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# Effectiveness of Stack Ventilation in a Two-Storey House in Hot and Humid Climate

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# Effectiveness of Stack Ventilation in a Two-Storey House in Hot and Humid Climate

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**Abstract**. The objectives of this research were to design stack ventilation and to study its effectiveness in a two-storey house in hot and humid climate of Bangkok, Thailand. Envelope openings at the rooftop and the entry door of the house were added to create height difference between inlet and outlet openings. Heat in the attic was utilized to make temperature difference in order to generate buoyancy for stack ventilation. The method of the study was experimentation in two existing houses, which had the same physical and had the most similar environment. The first house without stack ventilation was a base case. The second one was designed to integrate stack ventilation. Scientific instruments were installed in both houses at various positions. Air temperature, relative humidity and wind speed data were collected minutely for a few consecutive days for the evaluation of the experiment. It was founded that the house with stack ventilation had inside air temperature and relative humidity lower than those of the base case. The inside air temperature of the house with stack ventilation could be 0.7 Celsius lower than that of the base case. The relative humidity of the house with stack ventilation could have relative humidity of 12 % lower than that of the base case. Furthermore, the stack ventilation could make 1.06 air changes per hour with only 0.10% effective opening of building area having stack ventilation.

## 1. Introduction
Nowadays family structure in Thailand becomes single families. The daily life of most single families in Bangkok and vicinity areas is that all their members leave homes, commute to work places or schools in the early morning and come back home again at dawn or evening. Therefore, most of their homes have to be closed during the daytime to prevent burglarizing and rain penetration. Since ventilation is limited, heat and humidity accumulate in their homes during the daytime. Accordingly, the insides of their homes become warm and damp, uncomfortable condition for living right after coming back homes.

If a closed house can “breath” or dissipate heat and moisture out and draw fresh air coming in during the closed period, its interior will be more comfortable. Dwellers can have better quality of living condition. Stack ventilation is a method providing natural ventilation that can relieve this problem.

The objectives of this research were to design stack ventilation for a two-storey house and to study the effectiveness of the stack ventilation. Two typical mid size two-storey houses with 167 square meters were selected as a case study. The studied areas of the houses were common areas such as a hallway, a living-dining space, stairs and a stair hall on the upper floor. Bedrooms, bathrooms and a kitchen were not included in the study.

The method of this research was experimentation in two existing houses, in Bangkok, which had the same physical and had the most similar environment. The first house without stack ventilation was a base case. The second one was designed to integrate stack ventilation. Scientific instruments were installed in the two houses at various positions to collect data.

Situated on 13°N latitude, Bangkok has hot and humid climate. Average annual temperature and relative humidity are 28.7°C and 73.5% RH accordingly. Its diurnal temperature swing is less than 8°C. Average wind speed is 1.7 m/s with 39.46% of calm period. Average annual rainy days is 124 [1].

## 2. Theory and related works

Thermal force is referred to as a stack effect. Natural ventilation will occur through stack effect when there is a difference in height between an inlet and an outlet opening and when outdoor air is cooler than indoor air. When indoor air is warmer than outdoor air, variations in air density occur. The lighter weight of hot air rises and leaves through the higher opening, while a depression is created at the lower opening, inducing an inward airflow.

Stack ventilation is natural ventilation making air change in a building. For residential ventilation, ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) Standard 62-1989 gives 0.35 ACH (air changes per hour) ventilation rate requirements for houses [2]. Stack ventilation can remove heat accumulated inside a building and draw cooler outdoor air instead. The higher the temperature difference, the greater the height between an inlet and an outlet opening, and the larger opening size, the more air will flow. The equations of an airflow rate of stack effect were proposed by many authors such as Olgyay [3], ASHRAE [2] and Stein, Reynolds and McGuines [4]. Their equations were similar, only their proportional constants were different. The equation of airflow rate of stack ventilation given by Stein, Reynolds and McGuines is

$$Q = CA\sqrt{\frac{h(t_i - t_o)}{t_i}} \tag{1}$$

where $Q$ = airflow ($m^3$/sec.)
$C$ = constant of proportionality = 91.1 at 65% effectiveness (70 at 50% effectiveness)
$A$ = area of cross section through stack, or outlet ($m^2$)
$h$ = height difference, between inlets and outlets (m)
$t_i$ = (higher) temperature inside, within the height h (°C)
$t_o$ = (lower) temperature outside (°C) [4].

