ADAPTIVE BEHAVIOR SATISFACTION INDEX ANALYSIS FRAMEWORK FOR ENERGY EFFICIENT BUILDING ASSESSMENT

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To those who teach me since I was born

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ABSTRACT

Currently, sustainability is one subject that requires attention and application among the stakeholders of any nation. Many techniques for managing sustainability including 'sustainable building assessment' frameworks have been developed globally. However, the measures within these frameworks have not yet taken into consideration user's satisfaction from adaptive behavior in energy efficient indoor environment. Thus, the aim of this study was to develop the adaptive behavior satisfaction index analysis framework for assessing energy efficiency of buildings. Six objectives were identified to achieve this aim, through progress of five research phases and fifteen research steps. First, the study investigated the effect of building users' satisfaction from adaptive behavior on energy consumption. On the basis of literature review, a field survey of ten energy efficient office units, and subsequently expert input was conducted. The findings of first objective showed user satisfaction from adaptive behavior had effect on building energy consumption with regards to lighting and cooling. Second objective was to identify and establish building users' adaptive behavior in energy efficient indoor environment. In parallel, third objective was to identify and establish energy efficient building assessment characteristics. The fourth objective was to identify and establish, a suitable, user's satisfaction index analysis framework. To address second, third, and fourth objectives, literature review and expert input was conducted. Based on the findings, thirty six adaptive behaviors, three main characteristics of assessment framework, and Kano model was selected in the framework development. Aforementioned findings helped in the framework development, thus fulfilling the fifth objective. The adaptive behavior satisfaction index analysis framework was developed in a synectics session including professionals in the relevant field. Furthermore, a preliminary feasibility validation was conducted through users' input. The sixth objective, the feasibility of adaptive behavior satisfaction index analysis framework, was validated in a green certified building as the case study. In conclusion, the study successfully developed the aimed ABSI analysis framework. The final framework will be recommended as a design decision support tool for architects practicing energy efficiency.

ABSTRAK

Pada masa ini, kelestarian adalah salah satu perkara yang memerlukan perhatian dan perlaksanaan di kalangan pihak yang berkepentingan dalam mana-mana negara. Banyak teknik untuk pengurusan kelestarian termasuk rangka kerja 'penilaian bangunan lestari' telah dibangunkan di seluruh dunia. Walau bagaimanapun, langkah-langkah dalam rangka kerja ini belum mengambil kira kepuasan pengguna dari tingkah laku penyesuaian dalam persekitaran dalaman yang cekap tenaga. Oleh itu, tujuan kajian ini adalah untuk membangunkan rangka kerja analisis indeks tingkah laku penyesuaian kepuasan untuk penilaian bangunan cekap tenaga. Enam objektif telah dikenal pasti untuk mencapai matlamat ini, melalui kemajuan lima fasa penyelidikan dan lima belas langkah-langkah penyelidikan. Pertama sekali, kajian ini menyiasat kesan kepuasan pengguna dari tingkah laku penyesuaian ke atas penggunaan tenaga. Berdasarkan kajian literatur, kajian sepuluh unit pejabat yang cekap tenaga, dan kemasukan pakar telah dijalankan. Hasil objektif pertama menunjukkan kepuasan pengguna dari tingkah laku penyesuaian penggunaan tenaga untuk lampu dan penyejukan di dalam bangunan. Objektif kedua mengenal pasti dan mewujudkan tingkah laku penyesuaian pengguna dalam persekitaran tenaga dalaman yang cekap. Pada masa yang sama, objektif ketiga mengenal pasti dan mewujudkan ciri-ciri penilaian bangunan cekap tenaga. Objektif keempat mengenal pasti dan mewujudkan, kepuasan indeks rangka kerja analisis pengguna yang sesuai. Untuk menangani objektif kedua, ketiga, dan keempat, kajian dan kemasukan pakar telah dilaksanakan. Hasil daripada kajian tersebut, tiga puluh enam tingkah laku penyesuaian, tiga ciri-ciri utama rangka kerja penilaian, dan model Kano telah dipilih untuk pembangunan rangka kerja tersebut. Hasil kajian di atas membantu dalam pembangunan rangka kerja, sekali gus memenuhi objektif kelima. Indeks kelakuan penyesuaian kepuasan rangka kerja analisis telah dibangunkan dalam sesi synectics bersama para profesional dalam bidang yang berkaitan. Seterusnya, pengesahan fesibiliti telah dijalankan melalui input pengguna. Untuk mengesahkan objektif keenam, fesibiliti indeks kelakuan penyesuaian kepuasan, telah disahkan di dalam sebuah bangunan yang diiktiraf hijau sebagai kajian. Kesimpulannya, kajian ini telah berjaya membangunkan rangka kerja analisis yang bertujuan indeks kelakuan penyesuaian kepuasan. Rangka kerja yang di hasil akan dicadangkan sebagai alat sokongan tambahan bagi arkitek arkitek yang mengamalkan merekabentuk cekapa tenaga.

