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Computational analysis of thermal building in a no-uniform thermal environment

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Abstract

To predict of the thermal sensation of people located in no-uniform environment, it is very important to define the local heat transfer detail. In this context, the purpose was to make thermal comfort comparison between temperature settings of air conditioning. The temperature was maintained at five different levels which are 19ºC, 21ºC, 23ºC, 26ºC and 29ºC. A Computational Fluid Dynamic (CFD) model of an office was built. It was given similar geometries, boundary conditions and heat sources outputs as a real life test room that was used for measurement. In this study, CFD is applied to predict the thermal sensation of people with modified temperature setting. The comparison of thermal comfort parameters between the field measurement and modeling simulation was done and the result CFD was observed to predict the functionality of modified temperature setting. The analysis shows that the highest temperature setting which is 29ºC, indoor environment increase compared the lowest temperature setting. It is intended to contribute to the effort towards designing and instrumenting buildings that provide cleaner and more comfortable environment and for obtaining maximum energy savings.

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Keywords: thermal building; CFD simulation; thermal environment; heat transfer

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1. Introduction

The purpose of studying the environmental conditions inside buildings is to provide comfortable and healthy conditions for people. So do Chung et al. [1] have reported building as one of the major industries in the world has important roles to play with, which has high significant impact on the ecosystem and living environment. The building sector is one of the major end users of energy [2]. Furthermore, the air conditioning system is viewed as an important tool to sustain and improve thermal comfort of occupants, but this system is often the biggest energy consumer in building. In order to identify the thermal comfort perception of occupants as well as energy conservation potentials in tropical buildings, various thermal comfort assessments were conducted. In the last decade, there has been increased interest in the indoor atmosphere. Since the initial significant diffusion of simulation and design models, one of the major problems is their appropriateness to a particular user during the design process [3]. Three findings principal model users from Kendrick [4] can be distinguished, each of which has his own particular needs: buildings designers and operators, government policy makers and building physics researchers.

Primary goal during air conditioning designing of enclosed working space is to find adequate microclimate for people residing in that room [5]. Basically, it means that state of thermal comfort has been achieved. That implies thermodynamically balance between human body and the environment during physical activities. Physical quantities of greatest relevance for microclimate are air temperature in the room, air humidity, local air velocity and surface temperature of surrounding walls, windows and heating surfaces.

Malaysia has one of the fastest growing building industries worldwide where the corresponding energy demand would significantly increase in the next coming years [6]. Priority concern should be given to make sure that all the occupants inside the building are comfortable to stay which means they are not hot or too old. Ahmad [7] stated that through the knowledge of thermal comfort behavior of human and energy utilization behavior of buildings, the best strategy can be adopted. Malaysia is in the tropical regions and has high daily temperature which is 29 to 34^{o}C and relative humidity range in 70 to 90% of the year [8]. Daghigh [6] stress out the thermal condition in study office room has to be considered carefully mainly because of the high occupant density in these areas and because of the negative influences that an unsatisfactory thermal environment has on learning and performance. In this region, the hot and humid climate may have an adverse impact on occupant comfort indoors [9].

The significance of maintaining good indoor climate is self-evident when one considers that in every modern economy a significant part of the Gross National Product (GNP) is earned by people working in office buildings. GNP is defined the value of all the goods and services produced in an economy, plus the value of the goods and services imported, less goods and services exported [10]. Loomans [11] stated that in view of the importance of thermal comfort and indoor air quality, the design challenge is to achieve acceptable indoor environmental conditions for individual building occupant.

1.1. Air temperature

A general recommendation for design of heating and cooling processes for working offices and encloses areas, where no major physical activities are carried out, is that the temperature has to be held constant in between 21-23 °C. Thermal comfort depends also on vertical temperature distribution in the room. Allowed vertical air temperature difference between 1.1 m and 0.1 m above the floor (respectively of the person in sitting position) or between 1.7 m and 0.1 m above floor (respectively of the person in upright position) is less than 3 °C [12]. In another study, Zukowski [13] reported that the most comfortable state is that where floor temperature is the same or slightly higher that air temperature in head level.

