UNIVERSITI PUTRA MALAYSIA

ROOF SOLAR COLLECTOR AND VERTICAL STACK FOR ENHANCING INDOOR VENTILATION OF SINGLE-STOREY SHOPHOUSE IN MALAYSIA

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By

WARDAH FATIMAH MOHAMMAD YUSOFF

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

January 2012

This thesis is dedicated to:

My beloved parents (*Mohammad Yusoff Mahmud and Zainab Ismail*), husband (*Mohd Hassan Hafiz Mamat*) and children (*Qistina Atifah, Mohammad Azfar Nafiz and Mohammad Firash Aisar*).

Thank you for your support, patience and love.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chair: Professor Dato' Dr. Ar. Elias @ Ilias Bin Salleh

Faculty: Design and Architecture

The climatic conditions in Malaysia which result in small air temperature differences between the indoor and outdoor of naturally ventilated buildings have reduced the efficiency of stack ventilation. A viable alternative in enhancing stack ventilation is the utilization of a solar induced ventilation. In this thesis, a solar induced ventilation that utilizes a roof solar collector and a vertical stack is proposed for the application in small and medium enterprise (SME) premises. The aim is to enhance the air flow rate in the indoor working area. The research methodologies employed were experiment and simulation modelling. A prototype of the proposed strategy was constructed in the experiment to examine its ability in inducing stack ventilation in a hot and humid climate. Its potential performance was further evaluated using simulation modelling. The investigations involved the orientation of the solar collector and the height of the vertical stack. Simulation modelling was also employed to investigate the application of the prototype in the selected typology of SME building, which is a single storey shophouse. Results were analyzed and

presented in terms of five variables, namely temperature, air velocity, mass flow rate, air flow rate and air exchange rate.

The findings from the experiment show that the prototype is able to induce stack ventilation in a hot and humid climate. High air temperature difference between the stack air and the ambient air was attained by the prototype, which was 9.9 ºC, for 877 W/m^2 solar irradiance. The result of orientation study indicated that the recommended orientation throughout the year is west-facing. Meanwhile, the investigations of vertical stack height indicated that the higher the stack is, the lower the air temperature inside the stack, but the greater the induced mass flow rate. The application of the prototype in the selected building also demonstrated positive results, in which it was able to enhance the indoor air flow rate and air exchange rate, as well as reduce the indoor air temperature. The prototype with 1 m width solar collector and 4 m high vertical stack was able to reduce the indoor air temperature by an average 0.6 ºC, increase the indoor air flow rate of less than 0.1 m^3/s and provide the air exchange rate around 5 to 16 ACH. The air temperature reduction, air flow rate increment and air exchange rate were greater with the enhancement of solar collector width. The recommended width of the solar collector for the application in the selected building is 3 m. The prototype with 3 m width solar collector and 4 m high vertical stack was able to provide the highest indoor air temperature reduction of 2.6 ºC (for 446 W/m^2 solar irradiance), the highest indoor air flow rate increment of 0.24 m^3/s (for 750 and 839 W/m^2 solar irradiance) and the highest air exchange rate of 26 ACH (for 839 W/m^2 solar irradiance). In summary, the research shows potential application of the proposed strategy in enhancing the indoor ventilation of a single storey shophouse in Malaysia.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

ATAP PENGUMPUL SURIA DAN CEROMBONG MENEGAK BAGI MENINGKATKAN PENGUDARAAN DALAMAN RUMAH KEDAI SATU TINGKAT DI MALAYSIA

Oleh

WARDAH FATIMAH MOHAMMAD YUSOFF

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Keadaan iklim di Malaysia telah menyebabkan perbezaan kecil suhu udara di luar dan di dalam bangunan yang menggunakan pengudaraan semulajadi. Faktor ini telah mengurangkan keberkesanan pengudaraan apung semulajadi di Malaysia. Alternatif untuk meningkatkan pengudaraan apung semulajadi adalah melalui aplikasi pengudaraan secara induksi suria. Oleh itu, kajian ini mencadangkan pengudaraan secara induksi suria yang menggunakan atap pengumpul suria dan cerombong menegak, untuk aplikasi di premis perusahaan kecil dan sederhana. Aplikasi ini bertujuan untuk meningkatkan kadar pengaliran udara di ruang kerja dalaman. Kaedah kajian yang digunakan ialah eksperimen dan simulasi komputer. Prototaip pengudaraan secara induksi suria telah dibina untuk eksperimen. Eksperimen bertujuan untuk memeriksa keupayaan prototaip menginduksi pengudaraan apung semulajadi di iklim panas dan lembap. Kajian lebih lanjut terhadap potensi prototaip dijalankan menggunakan simulasi komputer. Kajian meliputi orientasi pengumpul suria dan ketinggian cerombong menegak. Simulasi komputer juga digunakan untuk mengkaji aplikasi prototaip pada jenis bangunan di mana perusahaan kecil dan sederhana dijalankan iaitu rumah kedai satu tingkat. Keputusan kajian dianalisis dan dilaporkan dalam lima pembolehubah iaitu suhu, kelajuan udara, kadar pengaliran jisim, kadar pengaliran udara dan kadar pertukaran udara.

