



THERMAL COMFORT ANALYSIS OF OFFICE SPACES
AT GOMBAK LIBRARY, INTERNATIONAL ISLAMIC
UNIVERSITY MALAYSIA.

BY

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ABSTRACT

The thermal comfort of a person is the condition of mind that expresses satisfaction with the thermal environment that plays a significant role in determining building occupant performance, productivity and energy efficiency. The ASHRAE Standard 55-2013 has opined that the maintenance of an indoor environment that is thermally acceptable by over 80% of the occupants will result in optimizing indoor space with the overall benefit to occupants' well-being, productivity and economic benefits. Therefore, the International Islamic University, Malaysia (IIUM) will be aligned on the path of achieving the requirements of Malaysia's green building index (GBI) when the library office space meets the conditions of thermal comfort. The study aims to investigate the effect of indoor environmental conditions on the thermal comfort of the staff of the IIUM library. The methodology adopted for the survey involves the concurrent measurement of environmental and personal variables through observations and user questionnaire survey respectively. The environmental variables include air temperature ($^{\circ}\text{C}$), relative humidity (%), air velocity (m/s) and radiant temperature ($^{\circ}\text{C}$) while the personal variables are metabolic rate (met) and clothing (clo). The data were collected from 29th to 31st of July 2015 (3 days) to coincide with the driest month of the monsoon season in Malaysia. Forty-four staff of the IIUM library involved in the survey completed a total of 528 responses across nine air-conditioned office space with four responses from each respondent per day, a concurrent measurement of the environmental variables were carried out for the duration of the survey. In line with best practice, the ASHRAE thermal comfort tool and descriptive statistics were used for the analysis of results. The thermal comfort tool allows for the determination of the synergetic impact of the environmental variables and personal variables on thermal conditions. In general, the findings show that the subjective response using the thermal sensation and thermal comfort scale fails to meet the minimum vote of 80% satisfaction, this finding was in tandem with the office space observed microclimate failure to satisfy standards requirement. Similarly, the PMV and PPD of -0.54 and 11% respectively are determined with the ASHRAE thermal comfort tool which failed to meet the minimum requirement for satisfaction. Finally, the study shows that the thermal comfort zone temperature was identified to be within the range of 22.9°C to 26.4°C and relative humidity of 69% to 73.5% while the average clothing value was 0.61 clo. Conclusively, the comparison of the thermal conditions (user's questionnaire survey and objective measurement) observed between the different office space and across the four floors show that the building's indoor thermal conditions was uncomfortable by failing to meet the requirements of both MS-2014 and ASHRAE Standard 55-2013.

Keywords: Thermal comfort, Thermal sensation, Comfort zone, Library, offices, Staff.

