

**ENERGY AND THERMAL COMFORT ANALYSIS FOR UNIVERSITY
LIBRARY**

WONG PEEK HUI

B04110178

BMCD

Email: bernice_ph@hotmail.com

**Draft Final Report
Projek Sarjana Muda II**

Supervisor: DR.TEE BOON TUAN

**Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka**

JUNE 2015

SUPERVISOR DECLARATION

“I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Design and Innovation)”

Signature :

Supervisor : DR. TEE BOON TUAN

Date :

**ENERGY AND THERMAL COMFORT ANALYSIS FOR UNIVERSITY
LIBRARY**

WONG PEEK HUI

**This Technical Report is submitted to
Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka
In partial fulfilment for
Bachelor of Mechanical Engineering (Design & Innovation) with honours**

**Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka**

JUNE 2015

DECLARATION

“I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged.”

Signature :
Author :
Date :

For my beloved Dad and Mum

AWKNOWLEDGEMENT

I would like to express my heartfelt gratitude to all those who have helped me complete this project. First and foremost, I would like to express my deepest gratitude to my supervisor Dr. Tee Boon Tuan for his patient guidance, enthusiastic encouragement and valuable suggestions during the project period. His willingness to give his time so generously has been very much appreciated.

Besides that, I would also like to send my sincere gratitude to Dr. Mohd Basri Ali as my project examiner for evaluating my final year project. He had given some suggestion and advice in order to improve my project. I am so grateful to the Faculty of Mechanical Engineering (FKM), Universiti Teknikal Malaysia Melaka (UTeM) for providing the necessary tools for data measurement and analysis. Furthermore, I would also like to extend my deepest thanks to the technician of the HVAC laboratory, En. Asjuri Bin Muhajir. Thanks for his help in assisting for data collection by using the required equipment.

In addition, I would also like to thank to various people for their contribution to this project such as the Mechanical Engineer, En Ainuddin Abu Kasim and Assistant Electrical Engineer, En Mohd Ibrahim of University Development office in giving me the information and answering my enquiries. Special thanks to all the respondents who took part in the questionnaire survey.

Finally, I wish to thank to my beloved parents and siblings for their support and encouragement throughout the completion of this project.

ABSTRACT

The main purpose of this study is to investigate the thermal comfort level in the UTeM's library and compare with the ASHRAE Standard 55 (2004) and Malaysia Standard MS 1525:2014. The physical measurements were carried out with occupants and without occupant condition. The analysis of this study included the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) for physical measurements and Thermal Sensation Vote (TSV) through subjective assessment. Besides that, the linear regression analysis is conducted between PMV and TSV with operative temperature by using SPSS software. The Building Energy Index (BEI) of UTeM's library is 260kWh/m²/year in year 2014. Based on the findings, technical design improvements are recommended in this study in order to improve the thermal comfort inside the library at the same time reduce the energy consumption.

ABSTRAK

Objektif kajian adalah untuk mengkaji keselesaan keadaan dalam bangunan perpustakaan UTeM dan membandingkannya dengan ASHRAE Standard 55 (2004) and Malaysia Standard MS 1525: 2014. Pengukuran fizikal dijalankan dalam keadaan kehadiran orang dan ketiadaan orang. Pengiraan Undian Andaian Purata dan Peratusan Andaian Ketidakpuasan bagi pengukuran fizikal and Undian Sensation haba mengikut kaji selidik subjektif telah digunakan untuk menganalisis kajian ini. Seperkara lagi, Statistical package for Social Science (SPSS) telah diaplikasikan untuk menganalisis linear regresi antara Undian Andaian Purata dan Undian Sensation Haba. Tenaga indeks bagi bangunan perpustakaan UTeM adalah $260\text{kWh/m}^2/\text{year}$ pada tahun 2014. Berdasarkan dapatan kajian, peningkatan reka bentuk teknikal akan dicadangkan bagi meningkatkan keselesaan keadaan dalam bangunan perpustakaan dan juga mengurangkan pengambilan tenaga.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	SUPERVISOR DECLARATION	ii
	DECLARATION	iv
	DEDICATION	v
	ACKNOWLEDGEMENTS	vi
	ABSTRACT	vii
	ABSTRAK	viii
	TABLE OF CONTENTS	ix
	LIST OF TABLES	xiii
	LIST OF FIGURES	xv
	LIST OF SYMBOLS	xviii
	LIST OF ABBREVIATIONS	xix
	LIST OF APPENDICES	xxi
1	INTRODUCTION	1
	1.1 PROBLEM STATEMENT	3
	1.2 OBJECTIVES	4
	1.3 SCOPES	4
	1.4 EXPECTED OUTCOMES	5
2	THEORY	6
	2.1 THERMAL COMFORT	6
	2.1.1 Environment Factors	7
	2.1.2 Personal Factors	9
	2.3 AIR CONDITIONING FOR THERMAL COMFORT	9
	2.4 AIR CONDITIONING SYSTEM	10