Penemuan eksperimen menunjukkan bahawa prototaip ini mampu menginduksi pengudaraan apung semulajadi di iklim panas dan lembap. Perbezaan suhu antara udara di dalam cerombong menegak dan udara persekitaran yang diperoleh adalah tinggi, iaitu 9.9 ºC, bagi 877 W/m^2 radiasi suria. Keputusan simulasi komputer untuk kajian orientasi mencadangkan agar pengumpul suria menghadap ke arah barat sepanjang tahun. Sementara itu, kajian bagi cerombong menegak pula menunjukkan bahawa semakin tinggi cerombong, semakin rendah suhu udara di dalamnya. Namun begitu, kadar pengaliran jisim didapati semakin bertambah. Aplikasi prototaip pada rumah kedai satu tingkat menunjukkan keputusan positif di mana ia dapat meningkatkan kadar pengaliran dan pertukaran udara, serta menurunkan suhu udara di dalam bangunan. Prototaip yang mempunyai 1 m kelebaran atap pengumpul suria dan 4 m ketinggian cerombong menegak berupaya menurunkan suhu udara secara purata 0.6 ºC, meningkatkan kadar pengaliran udara kurang daripada 0.1 m^3/s dan mencapai kadar pertukaran udara antara 5 ke 16 ACH. Penurunan suhu serta peningkatan kadar pengaliran dan pertukaran udara bertambah dengan pelebaran atap pengumpul suria. Kajian mencadangkan agar atap pengumpul suria mempunyai kelebaran 3 m bagi aplikasi di rumah kedai satu tingkat. Prototaip yang mempunyai 3 m kelebaran atap pengumpul suria dan 4 m ketinggian cerombong menegak berupaya memberi penurunan tertinggi suhu udara sebanyak 2.6 ºC (bagi 446 W/m^2 radiasi suria), peningkatan tertinggi kadar pengaliran udara sebanyak 0.24 m^3/s (bagi 750 dan 839 W/m^2 radiasi suria) dan kadar tertinggi pertukaran udara sebanyak 26 ACH

(bagi 839 W/m^2 radiasi suria). Kesimpulannya, kajian ini menunjukkan potensi aplikasi pengudaraan secara induksi suria yang menggunakan atap pengumpul suria dan cerombong menegak bagi meningkatkan pengudaraan dalaman rumah kedai satu tingkat di Malaysia.

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I certify that a Thesis Examination Committee has met on 9 January 2012 to conduct the final examination of Wardah Fatimah Mohammad Yusoff on her thesis entitled "**Roof Solar Collector and Vertical Stack for Enhancing Indoor Ventilation of Single-Storey Shophouse in Malaysia**" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the degree of Doctor of Philosophy.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

____

WARDAH FATIMAH MOHAMMAD YUSOFF

Date:

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LIST OF ABBREVIATIONS

ABL	Atmospheric boundary layer
ACH	Air change per hour
ASHRAE	American Society of Heating and Air-Conditioning Engineers
BIPV	Building integrated photovoltaic
CFD	Computational fluid dynamic
CIBSE	Chartered Institution of Building Services Engineers
GSCW	Glazed solar chimney walls
KLIA	Kuala Lumpur International Airport
LES	Large-Eddy simulation
MSW	Metallic solar wall
MTW	Modified Trombe wall
NI	Nebulosity Index
NPL	Neutral pressure level
NSDC	National SME Development Council
PDEs	Partial differential equations
PMV	Predicted mean vote
PV	Photovoltaic
RANS	Reynolds Averaged Navier–Stokes equation
RNG	Renormalization Group
RSC	Roof solar collector
SME	Small and medium enterprise
TW	Trombe wall

UBBL	Uniform Building By-Law
UKM	Universiti Kebangsaan Malaysia
UPM	Universiti Putra Malaysia