Stack ventilation in a house was designed and built in Bangkok. It was found that the force of outward flow was worthwhile [5]. A study of stack ventilation in a house via computational fluid dynamics program showed that it could make airflow rate of 1.76 ACH in a ground floor hall [6]. A stack effect experiment in an existing apartment with a greenhouse added at the rooftop to generate temperature difference revealed that a room with stack ventilation had three times more airflow during nighttime and 8.75 times more during daytime than an existing room or six times more during 24-hour period [7].

## 3. Methodology

The method of this research was experimentation in two existing houses with the same physical and most similar environment (figure 1). The first house without stack ventilation was a base case. The second one was designed to integrate stack ventilation. During the experiment, all windows of both houses were closed. Internal doors of every room were also closed.

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**Figure 1.** Two houses facing north in the experiment. The house on the left hand side had stack ventilation while the house on the right hand side was a typical house used as a base case.

Experimented houses were two-storey houses with four bedrooms (figure 2). Each house was situated on 200 square meters of land on the north rim of Bangkok. The total floor area of each house was 167 square meters. The front of the houses faced north. Their structures were reinforced concrete posts and beams with precast concrete floors. Their external and internal walls were made of autoclaved aerated concrete blocks with cement plaster finishing. Sliding windows were installed for all rooms except awning windows for bathrooms. The materials of the windows were aluminium frames with single green tinted glazing. Their hip roofs were made of cement tiles on steel roof frames. Ceilings of all rooms were made of gypsum boards.


**Figure 2.** Ground floor and second floor plans of the houses in the experiment

The studied areas were limited to common areas of the house such as a hallway, a living-dining space, stairs and a stair hall on the upper floor. Those areas occupied the area of 49.16 square meters. Bedrooms, bathrooms and a kitchen were in closed mode and without ventilation.

Seven temperature and relative humidity data loggers (figure 3) were calibrated and then installed in the two houses for the experiment. Data logger number 1, 2 and 3 were installed in the house with stack ventilation in the hallway on the ground floor, in the mid of living-dining space and in the stair hall on second floor accordingly. Data logger number 4, 5 and 7 were installed in the base case at the same positions in the house with stack ventilation accordingly. Data logger number 6 was installed outside between those two houses (figures 4 and 5).

**Figure 3.** Temperature and relative humidity data loggers and the calibration.

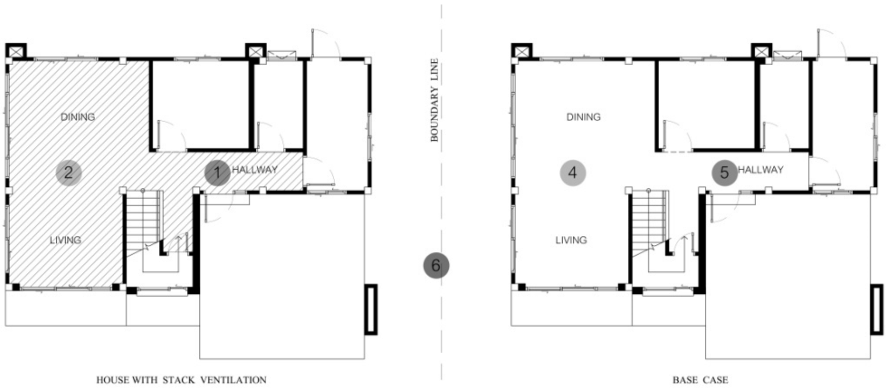


**Figure 4.** Position of temperature and relative humidity data loggers at 1-meter height above ground floor. Shaded areas indicated stack ventilation

