



UNIVERSITI PUTRA MALAYSIA

***NATURAL VENTILATION IMPACT ON SELECTED IEQ PARAMETERS
AND USERS' SATISFACTION IN CENTRAL SPACES OF SHOPPING
MALLS IN MALAYSIA***

IBIYEYE AMINAT IDOWU

FRSB 2017 5



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By

IBIYEYE AMINAT IDOWU

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

May 2017

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DEDICATION

This thesis is dedicated to Almighty Allah, He who taught Man by the pen and taught him that which he knew not.



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

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May 2017

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In order to consistently meet the demand for quality indoor environment, as well as gaining high users' satisfaction and attaining efficient energy usage, new trends have been developing in the design of Malaysian shopping malls. From fully air-conditioned models to newly designed ones that integrate passive ventilation strategies, and as such these shopping malls are operating under mixed-mode ventilation system. These passive ventilation strategies are implemented in order to improve the indoor environment and also to reduce energy consumption. However, the potential of these designs in terms of their indoor environmental quality (IEQ) performance and users' satisfaction with the malls' performance has not been studied. This research investigated the IEQ performance and users' satisfaction of two mixed-mode ventilated malls and one fully air-conditioned mall. The study was conducted in two phases: 1) Identification and classification of mixed-mode ventilated malls in Malaysia, and 2) building performance. The first phase was carried out in order to identify mixed-mode ventilated malls currently under operation in Malaysia and the results of this study were used as the basis for selecting the mixed-mode ventilated case study malls. The two mixed-mode ventilated malls were selected based on their design concepts ('enclosed' and 'hybrid'). For the IEQ performance, five measured environmental factors (air temperature, operative temperature, relative humidity, air speed, and CO₂) and five satisfaction factors (thermal, indoor air quality, air movement, workplace/present location, and overall building performance satisfaction) were evaluated in all case study malls using field measurements and questionnaire survey. Field measurements were done only within the naturally ventilated central spaces in the mixed-mode ventilated malls and only users within these spaces were surveyed. The results from the IEQ performance revealed that all three case study malls performed differently. Generally, the 'hybrid' concept mixed-mode ventilated mall proved to be superior to the 'enclosed' concept one and it was similar in performance to the air-conditioned mall in terms of users'

satisfaction except in the case of its overall performance satisfaction where its performance was better. Although all three case study malls failed to comply with the ASHRAE standard 55 for thermal comfort in an occupied space, yet thermal acceptance was high in all case study malls. The users within the naturally ventilated spaces of the 'hybrid' concept mixed-mode ventilated mall showed higher thermal tolerance and air movement was found to be of utmost importance to workers in the two mixed-mode ventilated malls. Findings from this study were able to prove that natural ventilation could be enhanced and use in malls to improve the IEQ performance and at the same time achieve high users' satisfaction. The results can potentially be used to help designers in creating malls that are more efficient in resources and also safer and healthier for users and the environment.



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

**KESAN PENGUDARAAN SEMULAJADI PADA PARAMETER IEQ
TERPILIH DAN KEPUASAN PENGGUNA DI RUANG PUSAT MEMBELI-
BELAH DI MALAYSIA**

