

THE IMPACT OF INDOOR COMFORT ON STUDENTS' EXPERIENTIAL
LEARNING IN ENGINEERING EDUCATION LABORATORIES

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ABSTRACT

There is vast and growing number of scientific literature on the improvement of physical learning environments. However, most of these empirical studies were separately focusing on either architectural or educational issues. This study is conducted with the aim to investigate the impact of indoor comfort, namely thermal, visual and acoustic (TVA) on students' experiential learning in engineering education laboratories (EEL). A case study of EEL has been conducted with investigative post occupancy evaluation (POE) approach: (1) objective measurements were completed with physical data on mean radiant temperature, relative humidity, air velocity, illuminance and sound pressure level, (2) subjective measurements were implemented in the form of questionnaire survey in obtaining quality rating of architectural/space features in the selected EEL, sick building syndrome (SBS) symptoms, and how students perceived indoor (TVA) comfort and satisfaction. A self-reported learning (SRL) was employed for investigating the impact of TVA on students' experiential learning observed from the context of cognitive, affective and psychomotor (CAP) learning domains. Three series of quasi-experimental studies, ranging from low, medium to high levels of physical activities of six centralized air-conditioned EEL located at the Universiti Tun Hussein Onn Malaysia (UTHM) with a total of six non-equivalent groups of students (N=143) were involved. Findings of this study suggested that SBS symptoms experienced among students can be used to investigate particular indoor environmental problems even in newly constructed laboratory buildings. While the quality of architectural features of EEL was rated as good, measured TVA variables were varied and results showed that students' perceived TVA comfort and satisfactions in both control and experimental groups were also different. Based on the integrated SRL, this study discovered that the impact of thermal comfort (i.e. temperature) on students' learning (i.e. cognitive domain) was higher in experimental groups for low and high levels of physical activity.

ABSTRAK

Kebelakangan ini tinjauan saintifik tentang penambahbaikan persekitaran pembelajaran semakin luas dan berkembang. Bagaimanapun, sebahagian besar kajian empirikal tersebut telah memberi tumpuan yang berasingan sama ada isu-isu seni bina atau pendidikan. Penyelidikan ini dijalankan untuk mengkaji kesan keselesaan dalaman iaitu, terma, visual dan akustik (*TVA*) ke atas *experiential learning* pelajar di dalam makmal pendidikan kejuruteraan (*EEL*). Kajian kes telah dijalankan berserta pelaksanaan pendekatan *investigative post occupancy evaluation* (*POE*): (1) pengukuran objektif tentang data fizikal *mean radiant temperature, relative humidity, air velocity, illuminance and sound pressure level*, (2) pengukuran subjektif (tinjauan soal selidik) telah dilaksanakan untuk mengumpul maklumat tentang kualiti ciri-ciri senibina/ruang *EEL*, simptom *sick building syndrome* (*SBS*), dan penerimaan pelajar terhadap keselesaan dan kepuasan *TVA*. *Self-reported learning* (*SRL*) telah digunakan untuk menilai kesan keselesaan *TVA* terhadap *CAP* pelajar. Tiga siri kajian kuasi-eksperimen, meliputi pelbagai tahap aktiviti fizikal iaitu dari rendah, sederhana dan tinggi dari enam makmal *EEL* dengan sistem pendingin hawa berpusat yang terletak di UTHM di samping enam kumpulan pelajar yang tidak setara dengan jumlah keseluruhan responden seramai 143 orang telah terlibat dalam kajian ini. Dapatan kajian ini mencadangkan bahawa simptom *SBS* yang dialami oleh pelajar boleh digunakan untuk mengkaji masalah persekitaran dalaman tertentu walaupun dalam bangunan makmal yang baru dibina. Kualiti ciri-ciri senibina di ruang makmal dinilai sebagai baik, manakala pembolehubah *TVA* yang diukur adalah berbeza serta penerimaan pelajar terhadap keselesaan dan kepuasan *TVA* di dalam kumpulan kawalan dan kumpulan eksperimen juga berbeza. Berdasarkan integrasi *SRL*, kajian ini mendapati bahawa kesan keselesaan termal (iaitu suhu) terhadap pembelajaran pelajar (domain kognitif) adalah lebih tinggi dalam kumpulan eksperimen terutamanya bagi aktiviti fizikal tahap rendah dan tinggi.

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LIST OF SYMBOLS AND ABBREVIATIONS

AC	-	Acoustic Comfort
ASHRAE	-	American Society of Heating Refrigerating and Air Conditioning Engineer, Atlanta
ASS	-	Acoustic Sensation Scale
ASV	-	Acoustic Sensation Vote
AT	-	Air Temperature (for subjective measurement)
AV	-	Air Velocity
CAP	-	Cognitive, Affective and Psychomotor
CLO	-	Clothing Values
EEL	-	Engineering Education Laboratory
EL	-	Experiential Learning
IESNA	-	Illumination Engineering Society of North America
ISO	-	International Standards Organization
PA	-	Physical Activities
RH	-	Relative Humidity
RO	-	Research Objective
RQ	-	Research Question
SRL	-	Self-Reported Learning
TC	-	Thermal Comfort
tr	-	Mean Radiant Temperature (for objective measurement)
TSS	-	Thermal Sensation Scale
TSV	-	Thermal Sensation Vote
TVA	-	Thermal, Visual and Acoustic
VC	-	Visual Comfort
VSS	-	Visual Sensation Scale
VSV	-	Visual Sensation Vote
WHO	-	World Health Organization

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The increasing investments and development of new buildings across university campuses in Malaysia is likely to envisage the importance of physical learning space because it has implications on how the education process takes place. While physical learning spaces are still matters, how students learn is a reflection on the relationship between 'person-environment' that influence and shape students' experiential learning (Kolb, 1984, p. 34-35). According to Kolb and Kolb (2005), 'the enhancement of experiential learning in higher education can be achieved through the creation of learning spaces that promote growth-producing experiences for learners' (Kolb & Kolb, 2005, p. 205). Realizing that learning spaces are very important for learners, there is a need to highlight how it's impacting students' experiential learning.