خلاصة البحث

الشعور بدرجة الحرارة المناسبة لجسم الإنسان هي حالة التكيف العقلي للشخص المعبرة عن ارتياحه وتكيفه مع البيئة الحرارية والتي تؤدي عادة دوراً مهماً في تحديد أداء العاملين داخل مكاتبهم أو المبنى الذي يتواجدون فيه، وتأثير ذلك على إنتاجهم وكفاءتهم اعتماداً على ما يبذلونه من طاقة. لقياس ذلك تم استخدام معيار شارى 55 للعام 2013م، وقد تبين أن المحافظة على البيئة الداخلية الدافئة والمتلائمة مع جسم الإنسان مقبولة لدى أكثر من 80% من العاملين داخل مكاتبهم وهذا بدوره سيؤدي إلى تحسين الكفاءة وبالتالي إلى زيادة الإنتاجية والمنفعة الاقتصادية. ولهذه الأسباب، درجت الجامعة الإسلامية العالمية بماليزيا على توفير بيئة حرارية تتلائم مع العاملين ويمكن تحقيق ذلك باستخدام معيار المساحات الخضراء والمباني المسماة بـ(جي بي أي) عند مداخل مكاتب العاملين لمعرفة توفير متطلبات ظروف الراحة الحرارية. لذلك هدفت هذه الدراسة إلى معرفة تأثير الظروف البيئية في الأماكن المغلقة على الراحة الحرارية لموظفي مكتبة الجامعة الإسلامية العالمية. منهج الدراسة المتبع لتنفيذ ذلك اعتمد على الأسئلة المباشرة، والاستبيان الشخصي لمعرفة المتغيرات البيئية على التوالي. المتغيرات المطلوبة قياسها شملت المتغيرات البيئية مثل: درجة حرارة الجو (درجة مئوية)، والرطوبة النسبية (%)، وسرعة الهواء (م/ث)، ودرجة الحرارة الإشعاعية (درجة مئوية). بينما المتغيرات الشخصية تضمنت معدل الأيض والملابس. وجمع البيانات تعكس حقيقة الواقع حيث تم جمع البيانات في الفترة الزمنية من 29 إلى 31 من شهر يوليو 2015م لمدة (3 أيام) بداية مع شهر الجفاف وهو المعروف بموسم الرياح الموسمية في ماليزيا. أوضحت النتائج بأن أربعة وأربعين من موظفي مكتبة الجامعة الإسلامية المشاركين في الاستطلاع قد استجابوا للرد على استبيان الدراسة علماً بأن المجموع الكلية للأفراد المشاركين كانت 528 موظفاً في تسعة مكاتب مكيفة بمقابل الرد على 4 استبيانات في اليوم الواحد لتنفيذ القياس المتزامن للمتغيرات البيئية خلال مدة الدراسة. وتماشياً مع أفضل الممارسات، استخدم معيار (ASHRAE) الحرارية كأداة لقياس الراحة، لمعرفة الفروقات المعنوية تم استخدام الإحصاء الوصفي لتحليل النتائج. بينما أداة الراحة الحرارية المستخدمة تسمح بتحديد تأثير التداخل بين المتغيرات البيئية، والمتغيرات الشخصية على الظروف الحرارية. مجملًا، أوضحت نتائج الدراسة إلى أن الاستجابة الذاتية باستخدام الإحساس الحراري، والشعور بالدفء المستخدم تبين أنه لا يفي بالحد الأدنى على رضا حوالي 80% من المشاركين في الدراسة، وكان هذا متوافقاً مع ضيق المساحات المكتبية التي بنيت دون مراعاة المتطلبات والمعايير. وكان ذلك متوافقاً مع المعايير الأخرى مثل معايير PMV و PPD من -0.54 و 11% على التوالي. وأخيراً، أوضحت الدراسة أيضاً أن منطقة درجة الحرارة تم تحديدها بأن تكون ضمن المدى ما بين 22.9 إلى 26.4 درجة مئوية، والرطوبة النسبية من 69% إلى 73.5%، في حين بلغ متوسط قيمة الملابس 0.61. قد تبين بشكل قاطع، أن المقارنة بين الظروف الحرارية (الاستبيان المستخدم والقياس الموضوعي) الذي تمت ملاحظته بين المساحات المكتبية المختلفة، و عبر الطوابق الأربعة تبين أن ظروف حرارة المبنى الداخلية كانت غير مريحة بسبب فشله في تلبية متطلبات كل من المعايير MS-2014 و ASHRAE القياسية 2013-55.

كلمات البحث: الراحة الحرارية، الإحساس بالحرارة، منطقة الراحة، مكاتب المكتبة، موظفين.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Building Services Engineering).

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DECLARATION

I hereby declare that this dissertation is the result of my investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Ganiyu Amao Musbawu

Signature.....

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LIST OF ABBREVIATIONS

A/C	Air-Conditioning
ACMV	Air Conditioning and Mechanical Ventilation Systems
AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CEN	The European Committee for Standardisation
CIBSE	Chartered Institute of Building Services Engineering
DBT	Dry Bulb Temperature
EE	Energy Efficiency
EN	European Standard
ET	Effective Temperature
GBI	Green Building Index
HI	Humidex Index
HVAC	Heating, Ventilation and Air Conditioning
IUM	International Islamic University Malaysia
ISO	International Organization for Standardization
KAED	Kulliyyah of Architecture and Environmental Design
LEO	Low Energy Office
MRT	Mean Radiant Temperature.
MS	Malaysia Standards
N. D	No Date
NV	Natural Ventilation
PMV	Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied
RH	Relative Humidity
SET	Standard Effective Temperature
TC	Thermal Comfort

