STUDY OF HYBRID NATURAL VENTILATION USING A COMBINATION OF TURBINE VENTILATOR AND SOLAR CHIMNEY

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ABSTRACT

Solar chimney is a common passive natural ventilation system. There is a small potential value when solar chimney is used independently. Therefore, solar chimneys are always applied in the form of integrating configurations. The aim of this study is to investigate the ventilation performance by integrating solar chimney and turbine ventilator. A small size solar chimney is proposed that ease its integration with turbine ventilator. The performance of solar chimney is studied experimentally by heating the solar chimney at constant heat flux. It is found that higher inclination angle and larger air gap depth is performing better. However, the performance start deteriorating after optimum value of inclination angle and air gap depth. Although no specific relationship can be found for inlet and outlet aperture area, but the inlet aperture area is recommended to be at least double the size of outlet aperture area. The integrated system is studied experimentally by heating the solar chimney under constant heat flux and/or by rotating the turbine ventilator at constant rotational speed. The results demonstrate that the ventilation performance of the solar chimney with rotating turbine ventilator is performing the best. The proposed solar chimney also shows the capability to encounter the flow reversal effect as the absence of wire mesh outperform the presence of wire mesh. All those results will be useful in the future solar chimney development either for designation or prediction to achieve the ventilation requirement.

ABSTRAK

PENGKAJIAN SISTEM HIBRID PENGUDARAAN SEMULA JADI DENGAN MENGGUNAKAN KOMBINASI VENTILATOR TURBIN DAN CEROBONG SURIA

Cerobong suria merupakan pasif sistem pengudaraan semula jadi yang biasa digunakan. Ia berpotensi rendah apabila cerobong suria digunakan bersendirian. Oleh itu, cerobong suria sentiasa digunakan dalam bentuk integrasi konfigurasi. Tujuan kajian ini adalah untuk menyiasat prestasi pengudaraan dengan mengintegrasikan cerobong suria dan ventilator turbin. Cerobong suria bersaiz kecil dicadangkan untuk memudahkan integrasi dengan ventilator turbin. Prestasi cerobong suria dipelajari secara eksperimen dengan memanaskan cerobong solar pada fluks haba seragam. Kajian mendapati sudut kecenderungan yang lebih tinggi dan kedalaman jurang udara yang lebih besar mempunyai prestasi yang lebih baik. Walau bagaimanapun, prestasi mula merosot selepas nilai optimum sudut kecederungan dan kedalaman jurang udara. Walaupun tiada hubungan khusus boleh didapati untuk bukaan masuk dan lubang keluar, tetapi bukaan masuk adalah disyorkan untuk sekurang-kurangnya dua kali ganda saiz lubang keluar. Sistem bersepadu ini dikaji dengan memanaskan cerobong suria di bawah fluks haba yang seragam dan / atau dengan memutar ventilator turbin pada kelajuan yang tetap. Keputusan menunjukan bahawa cerobong suria dengan ventilator turbin yang berputar menghasilkan prestasi pengudaraan yang terbaik. Cerobong suria yang dicadangkan juga menunjukkan keupayaan untuk menghadapi kesan pembalikan aliran kerana ketiadaan dawai jejaring menunjukkan prestasi yang lebih baik daripada kehadiran dawai jejaring. Hasil kajian ini akan berguna dalam pembangunan cerobong suria pada masa depan sama ada untuk reka bentuk atau kejangkaan untuk mencapai keperluaan pengudraan.

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LIST OF SYMBOLS

T_{abs}	-	Absorber temperature
T_s	-	Sun temperature
C_d	-	Coefficient of discharge
A	-	Opening area
η_{optica}	-	Optical efficiency
ε_{abs}	-	Emissivity factor
$\dot{m}$	-	Theoretical mass flow rate
$\dot{V}$	-	Volumetric flow rate
v	-	Air velocity
o	-	Outlet
r	-	Ration between outlet and inlet
L_s	-	Vertical distance between inlet and outlet of the solar chimney or stack height
T	-	Temperature
ρ_{f1}	-	Density of air in the flow channel
g	-	Acceleration due to gravity
θ	-	Angle of inclination with the horizontal surface
F_w	-	Drag force acting on the blade
ρ	-	Density of air
U_w	-	Wind speed at turbine ventilator
C_D	-	Drag coefficient
U_b	-	Air speed in the blade surface
P_1	-	Stagnation and static pressure at the duct inlet
P_2	-	Stagnation and static pressure at the duct outlet
ΔP_T	-	Total pressure drop due to duct
ρ	-	Fluid density
u	-	Fluid velocity
S_i^{porous}	-	Mass-distributed external force per unit mass due to a porous media resistance
g_i	-	Gravitational acceleration component along the i-th coordinate direction
$S_i^{rotation}$	-	coordinate system's rotation