Undoubtedly, providing comfortable learning spaces is beneficial to the teaching and learning process. For instances, continuous improvement towards comfortable learning spaces is crucial for students' achievement (Earthman, 2002), and it could be one of the avenues for universities to increase the number of students' enrolments (Price, Matzdorf, Smith, & Agahi, 2003). Recently, there is a growing interest in providing comfortable learning spaces with the aim to support teaching and learning activities (Boys, 2011; Kruger & Zannin, 2004), promote sustainability (Hodges, 2005), influence academic performance (Laiqa, Shah, & Khan, 2011; Mendell & Heath, 2005; Tanner, 2008), improve facility management (Douglas, 1996; Tay & Ooi, 2001), give an added value for facility management in higher

education institutions (Kok, Mobach, & Onno, 2011) as well as to improve the effectiveness of educational provision and increase value for money especially from the government's perspective (Amaturanga & Baldry, 2000). Therefore, this study inquires how learning space is impacting students' learning from architectural and educational perspectives.

1.2 Research background

Building occupants are affected by the quality of indoor environments. According to the World Health Organization (WHO), comfortable indoor environments are preferred and have been accepted as an essential element implicating health, general well-being and performance. However, indoor comfort is complicated and is determined not only by a single factor. In design practice, there are four important factors towards comfortable indoor environment, namely indoor air quality, thermal, visual and acoustic environments (Cole, Robinson, Brown, & O'shea, 2008; Dahlan, Jones, Alexander, Salleh, & Alias, 2009b). In a recent survey of how different factors influence occupants comfort in indoor environments, thermal comfort is ranked by occupants as the most influential factor compared to the other factors (Frontczak & Wargocki, 2011). In addition, failure to provide satisfactory and comfortable indoor environments has resulted in discomfort and illness (Cheong & Lau, 2003; Cheong et al., 2003; Kruger & Zannin, 2004).

While the comfort standards are still lacking (Cole et al., 2008), WHO emphasizes that thermal, visual and acoustic (TVA) conditions influence not only the occupants' comfort but also their satisfaction (WHO, 1990). In the context of building system, how occupants perceived indoor comfort and satisfaction have regularly been used as part of the diagnostic approach to measure building performance (Vischer & Fischer, 2005). In relation to thermal comfort, most of commercial and higher education buildings in Malaysia for example, are designed with air conditioning systems, while residential and schools building are designed with natural ventilation systems which are equipped with mechanical system such as ceiling fans towards comfortable thermal environment for the occupants (Abdul Rahman, 2000). In relation to visual comfort, windows offers connection (such as view to the outside) with outdoor environment but it jeopardizes the indoor thermal

environment with problems such as excessive heat gain, glare and thermal discomfort if it is not appropriately designed. Commonly, blinds or curtains are used to solve these problems. In relation to acoustic comfort, a problem occurs when difficulties to control excessive noise particularly from inside the buildings that are equipped with machines or from buildings constructed near to the main streets. Noise coming from machines or traffic may also contribute to occupants' discomfort.

Aside from thermal, visual and acoustic (TVA) environments, other factors may contribute to indoor comfort such as indoor air quality, odor, vibration and electromagnetic environment. While not all these factors are equally important to occupants, published research usually studied the TVA comfort and/or adding other factors to suit contextual comfort needs (Dahlan, 2013; Eckler, 2012; Frontczak et al., 2012; Jessop, Gubby, & Smith, 2011; Kruger & Zannin, 2004; Lan, Wargocki, Wyon, & Lian, 2011; Passero & Zannin, 2012; Yau, Chew, & Saifullah, 2012; Zannin & Marcon, 2007). Undoubtedly, a complex interaction between occupants and indoor environment must be well understood to achieve indoor comfort (Bluyssen, 2010). Hence, this study is conducted by focussing on TVA comforts as these variables are more familiar among building occupants in Malaysia context (Dahlan et al., 2009b; Dahlan, 2013).

Why this study is conducted in engineering education laboratories: Studies of indoor comfort have been conducted in various types of buildings. Most of scholars of indoor environmental comfort focused on residential properties and hostels (Dahlan, Jones, Alexander, Salleh, & Alias, 2009), health care facilities (Fransson, Västfjäll, & Skoog, 2007), office buildings (Choi, Aziz, & Loftness, 2010; Huang, Zhu, Ouyang, & Cao, 2012), classrooms both in secondary and tertiary institutions (Corgnati, Filippi, & Viazzo, 2007; Farooq & Brown, 2009; Puteh, Ibrahim, Adnan, Che'Ahmad, & Noh, 2012; Yatim, Zain, Darus, & Ismail, 2011) as well as lecture theatres (Cheong et al., 2003; Lee et al., 2012). Little is known on how students' perceived indoor comfort in laboratory spaces (Mishra & Ramgopal, 2014). Moreover, laboratories in higher education institutions simulate a real workplace setting for engineering students, where this place is usually exposed to thermal conditions, machines and equipment (Md Amin, Razzaly, & Akasah, 2012). In addition, indoor environment issue such as thermal discomfort was found to lead to sick building syndrome (SBS) symptoms (Lan et al., 2011) even in newly

constructed laboratory buildings (Md Amin, Akasah, & Razzaly, 2014). Therefore, this research is needed to investigate the interaction between occupants (students) and indoor environment (TVA comfort) of learning space (laboratory) and how it is impacting students' learning. This study also reflects the principle of 'learning by doing' through laboratory sessions, which has been well implemented especially in engineering education.

1.3 Problem statement

Providing physical learning environment such as comfortable learning spaces is beneficial to the teaching and learning process. Scholars provide evidences that the conditions of learning spaces influence positively or adversely on students' behaviour (Cash, 1993), attitudes (Weinstein, 1979), preferences and comfort (Dahlan et al., 2009b; Weinstein & Pinciotti, 1988), personality development (Roberts & Robins, 2004) and learning performances such as reading, calculating, understanding and typing (Lee et al., 2012). While there is a lack of concrete evidence on the impact of learning spaces' conditions on students' learning performance (Mishra & Ramgopal, 2015), it is claimed that learning spaces of higher education institutions in Malaysia, are defective environments particularly for engineering education (Mohd Tahir, Goh Abdullah, Usman, & Surat, 2009).

