UNIVERSITI PUTRA MALAYSIA

THERMAL PERFORMANCE OF WOOD WOOL CEMENT PANELS AS BUILDING ENVELOPE IN HOT- HUMID TROPICS

AR LOO KOK HOO

FRSB 2017 3

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By

AR LOO KOK HOO

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

March 2017

DEDICATION

This thesis is dedicated to:

The lovers of green architecture worldwide

My professional team working with me all these years

My Beloved Family

My Kind Parents: Who Provided Me Generously with Advice, Kindness, and Tenderness

My Partner: My Journey Mate in Life

My Lovely Children: Where I See My Promising Future

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

THERMAL PERFORMANCE OF WOOD WOOL CEMENT PANELS AS BUILDING ENVELOPE IN HOT- HUMID TROPICS

By

AR. LOO KOK HOO

March 2017

Chairman : Mohamad Fakri Zaky Ja'afar, PhD
Faculty : Design and Architecture

Environmental problems are gaining momentum by the days. Construction industry consumes 10% of all our energy usage, building and their production contribute over 50% of CO2 emission in the production of cement, bricks and steel. These materials are used as building envelopes, which is the single largest architectural element in all buildings. Therefore, it is timely for the industry to source for suitable and sustainable alternatives. The Thesis had identified Wood Wool Cement Panels (WWCP) having such potential as alternative material.

The objectives of the thesis are threefold, i.e. to investigate 1. Thermal performance of WWCP as external envelopes and compare it with conventional brick and plaster wall as building envelopes. 2. Validation of a suitable simulation software for performance comparison. 3. Comparing performance of WWCP versus conventional houses. WWCP has been used as one of the building materials in temperate countries but not common in Malaysia.

The methodology involved test cells field measurements and computer simulations. Two Test Cells were constructed in Universiti Putra Malaysia (UPM), one with WWCP envelope and the other with conventional brick and plaster. Field measurements over four months to monitor air temperatures, relative humidity, air properties and solar gains, followed by validation of IES<VE> software. Thereafter IES was utilized to further assess the performance of WWCP in the context of passive Terrace and Semi-Detached Houses, which are common housing prototypes in Malaysia. The results were tabulated, analysed and discussed.

The key findings on air temperature, mean radiant temperature, relative humidity, heat transfer and conduction gains had established WWCP comparable to, and in certain areas, performed better than conventional brickwall in thermal performance as evidenced in Test Cells, Terrace and Semi-Detached Houses results. Since there are few known researches on WWCP, the Thesis contributes significantly to provide valuable information for local building industry, policy makers, authority, and researchers on WWCP as an alternative building material suitable for the Tropics.

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

PRESTASI TERMAL SIMEN WUL SEBAGAI SELAPUT BANGUNAN DI CUACA TROPIKAL YANG PANAS LEMBAB

Oleh

AR. LOO KOK HOO

Mac 2017

Pengerusi : Mohamad Fakri Zaky Ja'afar, PhD
Fakulti : Rekabentuk dan Senibina

Momentum masalah alam sekitar kini kian meningkat setiap hari. Industri pembinaan menggunakan 10% daripada jumlah penggunaan tenaga dan produksi bahan bangunan menyumbang lebih daripada 50% pengeluaran CO2, khususnya dalam pengeluaran simen, batu bata dan keluli. Bahan-bahan ini digunakan sebagai bangunan dinding dan bumbung (selaput bangunan). Selaput bangunan merupakan unsur seni bina yang terbesar dalam semua bangunan. Oleh itu, memang tepat masanya bagi industri pembangunan mencari sumber alternatif yang sesuai dan berterusan. Tesis ini telah mengenali panel simen wul kayu (WWCP) yang mempunyai potensi sebagai bahan alternatif.

Objektif Tesis adalah bertiga, iaitu menyelidik 1) Prestasi termal WWCP dalam keadaan luar bilik berbanding dengan bata konvensional sebagai selaput bangunan. 2) Validasi komputer software penyelidikan yang sesuai untuk perbandingan termal 3) Perbandingan prestasi WWCP di rumah teres dan berkembar. WWCP telah digunakan sebagai salah satu bahan binaan di negara-negara yang beriklim sederhana tetapi tidak biasa digunakan di Malaysia

Cara pengkajian melibatkan pengukuran ujian sel di lapangan kosong dan simulasi komputer. Dua ujian sel telah dibina di Universiti Putra Malaysia (UPM), satu dengan WWCP dan satu lagi dengan batu-bata konvensional berplaster. Kerja pengukuran dijalankan dalam tempoh empat bulan untuk ukuran suhu udara, kelembapan bandingan, sifat-sifat udara dan cahaya suria, kemudian diikuti oleh pengesahan IES<VE>. Selepas itu, IES<VE> digunakan sepenuhnya untuk terus menilai prestasi WWCP dalam konteks rumah teres dan rumah berkembar, iaitu prototaip rumah yang terbiasa di Malaysia. Keputusan telah dijadualkan, dianalisa dan dibincangkan.

Keputusan pengkajian pada suhu udara, suhu radian mean, kelembapan bandingan dan pengaliran haba telah mengesahkan WWCP adalah setanding dengan, dan dalam bidang-bidang tertentu, lebih baik daripada batu bata konvensional dalam prestasi haba yang terbukti di ujian sel, rumah teres and rumah berkembar. Oleh sebab tidak terdapat banyak kajian tentang WWCP, Tesis ini menyumbangkan maklumat berharga untuk industri binaan tempatan, pembuat dasar kerajaan, majlis-majlis, pihak berkuasa dan penyelidik-penyelidik dalam bidang WWCP sebagai bahan binaan alternatif yang sesuai untuk tropika.

ACKNOWLEDGEMENTS

Of particular significance is my former lecturer in my undergraduate days, Mr. Jyanzi Kong, who proclaimed that a “complete” architect must practice the “Trinity of Architecture” that involves practice, research and teaching. It was under his influence that after practicing and teaching (part-time) for 15 years, I decided to take up a research program to complete the “Holiness of the Trinity” and urged to become a more “complete” architect. His encouragement and compassion introduced me into the terrors and delights of the PhD program that reinforced my continual search in Architecture.

