UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A MODEL TO PREDICT ROOM TEMPERATURE BASED ON ROOM GEOMETRY USING COMPUTATIONAL FLUID DYNAMICS

MOHAMMED W. MUHIELDEEN AL-GAILANI

DEVELOPMENT OF A MODEL TO PREDICT ROOM TEMPERATURE BASED ON ROOM GEOMETRY USING COMPUTATIONAL FLUID DYNAMICS

By

MOHAMMED W. MUHIELDEEN AL-GAILANI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the degree of Doctor of Philosophy

January 2017

Abstract of thesis Submitted to the Senate of Universiti Putra Malaysia, in Fulfilment of the Requirements for the degree of Doctor of Philosophy

DEVELOPMENT OF A MODEL TO PREDICT ROOM TEMPERATURE BASED ON ROOM GEOMETRY USING COMPUTATIONAL FLUID DYNAMICS

By

MOHAMMED W. MUHIELDEEN AL-GAILANI

January 2017

Chairman : Nor Mariah Adam, PhD, PE
Faculty : Engineering

Over the years, the growth in economic activities and the population increase in Malaysia have led to an increase in energy consumption in the home. The Uniform Building By-Law Act (UBBL) 1984 only recommends a minimum ceiling height in buildings. Overheating exists in Malaysian homes and the use of air conditioners is a short term solution that implies a higher use of energy to the government. The green building concept relies on a passive solution to lower energy consumption whereby innovative initiatives can be integrated into green buildings at the design stage. One passive method is to consider room geometry to achieve thermal comfort in a naturally ventilated tropical building. This study is concerned with the development of a model to predict room temperature using geometry in a residential building and so achieve thermal comfort inside the house. Data on the air temperature, air velocity and Relative Humidity were measured in 40 rooms in the in Klang Valley area as input data for the simulation work. FLUENT (CFD) software was selected for the simulation study where 3D geometry was modeled to simulate the air flow under turbulent k-ε standard, by including all the boundary conditions for the walls, the roof, the ceiling and the glass. The selected meshes are the hexhydro/map and the hexwedge/cooper with a 0.2 mesh size; these were used to collect accurate results. The room model that was generated had dimensions of Length: 4 m, Width: 3 m and Height: 2.6 m, instead of 2.5 m as illustrated in the UBBL, and this was validated with actual test rooms in the Klang Valley. The result shows the existing construction materials (concrete) for houses in Malaysia

is suitable material for thermal condition via heat transfer (q), (k) thermal conductivity, (ΔT) temperature difference between inside and outside temperature and (V) is volume, according to the developed equation $q = \frac{k\Delta T}{\sqrt[3]{V}}$, where is applicable to Malaysia and other tropical countries. The finding show the suitable height for all environmental conditions is 3 m.

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

PEMBANGUNAN MODEL UNTUK MENJANGKAKAN SUHU BERDASARKAN GEOMETRI BILIK MENGGUNAKAN DINAMIK BENDALIR PENGKOMPUTERAN

Oleh

MOHAMMED W. MUHIELDEEN AL-GAILANI

Januari 2017

Pengerusi : Nor Mariah Adam, PhD, PE
Fakulti : Kejuruteraan

Sejak kebelakangan ini pertumbuhan aktiviti ekonomi dan pertambahan penduduk di Malaysia telah menyumbang kepada peningkatan penggunaan tenaga isirumah. Undang Undang Bangunan Seragam 1984 (*Uniform Building By Law (UBBL) 1984)* hanya mengesyorkan ketinggian siling minimumdalam bangunan. Keadaan panas lampau wujud di rumah Malaysia yang mana penggunaan alat pengghawa dingin hanyalah sebagai kaedah penyelesaian sementara. Keadaan ini memberi implikasi penggunaan tenaga yang lebih tinggi kepada kerajaan. Konsep bangunan hijau adalah untuk mengurangkan keperluan tenaga secara pasif yang mana inisiatif inovatif diterapkan semasa tahap rekabentuk bangunan. Satu kaedah pasif adalah dengan menimbang saiz geometri bilik untuk mendapatkan keselesaan termal semasa pengalihudaraan tabii kawasan tropika. Kajian ini adalah berkenaan membangunkan model untuk meramal suhu bilik berasaskan geometri dalam bangunan kediaman untuk mencapai keselesaan termal dalam kediaman berkenaan. Data berkaitan yakni suhu udara, kelajuan udara dan kelembapan relatif telah disukat dalam 40 buah rumah kediaman di kawasan Lembah Klang sebagai input data untuk kerja kerja simulasi. Perisian FLUENT (CFD) telah dipilih untuk kajian simulasi geometri 3D dimodelkan untuk penngaliran udara dalam keadaan gelora standard$k$-ε, dengan mengambilkira semua keadaan lapisan sempadan untuk dinding, bumbung, siling dan kaca, Mesh yang dipilih adalah hexhydro/map dan hexwedge/cooper dengan dengan saiz mesh sebanyak 0.2 untuk mendapatkan ketepatan. Model bilik yang dijana dengan dimensi (panjang: 4 m, lebar: 3 m dan

tinggi: 2.6 m) dan bukan 2.5 m yang ditunjukkan dalam UBBL 1984, hasil ini teleh disahkan dengan bilik-bilik ujian sebenar di Lembah Klang. Hasilnya menunjukkan bahan binaan yang sedia ada untuk bilik adalah bahan binaan (konkrit) yang sesuai membenarkan haba untuk memindahkan ke bilik mengikut membangunkan persamaan $q = \frac{k\Delta T}{\sqrt[3]{V}}$, yang mana ini boleh terpakai di Malaysia dan negara beriklim tropikal. Hasil kajian menunjukkan ketinggian yang sesuai untuk semua keadaan persekitaran adalah 3 m.