LIST OF NOTATIONS

A	free area of inlet openings (m²)
C_D	coefficient of discharge of air channel inlet
C_f	specific heat of air (J/kg K)
dV	difference between wind speed and air velocity increase inside the vertical stack.
g	gravitational acceleration (9.81 m/s²)
$G_{b,T}$	beam radiation on the tilted surface
G_b	beam radiation on a horizontal surface
hw	convective heat transfer between absorber wall and air in the cavity
hrwg	radiative heat transfer between the absorber wall and glass cover
hrgs	radiative heat transfer between the glass cover and sky
hcw	conductive heat transfer through the absorber wall
hcg	conductive heat transfer through the glass cover
h_g	convective heat transfer coefficient between the glass cover and the flowing fluid (W/m² K)
h_{rs}	radiative heat transfer coefficient between the outer glass surface and the sky (W/m² K)
h_{rpg}	radiative heat transfer coefficient between absorber plate and glass cover (W/m² K)
h_p	convective heat transfer coefficient between the absorber plate and the flowing fluid (W/m² K)

h_{wind}	convective heat transfer coefficient due to wind over glass cover (W/m² K)
ΔH_{NPL}	height from midpoint of lower opening to NPL (m)
I	solar irradiance (W/m²)
K_R	terrain factor
m	mass flow rate (kg/s)
p	static pressure
Q	air flow rate (m³/s)
Re	Reynolds number
R	universal gas constant
R_b	ratio of beam radiation on the tilted surface to that on a horizontal surface
Sw	solar radiation absorbed by absorber wall
S_T	source term
s	inclination of the plane
T	temperature
T_c	indoor predicted comfort temperature
T_i	indoor air temperature (K)
T_o	outdoor air temperature (K)
T_a	ambient temperature (K)
T_f	temperature of the flowing fluid (K)
T_{inlet}	air temperature at the inlet of roof solar collector's channel (K)
T_g	glass temperature (K)
T_r	room temperature (K)

T_s	sky temperature (K)
T_p	absorber plate temperature (K)
t	time
U_b	overall heat transfer coefficient between absorber plate and room (W/m² K)
U_z	mean wind speed at height Z (gradient wind)
U_{ref}	mean wind speed at some reference height Z_{ref}
u, v, w	velocity components in the x, y and z directions
V	air velocity (m/s)
W_{rsc}	air cavity width of the roof solar collector (m)
x	length (m)
Z_{ref}	reference height
Z	height for which the wind speed is computed (gradient height)
Z_0	roughness length or log layer constant
Z_{min}	minimum height

Greek symbols

α_g	absorptivity of glass (0.06)
α_p	absorptivity of absorber plate (0.95)
τ	transmissivity of glass (0.84)
θ	angle of incidence, the angle between the beam radiation on a surface and the normal to that surface

θ_z	zenith angle, the angle between the vertical and the line to the sun
δ	declination
ϕ	latitude
ω	hour angle
γ	the plane's orientation
$\rho g_x, \rho g_y, \rho g_z$	body forces in the *x*, *y* and *z* directions
ρ	fluid density (kg/m^3)
μ	dynamic viscosity of the fluid
Γ	diffusion coefficient
$-\rho\overline{u'T'}, -\rho\overline{v'T'}, -\rho\overline{w'T'}$	turbulent heat fluxes
$-\rho\overline{u'u'}, -\rho\overline{u'v'}, -\rho\overline{u'w'},$	turbulent (Reynolds) stresses
$-\rho\overline{v'v'}, -\rho\overline{v'w'}, -\rho\overline{w'w'}$	turbulent (Reynolds) stresses

CHAPTER 1

INTRODUCTION

The thesis investigates the potential of solar induced ventilation in a hot and humid climate. The strategic aim is for the application of solar induced ventilation in industrial building, particularly in small and medium enterprises premises (SMEs). The application of this strategy in SME premises is expected to promote natural ventilation. Moreover, high ventilation rates are necessary for such building in maintaining healthy indoor air quality.

1.1 Research Background

The increase of global warming has encouraged many explorations of environmental friendly approaches in built environment such as low energy design, passive design, sustainable design and zero energy design. Though each approach has specific objectives to be achieved, its final aim is similar, which is for human well-being. Natural ventilation is one of the ways of achieving this aim. There are two natural ventilation strategies, namely cross ventilation and stack ventilation. Each strategy has its own driving mechanism. Cross ventilation is driven by wind forces, whereas stack ventilation utilizes air buoyancy. Although cross ventilation is more appropriate for hot and humid climate (Aynsley, et al., 1977), the potential of stack ventilation is also worth to be explored. This strategy can be an alternative to cross ventilation, especially when the building has a very deep plan layout and/or high ventilation rates are required (Awbi, 2003). Industrial building is among the buildings that has such condition. It normally has a deep plan layout and internally sub-divided functional spaces. It also requires high ventilation rates due to the presence of much contaminants of the air due to work processes. In the present research, the industrial building is focused on the SME premises.

