NATURAL VENTILATION PERFORMANCE OF AIR WELLED SINGLE STOREY TERRACE HOUSE

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I dedicate this Thesis to God Almighty, who has been my eternal rock and source of refuge. The thesis is also dedicated to my country – Malaysia, and UTM, as well as my beloved family for being great pillars of support.

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ABSTRACT

Terraced housing in Malaysia hardly provides its occupants with thermal comfort. More often than not, the occupants need to rely on mechanical cooling, which contributes to outdoor heat dissipation that leads to urban heat island effect. Alternatively, encouraging natural ventilation can eliminate heat from indoor environment. Unfortunately, with static outdoor air condition and lack of windows at terraced houses, the conventional ventilation technique does not work well, even for houses with an air well. Hence, this research investigates ways to maximize natural ventilation in terraced housing by exploring the air well and louvre's passive design. By adopting an existing single storey house with air well in Kuching, Sarawak, the existing indoor environmental conditions and thermal performance was monitored using scientific equipment, namely HOBO U12 air temperature and air humidity, HOBO U12 anemometer and Delta Ohm HD32.3 Wet Bulb Globe Temperature meter for six-month duration. The collected data was used as background study and benchmark for simulation. In this case, a simulation software – DesignBuilder® was utilised. The field study illustrated that there is a need to improve indoor thermal environment. Thus, the study further proposed improvement strategies to the existing case study house. The proposition is to turn the existing air well into solar chimney to take advantages of constant and available solar radiation for stack ventilation. The study also considers the effect of louvre windows to further accelerate the wind movement. The results suggest that the enhanced air well with proposed louvres were able to improve the indoor room air velocity and reduce air temperature. The enhanced air well with 3.5m height, 1.0m air gap width, 2.0m length with 45° tilted room opening louvres with 167mm slate gap were able to induce higher air velocity. During the highest air temperature hour, the indoor air velocity in existing test room increased from 0.02m/s in the existing condition to the range of 0.15 to 0.40m/s in the hottest month while during the lowest temperature month, the air velocity could be increased to the range of 0.25 to 0.53m/s. Installation of louvres at test room with solar chimney increases the percentage average air velocity of 16.5% and reduce percentage average air temperature to 1.1% compared to test room with solar chimney only. For indoor room temperature, the greatest mean air temperature could be reduced by up to 1.8°C compared to the outdoor air temperature during the hottest day. The findings revealed that the proposed air well and louvres could enhance the thermal and ventilation performance under Malaysia tropical climate.

ABSTRAK

Rumah teres di Malaysia mengalami masalah keselesaan terma. Keadaan udara statik dalam rumah teres menyebabkan suhu udara dalaman meningkat. Dengan itu, penghuni perlu bergantung kepada penyejukan mekanikal untuk memberi keselesaan terma tetapi menyumbang kepada kesan pulau haba. Sebagai alternatif, penggunaan strategi pengudaraan semulajadi untuk menyingkirkan haba dalam perumahan adalah digalakkan. Disebabkan oleh keadaan udara statik di persekitaran luar, teknik pengudaraan konvensional tidak berkesan bagi bilik yang berventilasi tunggal walaupun wujudnya cerobong udara. Keadaan terma dalaman dan keselesaan terma telah dipantau dengan perakam suhu dan kelembapan udara HOBO U12, anemometer HOBO U12, Delta Ohm HD32.3 meter selama enam bulan di rumah kajian di Kuching, Sarawak. Keputusan kajian tapak menggambarkan keselesaan terma adalah penting untuk dalaman bangunan. Oleh itu, kajian ini mencadangkan strategi penambahbaikan ke atas rumah kajian bercerobong udara yang sedia ada kepada cerobong solar dengan memanfaatkan tenaga suria untuk mewujudkan kesan timbunan ventilasi. Kajian ini juga menilai kesan ram tingkap untuk mempercepatkan pergerakan angin. Selain itu, perisian simulasi komputer DesignBuilder® telah digunakan untuk mengkaji usul dan menilai beberapa pembolehubah reka bentuk berkenaan dengan cerobong solar dan reka bentuk tingkap ram. Keputusan menunjukkan bahawa pengudaraan dalaman dipertingkatkan dengan berkesan dengan cadangan pemasangan tingkap ram yang dapat meningkatkan halaju udara dalaman. Versi cerobong solar cadangan berukuran tinggi 3.5m, lebar 1.0 m, panjang 2.0m dan slat ram berjurang 167mm berkecondongan 45° dapat meningkatkan halaju udara dalam keadaan udara luar statik. Pada hari panas, halaju udara dalaman dipertingkatkan daripada 0.02m/s dalam keadaan normal kepada 0.15 hingga 0.40m/s manakala pada bulan yang bercuaca sejuk, halaju udara boleh dipertingkatkan kepada 0.25 hingga 0.53m /s. Pemasangan ram di bilik kajian dengan cerobong solar meningkatkan peratusan purata halaju udara sebanyak 16.5% dan mengurangkan peratusan purata suhu udara 1.1% berbanding dengan bilik ujian dengan cerobong solar sahaja. Untuk bilik tertutup, suhu udara minimum tertinggi dapat dikurangkan sebanyak 1.8 °C berbanding suhu luaran pada siang hari terpanas. Penemuan kajian ini menunjukkan bahawa pengudaraan dalaman dapat dipertingkatkan dengan gabungan ram dan cerobong solar. Model tersebut dapat meningkatkan prestasi terma dan pengudaraan dalam iklim tropika Malaysia.