ACKNOWLEDGEMENTS

First of all, great thanks to the Most Gracious and Most Merciful, Allah (S.W.T) without His wish and help this work would not have been possible. I also would like to express the most sincere appreciation to those who made this work possible: advisory members, family and friends.

I would like to thankAssociate Professor Ir. Dr. Nor Mariah Adam for providing me with the opportunity to complete my PhD study under her valuable guidance, for the many useful advice and discussions, for her constant encouragement and guidance, and for co-authoring and reviewing some of my publications, where her practical experience and technical knowledge made this research and those publications more interesting and relevant. Also special thanks extended to Supervisory Committee members; Associate Professor Dr. Nuraini bt. Abdul Azizand Associate Professor Ir. Dr. Kamarul Arifin Ahmad, I am grateful for their willingness to serve on my supervisory committee, their constant encouragement, advice and many fruitful discussions have been very helpful.

Thanks and acknowledgements are meaningless if not extended to my parents who deserve my deepest appreciation. This achievement is heartily dedicated to my father who died in 1999, hopefully he is happy with this success. My deepest appreciation to my mother for the support that she has given me both financially and emotionally through all these years, I am grateful for the countless sacrifices she made to ensure that I could pursue my dreams and for always being there for me.

I would like to thank my special wife. Her support, encouragement, quiet patience and unwavering love were undeniably the bedrock upon which the past nine years of my life have been built. Her tolerance is a testament in itself of her unyielding devotion and love. My wife has been my best friend and great companion, loved, supported, encouraged, entertained, and helped me get through this agonizing period in the most positive way.

Mohammed W. Muhieldeen Al-Gailani
January 2017

I certify that a Thesis Examination Committee has met on 23 January 2017 to conduct the final examination of Mohammed W. Muhieldeen Al-Gailani on his thesis entitled "Development of a Model to Predict Room Temperature Based on Room Geometry using Computational Fluid Dynamics" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Edi Syams bin Zainudin, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Khairol Anuar bin Mohd Ariffin, PhD
Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Rizal bin Zahari, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Shaker A. Meguid, PhD
Professor
Nanyang Technological University
Singapore
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 6 July 2017

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment on the requirement for the degree of Doctor of Philosophy. The members of the supervisory committee were as follows:

Nor Mariah Adam, PhD
Professor, Ir
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Nuraini bt. Abdul Aziz, PhD
Associate Professor
Faculty of Architecture
Universiti Putra Malaysia
(Member)

Kamarul Arifin Ahmad, PhD
Associate Professor, Ir
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Univirsiti Putra Malaysia, as according to the Univeristi Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceeding, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the UniversitiPutra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholary integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ____________________________ Date: ______________

Name and Matric No.:Mohammed W. Muhieldeen Al-Gailani / GS33402

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this theses was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature:	____________________	Signature:	____________________
Name of Chairman of Supervisory Committee:	____________________	Name of Member of Supervisory Committee:	____________________

Signature:	____________________
Name of Member of Supervisory Committee:	____________________

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A	Area, (m^2)
D	Thickness of wall, (m)
C_p	Specific heat, (J/kg.K)
g	Gravitational acceleration, (m/s^2)
G_{rL}	Grashof number
h	Heat transfer coefficient, ($W/m^2.K$)
k	Thermal conductivity, (W/m.K)
Nu	Nusselt number
Q	Heat flux (W/m^2)
Ra	Rayleigh number
Re	Reynolds number
t	Time (second)
T_∞	Air Temperature, (ºC)
T_{sur}	Surrounding Temperature, (ºC)
ΔT	Temperature difference, (ºC)
T_s	Surface Temperature, (ºC)
$q_{CONV.}$	Convection heat flow, (W)
$q_{COND.}$	Conduction heat flow, (W)
u, c	Velocity (m/s)
V	Volume (m^3)
X	Local position along the X-direction under Cartesian coordinate
Y	Local position along the Y-direction under Cartesian coordinate
Z	Local position along the Z-direction under Cartesian coordinate
P	Prototype
m	Model
M	Metabolic heat production rate ($J/s.m^2$)
W	Mechanical work accomplished rate ($J/s.m^2$)

Greek Symbols

β	volumetric thermal expansion coefficient, (K^{-1})
α	Thermal diffusivity, (m^2/s)
ε	emissivity
ρ	Density (kg/m^3)
μ	Dynamics viscosity (N/m·s)
υ	Specific volume, (m^3/kg)
ω	Solid angle,(s^{-1})
θ	Angle (degree)

