Chapter 35
Mock-Up Green Building Thermal Comfort Studies

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Abstract Buildings account for about 40% of the global energy consumption and contribute over 30% of carbon emission, globally. A large proportion of this energy is used to achieve a thermal comfort within the building. To overcome this problem, green building elements in the construction reduce excessive energy consumption of the building. This paper reviews the effect of thermal comfort to electrical energy consumption through wall and roof material selection of each four mock-up green building in UniKL Green Building test-site. All the data are collected and descriptive analysis has been done to investigate the potential of green building as a method to reduce electrical energy consumption. Test results have been obtained and analysis has been performed to identify the characteristics of the four different materials of the wall (building envelope). The result from this study showed that mock-up green building that is built from green material could provide a better thermal environment than mock-up green building that is built from non-green material. The result also showed the amount of energy consumption could be reduced as less active cooling than the mock-up green building that is built from non-green material.

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35.1 Introduction

In this globalization era, the demand of electrical energy is increasing every year especially within the building sector. This raises concern on fossil fuels, which has been used widely in every country across the world as a source of energy and the implication for the environment. Global warming and air pollution are some of the effects that come from fossil fuels. Buildings account for about 40% of the global energy consumption and contribute over 30% of CO_2 emission with a large proportion of this energy is used for thermal comfort building [1]. It shows that there is a lot of excessive energy consumption is meant for achieving the thermal comfort within the building. To overcome this problem, green building is one of many methods used to reduce excessive energy consumption through thermal comfort. All specific requirements to achieve thermal comfort level should be considered. It is included the material of the building envelope/wall, type of roof, air ventilation and circulation, building positioning toward sun path, window glazing, and many others.

Green buildings will contribute to a healthy lifestyle, long lasting of the building, and cost effective. It also means to maintain natural resources and improve the built environment for the people, communities, and ecosystems to grow and live together in good condition [2]. There are a lot of benefits of green building such as they can save the environment and help in economic growth. Malaysia is one of the countries that are very committed to utilize the potential of green building. As an example, there are many green buildings that have been built by government, such as the Diamond Building of Suruhanjaya Tenaga at Putrajaya and Green Energy Office (GEO) building in Pusat Tenaga Malaysia, Bangi. Energy consumption in Suruhanjaya Tenaga building has reduced by 45%, and one of most contribution is from thermal comfort that requires space heating, cooling, and ventilation. It shows that thermal comfort in a building is very important because it consumes electrical energy.

Thermal comfort is defined as that condition of the human mind that shows satisfaction with the thermal environment surrounding and is determined by subjective evaluation, by ASHRAE Standard 55 (2013) [3]. It was found that building thermal comfort could be influenced by a combination of two factors; the environmental factors and personal factor. Environmental factor is the condition inside the building such as air temperature, air velocity, radiant temperature, and relative humidity. Personal factor is the condition of human body such as clothing, metabolic rate and also the behavior of human. There are many studies that have been done before to determine actual thermal comfort temperature in Malaysia climate. Department of Standards Malaysia, 2007 had established MS 1525: 2007 (Code of Practice on Energy Efficiency and Use of Renewable for Non-Residential Building) for non-residential building as shown in Table 35.1.

Table 35.1 The recommended indoor condition of MS: 1525: 2007

Recommended dry bulb temperature	23 °C–26 °C
Recommended relative humidity (RH)	55–70%
Recommended air movement	0.15–0.5 m/s
Minimum dry bulb temperature	22 °C
Maximum air movement	0.7 m/s

35.1.1 Impact of Building Material on Building Thermal Comfort

This study was made in Gombak, Malaysia on the hot and humid climate; a study on the thermal comfort in all residential buildings or dwellings. Specifically for hot and humid climates, the design of the building must be focused on lowering the indoor climate of the building to achieve thermal comfort standard. In order to achieve this, major design considerations must focus on building orientations, which can affect solar and thermal conditions and potential ventilation of buildings.