Oleh

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Dalam usaha untuk bersaing dengan permintaan bagi persekitaran dalaman yang berkualiti serta mencapai penggunaan tenaga yang cekap, haluan baru telah membangun didalam reka bentuk pusat membeli-belah Malaysia. Dari berhawa dingin sepenuhnya kepada yang baru direka yang mengintegrasikan strategi pengudaraan pasif; dan seperti yang beroperasi di bawah sistem pengudaraan mod campuran. Strategi pengudaraan pasif ini dilaksanakan untuk menambah baik persekitaran dalaman dan juga untuk mengurangkan penggunaan tenaga. Walau bagaimanapun, potensi reka bentuk ini dari segi kualiti persekitaran dalaman (IEQ) atau penggunaan masih belum dikaji. Kajian ini meneliti IEQ dan persembahan tenaga dua pusat membeli-belah berpengudaraan mod campuran dan satu pusat membeli-belah yang berhawa dingin sepenuhnya. Kajian ini dijalankan dalam dua fasa: 1) Pengenalan dan klasifikasi pusat membeli-belah berpengudaraan secara mod campuran di Malaysia, dan 2) Prestasi bangunan. Fasa kedua seterusnya dibahagikan kepada dua peringkat: prestasi tenaga dan prestasi IEQ. Kajian taksonomi telah dijalankan untuk mengenal pasti pusat membeli-belah berpengudaraan mod campuran yang kini sedang beroperasi di Malaysia dan hasil kajian ini telah digunakan sebagai asas untuk memilih kajian kes pusat membeli-belah berpengudaraan mod campuran. Kedua-dua pusat membeli-belah berpengudaraan mod campuran dipilih berdasarkan konsep reka bentuk mereka ('tertutup' dan 'hibrid'). Bagi pencapaian IEQ, lima faktor persekitaran diukur (suhu udara, suhu operasi, kelembapan, kelajuan udara dan CO₂) dan lima faktor kepuasan (keselesaan terma, kualiti udara dalaman, pergerakan udara, tempat kerja / lokasi sekarang, dan prestasi keseluruhan bangunan) telah dinilai dalam semua kes kajian pusat membeli-belah melalui ukuran lapangan dan kajian soal selidik. Pengukuran lapangan telah dilaksanakan hanya di antara ruang pusat berpengudaraan secara semulajadi dalam pusat membeli-belah berpengudaraan secara mod campuran dan hanya pengguna dalam lingkungan ruang tersebut sahaja diselidiki. Hasil daripada prestasi IEQ

mendedahkan bahawa ketiga-tiga kajian kes pusat membeli-belah terdapat perbezaan. Secara umumnya, konsep 'hibrid' pusat membeli-belah yang berpengudaraan mod campuran terbukti lebih unggul kepada konsep 'tertutup' dan ia adalah lebih dekat dalam prestasi kepada pusat membeli-belah yang berhawa dingin kecuali dalam prestasi keseluruhan di mana prestasinya adalah lebih baik. Walaupun, ketiga-tiga kajian kes pusat membeli-belah tidak mematuhi standard 55 ASHRAE untuk keselesaan haba dalam ruang yang diduduki, penerimaan terma di semua pusat kajian kes adalah tinggi. Pengguna di ruang pusat berpengudaraan secara semulajadi dalam konsep 'hibrid' pusat membeli-belah yang berpengudaraan mod campuran menunjukkan toleransi haba yang lebih tinggi. Pergerakan udara didapati lebih penting kepada pekerja-pekerja di kedua-dua pusat membeli-belah berpengudaraan mod campuran. Hasil dari kajian ini berkeupayaan untuk membuktikan bahawa pengudaraan semulajadi boleh ditingkatkan dan digunakan di pusat membeli-belah untuk meningkatkan pencapaian IEQ dan pada masa yang sama mencapai kepuasan pengguna yang tinggi. Keputusan berpotensi boleh digunakan untuk membantu pereka-pereka dalam mewujudkan pusat membeli-belah yang lebih cekap dalam sumber dan juga selamat dan sihat untuk manusia dan alam sekitar.

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I certify that a Thesis Examination Committee has met on 3 May 2017 to conduct the final examination of Ibiyeye Aminat Idowu on her thesis entitled "Natural Ventilation Impact on Selected IEQ Parameters and Users' Satisfaction in Central Spaces of Shopping Malls in Malaysia " in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

ACH	Air Changes Rate per Hour
AC	Air Conditioning
ASHRAE	American Society of Heating Refrigerating and Air-conditioning Engineers
cfm	Cubic feet meter
CO	Carbon monoxide
CO ₂	Carbon dioxide
DOSH	Department of Occupational Safety and Health Malaysia
HVAC	Heating Ventilating and Air Conditioning
IAQ	Indoor Air Quality
l/s	Litres per seconds
LVAQ	Limit Value for Air Quality
M ²	Square metre
m ³	Cubic metre
m ³ /h	Cubic metre per hour
m/s	Metres per seconds
NAAQS	National Ambient Air Quality Standards
OR	Odds Ratio
ppm	Parts per million
PPV	Predicted Percentage of Dissatisfied
PM	Particulate Matter
PMV	Predicted Mean Vote
SE	Standard Error