Thereafter my whole PhD journey owes an unrepayable debt to my former main supervisor, Prof. Dato Dr. Ar. Elias Salleh, who offered full support to my research, including getting the necessary grant from the university to build the Test Cells. Throughout the academic years, he gave insightful advice and valuable information helping me to solve various hurdles. I would also like to thank in particular Dr.Sabrina for her reading, concern, insightful comment and attention to the thesis.

After Prof Elias retired, he was kind enough to remain as an external member of my supervisory team; Prof Elias was replaced by Dr.Zaky, who in last part of my journey given equally tremendous helps to make the Thesis a success. They all are important people in magnifying my perceptions, sensitivities and intuition in architecture and instrumental in guiding me through many hairy moments in the course of the work.

Special thanks must also go to Dato Dr. Abdul Aziz, the managing director of Duralite (M) Sdn Bhd, who generously sponsored all the WWCP materials for the Test Cells and provided abundant information on the product. The construction industry needs more entrepreneurs like him that supports industrial research to make progress.

I am also deeply indebted to my office staffs. Mina taught me to format the word file according to UPM standard, Amir, Ibrahim and Kok Yew helped in producing the drawings, Husam taught me IES Software and sketch-up modeling. Ms. Woo tabulated the excel files. They were patient, cooperative and put up with my pressures with exceptional good humor.

There are many others to thank and space prevents me from naming them all. I made many new friends here who make my sojourn in UPM memorable. I extend heartfelt gratitude to them.

Last but not least, my family, who endured my habit of working throughout the night on the thesis all these years, serving coffee, biscuits and tea in the deep silence of the night became part of their routine lifestyles, without them this whole endeavor would lack any meaning.

May all beings be well and happy.

I certify that a Thesis Examination Committee has met on 14 March 2017 to conduct the final examination of Loo Kok Hoo on his thesis entitled "Thermal Performance of Wood Wool Cement Panels as Building Envelope in Hot-Humid Tropics" 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 Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Suhardi bin Maulan, PhD, LAr.
Associate Professor
Faculty of Design and Architecture
Universiti Putra Malaysia
(Chairman)

Mohd Fairuz bin Shahidan, PhD
Senior Lecturer
Faculty of Design and Architecture
Universiti Putra Malaysia
(Internal Examiner)

Mohd Hamdan Ahmad, PhD
Professor
Universiti Teknologi Malaysia
Malaysia
(External Examiner)

Wong Nyuk Hien, PhD
Professor
National University of Singapore
Singapore
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 6 July 2017

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the Degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Mohamad Fakri Zaky Ja'afar, PhD
Senior Lecturer
Faculty of Design and Architecture
Universiti Putra Malaysia
(Chairman)

Elias Bin Salleh, PhD
Professor Emeritus, Dato' Dr Ar.
Kulliyyah Of Architecture and Environmental Design (KAED)
International Islamic University Malaysia (IIUM)
(Member)

Sabarinah Sheikh Ahmad, PhD
Professor
Faculty of Architecture, Planning and Surveying
Universiti Technology MARA
(Member)

Paridah Md Tahir, PhD
Professor
Faculty of Forestry
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
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Name and Matric No : Ar. Loo Kok Hoo, GS17047

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: ______________________

Name of Chairman of Supervisory Committee: Dr. Mohamad Fakri Zaky Ja'afar

Signature: ______________________

Name of Member of Supervisory Committee: Professor Emeritus, Dato' Dr. Ar Elias Bin Salleh

Signature: ______________________

Name of Member of Supervisory Committee: Professor Dr. Sabarinah Sheikh Ahmad

Signature: ______________________

Name of Member of Supervisory Committee: Professor Dr. Paridah Md Tahir

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LIST OF ABBREVIATIONS

BCA	Building Control Authority
BREEAM	Building Research Establishment Environmental Assessment Method
BES	Building Energy Simulation
CFD	Computer Fluid Dynamics
CIDB	Construction Industry Development Board
CIMP	Construction Industry Master Plan
CO2	Carbon Dioxide
DB	Duralite Boards
EE	Energy Efficiency
ETTV	Envelope Thermal Transfer Value
GBI	Green Building Index
IBS	Industrialized Building System
IES	Integrated Environmental Solutions
ICE	Indoor Climatic Energy
IDA	Indoor Data Analysis
IWEC	International Weather for Energy Calculation
KTAK	Kementerian Tenage, Air dan Kommunikasi
KPKT	Ministry of Housing and Local Government
LEED	Leadership in Energy and Environmental Design
MAPEX	Malaysia Property Exhibition
MRT	Mean Radiant Temperature
OTTV	Overall Thermal Transfer Value
PMV	Predicated Mean Vote
RTTV	Roof Thermal Transfer Value

Tmrt	Outdoor Mean Radiant Temperature
Ta	Air Temperature
TAS	Thermal Analysis Simulations
TC1	Test Cell One
TC2	Test Cell Two
R-Value	Thermal Resistance
UBBL	Uniform Building By-Law
UPM	University Putra Malaysia
U-Value	Overall Heat Transfer Coefficient
WMO	Weather Monitoring Office
WWCP/WWCB	Wood Wool Cement Panels / Wood Wool Cement Boards

LIST OF SYMBOLS

C	Specific Heat Capacity
D	Globe Diameter
ε	Globe Emissivity
k, λ, or κ	Thermal Conductivity
T	Temperature (°C)
Ta	Air Temperature
Tg	Globe Temperature
ρ	Product Density
R	Thermal Resistivity
WH	Watt-Hour
W/mK	Watt per meter Kelvin
W/m2	Watt per meter square
W/m2K	Watt per meter square per degree Kelvin.
m/2	Meter per second

CHAPTER 1

INTRODUCTION

1.1. Introduction

The thesis comprises of a study on thermal performance of Wood Wool Cement Panel (WWCP) in the Malaysian tropical conditions. The reason to choose this subject matter is that WWCP has been used in the West for many years and was found as a good alternative material as building envelope, nevertheless, it is rarely known and was only recently introduced in Malaysia. Locally, brick and cement are still the common building materials. In the light of global warming and the importance of sustainable built environment, the research intends to investigate if WWCP a viable sustainable alternative to the construction industry here. Literature review indicated that there is minimum investigation in the same context, however, the potential of WWCP as alternative construction material that is sustainable, modular, flexible, mobile, speedy installation and economical for Malaysia is significant and will result in a new paradigm in the local construction industry.

