STRUCTURAL EQUATION MODELING OF ENERGY CONSUMPTION IN RESIDENTIAL BUILDING

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requirements for the award of the degree of
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Dedication

To Almighty ALLAH, My beloved Parents, My Family, My Respected Supervisors, Relatives, and Friends.

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ABSTRACT

Building energy consumption has become a serious issue due to increased energy demand, which contributes heavily to global warming. Based on the reports published by Energy Information and Administration of USA in 2015, Malaysia Green House Gas (GHG) emission is expected to increase by about 74% from 2005 to 2020 if proper mitigation is not put in place. Among the major contributor is building sector, which is generating a massive 40% of total greenhouse gas emitted. There are many literature describing the effect of carbon emissions by residential buildings. Nevertheless, lack of study focus on building energy consumption in relation to socioeconomic, dwelling and climate components. The aim of this study is to establish a structural relationship of socioeconomic, dwelling and climate factors on residential building energy consumption. Four objectives were identified to achieve the aforementioned aim. The first objective was to identify the independent and dependent factors affecting energy consumption in residential buildings. The second objective was to analyze and establish the critical independent factors of energy consumption in residential buildings. The third objective was to analyze and establish the critical dependent factors of energy consumption by residential building occupants. The fourth objective was to formulate a structural relationship based on the established critical independent and dependent factors as a strategy for improving energy consumption in residential buildings. Three benchmarked independent and six dependent factors were established. The descriptive research design employed in the study lead to the structural model development as the central focus of the study. A structured questionnaire consisting of 80 items were used for data collection. The research population was Johor residents and the survey employed 425 returned questionnaires. The collected information was analyzed using descriptive and Confirmatory Factor Analysis. The outcome of the five (5) hypothesized research questions show that Climate Factor has a significant and direct effect on building energy consumption and dwelling. Furthermore, results indicate that Socioeconomic and Dwelling factors have neither significant no direct effect on building energy consumption. Based on the results, a Building Energy Consumption structural relation was established using Structural Equation Modeling (SEM). The established structural relation was validated using convergent and construct validity. The structured model provides useful information to the Malaysian Construction Industry through improved design and awareness on issues related to residential building energy consumption.

ABSTRAK

Penggunaan tenaga bangunan telah menjadi satu isu yang serius disebabkan oleh peningkatan permintaan tenaga yang menjadi penyumbang besar kepada pemanasan global. Berdasarkan laporan yang diterbitkan oleh Maklumat dan Pentadbiran Tenaga Amerika Syarikat pada tahun 2015, pelepasan Gas Rumah Hijau (GHG) di Malaysia dijangka meningkat sebanyak 74% dari tahun 2005 ke 2020 jika langkah mitigasi tidak dilakukan dengan betul. Antara penyumbang utama adalah sektor bangunan, yang menjana 40% daripada jumlah gas rumah hijau yang dikeluarkan. Terdapat banyak literatur yang menerangkan kesan pelepasan karbon oleh bangunan kediaman. Walau bagaimanapun, kurang kajian khusus tentang penggunaan tenaga bangunan yang berhubung dengan sosioekonomi, kediaman dan komponen iklim. Tujuan kajian ini adalah untuk membangunkan hubungan struktur terhadap sosioekonomi, kediaman dan faktor-faktor iklim ke atas penggunaan tenaga bangunan kediaman. Empat objektif telah dikenalpasti untuk mencapai matlamat di atas. Objektif pertama adalah untuk mengenal pasti faktor-faktor bebas dan bergantung yang menjejaskan penggunaan tenaga dalam bangunan kediaman. Objektif kedua adalah untuk menganalisis dan menentukan faktor-faktor bebas yang kritikal daripada penggunaan tenaga dalam bangunan kediaman. Objektif ketiga adalah untuk menganalisis dan menentukan faktor-faktor bergantung yang kritikal daripada penggunaan tenaga oleh penghuni bangunan kediaman. Objektif keempat ialah untuk merumuskan hubungan struktur berdasarkan faktor-faktor kritikal bebas dan bergantung yang ditubuhkan sebagai strategi untuk meningkatkan penggunaan tenaga dalam bangunan kediaman. Tiga tanda aras tidak bersandar dan enam faktor bersandar telah dikenal pasti. Rekabentuk kajian deskriptif yang digunakan membawa kepada hubungan struktur model sebagai tumpuan utama kajian. Soal selidik berstruktur yang mengandungi 80 item telah digunakan sebagai alat untuk pengumpulan data. Populasi kajian adalah penduduk Johor dan kajian menggunakan 425 soal selidik berstruktur yang dikembalikan. Maklumat yang dikumpul dianalisis menggunakan analisis deskriptif dan analisis pengesahan faktor. Hasil daripada lima soalan (5) hipotesis kajian menunjukkan bahawa, Faktor Iklim mempunyai kesan yang besar dan secara langsung terhadap penggunaan tenaga bangunan dan kediaman. Tambahan pula, keputusan menunjukkan bahawa faktor Sosioekonomi dan Faktor Kediaman tidak mempunyai kesan ketara atau kesan langsung ke atas penggunaan tenaga bangunan. Berdasarkan keputusan, hubungan struktur Model Penggunaan Tenaga Bangunan telah dibangunkan menggunakan Pemodelan Persamaan Struktur (SEM). Hubungan struktur ditubuhkan telah disah menggunakan kesahihan menumpu dan membina. Model berstruktur menyediakan maklumat yang berguna kepada Industri Pembinaan Malaysia melalui reka bentuk yang lebih baik dan kesedaran mengenai isu-isu yang berkaitan dengan kediaman penggunaan tenaga bangunan.