SMEs provide high contribution to Malaysian economic sector as 99.2% of businesses in Malaysia are represented by them. Moreover, they also provide 56.4% of total employment in the country (Economic Planning Unit, 2010). National SME Development Council (NSDC) has approved a common definition of SME in the manufacturing, manufacturing-related services, primary agriculture and services sectors. The definition of SME is based on two criteria namely the annual sales turnover and the number of full-time employees. In Malaysia, specific definitions are given for SME in manufacturing sector as well as SME in services and other sectors. In manufacturing sector, SME is defined as an enterprise with annual sales turnover less than RM25 million, or less than 150 full-time employees. Meanwhile, in services and other sectors, SME is defined as an enterprise with annual sales turnover less than RM5 million, or full-time employees of less than 50. The specific classification of SMEs, whether they are micro, small or medium enterprises are shown in Tables 1.1 and 1.2. Hence, any enterprise that meets the specified criteria is classified as SME (National SME Development Council, 2010).

Table 1.1. SME classification based on annual sales turnover

Size	Manufacturing (including agro-based) & manufacturing-related services)	Primary agriculture	Services sector (including ICT)
Micro	Less than RM 250 000	Less than RM 200 000	Less than RM 200 000
Small	From RM250,000 to less than RM10 million	From RM200,000 to less than RM1 million	From RM200,000 to less than RM1 million
Medium	From RM10 million to less than RM25 million	From RM1 million to less than RM5 million	From RM1 million to less than RM5 million

(Source: National SME Development Council, 2010)

Table 1.2. SME classification based on number of full-time employees

Size	Manufacturing (including agro-based) & manufacturing-related services)	Primary agriculture	Services sector (including ICT)
Micro	Less than 5 employees	Less than 5 employees	Less than 5 employees
Small	From 5 to less than 50 employees	From 5 to less than 20 employees	From 5 to less than 20 employees
Medium	From 50 to less than 150 employees	From 20 to less than 50 employees	From 20 to less than 50 employees

(Source: National SME Development Council, 2010)

The total number of SMEs in Malaysia is about 548, 267. Services sector has the highest number of enterprises, which is about 474, 706, followed by manufacturing sector (39, 373 enterprises) and agriculture sector (34, 188 enterprises). Most of the enterprises are located in Selangor, which is about 98, 523. The other states which have more than 50, 000 enterprises are Kuala Lumpur (96, 818 enterprises) and Johor (56, 471 enterprises) (National SME Development Council, 2010).

1.2 Issues and Point of Departure

There are many SMEs which are registered with SME Corporation Malaysia, and their locations are widespread. Therefore, the selected SME for the present study is limited to the manufacturing sector that is located in Selangor. Manufacturing sector is selected instead of other sectors due to its working nature, which fabricates products. Hence, it involves many indoor activities. Moreover, the products manufactured may also involve hazardous materials. Thus, good ventilation is crucial in ensuring healthy indoor working environment. Meanwhile, Selangor is selected as it has the largest number of enterprises compared to the other states in Malaysia. The products of manufacturing sector are various such as food, beverage, textiles, wood, glass, aluminium and many more. Different products require different working processes. For this study, the working process which needs less stringent of environmental control of air contaminants and hygiene is selected. Hence, the manufacturing sector that involves glass product is studied.

There is no statistical data provided by SME Corporation Malaysia on the SME premises. Hence, a field study was executed in searching for a common building typology for SMEs that involve glass products. From the study, it is found that such enterprises are conducted in various types of buildings, namely the single storey and multi storey shophouses/shopoffices, the single storey industrial terraces and the detached buildings, such as factory (Figure 1.1). Among them, the single storey buildings, be it the shophouses/shopoffices or industrial terraces, are identified to have potential for the application of the proposed solar induced ventilation. This is because the multi storey shophouses/shopoffices encompass different premises at different levels, whereas the detached buildings are large with complicated layout plans. Hence, extensive research is necessary for the application of solar induced ventilation in these buildings.

Single storey shophouses/shopoffices

Multi storey shophouses/shopoffices

Single storey industrial terraces

Detached building

Figure 1.1. Building Typologies for SMEs that fabricate Glass Products

Among 10 listed SMEs that manufacture glass product, only one enterprise is operating in a single storey shophouse and two enterprises are in single storey industrial terraces. Further study was conducted on these two building typologies. The summary of the study are as follow:

1) The common spaces are an office/reception area and a working area.
2) The width of the shop lot is between 5 m (16 feet) to 7 m (24 feet), whereas the length is between 21 m (70 feet) to 23 m (75 feet).
3) The roof tilt angle is between 10º to 15º.
4) The roof material is asbestos or zinc.

5) The wall is brick.

6) The floor finishes is cement rendered.

7) The building height is between 5 m to 5.5 m.

The ventilation mode in the working area is either naturally ventilated or using mechanical fans. Meanwhile, the office/reception area is ventilated with either mechanical fans or air conditioners.