LIST OF SYMBOLS

T	temperature
T_a	air temperature
T_m	mean temperature
T_o	operative temperature
T_{mrt}	mean radiant temperature
T_n	thermal neutrality
°C	degrees Celsius
clo	clothing insulation unit
°F	degrees Fahrenheit
Ft	foot
kW	kilo watt
kWh	kilo watt hour
met	metabolic rate
m^2k/W	square meter kelvin per watt
mm	millimeter
m/s	meter per second
W/m^2	watts per square meter

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Over the years, increased greenhouse emissions and destruction of natural habitats have significantly impacted on the built environment that requires massive attendant resource inputs, potentially unhealthy and uncomfortable indoor environments, polluting both the indoor and outdoor environments (Barnett and Browning, 1995). These environmental impacts have significantly challenged the requirement for specifying and determining comfortable thermal conditions and countermeasure of the attendant energy required for cooling building indoor space.

The issues have become a global point of interest and caught a keen interest by many researchers around the world, apparently attributed to the realization that people spend most of their time (more than 90%) in an indoor environment (Lee and Chang, 2000). Thus, there is a significant increase in the study of thermal comfort of people staying in indoor environments, particularly in tropical regions (Fountain et al, 1994; Nicol and Roaf, 1996; Hussein et al, 2001; Cheong et al, 2003; Ahmad and Ibrahim, 2003; Zhao et al, 2004; Hwang et al, 2006; Kwok, 1998; Hussein et al, 2009; Qahtan et al., 2010; Shaharon and Jalaludin, 2012).

Some study analyses have examined the relationship between the availability of fundamental data and the provision of thermal comfort (Givoni, 1992; CIBSE, 2006; Thomas, 2006; ASHRAE, 2010 and Burdick, 2011). Achievement of building performance enhancement that meets the needs of privacy, comfort, recreation, and health maintenance require knowledge about the building historical data of engineering

and human health. As anything devoid of these has profound implications for the quality of both the natural and built environments.

In general, as observed from prior studies, a clear understanding of thermal conditions indices of an indoor space is essential for achieving thermal comfort. In addition to these primary data, systematic studies on thermal comfort are still needed for better understanding of the study. The present study is motivated by the need to take into consideration the indoor thermal comfort of an air-conditioned library office spaces located in the tropical climate of Malaysia, by assessing the office staff thermal condition perception regarding the office spaces microclimate. Clements-Croome and Baizhan (2000) demonstrated that productivity could be improved by 4 to 10% by improving the office environmental conditions.

In 2011, Xuan and Hongyan pointed that a library should be well-functioned and meet the human comfort criteria to provide a favorable environment. According to Popoola (1992), the library plays a central support role in the educational program and must be responsive to curriculum development, to the group and individual learning needs. The management staff coordinate the activities in the library, and their thermal conditions are significant to the operations.

1.2 STATEMENT OF THE PROBLEM

Occupant exposure to microclimatic factors in indoor space can lead to a series of thermal condition symptoms (cold or hot) and a general discomfort (Frontczak and Wargocki, 2011). The measures for removal of the causes of adverse exposure and improvement of indoor environment performance can be excessive and cost intensive, and there is no guarantee that occupant thermal condition symptoms after mitigation will disappear. In this study, the thermal condition of an air conditioned office space

was analysed, and found to be thermally cold. The finding is consistent with findings of past studies by Wong et. al. (2007) and Auliciems (1972), which showed that most air-conditioned buildings with a centralized system face the same problem, which is the space is often thermally too cold.

According to Shaharon and Jalaludin (2012), recent developments in the field of thermal comfort have led to renewed interest in the issue of workers' comfort and workspace quality in office space by the Malaysia government. Hence, the introduction of new energy-efficient building concepts and technologies, and revision of comfort standards to create a suitable thermal condition in avoiding occupant dissatisfaction, adverse effect on their productivity and overall building performance.

The effect of thermal discomfort was investigated for human health by Auliciems (1989) and Clements-Croome and Baizhan (2000), and found that human health has to be in good condition for them to continue functioning at the highest level which can be enhanced when the indoor thermal conditions are acceptable to the occupants. Conditions, where occupant feels too cold or too hot, will have a negative effect on such person thereby lowering their productivity with an adverse effect on economic and social indices.

1.3 RESEARCH QUESTIONS

In the light to understand the proposition provided, this study was prompted to answer the following research questions:

1. How does office space thermal condition vary during the office hours?
2. How does indoor microclimate affect office staff regarding thermal comfort and thermal sensation?
3. How does staff react to thermal conditions of their office space?