Published researches show that works have been done on the improvement of learning spaces (Earthman, 2002; Uline, Tschannen-Moran, & Wolsey, 2009). However, these studies have separately focused on either architectural or educational issues. The relationship between learning space and learning still remains unclear and considered as an "under-research topic" (Temple, 2008). Moreover, there is a lack of specific, standard and integrated methodology in assessing the conditions of learning spaces and its association with students' learning. An inconclusive assessment from architectural and educational perspectives calls for more studies and further attention to researchers to fill the research gaps. This study is therefore conducted to investigate the physical conditions of learning space by evaluating thermal, visual and acoustic (TVA) comforts in a laboratory setting and its impact on students' experiential learning. This study only focus on TVA variables because occupants in Malaysia were more familiar with the TVA environments (Dahlan et

al., 2009b; Dahlan, 2013). In particular, the study is conducted under actual setting of engineering education laboratories which involves case study, post occupancy evaluation (POE) along with objective and subjective measurements, while self-reported learning (SRL) was integrated to investigate the impact of TVA comfort on students' experiential learning, which is observed from the context of cognitive, affective and psychomotor (CAP) learning domains.

1.4 Research objectives

This study aims to investigate the impact of thermal, visual and acoustic (TVA) comfort of engineering education laboratories on students' experiential learning, observed in the contexts of the cognitive, affective and psychomotor (CAP) learning domains. Three research objectives were set in order to achieve the aim of this study and outlines as follow:

- (i) to evaluate how students rate the quality of architectural/space features in engineering education laboratories,
- (ii) to evaluate the thermal, visual and acoustic comfort in engineering education laboratories across three levels of physical activity, and
- (iii) to investigate the impact of thermal, visual and acoustic comfort on students' cognitive, affective and psychomotor learning across three levels of physical activity.

1.5 Research questions

Research questions (RQ) were formulated based on the research objectives. From RQ1.1 to RQ1.5 are related to the first research objective, and RQ2.1 to RQ2.6 are related to the second research objective, while RQ3.1 to RQ3.4 are related to the third research objective. The research questions are outlined as follows:

Research Question 1 (RQ1)

RQ1.1: What are the conditions of the architectural/ space features of the selected engineering education laboratories?

RQ1.2: Do students experience sick building syndrome (SBS) symptoms?

- RQ1.3:** Are students in the control groups more likely to experience SBS compared to students in the experiment groups?
- RQ1.4:** How do students rate the quality of space/ architectural features in engineering education laboratories?
- RQ1.5:** Do control groups and experiment groups differ in terms of total quality rating of engineering education laboratories for low, medium and high physical activities?

Research Question 2 (RQ2)

- RQ2.1:** What are the thermal, visual and acoustic conditions of engineering education laboratories?
- RQ2.2:** How do students rate their thermal, visual and acoustic comfort in all engineering education laboratories?
- RQ2.3:** Is there a difference in thermal, visual and acoustic comfort between experimental groups?
- RQ2.4:** How satisfied are the students in the thermal, visual and acoustic conditions between control groups and experiment groups, across three levels of physical activity?
- RQ2.5:** Is there a significant difference in the mean overall thermal, visual and acoustic satisfaction scores of engineering education laboratories between male and female students, across three levels of physical activity?
- RQ2.6:** Is there a significant difference in the mean thermal, visual and acoustic satisfaction scores in engineering education laboratories between control groups and experimental groups?

Research Question 3 (RQ3)

- RQ3.1:** Is there a difference in mean score for the impacts of thermal comfort on students' CAP learning domains between control groups and experiment groups?
- RQ3.2:** Is there a difference in mean score for the impacts of visual comfort on students' cognitive, affective and psychomotor learning domains between control groups and experiment groups?

- RQ3.3:** Is there a difference in mean score for the impacts of acoustic comfort on students' cognitive, affective and psychomotor learning domains between control groups and experiment groups?
- RQ3.4:** Is there a difference in the impact of thermal, visual and acoustic comfort on students' cognitive, affective and psychomotor learning domains across low, medium and high physical activities?

1.6 Theoretical and conceptual frameworks

A theoretical framework is practically and commonly used by educational researchers to refer to a structure for guiding, supporting or enclosing their research studies based on a theory or more. In the context of this study, experiential learning theory refers learning as a holistic process of adaptation to the world resulting not only in cognitive, but also taking into account of the total person including mind, emotion, spirit and behavior in its natural context (Kolb, 1984). Kolb states that learning process is viewed from experiential perspective: (1) process of adaptation, (2) process of transformation where knowledge is continuously created and recreated, and (3) learning transform experience in both objective (environmental) and subjective (personal) forms. In relation to the third perspective, Kolb (1984) emphasizes that the interaction between objective and subjective forms are inseparable from each other. Objective form can be explained such as human's external experience (e.g. treating environmental stimuli as independent variables that effect on dependent response characteristics), while subjective form is human's internal experience (e.g. the experience of joy and happiness) (Kolb, 1984, pg. 35).

