Faculty of Engineering

SPACE SPECIFIC THERMAL COMFORT MODELLING FOR INDIVIDUALLY OCCUPIED OFFICE

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SPACE SPECIFIC THERMAL COMFORT MODELING FOR INDIVIDUALLY OCCUPIED OFFICE

WAN NORMARDHIAH BINTI WAN ‘AIZUDDIN

A dissertation submitted in partial fulfilment
of the requirement for the degree of
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Dedicated to my beloved parent and family members, respected lecturers, and supportive people in my life

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ABSTRACT

In-office buildings, there has been an increasing need for a comfortable working environment as people work for longer hours throughout the day. Thermal comfort contributes not only to productivity and efficiency but even to human's health. Besides, the principal purpose of the HVAC system is to provide comfortable conditions for people. Therefore, the primary goal of this study was to evaluate the thermal comfort in a centrally air-conditioned individually occupied office. Environmental factors such as operating temperature, relative humidity, and airflow in the office were considered, which influence thermal comfort behaviour. The survey analysis using ASHRAE thermal sensation scale and comfort prediction using physical measurement was conducted as a preliminary result in thermal comfort evaluation. Based on the cooling load temperature difference method, the supply air was sufficient for the individually occupied office. Besides, Computational Fluid Dynamics was used to analyse the effect of HVAC component configurations such as supply and return diffuser number and position to the thermal comfort behaviour. The physical model of individually occupied office was modelled using CAD software while the temperature and distribution of air were simulated using Finite Volume Method by the Computational Fluid Dynamics tool. The results revealed that thermal comfort provides better conditions by reducing the volume flow rate from the supply air conditioning diffuser. In addition, the single supply with two return diffusers of the HVAC system improves the average airspeed in the office space by 37 % to the existing individual occupied office. This study can also be extended to various HVAC buildings such as retail facilities, hospitals, hotels, and educational facilities.

Keywords – Thermal comfort, Computational Fluid Dynamics, Air conditioning, Office space

ABSTRAK

Di bangunan pejabat, terdapat peningkatan keperluan untuk persekitaran kerja yang selesa kerana manusia bekerja lebih lama sepanjang hari. Keselesaan termal menyumbang bukan sahaja kepada produktiviti dan kecekapan bahkan kesihatan manusia. Selain itu, tujuan utama parameter sistem HVAC adalah untuk menyediakan keadaan yang selesa kepada manusia. Oleh itu, tujuan utama kajian ini adalah untuk menilai keselesaan termal dalam penghawa dingin terpusat di pejabat yang diduduki secara individu perseorangan. Faktor persekitaran seperti suhu operasi, kelembapan relatif dan aliran udara di pejabat dipertimbangkan yang mempengaruhi tingkah laku keselesaan terma. Analisis tinjauan menggunakan skala sensasi terma ASHRAE dan ramalan keselesaan menggunakan pengukuran fizikal dilakukan sebagai hasil awal dalam penilaian keselesaan termal. Berdasarkan kaedah pengiraan beban penyejukan, udara bekalan mencukupi untuk pejabat yang diduduki seseorang individu. Selain itu, Perkomputeran Dinamik Bendalir digunakan untuk menganalisis pengaruh konfigurasi komponen HVAC seperti bilangan dan kedudukan penyebar bekalan dan pengembalian terhadap tingkah laku keselesaan terma. Model fizikal pejabat yang diduduki secara individu dicipta menggunakan perisian CAD sementara pengedaran suhu dan udara disimulasikan dengan Kaedah Isipadu Terhingga menggunakan alat Perkomputeran Dinamik Bendalir. Hasil kajian menunjukkan bahawa keselesaan termal menyediakan keadaan yang lebih baik dengan pengurangan kadar aliran isipadu dari penyebar bekalan penyaman udara. Tambahan lagi, dengan penyebar bekalan masuk tunggal dengan dua penyebar keluar dari sistem HVAC menyediakan penambahbaikkan dalam kelajuan udara purata dengan 37 % berbanding ruang pejabat yang sudah ada. Kajian ini juga dapat diperluas ke berbagai bangunan seperti kemudahan runcit, hospital, hotel dan kemudahan pendidikan.

