Simulation of Office’s Operative Temperature Using ECOTECT Model

Abd Halid Abdullah¹, Siti Khatijah Abu Bakar², Ismail Abd Rahman³
¹,²,³ Faculty of Civil and Environmental Engineering, University Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor
Corresponding Author: abdhalid@uthm.edu.my¹, sitikhatijah.ab@gmail.com² and ismailar@uthm.edu.my³

Abstract— Operative temperature (OT) is the significant evaluation criterion for occupant’s thermal comfort since it integrates dry bulb temperature (DBT) and mean radiant temperature (MRT) with their respective heat transfer coefficients weightage. This paper presents the comparison of simulated OT with the measured value of a selected office building. Field measurement was conducted on a two-storey office building in the Universiti Tun Hussein Onn Malaysia (UTHM) campus. Then, the office building is modelled using Ecotect Thermal Analysis software. Simulation on the model was carried out to generate its OT and this value was compared with the measured value. It has been found that Ecotect program can be reasonably used in simulating OT as the mean discrepancies between both predicted and measured values are 1.6% for ground floor and 5% for first floor of the office because it is less then threshold value of 10% as agreed by most researchers.

Keywords - Thermal Comfort, Operative Temperature, Ecotect Program

I. INTRODUCTION

Computer simulation program has evolved from the natural human desire to reduce risk from the decision making process by developing simulation language with its ultimate goal – to reduce risk and making better decisions. Previously, designers used manual calculations such as Lighting and Thermal Method, and CIBSE Building Energy Codes for estimating the design performance and also to improve the earlier designs [1]. Today, performing modelling and simulation is becoming important in assessing and predicting building energy and environmental performance. In-line with advance in computer technologies, there are several computer simulation software packages that have adopted building performance simulation such as IES Virtual Environment, TAS, Ecotect and Energy Plus with more user friendly, easier and greater accuracy [1]. These computerised tools disclose wide range of situation which is most likely to occur in the real world. However, it will not assure 100% accurate and designer should bear in mind that uncertainties are always occur when they are working with simulation tools. Thus, in order to ensure that the simulation resembles as close as possible to the real condition, the process of verification should be done by comparing the simulated data with that of the measured data.

This work focuses on comparing the results predicted/generated from Ecotect computer simulation work with measured value from the field measurement carried out in an office building. The main parameter compared is the operative temperature which symbolises the condition of occupants’ thermal comfort inside the office.

II. LITERATURE REVIEW

A. Thermal Comfort

In general, comfort is regarded as desirable positive condition of a person or can be described as the absence of feeling discomfort. Thermal Comfort occurs when body temperatures are held with narrow ranges, low skin moisture and physiological effort of regulation is minimized. ASHRAE Standard 55 defines thermal comfort as conditions of mind that expresses satisfaction with thermal environment. The ‘condition of mind’ clearly shows the linking of thermal comfort with ‘psychological’ response and feeling satisfaction seems to be the best way to resemble comfort. There are six basic variables that influence the perception of comfort which include four environmental factors namely air temperature, mean radiant temperature, relative humidity, and air velocity; and two personal factors namely activity level and clothing insulation. These variables are used in determining a comfort zone. Comfort zone is defined in term of a range of operative temperature that provides acceptable thermal environmental conditions or in term of the combinations of air temperature and mean radiant temperature that people find thermally acceptable [2].

B. Description of OT

When calculating the indoor thermal climate, operative temperature (OT) can be used as a simple measure for the heat loss from a person [3] and also used to determine the temperature limit of the comfort zone. In determining OT, mean radiant temperature (MRT) seems to be a significant factor, especially in buildings where the envelopes are exposed to a strong solar radiation, and where conventional indoor temperature and humidity control cannot guarantee indoor comfort [4]. The MRT has significant effects to the changes of OT and also dependence on the location. In addition, OT is also time variable since indoor surface temperature is changing during the day depending on the outdoor climatic conditions [5]. According to ASHRAE Standard 55 – Thermal Environmental Conditions for Human Occupancy, OT is defined as the uniform temperature of an isothermal black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual environment. It is numerically the average of the dry bulb temperature (DBT) and mean radiant temperature (MRT), weight by their respective heat transfer coefficients (hi)
convective heat transfer coefficient; and $h_r$ is radiative heat transfer coefficient) [6]:

$$OT = \frac{(h_D DBT + h_M MRT)}{(h_C + h_R)}$$  \hspace{1cm} (1)