1.4 RESEARCH AIM AND OBJECTIVES

The aim of this study is to evaluate the effects of indoor microclimate at the IIUM library building on the thermal comfort of the office staff and determine the acceptable indoor thermal conditions of the air condition office spaces. The problem statement and aim above led to the formulation of the research objectives to achieve as follows:

1. To study the thermal behaviour of the IIUM library during the different period of the day.
2. To investigate the thermal sensation and thermal comfort level of the staff of the IIUM library.
3. To profile the thermal conditions of the IIUM library indoor environment.
4. To suggest optimum thermal conditions of the IIUM library towards energy efficiency.

1.5 SIGNIFICANCE OF THE STUDY

The findings of this study will help in bringing to the fore the IIUM library staff's satisfaction with the thermal conditions of their office spaces, which is important for its sake and because it influences productivity and health of the occupants (Huizenga et al., 2006; Chen and Chang, 2012). Furthermore, thermal comfort is imperative in both psychological and physical aspect where it could affect the morale of the people. Based on the degree of thermal comfort, office workers may complain (either feeling hot or cold), productivity may suffer and in some situations, people may refuse to work in a particular environment (Wargocki et al., 2002). Consequently, the study is important for establishing thermal comfort level for the IIUM library staff and at the same time conserving energy as part of the long-term implications of this study.

1.6 RESEARCH SCOPE AND LIMITATIONS

This study focuses on human perception to indoor space thermal conditions in open office spaces of the IIUM library. The samples were limited to the IIUM library staff, Gombak Campus. The staff were selected for the study because of their regular presence in the library building, they are there daily for at least eight (8) working hours. The relationship between gender and thermal comfort has been widely investigated (McIntyre 1982; Baker 1993; Baker and Standeven 1994; Oseland 1994; Griffiths *et al* 1988). Fanger (1972) and de Dear *et al* (1991a) demonstrated that gender is irrelevant to the comfort responses of subjects in the study of thermal comfort, hence, this study is not considering gender.

Also, the study was conducted in the month of July mainly to capture the climatic conditions of the month being the driest of the tropical monsoon climate of Malaysia; the study period is from 0800 hours to 1700 hour covering the office hours of the staff. However, the result at the end of the survey will be generalised to the entire indoor space of IIUM library because the respondents served as the representative of the entire occupants. In this study, the activities revolved around conducting building survey, indoor microclimate measurement and questionnaires survey among the staff of the IIUM library. This study exclusive detail of investigations are as follows;

- The microclimatic measurement includes air temperature (°C), relative humidity (%), air velocity (m/s) and mean radiant temperature (°C). The questionnaire survey includes metabolic rate, clothing value, thermal sensation, thermal comfort, and reactions to the thermal sensation.
- The study applies exclusively to indoor environments with air conditioning system over which the occupants have no control. The occupants of such buildings are inferred to have no option to open and close windows

1.7 OVERVIEW OF RESEARCH METHODOLOGY

In this dissertation, a comprehensive review of the previously work done by researchers regarding human thermal comfort in air-conditioned indoor spaces has been carried out. In this revision a specific attention is given to staff in the offices, and their perception of the indoor thermal conditions inside the office. Toward achieving the objectives of this research, a field study has been carried out at the IIUM library office spaces, by using a subjective questionnaire survey simultaneous with thermal environmental parameter monitoring.

1.7.1 Method

Conducted in July 2015, a survey and experimental study were carried out daily for three (3) consecutive days. The questionnaire surveys were conducted four (4) sessions in a day, twice in the morning and twice in the afternoon, with the simultaneous environmental data monitoring. The field studies have been carried out in nine (9) air-conditioned office spaces in the IIUM library building. Forty-four (44) library staff, of which 73% were female and 23% male, participated in the 3-day long survey.

1.7.1.1 Survey

This study used the ASHRAE (2010) thermal environment survey questionnaire with some modifications according to local conditions. The questionnaire was designed to reflect the respondents' subjective assessment of the indoor thermal environment.

The main contents of the survey include:

1. Respondents' background, such as gender, age, etc.;
2. Respondents' clothing and activity rate. The respondents were usually involved in sitting and conducting office task when answering the questionnaire survey, after a thirty-minute exposure to the environment.