Kata Kunci – Keselesaan termal, Perkomputeran Dinamik Bendalir, Penyaman udara, Ruang pejabat

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LIST OF ABBREVIATIONS

3D	–	Three-dimensional
AC	–	Air-conditioning
ACMV	–	Air-conditioning and mechanical ventilation
AHU	–	Air handling unit
ASHRAE	–	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CAD	–	Computer-aided design
CFD	–	Computational Fluid Dynamics
CLF	–	Cooling Load Factors
CLTD	–	Cooling Load Temperature Difference
COP	–	Code of Practices
DBT	–	Dry-bulb temperature
DPT	–	Dew point temperature
FEM	–	Finite Element Method
FVM	–	Finite Volume Method
HPC	–	High-performance computing
HVAC	–	Heating, Ventilating, and Air-Conditioning
IEQ	–	Indoor Environment Quality
RANS	–	Reynolds averaged Navier-Stokes
RH	–	Relative humidity
SC	–	Shading coefficient
SCL	–	Solar cooling load factor
SIMPLE	–	Semi Implicit Method for Pressure Linked Equations
TPV	–	Thermal preference vote
TSV	–	Thermal sensational vote
WBT	–	Wet-bulb temperature
WHS	–	Workplace (Health, Safety, and Welfare)

LIST OF SYMBOLS

A	–	Surface area
β	–	Thermal expansion coefficient
C_p	–	Specific heat
D	–	Diameter
ε	–	Rate of dissipation
f	–	Force
$\overrightarrow{f_b}$	–	Vector body force
$\overrightarrow{f_s}$	–	Vector surfaces force
g	–	Gravitational acceleration
H	–	Height
k	–	Thermal conductivity
K	–	Kinetic energy
λ	–	Bulk viscosity coefficient
L	–	Length
μ	–	Fluid viscosity
p	–	Pressure
ρ	–	Density
$\dot{q}_s$	–	Rate of heat transfer per unit area
$\dot{q}_v$	–	Rate of heat source per unit volume
$\dot{Q}$	–	Overall heat transfer per unit time
$\dot{Q}_i$	–	Heat gain per unit time
Re	–	Reynold number
σ	–	Viscous force
t	–	Time
$\vec{\tau}$	–	Vector stress tensor
$\bar{T}$	–	Mean indoor temperature
T_1	–	Room temperature
T_2	–	Outside temperature

T_a	–	Air temperature
T_o	–	Operative temperature
T_r	–	Mean radiant temperature
T_∞	–	Mean wall temperature
$\hat{u}$	–	Internal energy
U	–	Overall heat transfer coefficient
v	–	Velocity
$\vec{v}$	–	Vector velocity
$\bar{\vec{v}}$	–	Mean vector velocity
W	–	Width

CHAPTER 1

INTRODUCTION

1.0 Background of Study

In order to improve the attention, concentration, and performance of the occupants, a comfortable indoor thermal environment is essential in a building (Farooq & Brown, 2009). The definition of thermal comfort is a satisfaction condition of mind with the thermal surrounding. Thermal comfort can be maintained by considering the six significant factors classified into two groups of factors, which are personal and environmental. However, a designer can only influence the environmental factors since personal factors beyond the control of the designer (Raish, 2017). The environmental factors include the operative temperature, relative humidity, and airspeed in indoor space.

ASHRAE-55 has provided the standards to encourage comfort behaviour to occupants in an office building. This standard specifies the acceptable condition of thermal environmental for healthy adults in designed indoor spaces for occupancy of people at atmospheric pressure for periods of up to 15 minutes. Besides, the optimum thermal comfort preference can be obtained according to the occupant's activity and clothing.

However, in-office building, Heating, Ventilating, and Air-Conditioning (HVAC) systems serve the most crucial aspect of thermal comfort behaviour. However, working people that provide unsafely behaviour, inability to make decisions, and deteriorates in performing manual tasks are the effect in uncomfortably hot and cold environments. Essentially, the HVAC system needs to supply adequate air to maintain the optimum environmental factors in the buildings (EPA, 1997).