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LIST OF ABBREVIATIONS

ABSI	Adaptive Behavior Satisfaction Index
ACEM	Association of Consulting Engineers Malaysia
AEUI	Annual Area Energy Use Index
AHP	Analytic Hierarchy Process
ANN	Artificial-Neural-Network
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
ASMI	Athena Sustainable Material Institute
BEMS	Building Energy Management System
BREEAM	Building Research Establishment Environmental Assessment Method
BUS	Building Use Studies
BRE	Building Research Establishment
CAD	Computer Aided Design
CBE	Center for the Built Environment
CGD	Close Group Discussion
COPE	Cost-effective Open-Plan Environments
CRISP	Construction Related Sustainability Indicators Project
EI	Energy Intensity
EN	European Standards
EPI	Energy Performance Indicators
EUI	Energy Use Intensities
GBC	Green Building Challenges
GBI	Green Building Index
GEO	Green Energy Office
GGDM	Grounded Group Decision Making

HK-BEAM	Hong Kong Building Environmental Assessment Method
HDI	Human Development Index
HTM	Human Thermal Model
HVAC	Heating, Ventilation, & Air Conditioning
iiSBE	international initiative for Sustainable Built Environment
IEQ	Indoor Environmental Quality
ISO	International Organization for Standardization
IUCN	International Union for the Conservation of Nature
LEED	Leadership in Energy & Environmental Design-
LEO	Low Energy Office
MEWC	Ministry of Energy, Water and Communication
MS	Malaysian Standard
NEMA	National Electrical Manufacturing Association
NGOs	Non-Governmental Organizations
NRCC	National Research Council of Canada
PAM	Pertubuhan Akitek Malaysia
PLEA	Passive and Low Energy Architecture
POE	Post Occupancy Evaluation
PTM	Persatuan Tenaga Malaysia
SBtool	Sustainable Building tool
SIRIM	Standards & Industrial Research Institute of Malaysia
TNB	Tenaga Nasional Berhad
UNCHE	United Nations Conference on the Human Environment
UNWCED	UN World Commission an Environment and Development
UNWCED	Nation World Commission on Environment and Development
UNMDG	United Nations Millennium Development Goals
UNEP-SBCI	United Nations Environmental Programme for Sustainable Buildings and Construction Initiatives
USGBC	US Green Building Council
US EPA	United States Environmental Protection Agency
WSM	Weighed Sum Method
WCED	World Commission on Environment and Development
ZEB	Zero Energy Building

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter is an introductory explanation of the study accomplished in this research. The chapter includes following sections; Research Discipline, Background of building assessment tools, Problems associated with building assessment tools, Aim and Objectives, Scope of Study, Research Methodology, Significance of Study, and Thesis Outline.

1.2 Research discipline

Study is to introduce the Macro, Meso, and Micro research disciplines in this section, including; Sustainability, Managing Sustainability, and Sustainability managerial technique in building construction practice.

- **Sustainability:** Earliest introduction on ‘Sustainability’ or ‘Sustainable Development’ dates backs to 1980 called as World Conservation Strategy (Christensen, 2011). The term ‘Sustainable Development’ has been introduced by International Union for the Conservation of Nature (IUCN, 1980) as “must take account of social and ecological factors as well as economic ones: of the living and non-living resource base and of the long-term as well as the short-term advantages and disadvantages of alternative action”. This definition is supported and revised in the United Nation World

Commission on Environment and Development conference (UNWCED, 1987). The ‘Brundtland Report’ also defined sustainability as ‘Our Common Future’ state “…to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs” (UNWCED, 1987). Hence, there is dramatic development of sustainability issues in all research fields all over the world.

- **Managing Sustainability:** Expressed by Daub (2007), and Roca and Searcy (2012), there is lack of proper management effort in the diverse sustainability research field. Hence, there is a recent research trend called ‘Managing Sustainability’. There is no established definition on the terminology ‘Managing Sustainability’. This study defined the term ‘Managing Sustainability’ based on the fundamental definition of the word ‘Managing’ (as a verb); having control and supervising over the ‘Sustainability’ (as a noun). Defining sustainability, there are three main sustainability aspects to be considered; that is, social sustainability, economic sustainability, and environmental sustainability. These “three aspects are independent, inter-connected, and shall be considered as equal” (Poveda and Lipsett, 2011). Thus, this study defines ‘Managing Sustainability’ as ‘to control and supervise implementation of the different aspects of sustainability; including, social, economic, and environmental. The ‘Managing Sustainability’ aims to enhance effectiveness of sustainability techniques towards a sustainable ‘sustainability’ practice. There are a variety of international co-operations, international journals and conferences, and research institutes established under the subject of ‘Managing Sustainability’. Managing efficient energy or efficient energy management is one of the main categories in the Managing Sustainability which has been emphasized intensively by engineering researchers.

- **Sustainability managerial technique in building construction practice:** The use of ‘Sustainability managerial technique in building construction practice' is a traditional concern for building owners and consultants. Indeed, one of the evidences to this argument is the 'Hammurabi code'. The 'Hammurabi code' is the first building code dating more than 3000 years (Taylor, 2011). Focusing on more recent history, all industries related to building industry are influenced by 'Earth summit' conference organized in Rio de Janeiro. In 1992, it was the first United Nation conference where the attending countries came up with five agreements. Among the five agreements, 'agenda 21' considered the reevaluation of sustainability included more than hundred (100) diverse industries including the building industry. More recently, in 2000, the global momentum and initiatives towards sustainability in the building practices was established as the United Nations Millennium Development Goals '7' - MDG 7 (UNMDG, 2000). It was agreed by the number of countries to enhance sustainable building practices globally. Furthermore, the United Nations Environmental Programme for Sustainable Buildings and Construction Initiatives (UNEP-SBCI) is the other current international research efforts to enhance sustainable building practices.

