QUANTIFICATION OF THERMAL MASS IN BUILDING IN THE TROPICS

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ABSTRACT

The concept of thermal mass is a mechanism to absorb, store and release heat on building materials that aim to reduce peak temperatures and peak cooling loads. Buildings that have good thermal mass must be built with materials that suit with the local climate. Parameters that can represent the thermal mass is the heat capacity, effusivitas thermal, thermal diffusivity, and thermal time. The buildings are constructed with concrete material may simply have better thermal mass when compared to buildings constructed with wood of the same thickness as the concrete has a value greater heat capacity than the timber, but when two buildings constructed with concrete materials of different types, cannot be determined easily which buildings that have a better thermal mass. It is therefore necessary thermal mass calculations and simulations on each type of building to get optimum thermal mass. Optimum thermal mass is the value of thermal mass that has no effect anymore to changes in temperature and cooling loads in buildings. In this study conducted some simple modeling building cubic which consist of various combinations of building type, thickness, material, and geometry, in addition to the simulation and calculation parameters of the thermal mass of each combination of the building to determine the peak temperature of the building, the cooling load peaks and parameters of thermal mass. Furthermore, comparing and analyzing the results of simulation and calculation parameters of the thermal mass of the building all the combinations to get optimum thermal mass to the tropics.

Keywords: thermal mass, thermal mass parameters, peak cooling load, peak temperature

INTRODUCTION

Indonesia is a country located at the equator so it is included in a tropical climate which has the characteristics of an average temperature of 35°C [1]. This condition is less favorable for humans in performing their activities since the human productivity tended to fall when the air condition is uncomfortable as well as too cold or too hot. Thermal mass represents the ability of materials to absorb, store and release heat energy. Thermal mass is a energy conservation alternative that can reduce peak cooling loads and indoor air temperature swings in buildings also providing more comfortable indoor conditions. Indoor air temperature is primarily influenced by external climatological parameters such as solar radiation and outdoor temperature [2]. The thermal mass effectiveness of the building have been represents by several parameters such as heat capacity, thermal diffusivity, thermal effusivity (admittance) and thermal time. This paper presents the optimum value of thermal mass parameters of building through parametric study. The scope of this research focuses on Bandung, Indonesia region which feature tropic climate.

MODELING METHODOLOGY

This parametric study conducted by three different model type, there are cube model, cube with window, and cube with window with slope roof. The model was a simplified building construction, a close box where the walls, the roof, and the ground floor had the same composition. This model was used to stimulate four different envelopes materials and four different dimension.

The cooling energy required to temper the ventilation air to the space temperature set point is included. The scope of this study is to asses the passive behavior of thermal mass construction under these conditions which based on two cases, the case consist of :

- Case 1 : The model without air conditioner. The output of this model is indoor air temperature during a year (hourly)
- Case 2 : The model used air conditioner, using VRF type of air conditioner, the output is cooling load during a year (hourly).

