INDOOR ENVIRONMENTAL QUALITY, OCCUPANTS' SATISFACTION AND PERCEIVED PRODUCTIVITY IN GREEN BUILDING INDEX RATED OFFICE BUILDINGS

ASNIZA HAMIMI BINTI ABDUL THARIM

UNIVERSITI SAINS MALAYSIA

2018

INDOOR ENVIRONMENTAL QUALITY, OCCUPANTS' SATISFACTION AND PERCEIVED PRODUCTIVITY IN GREEN BUILDING INDEX RATED OFFICE BUILDINGS

by

ASNIZA HAMIMI BINTI ABDUL THARIM

Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

September 2018

ACKNOWLEDGEMENT

Alhamdulillah, in completing this PhD thesis, I would like to express my heartfelt gratitude to many people that have contributed either directly or indirectly to the completion of this thesis.

First and foremost, I would like to express my sincere gratitude to Associate Professor Dr Muna Hanim Abdul Samad, my supervisor, without whom this thesis would not have been possible. Thank-you for your guidance, wisdom, countless discussions, encouragement, and frequent laughter.

My co-supervisor, Dr Mazran Ismail, for his advice and guidance in the process to complete this dissertation. He was a source of inspiration, optimism, and helped me to examine the theoretical aspects of my work critically. I would also like to express my profound gratitude to Dr Ida Rosnita Ismail (UKM), for her scientific advice and knowledge regarding my research analysis using the PLS-SEM.

My special acknowledgements go to the Board of Directors and occupants at Energy Commission Malaysia (ST), Ministry of International Trade and Industry (MITI), Ministry of Works Malaysia (KKR) and Putrajaya Holdings Sdn Bhd (PJH) for the case study's venue permission and their willingness to participate in the questionnaire survey of this research.

My most sincere appreciation goes to the person in charge at the case study buildings as the following for helping me with building access and information needed in completing the data collection process of this thesis:

1. Madam Hamidah Abdul Rashid (Energy Commission Malaysia)
2. Mr Khairulnizam Hashim (Ministry of International Trade and Industry)
3. Madam Ruzita Bt Zainal (Ministry of Works Malaysia)
4. Mr Mohamad Azim Bin Rosli (Putrajaya Holdings Sdn Bhd)

Three additional individuals warrant special recognition, as this thesis would not have been possible to be completed without them. Hearty thanks go to Ar Azman Zainonabidin, Mr Mohd Nasurudin Hasbullah and Mr Mohd Zikri Mohd Zaki for their knowledge and support in the architectural aspects of this thesis.

I am also deeply indebted to the Ministry of Higher Education (Malaysia), Universiti Teknologi MARA, Malaysia and Universiti Sains Malaysia for sponsoring this research. I would also like to acknowledge here my gratitude to the faculty and staff at the School of Housing, Building and Planning, Universiti Sains Malaysia especially to Madam Normah Ismail for their technical support throughout my research process.

The completion of this thesis would not have been possible without the friendship, laughter, and adventures shared with countless others, Nursaadatun Nisak Ahmad, Nur'Ain Ismail (for her patience and endurance in formatting my thesis), Associate Professor Dr Thuraiya Mohd, Dr Asmat Ismail, Madam Noor Aileen Ibrahim, Fadhlizil Fariz Abdul Munir and colleagues in Quantity Surveying Department of UiTM Perak.

Above of all, I would like to extend a sincere thank you to my family Nuzul Effendi Abdul Tharim, Dr Asniza Hazamima Abdul Tharim, Norhafizah Ahmad, Awwal Rizki Nuzul Effendi, Athar Raheel Nuzul Effendi, Aira Riefa Nuzul Effendi and families who supported me throughout my studies with patience, comfort, love and motivation. Without their constant encouragement and much-needed discipline, I wouldn't be where I am today. Finally, I dedicated this thesis to the loving memory of my late father, Abdul Tharim Ngah Osman and mother, Saerah Abd Latif who always on my mind and forever in my heart.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

2^{nd} RVA	Renewal Certification 2nd RVA
AAC	Acoustic Comfort
ABC	Building Characteristic –Façade
ACE	Air Change Effectiveness
ACEM	Association of Consulting Engineers Malaysia
ACM	Cleanliness & Maintenance
AFU	Furnishing
AHU	Air Handling Unit
AIAQ	Indoor Air Quality
AOL	Office Layout
APC	Personal Control
ASHREA	American Society of Heating, Refrigerating and Air-Conditioning Engineering
ATC	Thermal Comfort
AVC	Visual Comfort
AVE	Average Variance Extracted
BABUC	Environmental Data Logger
BAS	Building Automation System
BCA	Building and Construction Authority
BMS	Building Management System
BOSSA	Building Occupants Survey System Australia
BREEAM	Building Research Establishment Environmental Assessment Method
BUS	The Building User Survey Methodology
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CBE	Centre for the Built Environment
CB-SEM	Co-Variance-Based Approach
CIDB	Construction Industry Development Board

CO^2	Carbon Dioxide
CR	Composite Reliability
CVA	Completion and Verification Assessment -Final Certification
DA	Design Assessment -Provisional Certification
DCS	District Cooling System
ECO	Ecology
EE	Energy Efficiency
EP	Environmental Protection
GBI	Green Building Index
GoF	Goodness-Of-Fit
HK-BEAM	Hong Kong Building Environmental Assessment Method
HTMT	Heterotrait-Monotrait
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
INN	Innovation
IP	Integrative Process
ISO	International Organization for Standardization
JKR	Ministry of Works Malaysia
KKR2	Komplek Kerja Raya
LEED	Leadership in Energy and Environmental Design
LT	Location and Transportation
LV	Latent Variables
MITI	Ministry of International Trade and Industry Malaysia
MP	Management Process
MS	Malaysian Standard
MS	Material and Resources
NLA	Nett Lettable Area
NRNC	Non-Residential New Construction
P	Pollution/Emission
P&C	Private and Confidential
PAM	Pertubuhan Akitek Malaysia
PJH	Putrajaya Holdings
PLS-SEM	Partial Least Squares Structural Equations Modelling