In the context of physical learning spaces, Kolb and Kolb (2005) highlights that "the enhancement of experiential learning in higher education can be achieved through the creation of learning spaces that promote growth-producing experiences for learners" (Kolb & Kolb, 2005, pg. 205). Based on this concept of learning spaces introduced by Kolb and Kolb (2005), a conceptual framework is formed to guide the researcher in investigating the actual conditions of learning spaces (this reflects the objective form of external experience), how students experienced their learning spaces (this envisages how they perceived the indoor environments of learning

spaces) which finally influence their experiential learning (this reflects the subjective form of internal experience). In other words, the actual conditions of thermal, visual and acoustic were the independent variables, how students' perceived indoor environment thermally, visually and acoustically were the mediator variables, while cognitive, affective and psychomotor learning domains were the dependent variables. The relationship between the concept of learning spaces and studied variables are summarized in Figure 1.6-1 below:

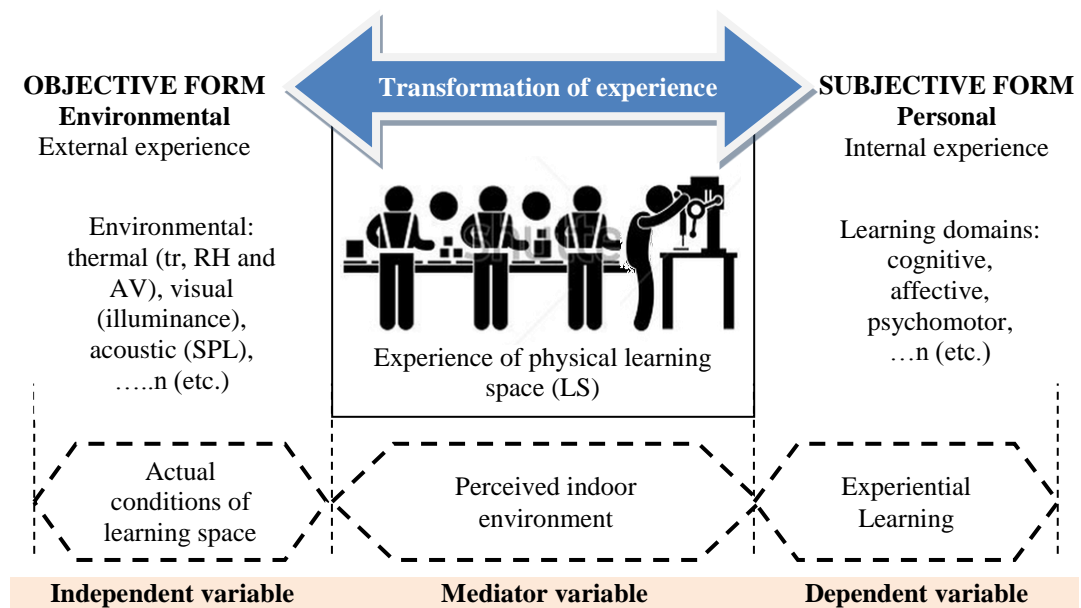


Figure 1.6-1: Conceptual research framework. Adapted from (Kolb, 1984)

1.7 Operational definitions

The findings in this study are reviewed based on the following operational definitions:

(i) Acoustic comfort

Acoustic comfort can be defined as having the right level and quality of sound to use the space as intended. Unwanted sound is named noise where there are two sources of it: firstly, internal noise that produced by machines or laboratories equipment, as well as noise from occupants (such as talking). Secondly, external noise that sourced from outside of the building such as noise produced by vehicles. This study only

focuses on sound pressure level (SPL) for objective measurement while sensation and satisfaction of SPL, internal and external sources of noise are used for subjective measurement of acoustic comfort.

(ii) Control group

Control group refers to a set of subjects, non-randomly selected and randomly assigned as a group/ groups without treating the environmental (thermal, visual and acoustic) variables as independent variables. Three non-randomly selected laboratories for the case study were EEL1 (Auto-CAD Laboratory), EEL3 (Electronic Laboratory), EEL5 (Highway, Traffic and Transportation Engineering lab), with occupants who used the selected laboratories during the data collection.

(iii) Engineering education laboratories (EEL)

This term is referring to the physical learning spaces that support ‘learning by doing’ activities in UTHM laboratories. There were four selected EEL from the Faculty of Technical and Vocational Education and two selected EEL from the Faculty of Civil and Environmental Engineering.

(iv) Experiential learning

In this study, experiential is defined as the person-environment relationship, where the interaction between objective and subjective forms is inseparable from each other (Kolb, 1984). In other words, experiential learning is a resemblance of: (1) human’s external experience e.g. indoor environmental factors such as thermal, visual and acoustic (TVA) conditions, (2) human’s internal experience e.g. learning (cognitive, affective, psychomotor) and the experience of comfort and satisfaction.

(v) Experiment group

Experimental group refers to a set of subjects, non-randomly selected and randomly assigned as a group/ groups that treated the environmental (thermal, visual and acoustic) variables as independent variables. These variables were manipulated artificially by the experimenter to determine its impact on dependent variables (students’ cognitive, affective and psychomotor, CAP based on students’ self-reported learning). The selected laboratories were EEL2 (Graphic Engineering Laboratory), EEL4 (Electric Technology Laboratory) and EEL6 (Geo-tech

Laboratory) with the student occupants who used these laboratories during the data collection.

(vi) Indoor comfort

This term is referring to the comfort/discomfort conditions of enclosed learning spaces. There are several factors contributing to indoor comfort, firstly the environmental factors such as indoor air quality (for examples volatile organic compounds, formaldehyde and other chemicals), thermal environment (mean radiant temperature, relative humidity, air velocity/movement) visual environment (for examples lighting level or illuminance, glare), acoustic environment (for examples noise or sound pressure level), ventilation, odours and colours. Secondly, personal factors (gender, levels of physical activity and preferences). Some other factors may exist. However, due to ethical, practical and instrumentation constraints, this study only consider environmental factors namely thermal (mean radiant temperature, relative humidity and air velocity/movement), visual (illuminance) and acoustic (sound pressure level) variables while personal factor taken is the levels of physical activities. In this study, indoor comfort is measured through objective and subjective measurements.

(vii) Objective and subjective measurements

The purpose of objective measurements is to measure physical or actual conditions of variables during data collection. Objective measurement refers to the physical measurement of thermal, visual and acoustic variables using appropriate instruments. Three types of instruments were used in this study. Firstly, two Thermal Comfort Stations Babuc A was used to measure thermal variables. Secondly, 4 in 1 Meter Kit Lutron Model L800 was used to measure visual variable and finally Sound Pressure level (SPL) Meter to measure acoustic variable.