CHAPTER	TITLE	PAGE
2.5	STANDARD	12
2.5.1	Malaysia Standard MS 1525: 2014	13
2.5.2	ASHRAE Standard 55-2004, Thermal Environment Condition for Human Occupancy	13
2.6	PREDICTED MEAN VOTE (PMV) AND PREDICTED PERCENTAGE OF DISSAT- ISFIED (PPD)	14
2.7	STATISTICAL PACKAGES FOR THE SOCIAL SCIENCES (SPSS)	15
3	LITERATURE REVIEW	17
3.1	THERMAL COMFORT STUDY AND VENTILATION EVALUATION OF AN OFFICE BY DAGHIGH, ET. AL. (2012)	17
3.1.1	Methodology	18
3.1.2	Results	18
3.1.3	Conclusion	20
3.2	THERMAL COMFORT IN LECTURE HALLS IN THE TROPICS BY YAU, CHEW, SAIFULLAH (2011)	21
3.2.1	Methodology	21
3.2.2	Results	22
3.2.3	Conclusion	25
3.3	THERMAL COMFORT IN THE HUMID TROPICS: FIELD EXPERIMENTS IN AIR-CONDITIONED AND NATURALLY VENTILATED BUILDINGS IN SINGAPORE BY R.J.DE.DEAR,K.G.LEOW AND S.C.FOO. (1991)	25
3.3.1	Methodology	25
3.3.2	Results	26
3.3.3	Conclusion	28

CHAPTER	TITLE	PAGE
3.4	THERMAL COMFORT IN BANGKOK RESIDENTIAL BUILDINGS, THAILAND BY RANGSIRAKA (2006)	28
3.4.1	Methodology	29
3.4.2	Results and Discussion	30
3.4.3	Conclusion	33
3.5	THERMAL COMFORT AND BUILDING ENERGY CONSUMPTION IN THE PHILIPPINE CON- TEXTBY ANDAMON (2006)	33
3.5.1	Methodology	34
3.5.2	Results	34
3.5.3	Conclusion	38
3.6	OVERALL CAMPARISON OF PREVIOUS STUDIES	39
4	METHODOLOGY	40
4.1	DESCRIPTION OF UNIVERSITY LIBRARY	41
4.1.1	Description of UTeM's Library Ground Floor	41
4.1.2	Description of UTeM's Library First floor and Second floor	42
4.1.3	Air-Conditioning System Use in The Building	43
4.2	EXPERIMENTAL METHOD	44
4.2.1	Physical Measurement Procedure	47
4.3	SURVEY	49
4.3.1	Selection of Respondents	49
4.4	ANALYSIS OF THE RESULTS	50
4.4.1	Comparing the Results of the Physical Measurements with Standards	50
4.4.2	Analysis of Votes Based on the Subjective Assessment	50

CHAPTER	TITLE	PAGE
	4.4.3 Comparison between Questionnaire and Physical Measurements	50
	4.5 CALCULATE THE BUILDING ENERGY INDEX	51
5	RESULT AND ANALYSIS	52
	5.1 EXPERIMENTAL RESULTS	52
	5.1.1 Ground Floor of UTeM's Library (With Occupants)	54
	5.1.2 Ground Floor of UTeM's Library (Without Occupants)	55
	5.1.3 First Floor of UTeM's Library (With Occupants)	57
	5.1.4 First Floor of UTeM's Library (Without Occupants)	59
	5.2 COMPARISON	60
	5.3 SUBJECTIVE ASSESSMENT	64
	5.3.1 Analysis of TSV	66
	5.4 ENERGY ANALYSIS	70
	5.4.1 Cost Saving Method	73
6	CONCLUSION	75
	6.1 CONCLUSION	75
	6.2 RECOMMENDATION	76
	REFERENCES	78
	APPENDIX	83