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LIST OF SYMBOLS

V_z	-	Mean wind velocity at height z (gradient wind)
V_g	-	Height where the gradient wind starts
V_{ref}	-	Mean wind velocity at reference height Z_{ref}
Z_{ref}	-	Reference Height
Z	-	Height for which the wind velocity V_z is calculated
Z_g	-	Height at which the "gradient wind" (V_g) is observed
Z_0	-	Roughness length or log layer constant
I	-	Solar intensity
Iu	-	Turbulence intensity
I_{sc}	-	Solar constant
I_o	-	Solar radiation
T_{sol}	-	Local solar time
T_{std}	-	Local standard time
E_t	-	The equation of time
L	-	Length/ gap size
α	-	An empirical exponent that depends on the surface roughness, stability and temperature gradient
↑	-	Increase/ high
↓	-	Decrease/ low
t_r	-	Total heat loss from skin surface of an imaginary occupants who has 1.0 met activity and 0.6 clo of clothing level
t_a	-	Real-time occupants in actual environment with actual clothing and real activity
t_o	-	Operative temperature
t_a	-	Air temperature
t_{mr}	-	Mean radiant temperature
h_r	-	Linear radiative heat transfer coefficient

h_c	-	Convective heat transfer coefficient
F_{p-i}	-	Angle factor between the person and surface
t_i	-	surface temperature
T_n	-	neutral temperature with +/-2ºK range
T_{amt}	-	Annual mean air temperature of the month
C_p	-	Pressure coefficient
V	-	wind velocity/ upstream velocity
ρ	-	Air density
P_w	-	Wind pressure
P_o	-	Static Pressure of free stream P_α
K-ε	-	K-epsilon Turbulence Model
T_{Alo}	-	Lower air well mean air temperature
T_{Aup}	-	Upper air well mean air temperature
T_t	-	Test room mean air temperature
T_o	-	Outdoor mean air temperature
RH_{Alo}	-	Lower air well mean relative humidity
RH_{Aup}	-	Upper air well mean relative humidity
RH_t	-	Test room mean relative humidity
RH_o	-	Outdoor mean relative humidity
P_{total}	-	Total pressure
P_{static}	-	Static Pressure
$P_{dynamic}$	-	Dynamic Pressure
μ	-	Viscosity of air
R_e	-	Reynolds Number
V_i	-	Air velocity of inlet
V_e	-	Air velocity of outlet

LIST OF ABBREVIATIONS

ABL	-	Atmospheric Boundary Layer
AC	-	Air conditioned
ACH	-	Air Change Rate
ACS	-	Adaptive Comfort Standard
AIAA	-	American Institute of Aeronautics and Astronautics
AR	-	Aspect Ratio
ASHRAE	-	American Society of Heating, Refrigerating And Air Conditioning Engineers
BBCC	-	Building Bio Climatic Chart
BCA	-	Building Construction Authority
BIM	-	Building Information Modelling
BRI	-	Building Related Illness
BS	-	Building Simulation
CET	-	Corrected Effective Temperature
CFD	-	Computational Fluid Dynamics
CO_2	-	Carbon Dioxide
DEM	-	Digital Elevation Model
EMPD	-	Effective Moisture Penetration Depth
EPA	-	Environmental Protection Agency
EPBD	-	European Parliament Board of Directive
ET	-	Effective Temperature
HVAC	-	Heating, Ventilating Air Conditioning
IES-VE	-	Integrated Environment Solution – Virtual Environment
IPCC	-	Intergovernmental Panel on Climate Change
LF	-	Laminar Flow
MCS	-	Multiple Chemical Sensitivity
MRT	-	Mean Radiant Temperature