Based on presented overview on the general research discipline, Sustainability understood as 'macro' discipline. Managing Sustainability understood as 'meso' discipline, and 'Sustainability managerial technique in building construction practice' as 'micro' discipline. From the introduced micro discipline study is narrowed to enhance 'building assessment tools'. This is presented in 'Background of building assessment tools' and 'Problems associated with building assessment tools'.

1.3 Background of Building Assessment Tools

Researchers in 'Sustainability managerial technique in building construction practice' are to manage the implementation of sustainability methods and techniques in building practices. This is carried out with the aid of four sustainability methods and techniques; including, (a) governmental status, (b) building codes, (c) private and professional associations or Non-Governmental Organizations (NGOs), and (d) marketing strategies (Taylor, 2011). Amongst, the largest contributor to enhance sustainability in building practices is the private and professional associations, NGOs (Taylor, 2011). Within which, mainly, NGOs have resulted with multi-perspective ‘Sustainable building assessment tools’ to enhance sustainability of building practices in specific regional areas. Even though these assessments tools were not originally designed to serve as design guidelines, it seems they are increasingly being used as such (Cole, 1998; Crawley and Aho, 1999).

In the building construction industry, sustainable assessment tools are specifically used to benchmark enhancement of sustainability in building practices (Christensen, 2011). Application of these assessment tools is a contribution of ‘Managing Sustainability’ to the building construction industry. These tools traditionally called ‘Environmental building assessment tools’, ‘Green building assessment tools’ and recently called ‘Sustainable building assessment tools’. Building assessment tools are categorized into physical assessment tools, monetary assessment tools, models, scenario analysis, multi-criteria analysis, sustainability-environmental appraisal tools, participatory tools, and transition management (Rorarius, 2007).

Sustainable building assessment tools are ‘mainly’ aimed to benchmark a ‘Capacity Building’ as a sustainable building case (social, economical, and environmental) in a specific geographic region. It includes existing buildings as well as new building; with diverse functionalities, such as, office buildings, residential buildings, commercial buildings, etc. (Haapio and Viitaniemi, 2008). These tools constitute a variety of criteria for sustainability assessment; including, energy efficiency, water management, waste management, land use, and etc. (Taylor, 2011). Basically, these criteria cover the greenery/environmental issues, with consideration on economic and social-friendly approaches. To correlate usability of tools with building lifecycle, it may benchmark building’s ‘sustainability’ in design phase, construction phase operational phase, and/or demolition phase (Haapio and Viitaniemi, 2008). According to Haapio and Viitaniemi (2008) tool’s end-users includes; architects, engineers, facility managers, building owners, consultants, authority, contractor, and/or academic researchers. The academic researchers indirectly use the sustainable building assessment tools as decision support tools in order to fulfill the requirement of building sustainability accreditation (Abdalla et al., 2011).

Furthermore, these tools are categorized based on assessment methods, as qualitative tools incorporating rating and/or labeling criteria, and as quantitative tools incorporating quantitative life cycle assessment of materials, energy, water, and etc. (Reijnders and Roekel, 1999).

There are some efforts being undertaken by International Organization for Standardization (ISO) to establish standardized requirements for building assessment tools (ISO/TS21929- 1:2006, ISO/TS21931-1:2006). The need for a comprehensive and global assessment tool still remains a challenging proposition to be undertaken.

1.4 Problems associated with building assessment tools

Since early 1990s, around sixty ‘building assessment tools’ have been established by private, professional associations, or NGOs all over the world. Building Research Establishment Environmental Assessment Method (BREEAM) was the first sustainable building assessment tool established by the Building Research Establishment (BRE) in UK in 1990. The other well-known tools in this discipline are; Hong Kong Building Environmental Assessment Method-HK-BEAM (Hong Kong: Business Environment Council, 1996), Leadership in Energy & Environmental Design-LEED (US Green Building Council-USGBC, 1998), and Sustainable Building tool (i.e. SBtool) which was formerly called GBtool as an international tool (Green Building Challenges-GBC, 1996). Following the global trend and the need of a localized Green Building assessment tool, a number of tools have been established in South East Asia; such as the Singapore Green Mark Scheme (Building and Construction Authority, 2005) and Green Building Index-GBI (Pertubuhan Akitek Malaysia-PAM, Association of Consulting Engineers Malaysia-ACEM, 2009). The Malaysia GBI was developed

'….specifically for the Malaysian-tropical climate, environmental and developmental context, cultural and social needs' (PAM, 2009).

With regards to problems with sustainable building assessment tools, there are some shortcomings addressed by researchers in the available literature. Gibson (2001) states that established tools do not work effectively towards sustainability. Poveda and Lipsett (2011) state there is no agreement amongst stakeholders to have a specific framework to evaluate the method of building assessment. Furthermore, Abdalla et al. (2011) mentioned two main shortcomings; Sustainable building assessment tools are not accurate in estimation project output in terms of energy consumption and other sustainability measures, more so, building assessment tools do not consider end-user sustainable program. Furthermore, Pemsel et al. (2010) express that lack of 'guidance and narrow focus' restricts the ability of tools in the assessment process. Moreover, there is lack of global standardized assessment tools (Christensen, 2011). According to literature, the current phenomenon of majority of building assessment tools is lack of focus on energy, environment, and/or economic aspects in the design phase of building life cycle.