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	R and R ² values for social sciences studies	16
3.1	PMV and PPD in lecture halls (Yau, Chew, & Saifullah, 2011).	23
3.2	AMV and TSV in lecture halls (Yau et al., 2011)	24
3.3	Summary of the indoor micro-climate data (Ridge, 1991)	27
3.4	Summary of metabolic and clothing data (Ridge, 1991)	27
3.5	Thermal comfort votes and operative temperature in air conditioned buildings (Ridge, 1991)	28
3.6	Number of respondents' age sample for each season (Rangsiraksa, 2006)	31
3.7	Mean indoor conditions for each season (Rangsiraksa, 2006)	31
3.8	R and R ² values for social science studies (Rangsiraksa, 2006)	32
3.9	Regression of mean ASHRAE scale response to Ta for the three different seasons and all seasons (Rangsiraksa, 2006)	32
3.10	Cross tabulation of ASHRAE scale response and TA for summer (Rangsiraksa, 2006)	33
3.11	Ayala Tower One (ATO) -2002 Air Conditioning Use and Consumption (Andamon, 2006).	37
3.12	Comparison on previous studies	39

TABLE	TITLE	PAGE
4.1	Total Air Handling Units in the UTeM's library building	44
4.2	The probes are used for this study	46
4.3	Physical Measurements are collected for this study	46
5.1	The physical parameters readings in the ground floor of library buiding	53
5.2	The physical parameters readings in the first floor of library buiding	53
5.3	The average results for ground floor and first floor of UTeM's library	61
5.4	Graph of PPD as a function of PMV for each condition	63
5.5	The respondents voted on the ASHRAE scale in the Ground Floor and First Floor of UTeM's library	64
5.6	R and R ² values for each condition	69
5.7	The electricity energy usage in year 2012, 2013 and 2014	70
5.8	The Building Energy Index for the year 2012, 2013 and 2014.	73

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	The environment factors affect the thermal comfort	6
2.2	The personal factors affect the thermal comfort.	7
2.3	Comfort zone: ASHRAE STD 55-2004.	10
2.4	The parts of chilled water air conditioning plant (“Central Air-Conditioning Plants Direct Expansion and Chilled Water,” n.d.)	11
2.5	Predicted percentage dissatisfied (PPD) as a function of pre- dicted mean vote (PMV) - ASHRAE 55 (2004)	15
3.1	Air-conditioned office –Predicted Percentage of Dissatisfied (PPD) as a Function of Predicted Mean Vote (PMV).(Daghigh et al., 2012)	19
3.2	Thermal comfort range based on Psychometric Chart – ASHRAE 55.	19
3.3	Relative Frequency of ASHRAE Thermal Votes(Daghigh et al., 2012)	20
3.4	Graph of PMV against operative temperature(Yau et al., 2011).	23
3.5	Graph of TSV against operative temperature(Yau et al., 2011)	24
3.6	Distribution of Indoor Climatic Measurements on ANSI/ASHRAE Standard 55-1992	35
3.7	Crosstabulation of Thermal Sensation Votes versus Thermal Acceptability Votes (Andamon, 2006)	35

FIGURE	TITLE	PAGE
3.8	2002 Energy use Calculations for Ayala Tower One (ATO) Annual Increase /Reduction of Energy Consumption(Andamon, 2006).	37
4.1	Flow Chart of the methodology throughout this study	40
4.2	Library of University Technical Malaysia Melaka	41
4.3	Computers are placed in the ground floor of UTeM's library building.	42
4.4	Reading corners in the ground floor of UTeM's library building.	42
4.5	Most of the book racks are placed in the first floor and second floor of the building.	43
4.6	Tables and chairs are provided for students and are placed nearby the windows in the first floor and second floor of the building.	43
4.7	Thermal Microclimate HD32.1from Deltalog10(Microclimate, 2009)	45
4.8	Experiment is carried out when no occupant (left) with occupants (right) in the ground floor of UTeM's library.	48
4.9	Experiment is carried out when no occupant (left) with occupants (right) in the first floor of UTeM's library.	48
5.1	Air velocity recorded every 30 seconds throughout the experiment with the present of occupants in the ground floor	53
5.2	Average relative humidity recorded every 30 seconds throughout the experiment with the present of occupants in the ground floor	53
5.3	Thermal comfort parameter air velocity recorded every 30 seconds during the experiment with the absent of occupants in the ground floor	56