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ACS	-	Air-Condition System
AMOS	-	Analysis of Moment Structure
AVE	-	Average Variance Extracted
BECSM	-	Building Energy Consumption Structural Model
BLA	-	Bath and Laundry Appliances
Btu	-	British thermal unit
CAGR	-	Compounded Average Growth Rate
CCTV	-	Closed Circuit Television
CESM	-	Climatic Energy Structural Model
CETDEM	-	Centre for Environmental Technology and Development in Malaysia
CF	-	Climate Factor
CFA	-	Confirmatory Factor Analysis
CIA	-	Central Intelligence Agency
CIDB	-	Construction Industry Development Board
CO2	-	Carbon Emission
CR	-	Composite Reliability
CRT	-	Cathode Ray Tube
DESM	-	Dwelling Energy Structural Model
DF	-	Dwelling Factor
DSM	-	Department of Statistics Malaysia
DVD	-	Digital Versatile Disk
DVR	-	Digital Video Recorder
EFA	-	Exploratory Factor Analysis
EIA	-	Energy Information Administration
EPBD	-	Energy Performance of Building Directives
FL	-	Factor Loading

GDP	-	Gross Domestic Product
GFCF	-	Gross Fixed Capital Formation
GHG	-	Green House Gas
GWh	-	Giga Watt hour
HA	-	Home Appliances
HVAC	-	Heating Ventilation and Air-Condition
IEA	-	International Energy Agency
IEO	-	International Energy Outlook
IMF	-	International Monetary Fund
KD	-	Kitchen Devices
KLIA	-	Kuala Lumpur International Airport
KMO	-	Kaiser-Meyer-Olkin
KWh	-	KiloWatt-hour
LA	-	Lighting Appliances
LCD	-	Liquid Cristal Display
LED	-	Light Emitted Diode
LNG	-	Liquefied Petroleum Gas
MBJB	-	Majlis Bandaraya Johor Bahru
MOSTI	-	Ministry of Science Technology and Innovation
MPJBT	-	Majlis Perbandaran Johor Bahru Tengah
Mtoe	-	Million ton of energy
NIC	-	Newly Industrialized Country
PTEM	-	Physical Technical Economic Model
PWD	-	Public Works Department
PKK	-	Pusat Khidmat Kontractor
RS	-	Refrigeration System
SEDA	-	Sustainable Energy Development Authority
SEESM	-	Socio-Economic Energy Structural Model
SEF	-	Socio-Economic Factor
SEM	-	Structural Equation Modeling
SPSS	-	Statistical Package for Social Sciences
TNB	-	Tenaga Nasional Berhad
TV	-	Television
UBBL	-	Uniform Building By-Laws