LIST OF ABBREVIATIONS

AC	Air Conditioning
ACEM	Association of Consulting Engineering Malaysia
ADPI	Air Diffusion Performance Index
AFFIRM	Awareness, Faculty, Finance, Infrastructure, Research, and Marketing
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineering
BEM	Board of Engineering Malaysia
BREEAM	Building Research Establish Environmental Assessment Method
CAC	Ceiling-based Air Conditioning system
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CFD	Computational Fluid Dynamics
CO_2	Carbon dioxide
DBKL	Dewan Bandaraya Kuala Lumpur
EPI	Environmental Performance Index
ESD	Energy Sustainable Development
GBI	Green Building Index
HQE	High Environmental Quality
IEM	Institution Engineering Malaysia
LED	Light Emitting Diode
LEED	Leadership in Energy and Environmental Design
MPC	Main Press Center
MySET	Malaysian Society, Engineering and Technology
PAM	Persatuan Arkitek Malaysia
RH	Relative Humidity
SBO	Sarawak Building Ordinance
UBBL	Uniform Building By Low
UK	United Kingdom
UNDP	United Nations Development Programme

CHAPTER 1

INTRODUCTION

1.1 Introduction

Malaysia has a tropical climate throughout the year where the weather is hot and humid, forcing its citizens to use their air conditioner during unbearably hot days and nights, which can be costly. The electricity tariff was increased in September 2013 and made worse by the new (GST) tax system in 2014. Medium and low cost residential buildings do not have high ceilinged rooms as they are built based on the minimum requirements as tabulated in the Uniform Building By-Law Act 1984 (UBBL). A ceiling fan is available in every house, but it is not capable of supplying a suitable quantity of fresh air to create comfortable conditions and this causes human body temperature to increase with the increase of activity intensity (overheating). According to (ASHRAE 2012), when the surrounding temperature is lower than body temperature, the body releases internal heat by perspiring. As sweat is released, it evaporates into the environment which is what causes the person to feel cooler. As the environment in Malaysia is hot and humid, a person tends to sweat more as the humid air is unable to facilitate the evaporation of sweat, which is formed to release internal heat (RH > 70%). The person will then tend to feel uncomfortable due to the friction between their body and their clothing. A fan can be used to help reduce heat load in a certain area as the air movement produced increases the rate of evaporation of sweat. Another alternative that can be used is the air conditioning unit, which is a more effective solution as it can provide thermal comfort for higher air temperatures (ASHRAE, 2012). It operates by the concept of heat transfer through air compression and expansion. The UBBL has set the standard for terraced houses for the minimum ceiling height which allows the occupants to feel comfortable as well as being affordable. It provides the minimum guidelines based on the minimum ceiling height, the temperature profile, the air change in the room and the RH.

The Uniform Building By Law 1984 (Chapter III, section 44) statesthat for terrace housesthe minimum height of ceiling as:

– Living room and Bedroom	2.50 meter
– Kitchen	2.25 meter
– Washroom	2.00 meter

The ASHRAE handbook is a publication of a non-profit organisation formally known as the American Society of Heating, Refrigerating and Air-Conditioning Engineers, and is used as a standard for the field of heating, ventilation, air-conditioning, and refrigeration

(HVAC&R). Many experiments were carried out to obtain the readings and then translate them into tables and equations for the purpose of providing a basic and standard platform for such systems. Data collected across the United States of America can be used as a benchmark for other countries as the area is large enough to provide sufficient results that have more or less similar parameters (environmental, geological, etc.) to the rest of the world.

In this handbook, aspects other than the mechanical area are also taken into consideration during the designing of air conditioning systems, such as human thermoregulation. A thorough understanding of how the human body reacts to the environment is vital to ensure not just comfort for the occupants, but safety as well. To know how much heat is needed to help achieve thermal comfort for the occupants of an area, the total amount of heat that is generated needs to be determined. In this case, every aspect that leads to heat load needs to be considered, whereby the net heat produced is equal to the metabolic heat production rate, also taking into account the energy produced by external work (ASHRAE, 2012):

Net heat produced ($J/s.m^2$) = M – W

M: Metabolic heat production rate ($J/s.m^2$)
W: Mechanical work accomplished rate ($J/s.m^2$)

This research is proposed based on the UBBL statement to estimate the optimum ceiling height for a room in order to develop a room model using the dimensional analysis Πtheorem which considers the air temperature, the RH and the volume of the room, and also follows international standards like ASHRAE to attain comfortable conditions inside residents' houses.

1.2 Problem statement

In the past, a ceiling fan has been sufficient to provide a cooling effect on a warm, sunny day. However, in recent years, more and more consumers have resorted to air conditioning on a regular basis to help reduce the heat tension. Apart from this, the number of units installed per area has increased significantly; where in the past one unit was sufficient, now at least two or three are required per house. To be able to keep up with the demand for electricity, the government has invested quite a large sum of money in efforts to upgrade current power plant facilities as well as building new sites for hydro power stations and an independent power plants (IPP). All these plans, however, come at a price as more land needs to be cleared to make way for site expansion, inevitably destroying the natural habitats of wildlife and water catchment areas, adding impetus to the already increasing global warming (Younggew Kim, 2013).

The government announced a plan to pursue nuclear energy a few years ago, but Fukushima nuclear disaster in 2011 caused the project plan to stop until the demand for energy become a crisis and the government was able to convince the people that nuclear power was the way forward. Until then, other efforts to increase production, reduce wastage, and conserve energy are the only solution (Aref D. L., 2010).