SPSS	Statistical Package for Social Sciences
TVOCs	Total Volatile Organic Compounds
US EIA	United State Energy Information Administration
US EPA	United State Environmental Protection Agency
WHO	World Health Organization
3D	Three Dimensional
$^{\circ}\text{C}$	Degree Celsius



CHAPTER 1

INTRODUCTION

1.1 Background of study

Malls, due to their large floor area and huge crowd capacity are not only faced with energy consumption issues but also with other issues ranging from social (e.g. tight competition with regards to services and customers' satisfaction) to environmental issues (e.g. Indoor Environmental Quality (IEQ)). These issues one way or the other are interwoven and has an impact on the malls' performance as well as on users' satisfaction. A typical example of a social issue is the shoppers' motivation for visiting a particular mall. Since the mall's strategy is to attract large number of customers as possible, malls do not only compete with each other in terms of their product offerings but also by creating exciting and comfortable indoor atmospheres for users (Anning-Dorson et al., 2013). The competition and market congestion have led developers and mall management into considering alternative methods in order to build more excitement for their customers. These include the incorporation of various entertainment outlets within the mall such as parks, cinemas, etc. (Rajagopal, 2009).

However, these entertainment outlets are just a fraction among other factors that attracts mall's customers. It is evident that several other motivating factors affect shoppers' behavior towards a particular mall, behavior such as their choice of visiting the mall (Anning-Dorson et al., 2013), and their spending behavior (Turley and Milliman, 2000; Chebat and Michon, 2003; Chebat et al., 2014). Several studies have attempted to identify these motivating factors, Chebat and Michon (2003), Michon et al. (2005), Singh and Prashar (2014) identified what they termed "the mall's indoor atmosphere" which constitutes the indoor odour. However, Turley and Milliman (2000)'s "mall's indoor atmosphere" included internal lighting, temperature, and cleanliness. El-Adly (2007) and Khayyambashi and Vahid (2014) identified "thermal comfort" among all other identified factors. Anning-Dorson et al. (2013) included "aesthetic and architectural motivation" which was defined as climatic comfort and elimination of noise pollution. Rajagopal (2009) argued that a mall's ambience and indoor comfort are two of the major factors that draw higher customer traffic to malls. Similarly, for Malaysians, the "indoor ambience" and the "interior design" are among the most important factors that influence their stay in a particular mall (Kamarulzaman et al., 2010).

All of the identified motivational factors ("indoor atmosphere", "indoor ambience", "thermal comfort", "indoor odour", etc.) are all indoor environmental condition connected to IEQ. And it (IEQ) is one of the major issues affecting the general well-being of building occupants in terms of their health and productivity (Heinzerling et al., 2013). Consequently, these factors affect the shoppers' shopping behavior in terms of the length of time they spend in the mall (Zafar et al., 2007; Kamarulzaman

et al., 2010), amount of money spent (Chebat and Michon, 2003; Chebat et al., 2014), the likelihood of them returning to the same mall, and their overall satisfaction (Chang and Fang, 2012; Chebat et al., 2014).

An example of the environmental issue faced by malls is the indoor contaminants issue. Since malls are normally located in close proximity to main roads, they are prone to attract contamination from vehicles' exhaust (Li et al., 2013). Furthermore, indoor contaminants emitted by different products and chemicals within the mall can exacerbate the problem of poor indoor air quality (Tang et al., 2005; Xu et al., 2014). Previous studies have identified these contaminants, their level of contamination, and the exposure risk they pose to both shoppers and retailers (Tang et al., 2005; Klinmalee et al., 2009; Li et al., 2013; Amodio et al., 2014; Xu et al., 2014). In Malaysia, adults (18 years above) spend about 48% of their leisure time in shopping malls as shopping constitutes their most popular and affordable form of outing (Zafar et al., 2007). Their continuous exposure to indoor contaminants can lead to both short and long-term health effects (Amodio et al., 2014). Short term effects can range from headaches, irritation to visual disorders while Long-term effects may include damage to vital internal organs as well as the central nervous system (Zhou et al., 2011; Ramírez et al., 2012; Amodio et al., 2014).