US	-	United State
UTM	-	Universiti Teknologi Malaysia
VCR	-	Video Cassese Recorder

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CHAPTER 1

INTRODUCTION

This chapter serves as an introductory description of the research outline of the various sections considered in this research. It comprises of the introduction to the chapter, background of the research, problem statement, aim and objectives, research hypothesis, research questions, the scope of the study, and significance of the study as well as research flowchart.

1.1 Background of the Research

The upward growth of the worldwide population has influenced the increasing need of buildings globally. These buildings play a vital role in providing shelter and offices for occupant's usage. However, it becomes a major issue of concern in the past decades, due to its role in global energy consumption. Carbon (CO2) and Greenhouse Gas (GHG) emissions produced by buildings cause depletion of the ozone layer. This lead to a serious environmental impact which has a direct effect on climate change and global warming (Luis *et al.*, 2008; Shafie *et al.*, 2011). Buildings contribute tremendously to GHG emission, it is responsible for 33% of worldwide energy-related GHG emissions (Robert & Kummert, 2012).

The International Energy Outlook report (2013) on the current position of global energy consumption reveals that energy will continue to grow by 56% in-between the year 2010 to 2040. This is due to fast changes in socio-economic and demographics (EIA., 2013). Despite the continuous campaigns on global energy awareness and mitigation of greenhouse gas emissions in the last 40 years, there is more than 100% growth in CO_2 emissions annually (Nejat *et al.*, 2015). Global carbon emission is expected to increase to 32 billion tons of CO_2 by projection in 2020 (IEA, 2013). This projection is expected to double (64 billion tons CO_2) by 2050 if proper climate change measures are not put in place (Nejat *et al.*, 2015; Wada *et al.*, 2012).

The trend of building energy consumption is on the increase in many countries around the world. For example, building sector consumes 41% of energy in the United States (BEDB, 2011). In China, 28.6% of the total energy is consumed by buildings (Zhu & Li, 2015). In Europe, building sector consumes up to 40% of the world's energy and consumes 25% of forest timber including 16% of the world's fresh water (Foucquier, 2013). In Malaysia, buildings consume up to 48% of the energy in the country (Chua & Oh, 2011; Jibrin *et al.*, 2014).

One of the identified areas of energy consumption in a residential building is the use of electrical appliances. Heating, Ventilation and Air Conditioning (HVAC) system, domestic appliances and lighting demonstrate a positive consumption of electricity in residential buildings (McLoughlin, 2012). Electricity consumption in residential buildings accounted for 6% direct CO_2 emission (Olivier *et al.*, 2013) and 11% indirect global CO_2 emission (IEA, 2013).

Malaysia has been named among the highest greenhouse gas emitting countries in the world (Shamsuddin, 2012). A growth of 7.9% Compounded Average Growth Rate (CAGR) was recorded from 1990 to 2006 (Shamsuddin, 2012). The world fact book by the Central Intelligence Agency (CIA) reveals that 118 billion kWh of electricity were produced by the Malaysian Government (CIA, 2013). Tenaga National Berhad (TNB) reported that the consumption of electricity in the country is 116,353GWh. Buildings in Malaysia consume a total of 54% of electricity in the country. This is equal to 63,354GWh. Commercial buildings consume 38,645GWh (33%) and residential buildings consume 24,709 GWh (21%) respectively (Tenaga, 2012).