One of the requirements for the green building index (GBI) is indoor air quality, which contributes 20% for the GBI rating, but the ceiling height mentioned only in the UBBL is not based on a study review of the data obtained for Malaysia but on world studies in 1970 because of the relative humidity, temperature condition and different climate performance of many countries. The guideline was never tested experimentally in Malaysia (Communication with Dato' Badaruddin Mohd Isa, Fire Chief Malaysia, 2014).

The UBBL shows minimum height but not the optimum height. Advent of green building uses physical dimensions to improve energy efficiency. Therefore, it is possible to design a thermally comfortable space using only the building geometry.

(Leopold, 2016) predicted indoor temperature and humidity in buildings found in a hot-humid region (Cameroon) using an artificial neural network for an hourly prediction; (Zhu, 2016) proposed an alternative method to predict future weather data generation for a future building energy demand simulation in Shanghai. The combination works of (Awbi, 1991 and Gan, 2010) using CFD to predict the room geometry with a critical size and room ventilation helped in the selectionof a suitable geometry for use in the United Kingdom.The target temperature of this study is 27 ºC, while the data have been collected when the air conditioning unit was off and the air movement inside the rooms was very slow,where, this target shows agreement with both (Zhu, 2016) in China and (Leopold, 2016) in Cameron.

Therefore, this research will be based on the development of a room model using CFD and will investigate the minimum geometry (volume, length and height) inside houses to obtain thermal comfort for its occupants. The application of this study is built on the fundamentals of thermal comfort in the ASHRAE handbook

1.3 Objectives

The overall objective of this study is to develop room model by estimating the minimum ceiling height for acceptable air temperature and achieve the thermal comfort condition. Specific objectives are as follows:
1- To determine the minimum geometry parameters (volume, area and ceiling height) in houses to reach to the thermal comfort zone for the occupants.
2- To acquire base data on room geometry, wall materials and room temperature.
3- To design new room model by using CFD and dimensionless parameters.

1.4 Scope and limitation

This study is concerned with determining the minimum geometry parameters for thermal comfort using the air temperature at two different locations in a room: near the ceiling and at the centre of the room. Various parameters or field measurements are measured while conducting the experiments. The experimental results are affected by some unexpected factors, such as the door, the window orientation, the indoor and outdoor climate (where there is a difference in the temperature between indoors and outdoors - $\Delta T \geq 5$ ºC), the construction material and the physical layout of the room.

Field data is limited to rooms with direct ceiling to exposed roof in the Klang Valley. The data collection conducted was for government buildings and privet houses between 2012 and 2013.The data collection was conductedon sunny days. The adopt methodology followed Cenjal (2014) and Shieh (2007).
Numerical simulation was done by the FLUENT version 16.4 where the air flow was assumed to be turbulent adopting model (k-ε) difference for room designfollowing Joel et al.,(1999). The indoor ventilation is a major issue and the air temperature, solar radiation, humidity and air velocity are of the most important parameters affecting the natural ventilation inside the buildings (Wahhad, 2016).

1.5 Thesis Outline

There are six main chapters altogether in this thesis.
Chapter 1 (Introduction) included the overview of the study, problem statement, scope and limitation and the objectives.

Chapter 2 (Literature Review) is a compilation of previous studies and other forms of literature that support the methods to be applied in Chapter 3. The review includes the basics of the Uniform Building By Low Act 1984, traditional and modern houses materials, green buildings, thermal comfort concept and CFD simulation application in ventilation studies.

Chapter 3 (Dimensional Analysis) the theoretical study related to the Buckingham Π theorem and the simulation part of theorem.

Chapter 4 (Methodology) will be the detailed explanation and step-by-steps on how to simulate the data that collected from the field study and boundary conditions.

Chapter 5 (Results) includes the discussion regarding the final findings of the study, the obstacles faced in obtaining them, as well as to how it compares to the standards which are already established by certified researchers and organizations.

Chapter 6 (Conclusion) draws an inference of the entire research and how it has accomplished its initially stated objectives. Any other suggestions of improvement to the study and how the findings may be of benefit to society is stated in this chapter.

REFERENCES

Aktacir, M. A., Büyükalaca, O., & Yılmaz, T. A case study for influence of building thermal insulation on cooling load and air-conditioning system in the hot and humid regions. Applied Energy, 87(2)(2010), 599-607.

AmirHosein GhaffarianHoseini,Umberto Berardi,Nur Dalilah Dahlan, Ali GhaffarianHoseini. What can we learn from Malay vernacular houses? Sustainable Cities and Society 13 (2014) 157–170.

Amirul Imran M. Ali, and Nadzirah Zainordin. User Perception towards Green Building Practice at PUSAT TENAGA MALAYSIA (Geo Building). 2nd International Conference on Environment, Agriculture and Food Sciences (ICEAFS'2013) May 6-7, (2013) Kuala Lumpur (Malaysia)

Anastasios I. Stamou. Improving the hydraulic efficiency of water process tanks using CFD models. Chemical Engineering and Processing: Process Intensification, Volume 47, Issue 8, August (2008), Pages 1179-1189.

ANSYS[a], Chapter 25: Using the solver, FLUENT V6.3 User Manual. FLUENT Inc. (2006).

ANSYS[b], Chapter 13: Modeling Heat Transfer, FLUENT V6.3 User Manual. FLUENT Inc. (2006).