Besides building orientation, material of building used to design is also important as it can change the indoor climate inside the building. Selection of material of the building is necessary, especially for walls, roofs, and glazing along with the shape of the building. Paper [4] has highlighted that the thermal properties of building materials can govern the relationship between average indoor climate of the building and the outdoor air temperature pattern where thermal conductivity, specific heat capacity, and density of the building material play an important role. For non-residential place, such as office buildings and schools, the use of insulation material is most effective to change the indoor the climate inside buildings in order to achieve thermal comfort temperature over various external conditions [5]. Although, it might not achieve comfort condition, suitable material for insulated wall can minimize thermal discomfort and also reduce energy consumption where air conditioning used for space heating and cooling [6].

35.2 Methodology

Experimental investigation of thermal comfort and energy consumption was conducted on four (4) mock-up green buildings that have been built with various different types of building material for wall/building envelopes. These four mock-up green buildings are named as $M1$, $M2$, $M3$, and $M4$. All of the mock-up green buildings have the same size, which is $3 \times 3 \times 3$ cubic meter and have the same type of windows which is casement window have is insulated with straw board. There are exhaust fans and air conditioner installed in $M3$ and $M4$, so energy consumption only measured for $M3$ and $M4$ only. For each mock-up green building, there is one door and three windows for each side, as seen in Fig. 35.1. Figure 35.2 shows the plan location of the Mock-up Buildings (*M*1, *M*2, *M*3, and *M*4), respectively.

All the four MUBs have an identical floor area of msq. (3 m × 3 m) and constructively different in terms of its wall material and compound, roof design, door, and window features—to investigate all these distinctive variables toward the internal thermal comfort of each MUBs. Table 35.2 depicts characteristics for each MUB.

(a) Specification of Building Material (wall) of Mock-Up Green Building

All the mock-up green buildings have been built from different types of materials for the wall. All types of construction materials used is conventional according to Malaysian building standard. There are three mock-up green buildings that have been built from green material that is *M*1, *M*2, and *M*3 and one mock-up green building that has been built from non-green material that is *M*4. The wall is made of 20 cm thick material block with 2–3 cm thickness of cement plaster and paint for both

Fig. 35.1 *M*1 Mock-up buildings on-site

Fig. 35.2 *M*2 Mock-up buildings on-site

Table 35.2 MUBs—building characteristics

	Wall	Roof	Roof design
Mock-up building 1 (MUB 1) 	Wool wood cement board	Composite cladding roofing element	5° inclination roofing design
Mock-up building 2 (MUB 2) 	Concrete-polystyrene lightweight cement mix	Metal decking without insulation	40° inclination with overhang roofing design
Mock-up building 3 (MUB 3) 	Clay cavity brick wall	Metal decking without insulation	20° inclination with overhang roofing design
Mock-up building 4 (MUB 4) 	White sand brick wall	Metal decking without insulation	20° inclination with overhang roofing design

interior and exterior side of the building. The floor is made from cement with 42 cm of thickness. The specification of each main construction material is shown in Table 35.3.

(b) Thermal Comfort Temperature and Relative Humidity Parameter

In this research, thermal comfort temperature and relative humidity standard are necessary in order to analyze data. Thermal comfort temperature is very important as a set point temperature. If the temperature taken is higher than the set point temperature, it means that the environmental condition inside the building will cause discomfort. From the literature review, the most suitable thermal comfort temperature and relative humidity standard were taken as a parameter during the research. Table 35.4 shows the parameters that will be used while doing this research.

Table 35.3 Specification of each main construction material

Type of material	Density (10^3 kg/m^3)	Specific heat capacity (J/kg °C)	Thermal conductivity (W/(m °C)
Polystyrene concrete block (*M*1)	0.8–1.0	1300–1500	0.1–0.5
Straw slab insulation, compressed (*M*2)	1.1–1.3	900–1000	0.09
Fired clay bricks (*M*3)	1.8–2.6	1400	0.60–1.30
Concrete block (*M*4)	1.3–1.7	880	1.7

Table 35.4 Thermal comfort temperature and relative humidity parameters

Thermal comfort temperature (°C)	23 °C–28.6 °C
Relative humidity	40–60%

35.3 Results and Discussion

(a) Selection of Data Sample

Data collection for this research is divided by two, which is data collected without using mechanical ventilation and air conditioner and data collected using the mechanical ventilation and air conditioner. The data that have been collected is temperature surrounding in all 4 mock-up green buildings and the power consumption.

