occupancy in the room increases both of the air temperature in the room and air temperature in the modified Trombe wall. In case of room air temperature is higher than the air temperature in the air gap, the experimental results shows that air velocity changes according to the differences in temperature between the wall system, room air temperature, and ambient temperature. The recorded of temperatures and air velocity of experiment #2 are shown in Fig. 10.

According to Fig. 10, by adding heat flux of 300watt to the room, equally, in both daytime and nighttime, room air temperature rise differently. The occupancy in daytime, air temperature of the room increases higher than the air temperature of the room during the nighttime occupancy. Because the high material density and the internal surface heat transfer were delayed for 3 hours, the natural ventilation using buoyancy force is low in early time of the day as shown in Fig. 10. In the nighttime, the air velocity in the wall system is so high that it helps decrease the air temperature in the room. Shown in Fig. 11, the comparison of volume airflow rate of unoccupied, daytime occupied and nighttime occupied room cooperate with the proposed system. The alteration of volume airflow rate as the heat source is presented in the room is different from that unoccupied room. The occupied room shows higher volume airflow rate than that of the unoccupied room.

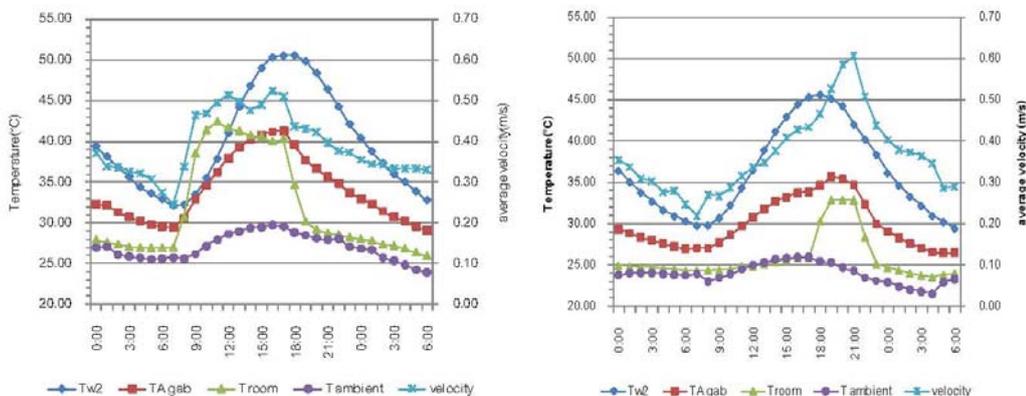


Fig. 10 Experiment #2: the results of surface temperature, air temperature and air velocity.

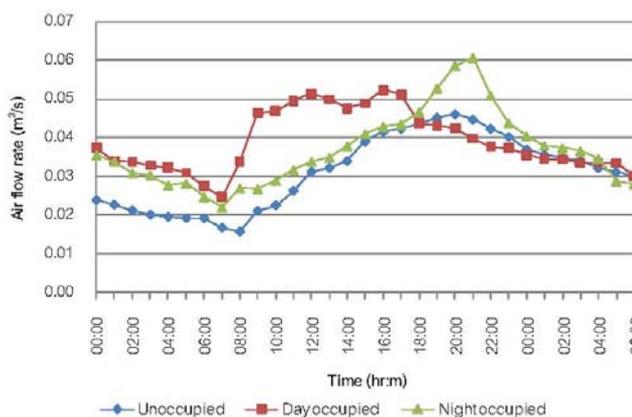


Fig. 11 Comparison of volume airflow rate.

4. CONCLUSIONS

This research proposed a modified Trombe wall that integrates cool air in crawl space and hot air from building envelope to promote a natural ventilation and heat protection.

The conclusions of the utilization of air in crawl space together with the modified Trombe wall to promote a heat protection (heat protection wall system) are: (1) The high density material delays the increase of air temperature in the wall system by 3 hours to produce highest natural convection was occur at 6.00 pm., (2) The high density material with heat resistance properties decreases the temperature about 7-10°C comparing to those without ventilation from the crawl space, 3) The natural convection and natural ventilation decreased the temperature swings of the wall surface and the room air by 8-13°C. 4) The utilization of air in the crawl space together with the high density material of the modified Trombe wall reduces of surface temperature of room's wall by 15-23°C. The heat protection wall system provides a good thermal resistance which importance to reduce the wall temperature and also reduce the thermal load of air conditioning system.

The conclusions of the modified Trombe wall with high density material to promote natural ventilation (ventilation wall system) are: (1) In the occupied room, air velocity changes according to the temperature differences between the wall system, room air temperature, and ambient temperature. (2) In the unoccupied room, air velocity changes according to the temperature difference between the wall system and room air temperature. (3) The proposed modified Trombe wall with high density material induces the natural ventilation in the nighttime is higher than that in the daytime.

The application of the ventilation wall system is appropriate to the space with natural ventilation in the nighttime such as houses. Furthermore, the ventilation of unoccupied space during the nighttime this system also produces a nocturnal ventilation in order to reduce the room temperature swing in the next daytime.

5. ACKNOWLEDGMENTS

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