Lützkendorf and Lorenze (2008) state "… due to the complexity involved, only a few tools (i.e. LEGEP in Germany and OGIP in Switzerland) exist that allow for a combined determination and assessment of cost, environment and to some extent occupational health and other social issues in the planning phase".

Christensen (2011) states 'user satisfaction', 'access to public transport', and 'development impact on community' as social sustainability criteria need to be considered in sustainable building assessment tools.

Indeed, private and professional associations and NGOs are expanding scope of building assessment tools gradually, and revising the tools frequently to enhance the building construction industry in 'managing sustainability'. Indeed, frequently revising the tools highlights the ground and need for research and development in this discipline.

For the further development of building assessment frameworks, Lützkendorf and Lorenz (2006) proposed an integration of instruments and measures of the design, construction and management phase, that is ‘integrated building performance’. It is argued that the application of integrated design and assessment tools can greatly assist in consolidating and improving property professionals’ knowledge and active services provided over the life of buildings (Lützkendorf and Lorenz, 2006).

Lützkendorf and Lorenz (2006) state assessing a building’s contribution to sustainable development requires an integrated building performance approach. This allows one to describe and assess buildings with respect to all dimensions of sustainable development including aspects of functionality and serviceability as well as the quality of planning, construction and management process. Lützkendorf and Lorenz (2006) state to enable assessment tools to influence the design of buildings, further development of tool is required. This will allow architects and engineers to use them to compare different solutions or optimizing sketches and designs during the whole design process, including the very early phases of conception or pre-design.

Lützkendorf and Lorenz (2008) express that in contrast to conventional assessment tool, integrated design and assessment tools can contribute to the simplification of the assessment process, and will reduce time and costs. Integrated design and assessment tools may be applied to the whole planning and design stage, and are capable of providing a concluding assessment of the finished design concept or of new/existing buildings, respectively. In addition, these tools take into account economic, environmental, and social aspects simultaneously.

According to Chen et al. (2009), another problem of current building assessment tools is that their evaluation processes are not convincing enough to provide a reasonable assessment result.

The focus of this study is on problems associated with existing building assessment tools in consideration of building users satisfaction. Building assessment tools cover the user satisfaction in compliance with Indoor

Environmental Quality (IEQ) through following standards of energy efficient building (for example; MS1525:2007). Indeed, building assessment tools cover the user satisfaction in considering Post Occupancy Evaluation (POE) criteria. SBtool is the first building assessment tool launched to consider the ‘user satisfaction’ as an independent criterion of building assessment index among other criteria. Considering the user satisfaction criterion in a building assessment development is completely compatible with fundamental definition of sustainability which indicates that “three aspects are independent”.

The user satisfaction in the SBtool seeks to analyze its ‘inter-connectivity’ with other sustainability criteria. The user satisfaction has been studied across diverse disciplines; for instance, building architectural design, building value management (Achterkamp and Vos, 2008), building asset management (Lorenz and Lutzkendorf, 2008), real estate management (Lorenze and Lutzkendorf, 2008), and construction management. Reviewing mentioned disciplines indicate that the user satisfaction has been analyzed independent from environmental and economic aspects of sustainable building practices (Zimmerman and Matin, 2001).

The user satisfaction criterion is inter-connected with the other criteria, specifically energy efficiency in the sustainable building assessment tools. As an example, if the level of user satisfaction in compliance with energy efficient lighting is low, the user will change the building lighting asset to the satisfactory level. But, the satisfaction level may not fulfill economic and/or energy performance levels. Zhun et al (2011) state that seven different sources can affect energy consumption of building; including, (1) Climate, (2) Building-related characteristics, (3) User-related characteristics, except for social and economic factors, (4) Building services systems and operation, (5) Building occupants’ behavior and activities, (6) Social and economic factors, and (7) Indoor environmental quality. Amongst these various sources, the research on ‘Building occupants’ behavior and activities’ is yet to be established (Tabak, and Vries, 2010). Among the diverse types of ‘building occupants’ behavior and activities’, the ‘adaptive behavior’ is a measure of user satisfaction which may enhance energy program (Goto et al. 2007, Haldi and Robinson, 2008, Hoes et al. 2009, Hwang et al. 2009, Liu et al. 2012). Other types of 'behavior and activities' are more relevant to job specifications or user psychology. This confirms the need to enhance sustainable building assessment tools in consideration with the user satisfaction from 'adaptive behavior' as a missing criterion.

Furthermore, tools actually pay less attention to functional variation in different types of buildings, which influence not only the emotional and physical well-being of human beings, but also the design and the management of buildings (Chen et al., 2009).

In conclusion, it has been proven that user satisfaction was not considered as an inter-connected criterion in compliance with other assessment criteria like energy efficiency in sustainable building assessment tools. Furthermore, this section concludes that among diverse aspects of user satisfaction, 'user satisfaction from adaptive behavior' is the focal criterion in inter-connection with other sources affecting energy consumption in building. Based on these conclusions, this study emerges with the idea to develop Adaptive behavior satisfaction index analysis framework for energy efficient building assessment. To sum up, the study is to address the following research question;

'How to calculate adaptive behavior satisfaction index for energy efficient building assessment?'

1.4 Aim and Objectives

This study aims to develop adaptive behavior satisfaction index analysis framework for assessment of energy efficient buildings. To address the aim of study, six objectives have been designed as following;

Objective 1: To investigate the effect of users' satisfaction from adaptive behavior on energy consumption of building.