Asmarashid Ponniran, NA Mamat, A Joret. Electricity profile study for domestic and ommercial sectors. International Journal of Integrated Engineering 4 (3) (2012).

Aref, D. L. Nuclear Energy: the Good, the Bad, and the Debatable. Massachusetts Institute of Technology (2010).

Arundel, A. V., Sterling, E. M., Biggin, J. H., and Sterling, T. D. 1986. Indirect health effects of relative humidity in indoor environments. Environmental Health Perspectives, 65, 351.

ASHRAE. 1985. ASHRAE Handbook. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (1992). Standard 55 - Thermal Environmental Conditions for Human Occupancy. Atlanta, ASHRAE Inc

ASHRAE. (2012). Standard 55 - Thermal Environmental Conditions for Human Occupancy. new edition Atlanta, ASHRAE Inc

Awbi H. B., (1991). Ventilation of Buildings Book. E & FN SPON Publisher.

Awbi H. B., Air movement in naturally ventilated buildings, Renewable Energy journal, (1996). PP. 241-247.

Basit M. A., Rafique M. Chungtai I. R. and Inayat M. H. Computer simulation of natural convection heat transfer from an assembly of vertical cylinders of PARR-2. Applied Thermal Engineering 27 (2007) p194-201.

Blocken, B., Defraeye, T., Derome, D. & Carmeliet, J. High-resolution CFD simulations for forced convective heat transfer coefficients at the facade of a low-rise building. Building and Environment, 44**,**(2009) 2396-2412.

Board of Engineering Malaysia hand book, 2009.

Braga, W. Simulation and theory of model. Experimental Mechanics 2011, Ellos, New York.

Chad L., Zhang R, Zhang Y, Hong H, Meng Q., Feng Y. A case study of climatic conditions: the evaporation from porous tile on roof thermal performance. Energy and Buildings, Volume 3, (1998), Pages 168-172.

Çengel Y. A., John M. Cimbala (2014) Fluid Mechanics: Fundamentals and Applications, 3rd Ed., McGraw-Hill

Cengel, Y. A. (2005) Heat and Mass Transfer A Practical Approach, McGraw-Hill.

Cheong, K.W.D., Djunaedy, E., Chua, Y.L., Tham, K.W., Sekhar, S.C., Wong, N.H., and Ullah, M.B. 2003. Thermal comfort study of an air-conditioned lecture theatre in the tropics. Singapore: Building and Environment 38 (2003) 63 – 73

Chiang C. M., Chi-Ming Lai, Po-Cheng Chou, Yen-Yi Li. The influence of an architectural design alternative (transoms) on indoor air environment in conventional kitchens in Taiwan. Building and Environment, Volume 35, Issue 7, 1 October (2000), Pages 579-585.

Chu, C.-M. & Jong, T.-L. Enthalpy estimation for thermal comfort and energy saving in air conditioning system. Energy Conversion and Management, 49**,** (2008) 1620-1628.

Chua Fuh Yiing, Naziaty Mohd Yaacob, Hazreena Hussein Procedia - Social and Behavioral Sciences 101 (2013) 120-129.

Dane Miller, Jeung-Hwan Doh, Kriengsak Panuwatwanich, Niek van Oers. The contribution of structural design to green building rating systems: An industry perspective and comparison of life cycle energy considerations. Sustainable Cities and Society 16 (2015) 39-48.

Darus, Z., Hashim, N.A., Salleh, E., Lim, C.H., Abdul Rashid, A.K., Abdul Manan, S.N., Development of Rating System for Sustainable Building in Malaysia, WSEAS Transactions on Environment and Development, Issue 3, Vol. 5, (2009).

Dong-Xue Zhao, Bao-Jie He, Christine Johnson, Ben Mou. Social problems of green buildings: From the humanistic needs to social acceptance. Renewable and Sustainable Energy Reviews. 51 (2015) 1594 - 1609.

Electricity Supply Department, Statistics of Electricity Supply Industry in Malaysia, Suruhanjaya Tenaga, Kuala Lumpur, Malaysia, (2005).

EPI, Environmental Performance Index, (2014).

Fanger, P Ole (1970). Thermal Comfort: Analysis and applications in environmental engineering. McGraw-Hill

Fergus Nicol. Adaptive thermal comfort standards in the hot–humid tropics. Energy and Buildings, Volume 36, Issue 7, July (2004), Pages 628-637.

FLUENT User's Guide, FLUENT Inc., New Hampshire, USA, (2006).

Fu E Tang.. An Energy Consumption Study for a Malaysian University. International Journal of Environment, Ecological, Geological and Mining Engineering, Vol:6 No:8 (2012).

Gan, G. Numerical evaluation of thermal comfort in rooms with dynamic insulation. Building and Environment, 35**,**(2000) 445-453.

Gandemer J., Guide K. The aerodynamic characteristics of windbreaks, resulting in empirical design rules. Journal of Wind Engineering and Industrial Aerodynamics, Volume 7, Issue 1, (1992), Pages 15-36.

Gao, C. F., Lee, W. L. & Chen, H. Locating room air-conditioners at floor level for energy saving in residential buildings. Energy Conversion and Management, 50**,**(2009) 2009-2019.