1.2. Mean radiant temperature

Mean radiant temperature (MRT) of a space is really the measure of the combined effects of temperatures of surfaces within that space on human body. A scale of seven degrees from -3 to +3 can be used to measure thermal sensation based on the scale of ASHRAE [14]. The larger the surface area and the closer are to it, the more effect the surface temperature has on the individual. MRT thus changes with position in the room and with it corresponding air temperature which provides thermal comfort. In general if MRT drops by 1°C, air temperature has to be raised by 1-1.5°C [5].

1.3. Velocity

Increasing air velocity can cause discomfort due to increased convective heat transfer from surface of a human body. ISO 7730 [12] limits local air flow velocity in offices and spaces where no major physical activities occur at 0.25 m/s. sense of draft is more pronounced with decreased physical activity. Also, discomfort caused by draft increases with air temperature drop.

In this study, the purpose of study was to make thermal comfort comparison between temperature settings of air conditioning. The temperature setting representing five levels which is 19 ^{o}C, 21 ^{o}C, 23 ^{o}C, 26 ^{o}C and 29 ^{o}C. A CFD model of an office was built. It was given similar geometries, boundary conditions as shown as in Table 1 and heat sources outputs as a real life test room that was used for measurement.

2. Materials and methodology

2.1. The room model

The experiments were carried out in workplace ergonomic simulator chamber WES-103 with the size of 3.6 m × 2.4 m x 2.4 m as illustrated in Fig. 1. In the chamber complete set of computer, system and printer for experimental. The thermal environments with different air temperatures level maintained (19°C, 21°C, 23°C, 26°C and 29°C) refer to ICOP 2010 (Industry Code of Practice on Indoor Air Quality 2010) in the chamber could be built up for this experimental study. The other thermal conditions including the air velocity (about 0.05±0.01 m/s) and the air humidity (about 60±5%) were kept invariable throughout the experiments. The field measurement was carried out by using thermal environment equipment.

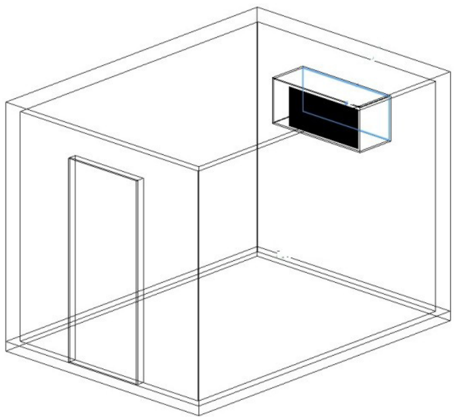

Fig. 1. Experimental chamber.

2.2. Simulation method

In recent years, CFD has been identified as the most sophisticated airflow modeling techniques that can generate the prediction analysis of airflow, heat transfer and contaminant transportation around and inside the buildings. CFD is widely applied in building design over few decades. The contribution of the CFD of the includes analyzing the impact of the building exhausts to the environment, predicting the smoke and fire risks, designing the natural ventilation system of building, identifying the indoor environment quality and so forth. Incorporation of CFD in the architectural process enabled the designer to overview the thermal performance of the microclimatic factors. The predetermined design decision made however is more cost effective compared to the post construction amendment. Thus, CFD simulation result is important to determine the performance of the building in pre-construction stage.

To build a CFD room model on the basis of a real life test laboratory where measurement had been carried out was difficult, but useful. The model could not be made totally identical to the test laboratory because it would be too time consuming. To reproduce all physical phenomena that play a role in heat and mass flow through a room is still difficult with CFD simulations. Detailed boundary conditions are listed in Table 1.

The heat flow was of major interest. Thermal characteristics of the fluids and materials involved were for the reason accurately calculated to reproduce all kinds of heat transfer. The fluid in the simulations (air) had temperature dependent characteristics such as conductivity, λ and laminar viscosity, μ based on air at reference temperature, °C and 50% relative humidity [15]. Both characteristics could vary according to a linear function of temperature, see equation (1). Specific heat capacity, c_p was set to 1005 J/(kg K), diffusivity, Γ_c, to 1.84 x 10^{-5} m^2/s and density, ρ was based on the ideal gas law:

$$\Phi = \Phi_{ref} + C(\theta_{air} - \theta_{ref}) \quad (1)$$

where Φ gives the output value for conductivity, λ or viscosity, μ when Φ_{ref} is the corresponding value at the reference temperature. C is a constant coefficient and θ_{air} and θ_{ref} are respectively the temperature of the room air and the reference temperature.