The scope of research included the construction of Test Cells comparing WWCP with conventional cement and bricks with field measurement. A validated building performance simulation software Integrated Environmental Solutions (IES) was used to appraise the thermal performance. The Thesis thereafter applied the same environmental data using IES simulations to study a typical naturally ventilated Terrace House and Semi-Detached House prototype in Malaysia to further evaluate the performance of WWCP in typical passive residential conditions. This chapter discusses various problems and issues related to the environment, develop the problem statement and formulate research questions that form the basis of the thesis investigation.

1.2. Background to the Study

Building envelope is the physical separator between the interior and exterior of a building. Components of the envelope are typically: walls, floors, roofs, fenestrations, windows, and external doors. A good building envelope responds to local climate well, involves using exterior wall materials and designs that are climate-appropriate, structurally sound and aesthetically pleasing. In Malaysia, the common materials for building envelopes in local housing are roof tiles and brickwall with cement plaster. As building envelope is the most significant architecture element of a building, the study centered on investigating the thermal performances of Wood Wool Cement Panel (WWCP) in the tropics as building envelope, compared WWCP with conventional brickwall and its resultant thermal performance and thermal comfort in typical passive Terrace and Semi-Detached Houses using computer simulations.

a. Thermal Insulation

Thermal insulation is the reduction of heat transfer (the transfer of thermal energy between objects of differing temperatures) between objects in thermal contact or in range of radiative influence, and provides a region of insulation in which thermal conduction is reduced or thermal radiation is reflected rather than absorbed by the lower-temperature body (Jane Lee & Robert Tiong, 2007). Thermal insulation can be achieved with specially engineered methods or processes, as well as with suitable object shapes and material such as brickwall, timber, glass or WWCP.

The insulating capability of a material is measured with thermal conductivity (k). Low thermal conductivity is equivalent to high insulating capability (R-value). In thermal engineering, other important properties of insulating materials are product density (ρ) and specific heat capacity (c).

b. MS1525

In March 2005, Kementerian Tenaga, Air dan Kommunakasi (KTAK) had proposed to the Ministry of Housing and Local Government (KPKT) that the Uniform Building By-Law (UBBL) be amended requiring the building envelope design of new air-conditioned non-residential buildings to meet requirements of MS1525 with regards to OTTV, daylight, RTTV. This new by-law had been scheduled to come into force in 2007. MS1525:2001 is the "Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-residential Buildings."

c. Overall Thermal Transfer Value (W/m2)

Overall Thermal Transfer Value (OTTV) is the external heat transmission to the internal spaces through walls, roof and windows. MS1525 has recommended that the OTTV of a building should not exceed 50 W/m2. This is an index reflecting the thermal efficiency of a building. The higher the OTTV, the lower its thermal efficiency and hotter it is. Although OTTV was useful indicator for the thermal performance of a building envelope, it had been shown in research works by NUS that it did not reflect accurately the relative performance of the different elements in an envelope system, specifically, it underestimated the solar radiation gain component through the fenestration system and did not represent the full extent of heat gain through the envelope (BCA, 2004).

d. Envelope Thermal Transfer Value (ETTV) and Roof Thermal Transfer Value (RTTV)

The Commissioner of Building Control of Singapore and National University of Singapore in 2004 jointly revised the parameter of OTTV by a new formula named "Envelope Thermal Transfer Value" (ETTV) and similarly reviewed and came out with another new formula for roof, known as “Roof Thermal Transfer Value” (RTTV) with three basic components:

a. Heat conduction through opaque walls,
b. Heat conduction through glass windows,
c. Solar radiation through glass windows.

These three components of heat input are averaged over the whole envelope area of the building giving ETTV more accurate representation of the thermal performance of the envelope. For energy conservation, the maximum permissible ETTV is set at 50W/m2 (BCA, 2004).

e. U-Values and thermal transmittance

The overall heat transfer coefficient (U-Values) is an approximate measure that simplifies the calculation of heat transfer through walls, floors and roofs. It combines the heat transfer coefficients for convective and radiative heat transfer from both surfaces with the conductive heat transfer to provide a single overall heat transfer coefficient for the surface. It is somewhat approximate, since the surface heat transfer coefficients for both convective and radiant heat transfer are dependent on the surface temperatures, measured in units of [W/m2K].

f. Thermal Conductivity of material (W/mK)

Thermal conductivity (often denoted k, λ, or κ) is the property of a material's ability to conduct heat. It appears primarily in Fourier's Law for heat conduction. Heat transfer across materials of high thermal conductivity occurs at a higher rate than across materials of low thermal conductivity. Thermal conductivity of materials is temperature dependent. The reciprocal of thermal conductivity is thermal resistivity. Thermal resistance is the reciprocal of thermal conductivity. It is measured in units of [R=m2.K/W].

g. Mean radiant temperature (MRT)

Mean radiant temperature (MRT) is a measure of the average temperature of the surfaces that surround a particular point, with which it will exchange thermal radiation. If the point is exposed to the outside, this may include the sky temperature and solar radiation (http://www.designingbuildings.co.uk/).