Objective 2: To identify and establish building users' adaptive behavior in energy efficient indoor environment.

Objective 3: To identify and establish energy efficient building assessment characteristics.

Objective 4: To identify and establish suitable user-satisfaction index analysis framework.

Objective 5: To develop Adaptive Behavior Satisfaction Index (ABSI) analysis framework for energy efficient building assessment.

Objective 6: To validate Adaptive Behavior Satisfaction Index (ABSI) analysis framework.

1.5 Scope of Study

This section addresses the scopes identified by the researcher in this study. The followings sections explain and justify 'Scope of study on applicable classification of the building assessment framework', 'Scope of study on energy efficient building', 'Scope of study on applicable building functionality', Scope of study on applicable building energy consumption aspects', 'Scope of study on applicable users of the framework' and 'Scope of study on building life cycle'

- **Scope of study on applicable classification of the building assessment framework:** This section elaborates scope of study in terms of various classifications on building assessment frameworks. According to Haapio and Viitaniemi (2008) there are two main kinds of environmental assessment classification; Athena Sustainable Material Institute (ASMI) classification system, and, IEA Annex 31 classification systems.

  Trusty and Meil (2000) introduced ASMI classification system also called ATHENA classification system. In this classification system, there are three classes of building assessment tools; level one, product comparison tools and information source; level 2, whole building design and decision support tools; and level 3, whole building assessment frameworks or systems. Secondly, international initiative for Sustainable Built

Environment-iiSBE (2001) introduced IEA Annex 31 classification system. According to IEA Annex 31, there are five classes of building assessment tools. First class; energy modeling software; second class, environmental life cycle analysis tools; third class, environmental rating system; fourth class, environmental design guideline or design checklist, and fifth class, environmental labeling and certification.

Based on introduced aim and objective, the scope of the current study is to develop the framework under second level of ASMI classification which is ‘Building design and decision support tool’. According to IEA Annex 31, this research’s final tool is classified under class three that is ‘environmental rating system’.

- **Scope of study on energy efficient building:** This section elaborates importance of scope of study on energy efficient building. This selected based on local needs on energy efficiency. It is a common issue among all countries to improve Human Development Index (HDI) as a measure of human Quality of Life. The increase in HDI will affect higher energy consumption. Figure 1.1 shows the correlation between HDI and energy consumption within countries and specifically highlights the critical position of Malaysia in this trend. The figure confirms that Malaysia has to foresee the future energy consumption and optimize its energy consumption in sustainable building design towards improving HDI.

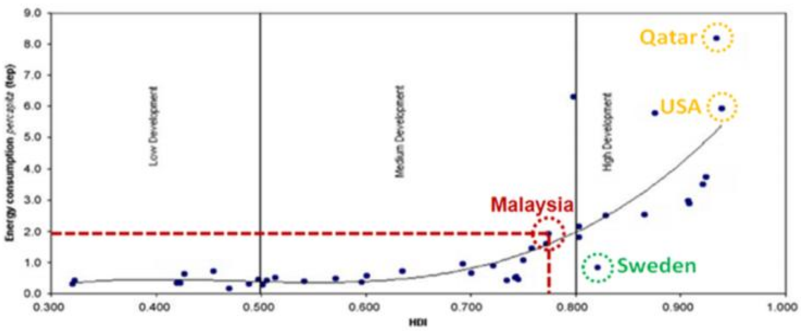

Figure 1.1: HDI versus Energy consumption within various countries (Adopted from Dias et al., 2006)

This momentum is recognized by the government of Malaysia. The key Ministry and agencies involved are; the Ministry of Energy, Green Technology and Water, Section of Economic Planning Unit, the Energy Commission of Malaysia, and Persatuan Tenaga Malaysia (PTM). In this regard, agendas have been set for the relevant Ministry and agencies by formulating Five-Year Plans. The government of Malaysia is seriously considering energy efficiency programs in the Ninth Malaysia Plan (2006-2010), and to a greater concern, in the Tenth Malaysia Plan (2011-2015). However, sustaining the quality of life for the needs of the population and at the same time managing Malaysia's resources has not been considered in parallel with energy efficiency issue.

In the Malaysian building construction industry, environmental concerns, energy crisis, and technology advances have brought up Energy Efficiency as the agenda for building performances since 1980s. In 1989, the Malaysian Ministry of Energy, Water and Communication (MEWC) introduced the Guidelines for Energy Efficiency in Non-Domestic Buildings. The guidelines were revised as the Malaysian Standard MS 1525:2001 which aimed to encourage the application of energy efficiency in new and existing buildings, while maintaining comfort, health and safety of the building-users has not been considered. Best practices as stipulated in the Malaysian Standard MS 1525:2007 "Code of Practice on Energy Efficiency and the Use of Renewable Energy for Non-Residential Buildings" have been adopted as guiding principles. The MS 1525:2007 in comparison with some other internationally well-known standards (such as American Society of Heating, Refrigeration, and Air-Conditioning Engineers-ASHRAE standard 55-2010 and ISO 7730:2005) does not support all downstream requirements of building user with regards to energy efficiency. There are only a few standards that specifically consider users' downstream requirements; such as European Standards (EN) 15251:2007. Indeed, updating and improving of MS 1525:2007, with existence of complimentary tools and framework. This is needed to ensure moving forward in energy efficiency standards for buildings in Malaysia.

