Investigation of Ventilation Induced by Square Inclined Solar Chimney

Md. Mizanur RAHMAN
Senior Lecturer, Mechanical Engineering
Head, Energy Research Unit (ERU)
Faculty of Engineering, Universiti Malaysia Sabah,
Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia
Email: mizanur@ums.edu.my

Wan Khairul MUZAMMIL
Lecturer, Mechanical Engineering
Head, Material and Mineral Research Unit (MMRU)
Faculty of Engineering, Universiti Malaysia Sabah,
Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia

Ling Leh SUNG
Post Graduate Scholar, Energy Research Unit (ERU)
Faculty of Engineering, Universiti Malaysia Sabah,
Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia

Mohd. Suffian bin MISARAN
Senior Lecturer & Head
Mechanical Engineering, Universiti Malaysia Sabah,
Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia

Ahmed JAWAD
Post Graduate Scholar, Energy Research Unit (ERU)
Mechanical Engineering, Universiti Malaysia Sabah,
Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia

Abstract **- Passive ventilation is one of the well-known valid options that can be used to reduce the dependency on mechanical cooling appliances. It is also used to improve the indoor air quality. Solar chimney assisted ventilation system is a well-known passive ventilation system that can be used in the building construction industries. The aim of this paper is to study the effects of square shape solar chimney on building ventilation for Sabah, Malaysia climate. Therefore, a square solar chimney is designed with the inlet and outlet areas are varied from 0.0056m^2 to 1.8m^2 and 0.104m^2 to 0.1264m^2 respectively. Two transparent glasses and two perforated plates are used to construct a squared solar chimney. The glasses and plates are placed in opposite sides of the solar chimney. The vertical and inclined solar chimneys are used in this experiment. The inclination angles are maintained 60^o to 90^o with horizontal axis. The air gaps between the absorber and the glazing are maintained 10cm to 14cm respectively. In this study, the volumetric flow rates are determined theoretically and experimentally. The results showed that the volumetric flow rate is maximum at optimum inclination angle which is 80^o from horizontal. The volumetric flow rate is reduced when the inclination angle is higher 80^o. The air gap has also significant effects of volumetric air flow rate and it reduces when the air gap depth is exceeding the optimum one is 14 cm.**

Keywords: Solar chimney, passive ventilation, hot and humid climate

1.0 INTRODUCTION

The ventilation in the building is an important factor that helps to remove indoor pollution and dilute contamination [1]. Many building in the urban and suburban areas are using mechanical appliances for ventilation and cooling [2] [3]. These also can be achieved by using solar chimney ventilation system. The components of the solar chimney are solar heat absorber, glazing and chimney. The solar chimney works base on the principle of natural convection flow, in which the driving force is buoyancy force. It is developed from the thermal gradient between absorber and ambient [4]. The absorber in the solar chimney absorbs solar irradiation from the sunlight and heated up. The heat energy is transferred from the absorber to the air through natural convection process. The hot air moved out through the chimney and the cold air from the house enter into the solar chimney. This is known as solar chimney assisted natural ventilation system [5]. The stack effect in the solar chimney creates the air flow inside the chimney, resulted hot air moves out from the system. This technology also assists to create air flow in the building and is allowing fresh outdoor air enter in to the building space. Therefore, it has higher potential values in the building constructions industries [5]. It is also intended to exploit alternative source of energy to save traditional energy without sacrificing indoor air quality and occupant comfort [6]. This technology has been studied experimental and theoretically by the different researchers to understand the effects of heat generation rate, size of chimney, gaps between glazing and absorber. The vertical and inclined solar chimneys are also used for building ventilation. Some of the researchers have been conducted performance analysis of vertical solar chimney while others have been studying the inclined solar chimney [6] [7] [8] [9] [10]. The solar chimney has significantly increased the air flow inside the building as well as increased the heat gain value [11]. The performance of the inclined solar chimney depends on the location and degree inclination of the solar absorber. In the inclined solar chimney, it is found that the maximum air flow is observed when the solar chimney inclination angle lies between 45° to 70° for latitude angle of 28.4°N. On the other hand for solar heating system, the best performance is observed when the air heater is placed at an angle 40^o to 50^o [4]. The other parameters such as ratio between inlet and out of the solar chimney, height of absorber and air gap that also alter the performance of the solar chimney [12]. Among the all the influencing parameters solar irradiation intensity is the most influencing parameters that can alter the performance of solar chimney [13].