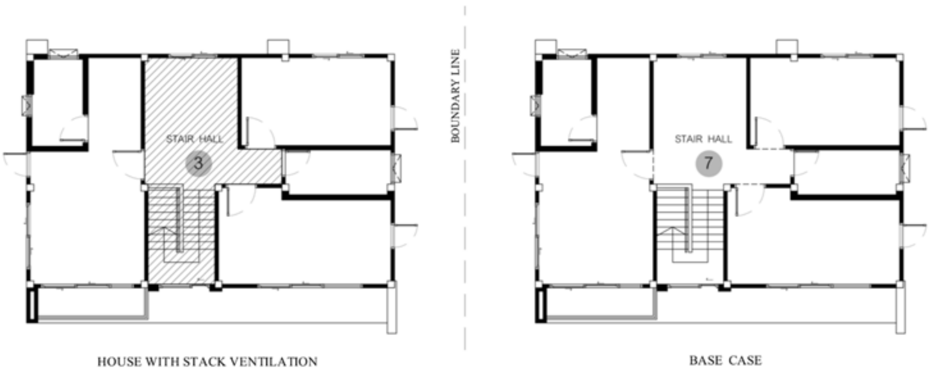


**Figure 5.** Position of temperature and relative humidity data loggers at 1-meter height above second floor. Shaded areas indicated stack ventilation

A hotwired anemometer was installed at an vertical opening slot over the second floor ceiling above a door of bedroom 3 in order to measure airflow of the stack ventilation designed (figure 6). Air temperature, relative humidity and wind speed data were recorded minutely for a few consecutive days in November 2016.

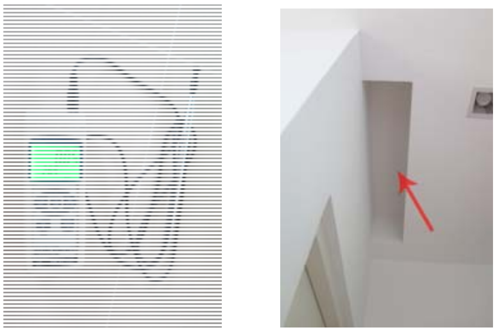

**Figure 6**. A hotwired anemometer and its location of installation at a vertical opening slot over second floor ceiling

## 4. Experimented house and stack ventilation design

The concept design of stack ventilation was based on minimal modification of the house. Attic heat was utilized to increase temperature difference. Air temperature of 43 °C could be found in the attic during the daytime. In addition, height between an inlet and outlets was magnified by placing an inlet opening on the entry door at a hallway on the ground floor and placing outlet openings at the top ridge of its hip roof. Three modified opening points were added from a typical house or a base case as the following

1. Opening at the entry door having a 0.351 square meter (figure 7) for inlet airflow
2. Vertical opening slots at the ceiling in front of bedroom 3 on the second floor having a 0.057 square meter (figure 8) for outlet airflow
3. Five rooftop openings having a 0.048 square meter (figure 9) for outlet airflow.

**Figure 7.** An opening on entry door looking from parking garage

**Figure 8.** Opening slots at the ceiling on the second floor

**Figure 9.** Five openings at rooftop.

## 5. Results and discussions

Hourly air temperature and relative humidity at the hallway on the ground floor of the house with stack ventilation were lower than those of the base case as shown in figure 10 and 11.

