EXPERIMENTAL INVESTIGATION OF AIR TEMPERATURE REDUCTION OF TURBINE VENTILATOR WITH VENTILATION DUCT IN ATTIC

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ABSTRACT

The aim of this study was to investigate air temperature reduction of turbine ventilator commonly used in hot-humid environment. A series of experimental investigations was performed under controlled laboratory conditions in an 8 m^3test chamber with 1 m of ventilation duct in simulation attic. Thermocouple sensors were installed in the test chamber and ventilation duct to observe the temperature changes from time to time. Wind speed towards turbine ventilator was set at 1.0 m/s to 5.0 m/s. From this study, a reduction of air temperature was recorded from 8.08°C to 9.58°C. It was also found in the low wind condition, air temperature reduction took a longer period to reach the air temperature equilibrium. Furthermore, warm air was accumulated in the vent area of the test chamber without the operation of turbine ventilator. From this study, it can be concluded that, turbine ventilator able to reduce air temperature and to withdraw heat in the form of warm air trapped in a space.

Keywords: Air temperature reduction, experimental investigation, turbine ventilator.

INTRODUCTION

Ventilation is required to expel or dilute pollutants and to control the thermal environmental conditions in buildings or indoor spaces. It must be adequate to ensure that acceptable levels for occupants' comfort and health can be achieved [1, 2]. Ventilation can be provided by various methods either natural or mechanical. In relation to building roofing, proper ventilation plays an essential role in extending the life of a roof which is referring to attic ventilation. In cold climate, attic ventilation is required to maintain a cold roof temperature in order to prevent ice dams from forming as well as to vent moisture that moves from the indoor space to the attic. In hot-humid climate, the primary purpose of attic ventilation is to remove hot and humid air from the attic which reduces mould growth and protects the shingles from excessive heat and thus lessen building cooling load. A phenomenon of hot and humid air trapped in attic space has caused problems to buildings as it will indirectly cause the rising of indoor temperature of living space and creating discomfort zone to occupant within the space [3]. Studies show that heat trapped in the attic space might cause attic temperature risen to 50% higher than the outdoor temperature [4, 5]. Hence, ventilation control in attic space is very important to decrease the energy transfer between the attics and living spaces.

It is reported in the literature, the strategies of attic ventilation assist to control temperatures in the attic and it is also has benefits in controlling high energy consumption and improving indoor environment [6]. Amongst these strategies of attic ventilation, turbine ventilator has been widely accepted and become a common ventilation feature in many types of buildings [7]. Turbine ventilator is labelled as low carbon technology due to its application on buildings which is eco-friendly and eco-saving [8]. It is very simple in use, durable and low costing. The turbine has vertical vanes and uses natural wind for rotation, which has the benefit of very less electricity usage [9, 5, 10]. This invention was initiated by Meadows, 80 years ago and was patented as "rotary ventilator" [11]. This device is used to extract hot and damp air out from an attic space, which is the space in between building roof and living space. The application of turbine ventilator still can work even when there is no wind blow or stagnant air at the outdoor. The existence of net free vent area at the vertical blades induce stack effect and extract hot and stale air out from the building provided there is sufficient temperature difference between outdoor and indoor [12, 13]. Turbine ventilator in such a case can meanwhile enhance the indoor air quality by ventilating the indoor air which often depends on the installation design.

As discussed in many studies, performance of turbine ventilator is affected by two major parameters: physical and operating parameters [8]. The physical parameters are size (diameter), duct size, height, blade design and number of blades. The operating parameters include outdoor wind speed, induced air flow, ventilation rate, rotational speed, and air temperature [8]. Throughout the literature, the outcome results of turbine ventilator performance are discussed in terms of: i) ventilation rate (in L/s, m^3/s and ACH; ii) air velocity (m/s) and; iii) air temperature (reduction) (°C) [7]. Most of the studies found in the open literature focus on air change hour (ACH) in order to determine the efficiency of turbine ventilator instead of air temperature reduction [10, 14-16]. There are only a handful of studies emphasise on air temperature reduction in investigating the performance of turbine ventilator in which these studies focus on simulation approach. For instance, investigated a rooftop ventilator by investigating air temperature reduction of turbine ventilator based on numerical simulation [17]. They found that when exhausted airflow was increased from 1 m/s to 3 m/s, it could be seen a mean temperature reduction from 27.71 to 27.26°C. From their simulation study, it can be concluded that air temperature reduction were affected by the airflow inside the turbine ventilator. Thus, it would be interesting to investigate air temperature reduction of turbine ventilator using experimental approach. With this motivation, the aim of this study was to investigate air temperature reduction of turbine ventilator commonly used in hot-humid environment based on experimental approach under controlled laboratory conditions.