For data collected without using the mechanical ventilation and air conditioner, it started on March 12, 2019 until March 14, 2019. Then, it continued on March 16, 2019 until March 19, 2019 which total up to 7 days of collecting data. During 7 days of collecting data, the weather condition was mostly sunny and partly sunny. Partly sunny means that the area received 40–70% of sunlight during daytime while mostly sunny means that the area received 70–90% of sunlight during daytime. This type of weather condition makes the outside temperature of the mock-up green building were very hot with a maximum temperatures of 37°C. The details about weather description, maximum and minimum temperature of all 7 observed days are shown in Table 35.5.

For data collected while using mechanical ventilation and air conditioner, 3 days have been chosen which started on March 15, 2019 until March 17, 2019. Energy consumption and temperature were measured for both mock-up green buildings to find out the relationship between energy consumption and thermal comfort temperature. During 3 days of collecting data, the weather condition was partly sunny and had a light rain. This type of weather condition makes the outside temperature of the mock-up green building was not very hot with maximum temperature of 34°C. The details about weather description, maximum and minimum of all three observed days show as in Table 35.5.

Table 35.5 Weather description of 1 observed week

Date	Weather condition	Temperature Hi/Low (°C)
12 March 2019	06.00–12.00 partly sunny	35/24
	12.00–18.00 mostly sunny	
13 March 2019	06.00–12.00 partly sunny	34/26
	12.00–18.00 mostly sunny	
14 March 2019	06.00–12.00 partly sunny	36/26
	12.00–18.00 partly sunny	
16 March 2019	06.00–12.00 partly sunny	37/25
	12.00–18.00 partly sunny	
17 March 2019	06.00–12.00 partly sunny	36/25
	12.00–18.00 mostly sunny	
18 March 2019	06.00–12.00 partly sunny	36/26
	12.00–18.00 partly sunny	
19 March 2019	06.00–12.00 partly sunny	36/26
	12.00–18.00 partly sunny	

(b) Findings of Data Collected Without Using Mechanical Ventilation and Air Conditioner

The finding is confirmed in the boxplot in Fig. 35.3 below which shows the difference in median and standard deviation between mock-up green building $M1$, $M2$, $M3$, and $M4$. It can be seen that, the $M3$ has the lowest median temperature that almost reaches the thermal comfort temperature standard (28.6°C) that is 28.9 °C while $M4$ has the highest median that is 32.5 °C. For standard deviation, the thickness of the boxplot indicates the difference where $M3$ has the lowest standard deviation, and $M4$ has the highest standard deviation. In this boxplot, it can be seen that all the mock-up green building that have been built from green material ($M1$, $M2$, and $M3$) have a lower median temperature and standard deviation compared to mock-up green building $M4$ that is built from non-green material ($M1$).

By determining the detailed sigma level (z benchmark for overall capability), the percentage of occupant satisfaction can be determined as an indicator for the relative overheating from the perspective of the occupants. Below is the process capability report for all the mock-up green building by using the highest level of 28.6 for residential area without A/C or mechanical ventilation. This will show the percentage of occupant satisfaction and the percentage of active cooling needed. From the result of process capability of $M1$ in Fig. 35.4 below, Z bench value is −0.31 means that only in 38.21% the occupants can be satisfied which makes almost 61.79% more active cooling is necessary.

From the result of process capability of $M2$ below in Fig. 35.5, Z bench value is −0.62 means that only in 26.76% the occupants can be satisfied which makes almost 73.24% more active cooling is necessary. From the result of process capability $M3$