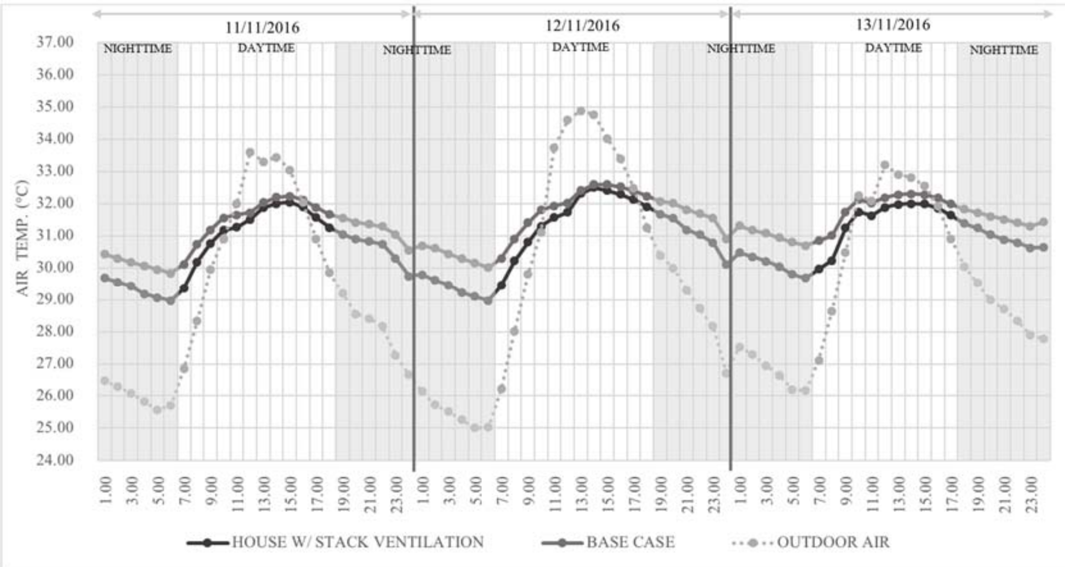


**Figure 10.** Hourly air temperatures at the hallway on the ground floor

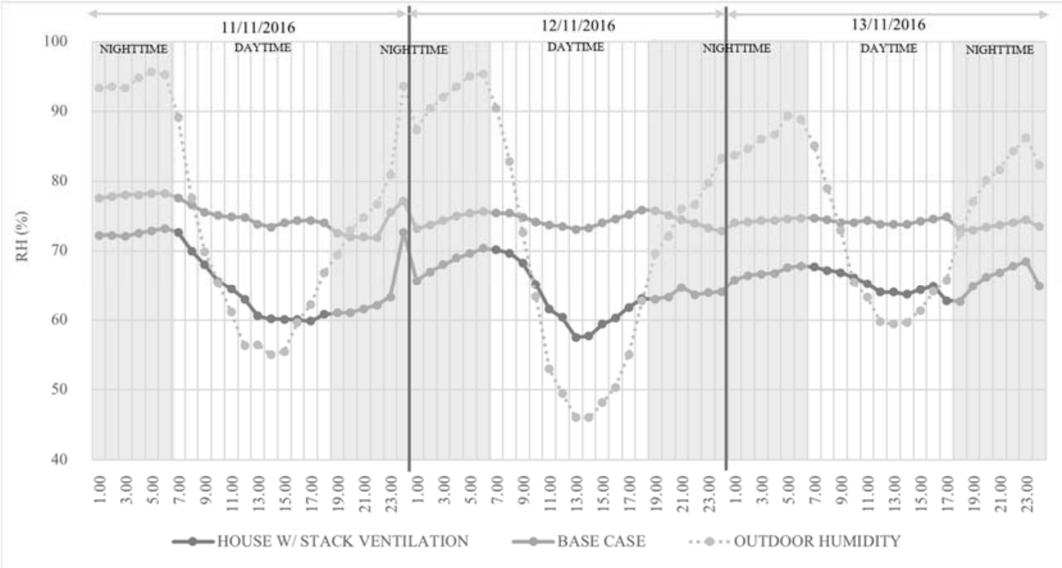


**Figure 11.** Hourly relative humidity at the hallway on the ground floor

Average air temperature and relative humidity during 24 hours at the hallway on the ground floor of the house with stack ventilation were 30.8 °C and 65.5% accordingly and of the base case were 31.4°C and 74.5% accordingly. The house with stack ventilation had 24-hour average air temperature 0.6°C lower than that of the base case. The lowest difference of air temperature 1.1°C was found at 4:00. Average 24-hour relative humidity at the hallway of the house with stack ventilation had 9% RH lower than that of the base case.

At the living-dining space on the ground floor, hourly air temperature of the house with stack ventilation was slightly lower than that of the base case as shown in figure 12. However, the relative humidity of the house with stack ventilation was much lower than that of the base case as shown in figure 13.

