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EVALUATING DIFFERENT SCENARIOS FOR OPTIMIZING ENERGY CONSUMPTION TO ACHIEVE SUSTAINABLE GREEN BUILDING IN MALAYSIA

Morteza Khalaji Assadi[1], Seyed Mojib Zahraee[1], Mohammad Hossein Zaeimbashi Isaabadi[2] and Khairul Habib[1]
[1]Department of Mechanical Engineering, Universiti Teknologi Petronas, Bandar Seri Iskandar, Perak, Malaysia
[2]Faculty of Civil Engineering, Department of Structure and Material, Universiti Teknologi Malaysia, Skudai Johor, Malaysia
E-Mail: morteza.assadi@petronas.com.my

ABSTRACT

One of the most users of energy in the construction industry is residential buildings that use the high value of energy. Because of the high effect of construction activities on environment, serious attention should be given to sustainability concept in construction activities. There are climate factors such as temperature, humidity and pressure that have a considerable effect on the sustainability of green buildings based on energy consumption. The main goal of this paper is to achieve a sustainable green building by optimizing the energy consumption based on two significant factors which are temperature and humidity. To achieve this goal, the design of experiments (DOE) and building simulation are applied. A two-storey house in Malaysia was selected as the case study. The final result shows that to achieve the optimum value of cooling load to have a sustained design of green residential buildings all the significant factors should be placed on a low level which it means that temperature and humidity should be equal to 20 degrees Celsius and 60% respectively.

Keywords: energy consumption, green building, sustainability, building simulation, design of experiments.

INTRODUCTION

Recently green building has taken the most attention in the worldwide since to reduce energy consumption in the buildings [1]. Green building includes a building that is operated, designed and constructed in the resource effective [2]. It should be noted that most of the green buildings are not energy effective [3]. On the other hand, construction industry has a significant influence on the environmental concern, ecosystem and it there is an essential need to develop a sustainable design of construction activates [4]. Malaysia is one of a developing and tropical country that it has experienced a raise of energy using up rank. Statistically, the total of energy use of Malaysia has approximately reduplicated from 2000 to 2010 [5].

In the last decade many new methods used to implement sustainable design and proficient energy analysis and optimization. In one study, it has reviewed the energy consumes of a five floor workplace structure in tropical climate countries in Saudi Arabia that was used Visual DOE4 software. The achieved results declared that growing the insulation width is not a significant infiltration on energy effectiveness [6]. Another study selected a school building in a tropical region to assess the weather factors to improve energy efficiency. They claim that factors such as shading, night ventilation, lighting control, access, and windows dimension have a considerable influence on the energy efficiency in in school buildings [7]. In another investigation, a housing building was chosen to study the reflexive climate control that are freshen in nature in Singapore's hot and humid climate. To achieve this goal, they assessed the effect of some microclimatic parameters like orientation, wind, and shading of enclosed buildings on reducing of warm by using roof thermal buffer, window shades with thermal analysis software (TAS) [8].

Recently, some investigations were done by using the statistical analysis and computer simulation in order to improve the performance of construction process such as concrete pouring process [9, 10] and energy consumption in buildings. In one study a two-storey building which located in Malaysia was selected to mode energy consumption using dynamic building simulation. Experimental design (DOE) approach was implemented to find the best combination of factors. Final result indicated that changing ceilings and ceiling materials play a significant role to decrease energy consumption [11]. Additionally, in another study, statistical Taguchi method was done to find the optimum value of the main parameters of buildings that are window, ceiling, and wall by considering the effect of uncontrollable factors such as humidity, temperature, and air flow in residential buildings [12]. In another research, building simulation and DOE were combined to evaluate the effect of main climate factors on energy saving and cooling load. Final result showed that the temperature and humidity have the most significant effect on the energy saving [13].

DOE is known as an experiment or series of experiments that are done through changing the input process variables, which may have an effect on the output responses [14]. On the other hand, simulation can generate and evaluate to provide perception about the performance of system but it is time consuming and difficult work [15]. This paper aims at evaluating the effect of two important factors that are temperature and humidity on the energy consumption in the residential buildings. To achieve this goal, building simulation and statistical method named Design of Experiments (DOE) is applied to obtain a sustainable design of residential building based on the optimum energy consumption.