Table 1. Boundary conditions in chamber room.

Walls	Temperature (°C)
East	23.0
South	24.5
North	23.5
West	23.5
Ceiling	24.5
Floor	24.0
	Heat Sources, Q (W)
Person	144
Laptop	50
Lamp	60
Supply	
Temperature	19.0°C
Volume flow rate	0.058 m3/s
Turbulence intensity	30%

3. Result and discussion

The illustrations display only one section through the room. It must be emphasized that the situation in a real office is complex, variations in temperature and air speeds may be found in all directions.

No obstacles, such as furniture were introduced into the CFD chamber. Means that air could move freely in the entire indoor space. Slightly different air speeds than normally found in an office could therefore be expected in the simulations, yet the overall flow pattern is similar.

The simulated result was expressed in Fig. 2. The illustration displays only one section through the chamber. It is must be emphasized that the situation in a real office is complex, variations in temperature and velocity may be found in all directions. In Fig. 2 there are five output pattern of simulation, figure (a) output comes from thermostat setting 19°C, Figure (b) output comes from thermostat setting 21°C, Figure (c) output comes from thermostat setting

23°C, Figure (d) output comes from thermostat setting 26°C and last but not least Figure (e) output comes from thermostat setting 29°C. These outputs show the simulation thermal sensation parameters in the chamber. All parameters were tested under no wind condition from outdoor environment.