POE	Post Occupancy Evaluation
PRO	Perceived Productivity
PROBE	Post-Occupancy Review of Buildings and their Engineering
PWD	Public Works Department
REHDA	Real Estate and Housing Association
RIBA	Royal Institute of British Architects
RP	Regional Priority
RVA	Renewal Certification
SAT	Occupants' Satisfaction
Scan SPOES	Post Occupancy Evaluation Survey
SPSS	Social Package Statistical Science
SSPM	Sustainable Site Planning and Management
ST	Suruhajaya Tenaga (Energy Commission)
UK	United Kingdom
USA	United States of America
USGBC	United State Green Building Council
USM	Universiti Sains Malaysia
VAV	Variable Air Volume
VIF	Varian Inflation Factor
VLT	Visual Light Transmission
VOC	Volatile Organic Compound
WaE	Water Efficiency
WsE	Waste Efficiency

LIST OF SYMBOLS

°C	Degree Celsius
%	Percentage
W/m2	Heat Flux
m/s	Meter per second
dB	Decibel
ppm	Parts-per-millions (ppm)
°C	Indoor Air Temperature (°C)
°C	Outdoor Air Temperature (°C)
%	Indoor Relative Humidity (%)
%	Outdoor Relative Humidity (%)
°C	Mean Radiant Temperature (°C)
m/s	Air Velocity (m/s)
W/m^2	Solar Radiation Intensity (W/m2)
dB	Background Noise (dB)
Lux	Illumination (lux)
ppm	Carbon Dioxide –CO2 (ppm)
R^2	coefficient of determination
f^2	effect size
B	path coefficient
Q^2	predictive relevance
q^2	relative impact
p-value	Significant Value

PERSEKITARAN DALAMAN BANGUNAN, KEPUASAN PENGHUNI DAN PRODUKTIVITI KENDIRI DALAM BANGUNAN PEJABAT YANG MEMENUHI INDEKS BANGUNAN HIJAU MALAYSIA

ABSTRAK

Kajian ini bertujuan untuk melihat ukuran secara objektif dan subjektif persekitaran dalaman bangunan (IEQ) keseluruhan milik bangunan pejabat bagi kategori Binaan Baru Bukan Kediaman (Non-Residential New Construction, NRNC) di bawah Indeks Bangunan Hijau (Green Building Index, GBI) di Kuala Lumpur dan Putrajaya, Malaysia. Kajian turut bertujuan mengenalpasti kesan pelbagai rekabentuk fasad bangunan bagi bangunan pejabat hijau. Kajian ini bukan sahaja menumpukan kepada aspek IEQ bangunan terpilih, ia juga menguji hubungan antara IEQ dan Produktiviti Kendiri Penghuni bangunan dengan Kepuasan Penghuni sebagai pengantara. Metodologi kajian yang digunakan terbahagi kepada dua jenis iaitu pengukuran objektif (kerja lapangan) dan subjektif (borang soal selidik dalam bentuk penilaian pasca penghunian-POE). Pengukuran objektif telah dijalankan ke atas Bangunan ST, Bangunan PJH, Bangunan MITI dan Bangunan KKR2 untuk melihat prestasi IEQ semasa oleh bangunan pejabat terpilih. Persekitaran dalam dan luar bangunan dipantau dalam kajian ini untuk menilai prestasi persekitaran dalaman bangunan-bangunan ini dengan pelbagai rekabentuk fasad bangunan. Borang POE untuk penilaian IEQ juga telah diedar dan dikutip daripada penghuni bangunan. Menggunakan teknik persampelan bertujuan, 324 respons telah dianalisis menggunakan PLS-SEM. Keputusan daripada pengukuran objektif (kerja lapangan) menunjukkan prestasi semasa bangunan kajian kes adalah di dalam julat yang

ditetapkan oleh GBI NRNC *Tools*. Didapati bahawa, secara keseluruhannya, dinding kaca (*low-e*) dengan fasad teduhan sirip menegak Bangunan PJH menunjukkan prestasi IEQ terbaik dalam kajian ini. Sementara itu, keputusan pengukuran subjektif (POE) kajian ini menunjukkan hubungan yang signifikan antara IEQ dan Produktiviti Kendiri Penghuni dengan Kepuasan Penghuni sebagai pengantara. Dalam teori, kajian ini menyumbang kepada literatur yang ada dengan menambah ciri bangunan (fasad) sebagai peramal kepada model IEQ serta menambah peranan Kepuasan Penghuni sebagai mediator antara IEQ dan Produktiviti Kendiri Penghuni dalam bangunan pejabat.