On the other hand, the purpose of subjective measurement is to obtain how students' perceived indoor environments (thermal, visual and acoustic comfort) of their engineering education laboratories. Subjective measurement is conducted by distributing questionnaire survey forms (instrument) to those students who used the laboratories. Two scales were used namely thermal, visual and acoustic (TVA) sensation votes, and TVA satisfaction votes. Both measurements were conducted in all selected engineering education laboratories.

(viii) Physical activity

This term refer to different activities based on three characteristics namely thermal, visual and acoustic environments. For thermal comfort, level of physical activities was based on ASHRAE (2004), followed by visual comfort which was based on visual tasks activities as recommended by Illumination Engineering Society of Northern America (IESNA) (Rea, 2000); while acoustic comfort was based on noise level such highlighted by the US Department of Health and Human Service (1998). (See Table 3.3-2 for more details, pg. 63).

(ix) Self-reported learning (SRL)

Self-reported learning (SRL) is a new approach used in this study to allow students to self- report on how indoor comforts impact their learning (cognitive, affective and psychomotor) whilst performing lab tasks in controllable/ uncontrollable indoor conditions of centralized air-conditioned engineering education laboratories. The SRL is integrated in the questionnaire survey as part of subjective measurement.

(x) Thermal comfort

According to ASHRAE Standard 55 thermal comfort is defined as “a state of mind which expresses satisfaction with the thermal environment”. There are several factors influencing thermal comfort such as metabolic rate, clothing insulation, air temperature, mean radiant temperature (t_r), relative humidity (RH) and air velocity (AV). This study only focused on t_r , RH and AV for objective measurements while sensation and satisfaction of thermal environment were used for subjective measurements of thermal comfort.

(xi) Visual comfort

Visual comfort can be defined as the subjective impression of comfort caused by visual stimuli such as lighting level, internal and external glare under particular viewing conditions. Scholars commonly use the terms of visual discomfort to elaborate the degree of discomfort which raise health issues such as eye strain, watery eyes and headache. This study only focused on lighting levels or illuminances for objective measurements while sensation and satisfaction of lit environment, internal and external glare was used for subjective measurements of visual comfort.

1.8 Significance of the study

Learning by doing in laboratories in engineering education programs has been practiced in Malaysian higher education institutions and especially at the Universiti Tun Hussein Onn Malaysia where engineering education is the core business. Very little study of indoor environmental parameters in laboratories setting is been conducted, hence motivate the researcher to investigate further how thermal, visual and acoustic comfort may impacts on students' experiential learning. The significance of this study is outlined below:

- (i) this research is important to better understand the variables in assessing indoor environmental comfort of learning space such as engineering education laboratory while maintaining students' satisfaction by implementing investigative post occupancy evaluation approach, in the context of Malaysia climate,
- (ii) the findings of this study provide evidence-based documentation of the interaction between indoor environment comfort of engineering education laboratories and its impact on students' cognitive, psychomotor and affective learning domains, which was observed from experiential learning theory (Kolb, 1984) perspective,
- (iii) this study is testing the independent variables (thermal, visual and acoustic comfort) and discovering its impact on students' experiential learning through investigative post occupancy evaluation (POE) approach along with the integration of self-reported learning,
- (iv) this study is in line with searching for a comfortably built learning environments which were previously studied but separated to either on architectural or educational issues. It should also be beneficial to higher education administrators' decisions upon the improvement of future learning facilities and hence support learning activities,
- (v) finally, this study is designed to highlight the importance of occupant's feedback, in which students are the building users who perform daily routines under actual conditions of their EEL. Any direct/indirect impact of building conditions may significantly influence their EL in higher education.

This study is different from other research because it provides a documentation and reliable data of indoor environmental conditions particularly in the context of Malaysia with its possible influences or contributions to experiential learning. This research is also important to higher education institutions, to make considerations on students' satisfaction and how they perceived indoor comfort towards the enhancement of experiential learning of the learning spaces, while maintaining existing and new buildings e.g. engineering education laboratories.

1.9 Scope of the research

The scope of the research is explained as follows:

- (i) It should be noted that there are several variables contribute to indoor comfort. However, the studied environmental factors only focused on thermal, visual and acoustic variables, while the personal factor only focused on levels of physical activities range from low, medium to high.
- (ii) This study investigated the impact of thermal, visual and acoustic comfort (independent variables) of centralize air-conditioned engineering education laboratories on students' experiential learning, which observed from the context of cognitive, affective and psychomotor learning domains (dependent variables). It does not cover other variables such as the indoor air quality, odour etc.
- (iii) The case study for engineering education laboratories ranges from low, medium and high levels of physical activity. The researcher attempts to consider engineering education laboratories with higher level of physical activity such as laboratories that exposed to extreme thermal environment, which are available in the Faculty of Mechanical and Manufacturing Engineering, UTHM (example to name here). However, due to practical constraints (funding, instruments, laboratories' schedule and time) only six engineering education laboratories were selected for the case study.
- (iv) The space/architectural features of engineering education laboratories were investigated to obtain students perception on the quality of their laboratories.

- (v) Investigative post occupancy evaluation (POE) approach is used to achieve the objectives of the study. The POE comprised objective and subjective measurements on the thermal, visual and acoustic variables, using appropriate instruments such as Thermal Comfort Station, lux meter and sound pressure level (SPL) meter and questionnaire survey forms to obtain the data.
- (vi) This study is based on the proposed self-reported learning (SRL) expressed by undergraduate and postgraduate students who studied at the Faculty of Technical and Vocational Education, and the Faculty of Civil and Environmental Engineering, UTHM. These faculties are preparing students to become professional and technical teachers/lectures and professional engineers, while healthy and comfortable indoor environments might enhance their experiential learning.