μ	-	dynamic viscosity coefficient
δ_{ij}	-	Kronecker delta function (it is equal to unity when $i = j$, and zero otherwise)
k	-	turbulent kinetic energy
ε	-	turbulent dissipation
h	-	thermal enthalpy
Q_H	-	heat source or sink per unit volume
q_i	-	diffusive heat flux

LIST OF ABBREVIATION

GHG	-	Greenhouse gas
RE	-	Renewable energy
EFB	-	Empty fruit bunches
CO_2	-	Carbon dioxide
N_2	-	Nitrogen
CH_4	-	Methane
NH_3	-	Ammonia
H_2	-	Hydrogen
O_2	-	Oxygen
S	-	Sulphur
CO	-	Carbon Monoxide
POME	-	Palm Oil Mill Effluent
CDM	-	Clean Development Mechanism
MJ	-	MegaJoule
m^2	-	Meter square
^oC	-	Degree Celsius
W/m^2	-	Watt per meter square
km^2	-	Kilometer square
mm	-	Millimeter
MW	-	Megawatt
Wh/m^2	-	Watthour per meter square
PV	-	Photovoltaic
LEO	-	Low Energy Office
GEO	-	Green Energy Office
ZEO	-	Zero Energy Office
DCEE	-	Demonstration, Cool, and Energy Efficient House
SCH	-	Smart and Cool Home
CTH	-	CoolTek House
ACH	-	Air change per hour
EAHE	-	Earth to air heat exchanger

RSC	-	Roof solar collector
VAWTEX	-	Vertical axis wind extracto
DC	-	Direct current
EC	-	Electronic commutating
GI	-	Galvanized iron
CFD	-	Computational Fluid Dynamic

CHAPTER 1

INTRODUCTION

Chapter 1 is an introductory chapter, where the present study and problem/s are going to be discussed initially. After the problem/s are identified, the project objectives and scopes are highlighted. A guideline of the way and development of the study to be carried out is drafted. Besides, the significance of this study is also discussed in this chapter. Last but not least, the organization of the thesis is at the end of this chapter.

1.1 Introduction

The sun, being the center of the solar system, generates large amount of energy every day. The energy radiates and reaches the Earth is approximately a two billionth of the Sun's energy output. This huge energy can be a main source of Earth's energy which is more than enough to supply the world's energy demands (Robert, 2006).

Malaysia is located at the equatorial regions which receive very high solar radiation throughout the year. The average solar radiation is about 400-600 MJ/m^2 per month and the average sunshine duration is about 4-8 hours per day. This makes Malaysia a unique country that has favorable climatic conditions and promising potential to harvest solar energy. Solar energy has potential value and also has bright future as it is a promising reliable backup energy source (Mekhilef *et al.*, 2012). Few technologies that harvest solar energy are photovoltaic cell, solar concentrator, solar chimney, solar air heater, and solar dryer (Fudholi *et al.*, 2010; Quesada *et al.*, 2012; Zhai *et al.*, 2011; Zhou *et al.*, 2010)

Unfortunately, Malaysia high solar radiation intensities are coupled with high relative humidity value. This hot and humid climates has posed difficulties to achieve thermal comfort for building indoor environment Ariffin *et al.*, 2002. Although some applied methods such as reflector aluminum foil, movable devices shading the windows, walls, and roof can be effective means of cooling, but most of those deteriorate quickly under hot and humid climates (Khedari *et al.*, 1996). In addition, houses have various modern styles considering only the beauty of the outside and neglecting the thermal comfort of the residents. Closed roof enclosures and simple brick walls are common structure of most residential houses lead to excessive heat accumulation and overheating. As a result, high cooling demand due to internal heat gain and heat transmission through the roof and wall (Khedari *et al.*, 1996; Khedari *et al.*, 2002; Macias *et al.*, 2009).