INDOOR ENVIRONMENTAL QUALITY, OCCUPANTS' SATISFACTION AND PERCEIVED PRODUCTIVITY IN GREEN BUILDING INDEX RATED OFFICE BUILDINGS

ABSTRACT

The aim of this research is to examine the objective and subjective measurements of overall indoor environmental quality (IEQ) in Green Building Index (GBI) Non-Residential New Construction (NRNC) office buildings located in Kuala Lumpur and Putrajaya, Malaysia. This is also to identify the influence of various façade designs that are implemented in the selected GBI NRNC office buildings. This research not only focuses on the aspects of the IEQ levels in the selected case study buildings, but it also tests the relationship between IEQ and Occupants' Perceived Productivity with Occupants' Satisfaction as mediator. The research methodology adopted for this research is divided into two types which are the objective (fieldwork) and subjective (questionnaire survey in the form of post occupancy evaluation) measurements. Subsequently, in order to investigate the current performance of IEQ in the selected GBI NRNC office buildings, a series of fieldwork measurement were conducted in the buildings i.e., ST Building, PJH Building, MITI Building and KKR2 Building. Indoor and outdoor environments were monitored in this research to evaluate the IEQ performance of these building with various façade design. Concurrently, the POE survey on IEQ assessment were distributed and collected amongs occupants in the buildings. Using the purposive sampling techniques, 302 responses were analyzed using the partial least squares structural equation modeling. Results from the objective measurement (fieldwork) revealed that the current performance of the selected case study buildings were acceptable within the range stipulated by GBI NRNC Tools. It was found that, in overall, the PJH Building's low-e curtain walling façade with vertical fins shading façade design provide the best performance of IEQ in this research. Meanwhile, the subjective measurement (POE survey) results of this research revealed that there was a significant relationship between IEQ and Perceived Productivity with Occupants' Satisfaction as mediator. Theoretically, this research contributes to the literature by validating the IEQ model to include the building characteristic (façade) as one of the IEQ predictors and also to include the mediating role of Occupants' Satisfaction between IEQ and Perceived Productivity in an office building.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Sustainability in the construction industry is defined as the degree of growth and expansion that fulfil the needs of the current state of development without compromising the needs of future generations (Duchin, 1995). The construction industry has often been accused of leaving a trail of destruction in its wake which affects the environment in numerous aspects, ranging from excessive consumption of resources to direct environment pollution (Ding, 2008) that include climate change, ozone exhaustion, loss of biodiversity and many others (Kibert, 2008). Therefore, the implementation of sustainable development in the construction industry is seen as the best way to address, reduce and eliminate these interrelated problems in order to conserve the environment for the sake of future generation and planet (Waas, Verbruggen, & Wright, 2010).

Implementing sustainable construction practice requires a performance with the least critical environmental impact, while inspiring a holistic cultural, social and economic improvement. Using sustainable construction does not mean that the project is designed and constructed in a totally new way. Contractors, developers and the design team may continue to use the traditional design and construction practices on these green projects in all aspects from the inception to the completion of the building construction and management. Previous studies by various researchers show that the market for sustainable buildings is increasing as the people in the construction industry has acknowledged that sustainable construction may ease the negative impact on the environment and bring significant improvement to the social and environmental benefits of all nations worldwide (Ries, Bilec, Gokhan, & Needy, 2006; Thormark, 2006; Wang, Zmeureanua, & Rivard, 2005). Therefore, as more owners and clients seek to develop sustainable buildings, the construction industry is adapting to new requirements in order to meet the concerns of the owners. Recently, there has been a significant change in the construction industry whereby there has been a surge of interest in green design and sustainable materials. Sustainable materials are the potential resource to mitigate the impact on the environment and bring significant and holistic benefits (Laura, Daniel & Javier, 2013).

The use of green and sustainable building features, materials and design in building construction is becoming standard practice nowadays as federal, state and local authorities in many countries such as the United Kingdom (UK), United States of America (USA), Australia, Japan as well as Malaysia are modernizing building codes and ordinances to require buildings to go green and sustainable by conserving energy, water and improve the indoor air quality. As a result, the implementation of an energy rating guideline, tools and ratings to assess environmental and energy performance of a building is becoming more important. Buildings have a momentous and continuous impact on the environment due to the fact that buildings consume a significant number of resources and energy as well as being responsible for a large portion of carbon emission to the environment. The green building movement emerged to mitigate these effects and to improve the building construction process. Therefore, the momentum of green building and sustainable construction are salient, and it is motivated relatively by the increasing awareness of the environmental impact of the built environment and indoor spaces and its implications on the health of users (Erica, 2008).

At present, the development and introduction of sustainable building codes is taking place around the world with vast support from prominent organizations (Hanna, 2011). Consequently, the establishment of green building certification systems worldwide is seen as one of the significant initiatives in the emerging green building movement, it is also believed to be one of the most prominent and systematic approach to promote sustainable environment in other countries (Liang, Chen, Hwang, Shih, & Lo, 2014). The first green building certification introduced in the UK was known as the Building Research Establishment Environmental Assessment Method (BREEAM). Since then several countries have developed their own green standard (Potbhare, Syal, Arif, Khalfan, & Egbu, 2009) including the Leadership in Energy and Environmental Design (LEED) USA, Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) Japan and Green Star Australia (Zimmerman & Kibert, 2007).

Consequently, in order to accelerate the growth of the sustainable construction industry in Malaysia and to show the level of commitment of the government in implementing "green" initiatives for the country, The National Green Technology Policy was launched by the Former Prime Minister of Malaysia Tun Dr Mahathir Mohamed in July 2009 with the aims to be a driver to support the national economy and promote sustainable development in Malaysia. The intention to drive the national sustainable construction and development through green technology was clearly mentioned and stated in Objective number 4 of the National Green Technology Policy : "to ensure sustainable development and conserve environment for future generation".