FIGURE	TITLE	PAGE
5.4	Average relative humidity recorded every 30 seconds throughout the experiment with the absent of occupants in the ground floor	57
5.5	Thermal comfort parameter air velocity recorded every 30 seconds during the experiment with the present of occupants in the first floor	58
5.6	Physical parameter relative humidity recorded every 30 seconds throughout the experiment with the present of occupants in the first floor	58
5.7	The air velocity values are recorded during the experiment without occupants in the first floor of UTeM's library	60
5.8	Average relative humidity recorded every 30 seconds throughout the experiment when no occupants present in the first floor	60
5.9	Distribution of subjective response on air temperature based on the ASHRAE Thermal Sensation Scale	65
5.10	Regression line between Thermal Sensation Vote (TSV) and Operative Temperature	66
5.11	Graph of PMV versus operative temperature in the ground floor of UTeM's library	67
5.12	Graph of PMV versus operative temperature in the first floor of UTeM's library	68
5.13	Sample calculation for the total electric usage on January 2012	71
5.14	Sample calculation for the total electric usage on January 2014	71
5.15	The total electric usage for each months of the year 2012, 2013 and 2014.	71
5.16	Sample calculation for the Building Energy Index (BEI)	72

LIST OF SYMBOLS

SYMBOLS	DESCRIPTION
°C	Degree Celcius
°F	Fahrenheit
h	Hour
K	Kelvin
k	Kilo
m	Metre
%	Percent
s	Seconds
W	Watt

LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
AC	Air-conditioned
ACH	Air Exchange Rate
ACMV	Air-conditioning and Mechanical Ventilation
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
ATO	Ayala Tower One
BEI	Building Energy Index
CET	Corrected Effective Temperature
CLO	Clothing Insulation Value
CO ₂	Carbon Dioxide
DR	Draft Rate
HVAC	Heating, ventilation and air-conditioning
IAQ	Indoor Air Quality
ISO	International Organization of Standardization
MET	Metabolic Rate
MRT	Mean Radiant Temperature

MS	Malaysia Standard
NV	Natural Ventilated
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
RH	Relative Humidity
SBS	Sick Building Syndrome
SPSS	Statistical package for Social Science
TA	Dry Bulb Temperature
TC	Thermal Comfort
TG	Globe Temperature
TSV	Thermal Sensation Vote
UPM	University Putra Malaysia
UTEM	Univeristy Teknikal Malaysisa Melaka
V	Air velocity

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Flow chart of Projek Sarjana Muda 1	83
B	Project timeline Gantt Chart for Projek Sarjana Muda I	84
C	Project timeline Gantt Chart for Projek Sarjana Muda II	85
D	Questionnaire	86
E	The Centralized Air-conditioning System Used in UTeM's Library	87
F	Air Handling Units Plan in the Ground Floor and First Floor of UTeM's library	88
G	Regression by SPSS	89
H	The Tarrif Rate and Pricing Rate for Electricity	93
I	Results in Ground Floor with Occupants	94
J	Results in Ground Floor without Occupants	96
K	Results in First Floor with Occupants	98
L	Results in First Floor without Occupatns	100
M	Library Plan	102