MS	-	Malaysia Standard
N.A.	-	Not Applicable
NV	-	Natural Ventilated
NZEB	-	Net Zero Energy Buildings
OT	-	Operative Temperature
PCM	-	Phase Change Material
PMV	-	Predicted Mean Vote
PPD	-	Predicted Percentage of Dissatisfied
PVC	-	Polyvinyl Chloride
RANS	-	Reynolds-Averaged Navier-Strokes Turbulence Model
RH	-	Relative Humidity
RMS	-	Average Root Mean Square
RNG	-	Renormalization K-ε Turbulence Model
RSC	-	Roof Solar Chimney
SBS	-	Sick Building Syndrome
SC	-	Solar Chimney
SET	-	Standard Effective Temperature
SP	-	Static Pressure
TB	-	Turbulent Flow
TR	-	Transitional Flow
UBBL	-	Uniform Building By Law
VP	-	Velocity Pressure
WWR	-	Window to Wall Ratio

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This research studies natural ventilation through the louvres window and solar chimney (enhanced air well on existing case study house) to improve thermal performance in typical Malaysian single storey terrace housing. In this study, the air well in an existing single storey terraced house were modified towards solar chimney configuration to enhance the natural ventilation performance. The first chapter introduces the research background, significance, objectives, research questions, research scope and framework of research methodology.

1.2 Problem Statement

Energy consumption has been a critical and sensitive global issue for a few decades now. The building industry has been considered to be a high energy consumption industry where huge amount of fuel and energy are consumed throughout the building life span. In order to reduce the energy consumption along the building operational period especially for the tropic countries, passive cooling design plays an important role. Most buildings are designed with air-conditioning system in mind, thus the passive cooling design solution has been eliminated in order to prevent cold air leakage which would then lead to high costs of energy consumption. However, most users and occupants do not realize that thermal comfort generated by effective passive cooling system is closely related to the energy consumption cost. With effective passive cooling system, they can cut down their monthly electricity bill.

Climatic thermal comfort can be achieved via effective ventilation system in order to achieve biological comfort of occupants. There are two types of ventilation system; natural ventilation system and mechanical ventilation system. The cooling effect generated by the natural ventilation system can be achieved via the pre-construction design for the building by taking the advantages of the wind forces or the air pressure difference, as well as the temperature difference between indoor and outdoor of the building. The main aim to achieve good ventilation for indoor environment is to provide fresh air in order to prevent carbon dioxide (CO_2) from exceeding the unacceptable level by occupants (Awbi, 1998). According to Bansal (1992), solar chimney is one of the alternatives for a building to achieve passive cooling. In Malaysia, air well is believed to fulfil the same function. However, many fail to work.

According to previous researchers, the properties of the solar chimney can be identified via the length, the material, the thickness of material, the air gap width, the optimum aperture type and so forth. The parameters of the solar chimney play an important role in giving the effect on the result of performance of solar chimney. Appendix A summarizes the parameters suggested by the previous researchers. However, the indication is not finalized and only presented as reference. Appendix B shows the problem statements summarized in diagram form which is the dilemma of thermal comfort in Malaysia terraced houses.

1.3 Research Statements

Ventilation plays an important role in providing fresh air and healthy room environment for human habitat. Without the consistent ventilation and air circulation, the indoor environment becomes suffocating, stifling hot, stuffy and leads to sick building syndrome. According to Laumbach (2008), sick building syndrome is mainly caused by indoor environmental problems and individual risk aspects. The indoor environmental aspects include air pollutants, poor ventilation, poor indoor air quality, temperature, relative humidity and so forth. Thus, the performance of the building thermal envelope and configuration system become important. Thermal performance in the building directly regulates the behavioural and comfort of users of the building. Local climate conditions, such as annual ambient temperature, relative humidity, intensity of solar radiation, wind velocity and direction, would give the impact to the thermal comfort of occupants. In Malaysia, due to the high intensity of solar radiation, the direct penetration of sunlight leads to the heat transfer from the glazing to the internal of the building (Nugroho,2014). However, the high intensity of the sunlight could be a benefit by modifying the configuration of the building system in order to achieve the thermal comfort for occupants.