1.10 Thesis outline

This chapter outlines the introduction to the thesis, setting out the reasons why this study is currently being conducted and the focus of the researcher's attention. Then the thesis is organized into a further four chapters. A brief outline of each chapter is described as follows:

Chapter 2: Literature Review presents a review of the current literature on building-related factors affecting occupants' comfort, followed by indoor environmental conditions such as factors influencing thermal, visual and acoustic comfort. Theoretical perspective on learning is also included; learning domains (cognitive, affective and psychomotor), constructivist theory on learning, experiential learning theory (including experiential learning spaces, and learning space from different perspectives). A concise summary is given at the end of this chapter.

Chapter 3: Research Methodology chapter presents the methodological approach adopted in the study. Fundamentally, the research design and sampling technique are given in this chapter. It also provides the methods of data collections and instruments including the inventory checklist, instrumentation testing as well as questionnaire (validity and reliability). Data analysis is also included.

Chapter 4: Research Findings describes each case study for engineering education laboratories conducted. This chapter also presents comprises of an empirical study that aim to investigate the impact of thermal, visual and acoustic (TVA) comfort on students' cognitive, affective and psychomotor in engineering education laboratories. Findings of this study are organized according to research questions. An overview of the key research findings is given at the end this chapter.

Chapter 5: Research Discussions, Conclusions and Recommendations summarize the key findings of the research and discuss it based on the research context. This chapter also highlights the theoretical and practical contributions of the thesis, while the limitations of the research are outlined. Suggestions for futures research are also offered and conclusion of the findings is given at the end of the chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter describes relevant body of knowledge encompasses architecture, indoor environmental comfort and learning fields. Over 100 relevant scientific sources from 1980 to 2014 were referred solely to build good understanding in the area of interest. Firstly, the literature review is made on building variables that affecting occupants' comfort. Secondly, important aspects of indoor environmental comfort particularly thermal, visual and acoustic (TVA) variables were extensively reviewed. Finally, relevant and recent literatures were based on theoretical perspective on learning, focusing at constructivist theory of learning, experiential learning theory of Kolb, experiential learning space emphasized by Kolb and learning space from different perspectives is also given in this chapter. The conclusion is drawn at the end of the chapter. Table 2.1-1 shows the body of the literature review with three main sections summarized by the researcher.

Table 2.1-1: The body of the literature review

Section 2.2	Section 2.3	Section 2.4
Building design	Indoor environmental conditions	Theoretical perspective on learning
<ul style="list-style-type: none"> • Architecture/ space characteristics • Building design • Appearance and colour • Window design • Post occupancy evaluation (POE) 	<ul style="list-style-type: none"> • TVA standards and requirement • TVA variables and measurement • How indoor environment affects human health and comfort 	<ul style="list-style-type: none"> • Taxonomy of learning • Constructivist theory on learning • Kolb's experiential learning theory • Learning space in experiential learning • Learning space from different perspectives

2.2 Architecture and evaluation of building

This section is divided into several subsections which emphasize considerations of building design in searching what architectural/space features may affect occupant comfort. Firstly (Section 2.2.1), the role of architectural/space characteristics is discussed because it contribute to occupants' comfort. Secondly, Post Occupancy Evaluation (POE) as part of main component of architecture is included in Section 2.2.2. Finally, a summary of this sub-section is given in Section 2.2.3.

2.2.1 Architectural/space features that influence occupant comfort

Building design refers to wide aspects of architecture, engineering and technical aspects of the design, while a well-designed building enhances human lives, communities and culture (Baird, 2010b) in which the design practically meet specific requirements, such as residential, commercial and institutional or educational buildings. In educational buildings, the design concept for engineering education laboratory (EEL) is claimed to be emerging from basic requirements for a particular need to the design laboratory environments that are responsive to present needs and capable of accommodating future demands (Watch, 2012).

Why architectural/space feature is important for user comfort? In recent years, environmental sustainability is one of the main driven factors in designing better building for future needs (Watch, 2012). Laboratories consume a lot of energy for instance laboratories can contain large numbers of containment, exhaust devices and heat-generating equipment while its design must meet energy use, health and safety codes. While opportunities for improving efficiencies and meeting health and safety standards, design of laboratory buildings should aim for sustainability, for examples: increased energy efficiency, reduction or elimination of harmful substances and waste, efficient use of materials and resources, and recycling and increased use of products with recycled content (Watch, 2012). Moreover, the improvements to the interior and exterior environments of laboratory buildings are also leading to increased comfort, satisfaction and productivity (Binol, 2008; Smith & Pitt, 2011a).

Besides sustainability, architectural/space features influence occupants' comfort from the contexts of operational (such as space needs and furniture layout), environmental (such as temperature, lighting, noise and overall comfort), personal control (of heating, cooling, ventilation, lighting and noise) and satisfaction aspects (such as design, needs, productivity, and health) (Baird, 2010b). Space feature which is also named interior layout has direct association with occupant comfort and convenience (Merrell, Schkufza, Li, Agrawala, & Koltun, 2011; Mohammad, Ahmad, Mursib, Roshan, & Torabi, 2014). In the following sub-section, particular focus is given for operational aspect particularly the laboratory design, appearance and colours of space and window design.

2.2.1.1 Space design for laboratory

Collaborative research on laboratories can be supported by architects and design teams through several design implementations (Watch, 2012). Firstly, creating flexible engineering systems and casework that encourages research teams to alter their spaces to meet their needs. Secondly, designing space and write-up areas as places where people can work in teams. Thirdly, creating "research centres" that are team-based. Fourthly, encouragement of the research teams can be made by creating all the space necessary for research team members to operate properly near each other, and minimizing or eliminating spaces that are identified with a particular department. Fifthly, establishing clearly defined circulation patterns, and finally providing interior glazing to allow people to see one another. In other words, space layout of the laboratories should support students' activities comfortably and adequately.

On the other hand, furniture layout is one of important elements in space planning to meet functional and visual criteria. The functional criteria reflects how well the layout supports the occupant activities that take place in the space (such as conversation, or physical activities and movement while the visual criteria concern the perception of the layout as a visual composition (Merrell et al., 2011). Consequently, laboratories should have proper furniture and engineering services to support for instance students' research activities.