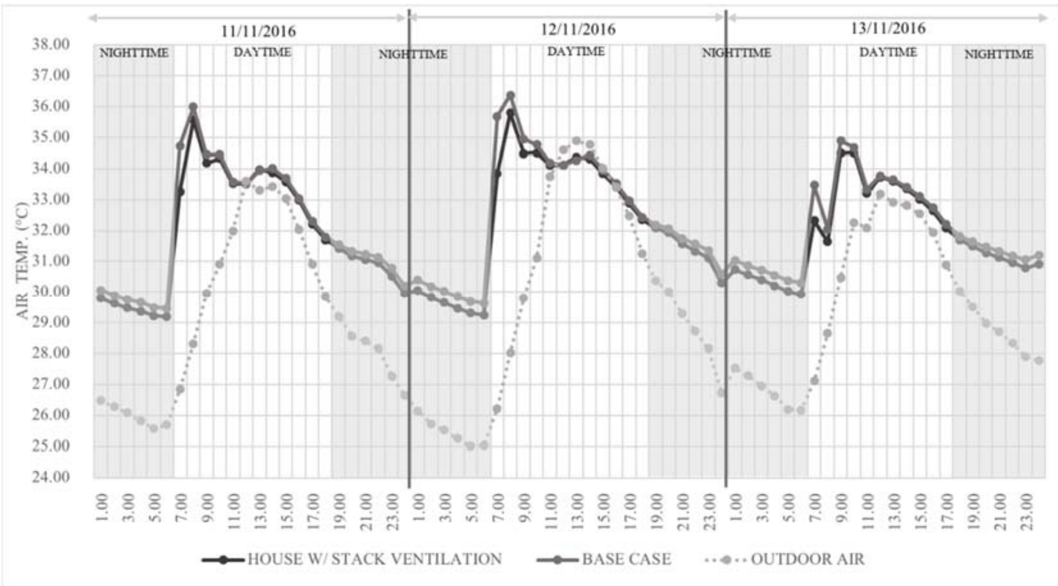


**Figure 12.** Hourly air temperature at the living and dining space on the ground floor

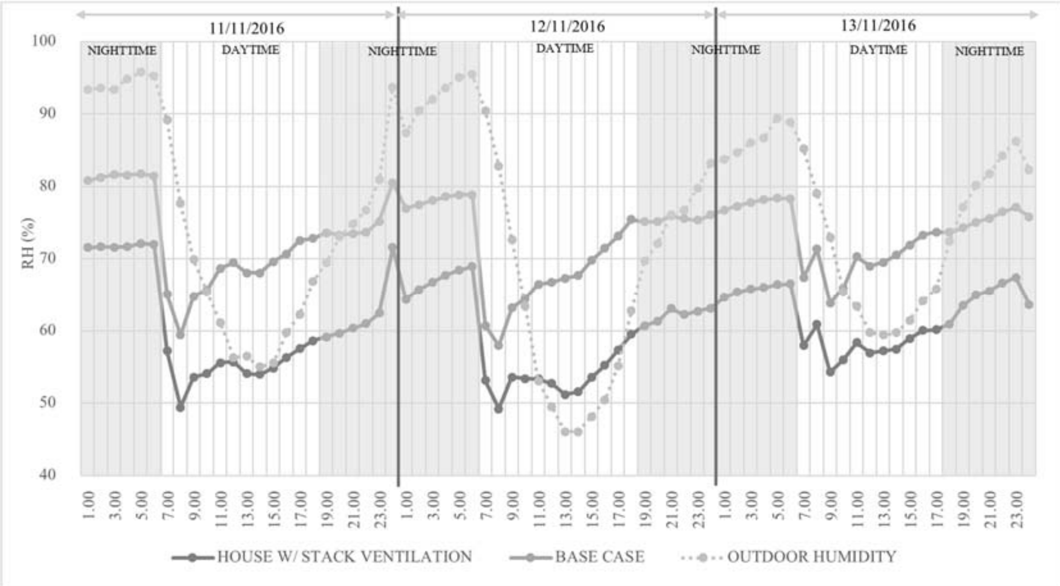


**Figure 13.** Hourly relative humidity at the living and dining space on the ground floor

Average air temperature and relative humidity during 24 hours at the living-dining space on the ground floor of the house with stack ventilation were 31.9°C and 61.1% accordingly and of the base case were 32.1°C and 73.1% accordingly. The house with stack ventilation had 24-hour average air temperature 0.3°C slightly lower than that of the base case. The lowest difference of air temperature 1.8°C was found at 7:00. Average 24-hour relative humidity at the living-dining space of the house with stack ventilation had 12.1% RH much lower than that of the base case.

On the second floor, hourly air temperature and relative humidity at the stair hall of the house with stack ventilation also lower than those of the base case all day long as shown in figures 14 and 15.