One enterprise which is located in a single storey shophouse in Bangi, Selangor was selected for further investigation of the indoor environmental conditions. It was chosen due to the presence of many interior partitions compared to the other enterprises. The interior partitions and the deep layout plan have made cross ventilation less efficient. The field measurement executed at the indoor working area of the selected SME premise had shown that the average indoor air velocity from 9 am to 5 pm was around 0.33 m/s only. This air velocity is lower than the favourable air velocity for thermal comfort in hot and humid climate which is 1 m/s (Sapian, 2004). Therefore, the owner has opted for mechanical fans to ventilate all the internal spaces, except the design studio, where an air conditioner is used. The utilization of mechanical fans and air conditioner have increased the utility bills, thus escalating the business operating cost. This can be reduced if the natural ventilation strategy is applied. As cross ventilation is less efficient due to the deep layout plan and many interior partitions, the stack ventilation is seen as an alternative.

However, stack ventilation in Malaysia is less efficient due to small air temperature difference between the inside and outside of naturally ventilated buildings. Solar induced ventilation is a viable alternative in enhancing stack ventilation (Awbi, 2003; CIBSE, 2005). There are three distinguished solar induced ventilations namely Trombe wall, solar chimney and roof solar collector (Awbi, 2003). Roof solar collector is able to capture more solar radiation in the tropics compared to Trombe wall and solar chimney (Awbi, 2003; Mathur, et al., 2006b). However, its drawback is the stack height which is restricted by the roof slope (Awbi, 2003; Harris & Helwig, 2007). In enhancing the stack height, it is recommended to combine the roof solar collector with a vertical stack. The vertical stack functions as conventional chimney with no collection of solar radiation. The reason is to have higher air temperature, hence higher pressure inside roof solar collector than the vertical stack. Consequently, the air inside the roof solar collector rises and flows into the vertical stack due to the pressure difference between these two zones.

This thesis investigates the potential of solar induced ventilation that utilizes roof solar collector and vertical stack in enhancing indoor ventilation in a hot and humid climate. The proposed solar induced ventilation is suggested to be applied in SME premises. The selected premise is located in single storey shophouses in Bangi, Selangor. The business conducted in the premise is the fabrication of glass and aluminium products, which is categorized in the manufacturing sector.

1.3 Problem Statements and Research Questions

Stack ventilation is an alternative to cross ventilation. One of the factors that influences the air flow rate induced by stack ventilation is the indoor and outdoor air temperature differences (Awbi, 2003; Aynsley, et al., 1977; Bassiouny & Koura, 2008; Brown & DeKay, 2001). However, the climatic conditions in Malaysia have made stack ventilation less efficient due to the normally low temperature differences between indoor and outdoor air (Kubota, et al., 2009; Nugroho, et al., 2007; Rajeh, 1989). The air temperature difference between indoor and outdoor of naturally ventilated building in Malaysia is normally less than 5 ºC (Rajeh, 1989). This is also concluded by Nugroho et al. (2007), who had conducted a measurement on the indoor and outdoor air temperature of a single storey terrace house in Johor Bharu, Malaysia. The measurement on 21 March 2006 indicated that the air temperature difference between the master bedroom and the outdoor was between 0.6 ºC to 3.1 ºC from 8 am to 7 pm. Meanwhile, from 12 pm to 1 pm, the air temperature difference was around 1 ºC only. The finding is also in concurrence with Kubota et al.'s (2009) finding on the field measurement of a terrace house, which also results in 1 ºC of indoor-outdoor air temperature difference at 12 noon. Thus, the small air temperature difference has made the stack ventilation less efficient. The field measurement conducted in the indoor working area of selected SME premise indicated that the average air temperature difference from 9 am to 5 pm was 1.7 ºC. Meanwhile, the highest air temperature difference of 2.7 ºC was achieved at 12 pm, whilst the lowest air temperature difference of 0.1 ºC was attained at 9 am.

The performance of stack ventilation is more reliable in cold climate (Awbi, 2003; Aynsley, et al., 1977). In hot climate, the outdoor air temperature may become higher than the indoor air temperature. This condition causes the reversal flow whereby warmer outdoor air enters through the upper openings of the building. However, this reversal flow can be avoided through the utilization of solar induced ventilation strategy (CIBSE, 2005). The strategy is able to provide higher temperature differences between the inside and outside air, thus enhancing the stack ventilation (Awbi, 2003; Bassiouny & Koura, 2008).

The present research investigates the potential of solar induced ventilation in enhancing the stack ventilation in hot and humid climate. In investigating this potential, the research questions addressed in the thesis are as follows:

Main research question:
How can solar induced ventilation be utilized to enhance the air flow rate of a single storey shophouse?

Sub-research questions:

1) What is the potential prototype of solar induced ventilation for hot and humid condition?
2) Is the prototype able to induce stack ventilation in hot and humid condition?
3) What is the effective orientation of the prototype's solar collector?
4) What are the effects of vertical stack height on the air temperature and mass flow rate of the prototype?
5) Can the prototype application in a single storey shophouse reduce the indoor air temperature as well as enhance the indoor air flow rate and air exchange rate?