Although residential buildings consume less energy compared to commercial. This study focuses on residential buildings because the overall energy use per m^2 of residential buildings is half of that of a commercial building (Jiang, 2011). Thus, building energy consumption analysis towards conservation should concentrate on the level of the influencing factors (Ma *et al.*, 2017). The influencing factors used in this research is the socio-economic factor. Socio-economic factors can only have an influence on residential buildings but not on the commercial building.

Electricity generation in Malaysia is from a mix fuel sources, namely natural gas, coal and hydro. In 2008, TNB reported that fuel source for electricity generation is, natural gas 54%, coal, 28% and hydro 17% (TNB, 2008). The current position of mix fuel for electricity generation in 2014 as reported by TNB is natural gas 54%, coal, 35% and hydro 10% (TNB, 2014). The increase and substantial dependence of electricity generation on coal and natural gas have provided reasons for concerns. The power industry TNB contributed 60 million tons of carbon emission, this is about 32% of the total emission in 2005, and this will increase to 153 million tons, about 47% in 2020 (Shamsuddin, 2012). This is due to the over dependency on natural gas and coal for power generation.

For decades, researchers have worked tirelessly on how to tackle issues related to global warming and carbon emission. However, the future forecast on the issue is still uncertain as the problem continuously growing over a period of years. Based on these conclusions, this study appears with the idea of providing a structural relationship of building, socio-economic and climate factors in providing an information which will provide the construction industries with information that will be of benefit in term of energy efficiency improvements and design of residential buildings.

1.2 Problem Statement

The major component that contributes to climate change is urban development (construction activities) which is generating a massive 50% of total greenhouse gas discharges (Griggs *et al.*, 2013). The Malaysian construction industry is well established and is quite inspiring in its role of providing structural development to its developmental vision of 2020 (Ibrahim *et al.*, 2010). However, the industry is faced with a series of challenges, particularly its contribution to carbon emission (Shamsuddin, 2012). The industry is responsible for an environmental threat in terms of natural resource consumption and is emitting million tons of carbon annually (Klufallah *et al.*, 2014).

The Malaysian building sector is responsible for the emission of 5,301 ktons of GHG with an annual growth rate of 6.4% in 2010, this is equivalent to 20% of the total GHGs emitted in the country (UNDP, 2009; Zaid & Graham, 2012). The forecast is expected to reach 8,088 ktons of GHG emission in the year 2014 (Zaid *et al.*, 2015). Another weak point of the industry is its failure to blend the construction production process and the design process (Ibrahim *et al.*, 2010). The effort achieved by the Industrialized Countries of the 1970s and 1980s (Hong Kong, South Korea, Singapore and Taiwan) towards energy efficiency is as a result of meeting the consumer's demands (Zaid *et al.*, 2015). This approach is missing in the Malaysian construction industry. This study found this problem as a matter that needs proper investigation and possible solution.

In an attempt to provide a better solution to the above problem, this study focus is on building energy consumption in relation to socio-economic, dwelling and climate factors. From the previous studies, socio-economic, dwelling and climate are the major attributes to residential energy consumption. There is numerous literature describing the influence of socio-economic on building energy consumption (Chen *et al*., 2013; Elisha *et al*., 2015; Elnakat & Gomez, 2015; Permana *et al*., 2015; Ryan, 2014; Yue *et al*., 2013). In addition, some researchers focus on Dwelling Factors (Baker & Rylatt, 2008; Bedir *et al.*, 2013; Kavousian *et al*., 2013; Ramírez-Villegas *et al.*, 2016) while others have considered climate as a factor *(Aldossary et al*., 2014; Fumo *et al.*, 2010; Huang *et al.,* 2015; Mirrahimi *et al*., 2016).