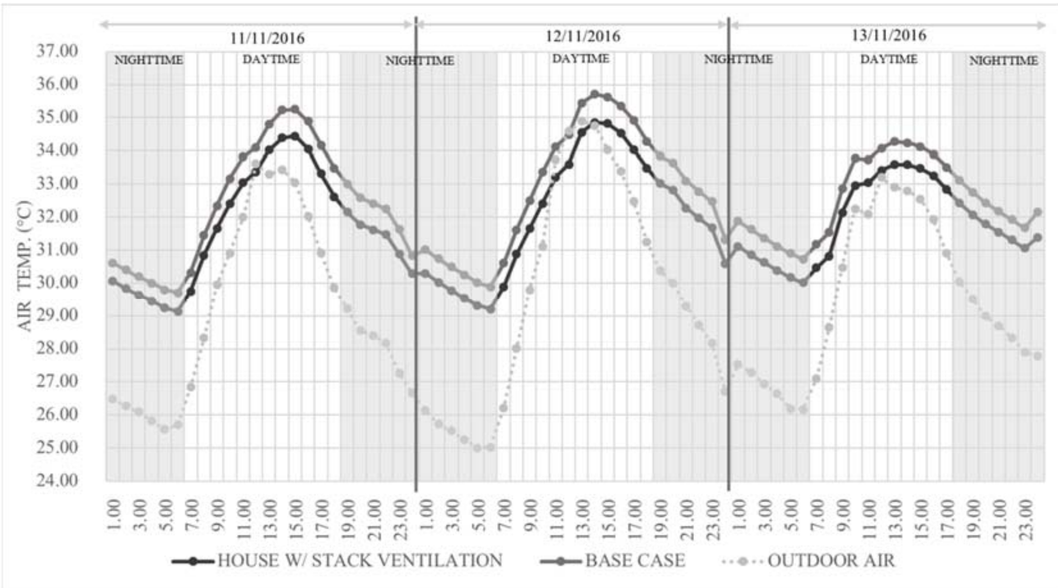


**Figure 14.** Hourly air temperature at the stair hall on the second floor

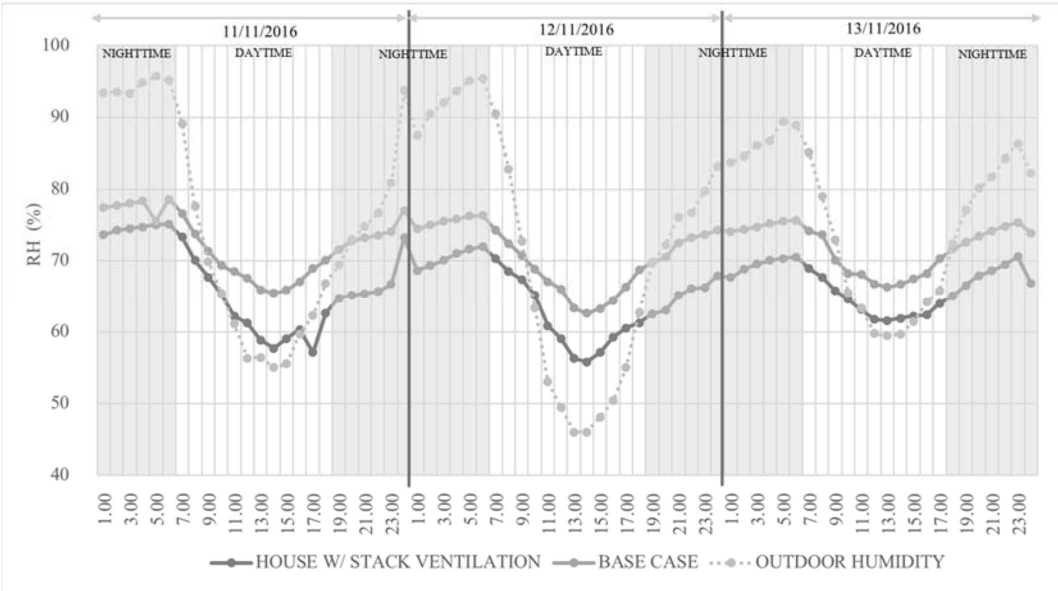


**Figure 15.** Hourly relative humidity at the stair hall on the second floor

Average air temperature and relative humidity during 24 hours at the stair hall on the second floor of the house with stack ventilation were 31.8 °C and 66.3% accordingly and of the base case were 32.5°C and 73.9% accordingly. The house with stack ventilation had 24-hour average air temperature 0.7°C lower than that of the base case. The lowest difference of air temperature 0.9°C was found at 10:00. Average 24-hour relative humidity at the stair hall of the house with stack ventilation had 5.6% RH lower than that of the base case.