MRT can be measured using a globe thermometer. This is a hollow copper sphere painted matt black (to give it a high emissivity) with a temperature sensor at its centre. MRT highly influences outdoor thermal comfort (Tmrt). Tmrt is the uniform surface temperature of a black enclosure in which a human body exchanges the same heat by radiation as in the actual non-uniform ambience

(ASHRAE, 2004; Gaitani et al., 2016). The equation 1.1 theoretically calculates Tmrt in terms of ºC (Thorsson, Lindberg, Eliasson, & Holmer, 2007).

$$Tmrt = \left[(Tg + 273.15)^4 + \frac{1.1 \times 10^8 Ws^{0.6}}{\varepsilon D^{0.4}} \times (Tg - Ta)\right]^{0.25} - 273.15 \quad (1.1)$$

Where Tg is globe temperature, Ta is air temperature, Ws is wind speed, ε and D is the globe emissivity and diameter respectively. MRT also has a strong influence on thermos-physiological comfort indexes such as physiological equivalent temperature (Glotzer et al, 2009) or predicted mean vote (PMV).

h. Conventional Passive Terrace House and Semi-Detached House

The conventional Terrace House and Semi-Detached Houses are the common housing prototype in Malaysia. The samples in the Thesis are deduced from the common typology since there is not much published literature that affirms the specific attributes of such houses. It is assumed that the houses have three bedrooms, one living room, and one dining area with area of about 180m2.

i. Building Envelope Materials in Malaysia

Energy has great importance in sustainable development with buildings having considerable share in energy consumption. Residential sector has about 16-50% of total energy consumption in the world. Malaysia as a developing country has 19% energy consumption in residential sector in comparison with other sections (E.C, 2007; Saidur, 2009; Saidur et al., 2007). Wong and Li (2007) have studied passive climate control in naturally ventilated residential building in tropical climate of Singapore. They examined efficiency of influence of microclimatic criteria (orientation, shading of surrounded buildings and wind), minimizing of heat gain by utilization of roof thermal buffer, optimization of building materials and shading of windows. They applied thermal analysis software (TAS) and found that thermal buffer is a most efficient method for energy saving. Building envelope plays important role as thermal buffer. The materials for building envelope in Malaysia varies from traditional brickwall, timbers, curtain walls to cladding panels. The Thesis only focus on WWCP and brickwall with cement plaster in naturally ventilated Terrace and Semi-Detached Houses. The U values is assumed to be ranging from 2.7-2.8 W/m2K.

j. Wood Based Products

Stuart L. Hart (1997) highlighted the over exploitation of renewable resources and deforestation for emerging economies and survival economies while developed economies having scarcity of material and insufficient reuse and recycling causing depletion of world resources as indicated in Figure 1-1:

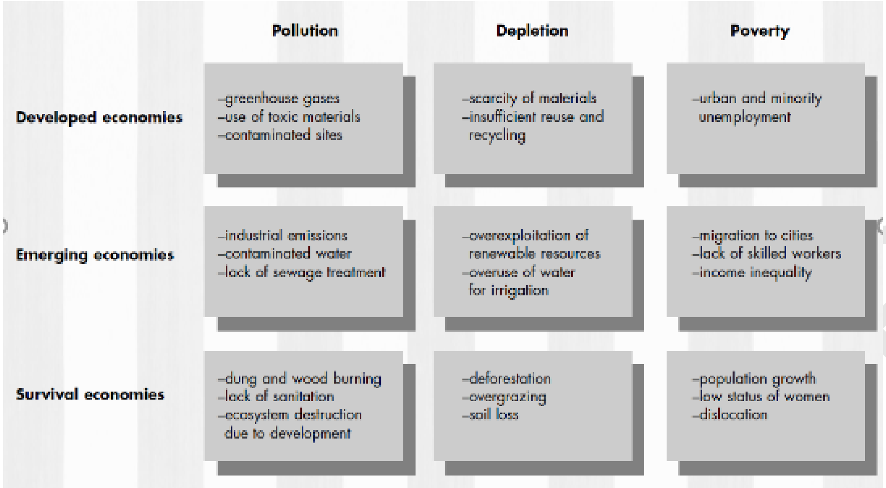

Figure 1.1 : Major Challenges to Sustainability

As human society progresses, we cannot stop development but a carefully planned strategy is needed with minimum disturbance to nature, new sustainable building materials must be explored to replace, at least, partially or progressively conventional materials. The importance of sustainable and ecological design is crucial to minimize damage to environment, provide alternative for end-users without lowering living standards, create an environment that is sustainable, energy saving and optimum human comfort. There is a need to explore possibilities of new alternative sustainable materials as building envelopes since they contribute more than 60% of building surface in terms of walls and roof. Building envelope involves insulations, materials, construction systems, forms, massing, orientation, enclosures and shadings. Development of wood based products with cultivated trees is one of the popular solutions for building industries particularly in the West. However, this practice is not common in third world countries. According to The Norwegian EPD Foundations[1], wood based products are basically divided into three main categories 1. Building boards, 2. Insulation material, 3. Window and doors developed from the whole chain of manufacturing process (Kreschmann et al 2007):

[1]http://www.epdnorge.no/getfile.php/PDF/PCR/NPCR%20015%20Wood%20and%20wood-based%20products%20for%20use%20in%20construction.pdf

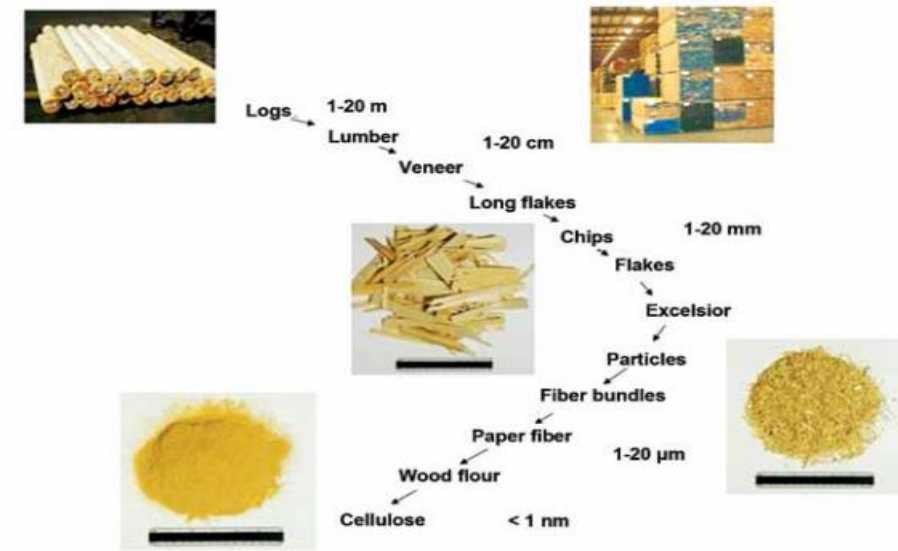

Figure 1.2 : Basic wood elements, from largest to smallest
(Kreschmann et al 2007)