Later , the 4 pillars of green development were introduced by the Ministry of Energy, Green Technology and Water of Malaysia which comprise 4 main pillars ; energy, environment, social and economy. The main target of the environment pillar is to conserve and minimize the impact on the environment by adopting Green Technology in construction and development of Malaysia. In order to expand the use of green technology in Malaysia, the Green Building Index (GBI) was launched by the government on 21st of May 2009 and it is one of the incentives announced in the 2010 Budget under the heading of "Promoting Construction of Green Building". The GBI is a green rating index of environmentally friendly building with the ability to save utility costs and preserve the quality of the external and internal environment.

While the construction industry have leaned towards green and sustainable building , it is often given prominence by organisations. However, the health and well-being considerations of the workplace as well as the indoor space are more difficult to measure and have not been given due consideration. Therefore, it is crucial that sustainable construction not only focus on environmental sustainability but also the integration of all aspects that can contribute to improved health, satisfaction and well-being of building users (Andrew & Michael, 2011). Some research suggest that occupants of environmentally sustainable buildings feel better psychologically, although this area of research is still in its infancy. The construction of green and sustainable buildings has increased due to the increasing level of awareness on the sustainability issues around the world with the aims to reduce the adverse environmental impact of building indoor space and increase the level of satisfaction of the occupants (Korkmaz, Horman, Molenaar, & Gransberg, 2010; Green Building Council of Australia, 2011).

1.2 Problem Statement

Malaysia is classified as a tropical country with a hot and humid climate throughout the year. Normally the first six months are sunny while the second half of the year are considered as the wet months. Szokolay (2008) described the hot and humid tropical climate as one of the extreme and hardest climate to compromise in terms of building design. The global warming phenomenon that the world is facing today has contributed to the increase in outdoor and indoor temperatures. To date, however the construction industry seems to have focused only on finding the right mechanism for an environmentally sustainable final result, such as energy efficiency or water conservation in order for the building to be certified as green, with a lack of continuous assessment on the building performance after the certifications (Yang, 2012).

The primary objective of a building is to provide shelter, space and comfort for the people to live, work and interact in them (Bessoudo, Tzempelikos, Athienitis, & Zmeureanu, 2010). With the aims of providing more green technology building in Malaysia with green building design, these primary objectives of a building should not be neglected by the government and developers as well. A building cannot be categorized as a green building merely because of the use of recyclable materials in its construction. In order to achieve a standard of sustainable building construction, the building must be able to imitate and blend with nature as if it were a part of it. Therefore, measuring the exact financial cost and impact of greener buildings was difficult as the cost of poor indoor environment, air quality and comfort are hard to measure and identified without a proper investigation on the internal and external factors of the building. In this respect, it is worthwhile to consider and take into account the role of building façade as not only being a wrapper of a building but also a barrier with various vital functions that influence the indoor environmental quality and comfort (Drake, 2007).

The achievement of IEQ in naturally ventilated buildings is determined by the thermal performance of façade (Gratia & De Herde, 2004; Anshuman & Kumar, 2005; Wang & Wong, 2007) to a large extent ranking second under local climate characteristic. However, will similar results be obtained when a research on mechanical ventilated building in relation with indoor environmental in a hot and humid country such as Malaysia?. Therefore, there is a need to investigate the relationship of the IEQ in providing comfort thus increasing the productivity for an indoor space in a green rated office building. The IEQ can be used as the criteria to evaluate the performance of various building facade design. Nevertheless, the comfort of the occupants is one of the most effective criterion to integrate the overall IEQ satisfaction in an office building with various façade design.

Hence, some researchers did not find a positive association between the indoor air quality satisfaction and the green building. Gou, Prasada, and Lau, (2013) suggested the need for research in the additional factors influencing the indoor air quality satisfaction of indoor occupants of a tropical country be conducted. It is vastly believed that the green building can provide a better indoor environment that positively contribute to the health, well-being, productivity and performance of the users. If these green buildings are designed well, it can increase the level of comfort and create healthier working conditions.

However, most of the certifications process happen in the designing and construction process and does not focus on the human factor in the post occupancy stage (BREEAM, LEED, Green Star and many others). Numerous studies have been conducted on the aspects related to certified building whereby a majority of these studies focused on the LEED certified building. For example, the IEQ aspects of the green building rating marks/score criteria were rated without considering the perceptions and feelings of the occupants in the post occupancy period. Thus, a more holistic study on green building is needed that does not merely end at the certification process but one that will comprise its life cycle for the green process to be truly categorized or recognised as sustainable. One of the aspects is the post occupancy conditions of the building after ratings awarded by combining the objective and subjective measurement of the variables. Does this really reflect the ratings given?

In Malaysia, research on rated GBI building and the standard itself had been conducted by many researchers throughout the country. However, none of them conducted an in-depth research on Malaysian green office buildings with various façade design particularly on the aspect of occupants' satisfaction and productivity. Therefore, in optimising the overall indoor comfort, it is paramount to intellectually examine its performance relative to the local climate, internal occupancy comfort criteria for the building in association with the overall thermal comfort of occupants' perception and performance.

Consequently, the proper selection of the various façade design that suits the Malaysian climate is very crucial in optimizing the indoor environmental condition of buildings in Malaysia especially for an office building. A study by Lebowitz, Holberg, Boyer and Hayes, (1985) found that people in developed countries spend most of their time, 75-90%, inside of the building. Therefore, the indoor environmental state of these buildings must be in the best condition to ensure the satisfaction of the occupants which will lead to an increase in job performance. However, there has been a dearth of comparative studies on various types of architectural building façade design focusing on the aspect of its shading properties.