2.2.1.2 Appearance and colour

Appearance within space refers to surface reflectance and finishing materials usually in colour and percentage of reflectance. Lighting especially when daylight reflected on interior surfaces, surface with light colour reduce the luminance contrast between windows and surrounding surfaces, thus the amount of reflected light into the space will increase. Basically, reflectance values are ranks according to the location of the surfaces. For example, surface reflectance on ceilings is between 70-80%, while on wall is range between 40-80% and lower percentage can be found on the floor (20-40%). Table 2.2-1 and give recommended surface reflectance for ceilings, walls and floors (Rea, 2000).

Table 2.2-1: Different surfaces, colours and recommended reflectance factors

Surfaces	Recommended reflectance (%)	Colour	Reflectance (%)
Ceilings	70 - 80	White	80 - 90
Walls	40 - 80	Pale yellow & rose	80
Floors	20 - 40	Pale beige & lilac	70
		Pale blue & green	70 - 75
		Mustard yellow	35
		Medium brown	25
		Medium blue & green	20 - 30
		Black	10

Table 2.2-1 indicates values for surfaces finishing reflectance for different colours respectively. In other words, the whiter the colour the higher the reflectance factor will be which is given in percentage values. Vice versa, the darker the colour, the percentage of reflectance factors is lower. For instance, white is 80% to 90% reflectance, mustard yellow is 35% and black is 10% (Rea, 2000).

Why appearance and colour are very important in building design: Environmental colours have effects on human sensation. According to Smith (2000), some basic principles is referred in designing colour scheme especially for lit environment. Firstly, bright colours create pleasant environment which is stimulating, while dark colour produce the opposite effect which can lead to depression. Secondly, warm colours are commonly associated with excitement. Thirdly, cold colours have calming or soothing effects, while the sensation of colour of an object is much influenced by the object's background colour and lighting

sources. Finally, different colours can be used in balancing the effects of hot/cold physical environments.

In line with lighting requirement, colour appearance of light source should be taken into account. The term correlated colour temperature (CCT) is expressed in Kelvin (K). To satisfying the needs of the task, the colour appearance and colour rendering properties of the lamps should suit the type of interior; in particular, the type of activity, the illuminance and the colour scheme employed. For example, the higher the CCT the cooler the appearance of the source, the reddish-yellow flame of a candle is about 1900K, the ordinary incandescent lamp about 2800K, and cool bluish white source of sky daylight over 6500K. In other words, the higher the colour temperature, the cooler would be the appearance of a lit space. Table 2.2-2 presents different groups of colour, appearance and correlated colour temperature.

Table 2.2-2: Colour appearance and correlated colour temperature

Color appearance group	Colour appearance	Correlated color temperature, K
1	Warm	<3300
2	Intermediate	3300≤5300
3	Cool	>5300

Fundamentally, indoor colour had effects on mood and cognitive performance, for example violet interiors were more positively perceived by occupants when compared to yellow (Yildirim, Akalin-Baskaya, & Hidayetoglu, 2007). Recent study emphasizes that an appropriate colour may contribute to longer span of concentration in learning, improving performance and influence positive emotion and perception to its surrounding (Jalil, Yunus, & Said, 2012). Moreover, the study concluded that interior colour effects student's alertness or attention which later supports their self-efficiency and motivation in learning process. Hence, consideration of appearance and colour of interior space will be considered in this study as part of the important variable for architectural characteristic quality rating.

2.2.1.3 Window

Phillips (2004) has classified windows into two main types. The first type is windows on the side of buildings, and the second is the opening light on the roof or

roof lights. Both windows and openings on buildings allow daylight to come through due to the nature of glass or transparent material (Phillips, 2004).

Basic window strategies have been highlighted (Lechner, 2009). The placement of windows is very important as this structure is the primary source of daylighting in a space. Furthermore, window size, glazing, and orientation affect the distribution of daylighting. Figure 2.2-1 illustrates the distribution of daylight in a space with different window placements. The illumination level rapidly drops at the edge of the room that is the farthest from the window (above). The distribution of daylight will look better if the placement of window is higher on the wall (below). Figure 2.2-2 illustrates illumination contours with different types of window size. According to Lechner (2009), uniformity of daylight in a space is better from wide horizontally window (left) rather than narrow vertically window (right).

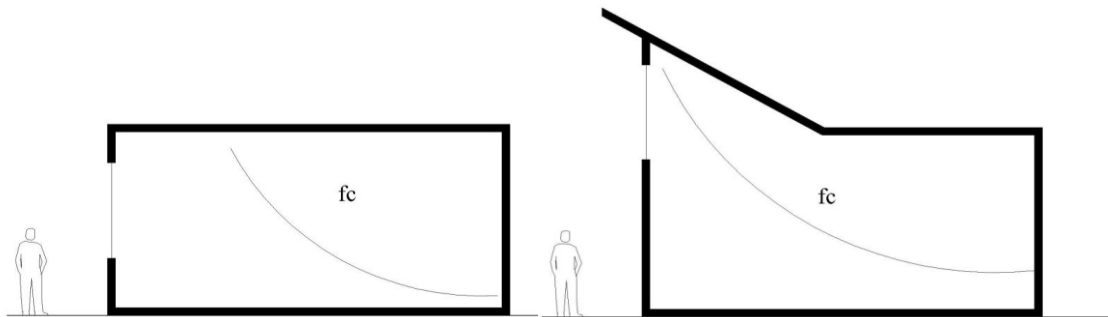


Figure 2.2-1: Daylight penetration increase with window height (Lechner, 2009)

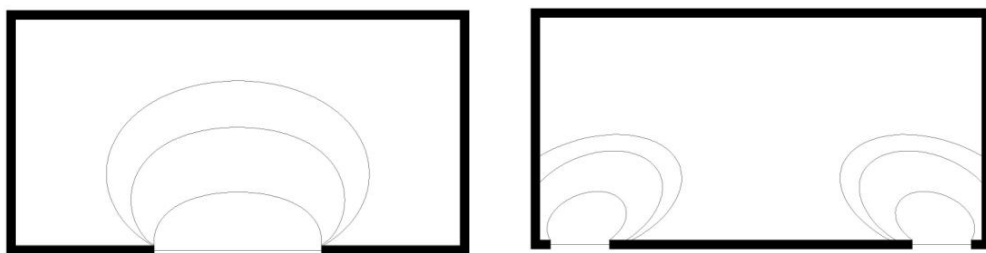


Figure 2.2-2: Distribution of daylight in space improved by allowing daylighting from more than one aperture (Lechner, 2009)

Windows can bring both positive and negative experiences: access to view and daylight, but also glare and thermal discomfort. The wider the window design, the more consideration should be taken to thermal environment especially in the tropics (Aries, Veitch, & Newsham, 2010) . Evidently, thermal discomfort which is associated with poor window design may influence indoor comfort (Dahlan et al., 2009a).