Most of the wood based products are used as internal architecture elements - trusses, floors, partition boards, ceilings, columns, window and door frames, insulation and so on. The building board can be classified by particle size, density and process (Suschsland and Woodson, 1986):

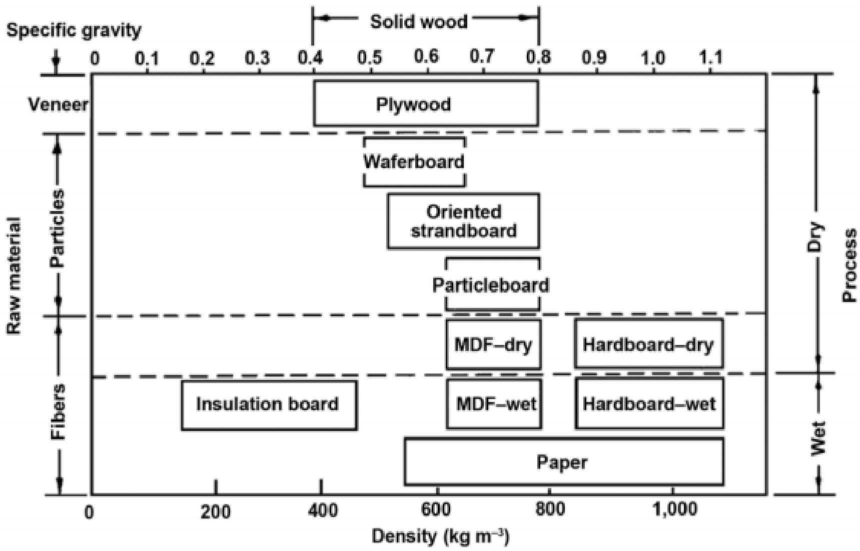

Figure 1.3 : Classification of wood composite panels
(Suschsland and Woodson, 1986)

The focus of the Thesis is on building board used as building envelopes. The most commonly and widely used wood based composite board for external building envelope is cement-bonded composite materials, when combined with water, reacts in a process called hydration to solidify into a solid stone-like mass and bind aggregates materials. The surface can take cement and plaster. The low-density composite can be used as interior ceiling and wall panels while the high-density panels can be used as floors, walls, fire walls, load bearing wall[2]

Figure 1.4 : Wood Wool Cement Panels (WWCP)

As cement, phosphate binders can be used to produce bulk composites. When conventional cement is used in fiber based products, typical cement loading is approximately 30% or higher; phosphate cements may be used in a similar manner. The slurry formed by the acid–base reaction may be mixed with fiber or any other extender to produce solid composites (Jeong and Wagh 2003). Phosphate binders may also be used for coating wood-based composite panels to enhance surface properties.

1.3. Issues and Problems

Roodman et al (1994) indicated one tenth of the global economy is related and dedicated to constructing, operating and equipping building and construction. Dimson (1996) further mentioned that construction industry consumes 25% of jungle and raw woods, 40% of raw sands and gravels worldwide each year. This sector also responsible for huge wastage, greenhouse effect and environmental damage (Barret, 1999). The term “sustainable development” or “sustainable construction” was becoming important from 1990s onwards, defined in Brundtland Report as “development that meets the needs of the present without compromising the future generations to meet their own needs” (WCED, 1987) and a balanced and holistic approach is urgently needed.

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[2] Wood-Based Composite Materials from General Technical Report FPL-GTR-190 http://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr190/chapter_11.pdf, Pg. 11-24

Malaysia now is classified as “newly industrialized country” or emerging economy. (Mankiw, 2008). The construction activities contributed crucial environmental and social impacts with the exploitation of resources, uncontrolled development and planning resulted in deterioration of environment. (Aiken et al 1982, Begum, 2008) (Sani, 1999) Accordingly, in recent years, Malaysia experienced economic growth in population and housing well above the national average and housing contributes to 70% of the building industry (Ministry of Housing and local Government Malaysia 1999). The rate of jungle being cleared and hill being cut down for housing is alarming – all in the name of “development”. Man, no longer lives in harmony with nature. Housing is designed with little consideration to climate, consuming excessive energy, with absence of cross ventilation, no sun shading, inappropriate orientation, wrong choice of materials that cause a rise in energy consumption to cool the houses and wastage.

Begum et al (2008) in their findings revealed that pertinent important environmental problem in Malaysia are deforestation, water pollution, air pollution, ground water contamination and soil erosion. The government and other stakeholder (CIDB or Master Builders Association) should implement various measures to alleviate the problems. This involves developers, builders and related professionals. Malaysia has undergone a major structural transformation, moving from agriculture to manufacturing-based economy, with significant social changes and has significant impacts to the natural environment. Unless environmental considerations and related ecosystems are protected as integral parts of development planning and decision making, the situation would get worse.

Abidin (2009b) cautioned that construction has the most detrimental effects on environment. His survey concluded that developers are aware of the rising issues on sustainability but little efforts are made to improve the situations. Government and non-government bodies must joint with concerted effort to stimulate actions and strategies for a sustainable built environment. Abidin N.Z (2009a, 2009b, 2010) further argued that the adverse impacts to the environment from construction industry lead to issues on environmental dissatisfaction. The levels of understanding by the Malaysian government, non-government bodies, and professionals are not enough and no pro-activity to alleviate the problems. Creating sustainable construction requires research methods and commitment by all players to stimulate actions and strategies.