Gastelurutia J., Ramos J. C. Larraona G. S., Rivas A., Izagirre J., Luis del Rio. Numerical modeling of natural convection of oil inside distribution transformers, Applied Thermal Engineering (2011) 31, p493-505.

Glory Kong. Combined Air-Conditioning and Air Circulation for Thermal Comfort. Project, UCSI University. (2015)

Hardy, J.D. Thermal comfort and health. ASHRAE Journal (1971)13:43.

Hatch, M. T., and Wolochow, H. (1969). Bacterial survival: consequences of the airborne state (pp. 267-295). In R. L. Dimmick, and A.B. Akers (ed.), An Introduction to Experimental Aerobiology, Wiley-Interscience: New York.

Hoseini, A.H., Hoseini, A.G, Makaremi, N. and Hoseini, M.G., The concept of Zero Energy Intelligent Building (ZEIB): A Review of Sustainable Development for Future Cities, British Journal of Environment & climate Change, (2012).

Ioannou A., Itard L.C.M., Energy performance and comfort in residential buildings: sensitivity for building parameters and occupancy, Energy Build. 92 (2015) 216–233.

Ir. Ahmad. (2012). Nuclear energy: an option ahead for the world. MySET 21st Century Professionals Newsletter: 2421-07-WKL.

Jaluria Y. Natural convection - HMT: the science and applications of heat and mass transfer, vol. 5, Pergamon Press Ltd., Oxford, England (1980) ISBN 0-08-025432-2.

Joel H., Ferziger and Milovan Peric. (1999). Computational Methods for Fluid Dynamics. Springer-Verlag Berlin Heidelberg New York.

Kameni Nematchoua Modeste, René Tchinda, Noël Djongyang. Numerical study for thermal comfort and energy saving using small fan to assisted air conditioner. Universal Journal of Environmental Research and Technology. (2013) Volume 3, Issue 5: 555-570

Kelly S., Shipworth M., Shipworth D., Gentry M., Wright A., Pollitt M., Predicting the diversity of internal temperatures from the English residential sector using panel methods, Appl. Energy 102 (2013) 601–621

Kindangen J., Krauss G., Depecker P. Effects of roof shapes on wind-induced air motion inside buildings. Building and Environment, Volume 32, Issue 1, January (1997), Pages 1-11

Kleinstreur, C. Engineering Fluid Dynamics - An Interdisciplinary system approach. Cambridge University Press, Cambridge shire, UK (1997).

KukrejaV. K., Shelly Arora, Dhaliwal S.S. A computationally efficient technique for solving two point boundary value problems in roof design. Applied Mathematics and Computation, Volume 8, (1997), Pages 1170-1180

Kulkarni, R. (1998) Natural convection in enclosures with localized heating and cooling, PhD Thesis, Department of Mechanical Engineering, University of Wollongong, Australia.

Langhaar, H. L. Dimensional analysis and theory of models, Robert E Krugher publishing Co., Inc, New York. ISBN 0-88275-682-6(1980).

Laws of Malaysia, Uniform Building By-Laws (1984). International Law Book Services, Selangor.

Liew, P. Y., Achievability of Green Building Index Malaysia, Faculty of Engineering and Science, University Tunku Abdul Rahman, (2012).

Lin W. X. and Armfield S. W. Natural convection cooling of rectangular and cylindrical, International Journal Heat and Fluid Flow 22 (2001), p72-81.

Leopold Mba, Pierre Meukam, Alexis Kemajou. Application of artificial neural network for predicting hourly indoorair temperature and relative humidity in modern building in humid region. Energy and Buildings 121 (2016) 32–42.

Mateo F., Carrasco J.J., Sellami A., Millán-Giraldo M., Domínguez M., Soria-Olivas E., Machine learning methods to forecast temperature in buildings, Expert Syst. Appl. 40 (2013) 1061–1068

McCullough, E. A., Jones, B. W., & Huck, J.. A comprehensive data base for estimating clothing insulation. Ashrae Trans, 91(2), (1985)29-47.

McIntyre, D.. Preferred Air Speed for Comfort in Warm Conditions. ASHRAE. Transactions 84 (2), (1978)264 – 277

Mehrbakhsh Nilashi, Rozana Zakaria, Othman Ibrahim, Muhd Zaimi Abd. Majid, Rosli Mohamad Zin, Muhammad Waseem Chugtai, Nur Izieadiana Zainal Abidin, Shaza Rina Sahamir, Dodo Aminu Yakubu. A knowledge-based expert system for assessing the performance level of green buildings. Knowledge-Based Systems. 86 (2015) 194 - 209

Metibogum, L., Mat Raschid, M.Y., Green Building Technology in Context of Sustainable Housing Affordability in Malaysia: An review, International Journal of Engineering Research and Development (IJERD), (2013).

Mohd Peter Davis, Nurizan Yahaya, Bukryman Sabri, Anniz Fazli Ibrahim Bajunid, Chou Kan Yin and Mazlin Ghazali. A Modern Housing Solution for 700 million Families in Developing Countries. Procedia - Social and Behavioral Sciences 49 (2012) 237 – 244

Mohd Peter Davis, S. Shanmugavelu and Normariah Adam. Overheating in Malaysian houses. Affordable Quality Housing Seminar, UPM, 7, May (2012).