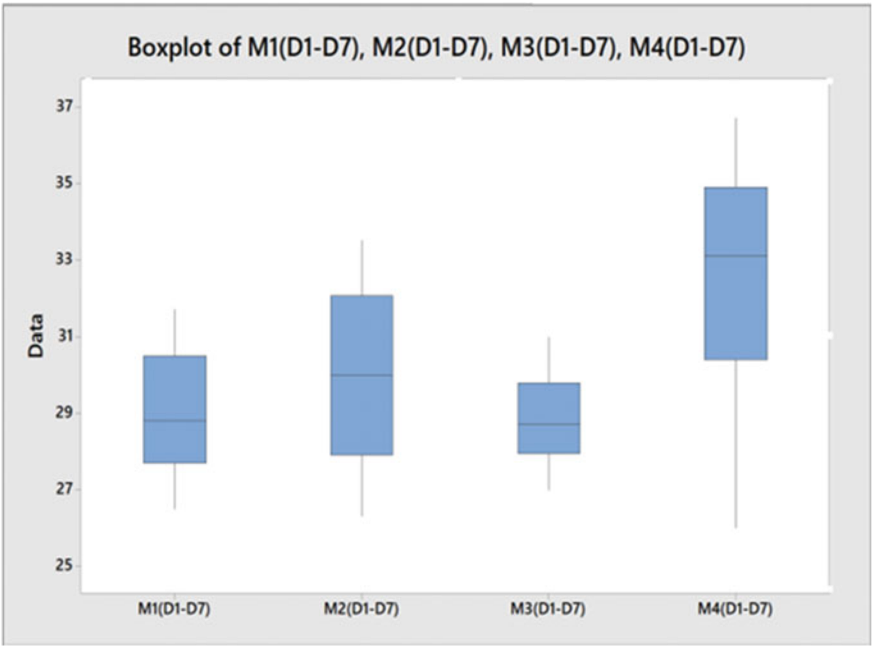

Fig. 35.3 Boxplot of $M1$, $M2$, $M3$ and $M4$

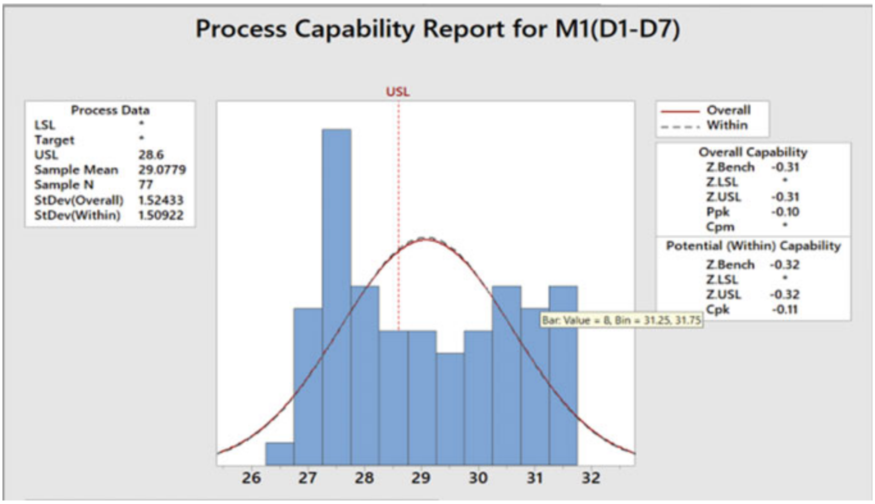

Fig. 35.4 Process capability report of $M1$

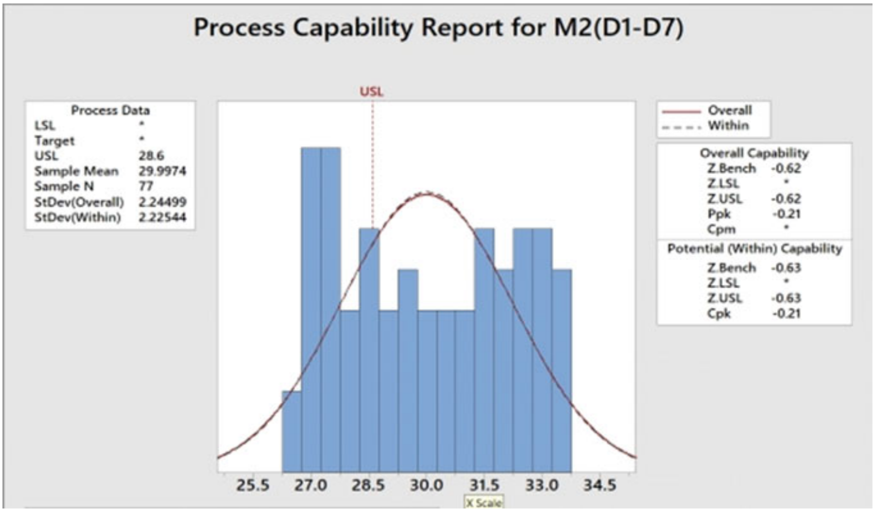

Fig. 35.5 Process capability report of $M2$

below in Fig. 35.6, Z bench value is −0.27 means that only in 39% the occupants can be satisfied which makes almost 61% more active cooling is necessary. From the result of process capability of $M4$ below in Fig. 35.7, Z bench value is −1.37 means that only in 8.53% the occupants can be satisfied which makes almost 91.47% more active cooling is necessary (Table 35.6).