Faridah Shafii (2006) presented the construction scenario of Southeast Asia and the developments in sustainable construction taking place in the region, discussed the barriers to the implementation of sustainable construction and a list of recommendations. The status of sustainable construction in Southeast Asia is still in infant stage, lack of awareness, training and education, ineffective procurement systems, short of encouraging public policies, regulatory frameworks, capacities, technologies and tools, total and ardent commitment by all players in the construction sectors leads to a dilapidating environment.

Rapid urbanization also means increased demand for more construction materials and depletion of more natural resources. The process of producing building materials used up large amount of energy emits substantial quantity of carbon dioxide (CO2), waste and toxic materials that are harmful to the environment. Architects and the building industry stakeholders should look into the issues seriously, differently, creatively, think outside the box and explore environmental problems in the design process with inter-discipline collaborations for solutions.

Although the issues of sustainability and ecology in creating and promoting awareness on sustainable architecture amongst the professionals involved in the building industry and implementation of new knowledge is gaining momentum, a study of perception on sustainable architecture shows out of 100%, 60% of them lacked familiarity on sustainability, 79% agreed that sustainability is important and 85% felt more support is needed. Overall the awareness is not sufficient in Malaysia (Ahmad, 2004).

Tom Woolley (2008) highlighted the present global scenario that

- We consume 10 times our fair share of global recourses
- We will need 10 planets to sustain our current use of resources
- The construction industry consumes 10% of all our energy usage
- Building and their production contribute over 50% of CO2 emissions
- We waste up to 40% of materials coming to site
- Construction waste is one of the main contributors to landfill.

The construction industry “needs to integrate sustainability within the whole life cycle of a building from design through construction to operation” (Dawood, 2009). Architect should have the knowledge to reduce the impact of buildings on the environment through designing an energy efficient building, unfortunately most design decision made are for aesthetic without much knowledge on the environmental sciences. An energy efficient (EE) design requires a complex computational quantitative calculation to predict the energy performance of a building known as Building Energy Simulation (BES).

In view of the present problems, various countries have developed standards and indices to guide building industries on sustainable development. Singapore had developed Green Marks to ensure all new developments comply with sustainable standards. Green Plot Ratio is used as ecological measure and greenery coverage for architecture and planning (Ong, 2003). England is adopting BREEAM, America is using LEED while Malaysia had developed her own Green Building Index (GBI) for design guidelines. It is the responsibility of every nation and individual to collectively work together to find solutions to this global problem.

Hence buildings as major resource consumer contributes substantially to environmental deterioration. In this scenario, building envelope acts as interface between the building and the environment and controls the interactions between them, has significant impact on the initial and running costs, energy efficiency and indoor environment of the building. Building envelope is significant to the functional performance of the building through its integration with other building systems. (Jane Lee, Robert Tiong 2007). It is under this scenario that the Thesis attempts to establish an alternative material for building envelope and identifies the potential of WWCP.

From the above literature review, the thesis identified the issues and problems we are facing:

- Over and rapid urbanization without due consideration to environment causing chain reactions from Mother Earth endangering the human habitat. Global warming, greenhouse effects, floods, tsunami, melting of iceberg in the north and south poles, climate disorder and so on are real problems of the day.
- Construction industry related to urbanization contributes significantly to these problems. Economic development clears unnecessary greenery; production of building materials used up plenty natural resources and emits excessive CO_2 to the atmosphere. The wastage from these activities further aggravates the scenario. Alternative solutions are needed to elevate the problems.

There is limited research on alternative solution to the problems we faced. This is relevant to the Terrace and Semi-Detached Houses in Malaysia where cement and brick is assumed to be the solution for all.

Norman Foster in his RIBA October Talk 2010 indicated the “Triangle of Sustainable Design” where basic passive design of buildings at the bottom of the triangle contributes most energy and cost savings with maximum environmental gain. As sustainable design moves up the Triangle with technology integration, cost increases and environmental gain reduces.

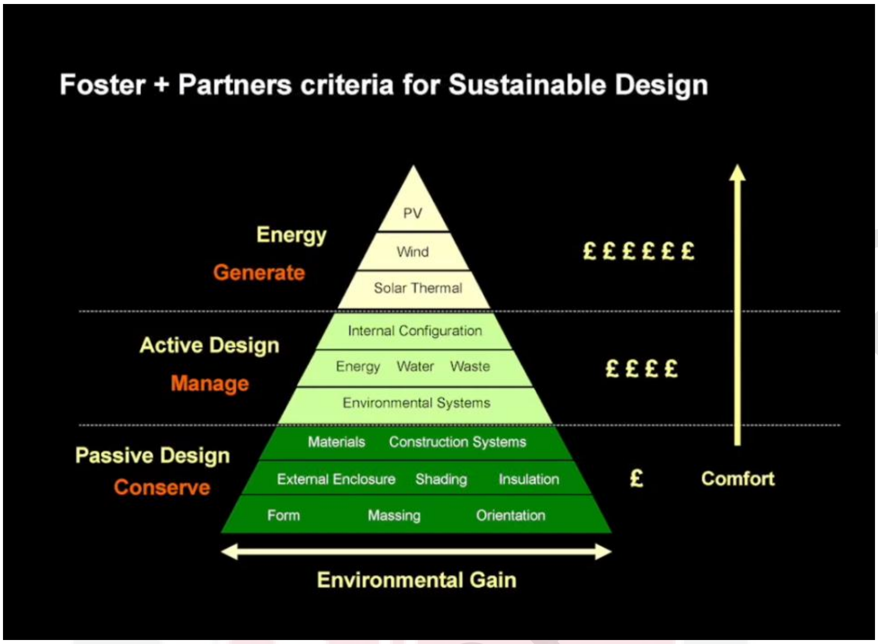

Figure 1.5 : Triangle of Sustainable Design (Norman Foster 2010)

This means some of the solutions to our environmental problems may lie at the bottom of the Triangle that involve materials, construction systems, forms, massing, orientation, enclosures, shadings, and insulations. In other words, when buildings are designed conforming to the optimum performance of these basic elements, environmental problems may be lessened. This is more significant when WWCP is acting as building envelope, which has the largest surface area exposed to the external environment, the finding eventually may provide a good option for the Tropics. It is this basic issue that formed the background of the research.