On the other hand, some researchers consider the influence of building energy consumption in residential buildings in a hybrid approach. These hybrid approaches are socio-economic and dwelling, dwelling and climate and socio-economic and climate (Figure 1.1). Socio-economic and dwelling factors influence on building energy consumption is studied by (Jones *et al.*, 2015; Kelly, 2011; Longhi, 2015; McLoughlin, 2012). In addition, dwelling and climate was studied by (Chong, 2012; Huang *et al.*, 2015; Kavousian *et al.*, 2013; Mirrahimi *et al.*, 2016) and the last group consider socio-economic and climate (Blázquez *et al.*, 2013; Kavousian *et al.*, 2013; Rehdanz, 2007; Štreimikienė, 2014). This study identified these 3 factors as the key influencing factor of energy consumption in the residential building. Residential building energy consumption can best understand when considering these 3 factors (Jones *et al.*, 2015). The study realizes that there is no any study conducted which combine these 3 factors (socio-economic, dwelling and climate) in providing a useful information on building energy consumption. Figure 1.1 shows a picture of the previous studies in relation to socio-economic, dwelling and climate.

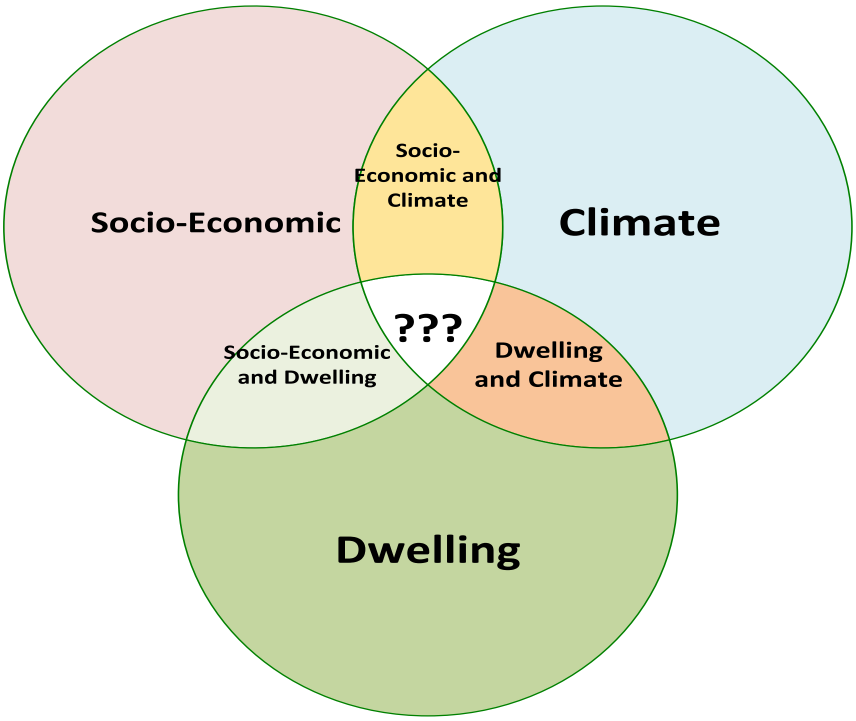

Figure 1.1 Research Gap

A better understanding of the factors of residential building energy consumption provides a beneficial information. The information can be utilized in two ways, the first one is on the implementation of energy policy and the second one is to help in predicting the future energy consumption. Because of this reason, this study finds it mandatory to further investigate the relationship of these factors and building energy consumption. This is in order to provide the construction industries with a reliable managerial information towards building energy consumption.

1.3 Research Questions

The Research Questions in this thesis is poised to fulfill the objectives in order to achieve the main aim of the research. Four questions were listed as follows:

i. What are the independent and dependent factors influencing consumption of energy in residential buildings?
ii. To what extent socio-economic, dwelling and climate factors influence consumption of energy in a residential building?
iii. To what extend occupants understanding influence energy consumption in residential buildings?
iv. Do the occupants understanding of these factors improve energy efficiency in residential buildings?

1.4 Aim and Research Objectives

The aim of the study is to identify a structural relationship of socio-economic, dwelling and climate factors for improving energy efficiency based on the understanding of the impacts on residential building energy consumption by the occupants. This can be achieved through the following objectives:

i. To identify the independent and dependent factors affecting energy consumption in residential buildings.
ii. To analyze and establish the critical independent factors of energy consumption in residential buildings based on socioeconomic, dwelling and climate grouping.

iii. To analyze and establish the critical dependent factors of energy consumption based on energy usage by residential occupants.

iv. To formulate a structural relationship based on the critical established independent and dependent factors as a strategy for improving energy efficiency in residential buildings.