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MATERIALS AND METHODS

Building simulation

A residential building in Kuala Lumpur, the capital city of Malaysia, was selected as the case of this study. Total building area is 700 m^2. In this case, computer applications like Energy Plus for energy analysis and Revit Architecture application for simulation has been implemented to make easy energy analysis and material simulation processes [11]. Energy Plus is an extensive and complete simulation software that has been applied to simulate the building in this paper.

Design of experiments

In DOE, the factors are parameters that are varied which are under experimenter's control, while the responses are dependent variable which is cooling load in this case. The 2^k factorial design is one of very useful type of DOE approach. Each of the factors is allowed to take on two values or levels (High and Low). It has been investigated to be economical and effective in indicating interaction effects. Therefore, this paper will use 2^k factorial design to evaluate the effect of several parameters on the cooling load [16]. In order to implement DOE, the following steps are followed. The steps are [16]:1. Choosing the factors and their levels 2. Choosing a response variable 3. Choice of experimental design 4. Performing experiment 5. Data analysis 6. Conclusions and recommendations. In this paper two factors were chosen to examine their effects on the energy saving in the selected case. The variation ranges or levels of factors is indicated in Table-1.

Table-1. Factors and levels.

FACTOR	LEVEL		
	Low (-1)	0	High (1)
Temperature	20	23	26
Humidity	60	70	80

In full factorial design with two factor 2^2 =4 experiments are done with two replications. In addition, three centre points are considered to assess the curvature of experiment to determine that the proposed model is linear or quadratic. Design-Expert 6.0.5 is the software that is used for doing the statistical analysis.

RESULT AND DISCUSSIONS

Performing simulation experiment

Based on two factor and full factorial experiment, the number of experiments is equal to: 2^2 * 2(replicates) + (3 center points) = 11. Table-2 shows the result of 11 experiments that was implemented using the simulation software.

Table-2. Result of simulation experiment.

Run order	Temperature	Humidity	Cooling load		
			Replicate 1	Replicate 2	
1	26	80	289780	290450	
2	26	60	250600	245470	
3	20	80	278100	270179	
4	20	60	199200	199450	
5	23	70	297670	297800	290670

Significant factors

Analysis of variance (ANOVA) Table is designed to show the significant factors. It should be noted that if the P-value of a factor or effect is less than 0.05, it is considered as significant [16]. The significant effects that emerge from this analysis are the main effects of A (Temperature), B (Humidity) and two-way interaction (AB) that have the highest effect of the energy saving.

As can be seen in Table-3 the curvature is significant. So it is claimed that our model is quadratic so a second order model is required. To do this, augmentation design is conducted to obtain the second order regression model. To obtain this the design is augmented by adding the axial points and new runs. Table 4 indicates the ANOVA table for the augmentation design. Based on the p-values that are less than 0.05, the significant factors are B (Humidity) A^2 and B^2 in the second order model.

Second order regression model

After finding the significant factors, the following second order regression model was proposed by considering the coefficient of each factor. It can be concluded that to obtain the minimum cooling load, factor B (Humidity) should be placed at the low level. This formula can be used to calculate different value of cooling load.

$$\text{Cooling Load} = +2.956E+005 + (24968.16*B) + (-10011.91*A^2) + (-16351.12*B^2) \quad (1)$$

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Table-3. Analysis of variance (ANOVA) for cooling load.

Source	Adj SS	DF	Adj MS	F	P	Remarks
Model	9.460E+009	3	3.153E+009	242.35	< 0.0001	Significant
A	2.092E+009	6	2.092E+009	41.26	< 0.0001	Significant
B	6.832E+009	4	6.832E+009	30.64	< 0.0001	Significant
AB	5.358E+008	1	5.358E+008	0.07	0.0007	Significant
Curvature	3.937E+009	1	3.937E+009	93.81	< 0.0001	Significant
Pure error	7.807E+007	6	1.301E+007			
Cor Total	1.347E+010	10				

Table-4. ANOVA for response surface quadratic model.