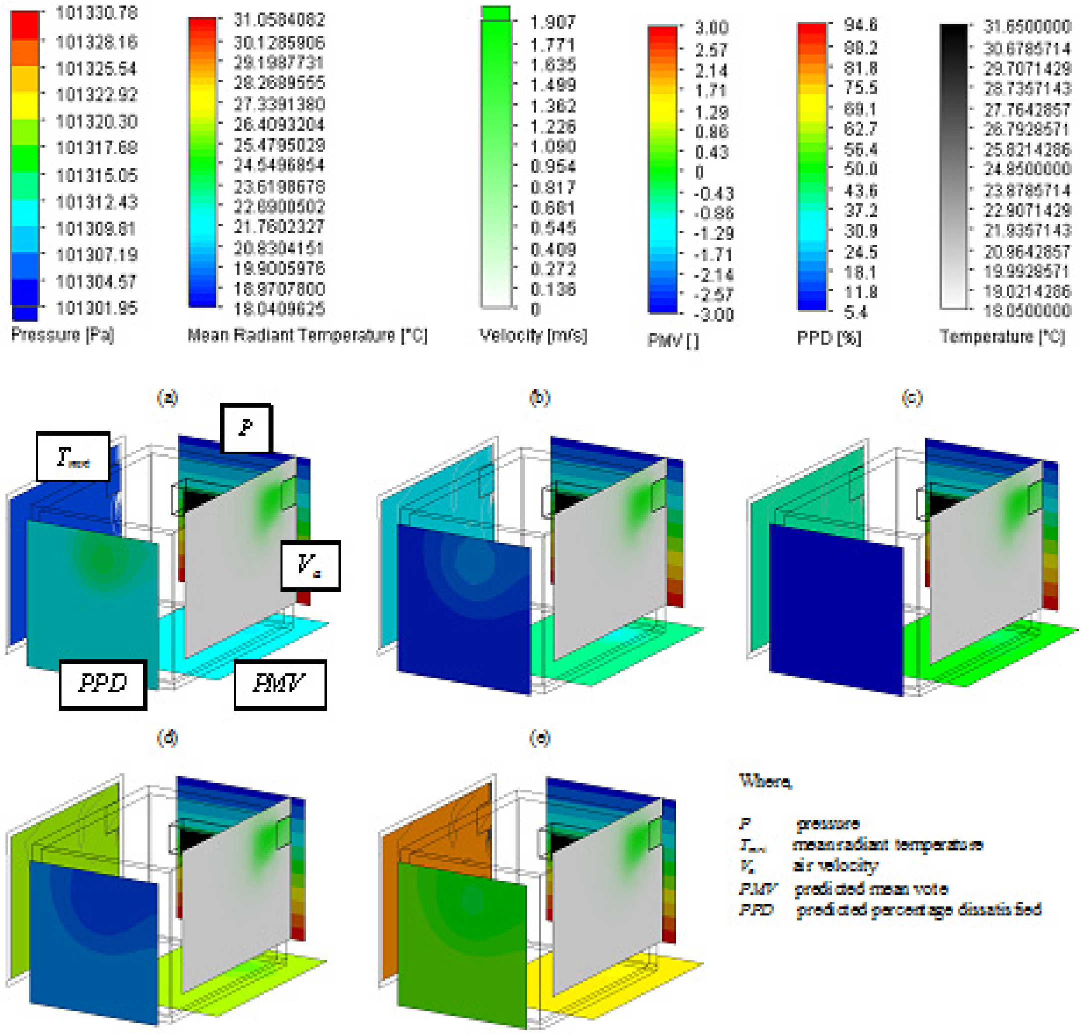

Fig. 2. The typical outputs pattern of CFD simulation with thermostat setting; (a) 19°C, (b) 21°C, (c) 23°C, (d) 26°C, (e) 29°C.

Evaluation of comfort sensation

The PMV index is the predicted mean rating from a large number of people on a psycho-physiological scale. The scale has seven different ratings ranging from cold (-3) to hot (3) as shown in Table 2. The PMV index tells if occupants feel too warm or too cold under given circumstances. The information about which percentage of the occupants would be dissatisfied is provided by the PPD, which can be derived from the PMV according ISO7730 [12]. Based on ISO7730 [12], the comfort range was taken to be the conditions when the PMV has the values between -1 and 1. All the comfort indices are presented for an individual with an activity level of 1 Met and a level of clothing insulation of 0.5 Clo. Fig. 3 presents the comparison thermal sensation between temperatures maintained in the chamber.

According to thermal sensation scale the comfort zone of workplaces must be neutral or 0 of PMV reading. Thus, it can be conclude that workers are not comfortable to perform their office works when the room temperature maintains at 19°C. This is because they will be overcooled if they stay for eight hours in the office. Previous study by Ayako et al. [15] which recorded overcooling effect found that there is no medical definition of the symptom of the unusual feeling of coldness. However, a lot of people suffer from the unusual feeling of coldness at some body parts, such as the hands, feet, and lower back, in winter and in a cold or an air-conditioned environment either at school, workplaces and colleges.

The results of PMV index at 21 °C show readings between -3.00 to 0.05. Other than that the PPD also shows reading around 5% - 99.42% at this study. Thus, the thermal assessment for the environmental chamber is regarded cool at 19°C by following the thermal comfort scale. In conclusion, this range of room temperature (21 °C) is categorised as uncomfortable for office room temperature.

Additionally, human thermal comfort will be influenced by psychological as well as physiological factors. Several comfort indices, such as PMV and PPD have been developed by father of thermal comfort such as Fanger and Nicol [16]. These indices attempt to correlate human thermal comfort with environmental conditions. Previous study on thermal comfort have found that, thermal comfort can also be corelated with workers' productivity, safety and health.

The study by Dua [17] states that there are many symptoms workers can show went they feel uncomfortable at workplaces. These include sign of depression, stress and anxiety which may lead to decreasing performance indicated by increasing absenteeism and lower productivity.

The results of PMV index at 23°C show reading between -0.39 to -0.9. Other than that the PPD also shows reading around 5% - 22.1% at this chamber. Thus, the thermal comfort assessment for this chamber is at a comfort zone when the temperature setting is 23°C by following the thermal comfort scale.