1.5 Research Hypothesis

The following null hypotheses were tested at 0.05 levels of significance:

H_0 1: Socio-Economic Factors have no significance and no direct effect on residential building energy consumption.

H_0 2: Socio-Economic Factors have no significance and no direct effect on the dwelling.

H_0 3: Dwelling Factor has no significance and no direct effect on residential Building Energy Consumption.

H_0 4: Climate Factor has no significance and no direct effect on Dwelling.

H_0 5: Climate Factor has no significance and no direct effect on Building Energy Consumption.

1.6 Scope of the Research

The focus of this research is on residential building energy consumption. This study focuses on residential buildings because literature proves that there is an increasing energy consumption in Malaysia (Kubota *et al.*, 2011). Malaysia being a developing and industrialized nation, energy consumption has doubled in the last 2 decades due to the residential building energy consumption (Klufallah *et al.*, 2014). In the year 2010 Malaysia had 7.3 million residential buildings this number is expected to increase by around 150,000 each year (Al-Obaidi *et al.*, 2014). Any attempt in reduction and suitable utilization of energy usage by residential occupants will be of great importance to environmental problems and sustainability related issues (Van der

Werff & Steg, 2015). This research focuses more on residential buildings because of this reason.

The residential buildings considered in this research are; Terraced, condominium and cluster building. These types of buildings were identified as the main residential building types in Malaysia (Kubota *et al.*, 2011). The central focus of this study is on "operational energy" (energy used in the building throughout its lifespan). The study is not for measuring the usage of the appliances (energy auditing) rather, is on the assumptions of rational energy usage practice according to individuals' understanding of building energy consumption.

The research respondents are the household head of the residential houses types (Terraced, cluster, and condominium) selected in the study. The questionnaire respondents were Malay, Chinese, Indians as the three main ethnic groups in Malaysia (DSM, 2015). The target respondents are the residents of Johor Bahru. Johor, Malaysia.

Johor state Malaysia serves as the data collection area, under two councils namely MPJBT (Majlis Perbandaran Johor Bahru Tengah) and MBJB (Majlis Bandaraya Johor Bahru). The two district covers the metropolis of Johor Bahru which serves as the location of the research area. Johor state is the second largest state in Malaysia after Selangor and based on the study by (Kubota *et al.*, 2011) on "Energy Consumption and Air-Conditioning usage in Residential Buildings in Malaysia" which was conducted in Johor shows that the rate of energy consumption in residential buildings is on the increase. This study considers the household head of residential building in Johor, this is in order to come up with new findings with a recent information on the current situation in residential building energy consumption in Malaysia.

1.7 Significance of the Research

This research is set to identify the structural relationship of socioeconomic, dwelling and climate factors in building energy consumption. The significance of this research could be seen in three aspects as:

i. Significance to the construction industry,
ii. Significance to residential building occupants and
iii. Significance to academic.

i. The need for this study becomes necessary due to the vibrant importance of construction industry's efforts attached to building energy practice in the field of residential buildings. The fact that this discipline plays a vital role in reducing carbon emission and contributes to energy efficiency development in many countries across the globe. In line with this, it is hoped that the findings from this study will provide a better solution to the construction industries in the choice of building design. It will also assist the construction industry professionals in the modification of the existing concept towards designing and reduction of carbon emission from the residential sector.

ii. It is believed that without a significant increase in energy efficiency and significantly decrease of electricity demand from the domestic sector, it is merely impossible to lower carbon emission. Therefore, this research provides important information through empirical research. The most vital factors that donate to the general understanding of residential building occupants on energy consumption was provided. Findings of this research will give a better understanding of energy behavior practice by residential building occupants.

iii. More fundamentally, the fact that building energy practice has been recognized as one of the strategies that can be used to reduce carbon emission. This research provides students, researchers, and scholars with literature related to the field of building energy. The findings from this study will add to the wealth of literature and serve as a reference information material to researchers and construction industries in the areas of building energy consumption. The government, Construction industries, estate developers and policy makers can find the outcome of this research useful in term of energy conservation.