METHODOLOGY

A test chamber was built with dimension of 2 m x 2 m x 2 m in Energy Testing Unit. In this study, a 14-inch curved-blade aluminium made turbine ventilator was used representing the size of turbine ventilator commonly chosen in the household of hot-humid countries [15]. A ventilation duct (flexible duct) with a diameter of 0.15 m and length of 1 m was directed from the vent of the test chamber to the opening of the turbine ventilator (Figure 1). Thermocouple sensors were placed in six points along the duct in order to observe changes of temperature and four points of thermocouple sensors were placed in the test chamber. The temperature changes at the vent of the test chamber ($T_{vent,chamber}$) and the opening of turbine ventilator ($T_{vent,turbine}$) was compared in this paper. In addition, a pre-conditioning chamber was also built and connected to the test chamber to induce warm air into the test chamber by using heat blower. Meanwhile, a blower fan with airflow straightener was placed 1 m away from the turbine ventilator to blow air towards it in order to simulate outdoor wind speed and a controller was used in adjusting the wind speed. Table 1 shows a summary of physical measurement and characteristics of the experimental set up.

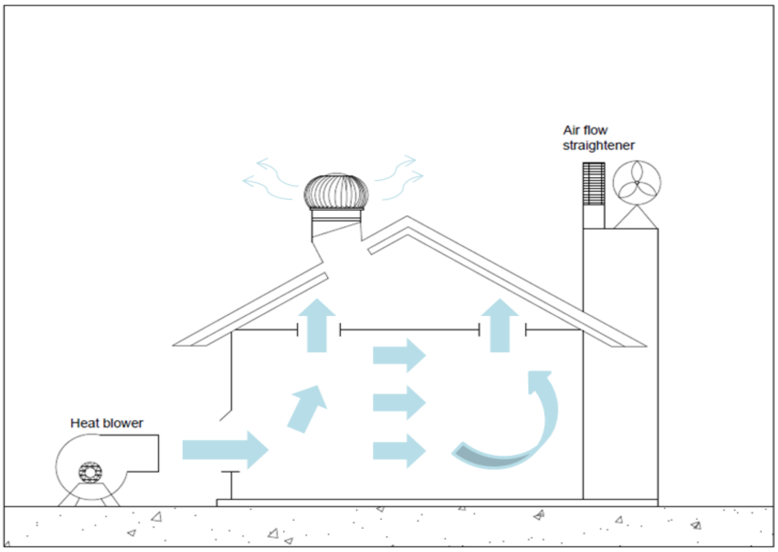


Figure 1. Schematic diagram of the experimental set up

Table 1. Summary of physical measurement and characteristics of experimental set-up

Turbine Ventilator	
Vent diameter	14 inch (0.3556 m)
Material	Aluminium
Number of blades	24 blades
Shape of blades	Curved
Ventilation duct diameter	0.15 m
Ventilation duct area	0.01767 m^2
Placement of thermocouple	6 points
Test Chamber	
Volume	8 m^3
Placement of thermocouple	4 points

Data were collected using data logging system (DataTaker800) which was logged for every period of experimental run. Warm air was induced into the test chamber to pre-condition the air until it reached 40°C of mean air temperature in the test chamber. Blower fan was switched on and controlled at 1.0 m/s, 2.0 m/s, 3.0 m/s, 4.0 m/s and 5.0 m/s. Each testing was carried out for three hours to observe the temperature change within the chamber.