However, there is also a simplified OT calculation which can give acceptable and reasonably accurate result. In particular, for occupants engaged in near sedentary physical activity, not in direct sunlight, and not exposed to air velocities greater than 0.2 m/s, the relationship can be simplified and expressed by [7]:

$$OT = \frac{DBT + MRT}{2}$$  \hspace{1cm} (2)

C. Obtaining Good Data

One of the important factors in obtaining good data from the simulation is the accuracy of the input data. A simulation is valid if the input data is correct and appropriate, A. M. Law suggested that in order to obtain a good data, the data should be taken from the existing system in order to be used in the simulation (if the system is similar) [8]. The data available may be from historical records or collected during experimental study. However, if the person who provides the data is different from the simulation analysts, there are two basic principles need to be followed [8, 9]:

- The required data are specified precisely in term of type format, amount, and conditions under which it should be collected and why it is needed, to the people who provide the data.
- Understand the process that produced the data rather that treating the observations as just abstract numbers.

However, it is still rarely feasible to collect sufficient experimental data or to apply a given analysis tool to a sufficient number and range of test cases to achieve complete confidence to all situations. Therefore, analysis tool developers agree that, model that have been verified for a few climates can be used with some degree of confidence to predict performance in other climates [10].

Simulation analyst should bear in mind that building simulation is full of uncertainties. There are several studies conducted by comparing the simulated value with the measured value. Researchers suggested that the acceptable percentage difference between simulation and measurement results should be in the range of 5 to 10% [7,10]. However, F. Maamari et. al suggested a wider tolerance where the acceptable percentage difference between simulated and measured results should not be more than 15% [11]. Thus, in this study, if the percentage difference is within the suggested tolerance, the result is considered reasonably accurate.

D. Ecotect Software

Ecotect is a complete building design and environmental analysis tool that covers the broad range of simulation and analysis function, when it is required to truly understand how a building design will operate and perform. Ecotect is a software package with a unique approach to conceptual building design. It couples an intuitive 3D design interface with a comprehensive set of performance analysis functions and interactive information displays. It uses a unique system of progressive data input to reduce user’s burden. Initially, it only needs simple geometric details. As the design model refined and more accurate or detailed feedback is required, the user makes more choices and enters more data as it becomes important [12]. Ecotect provides thermal, lighting and acoustic analysis which includes hourly thermal comfort, monthly space loads, natural and artificial lighting levels, acoustic reflections, reverberation time, and project cost and environmental impact as well [13].

III. RESEARCH METHOD

The primary objective of this study was to compare operative temperatures of the simulated results with those of measured data and determine the accuracy of Ecotect Thermal Analysis program in modelling and simulating indoor thermal environmental performance. The selected office building – Development and Property Management Office, University Tun Hussein Onn Malaysia (UTHM) was used in this study. The office building was originally a double storey residential house which was then renovated and converted into an office building. It comprises 3 office rooms on both floors and operates from 8 am to 5 pm daily during weekdays.

A. Field Measurement

Field monitoring and measurement of thermal performance was carried out for 13 consecutive days in March 2010. During the period, indoor thermal parameters were measured both on working days and weekends. Measured parameters included air temperature, relative humidity, mean radiant temperature and the effect of indoor thermal environment on human comfort (Predicted Mean Vote and Predicted Percentage Dissatisfied). During the measurement period, the hottest days identified were on 11th and 13th March representing the hottest day during weekday and weekend respectively. However, in this study, data on 13th March is chosen to be used as input data for computer simulation so that the resulting condition in the office building could be identified and compared.

Two sets of Thermal Comfort Station BABUC A were used to measure the indoor thermal parameters. The equipments were set up on the ground floor and first floor respectively in the office room at height 1.1m above the floor to represent the height of occupants at seated level and located in the vicinity of workers’ desks representing their condition as they spend most of their time there during office hours. During the measurement, metabolic rate was set to be 1.2 met on each floor which was sedentary activities while occupants’ clo value (occupant clothing insulation) was set
to be 0.5 which was selected from working clothing in InfoGAP. The locations of the equipments are shown in Figures 1 and 2.