From the experiment, it was found that the house with stack ventilation had airflow. Wind speed at an opening slot over second floor ceiling could be detected as shown in figure 16.

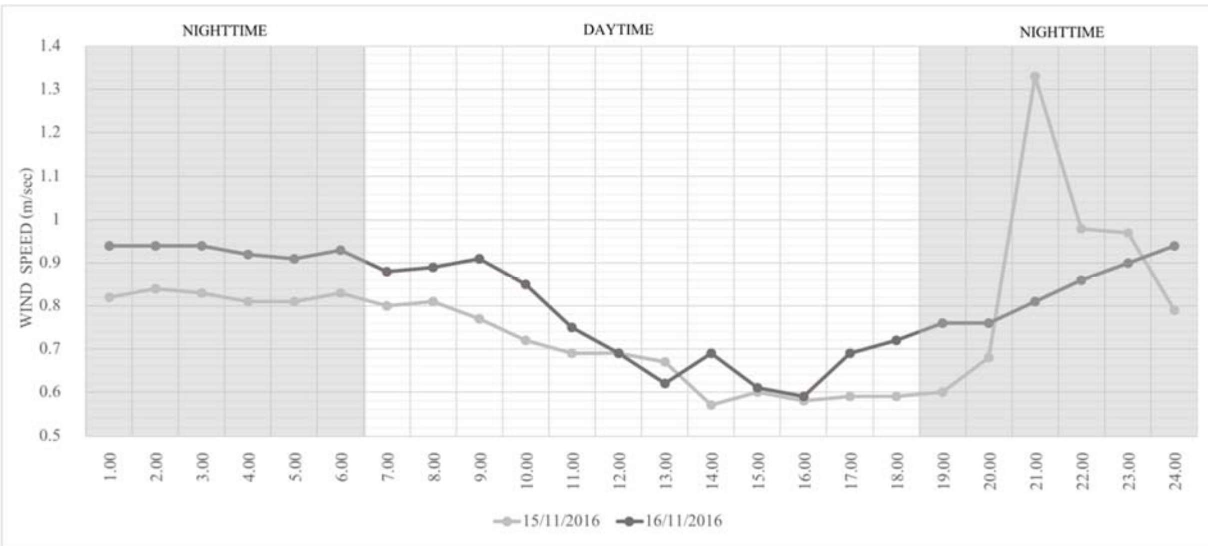


**Figure 16.** Hourly wind speed at an opening slot over second floor ceiling

Average 24-hour wind speed at an opening slot over second floor ceiling was a 0.79 meter per second. The daytime and nighttime average wind speed at the opening slot was a 0.72 and a 0.87

meter per second accordingly. Air changed by stack ventilation was 37.53 litters per second or ACH of 1.06 could be achieved.

## 6. Conclusions

It was found that for a closed house stack ventilation could reduce heat and moisture accumulated inside the house. On the second floor where buoyancy made hot air rise and accumulate, the house with stack ventilation had average indoor air temperature 0.7 °C lower than that of the house without ventilation and the lowest value 0.9°C was found at 10:00. On the ground floor, the average indoor air temperature at the hallway and living-dining space of the house with stack ventilation were 0.6°C and 0.3°C lower than those of the house without ventilation accordingly.

Stack ventilation could reduce inside humidity well especially on the ground floor. The living-dining space and the hallway of stack-ventilated house had average 12.1% RH and 9% RH lower than those of the house without ventilation. On the second floor, average 5.6% RH was lower than that of the house without ventilation.

In conclusion, stack ventilation functioned well. Ventilation rate of 37.53 litres per second was found. 1.03 ACH ventilation rate could be achieved in the stack-ventilated spaces with small effective opening only 0.10% of stack-ventilated area while ASHRAE Standard 62-1989 gives 0.35 ACH ventilation rate requirements for houses.

## Acknowledgements

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