1.4 Research Aim and Objectives

The aim of the research is to investigate the potential of a proposed solar induced ventilation strategy in enhancing the air flow rate of a single storey shophouse. There are four objectives laid for the research, namely:

1. To determine a potential prototype of the combined roof solar collector and vertical stack.
2. To examine the prototype's ability to induce stack ventilation in hot and humid condition.
3. To evaluate potential performance of the prototype through simulation modelling.
4. To test the performance of the prototype in a single storey shophouse through simulation modelling.

1.5 Scope and Limitations

The research focuses on health ventilation, which is maintaining good indoor air quality. The effects of indoor air quality can be divided into two categories, namely the people's health and the people's comfort (Awbi, 2003). The research is limited to the comfort criterion only, which is the provision of ventilation rates in preventing odorous and stuffy environment (Figure 1.2).

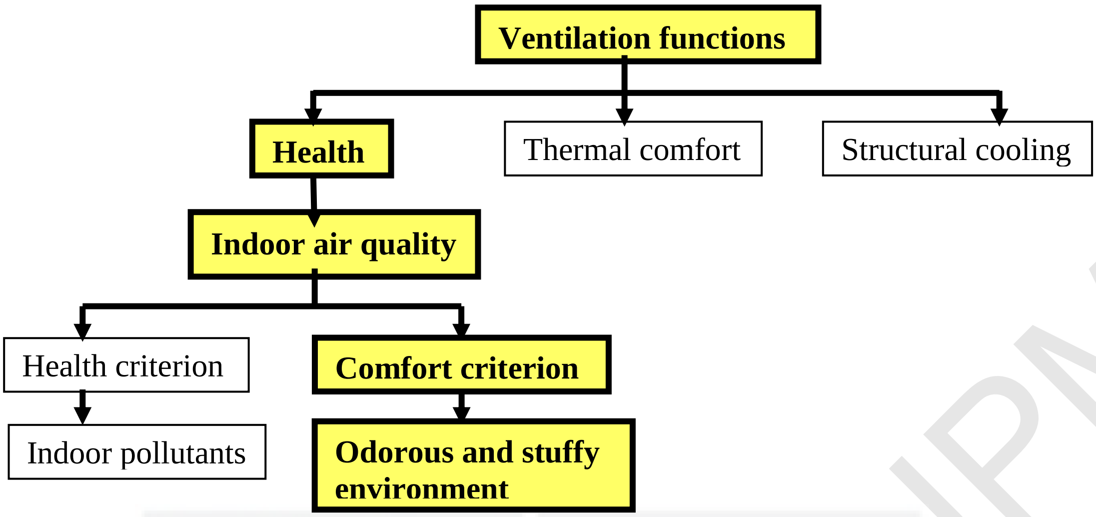

Figure 1.2. The Scope of the Research
(Source: Awbi, 2003)

The research investigates the potential of solar induced ventilation for the application in single storey shophouses. Many studies of solar induced ventilation in hot and humid climate to date are executed for the application in residential or single room buildings. The solar induced ventilation study for the application in commercial or industrial buildings is yet to be conducted.

The dimensions and materials used in developing the solar induced ventilation prototype for the experiment are derived from the literature study. The effective configurations suggested by the literature are applied to the prototype, such as the effective length of roof solar collector's channel, the effective tilt angle of roof solar collector and the effective ratio of inlet area to outlet area. Hence, further investigations on its potential performance are limited to the critical characteristics only, namely the solar collector orientation and the vertical stack height.

The performance of the proposed solar induced ventilation is evaluated based on five variables, namely air temperature, air velocity, mass flow rate, air flow rate and air exchange rate. The investigations of air flow rate, air exchange rate and air temperature inside the single storey shophouse are limited to the indoor working area only.

Further enhancement of the prototype performance in increasing air flow rate and air exchange rate as well as reducing air temperature in the indoor working area of the shophouse is limited to the width investigations only.

1.6 Research Methodology

The methodologies applied in the thesis are literature review (in exploring the appropriate prototype model), experiment and simulation modelling. These methodologies were executed in addressing the research questions and objectives, as shown in Figure 1.3 and Table 1.3.