Subsequently, this research was conducted to investigate the Indoor Environmental Quality (IEQ) performance of various rated GBI Non-Residential New Construction (NRNC) office building in Malaysia which is a hot and humid country. Secondly, this research emphasised on identifying the influence of various façade designs in selected green rated office building with the IEQ conditions. This research also focuses on the subjective aspects of the research: the satisfaction of the occupants and perceived productivity in the selected case study buildings. This research is limited to the occupants and the case study of selected GBI NRNC office buildings in Malaysia. The aspects of building that need to be drawn are generally in terms of the IEQ variables such as the air temperature, relative humidity, mean radiant temperature, air velocity, acoustic (background noise), visual (indoor lighting) and indoor air quality (IAQ). These variables are measured against the perceptions and satisfaction of the building occupants through post occupancy evaluation (POE) survey. However, this research does not intend to do an in-depth study of the certification of GBI, but rather it is impartial in identifying the performance of these rated buildings in the post occupancy period that relates to the overall satisfaction of IEQ for various GBI NRNC office building with various façade design.

1.3 Research Aim

The aim of the research is to examine the objective and subjective measurements of overall IEQ in GBI NRNC rated office buildings in Malaysia.

1.4 Research Questions

The research aim leads to a research conducted on case study buildings of GBI NRNC with different types of facade Hence, the research seeks to answer the following research questions :

1. What are the performance levels of IEQ in Malaysian rated GBI NRNC office buildings?
2. What is the influence of various façade designs that are implemented in the selected GBI NRNC office buildings?
3. What is the relationship between IEQ and occupants' perceived productivity with satisfaction as mediator in rated GBI NRNC office buildings?

1.5 Research Objectives

The introduction and the problem statement above led to the formulation of the research objectives. The research aims to achieve the following research objectives:

1. To determine the performance level of IEQ in Malaysian rated GBI NRNC office buildings.
2. To identify the influence of various façade designs that are implemented in the selected GBI NRNC office buildings.
3. To examine the relationship between IEQ and occupants' perceived productivity with satisfaction as mediator in rated GBI NRNC office buildings.

1.6 Research Hypothesis

The hypothesis for this research as shown in Table 1.1 .

Table 1.1: Research Objective and Hypothesis

	Research Objective	Research Hypothesis
1	To determine the performance level of IEQ in Malaysian GBI rated NRNC office buildings.	H1: The current performance of IEQ in Malaysian GBI rated NRNC office buildings with various façade designs is expected to fulfil the GBI NRNC requirements.
2	To identify the influence of various façade designs that are implemented in the selected GBI NRNC office buildings.	H2: Different façade designs deliver different influence on the level of IEQ in GBI NRNC office buildings.

3	To examine the relationship between IEQ and occupants' perceived productivity with satisfaction as mediator in GBI rated NRNC office buildings.	H3: There is a positive relationship between IEQ with Occupants' Perceived Productivity. H4: There is a positive relationship between IEQ with Occupants' Satisfaction. H5: There is a positive significant relationship between Occupants' Satisfaction and Perceived Productivity. H6: There is a direct and indirect effect on the relationship between Indoor Environmental Quality (IEQ) and Perceived Productivity via Occupants' Satisfaction (mediator).

1.7 Research Scope

The scope of this research focuses on the measurement of IEQ in a working space of a GBI NRNC rated office buildings in Kuala Lumpur and Putrajaya, Malaysia covering the objective and subjective measurement. Objective measurement is conducted in the form of case study buildings by using the fieldwork equipment measurement while the subjective measurement is conducted by distributing pilot questionnaires to the building occupants that comprise the aspects of the perception and satisfaction of the users in four green rated office buildings with different façade designs. The questionnaire survey also included the demographic profile information of building occupants with their perception and satisfaction on nine (9) variables of the IEQ namely the thermal comfort , acoustic comfort , visual comfort, IAQ, office layout, furnishing, personal control, cleanliness and maintenance and lastly the building characteristic focusing on façade design influence.

As for the fieldwork measurement , this research focuses on the IEQ conditions and performance of the four-different façade design of GBI NRNC office building. There are seven (7) variables of the IEQ which comprise thermal comfort (air temperature, relative humidity, mean radiant temperature, air velocity), acoustic comfort (background noise), visual comfort (indoor lighting) and lastly the IAQ (carbon dioxide -CO^2 concentration) of the indoor working space. Thus, for the sampling, this research used the selected sampling for the objective measurement to fulfill Objective 1 and 2 where the non-probability stratified sampling of building occupants is employed for the subjective measurement to determine Objective 3 of the research. Hence, Putrajaya and Kuala Lumpur were chosen as the location of the case study buildings because most of the GBI NRNC office were located in these zones (GBI, 2018).

1.8 Research Framework

The following is the research framework of the study:

Figure 1.1 is the research framework developed based on the research variables :