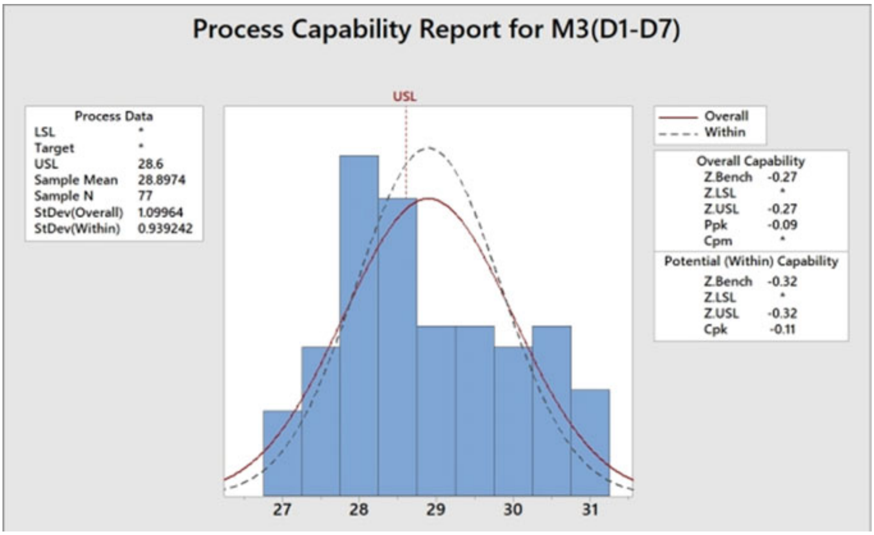

Fig. 35.6 Process capability report of $M3$

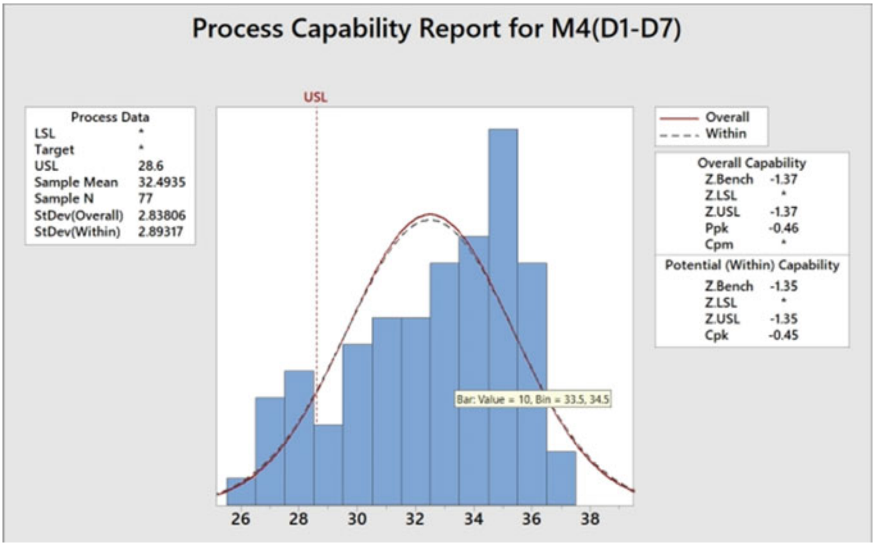

Fig. 35.7 Process capability report of $M4$

Table 35.6 Comparison of data analysis (temperature) from each mock-up green building