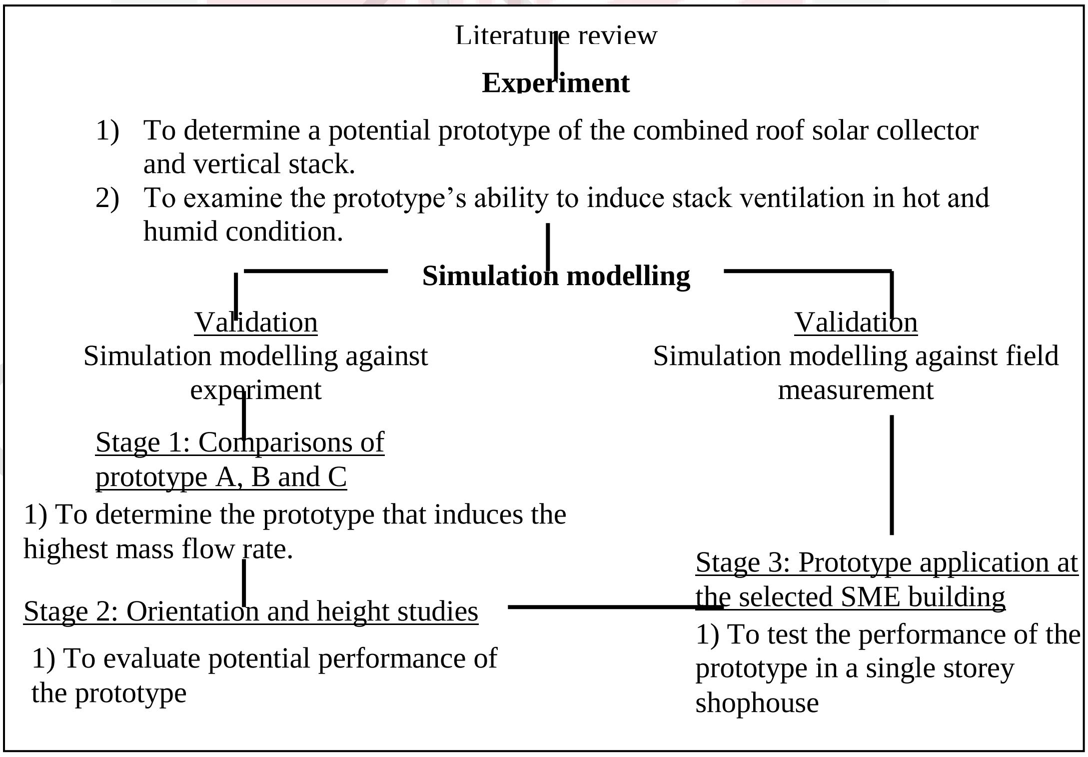

Figure 1.3. Summary of the Methodologies used in investigating the Proposed Prototype

Table 1.3. Summary of research questions, objectives, methodologies and expected output

Research questions	Research objectives	Research methodologies	Expected Output
What is the potential prototype of solar induced ventilation for hot and humid condition?	To determine a potential prototype of the combined roof solar collector and vertical stack.	-Literature review - Experiment	-The development of prototype that utilizes roof solar collector and vertical stack
Is the prototype able to induce stack ventilation in hot and humid condition?	To examine the prototype's ability to induce stack ventilation in hot and humid condition.	- Experiment	-Temperature differences between the stack air and the ambient air
What is the effective orientation of the prototype's solar collector?	To evaluate potential performance of the prototype through simulation modelling.	-Simulation modelling	-Air temperature increment inside roof solar collector to determine the effective orientation
What are the effects of vertical stack height on the air temperature and mass flow rate of the prototype?		-Simulation modelling	-Air temperature and mass flow rate inside vertical stack
Can the prototype application in a single storey shophouse reduce the indoor air temperature as well as enhance the indoor air flow rate and air exchange rate?	To test the performance of the prototype in a single storey shophouse through simulation modelling.	-Simulation modelling	-Indoor air temperature reduction as well as air flow rate and air exchange rate increment of a single storey shophouse

1.7 Research Framework

The overall research framework is summarized in Figure 1.4.