On the other hand, a study has been conducted to explore the relationship between personal factors (such as gender and seasonality of mood shifts), buildings (such as view type, view quality, window distance, and social density), and perceived environmental conditions (such as light quality and office impression) and physical and psychological discomfort, sleep quality, and environmental utility (Aries et al., 2010). Aries et.al found that attractive window views are beneficial to building occupants by reducing discomfort. However, being nearer to a window decreased the lighting quality and thus can result in thermal and glare problems (environmental utility). Moreover, Aries concluded that by reducing discomfort at work can improve sleep quality, where its physical conditions may results in improved quality of life (Aries et al., 2010).

Overall, occupants' feedback is very important to the design team as Baird (2010) highlighted that improving practices in architectural and technical aspects of building is motivated by lessons learnt from previous building design. In other words, building performance can be examined and improved based on the users' or occupants' point of view. In order to obtain users' or occupants' feedback in relation to building design, appropriate methods should be implemented such as Post Occupancy Evaluation (POE) in the following sub-section.

2.2.2 Post Occupancy Evaluation (POE)

Post Occupancy Evaluation (POE) is the “examination of the effectiveness for human users of occupied design environments” as defined by Zimring and Reizenstein (Zimring & Rezeinstain, 1980). Generally, POE is to assess occupants' satisfaction in relation to a specific space (Zimmerman & Martin, 2001). POE was initiated in the early 1960s through architectural practice research which lead to the publication of Part M: feedback, of the RIBA (Royal Institute of British Architects).

RIBA proposed a holistic process and describes the activities from praising the client's requirements through to post construction evaluation.

POE assesses how well buildings match users' needs and it also identifies ways to improve building design, performance and fitness for its purpose. It involves the systematic evaluation of opinions on the buildings in use, from the perspective of the people who use them (Turpin-Brooks & Viccars, 2006). Several studies have been completed with a particular focus of POE of environmental aspects of educational buildings (Fianchini, 2007; Geertshuis, Holmes, Geertshuis, Clancy, & Bristol, 2002; Hassanain, 2011; McGrath & Horton, 2011).

Fundamentally, POE consists of three levels of assessments. First is the indicative level, followed by investigative and diagnostic levels. Each level has different purposes with various methodologies to approach and implement POE (Turpin-Brooks & Viccars, 2006). The indicative level only provides building owners/managers with simple information and general overview regarding the daily operation of their buildings. Table 2.2-3 shows three levels of POE.

Table 2.2-3: Choosing the right level of POE (Turpin-Brooks & Viccars, 2006)

Level of POE	Aims	Methods	Timescale	Comments
Indicative	Assessment by experienced personnel to highlight POE issues	Walk through evaluation. Structured interviews? Group meetings with end-users? General inspection of building performance? Archival document evaluations?	Short inspection period	Quick, simple, not too intrusive/ disruptive to daily operation of building. Judgemental and overview only
Investigative	In-depth study of buildings' performance and solution to problems	Survey questionnaires and interviews. Results are compared with similar facilities. Report appropriate solutions to problems	From one week to several months	In-depth/ useful results. Can be intrusive/ time consuming, depending on the number of personnel involved
Diagnostic	Show up any deficiencies (to rectify) and collect data for future design of similar facility	Sophisticated data gathering and analysis techniques Questionnaires, surveys, interviews and physical measurement	From several months to several years	Greater value in usability of results. More time consuming.

The investigative level however, focuses in-depth on particular problems and may consume longer duration to complete the assessment. Moreover, the investigative level provides useful results where comparison can be made with other similar buildings. On the other hand, the diagnostic level can be the best option if building owners have no financial, time and hustle constraints. Among these three levels of POE, the investigative level is most suited to enable some comparison and achieve the objective of this study (Turpin-Brooks & Viccars, 2006).

How POE and indoor environmental research are interrelated: For example in thermal comfort research, two types of methodical frameworks can be implemented in any type of buildings (Nicol & Roaf, 2005). The first is through laboratory study, where objective measurements (to physically measure i.e. temperature) and subjective measurements (to obtain occupants' perception) are performed in determining thermal comfort. All relevant variables (air temperature, humidity, air velocity) are measured in an advanced experimental control. The field study of thermal comfort uses the same approach, but the subjects are in their own familiar environment and their clothing according to their preferences. It should be noted that both the field study of thermal comfort and post-occupancy evaluation happen in the real built environment.

Practically, in the field study of thermal comfort, the occupant reports their own feelings during the administration of the survey through subjective response (i.e. "I feel cold now"). Nevertheless, POE interprets the occupants' daily life within the same environment in which the workspace environment affects occupants' performance. POE can be used to improve occupants' work environment, functional comfort, productivity, and to make the physical environment into a tool for work (Gou & Siu-Yu Lau, 2013). Evidently, indoor comfort not only focuses on thermal environment, it also comprises of other aspects such as indoor air quality, visual environment and acoustic environment. Cole summarized the approach to comfort provisioning in building design practice (Cole et al., 2008). Figure 2.2-3 illustrates the design team (architect, mechanical and electrical engineers) contribute to the effectiveness of building design and its systems.

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