In addition, most of the houses in Malaysia have mechanical cooling appliances such as air conditioning unit, electric fan to enhance thermal comfort [14]. These appliances produce unexpected heat during operation that increases the local temperature. Other than this, the population growth and living standards improvement are significant in Malaysia. These are also responsible for the increase of energy demand in the domestic sector [15]. Therefore, the main aim of the present research works would be focusing on the performance investigating for square shaped inclined solar chimney. Different model solar chimneys are designed with two inlets and two absorber facilities. There are five models with different inclination angle varied from 60º to 90º with horizontal axis are tested in the laboratory.

2.0 DEVELOPMENT OF THEORY

In the solar chimney, due to temperature difference or density difference, a draft force is created that push the air from inside of the chimney to outside. The flow in the solar chimney is known as natural convection flow and draft is generated in the chimney is due to the stack effects [16]. The draft can be estimated from the natural draft pressure (ΔP)equation.

$$\Delta P = (\rho_a - \rho_c)gh - - - - - - - - (1)$$

Where as ρ_a is the ambient air density; ρ_c is the density of air inside the chimney; g is the acceleration due to gravity and h is the chimney height.

The major and minor losses of pressure per unit volume of fluid flow in the chimney can be obtained from the following equation [17].

$$\Delta P_{loss} = \frac{\rho_c \times fhv^2}{2\,d_h} + \sum \frac{k\rho_c v^2}{2} - - - - - - - - (2)$$

Where f is the friction coefficient; d_h is the hydraulic diameter of the chimney; k is the minor loss coefficient. The theoretical air velocity (v) and volumetric air flow (q) inside the chimney can be estimated by combining the equation 1 and equation 2.

$$v = \sqrt{\left[\frac{(\rho_a - \rho_c)gh}{\frac{\rho_c \times fh}{2\,d_h} + \sum \frac{k\rho_c}{2}}\right]} = \sqrt{\left[\frac{2(\rho_a - \rho_c)gh}{\frac{\rho_c \times fh}{d_h} + \sum k\rho_c}\right]}$$

$$\therefore \quad v = \sqrt{\frac{2gh(\alpha - 1)}{\frac{fh}{d_h} + \sum k}} - - - - - - - - (3)$$

$$q = A\sqrt{\frac{2gh(\alpha - 1)}{\frac{fh}{d_h} + \sum k}} - - - - - - - - -(4)$$

Where, α is the density ratio between ambient air and the inside chimney air.

The performance of the solar chimney depends on the physical geometry of the chimney as well as on the environmental conditions. Therefore, the design parameters such as chimney angle, gap between absorber and glass etc. are consider as variables [12] [18]. The daily average solar radiation and sunlight hours for Malaysia are varied from 4000 – 5000 Wh/m^2 and 4 – 8 hours respectively. In kota Kinabalu the average temperatures, especially in hot day around 30 – 32 °C, it can be reach up to 38 °C and at night the temperature can be go down to 22 °C [19] [20] [21].

3.0 EXPERIMENTAL IMPLEMENTATIONS

A square solar chimney was designed for ventilation as well as for experiments. Different inlet and outlet areas chimneys model were used for experiments. The dimension of the solar chimney

TABLE 1: DIMENSION OF SOLAR CHIMNEY

Absorber Angle	Air gap (m)	Area (m^2)	
		Inlet	Outlet
90^0	0.10	0.056	0.104
	0.12	0.045	0.115
	0.14	0.034	0.126
	0.16	0.022	0.138
85^0	0.10	0.169	0.104
	0.12	0.151	0.115
	0.14	0.133	0.126
	0.16	0.115	0.138
80^0	0.10	0.347	0.104
	0.12	0.322	0.115
	0.14	0.297	0.126
	0.16	0.272	0.138
75^0	0.10	0.597	0.104
	0.12	0.565	0.115
	0.14	0.532	0.126
	0.16	0.500	0.138

Transparent glasses are used in the two side of the chimney so that the solar energy can be received by the thermal absorber. Perforated plates were also used, so that air from the ambient can be entered into the chimney. The details about the chimney are shown in the Figure 1.

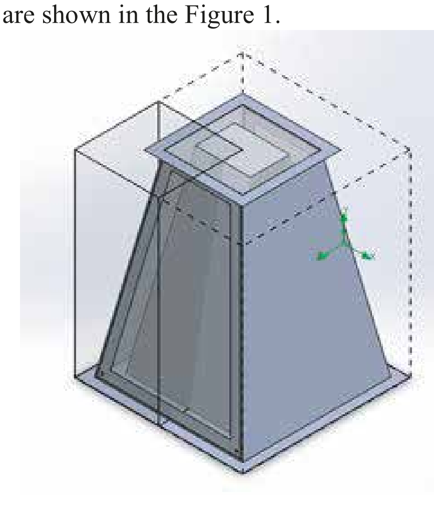

FIGURE 1: SQUARE INCLINED SOLAR CHIMNEY MODEL

Different solar chimney inclination angle and air gap are used during experiments. The solar chimney angle is varied from 75º to 90º from horizontal axis with increment of angle of 5º.