**Figure 1.** Location of the Thermal Comfort Station on the ground floor

**Figure 2.** Location of the Thermal Comfort Station on the first floor

**B. Ecotect Modelling and Simulation**

The office building was modelled as close as possible with the existing one (Figure 3). Firstly, the information of site location and the orientation of the building were input into the model. In order to run Ecotect simulation, Malaysia weather year hourly data provided by Ecotect was retrieved. Since the outdoor weather data used was not from the actual site, the discrepancy was expected in the result. Thus, in order to minimize the discrepancy, hourly data for 13th March (the hottest day during the measurement) were replaced with hourly weather data for Batu Pahat Station obtained from the Malaysia Meteorological Department.

It has to be noted that, when modelling the building, it must comprise one or more fully enclosed thermal zone. So that, each zone can be calculated in order to analysis its thermal performance. As the model was constructed, the element properties were then assigned. The materials assigned were selected from Ecotect element library. However, some of the materials selected were edited to ensure the properties are as close as possible to the actual material properties. In addition to the building model, it is assumed that the building is well sealed and there are no openings that allow (or to minimize) air exchange with the outdoor.

**Figure 3.** Visualisation of the office building modelled in Ecotect

**IV. RESULT AND DISCUSSION**

In order to determine the accuracy of Ecotect Thermal Analysis program, the result obtained by Ecotect simulation and field measurement were compared by analyzing percentage difference. The percentage difference between simulated and measured results was calculated by using the following equation:

\[
PD = \left( \frac{ES - FM}{FM} \right) \times 100
\]

where:

- **PD** = Percentage difference
- **ES** = Ecotect simulation
- **FM** = Field measurement

Figures 4 and 5 illustrate the hourly indoor operative temperature with varying percentage temperature difference between measured and simulated results on both ground and first floor, respectively. It has to note that, indoor temperature generated from Ecotect is not a straight air temperature. It is environment temperature which is formed from a component of mean radiant temperature and air temperature. It provides a better comfort indicator than air temperature [13]. Hence, indoor temperature obtained from Ecotect must not be compared to air temperature.
Several factors affecting the discrepancies during computer simulation process were identified and were listed as follows:

- The dissimilarity of actual data on site location and weather data input in Ecotect may influence the simulated indoor temperature profile. In addition, nearby facilities and existing plants surrounding the actual building helps to shade the building, thus, cooling down the ambient outdoor temperature. Compared to the model in Ecotect, nearby facilities were not considered during the simulation process. Since outdoor condition has a significant effect on the indoor temperature, taking consideration to calculate the effect of the nearby facilities and plant during simulation process may minimize the difference.

- In the actual room, the equipments were located at the specified location. Thus, the indoor temperature measured by the sensor was influenced by radiant temperature from the nearby wall, floor and office equipments. While simulated indoor temperatures in Ecotect represents the spatial average over the entire zone. The presence of east facing glass door and windows has contributed to the high radiant temperature within the zone resulting to higher average calculated indoor temperature in Ecotect.

- The discrepancy in indoor temperature also may be due to the dissimilarities between input data of building materials in Ecotect with those of the actual conditions. The difference of thermal properties of building materials mainly for wall, roof and glazing may contribute to higher prediction of heat gain in Ecotect model. For example, the difference between transparency values of translucent element has affected the amount of direct solar penetration; thus, vary the measured and simulated indoor temperature.

- Uncontrolled air infiltration due to the existing opening or airflow path might allow the air exchange with the outdoors. However, in Ecotect, the infiltration rate was fixed and the difference in air infiltration value also might lead to the discrepancies between measured and simulated results.

V. CONCLUSION

A computer simulation program has been developed to assess and predict the energy and environmental program of the building. One thing that user should bear in mind, the computer simulation program will not 100% resemble to that of the existing conditions and this has led to the discrepancies between both simulated and measured results. However, there are limitation values that allow discrepancies to occur. Researchers provide a wide acceptable tolerance up to 15% so that the simulation result will be considered reasonably accurate if it is within the suggested tolerance.
From the result obtain, it shows that Ecotect overestimate the internal operative temperature. However, it shows a good agreement between simulated and measured results which indicate the discrepancy value within the acceptable tolerance of 10%. This result proves that Ecotect program can be used for indoor thermal environmental simulation studies.

Furthermore, this study found that, the external factors identified to affect the accuracy of the result are the differences between building material input data with the actual material, the weather data as well as external shading nearby the existing building. Moreover, specified thermal sensor located in the actual building which measured indoor temperature at one point compared to the simplified calculation of temperature in Ecotect also contributed to the discrepancies to occur.

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REFERENCES