RESULTS AND DISCUSSION

Air temperature reduction within test chamber

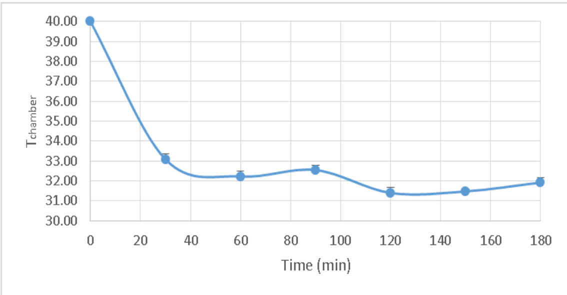
Table 2 shows results of air temperature reduction recorded within the test chamber. It can be seen that different wind speed affected the reduction of air temperature in the test chamber. The highest air temperature reduction was found at 5.0

m/s with a value of 9.58°C. At the lowest wind speed (1.0 m/s), the air temperature reduction was found to be 8.08°C. In addition, the increasing of wind speed resulted in the increasing of air temperature reduction. This was due to the temperature of a mass of air depends on the velocity of the air molecules and their mass, and thus temperature generally increases [19]. However, when the wind speed increased from 2.0 m/s to 3.0 m/s, 4.0 m/s and 5.0 m/s, the air temperature reduction only a slightly increasing was recorded which was from 0.05°C to 0.51°C as compared to a steep increase from 1.0 m/s to 2.0 m/s which was 0.99°C. After that the air reduction temperature had started slowing down after 2.0 m/s. Further investigation using numerical simulation based on contour line should be conducted in the future to observe temperature distribution in the test chamber.

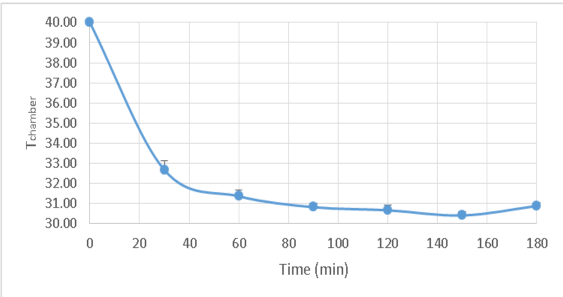
Table 2. Air temperature reduction within the test chamber\

Wind speed (m/s)	$T_{initial}$	T_{end}	$\Delta T_{chamber}$
1.0	40.00	31.92	8.08
2.0	40.00	30.93	9.07
3.0	40.00	30.88	9.12
4.0	40.00	30.50	9.50
5.0	40.00	30.42	9.58

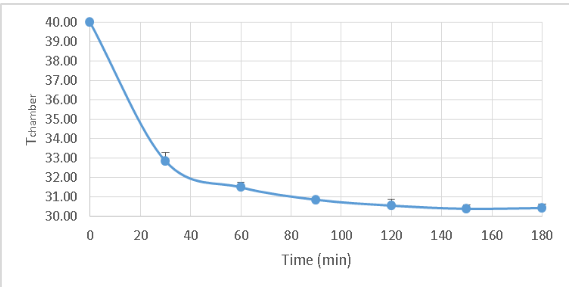
When the temperature change in the test chamber was observed half-hourly, it was found with the wind speed of 1.0 m/s, the air temperature in the test chamber did not reach a constant temperature and still fluctuated for 60 minutes. The results of 1.0 m/s was then compared to 3.0 m/s and 5.0 m/s of wind speed, it was discovered that the temperature reduction decreased gradually for both and the fluctuation stopped at the end with 5.0 m/s of wind speed and remain constant after that {Figure 2(a)(b)(c)}. As such it can be concluded that at higher value of wind speed, the air temperature reduction in the test chamber reached an equilibrium stage within in a shorter period of time.