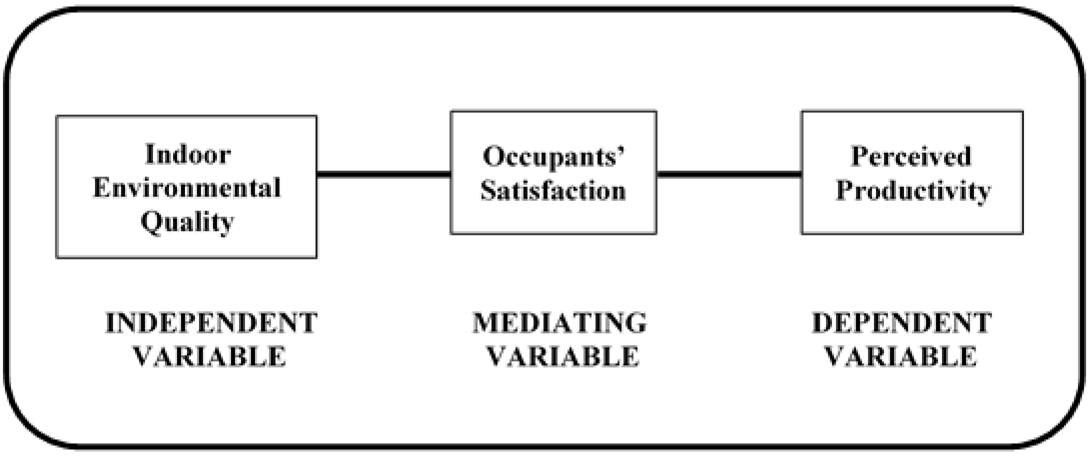

Figure 1.1: Conceptual Research Framework

1.9 Significance of Study

An extensive empirical research on IEQ in a hot and humid climate in various green aspects had been conducted in this country, however research focusing on the IEQ remains relatively new especially on GBI NRNC office buildings with various façade design. Therefore, this research provide a significant contribution in various aspects:

1. It covers both the objective and subjective measurements of IEQ variables covering the aspects of environmental and non-environmental dimensions of the IEQ.
2. It is a research on GBI NRNC office buildings in Malaysia.
3. It encompasses various façade designs of office buildings.
4. It developed a comprehensive structured POE focusing on IEQ assessment that can be used to assess the perceptions and satisfaction of building occupants on IEQ and their perceived productivity in an office building.
5. Finally, this research developed an IEQ model framework to measure the satisfaction and perceived productivity of the occupants in an office building.

1.10 Research Limitations

All of the following are the three (3) main limitations of this research:

1. Case Study Building

   Firstly, the research was limited to rated GBI NRNC office buildings located in Kuala Lumpur and Putrajaya, Malaysia. Therefore, a further limitation of this research is signified by the fact that the case study building selected for this research is only partially representative of the total number of NRNC office buildings that have been certified by GBI Malaysia up to the date of study conducted. Recently, as updated on Januari 2018, there was a growing number of certified office buildings in the selected area. However, this research referred to online data published in 2015 as the data collection was conducted in 2016.

A limitation of the research based on its characteristic was that only four GBI NRNC office buildings were selected in this research. This limited number of case study building is compromised with the difficulties encountered in engaging buildings for the research. Thus, resulted in selecting case study buildings that were accessible and willing to participate in the research. However, each of the green office building selected in this research had its own characteristics (e.g. design, material used, location, orientation, age, size, construction) together with various management style, work criteria and different occupants. Hence, these differences have to be taken into account when conducting the POE and fieldwork measurement for this research.

2. Measurement Procedure

The second limitation of this research was the limited availability of equipment or sensors for simultaneously measuring different case study buildings in various locations and on different days. Therefore, this research measurement processes were conducted in different case study locations during different days and time of measurement which made it difficult to make a reasonable comparison between the four (4) case study buildings because of the discrepancies. However, this limitation was overcome by using the relativeness index as elaborated in Chapter 5 of this thesis. The measurement limited to seven (7) IEQ parameters namely: air temperature, relative humidity, mean radiant temperature, air velocity, acoustic (focusing on the background noise), visual (concentrating on indoor lighting) and lastly IAQ (measuring only the aspect of its CO^2 concentration). Hence, due to certain private and confidential (P&C) policy by one of the case study building regarding accessibility of time, thus the fieldwork measurement was conducted between 9.00 a.m. until 5.00 p.m. everyday in all case study buildings. However, as 30 minutes was allocated to set up and pack the equipment, the measurements were analysed only from 9.30 a.m. to 4.30 p.m. for analysis purposes. These fieldwork measurements in the four (4) selected GBI NRNC office buildings were conducted simultaneously with the POE survey to the occupants of the building.

3. Post Occupancy Evaluation (POE)

The modified POE survey for this research expanded the scope by capturing the perception of the occupants and how the building characteristic (focusing on façade) influence IEQ satisfaction in the case study buildings. These additional questions related to the façade design of buildings were added to the adapted and edited POE, from Centre for the

Built Environment (CBE) survey and Building Occupants Survey System Australia (BOSSA), for this research with the intention of enquiring and subjectively analysing the façade aspect that relates with the objective measurement analysis of the same case study buildings. Subsequently, the incorporation of these additional questions was constrained by the length of the POE survey thus making it difficult to sustain the interest of respondents in answering the survey. Therefore, demographic profile of the respondent was allocated in the final part of the POE survey to give ample time for respondents to focus on Likert scale questions.

The second limitation of the POE survey was the fact that self-assessment is not free from personal bias. For example, several questions were used to measure occupants' perception with IEQ variables in the buildings but only a few questions were used to evaluate occupants' overall satisfaction and perceived productivity on the aspect of IEQ. Moreover, the respondents in the survey were chosen randomly because of the inability of the researcher to obtain full information of the building occupants, therefore, a non-probability purposive sampling was adopted for this research. However, this obliges as a valued example of the challenges on conducting POE survey in practice, where survey design, timing of the survey, constraints in getting information, the willingness of the occupants to participate in the survey and hopes of the research outcomes, are all part of the limitations of the research that has to be taken into consideration in data collection and analysis of findings.