Source	Sum of Square	DF	Mean Square	F Value	Prob>F
Model	1.420E+010	5	2.839E+009	12.12	0.0004
A	9.248E+008	1	9.248E+008	3.95	0.0723
B	8.514E+009	1	8.514E+009	36.36	0.0001
A^2	1.322E+009	1	1.322E+009	5.65	0.0367
B^2	3.527E+009	1	3.527E+009	15.06	0.0026
AB	5.358E+008	1	5.358E+008	2.29	0.1586
Residual	2.576E+009	11	2.342E+008		
Lack of fit	2.495E+009	3	8.317E+008	82.48	0.06
Pure error	8.067E+007	8	1.008E+007		
Cor total	1.879E+010	17			

DISCUSSIONS

Construction managers try to design and implement green buildings based on energy consumption in a resource effective way. Climate factors paly a leading role in optimizing the energy consumption in sustainable green buildings. This paper aims at evaluating the effect of two important factors that are temperature and humidity on the energy consumption in the residential buildings. To achieve this goal, building simulation and DOE was applied to obtain a sustainable design of residential building based on the optimum energy consumption. After doing the DOE analysis, second order regression model was developed in order to find the optimum setting. For determining the optimum value of each significant factor, the 3D response surface and contour plot are used. They are the graphical illustration of the regression equation.

At the lowest level of the surface inclination in Figure-1, the minimum cooling load is achieved at the lowest level of the temperature (20 degrees Celsius) and the lowest level of humidity (60 %) based on the time contours trend. As can be seen, in Figure-2 the minimum cooling load occurs in the point of 2.278E+005 that is related to the Temperature (A) = 20 degrees Celsius and Humidity (B) = 60 %.

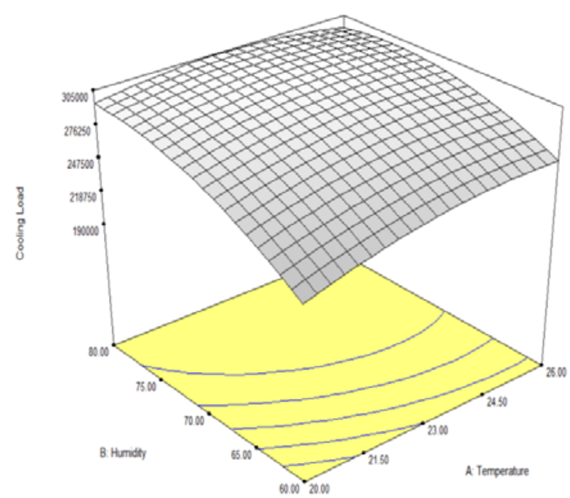

Figure-1. 3D response surface.

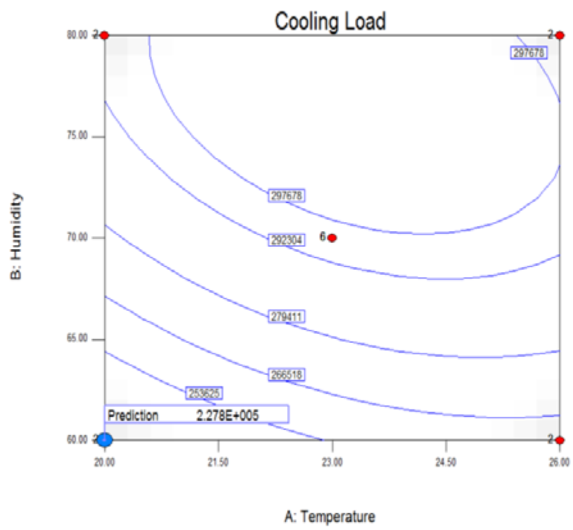

Figure-2. Contour plot.

CONCLUSIONS

Green building has taken the most attention in the worldwide since to reduce energy consumption in the buildings. One of the most users of energy in the construction industry is residential buildings that consume the biggest share of energy. Because of the high effect of construction activities on environment, serious attention should be given to sustainability concept in construction activities. Generally, building elements behave differently in terms of energy performance depending on the location, climatic condition and physical properties. In this study, the building simulation and design of experiments was combined for evaluating the performance of air quality (temperature, humidity) for saving cooling loads in residential buildings in Malaysia. Based on the final results of the simulation and energy analysis of the case study building, both of the temperature and humidity and two-way interaction between them have a significant effect on the energy saving. To obtain the optimum value of cooling load to have a sustainable design of green residential buildings all the important factors should be placed on a low level which it means that temperature and humidity should be equal to 20 degrees Celsius and 60% respectively. More investigation can be done by implementing other statistical methods such as response surface methodology to find the optimum setting of climate factors and main factor for example wall, roof, and window.

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