Nagarajan, R. Simulation Analysis: Full and partial, advanced transport phenomena. Department of Engineering, Indian Institute of Technology, Madras (2010).

Ng, B.H., & Akasah, Z.A., An Overview of Malaysia Green Technology Corporation Office Building: A Showcase Energy Efficiency Building Project in Malaysia, Journal of Sustainable Development, Vol. 4, No. 5, (2011).

Ng, K. C., Kadirgama, K. & Ng, E. Y. K. Response surface models for CFD predictions of air diffusion performance index in a displacement ventilated office. Energy and Buildings, 40**,**(2008) 774-781.

Nora H., (2014). Malaysia's Environmental Performance Index. The Ministry of Natural Resources and Environment (NRE) and Universiti Teknologi Malaysia (UTM)

Novak M. H. and Nowak E. S. The CAV program for numerical evaluation of laminar natural convection heat transfer in vertical rectangular cavities. Computer Physics Communication (1993) 78, p95-104.

Olgyay G. Environment, Land Use, and Development: The Case of Vermont. The Effect of Modern Agriculture on Rural Development, (1973), Pages 85-95

Pachauri, R.K., and Reisinger, A.. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland. (2007) pp 104

Pheh Guan Choon, Determination of Optimum Ceiling Height for A room in the Laboratory. (2004), Master thesis.

Prianto E. Optimization of architectural design elements in tropical humid region with thermal comfort approach. Energy and Buildings, Volume 35, Issue 3, March (2003), Pages 273-280

Richard Clarida, Jordi Gali. Sources of real exchange-rate fluctuations: How important are nominal shocks? Carnegie-Rochester Conference Series on Public Policy, Volume 41, December (1998), Pages 1-56

Rodriguez I., Castro J., Perez Segarra C. D., Oliva A. Unsteady numerical simulation of the cooling process of vertical storage tanks under laminar natural convection, international Journal of Thermal Sciences 48: p708-721 (2009).

Sahoo N. Dimensional Analysis and hydraulic similitude. Fluid Mechanics, IIT Guwahati, India (2012).

Saidur R., H.H. Masjuki, M.Y. Jamaluddin, An application of energy and exergy analysis in residential sector of Malaysia, Energy Policy 35 (2007) 1050–1063.

Saidur R., H.H. Masjuki, M.Y. Jamaluddin, S. Ahmed, Energy and associated greenhouse gas emissions from household appliances in Malaysia, Energy Policy 35 (2007) 1648–1657

Saidur R., Energy consumption, energy savings, and emission analysis in Malaysian office buildings, Energy Policy 37 (2009) 4104–4113.

Samari, M., Gordrati, N., Esmaeilifar, R, Olfat, P., and Mohd Shafiei, M. W., The Investigation of the Barriers in Developing Green Building in Malaysia, Candidate Center of Science and Education, Modern Applied Science; Vol. 7, No. 2, (2013).

Santamouris M., Alevizos S.M., Aslanoglou L., Mantzios D., Milonas P., Sarelli I., Freezing the poor—indoor environmental quality in low and very low income households during the winter period in Athens, Energy Build. 70(2014) 61–70.

Sekhar SC. 1995. Higher space temperatures and better thermal comfort – a tropical analysis. Singapore: Energy and Buildings 23 (1995) 63 – 70.

Sert, C. Part 6- Dimensional analysis and similitude. ME305 Fluid Mechanics 1. Meddle East Technical University, Ankara, Turkey (2001).

Simone, Angela; Olesen, Bjarne W. Preferred Air Velocity and Local Cooling Effect of desk fans in warm environment. Proceedings of the 34th AIVC conference (2013).

Stamou, A. & Katsiris, I. Verification of a CFD model for indoor airflow and heat transfer. Building and Environment, 41**,**(2006) 1171-1181.

Stavrakakis, G. M., Zervas, P. L., Sarimveis, H. & Markatos, N. C. Development of a computational tool to quantify architectural-design effects on thermal comfort in naturally ventilated rural houses. *Building and Environment*, 45**,**(2010) 65-80.

Stefano Schiavon, Arsen K. Melikov. 2008. Energy saving and improved comfort by increased air movement. Energy and Buildings 40 (2008) 1954–1960.

Stern, F. Chapter 5 Dimensional analysis and modeling. 58:160 Intermediate Mechanics of Fluids, University of Iowa, USA (2010).

Suhaida Mohd Sood, Dr. K. H. Chua, Dr. Leong Yow Peng.. Sustainable Development in the Building Sector: Green Building Framework in Malaysia.ST-8: Best Practices & SD in Construction Paper #: 08-02(2011).

Surat Atthajariyakul, & Charoenporn Lertsatittanakorn. 2008. Small fan assisted air conditioner for thermal comfort and energy saving in Thailand. Thailand: Energy

Conversion and Management 49 (2008) 2499–2504

Tan, C.S., K. Maragatham, and Y.P. Leong. Electricity Energy Outlook in Malaysia. IOP Conference Series: Earth and Environment Science 16 (2013) 21-26.

Tenaga Nasional Berhad. (2014). Electricity tariff schedule. Available from: http://www.tnb.com.my

Tetsu Kubota, Doris Hooi Chyee Toe. Application of passive cooling techniques in vernacular houses to modern houses: A case study of Malaysia. Procedia - Social and Behavioral Sciences 179 (2015) 29 - 39.