1.1 Research Problem

Nowadays, air-conditioned ventilation is essential in a building. It influences not only to human's productivity but also the health. According to Jianyun et al. (2020), an outbreak of coronavirus disease 2019 in an air-conditioned restaurant in Guangzhou, China, involved three family clusters, most likely caused by the strong airflow from the air conditioner which could have propagated droplets from one table to another. Besides, with the modern office revolution, the individually occupied office serves many benefits in terms of privacy, concentration, and health (News Company, 2018). However, thermal comfort in workplaces, which is given the advancement in air-conditioning (AC) technology, seems like a far-fetched idea. There is always a worker who feels it is too hot, or it is too cold in their private office space. Occupants in an office building working in an uncomfortably environmental condition contribute to unproductivity and an unhealthy working environment. For example, the ability to concentrate on a particular task may start to decline, increasing the risk of errors occurring, employees may procrastinate work and contribute to health risks such as allergies reaction and asthma. Since every employee dream on the optimal spot thermally in an office (Harish, 2019), then an estimation tool is needed to assess the optimum comfort behaviour level in private office based on parameters considered. Therefore, what is the thermal comfort condition in air conditioning individually occupied office based on the environmental factors? And what is the effect of the HVAC component configuration on temperature and airflow distribution by using Computational Fluid Dynamics (CFD) tool?

1.2 Research Objective

The objectives of this study are:

i. To evaluate thermal comfort in an individually occupied space in an office building by considering thermal comfort parameters, which are operative temperature, relative humidity, and airflow in the space.

ii. To model the effect of HVAC component configuration on thermal comfort behaviour using Computational Fluid Dynamics (CFD).

1.3 Scope of Work

The scope of works in this research as follows:

i. The study is focused on individually occupied office space.
ii. The study will be conducted by simulation using Computational Fluid Dynamics (CFD) tool.
iii. The solution is focused on the HVAC component configuration, specifically on supply and return air diffuser positioning and number.

CHAPTER 2

LITERATURE REVIEW

2.0 Overview

This chapter reviews previous research on thermal comfort studies and model issues, especially in the individually occupied office. The purpose of this chapter is to introduce the reader, thermal comfort in the office environment, and standards and regulations related to thermal comfort.

There are some essential parameters discussed in this chapter, such as space temperature, relative humidity, and airflow behaviour that would affect the work performance of the occupants in the space. These parameters become the references throughout the Computational Fluid Dynamics (CFD) model study to ensure the model can provide accurate simulation results to the actual conditions in the individual occupied office.

2.1 Thermal Comfort

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standard 55 has defined thermal comfort as "that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation."

A balance between the rate of metabolic heat production and losses relied on human thermal comfort caused by trade with the surrounding environment (Rowe, 2001).

Two primary factors affect the conditions for the thermal comfort of occupants, which are environmental factors (dry-bulb air temperature, temperature of radiant, airspeed, and relative humidity) and individual factors (metabolic rate and clothing thermal insulation). Figure 1 shows the human body's thermal contact with the environment.

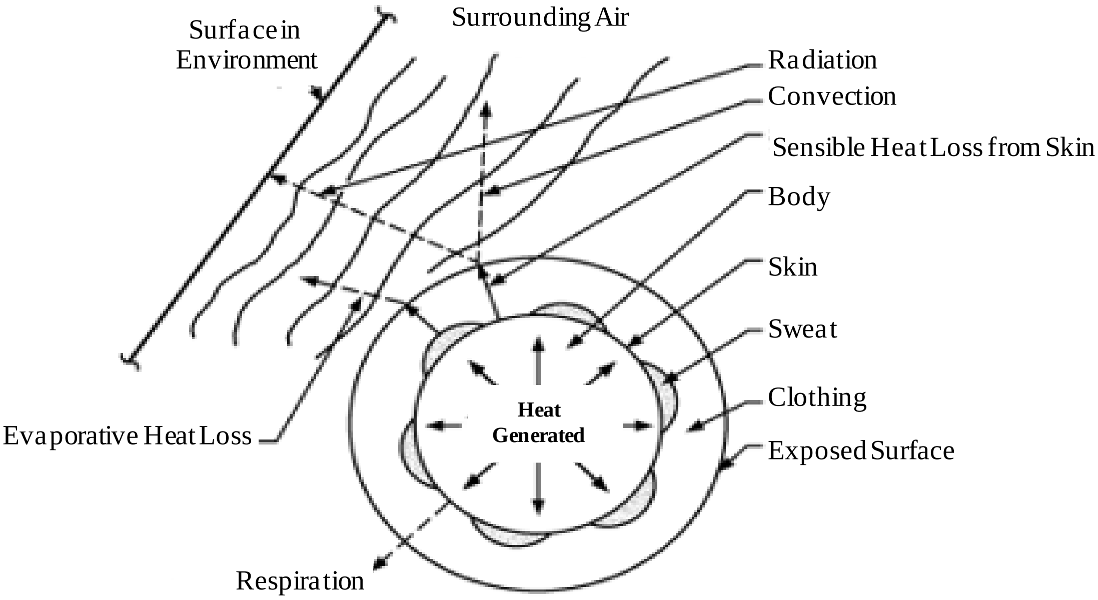

Figure 1: Human Body Interaction with Environment (ASHRAE-55)

Moreover, as 'warm-blooded' mammals, to stay healthy and active, human beings require an almost constant internal body temperature. The body releases metabolic energy, and it flows to the environment. The body should be managed to maintain the internal organs, and the brain, at about 37 ˚C temperature. Since the occupants are moving about with the changes of the indoor environment, then the interaction between the human body and the environment is declared as a dynamic process (Nicol, 2013).