It is also important to acknowledge the challenge of energy usage in malls. Since malls generally are immense energy consumers due to their huge cooling and lighting demand, energy consumption is one additional issue a shopping mall has to deal with. Discovering means of improving energy performance in shopping malls can significantly lead to long-term energy and carbon emission savings. Still, energy saving in malls could be one of the simplest means of increasing profits, as reducing energy consumption can directly increase margins without the need to increase sales (Carbon Trust, 2012). Although energy is of crucial importance, it is only an aspect of building performance in general that should not be pursued to the neglect of other indoor environment factors affecting building occupants/users such as thermal comfort and indoor air quality (Lisa et al., 2015).

Thus, it is evidence that a balance needs to be maintained with regards to energy savings, occupants'/users' comfort, health, and wellbeing in shopping malls. To attain this balance, shopping malls are encouraged to take advantage of natural ventilation and daylighting within their indoor space to reduce energy load from air-conditioning and electric lightings.

In response to this, new design trends have started to evolve in the Malaysian shopping malls; for instance, openings are created within the shopping spaces to admit outdoor air into the indoor environment. These malls thus, operate on both mechanical and natural ventilation in different spaces within the buildings. This practice of combining natural ventilation and mechanical ventilation in a building is referred to as "mixed-mode ventilation", which offers huge advantages for energy reduction while still maximizing comfort (Brager, 2006; Brager et. al, 2007; Deuble

and de Dear, 2012; Hamlyn et al., 2012; Huang et al., 2014; Thomas, 2014). In addition to creating an exciting atmosphere for occupants as it allows movement between different indoor conditions within the same roof (Federico, 2008).

Mixed-mode ventilated buildings also performs excellently particularly with regards to thermal comfort and indoor air quality (Brager, 2006; Emmerich, 2006; Brager and Lindsay, 2008; Deuble and de Dear, 2012; Brager and Pigman, 2013). Furthermore, occupants of mixed-mode ventilated buildings have been revealed to be more satisfied with their indoor condition which in turn leads to their high productivity compared to their counterparts (Brager, 2006; Brager et. al, 2007; Brager and Pigman, 2013).

1.2 Problem statement

Despite the social and environmental advantages that mixed-mode type of shopping malls can offer, mixed-mode ventilation in malls is still a new concept in Malaysia (Ibiyeye et al., 2015). And no documented IEQ study has been carried out on this type of malls in Malaysia so far. Thus, users' acceptance of its performance under hot-humid climatic condition is unknown. Furthermore, no comparison has been made between these malls (that operates on mixed-mode ventilation) and those that operate fully on air-conditioning to evaluate their IEQ performances. Although some IEQ studies have been conducted on shopping malls, almost none has been carried out under hot-humid climatic conditions. In recent years, IEQ studies in malls focused mainly on IAQ (Li et al., 2013; Amodio et al., 2014; Xu et al., 2014; Hu and Li, 2015; Tao et al., 2015), visual (Al-Jubouri, 2012), and acoustic comfort (Della Crociata et al., 2013; Meng and Kang, 2013). Little attention has been given to occupants' thermal comfort in shopping malls.

The 'introduction section' of this chapter has shed light on the advantages that may be derived from mixed-mode ventilation in buildings with regards to occupants'/users' thermal comfort, indoor air quality, and energy savings. Since no IEQ study has been reported regarding mixed-mode ventilated malls in Malaysia, it is, therefore, necessary to study the IEQ performance of these types of malls. Consequently, in order to have a broad understanding and analysis on the performance of these mixed-mode ventilated malls, a comparison between them and those that operate fully on air-conditioning needs to be done. Therefore, this research will investigate the IEQ performances of mixed-mode ventilated and fully air-conditioned malls, an evaluation into the users' perception (shoppers and retailers) towards the mall's IEQ performance will also be carried out.

1.3 Research Questions

Main research question: How do shopping malls with different ventilation modes perform with regards to IEQ and what are the effect of this performance on users' perception and overall satisfaction?