The results of PMV index at 26°C show readings of 0.93 to 1.59. Other than that the PPD also shows reading around 17.1% - 56% at this chamber. Thus, the thermal comfort assessment for the environmental chamber is slightly hot at 26°C by following the thermal comfort scale. In conclusion, this range of room temperature (26°C) is categorised as uncomfortable for office room temperature because hot condition can lead to sweating workers

Literature suggests that, usually office workers face overcooling problems more frequently than overheating problem in office room. According to Shikdar and Sawaqed [18] workers do not feel comfortable will complaining of discomfort and dissatisfaction at work could reduce their productivity. Ismail et al. [19] support this indication with their finding out of an investigation undertaken in automotive paint shop. Their job satisfaction analysis reveals that sweat causing environment or exposure to heat will cause significant discomfort.

The results of PMV index at 29°C shows readings between 1.1 to -1.96. Other than that, the PPD also illustrates reading around 30.4% - 74.9% at this chamber. Thus, the thermal comfort assessment for the environmental chamber is regarded very hot and uncomfortable at 29°C by following the thermal comfort scale.

According to thermal sensation scale the comfort zone of workplaces must be neutral or 0 of PMV reading. Thus, it can be conclude that at 29°C room temperature are not comforts for workers to perform their work task because they will feel overheating stay eight hour in their office room.

Table 2. Subjective scale of thermal comfort from ANSI/ASHRAE 55 standard [14].

Very cold	Cold	Slightly cold	Neutral condition	Slightly hot	Hot	Very hot
-3	-2	-1	0	1	2	3

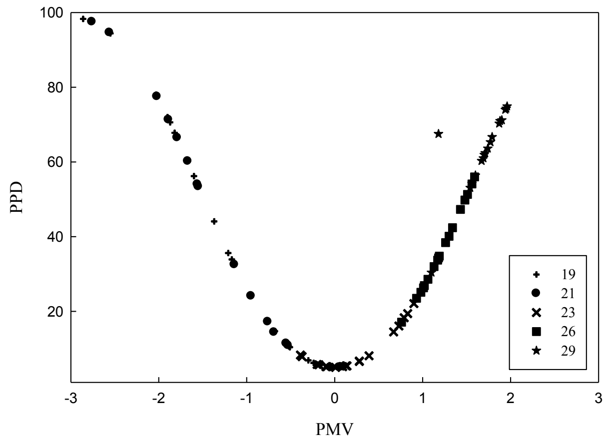

Fig. 3. Comparison thermal sensation between temperatures setting in the chamber.

4. Conclusion

This study presents an attempt to bring the building's atmosphere to the attention of a wider group of heating and ventilation engineers and environmental scientists, through the description of a computational method. Results have been presented and appear physically plausible. The analysis shows that the highest temperature setting which is 29 °C, indoor environment increase compared the lowest temperature setting. It is intended to contribute to the effort towards designing and instrumenting buildings that provide cleaner and more comfortable environment and for obtaining maximum energy savings. People with ''pro-environmental'' attitude tend to be more ''forgiving'' in accepting their immediate indoor built environment in green buildings. This could have far-reaching implications for energy savings in that the adaptive thermal comfort could be more widely adopted in both naturally ventilated and air-conditioned buildings if the general public's are willing to tolerate a larger temperature range in buildings. Relaxing culturally-induced clothing norm and occupant expectations of closely controlled indoor environments could lead to significant progress in achieving a proper balance between thermal comfort, energy use and minimum environmental impact. However, not all climate variables have similar salience for human perception, and expectations, culture, religion, education and experience tend to mediate our perception of the thermal environment. More work in the socio-economic and cultural area is required, and post-occupancy evaluation of the built environment and the corresponding energy consumption would lead to a better understanding of the underlying issues affecting indoor thermal comfort and the corresponding energy use in the built environment and population growth [20].

Further work is still required, basically comparison between predictions and experimental measurements. In this specific case of office, there is much work to be done, if we are to understand how well to protect equipment's office that form such an important part to stay long without broken. Furthermore, this modelling procedure is applicable to any problem of heating, cooling, insulation and ventilation of domestic, commercial, industrial and public building, predicting, within practical resources, the thermal and fluid dynamic behaviour of the relevant systems. It is intended to contribute to the effort towards designing and instrumenting buildings that provide cleaner and more comfortable environment and for obtaining maximum energy savings.

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