The hot and humid condition in Malaysia is the main dilemma and issue for the occupants is thermal comfort. In addition, the configuration of the terrace house, which is the most common residential type occupied by citizens does not consider the problem of single sided ventilation. Single sided ventilation could not provide effective ventilation (Nugroho et al., 2006). Under the circumstances of the limited layout design, the alternative of passive cooling- solar chimney and louvre window would be the way to increase the ventilation rate and air velocity in the room in order to achieve the energy saving purpose. Thus, to propose a passive cooling system which could complement the single opening of the terrace house in order to create cross-ventilation is important. It is possible to achieve the thermal comfort via low indoor air temperature and high air velocity.

Air well stated in Uniform Building By Law 1984 as basic ventilation requirement for utility, mechanical room and washroom with stated sizes and dimension. Designers tend to fulfil requirements by providing the minimum dimension, which does not achieve the effectiveness and function of air well. Thus, the configuration of provided air well does not take into consideration for the effectiveness measure. Developer and designer tend to ignore the potential of air well because enclosed spaces are taken into consideration of usable nett floor area. As a result, the measure of natural daylighting and natural ventilation of modern terraced housing are not addressed properly, and lead to the needs of mechanical ventilation system. This has increased the energy consumption. The application of air well is not widely promoted since the wide exposed opening invites the security issues. In the end, occupants tend to seal it up to avoid problems.

There are various kinds of passive cooling approaches to achieve energy efficiency for building. According to N.B.Geetha and Velraj (2012) (Appendix E), there are three types of passive cooling methods, which are solar heat protection, heat modulation or amortization technique and heat dissipation technique. Solar chimney falls under the category of dissipation technique without thermal energy. Natural ventilation happens with the assistance of solar chimney by uplifting the hot air via temperature gradient. Other than that, the application of external louvres at window (inlet) could increase the Bernoulli Effect of air flow when uplifting happened via solar chimney. The combination of these building components has high potential to improve ventilation performance in the terrace houses. Diagram in Appendix A indicates the research gap of this study and diagram in Appendix D indicates the summary of problem statement. Thus, this study deduces that indoor ventilation could be enhanced with combination of both pressure gradients via Venturi effect as well as indoor and outdoor temperature gradient caused by solar induced stack ventilation. Another than that, Diagram ini Appendix B elaborate Appendix C with previous research categories, in order to benchmarking the current study in natural ventilation field. The possibility to improve natural ventilation in terraced house is summarized in Appendix F.

In this study, a single storey terraced house located at Kuching Sarawak was selected as case study building. The house is designed with 2m length x 1m width air well to ventilate bedroom and bathroom. However due to the limited of space in the terraced house, air well was designed with minimal cost and dimension according to Uniform Building By Law requirement. The window of the bedroom is typical wide aperture which unable to induce ventilation. The study started with measurement of the thermal performance for existing bedroom with single-sided ventilation. The thermal performance of existing air well was studied as well. The modification of the air well into solar chimney and window louvres were carried out with Computational Fluid Dynamic (CFD) software in referred to the measurement result.

Furthermore, the research study the thermal performance of the existing building which applied single-sided ventilation. The effectiveness of the single-sided ventilation was analysed based on the field measurement data. Similar to air well of the existing case study building, the collected data were analysed in order to examine the potential of air well to be applied in tropical climate. Via the field measurement, the research background were verified and the objective of the study were outlined .

1.4 Research Objectives

The main objective of the research is to study natural ventilation by evaluating and investigating the effectiveness of external louvres and enhanced air well that act as solar chimney to improve the natural ventilation in a Malaysian single storey terrace house. The term solar chimney applied to indicate enhanced air well in this study. Since the wind velocity of outdoor and indoor is not significant in Malaysia tropical context compared to the temperate country, the stack ventilation might be a better alternative. Solar chimney and louvre window geometry could improve the stack ventilation for the low air movement residential building, which in turn, give better thermal comfort for occupants.

Other specific objectives:

1. To study the thermal performance of typical existing single storey terrace house with air well in Malaysia via field measurement.