- **Scope of study on applicable building functionality:** In construction industry, buildings are classified as; residential, office, commercial, industrial and so on. In current research, ‘office building’ is selected as the applicable building functionality; because the ‘office buildings’ are highest energy consumer buildings in Malaysia (MS 1525:2007). Another justification to this scope selection is availability of energy consumption data in office buildings. Furthermore, the momentum of the Malaysian government towards energy efficient buildings which is parallel to this scope selection.

- **Scope of study on applicable building energy consumption aspects:** According to MS 1525:2007 minimum requirement of Building Energy Management System is the availability of the data on energy consumption. The dataset on energy consumption in office buildings was provided for four aspects; including, air conditioners, lighting, building facilities (lifts and pumps), and work equipment.

  To measure the user satisfaction from adaptive behavior, the research selected air conditioners and lighting among diverse building energy consumption aspects. The ‘Phase I’ of research methodology resulted in the effect of between user satisfaction and building facilities (e. g. lifts and pumps) and work equipment is considerably very low.

  In general, the increased in living standard, has resulted in the increase of electricity usage, particularly in hot and humid periods. This has caused by the growing demand for air conditioners to provide thermal comfort for the building-users (Wong et al., 2008). In an energy audit on 68 office buildings in 2006 it reported that the major energy users in Malaysian office building is air conditioners (57%), followed by lighting (19%), lifts and pumps (18%) and other equipment (6%) (Saidur et al., 2009). Furthermore, as stated by Standards & Industrial Research Institute of Malaysia (SIRIM), air conditioning and lighting were identified as major energy using equipment in office buildings (MS 1525:2007). Thus selection of air conditioners, lighting matches with highest energy using equipment in office buildings.

- **Scope of study on building life cycle:** Building life cycle may include; feasibility, design, construction, operation and maintenance, and demolition. This study's scope is the 'design' phase of building life cycle. This complements the scope of study on classification of the framework. The selection of 'design' phase is significant in comparison with the traditional approach to evaluate user satisfaction in operational phase of the project life cycle.

- **Scope of study on applicable users of framework:** According to Haapio and Viitaniemi (2008), scope on users of the building assessment framework may include; design professionals, contractors, building owner, consultants, building users, facility managers, researchers, and authorities. This research has determined 'Architect practicing Energy Efficiency' as the scope on user of framework. The framework user can use it as building design decision support framework. This is adapted to the scope on building life cycle.

1.6 Research Methodology

This section presents a brief on the research sequences and the methods used in this study. Detail explanation of the research methodology will be discussed in Chapter 3, Research Methodology. The methodology engaged to achieve the aim and objectives of the research designed into five phases, including fifteen research steps. The presented data collection, data analysis and result in this study were to conjure up the validity of the engaged research steps and the developed framework. 'Phase I' addresses the preliminary study to the total research. 'Phase II' as literature review phase, and 'Phase III' as data gathering and data analysis phase and 'Phase IV' as framework development phase address the development of framework. The final 'Phase V' is a case study to minimize the unforeseen biases of 'Phase IV'. This progression is shown in Figure 1.2.