a) At wind speed of 1.0 m/s



(b) At wind speed of 3.0 m/s

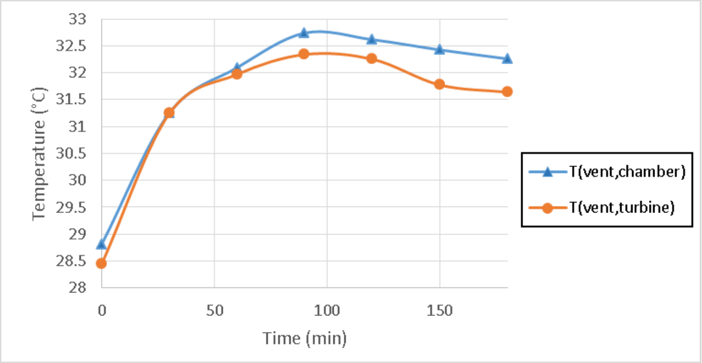


(c) At wind speed of 5.0 m/s

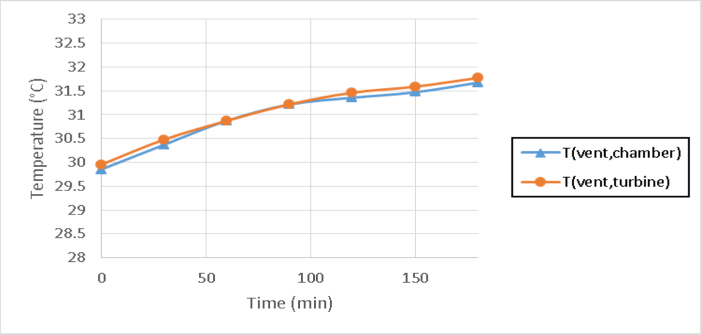
Figure 2. Plot of temperature changes which was half-hourly observed at various wind speed

Air temperature reduction within the ventilation duct

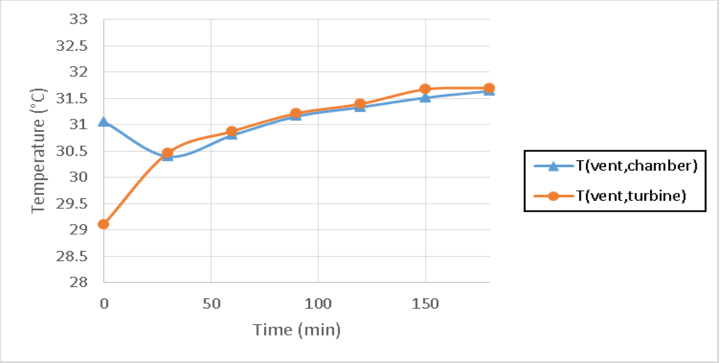
At wind speed of 1.0 m/s, temperature in the vent of test chamber was higher as compared to the opening vent of turbine ventilator throughout three hours of experiment (Figure 2(a)). When the wind speed increased to 3.0 m/s, temperature at these two openings showed a closer gap as illustrated in Figure 2(b), in which the air temperature at the opening of turbine ventilator was only found to be a slightly higher. When it was speeding up to 5 m/s, the air temperature in the vent of the test chamber indicated a high value at the beginning and started to cool down with the assistance of the turbine ventilator operated in the first 30 minutes (Figure 2(c). It was also found that the warm air was accumulated in the vent of the test chamber before the operation of turbine ventilator. This shows that heat was trapped in a space without proper ventilation and could possibly radiate into the space [3]. It was also found that the air temperature along the duct was within the range of 28.5°C to 32.7°C even with the test chamber air temperature of 40°C.



(a) At wind speed of 1.0 m/s



(b) At wind speed of 3.0 m/s



(c) At wind speed of 5.0 m/s

Figure 3. Plot of temperature changes in the vent of test chamber and opening of turbine ventilator which was half-hourly observed at various wind speed

CONCLUSIONS

From this study, it was found the air temperature reduction of turbine ventilator was in a range of 8.08°C to 9.58°C with various wind speed controlled at 1.0m/s to 5.0m/s. The air temperature in the test chamber with low value of wind speed required a longer ventilation time to reach constant stage and higher wind speed indicated a better performance to withdraw the warm air in the test chamber. Besides, warm air was accumulated in the vent of the test chamber without the assistance of turbine ventilator. Turbine ventilator able to ventilate the indoor air effectively, however the feasibility of turbine ventilator was depending on the wind condition in terms of wind speed. Further investigation should be carried out in the future to numerically investigate temperature distribution and air velocity in the test chamber and ventilation duct based on simulation approach. Besides, further investigation should also be carried out based on a real case study to investigate the performance of turbine ventilator in relation to physical and operating parameters.

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