1.3.1 Sub-research questions:

1. How do malls with different ventilation modes perform with regard to IEQ?
2. How do users (shoppers and retailers) of these malls perceive the IEQ of their building and to what extent do their preferences of individual IEQ factor differ in each building?
3. How do retailers' preferences affect their overall workplace satisfaction?

1.4 Research Objectives

In order to address previously identified need to study the IEQ performances of these shopping malls and to answer the above research questions, this study seeks to:

1. To evaluate the IEQ performances of malls operating on different ventilation modes (mixed-mode and fully AC) in Malaysia and identify any differences in their performances.
2. To determine the users' perception of IEQ and identify significant differences and similarities in perception in each mall and between users.
3. To develop a pattern of the impact of retailers' perception of IEQ factors on their overall workplace satisfaction using the Kano satisfaction model.

1.5 Significance of study

The work presented in this thesis is intended to highlight the importance of IEQ (i.e thermal comfort and IAQ) and users' satisfaction in energy efficient retail building design. The first stage of this study which covers the method involve in identifying and classifying presently operating mixed-mode ventilated malls in Malaysia will provide insights into the basis for the classification of mixed-mode ventilated retail buildings. Existing malls, especially those that rely primarily on air-conditioning will benefit greatly in energy saving and keeping users satisfied if they incorporate passive design strategies as those observed in the mixed-mode ventilated malls. On the other hand, for new malls, results from this study will act as precedents to look up to during the design phase. It will also potentially create awareness among designers and building owners on the growing effort of improving and encouraging energy efficiency in the commercial building sector.

Generally, the results from this study will:

1. Provide a better understanding of users' expectations and concerns for their IEQ and overall satisfaction. This can be a strong marketing strategy for any malls has it will ultimately help in creating malls that are more efficient in resources and also safer and healthier for people and the environment.
2. Inform architects, designers, planners and managers of how different building design features, ventilation strategies, and technologies may affect the building's IEQ, users comfort, and also their satisfaction.

3. Open more opportunities for future IEQ studies to be carried out in hot-humid climatic regions particularly in Malaysia.

1.6 Methodology

In order to achieve the stated objectives, this study was conducted in two phases 1) Identification and classification of mixed-mode ventilated malls in Malaysia, and 2) IEQ performance (See Figure 1.1). This study adopted a quantitative approach with multiple sources of data to achieve the stated objectives. The first phase which aims at exploring different application modes of mixed-mode ventilation strategy in Malaysia's existing shopping malls was achieved through the review of relevant literature, site visitations, and observations. The results from this phase (phase 1) were used as the basis for selecting the two mixed-mode ventilated malls use in this study; these results are presented in Chapter 4.