2. To explore the configuration of louvre window in relation to enhancing the airflow speed

3. To explore the configuration of existing air well to solar chimney with respect to improve stack ventilation

1.5 Research Questions

1. What is the current thermal performance of the typical existing single storey house with air well in Malaysia?
2. What is the appropriate configuration of the air well geometry that can enhance the ventilation by increasing the air movement to improve indoor thermal environment?
3. What is the appropriate louvres configuration that can enhance the air flow speed in an indoor environment?

1.6 Scope of Research and Limitation of Study

The scope of the research study is to evaluate the effectiveness of proposed solar chimney and louvre window configuration in single storey terrace house in Malaysia. There are numbers of research papers on the geometry of solar chimney (Nugroho, 2007d; Sakonidou et al., 2008; Zhai et al., 2011; Z.D.Chen, 2003). However, the relationship between the louvres window (inlet) and solar chimney has not been studied especially in Malaysia terrace house context. Terrace house in Malaysia has limited external facing walls which allow cross ventilation to happen especially for the middle room. The limitation leads to the problem of insufficient ventilation and air change which can cause sick building syndrome to the occupants.

Thermal comfort in relation to air flow speed is the main target and objective for this research study. The building with good ventilation performance is considered as effective and functional building design. There are few parameters regulating the occupant's thermal comfort: the air temperature, metabolic rate of human body, clothing, relative humidity, air speed, and others (Givoni.B., 1981; Abdul Razak, 2004; Nugroho, 2007d). In this research study, the scope of is on the air temperature and air velocity. Average air velocity in Malaysia indoor environment is within the range of 0.04 to 0.47m/s (Hui, 1998c; Nugroho, 2007d). In order to achieve the thermal comfort range, the required air velocity for indoor environment has to be within 0.2 to 0.8m/s according to Shafizal Maarof and Jones (2009) and Nugroho (2007d) in the condition of ambient temperature range between 28ºC to 32ºC and relative humidity lower than

70%. In order to determine the air velocity and room air temperature as the variable, the other affecting parameters such as relative humidity, activities, clothing factor and so forth would set as assumption value and not considered in the experiment. The relative humidity will be set at dry bulb temperature value which considered as fall in between the conducive range for living environment (Nugroho, 2007d).

For the research to be carried out, a typical bedroom with single-sided exposed fenestration in a single storey terrace house which is attached to a 2m x 1m air well is selected for the field measurement and research study. Hence, the measurement result and analysis will be applied as the base case study model. The modifying and improving the configuration would be based on the base case model results. The method has been used by previous researchers as the research method in order to compare the findings results with the real-life experimental result (Ossen, 2005b, Nugroho, 2007d).

After determining the setting for base case study, the study is going to carried out using the computer simulation program - DesignBuilder. The use of software involved the limitation and fixed parameters. In general, the limitation of the software includes the cost for the software, the unintuitive interface, as well as other setting which could be the technical issues. The details of the limitation will be discussed further.

The setting for the weather data in the simulation software is performed under Kuching climatic data 2013 (air temperature, air velocity and solar radiation). The accuracy of the software results is examined via process of verification and validation, which is discussed in the following chapter.

1.7 Significance of Study

The outcome of the research is expected to emphasise on the effectiveness of the proposed solar chimney (enhanced air well) and external louvre window system in promoting the thermal and ventilation performance in single storey terrace houses in

Malaysian context. It will enhance thermal and ventilation condition of building by inducing air velocity via stack effect as well as Venturi effect. The study suggests and recommends the appropriate solar chimney and louvre configurations on passive ventilation system. Hence, it can further reduce the indoor temperature and increase air velocity in a typical terrace house in Malaysia. Other than the stated advantages as above, the application of solar chimney has other advantages on various aspects as indicated in Figure 1.1. The most significant aspect is thermal comfort and energy efficiency. Therefore, the findings of the study are believed to be able to enhance the designer options and act as reference to design a functional solar induced ventilation tool in building, in order to improve the thermal comfort and energy efficiency.

Furthermore, in this research, the research method was initiated with background study and proceed with exploration via design. Field measurement for the existing case study building was carried out in first place to identify the dilemma of tropical houses discomfort issue and follow with the solutions by proposing the enhanced air well and external louvres design. The progression study strengthens the research aim, supported with background data.