The gap is also varied from 0.10 m to 0.16 m with increment of 0.02 m. The performance of solar chimney is measured in terms of velocity enhancement and mass flow rate. For all cases, the height of the chimney has been kept constant which is 1 m. All the experiments are carried out at Thermal and Environmental Lab, Energy Research Unit, Universiti Malaysia Sabah.

4.0 EXPERIMENTAL PROCEDURE

In this study, all the experiments are started from cold condition, where the chimney temperature was same as ambient temperature. The highest daily solar average global radiation for Kota Kinabalu Sabah is 495.90 W/m^2 [22]. Therefore, the absorber is heated with an electric heater at constant heat flux (500W/m^2). A voltage variable transformer is used to adjust and to ensure required power input on the solar chimney system. A digital multi-meter and a digital clamp multi-meters are used to determine the input power in the system. The voltage and current data are recorded in every 2 minutes interval. The K type thermocouples are having temperature range of 0 to 250^{0}C are used to measure the temperature in different points in the solar chimney. Total five thermocouples are placed at the heat absorber and two thermocouples are placed at the air gap in the solar chimney. Ambient temperature is also recorded during experiments by using a thermocouple. All the thermocouples are connected with data logger to acquire temperature data automatically with interval 30 second. A hot air anemometer is used to measure the air flow rate during experiment and recorded data every 2 minutes interval.

5.0 EXPERIMENTAL RESULTS

The experimental results are shown in the Figure 2 and in the Figure 3. In vertical chimney model, the air flow rate is decreased with the increased of air gap. In the incline chimney models 80° and 85° the air flow rate is increased until the air gap is become 14 cm and the flow rate is dropped significantly with the increment of air gap further. For the model inclined chimney angle 75° the air flow rate is increased with increased of air gap. According to Lal et al., in the 25 m^3 volume space with solar chimney air gap 14 cm and one ton split air conditioning unit are able to reduced energy consumption by 10 to 20% [23]. Tongbai & Chitsomboon is also reported that the optimal air gap in the solar chimney should be between 14 cm to 16 cm for 1 meter long solar chimney, beyond this air gap, the air flow rate decreased significantly [24]. The gap increased may be increased heat losses from the absorber that reduced significant amount of flow rate. In addition, the cold inflow or flow reversal is a phenomena that has significant effects on the chimney performance [25]. The cold inflow is observed at the exit of the chimney and this phenomena occurs when the chimney pressure is lower than the ambient pressure. This is only possible at higher air gap and the temperature distribution in the chimney and in the air gap are not uniform [25] [26]. From the Figure 2, it is also found that the relations between flow rate and air gap in the solar chimney are nonlinear. Two degree polynomial regression model are stratify all the data since the R^2 values for all the model curves are more 0.80.

The relation between flow rate and inclination is drawn in the Figure 3. It is found that in the 16 cm air gap solar chimney, the air flow rate significantly varies with the inclination angle. The air flow rate is observed at 75° inclination solar chimney. Lal et al is also found that solar chimney performance is also depends on the location and inclination angle [23]. In the place where latitude angle 28.4°, the solar chimney optimum flow could be achieved at inclination angle lies between 45° to 70° and air gap 10 to 35 cm. At higher angle of inclination, the solar chimney model is experienced with flow reversal or cold in flow that reduces flow rate significantly. In addition, the impulsive force in the Y axis in the solar chimney may be change due to the change of angle. That may be had negative effect on chimney flow. Additionally, two degree polynomial regression models are run for different chimney model data. For all air gaps, the relation between flow rate and inclination angle are significant except for air gap 0.12 m air gap solar chimney is not significant since R^2 value is less than 0.80. This is because of entrance effect.

The experimental results are also compared with theoretical values for different air gap and inclination angle and presented in the Figure 4 and Figure 5.