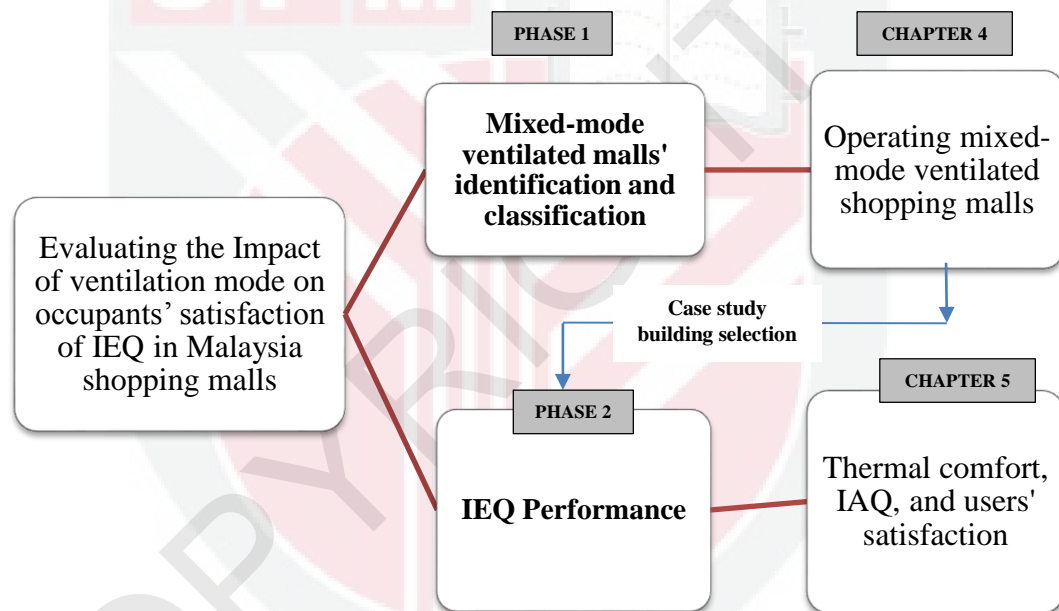


Figure 1.1 : Research phases

The second phase (phase 2) was done to evaluate the IEQ performances and users' satisfaction of the selected case study malls, for this purpose, the ASHRAE Performance Measurement Protocol for Commercial Building was adopted. This involves both objective and subjective measurement of selected IEQ factors. Finally, the Kano satisfaction model was used to group the measured IEQ factors into an order of preference. The results from this phase are presented in Chapter 5. Figure 1.2 represents a summary of the flow of the research method for the second phase of the study. The justification for the overall methodology and subsequent methods chosen for both the study phases are presented in detail in chapter 3.