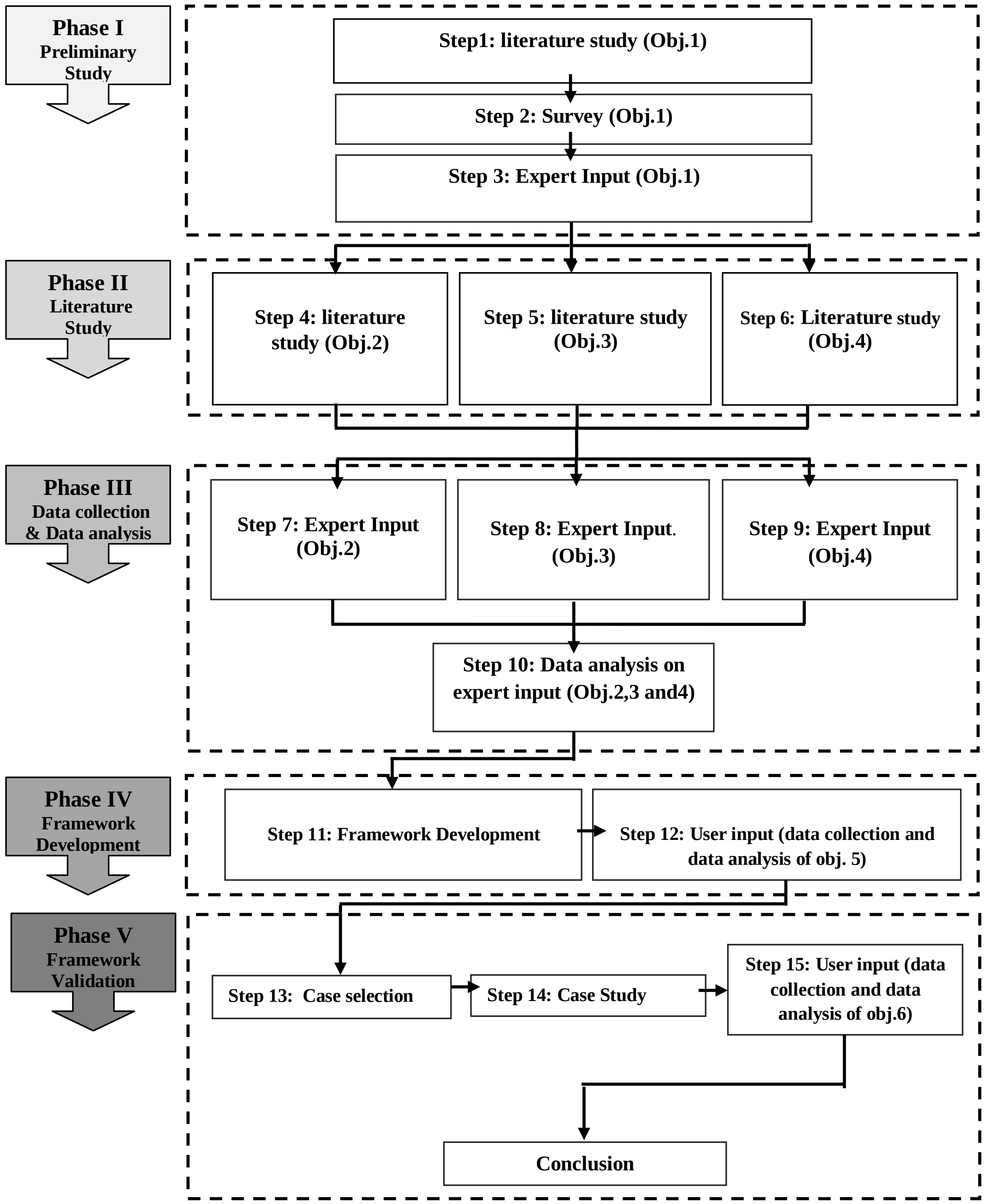

Figure 1.2: Research flow diagram

<u>Phase I: Preliminary study (to fulfill requirement of first objective)</u>

- **Step 1: Literature Study:** In this step a Systematic Literature Review Analysis was conducted to investigate effect of user satisfaction from adaptive behavior on building energy consumption. This step concluded with a hypothesis. Based on the result of this step, the study carried out a survey and included expert input.

- **Step2: Survey (data collection and data analysis):** In this step a survey was conducted to test the 'hypothesis' established based on literature review. Data gathering involved structured interviews with ten staff representing different office units in a green certified office building. Data analysis was conducted by means of correlation analysis.

- **Step3: Expert Input (data collection and data analysis):** In this step an expert validation was conducted on the survey findings. Data collection included field expert Delphi structured close group discussion. It was carried out in four sessions of close group discussion with the involvement of seven participants. The participants were experts who had expertise in building energy efficiency assessment framework development and implementation. Data analysis was conducted using Grounded Group Decision Making (GGDM) method. Since GGDM is a relatively new method of data analysis, the Weighed Sum Method (WSM) was applied as a control data analysis method.

<u>Phase II: Literature Study</u>

- **Step 4: Literature Study (to fulfill requirement of second objective):** This step was to conduct Systematic Review Analysis on adaptive behavior in energy efficient building.

- **Step 5: Literature Study (to fulfill requirement of third objective):** This step was to conduct Systematic Review Analysis to identify energy efficient building assessment framework characteristics.

- **Step 6: Literature Study (to fulfill requirement of fourth objective):** This step was to identify several satisfaction Index analysis frameworks based on Systematic Review Analysis.

Phase III: Data Collection and Data Analysis

- **Step 7: Expert Input (to fulfill requirement of second objective):** This step was to validate the literature findings on adaptive behavior in energy efficient indoor environment. It included field expert Delphi structured close group discussion. It was carried out in three sessions of close group discussion with a total of seven participants. Two were field-experts who had experience in building energy management and five were field-experts who had experience in building facility management.

- **Step 8: Expert Input (to fulfill requirement of third objective):** This step was to validate literature findings on building energy efficient assessment framework characteristics. It included field expert Delphi structured close group discussion. It was carried out in five sessions of close group discussion with a total of nine participants. All had expertise in building energy efficiency assessment framework development and implementation.

- **Step 9: Expert Input (to fulfill requirement of fourth objective):** This section was to select suitable satisfaction index analysis framework to be implemented. It included field expert Delphi structured close group discussion. It was carried out in two sessions of close group discussion. This included fifteen structured interviews with experts who have experience in satisfaction measurement field of research.

- **Step 10: Data analysis on expert input:** In this study data analysis was conducted using WSM and GGDM method. Since GGDM is a relatively new method of data analysis, this study applied WSM as a controlling data analysis method.

Phase IV: framework development

Step 11: Framework Development: This step was to develop ABSI framework. It included Synectics Session involving five experts who had experience in building environmental design assessment framework development and implementation.

- **Step 12: User input (data collection and data analysis):** This step was to get preliminary validation of the developed framework. The preliminary validation was done by expected users of the framework. It included a Delphi structured close-group discussion with five building architectural consultants who are practicing energy efficient building design consultancy.

Phase V: Framework Validation

- **Step 13: Case selection:** This step was to select the appropriate building as case study. It included a Delphi structured close-group discussion with five building architectural consultants who are practicing energy efficient building design.

- **Step 14: Case Study**: This step was to address unforeseen biases of the developed framework through a case study. The case study was conducted engaging three graduate students (Masters in Architecture) as users of framework within selected case study building.

- **Step 15: User validation (data collection and data analysis):** This step was to validate the feasibility of framework. It included a Delphi structured close-group discussion with the three framework users in the case study.