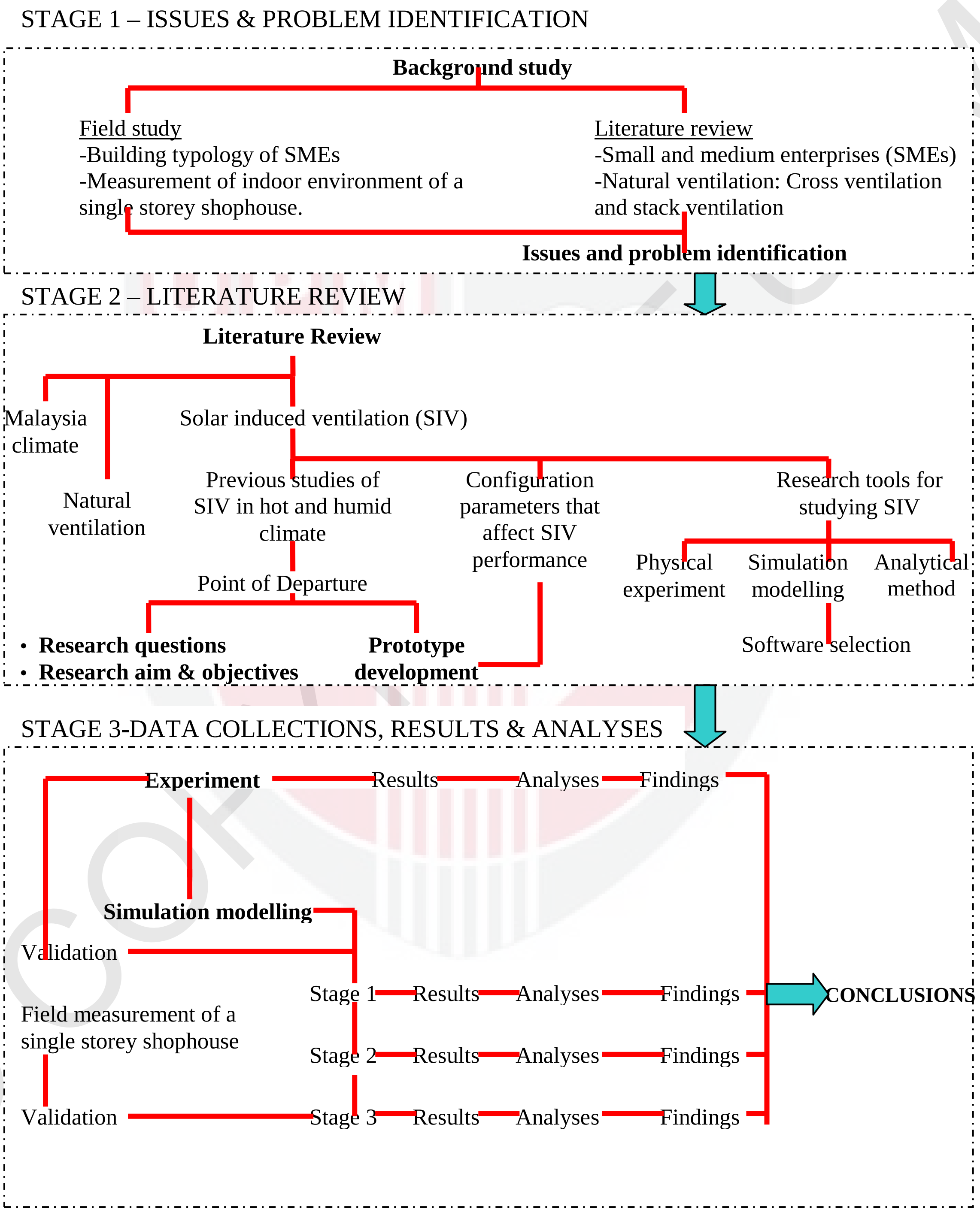

Figure 1.4. Summary of Research Framework

1.8 Research Significance

The research contributes to the enhancement of stack ventilation in single storey industrial buildings in Malaysia. The performance of stack ventilation in Malaysia is normally less efficient due to low air temperature differences between the inside and outside of the buildings. However, the utilization of the proposed strategy is expected to create higher air temperature differences, thus inducing greater air flow rate. It can also be an alternative when the effect of natural cross ventilation is less efficient due to internal obstructions to air flow. The application of solar induced ventilation at SME premises helps to enhance the ventilation rates, and consequently improve the indoor environment.

1.9 Thesis Organization

The thesis is divided into seven chapters. Chapter 1 is the introduction to the research. The introduction chapter discusses on the research background, the issues, problems and point of departure, the research questions, aim and objectives, the scopes and limitations and the significance of the research. Moreover, it also provides a brief explanation on the methodologies employed in the research.

Chapter 2 reviews the fundamental theories of natural ventilation, as well as the solar induced ventilation studies. This review helps in developing the proposed prototype and selecting the appropriate methods for the present research

Chapter 3 discusses on the theoretical background of the proposed prototype. This theoretical background explains the energy balances involved in the proposed prototype.

Chapter 4 presents and discusses the experimental setup which comprises the development of the prototype, the measuring equipments and the measurement time and procedures.

Chapter 5 discusses the Computational Fluid Dynamic CFD analysis. In this chapter, the validations of the simulation setting up and procedures as well as the simulation modelling of the proposed prototype are presented.

Chapter 6 discusses the results and findings of the research. The results include the experimental results and the simulation modelling results.

Chapter 7 concludes the overall findings and suggests the potential area for future studies. The recommendations made for future studies are mainly on the areas of limitation in the present research, as well as the potential enhancement of the proposed solar induced ventilation strategy.

1.10 Summary

This chapter discusses the related issues and problems as well as presents the point of departure, the research questions, aim and objectives, the scope and limitations, the research methodology and framework, and the research significance. The thesis organization is also presented in providing brief description on the works that have been executed. The next chapter presents the review of natural ventilation theoretical background and solar induced ventilation studies.

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