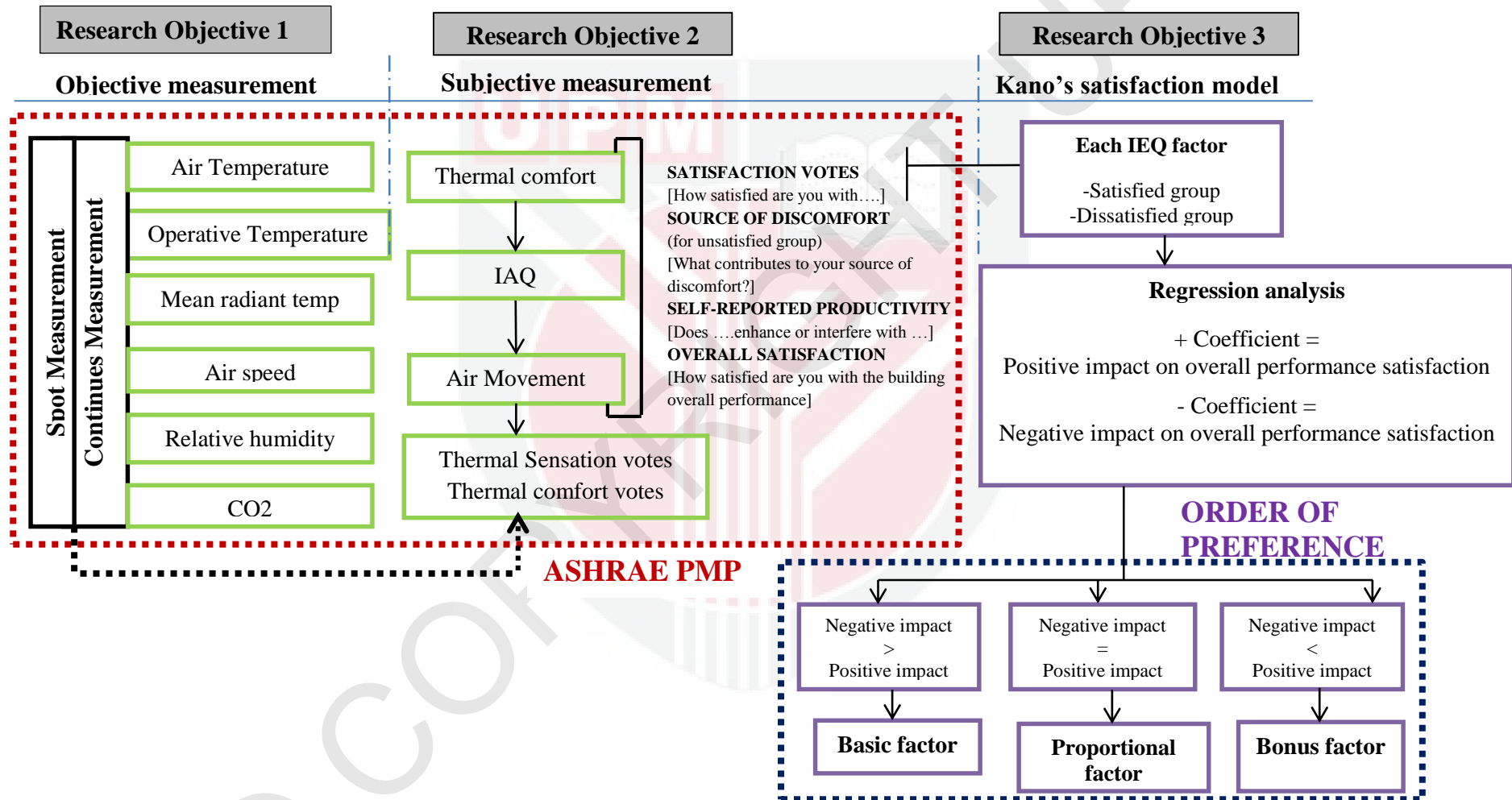


Figure 1.2 : Flow of the research method for the second phase of the study.

1.7 Scope of Study

This study was carried out within the naturally ventilated central spaces of the mixed-mode ventilated case study malls. For the IEQ evaluation, this study only focuses on two selected IEQ parameters which are, thermal comfort and Indoor Air Quality (IAQ) as both factors have been revealed to be of utmost importance to workers (Lai et al., 2009) and also specifically to users of retail buildings (Martellotta et al., 2016). Other indoor environmental factors such as visual and acoustic comforts were not considered in this study. While for the IAQ aspect, the issue of outside air pollutant, especially from traffic, was not taken into consideration in the objective physical measurement. CO₂ was the only IAQ parameter considered in this study as it has been revealed to be used as an indicator of the build-up of other contaminants and the performance of ventilation systems and often taken as an indication of air quality in general (ISO 28802 2012; Ken, 2013). However, indoor air movement was also evaluated as this is relevant since two of the case study malls runs on mixed-mode ventilation and are provided with openings to improve air movement. In addition, air movement is an important element in achieving thermal comfort for occupants of naturally ventilated spaces. Altogether, five environmental factors were considered for the objective measurement (air temperature, operative temperature, relative humidity, air speed, and CO₂ concentration level) and five satisfactory factors (thermal satisfaction, air quality satisfaction, air movement satisfaction, present location/workplace satisfaction, overall building performance satisfaction) for subjective measurements and these were used for the study's analysis.

1.8 Thesis structure

This thesis is organized into six chapters. Chapter 1 introduces the background, the purpose, and objectives of the research. Chapter 2 reviews literature related to this research including previous studies on shopping malls, thermal comfort, indoor air quality, mixed-mode ventilation and its application in shopping malls. Chapter 3 represents the justification for the overall methodology and methods chosen for both study phases. Chapter 4 presents in full account the results, discussions and finally the conclusion of the first phase of the study (Identification and classification of mixed-mode ventilated malls in Malaysia) which aims at exploring different application modes of mixed-mode ventilation strategy in Malaysia's existing shopping malls under the following objectives: 1) to identify shopping malls operating under mixed-mode ventilation, 2) to investigate and identify the specific passive design features of these malls, 3) to classify and group the identified malls under different categories of mixed-mode ventilation strategy. The results presented in this chapter were used as the basis for selecting the two mixed-mode ventilated malls used for the next phase of the study presented in Chapters 5.

Chapter 5 present in full account the results, discussions and finally the conclusion from the second phase of the study (IEQ performance). The IEQ study was aimed at evaluating and analysing the IEQ performances of all the case study malls and the users' satisfaction with regards to the malls' performance. This part aims to fulfill all the research objectives (stated in sub-section 1.4 of this Chapter) which are: 1) To

evaluate the IEQ performances of malls operating on different ventilation modes (mixed-mode and fully AC) in Malaysia and identify any differences in their performances, 2) To determine the users' perception of IEQ and identify significant differences and similarities in perception in each mall and between users, and 3) To develop a pattern of the impact of retailers' perception of IEQ factors on their overall workplace satisfaction using the Kano satisfaction model. Finally, Chapter 6 presents the general conclusion for both the study phases and discusses recommendations for future research.



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