Date	Weather condition	Temperature Hi/Low (°C)
15 April 2019	06.00–12.00 partly sunny	34/24
	12.00–18.00 partly sunny	
16 April 2019	06.00–12.00 partly sunny	34/26
	12.00–18.00 partly sunny	
17 April 2019	06.00–12.00 partly sunny	34/26
	12.00–18.00 partly sunny	

Table 35.7 shows the summary of finding of data collected without using mechanical ventilation. The table shows the data analysis of ability of each mock-up green building to achieve thermal comfort standard. From the result of data analysis at the

Table 35.7 Comparison of data analysis from each mock-up green building

Mock-up green buildings	Mean	Standard deviation	Percentage of occupant satisfaction (%)	Percentage of active cooling needed (%)	Maximum temperature (°C)
$M1$	29.48	1.524	38.21	61.79	31.7
$M2$	30	2.245	26.76	73.24	3.5
$M3$	28.9	1.1	39	61	31
$M4$	32.09	2.838	8.53	91.47	36.7

Table 35.8 Total energy consumption and difference of energy consumption between $M4$ and $M3$

Dates	Energy consumption needed to provide a 100% satisfaction to occupants for $M3$ (kWh)	Difference of energy consumption between $M4$ and $M3$ (kWh)
April 15, 2019	$[(40/100) \times 7.6] + 0.1892 =$ 3.23 kWh	7.6 KWh–3.23 kWh = 4.37 kWh
April 16, 2019	$[(40/100) \times 7.7] + 0.1818 =$ 3.26 kWh	7.7 kwh–3.26 kWh = 4.44 kWh
April 17, 2019	$[(40/100) \times 7.6] + 0.1855 =$ 3.22 kWh	7.6 kwh–3.22 kWh = 4.38 kWh
Total	9.71 kWh	13.19 kWh

Table 35.8, it can be seen that mock-up green building that is built from green material can provide better temperature environment than the mock-up green building that is built from non-green material.

From the capability process report of $M3$ for 3 observed days, the energy consumption needed is reduced as green building $M3$ with exhaust fans provide 60% of requests temperature, so only 40% of energy consumption needed from the air conditioner or fans in order to achieve thermal comfort temperature standard. The total energy consumption of green building $M4$ is used as an indicator in order to estimate the energy needed by green building $M3$. 40% of energy consumption from $M4$ of each observed day has been calculated and will be added to the energy consumption of green building $M3$ in order to estimate the total energy consumption needed by green building $M3$ to provide a 100% satisfaction of thermal comfort temperature to occupants.

Table 35.8 shows the total energy consumption needed by green building $M3$ to provide a 100% satisfaction to occupants and the difference in energy consumption between green building $M4$ and $M3$ that indicate the total energy that can be saved by using green building $M3$. From the Table 35.8, it can be seen that the total energy consumption of green building $M3$ that provides 100% satisfaction to occupants is 9.71 kWh, less than the total energy consumption of green building $M4$ that is 22.9 kWh from Table 35.8. It also can be seen that the difference in energy consumption between green building $M4$ and $M3$ indicates the total energy that can be saved from green building $M3$ that is 13.19 kWh. This proves that the mock-up green building $M3$ that has been built from green material can reduce energy consumption two times better than mock-up green building $M4$ that has been built from non-green material.

35.4 Conclusion

Based on the research studies, it can be concluded that mock-up green buildings that have been built from the composite green materials ($M1$, $M2$, and $M3$) can provide a better temperature environment inside the building compared to the non-composite $M4$. This is because of specification of the construction material that gives effect toward the heat penetration of each wall of mock-up green building. From all the mock-up green building, $M3$ is the most ideal in terms of providing thermal comfort temperature to surrounding. In terms of energy consumption, it can be seen that green buildings that have been built from green material can reduce energy consumption. The research has proven that mock-up green buildings that are built from green material need less active cooling than mock-up green building that is built from non-green material.

Specification of construction material is very important to be considered because it can be seen that there is huge difference between mock-up green buildings $M1$, $M2$, $M3$, and $M4$ in terms of providing a better temperature environment. Mock-up green building $M3$ that built from fired clay brick is the ideal because of its specification that have low thermal conductivity and high specific heat capacity. So, build a building with a good specification is also one of many methods to reduce energy consumption in hot and humid climate countries such as Malaysia for the long term.

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