1.11 Research Methodology

This research focuses on the performance of GBI NRNC office building on a case study of four different types of architectural façade design in relation with the aspects of IEQ of the indoor working space in relation to the satisfaction of the occupants.The research employed both objective (fieldwork) and subjective (POE survey) measurements method of data collection. Therefore it can be concluded that, this research adopted a quantitative approach in order to fulfill the research objectives and questions. This research was conducted in three phases as the following:

1. **Phase 1: Literature Review**

   The first phase in doing this research is studying and collating related literature review from various trusted sources such as books, journals, theses, magazine and online trusted reading materials (internet) and developing a structured research framework as an overview for the proposed research questions, issues and problems.

2. **Phase 2: Data Collection**

   Data for the proposed research was collected through: Pilot Study conducted at KKR2 office building (as described in the Chapter 3: Research Methodology of this research) , Fieldwork (Case Study) and Questionnaire Survey (POE) . Data collection was conducted during the dry season in Malaysia (as referred to the Meteorological Department of Kuala Lumpur) – normally from January to May (Malaysian Meteorological Department MET, 2015). The dry season was chosen as a worst case scenario for this research in order to find the most reliable findings of occupants' perception and preference of IEQ in the selected office buildings in an extreme weather climate.

a) ***Objective Measurement (Fieldwork):*** BABUC Data Logger and other related instruments in measuring IEQ parameters is used in the objective measurement of this research as described in Chapter 3: Research Methodology of this research.

b) ***Subjective Measurement (POE Survey):*** The questionnaire is designed in sections as to present a more systematic data. For this research, the questionnaire survey is divided into two main sections. The first section deals with the occupants' perception and satisfaction on IEQ variables by using the seven-point Likert scale for nine (9) independent variables of IEQ as mentioned earlier. Occupants of the selected building were also questioned on the internal design and layout of office indoor environment as well as on the effects of the heat radiation in their working space in relation to their work performance. The first section also included questions on the overall satisfaction of the occupants on the building performance and finally, there were also questions on the perceived productivity of the occupants in the case study building. Meanwhile, the second section of the questionnaire survey deals with demographic information of the respondents such as gender, age, designation, education and workplace criteria.

3. **Phase 3: Data Analysis**

In the last phase, data collected from the objective measurement (fieldwork) and subjective measurement (POE survey) is analyzed by using the excel graph analysis, Social Package Statistical Science (SPSS) and Partial Least Squares Structural Equations Modelling (PLS-SEM) to conclude the findings of the research conducted in Phase 1 and 2.

The methodology process is elaborated further in Chapter 3: Research Methodology of this thesis. Hence, Table 1.2 shows the summary of this research:

Table 1.2: Research Summary

	Research Objective	**Research Method**	**Research Analysis**
1.	To determine the performance level of IEQ in Malaysian rated GBI NRNC office buildings.	Objective Measurement (Fieldwork)	Graph Analysis (Excel)
2.	To identify the influence of various façade designs that are implemented in the selected GBI NRNC office buildings.	Objective Measurement (Fieldwork)	SPSS Version 22: Correlation Analysis/ Kruskal Wallis H
3.	To examine the relationship between IEQ and occupants' perceived productivity with satisfaction as mediator in rated GBI NRNC office buildings.	Subjective Measurement (Questionnaire Survey of POE)	PLS-SEM Version 3.4 and SPSS Version 22: Correlation Analysis/ Kruskal Wallis H

1.12 Organization of Thesis

This thesis comprises six (6) main chapters. The first chapter provides an overview of the research to be conducted, including research aims, research objectives, research questions, research methodology, research scope, significance of research, and the limitation of this research. It highlighted the outline of the whole thesis. While

Chapter 2 of the thesis focuses on the literature review of previous research conducted by various researchers on sustainability, green building, sustainable rating tools, GBI Malaysia, IEQ, POE as well as the relationship between IEQ with occupants' satisfaction and productivity in an office building. Hence, the research methodology of this research is portrayed in detail in Chapter 3 focusing on the objective and subjective measurement procedure of the research. Chapter 4 of this thesis emphasises on the selected case study office buildings specifications, layouts, façade design and finally on the objective measurement procedure conducted in the buildings. Meanwhile, in Chapter 5 of the research discusses in depth the data analysis process and procedure for objectives and subjective measurement findings of the research. The research data is analysed using various analysis techniques namely the excel graph analysis, SPSS statistical analysis, and PLS-SEM. Chapter 5 also elaborates in the discussion section on the correlation between the objective and subjective results of this research. Finally, in the last chapter, Chapter 6 concluded the thesis with a conclusive discussion of the thesis that answers the research objectives and provides suggestions for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Green building often encompasses the planning stage throughout the ultimate end of building life cycle, which comprises the design, construction, operations and renewal of the building structures. The green building brings together a huge range of knowledge, practices, techniques, and skills to reduce and eradicate the negative impacts of buildings on the environment and human health. Hence, this requires close collaboration and understanding between the design team, client, and developers at all stages of a project.

Woo (2010) believed that green buildings have been shaped to lower the impacts to the environment and improve the health quality of the building occupants. Therefore the green buildings could be considered a technological innovation because it encapsulates a system that uses environmentally aware approaches to modifying conventional construction practices (Ofori-Boadu, Owusu-Manu, Edwards, & Holt, 2012). Hence, the green building often represents a complex integration of innovative green materials, products, processes, system and technologies. Green building means improving design, construction and landscaping practices so that it will last longer, cost less and will not be harmful to our health thus creating healthy living. It also means protecting natural resources and improving the built environment so that people, communities, and ecosystems can thrive and prosper through wise uses of natural resources and recycled materials (John & Michael, 2007). However, beside its enormous advantages, green buildings are not yet perceived as attractive projects by most clients and developers. It is mainly because most builders associate green features and construction with expensive technologies that add extra costs to the overall budget allocation of the building (Matthiessen & Morris, 2007; Sherwin, 2006). Nevertheless, a careful design process and comprehensive material selection method of the green building may result in desired environmental goals for the building and save energy consumption in the long term.