1.4. Research hypothesis and questions

Wood Wool Cement Panels (WWCP) was introduced to Malaysia less than 10 years, if the performance is proven comparable to conventional plastered brickwall, a potentially good alternative solution may be found for the tropics. Based on the research background, problems and issued discussed, the research hypothesis adopted:

a. WWCP could be a viable alternative building material for building envelopes in the tropical conditions of Malaysia.
b. The material can provide the necessary thermal comfort requirements compared to the conventional brick and cement.

In designing the research, the following research questions were developed:
Main Research Question:

a. What is the thermal performance of WWCP in the tropics?

Sub-Research Questions:

b. How does WWCP perform in a naturally ventilated Terrace House and Semi-Detached House in local context?
c. What is the thermal comfort in a WWCP house compared to conventional brick and cement house?

1.5. Research Objectives

The research objectives are to investigate:

a. The thermal performance of WWCP as alternative material in building envelopes.
b. Evaluate the material in terms of building performance and thermal comfort in a naturally ventilated Terrace and Semi-Detached Houses.
c. Implications of the findings to architecture.

1.6. Literature Review

The literature review explored the research works by various scholars and information in the followings areas:

a. The problems and issues in the construction industry of Malaysia;
b. Analysis of the climate and its design conditions in Malaysia;
c. Issues of building envelopes;
d. Concept of thermal performance and thermal comfort in the tropical conditions and related research works on the topics;
e. Available research works on wood wool cement panels;
f. Computer simulations using validated software accepted by the academia;
g. Knowledge gap in thermal comfort study;

Chapter 2 Literature Review shall identify the knowledge gap and provides comprehensive background knowledge to validate the significance of the thesis.

1.7. Significance of the research

The research of a sustainable product such as WWCP has significant impact and knowledge contribution to the local industry. The material from wood flours mixed with Portland cement has the properties of insect and termite resistance, solar resistance, water resistance. Its modular and flexible nature has good potentials for the development of tropical building envelopes, if the study on application of WWCP is proven feasible as alternative building materials:

i. The research established a new sustainable product as one option for building industry in Malaysia.
ii. The new knowledge shall open another paradigm in the construction industry. This means cutting down less forest, consume less energy, emits less carbon dioxide to the atmosphere and reduces the effect of global warming. Since construction industry contributes more than 40% of the human activities in a habitat.
ii. The result provides references to legislator, developers, architects and builders on new material in promoting sustainable design.
iv The findings provide a design guideline for designers and environmental planning

There is no known research on WWCP as building envelopes in the tropics, the successful testing of its satisfaction on thermal performance and human thermal comfort shall offer another new paradigm in architecture and development of sustainable architecture that produce future built environment that is green, water resistance, termite resistance, heat resistance, consume less natural resource, emits less carbon dioxide and hence helps to reduce global warming. The prefabrication construction of WWCP increases speed, reduces cost and ready for mass production. The product could be the major contributor in green architecture – architecture of the future.

1.8. Scope of research

The research was confined to Malaysian climate, two Test Cells and two common house typologies, one is Terrace House and another Semi-Detached House, both assumed to be under naturally ventilated conditions. The field data were collected over a period of 4 months, from February to March and from September to October 2010, however, as the variations were similar without significant difference, the thesis selected typical sets of readings for study, i.e. March (16 days) and September (10 days).

The house typology was developed from samples collected from Malaysia Property Exhibition (MAPEX) which is assumed to be the most common typology in the local market. Passive design strategies were incorporated in the design of house typology guided mainly by the relevant passive design strategies listed in the MS 1525.

The study of the house typology was using computer software Integrated Environmental Solution Virtual Environment [IES<VE>] specifically via ApacheSim, Macroflo, Suncast, microflo and VistaPro, respectively. The IES<VE> programme has since 2000 been accepted as the building performance simulation for the accreditation of LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), Green Star (Australia), GBI (Malaysia) and commonly used by other researchers in the field of building performance simulation.

WWCP was investigated as composite materials having 76mm thick WWCP with 12.5mm cement rendered on both sides as building envelopes. The comparison base Test Cell consists of sand brick of 100mm thick with cement plaster of 12.5mm on both sides. The weather data used for IES simulation is from Subang weather station - Kuala Lumpur IWEC.fwt (1999).

1.9. Research methodology

As the problem requires comprehensive investigation, a mixture of qualitative and quantitative methods was used. Quantitative method research was used that involved instrument to collect performance data, census data and statistical analysis; Qualitative research investigates the observation data, text, graphs and image reference from the experimentation.

The research was designed with a review of literature on the issues and problems of the construction industries in Malaysia to identify the problems and formulate the research questions. Thereafter, the process followed by

a) Investigation of the thermal performance of materials - Two Test Cells were built; the base cell was using conventional brickwall and cement plaster while another was using WWCP. Field measurements were recorded.
b) Computer validations and simulations - The Test Cells were then simulated using IES computer software, and compared the field data versus simulated data. This step would validate if IES simulations data was close to the field data and confirm if the variants were within acceptable range.
c) Investigation on typical houses - the Thesis would then use IES to simulate a typical Terrace and Semi-Detached Houses common in Malaysia for thermal performance and thermal comforts. This step would verify the suitability of WWCP used in our local housing typology. The methodology was summarized in Figure 1.6.