CHAPTER 1

INTRODUCTION

1.0 OVERVIEW

Air-conditioning (AC) and mechanical ventilation (ACMV) systems are installed inside a building is used to control the air temperature and improve the indoor air quality (IAQ) in order to create a better thermal condition. Thermal comfort is an important factor for designing a high quality building in order to provide a comfortable environment and good health for the people who stay inside the building. A room with thermal comfort means where 80% of the occupants inside the building could accept the environment (Sookchaiya, Monyakul, & Thepa, 2010). In order for occupants to be thermally comfortable within the available space, four environmental parameters need to be present in adequate proportion (Ibrahim, n.d.). These parameters are air temperature, air movement, mean radiant temperature, and relative humidity. Air conditioning is used to control the indoor temperature which provided comfort and good health for the occupants but there are still many people in such condition suffer from nose irritations, stuffed nose, rainy nose, eye irritations, coughing, and tightness in the chest, fatigue, headache, rash, and a lot more. These symptoms are normally called “Sick Building Syndrome” or SBS which is affected by humidity (Sookchaiya et al., 2010).

British Standard BS EN ISO 7730 defines the term “Thermal comfort” as : ‘That condition of mind which expresses satisfaction with thermal environment’. (Shaharon, M.N et al., 2012) Thermal comfort was also defined by the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) as the state of mind which expresses satisfaction with thermal environment. (Shaharon, M.N et al., 2012). The ANSI /ASHRAE Standard 55 ,Thermal Environmental Conditions for Human Occupancy is used extensively as a reference for comfort levels (Andamon, 2006). According to ISO 7730, ASHRAE standards and Fanger theory there are six variables that affect on thermal comfort. These six factors can be divided into two sections which are environmental factors and personal factors. The environmental factors are air temperature, relative humidity, air movement and globe temperature. On the other hand, the personal factors are clothing insulation value (CLO) and metabolic rate (MET) (Azizpour, Moghimi, Mat, Lim, & Sopian, n.d.).

According to ASHRAE standard, a recommended comfort operative temperature for human living under climate condition such as those found in tropic country like Malaysia is around $24^{\circ}\text{C}\pm 1^{\circ}\text{C}$. The recommended indoor air velocity is between 0.15 and 1.5 m/s. A relative humidity between 40%-60% is considered healthy and comfortable in a comfort controlled environment according to ASHRAE standard. The Department of Standard Malaysia recommended indoor design temperature range from 23°C to 26°C .

Basically, the building sector is an energy intensive sector as huge amounts of energy need to generate in order to maintain artificial indoor climates that provide thermal comfort for its occupants that would allow them to conduct various activities in a conducive environment (RS Wafi et al., 2008). Electricity consumption in residential and commercial sectors is mainly come from the electric usage of the air-conditioning system. The design and installation of air-conditioning system to control thermal environment to achieve human thermal comfort and health inside the building should comply with the ASHRAE Standard 55-2004 which is most appropriate (Sookchaiya et al., 2010).

The main purpose of designing buildings is to make sure that most of occupants in the building are satisfied with the thermal condition. This is because most people generally spend 85-90 % of their time indoors and then providing a comfortable and healthy environment is imperative. (RS Wafi et al., 2008) Staff and students also spend most of their time in indoor. University library is a place for the university students to do their research and also a place for them gains knowledge, search for information and a lot more. Therefore, a more comfort environment is needed. A better environment can increase student's attention, concentration and productivity and minimize the possibility of heat stress when they are doing homework or research in the library. Hence, air-conditioning and mechanical ventilation system is installed into the library building especially in tropical country like Malaysia.

There are two personal factors will affect the thermally comfortable in a space, hence subjective assessment is carried out to investigate how many people dissatisfied the condition. A questionnaire survey that is to seek occupant input for the level, the frequency and the time of the thermal comfort problem as well as the general condition of the thermal environment. (Shaharon, M.N et al., 2012) Statistical package for Social Science (SPSS) is used to analyze the data collected from the subjective assessment. On the other hand, there are also various indices have been developed to describe the thermal comfort experienced inside a building such as Effective Temperature Index, Comfort index, Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) and Corrected Effective Temperature (CET) index are common indices. (Ibrahim, n.d.)

1.1 PROBLEM STATEMENTS

This project is focusing on the air-conditioning system as it plays an important rule for providing a comfortable indoor environment for the occupants. By improving the Air Conditioning Mechanical Ventilation (ACMV) control, it can save the energy consumption in a building. Human thermal comfort needs to be evaluated so that the occupants of the building will not feel too cold or too hot. The Human thermal comfort level can be evaluated by using the ANSI/ASHRAE standard and