1.8 Research Process Framework

The research process framework employed in this study is classified into three phases. The first phase is taking about the identification of the main research factors. The identified factors are reviewed through the sources of Journals, conference papers, thesis and previous studies related to building energy consumption. The literature reviewed was classified into five major groups. These are the construction industry, socioeconomic related factors, dwelling related factors, climate-related factors and electrical appliances commonly use in residential buildings. From these five groups, pilot questionnaire items were developed. This is how objective one was achieved.

The second phase is the main survey, which includes data collection and data analysis. The data, which serve as the backbone of this research was obtained through a face-to-face administered questionnaire. The descriptive survey approach used was achieved using a 5-point Likert scale structured questionnaire. The method is fast, less expensive and efficient in term of large population sample (Creswell, 2012) and it may produce a more honest response (Stangor, 2011). The range of the 5-point Likert scale questionnaire is from (1 to 5) with the interpretation of strongly disagree as 1 to strongly agree as 5. A questionnaire template is shown in appendix A1 and A2.

The questionnaire instrument contains 80 items excluding demographic section. The 31 items of the questionnaire represent the independent factors. These are 14 items for socioeconomic, 11 items for Dwelling Factors and 6 items of Climate. The remaining 49 items are the independent factors. These are electrical appliances commonly used in residential buildings, which are categorized into six different categories. They are Refrigeration System 9 items, Kitchen Devices 8 items, Air-Condition System 8 items, Bathroom and Laundry Appliances 7 items, Lighting

Appliances 8 items and other Home Appliances 9 items. The data were analyzed using CFA and EFA. This is how objectives 2 and 3 were achieved.

The last phase is about the development of the structural model, validation process and concluding remark of the overall study. Factor Loadings (FL), Average Variance Extraction (AVE) and Composite reliability (CR) were used in validating the model using convergent validity, construct validity and discriminant validity between each possible pair of constructs (Byrne, 2010; Zainudin, 2012). Details of the research methodology step fully explain in research methodology chapter (Chapter 3). Figure 1.2 shows the research framework flow chart.

1.9 Structure of the Thesis

This research considered socio-economic, dwelling and climate factors in providing useful information on building energy consumption to the construction industry. The research consists of six chapters as follows:

i. Chapter 1 is on the Introduction of the Research, this includes a brief introduction, background of the researcher, problem statement, research questions, aims and research objectives. In addition, research hypothesis, the scope of the research, research process framework and brief summary of the chapter.

ii. Chapter 2 is on Literature Review on the general aspects of Building Construction Industry, buildings energy, socio-economic related factors, dwelling related factors, climate-related factors and summary of the chapter.

iii. Chapter three is on Methodology of this research which includes, research design and why it was chosen, research sampling technique, data collection and data analysis process, the validity and reliability of the research instrument and summary of the chapter.

iv. The fourth chapter is on Results and Discussion which includes the analysis and discussion of the pilot study and demographic analysis. It further shows the analysis of the independent and the dependent factors of the study and summary of the chapter.

v. The fifth chapter is on Structural Equation Modeling development, 4 Structural models were developed. These are SEESM, DESM, CESM and BESM. In conclusion, a summary of the chapter was presented.

vi. The sixth chapter is on Conclusion and Recommendation of the research, limitation, and summary of the research.