1.7 Significance of Study

This section explains the significance of the current research. Indeed, this issue is grounded problem statement. The following is to address the significance of the study to the construction industry.

In construction industry, building life cycle includes feasibility, design, construction, operation and maintenance, and demolition. It is now obvious that ‘study on user satisfaction requirement’ will enhance sustainability of building in diverse dimensions; such as, functionality, serviceability, adoptability, human comfort requirement, well- being, and risk reduction of investment and negative impact on the nature (Lutzkendorf and Lorenz, 2008). Focusing on the energy efficient building, user satisfaction evaluation has been traditionally considered in the operation and maintenance phase of building life cycle. User satisfaction measurement in this phase has been evaluated by engaging ‘Post Occupancy Evaluation’ (POE) studies (PAM, 2009). Furthermore, POE result has been considered in building assessment frameworks as one of indexes. Significance of the current research is to propose an assessment index analysis framework for evaluation of building user satisfaction from adaptive behavior in the ‘Design’ phase (Figure 1.3). Indeed, such evaluation will aid building design and construction team to have a metric assessment on downstream requirement of the end-user satisfaction. In fact, this study has considered energy efficient building consultants of construction team as users of the framework.

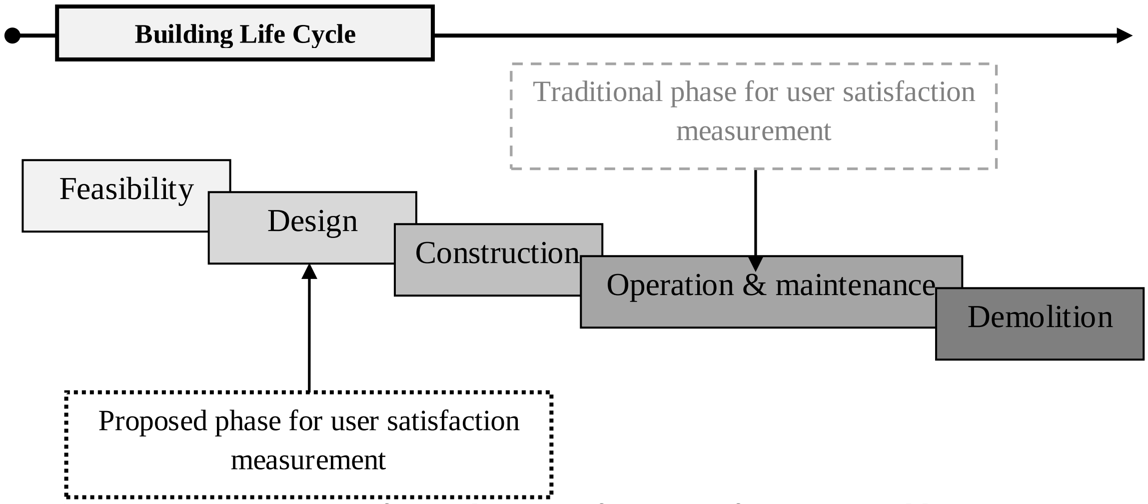

Figure 1.3: Comparison of consideration of user satisfaction in Building Project Life Cycle, traditional approach verses proposed approach

Furthermore, it is obvious that 'study on user satisfaction requirement' will enhance sustainability of building in diverse dimensions; such as, functionality, serviceability, adoptability, human comfort requirement, well-being, and risk reduction of investment and negative impact on the nature (Lutzkendorf and Lorenz, 2008).

1.8 Thesis Outline

This research basically follows the afore-mentioned six objectives to address the aim. To do so, the report of the research is presented in eight chapters corresponding to university thesis manual. This includes; Chapter '1': Introduction, Chapter '2': Literature Review, Chapter '3': Research Methodology, Chapter '4': Data Analysis, Chapter '5': Framework Development, Chapter '6': Case study, Chapter '7': Finding and Discussion, Chapter '8': Conclusion.

- Chapter '1': Introduction,

  First chapter presents introduction to the research. In this chapter rational to the research, identified aim and objectives and brief research methodology is presented.

- Chapter ‘2’: Literature Review,

  Chapter ‘2’ presents critical reviews on the related literatures to each objective. Validated finding of literature review is implemented in the final model. This chapter mainly presents Phase II of the research methodology flow.

- Chapter ‘3’: Research Methodology,

  Chapter ‘3’ addresses the grounded research methodology of the study in detail. In this chapter methods and techniques undertaken to conduct the data collection are explained. This chapter mainly presents rational of research methodology flow carried out in this study.

- Chapter ‘4’: Data analysis,

  Chapter ‘4’ presents results of survey and validation done on literature by means of ‘expert input’. In chapter ‘4’ data analysis corresponds to ‘Phase I & III’ of the research methodology.

- Chapter ‘5’: Framework Development,

  Chapter ‘5’ presents the development of the framework and user input as preliminary validation of developed framework. This chapter corresponds to ‘Phase IV’ of research methodology.

- Chapter ‘6’: Case study,

  Chapter ‘6’ addresses case selection, the case study done to validate developed framework and the final user validation. This chapter presents ‘Phase V’ of the research methodology.

- Chapter ‘7’: Discussion,

  Chapter ‘7’ discusses on strength and weakness of each objective finding including the final developed framework.

- Chapter ‘8’: Conclusion,

Chapter ‘8’ as the final chapter records conclusion to each objective. This chapter also highlights the limitations faced in this research, recommendations and possible future studies.

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