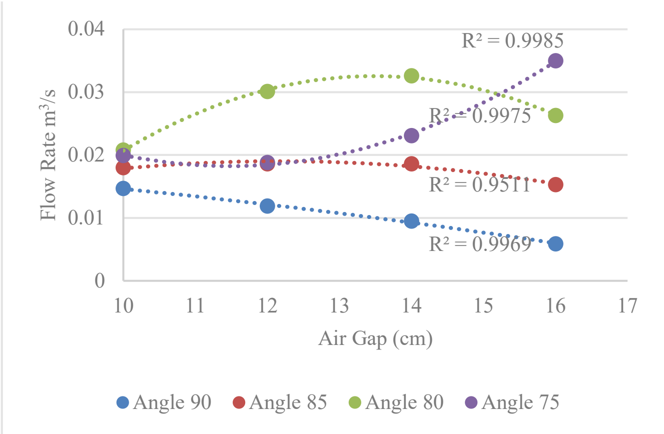

FIGURE 2: RELATION BETWEEN AIR FLOW RATE AND AIR GAP FOR DIFFERENT CHIMNEY MODEL

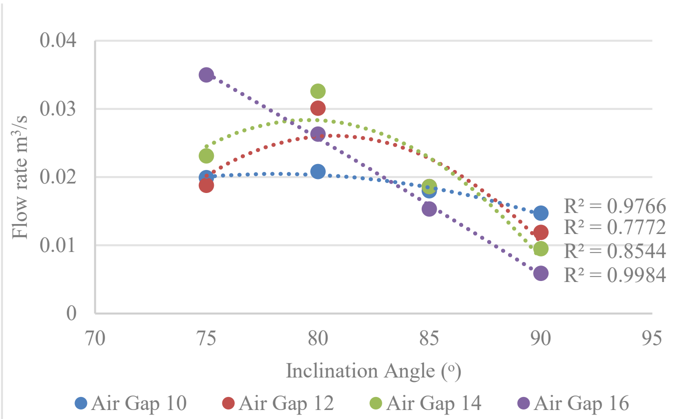

FIGURE 3: RELATION BETWEEN AIR FLOW RATE AND

INCLINATION ANGLE DIFFERENT CHIMNEY MODEL

It is found that in the figure 4 the experimental results are more scatter than theoretical values this is because the due to loss coefficient in the system. The theoretical coefficient is depended on the minor and major loss in the solar chimney. The flow character such as laminar or turbulent is also going to effect the air flow rate in the solar chimney. The theoretical air flow rate is also calculated for different opening area. It is also found significant difference with experimental result. Since the losses in the solar chimney depends on the velocity and according to continuity equation the velocity of air depends on the opening area. Therefore, air flow in the chimney during experiments are different theoretical value.

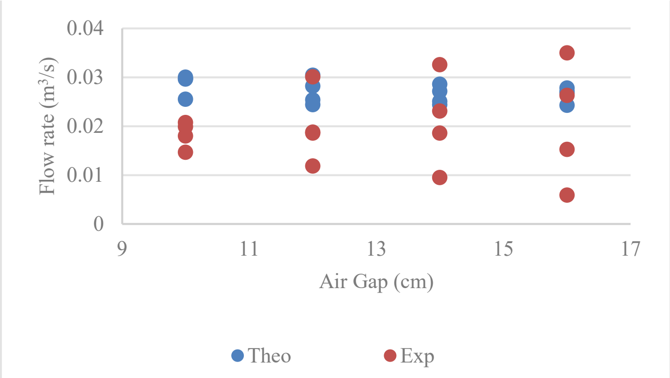

FIGURE 4: COMPARISON BETWEEN EXPERIMENTAL VALUES WITH THEORETICAL VALUE FOR DIFFERENT AIR GAP

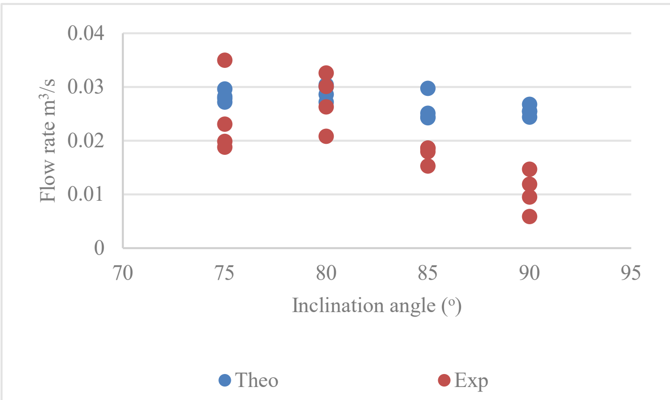

FIGURE 5: COMPARISON BETWEEN EXPERIMENTAL VALUES WITH THEORETICAL VALUE FOR DIFFERENT INCLINATION.

6.0 CONCLUSION

The aim of this paper is to verify square shape solar chimney for building ventilation. It is found that solar chimney air gap and inclination angle have significant effect on air flowrate. The maximum air flow is observed at the solar chimney inclination angle for 80° and air gap at 14 cm. This value is satisfied with other research works as well as theoretical value.

7.0 ACKNOWLEDGEMENTS

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