Despite of significant solar energy potential, commonly applied method to achieve thermal comfort is via mechanical systems. Although these systems are effective, but the economic (construction, operation, and maintenance cost) and environment penalties (greenhouse gas emission) are high (Belfuguais and Larbi, 2011; Hirunlabh *et al.*, 2001; Khanal and Lei, 2011; Maerefat and Haghighi, 2010a; Ziskind *et al.*, 2002). Furthermore, the energy consumption in building sector is expanding significantly due to the change of life standards and population. On top of that, most of the energy is generated from the non-renewable resources (Li *et al.*, 2014; Maerefat and Haghighi, 2010a; Pacheco *et al.*, 2012). Due to the increasing cost, security of energy supply, and environmental reason, tremendous interest and study has begun on solar and passive systems (Li *et al.*, 2014; Maerefat and Haghighi, 2010b).

One of the most effective method to cool a building is to avoid heating by solar radiation. According to the data collected by researchers, most of the heat supplied to the building comes from the roof (horizontal surface) than those receive by the vertical wall. Thus, method to keep the sun’s energy out of the roof can reduce indoor air temperature and achieve thermal comfort (Amer, 2006; Maerefat and Haghighi, 2010b). By looking into the pros and cons of the available techniques, solar chimney seems to be a good potential energy conservation strategy and cost effective systems to assist natural ventilation system (Zamora and Kaiser, 2009; Zhai *et al.*, 2011).

1.2 Problem Statement

The efficiency of solar chimney depends on the availability of solar energy as well as the solar intensity. Thus, solar chimney is an unstable system as solar radiation fluctuate throughout the day. In addition, solar chimney is not able to perform during overcast condition and night time due to lacking of or unavailability of solar energy (Kaneko *et al.*, 2006).

Some studies show that solar chimney is inefficient in hot and humid climate. This is due to insufficient stack ventilation cause by small temperature difference between the interior and exterior environment (less than 5°C). Other than that, the presence of air speed or wind is also deteriorating the performance of solar chimney (Khanal and Lei, 2011; Tan and Wong, 2012, 2014; Yusoff *et al.*, 2010). As a result, there is little potential in inducing sufficient natural ventilation with solely solar chimney (Chan *et al.*, 2010; Chungloo and Limmeechokchai, 2007; Hirunlabh *et al.*, 2001; Khedari *et al.*, 2000b; Waewsak *et al.*, 2003; Zhai *et al.*, 2011).

Another problem face by solar chimney that has less attention on is the resistance. Most of the common solar chimney has air entering at the right angle. As a result, high flow resistance at the solar chimney inlet. These inlet losses decrease the allowing flow to be entrained into solar chimney and reduce its performance (Bassiouny and Korah, 2009; Harris and Helwig, 2007; H. Li *et al.*, 2014; Tan and Wong, 2012).

1.3 Objectives

In order to overcome most of the above problems, one of the suitable valid option is to integrate solar chimney with turbine ventilator. This is because the availability of solar and/or wind energy at a reasonable intensity can be expected during a large part of any day (Shun and Ahmed, 2008). Another reason is their limitation can be overcome by each other's advantages. Thus, this integration system is expecting to further enhance its performance compare to their individual system (Chan *et al.*, 2010).

So, this project is developed to prove the hypothesis. The main objective of this project is to study the ventilation performance by integrating solar chimney with turbine ventilator. In conjunction to achieve the objective, the following sub-objectives are addressed:

- Modify a small size solar chimney that ease the integration of solar chimney and turbine ventilator.
- Investigate the performance of the modified small size solar chimney.
- Determine the performance improvement of the integrated system by comparing the integrated system to their own individual system.

1.4 Scope of Work

In order to achieve the objective of the research, the study is focused on the performance of modified solar chimney initially. The solar chimney models with inclination angle, air gap depth, as well as inlet and outlet apertures area ranging from 75^o to 90^o, 10cm to 16cm, as well as $0.02m^2$ to $0.6m^2$ and $0.1m^2$ to $0.14m^2$ respectively are studied under constant heat flux ($500W/m^2$). After that, the performance of integration of solar chimney with or without static or rotating turbine ventilator at constant heat flux and constant rotational speed is covered in this study. Other than that, the effect of wire mesh with pore size 0.64mm X 0.64mm is also evaluated in the study. The performance of solar chimney or the integrated system is evaluated based on volume flow rate.

1.5 Research Activities

According to the research activities flow chart show in Figure 1.1, the research start with intensive literature review on solar chimney and turbine ventilator assisted ventilation system.

In designing and developing suitable models, the parameters and criteria need are set accordingly. Based on those, suitable models are developed and fabricated. After that, the experimental works are conducted with suitable procedures and measuring equipment under appropriate operating conditions.

All the data obtains from the experiment are carefully arranged, analyzed and discussed. Finally, all the outcomes and important findings are summarized and concluded with some suggestions and recommendation.