Accordingly, buildings have a significant and continuously increasing impact on the environment because they consume and emit a large amount of carbon emission and energy. Thus the green building movement emerged to mitigate these effects and to improve the building construction process through encouraging the use of more environmentally friendly recycled materials, appropriate material selection process, implementation of sustainable techniques to save natural resources and reduce waste consumption that subsequently will contribute to better indoor environmental quality (Thormark, 2006; Wang, Rivard, & Zmeureanu, 2006; Moeck & Yoon, 2004). The United State Green Building Council (USGBC) believed that green building can minimize and eliminate the negative impact of buildings on the environment and occupants (Yiing, Yaacob, & Hussein, 2013). Hence, this can be done by encouraging the use of more environmentally friendly materials, implementing techniques that can save resources and reduce waste consumption, and the improvement of indoor environmental quality for the end user (Thormark, 2006).

There are numerous other potential benefits of green building including environmental, economic and social benefits. The environmental benefits include protecting, conserving and restoring biodiversity and natural resources. In addition, the economic benefits include reducing the life-cycle cost of the building and enhancing profit and rental value. As for social benefits, the implementation of green building can improve the occupants' comfort and health thus improving the overall quality of life. Other benefits of green building include the improvement of indoor environmental quality, reduction on health costs, increase on employees' productivity as well as increased occupants' satisfaction on the aspects of indoor comfort conditions (Ross, Lopez-Alcala, & Small, 2006; Edwards, 2003; Kats, 2003), and significantly improve on IAQ with access of lighting that serve to promote physical and mental well-being (Heerwagen, 2001). Previous study shows that the benefits attained from improved occupant well-being and productivity have the potential to significantly outweigh the incremental costs related with IEQ improvements in a building (Singh, Syal, Korkmaz, & Grady, 2011). Moreover, a study by Gabay, Meir, Schwartz and Werzberger (2014) indicated that numerous benefits of the green building include: minimal energy use; minimum requirement for water, material, and energy resources throughout its life cycle; conducive to occupant health productivity; and minimal waste, pollution, or environmental degradation. With the blooming of the green building concept, the sustainable building standard or tools for green buildings have been developed worldwide to promote the construction of green buildings in the industry. According to Liang, Chen, Hwang, Shih and Lo (2014), among the numerous efforts in the emerging green building is the establishment of green building certification systems as one of the most prominent and systematic approaches toward promoting sustainability in construction. This sustainable building standard is believed to be able to provide an efficient framework for assessing building environmental performance and integrating sustainable development into building and construction processes while assisting in determining performance measures to guide the sustainable design and decision-making processes (DEWA, 2003).

Earlier research by Lebowitz, Holberg, Boyer and Hayes (1985) found that people in developed world spend almost 75-90 percent of their time inside a building. The similar finding was found by Klepeis et al. (2001) and Singh (1996) who believed that research suggests people tend to spend 80-90 percent of their time indoors. These facts highlighted the importance of building indoor environment quality improvements and the need for validating the related well-being and productivity benefits available in rated green buildings (Singh, Syal, Korkmaz, & Grady, 2011). With most people spending 80-90 percent of their lives inside buildings, the green rated building must able to satisfy the objective and subjective requests linked to vital functions of the occupants in existing and future buildings. Later, there will be an increasing focus on energy uses and indoor environmental quality in these rated green building in ensuring the optimum indoor environmental quality is achieved in the post-occupancy period (Wolkoff & Kjaergaard, 2007). Chen, Yuan, Hu, Glicksman and Yang (1998) stated that indoor environment is crucial for people's health and welfare, because 90 percent of a typical person's time is spent indoors. Consequently, their productivity is also related to indoor environment. They also pointed out that the satisfaction level and expectations of occupants in a built environment comprises the illuminations, acoustics, air quality, diet, thermal comfort and social environment; all of which reflect on their physiological and mental sensations such as sight, hearing, smell, taste, touch and mentality. Thus, green construction is mainly aimed at reducing environmental impact and improving the safety, health and productivity of a building's final occupants (John & Michael, 2007). The main aims of this green construction are to create facilities and building that are sustainable with huge attention focused on the satisfaction and sustainability of the end users and end use of the green building.

2.2 Sustainable Building Rating System

Sustainable development has been a worldwide movement that has been evolving for the last two decades (Kibert, 2008). Similarity, the development and introduction of sustainable building standards is taking place around the world (Hanna, 2011). Over the past decade, the sustainable building rating system for green buildings has been developed worldwide to promote the construction of green buildings in the industry. According to Liang et al. (2014), among the numerous efforts in the emerging green building is the establishment of green building certification systems as one of the most prominent and systematic approach toward promoting sustainability in construction. The transition from traditional practices to sustainable design and construction will require action on many fronts and support from prominent organizations. Among benefits of these systems are they can guide the development of the construction industry towards best practices and improve the quality of buildings for tenants and occupants. The sustainable building rating system is a concept of sustainable practices and environmental responsibility which normally is an elective standard as opposed to a mandated regulation involving multiple constituents (building owner, design professionals, construction professionals, and code officials). Therefore, it is a crucial tool to measure and evaluate green buildings in most of the countries worldwide including Malaysia.

There are many great building certification tools globally to assess the environmental performance of a building and its sustainability (Todd, Crawley,