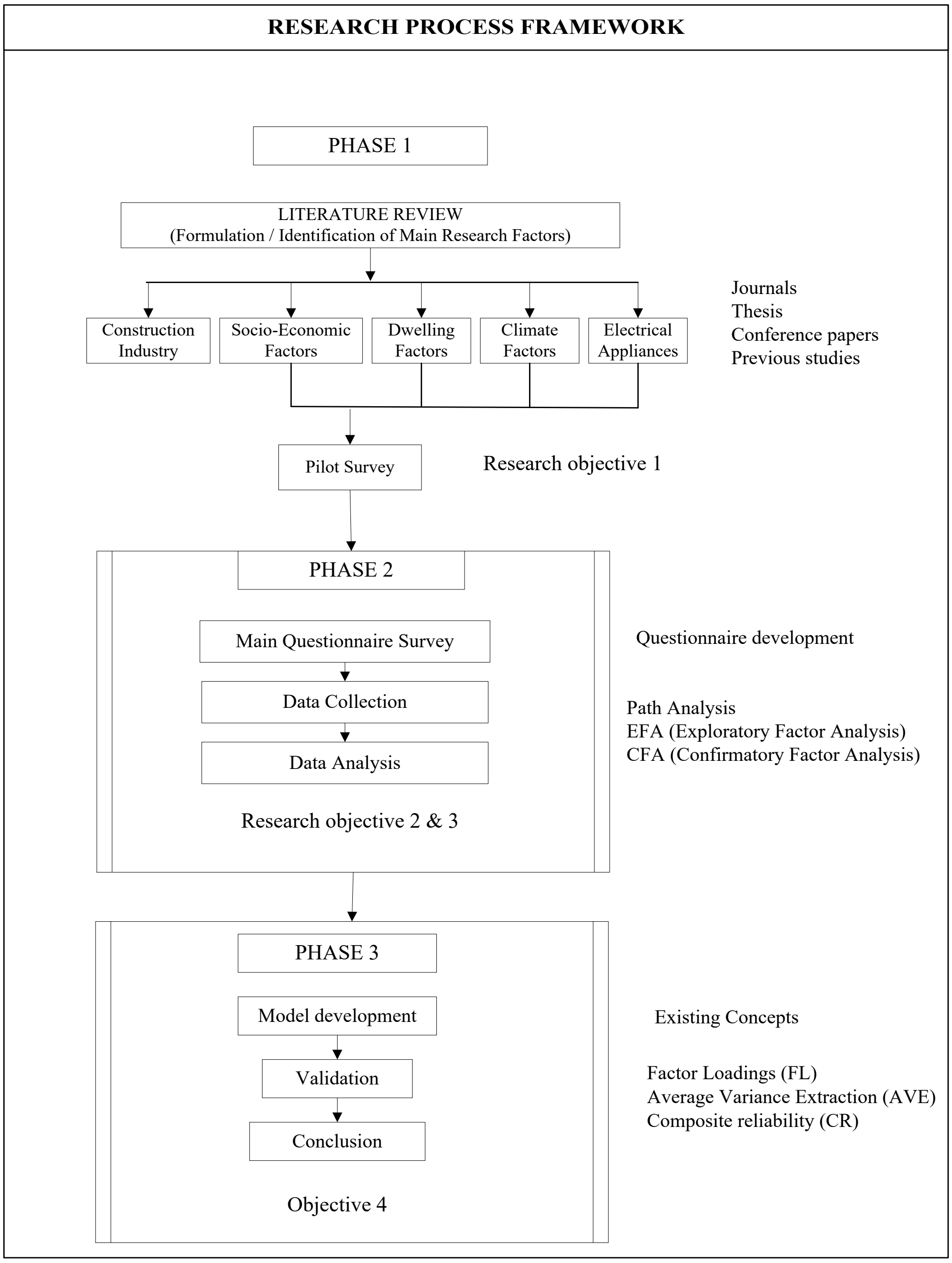

Figure 1.2 Flowchart of the Research Process Framework

1.10 Summary of the Chapter

This chapter discusses the problem statements, aim and objectives and the scope of the research. It equally discusses the significance of the research to the construction industry, residential building occupants, and the academia. In conclusion, the next chapter "Chapter 2" discuss the overall literature reviewed in this research.

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