However, thermal comfort can be controlled through the HVAC system. The HVAC system is an air treatment process that regulates the temperature, humidity, cleanliness, and conditioned space distribution, which sometimes referred to climate control. Humidity can be controlled either locally or via the air-conditioning (AC) system by providing humidification or dehumidification systems. HVAC systems are also critical to the safety of occupants because a well-regulated and controlled system will keep the spaces clear from mould and other harmful organisms (I. A. Bhatia, 2012; Md Yusof, 2011).

Therefore, the HVAC component, such as diffusers needs to provide good behaviour of airflow. According to ASHRAE Handbook Fundamental (2017), the discharge temperature cannot be more than 8 °C above the room temperature, and the terminal speed of 7.6 m/s from the diffuser shall reach up to 1.4 m from the floor. This medium avoids short-circuiting airflow to the return diffuser; otherwise, it is necessary to increase the rate of ventilation by 25 %.

2.2 Office Environment

Thermal comfort is an essential requirement for building users, which is a crucial metric of a building's overall Indoor Environment Quality (IEQ), which influences the health and productive performance of building occupants (Tom Lawrence, Abdel K. Darwich, 2018). Working in optimal conditions, in office buildings, allow occupants to think and work better. Thermal comfort not only leads to well-being but also the efficiency of the task conducted. (Crahmaliuc, 2019).

However, in-office building, preserving thermal comfort is particularly challenging, where the buildings are not only exposed from the sun to solar heat but also gain significant internal heat from occupancy. Offices and commercials in the non-domestic building sector are the most energy-intensive categories, and usually accounting for over 50 % of the total energy consumption for non-residential buildings (Damiati et al., 2015; Korolija et al., 2011).

2.3 Standards, Regulation and Code of Practice

Overall, the elements of the environment seem to have the most valid points that could affect the individual's thermal comfort (Alwetaishi, 2016). There are several standards, regulations, and code of practices (COP) shall be followed related to parameters of thermal comfort, which are operating temperature, relative humidity, and airflow.

2.3.1 Operative Temperature

Air temperature is a crucial factor that concerns people when considering a new location (Alwetaishi, 2016). According to ANSI/ASHRAE Standard-55 (2017), the operating temperature is the mean temperature of the air and the weighted average radiant temperature by a coefficient of the convection heat transfer and the coefficient of linear radiant heat transfer for the occupant, respectively. It is appropriate for occupants engaging in practically sedentary physical activity (with metabolic rates ranging from 1.0 to 1.3 met), not specifically in direct solar heat gain, and not exposed to airspeeds up to 0.20 m/s (40 fpm), to estimate the precision of the interaction:

$$T_o = \frac{T_a + T_r}{2} \tag{2.1}$$

where T_o is operative temperature, T_a is air temperature, and T_r is mean radiant temperature.

Besides, the Workplace (Health, Safety, and Welfare) Regulations (WHS)-2011 deals directly with indoor office temperature (Regulation 7) and specifies that:

- The temperature shall be reasonable in all workplaces within the buildings during working hours. Temperatures of the workplace either too high or too low may lead to fatigue, heat illness, and medical conditions associated with cold.
- It is necessary to provide sufficiently thermally insulated to the workplace regarding the physical activity of the workers.
- Excessive temperature consequences from sunlight must be avoided.

WHS COP then states that the workplace temperature should provide reasonable comfort without clothing selection consideration. The workplace temperature should typically be at least 16 °C. The temperature should be at least 13 °C if there is a rigorous physical effort to work. Nevertheless, depending on other parameters such as airflow, relative humidity, and clothing for employees, these temperatures may not automatically offer appropriate warmth. Temperature measurements should be taken at working height, near the workstations, and away from windows. Table 1 shows the typical indoor temperature recommended for office buildings according to the ASHRAE Handbook of HVAC Application 2019.