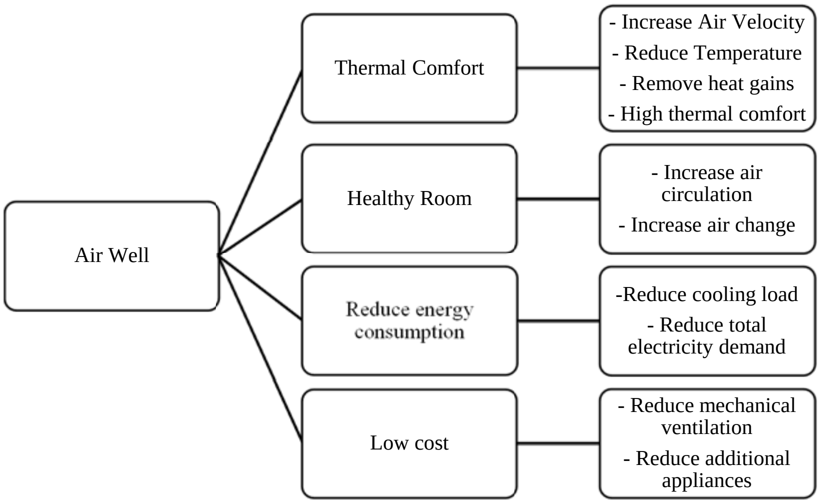

Figure 1.1: Benefits of solar chimney application in residential building (Nugroho, 2006)

1.8 Research Hypothesis

The hypothesis for the research study is that "enhanced air well and louvre window" design will achieve the following:

1. Improved air velocity in the indoor building environment.
2. Enhanced of thermal performance of indoor environment

1.9 Thesis Organisation

This thesis is divided into six chapters, beginning with the introduction to the study and wrapping up with the conclusion of the findings in the study.

Chapter 1 reviews the general perspectives of the research and clarifies the aims of the research. Other than that, Chapter 1 listed down the research objectives, hypothesis of study, research questions, significance of study, and summary of the research scope and limitation. The overall framework of the research was stated in the first chapter to project the overall process of the study.

Chapter 2 presents the literature review and analysis of climate and comfort condition for Malaysia and Kuching city (1.5600° N, 110.3450° E, Time zone: +8). Chapter 2 reviews on climatic factors which directly influence the thermal comfort such as wind, solar radiation, air velocity, air humidity and air temperature in respect to the research intention, concept, and analysis of climatic data. The understanding on the climatic data is important in order to carry out the study, since it directly gives impact to the thermal comfort of occupants and building design. In the last section of this chapter, review on thermal comfort definition, thermal comfort in tropics as well as ventilation requirement under Malaysian tropical climate are discussed. ASHRAE rating index in Malaysia's climatic context was used to determine and define the comfort zone under natural ventilation condition in the end of this chapter.

Chapter 3 is divided into two sections. Section one reviewed the natural ventilation of buildings in Malaysia climatic context. The mechanism, strategies and techniques of natural ventilation were described in this chapter as well. This chapter also covers the study of terrace houses in Malaysia, which includes the regulations of terrace houses, classification, building material, topography and ventilation factors, layout study and urbanization factors which affect the design of terrace houses. Section two gives a review of solar chimneys, which includes the history, the generic form, and ventilation of solar chimneys, important parameters, limitations and problems of air well in tropical context, and examples of buildings with air well or solar chimneys.

Chapter 4 reviews the methodology of the research implemented in this study. Various kind of research method in natural ventilation were reviewed. The justification of research tools selection, the procedure in carrying out the field measurement and optimization, verification and validation of selected CFD, and details of final model are also described in this chapter.

Chapter 5 covers the findings and analysis of the field measurement results. The case study house thermal performance was measured with experimental instruments, in order to obtain the real time indoor and outdoor air temperature, relative humidity, and air velocity. In this chapter, the air well thermal performance, the single-sided room thermal performance as well as outdoor weather were measured and discoursed. The impact of the existing thermal performance summarizes up the Chapter 5.

Chapter 6 discusses about the alternative measures proposed for poor existing thermal indoor environment performance in terraced house. Exploration on the external louvres and enhanced air well (solar chimney) configurations were carried out. The parameters for louvres and air well were explored and discussed in this chapter. The chapter will be ended up with discussion on simulation for the louvres and solar chimney model on design days.

Chapter 7 describes the research summary, final conclusion with respect to the results of the research study. Contributions discussed in architectural perspective other than technical way. In the last part of the chapter, future research recommendations were identified.

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