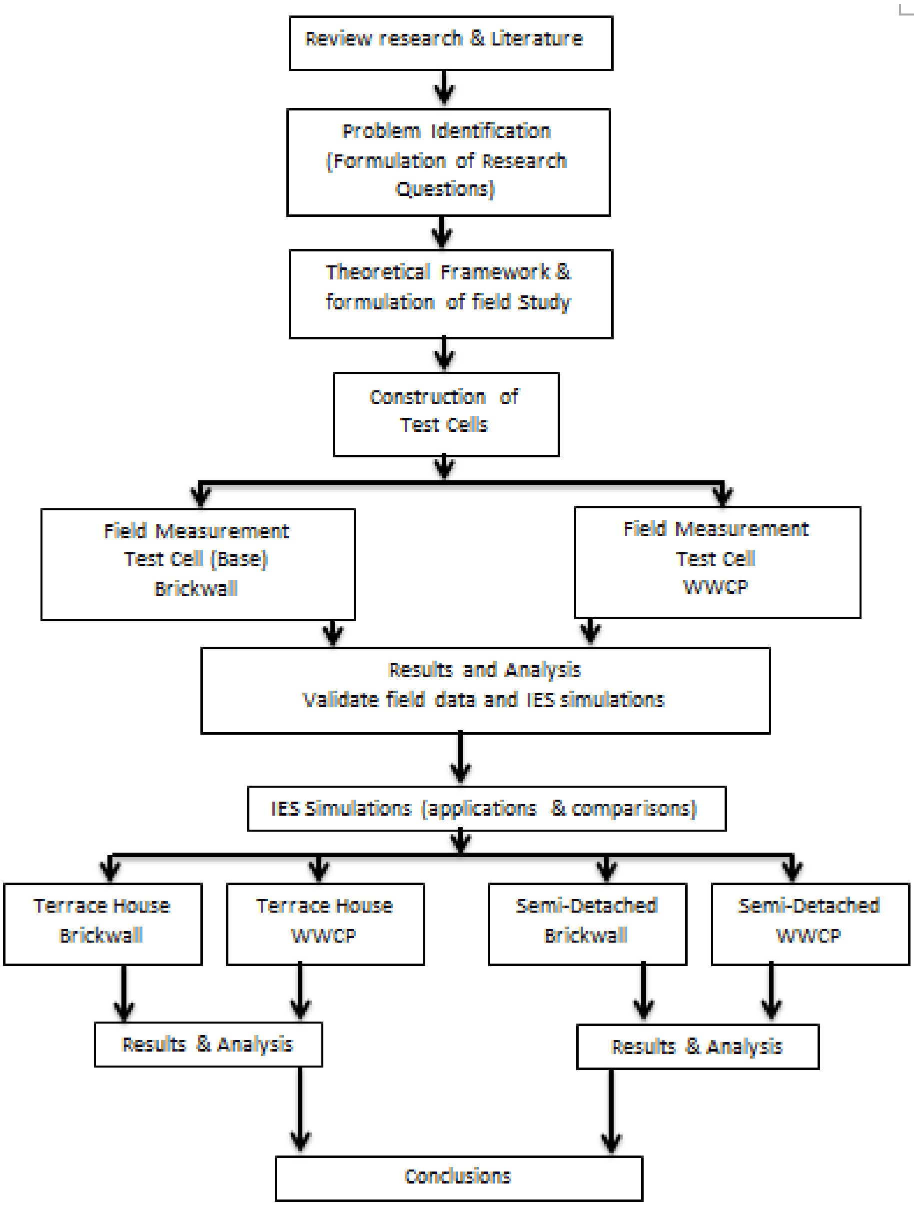

Figure 1.6 : Research Methodology

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1.10. Research Framework

The whole research was illustrated as research framework:

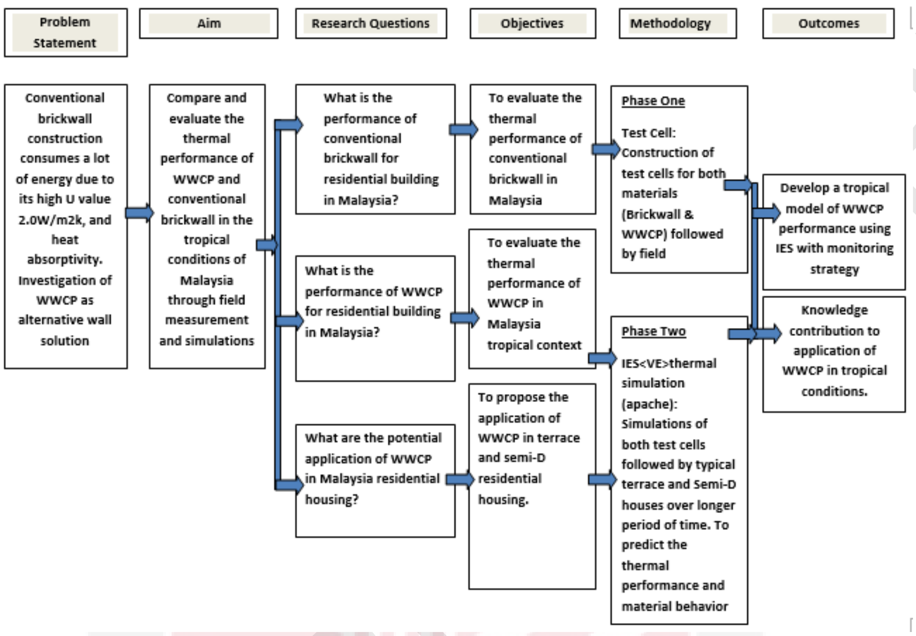

Figure 1.7 : Research Framework

1.11. Thesis Structure

Chapter 1 as introduction outlined the overall scope of the thesis included the background of the problems and issues, research objective, hypothesis and research questions.

Chapter 2 on literature reviews attempted to understand the related research works on the subject matter as a point of departure for investigation. This included not only materials on WWCP, but various issues on environmental sciences - thermal performances, thermal comfort, knowledge gap in thermal envelope studies and so on related to the Tropics.

Chapter 3 presented the climate of Malaysia, analysed the weather of Kuala Lumpur and established the neutrality temperature for Malaysia.

Chapter 4 described the methodology and setting up of Test Cells in University Putra Malaysia (UPM), presented the concept, validation and application of IES software as well as developing typical hypothetical housing prototypes.

Chapter 5 presented the results and analysis of field measurement

Chapter 6 presented the results and analysis of IES simulations.

Chapter 7 presented the results of thermal comfort using IES simulation and discussed the thermal properties of WWCP.

Chapter 8 concludes the investigation of the Thesis.

Therefore, Chapters 5 to 7 are the core research works of the thesis while Chapter 8 concludes the whole investigation with recommendations for future research on the subject matter.

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