UNIVERSITI PUTRA MALAYSIA

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

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By

MOHAMMED W. MUHIELDEEN AL-GAILANI

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January 2017

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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

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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.

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Mohammed W. Muhieldeen Al-Gailani
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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.

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