Thammanoon S., Sumaeth C., Supachai G., Susumu Y. Enhanced efficiency of dye-sensitized solar cell using double-layered conducting glass. Thin Solid Films, Volume 516, Issue 21, 1 September (2008), Pages 7802-7806.

Tomohiro Kobayashi, Tomoyuki Chikamoto, Keishi Osada. Evaluation of ventilation performance of monitor roof in residential area based on simplified estimation and CFD analysis. Building and Environment 63 (2013) 20-30

Tseng Y. S., Lin C. H., Yuann Y. R., Wang J. R. and Tsai F. P. Analyzing the alternative shutdown cooling behaviors for Chinshan Nuclear power plant using CFD simulation. Annals of Nuclear Energy (2011) 38, p2557-2568.

UNDP, Achieving Industrial Energy Efficiency in Malaysia, United Nations Development Programme (UNDP), Malaysia, (2006).

UBBL Act. 1984, Uniform Building By Law, (1984).

Wahhad, A. M. A. Effects Of Selected Shading Devices On An Office Room Temperature Distribution.Mechanical Engineering. Selangor, UPM (2007).

Wahhad, A. M. A. Development Of Optimum Window Size in A Tropical Climate With The Use of Computational Fluid Dynamics and Experimental Works. PhD Thesis (2016).

Webb W. S., Francis N. D., Dunn S. D., Itamura M. T. and James D. L. Thermally induced natural convection effects in yucca Mountain drifts, Journal of Contaminant Hydrology 62-63: p713-730 (2003).

World Resources Institute (2014).

Xing, Y., Hadzic, I., Muzaferija, S. & Peric, M. CFD Simulation of Flow−Induced Floating−Body Motions. *Fluid Dynamics and Ship Theory Section.* Hamburg, Germany, Technical University of Hamburg (2001).

YauY. H,. PeanH. L. The climate change impact on air conditioner system and reliability in Malaysia - A review. Renewable and Sustainable Energy Reviews 15 (2011) 4939-4949.

Yeo An Thai, Framework Development for Effective Implementation of Green Building in Malaysia. Master Thesis(2015).

Younggew Kim. Nuclear Power Plant: All things considered, Can nuclear power be beneficial to mankind? What is needed to make nuclear power more sustainable? Master thesis (2013)

ZhuMingya, Yiqun Pan, Zhizhong Huang, Peng Xua. An Alternative Method To Predict Future Weather Data For Buildingenergy Demand Simulation Under Global Climate Change. Energy and Buildings 113 (2016) 74–86

Zufeng Pei, Borong Lin, Yanchen Liu, Yingxin Zhu. Comparative study on the indoor environment quality of green office buildings in China with a long-term field measurement and investigation. Building and Environment. 84 (2015) 80-88.

LIST OF PUBLICATIONS

M.W. Muhieldeen, N.M. Adam, B.H. Salman. Experimental and numerical studies of reducing cooling load of lecture hall. Energy and Buildings 89 (2015) 163–169 (Q1).

M. W. Muhieldeen, N. M. Adam, N. A Abdul Aziz. Develop of Mathematical Model to Predict Temperature in room Based on Geometry. Applied Thermal Engineering Journal (Q1). (under review).

M. W. Muhieldeen, N. M. Adam, Glory K.P.L., M. M. AL-Imam. Saving Energy Costs By Controlling Air-Conditioning and Air Circulation using CFD To Achieve Thermal Comfort. Applied Energy (Q1). (under review).

M. W. Al-Gailani, N. M. Adam and Azizah Salim, Passive Strategies to Cool Terraced House in Serdang, Proceedings Affordable Quality Housing 13-15 Mar 2013, Putrajaya.

UNIVERSITI PUTRA MALAYSIA

STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT

ACADEMIC SESSION : ____________________

TITLE OF THESIS / PROJECT REPORT :

DEVELOPMENT OF A MODEL TO PREDICT ROOM TEMPERATURE BASED ON ROOM GEOMETRY USING COMPUTATIONAL FLUID DYNAMICS

NAME OF STUDENT: MOHAMMED W. MUHIELDEEN AL-GAILANI

I acknowledge that the copyright and other intellectual property in the thesis/project report belonged to Universiti Putra Malaysia and I agree to allow this thesis/project report to be placed at the library under the following terms:

1. This thesis/project report is the property of Universiti Putra Malaysia.
2. The library of Universiti Putra Malaysia has the right to make copies for educational purposes only.
3. The library of Universiti Putra Malaysia is allowed to make copies of this thesis for academic exchange.

I declare that this thesis is classified as :

*Please tick (√)

☐	**CONFIDENTIAL**	(Contain confidential information under Official Secret Act 1972).
☐	**RESTRICTED**	(Contains restricted information as specified by the organization/institution where research was done).
☐	**OPEN ACCESS**	I agree that my thesis/project report to be published as hard copy or online open access.

This thesis is submitted for :

☐	**PATENT**	Embargo from_____________ until ______________ (date) (date)

Approved by:

(Signature of Student) New IC No/ Passport No.:	(Signature of Chairman of Supervisory Committee) Name:
Date :	Date :

[Note : If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization/institution with period and reasons for confidentially or restricted.]