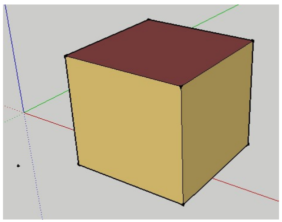

Figure 1. *Cube*

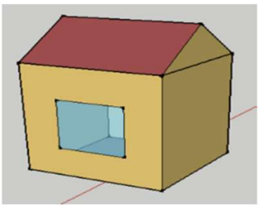

Figure 2. *Cube with window and slope roof*

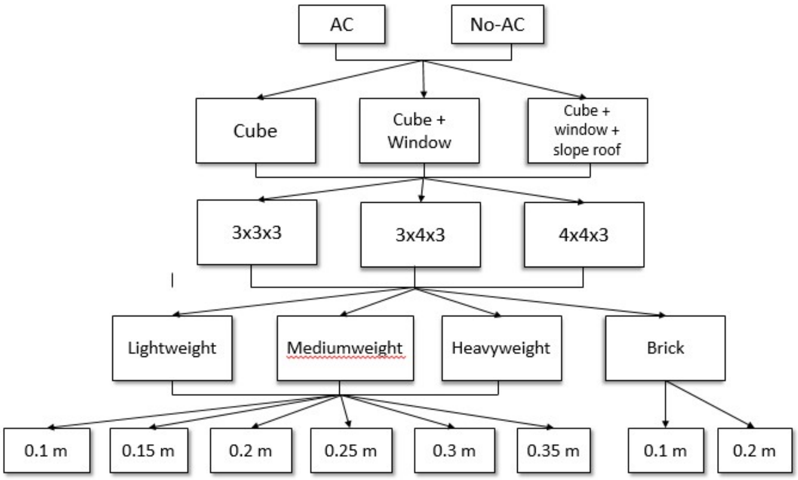

Figure 3. *Combination of building*

The total combination of building is about 480 combination. The model provide just one floor with height about 3 m.
The glazing system on this simulation is utilize the simple glazing system window.

ENERGY SIMULATIONS

Simulation parameter : fixed parameters

The following fixed building parameters were implemented in all simulation models (case 1 and case 2) :

- location – Bandung, Indonesia,

- building type – office building,
- shape – rectangular floor plan,
- window to wall ratio – 30%
- glazing orientation – west
- height dimension – 3 m

For special case 2, due the utilize of air conditioner, in this simulation using VRF, the temperature set point is 25^0 C for all schedule

Simulation parameter : variable parameters

- thickness – for all concrete type, the increment is 5 cm (10 cm-35 cm), for brick the increment is 10 cm (10cm-20cm)
- building dimension – 3 m x 3 m, 3 m x 4 m, 4 m x 4 m

THERMAL MASS PARAMETER

Thermal mass have several parameters that represents the effectiveness of thermal mass of the building. The parameters that have been considered is:

- **Heat Capacity**

Heat capacity (HC) parameter which indicates how much capacity a material / substance to accommodate the heat.

$$HC = L \times \rho \times c \tag{1}$$

HC = heat capacity, (J/m^2K)
L = thickness, (m)
c = specific heat capacity, (J/kgK)
ρ = density, (kg/m^3)

- **Thermal Diffusivity**

Thermal diffusivity (α) is an indication of the speed of temperature for through the thickness of a wall [5]

$$\alpha = \frac{k}{\rho c} \tag{2}$$

α = thermal diffusivity, (m2/s)
k = thermal conductivity, (Wm/K)
ρ = density, (kg/m^3)
c = specific heat capacity, (J/kgK)

- **Thermal Effusivity (Admittance)**

Thermal effusivity (e) is the rate at which material can absorb and release heat. Used to indicate the material capacity to absorb and release heat [5]

$$e = (k\rho c)^{0.5} \tag{3}$$

e = thermal effusivity, ($W/m^2Ks^{0.5}$)
k = thermal conductivity, (Wm/K)
ρ = density, (kg/m^3)
c = specific heat capacity, (J/kgK)

- **Thermal Time**

Thermal lag (t) is the time that envelope needed to reach steady state when the temperature of outside wall surface and indoor wall surface are equivalent [3]. It is kind to delay the heat flux flow through the envelope to the indoor building. Thermal time value is depend on type of material and thickness.

$$t = \frac{L^2}{\alpha} \quad (4)$$

t = time lag (s)
L = thickness (m)
α = thermal diffusivity (m^2/s)

RESULTS

Tables 3 and 4 below, shown the best performance in every types of building. These peak indoor air temperature and peak cooling load were the lowest among 360 combination of buildings, constructed by lightweight concrete material. On these tables also shown the results of the thermal mass parameters that represent each of these buildings type.

Table 1. *Indoor Air Temperature*

Cube	Temperature (^0C)	Thermal Diffusivity (m^2/s)	Thermal Effusivity ($W/m^2Ks^{0.5}$)	Heat Capacity (kJ/m^2K)	Thermal Time (s)
3x3x3m, Lightweight, 0.35 m	32.65	4.93 x 10^{-7}	754.9	2257.92	248513
Cube + Window	Temperature (^0C)	Thermal Diffusivity (m^2/s)	Thermal Effusivity ($W/m^2Ks^{0.5}$)	Heat Capacity (kJ/m^2K)	Time (s)
4x3x3m, Lightweight, 0.35 m	36.76	4.93 x 10^{-7}	754.9	1881.6	248513
Cube + window + slope roof	Temperature (^0C)	Thermal Diffusivity (m^2/s)	Thermal Effusivity ($W/m^2Ks^{0.5}$)	Heat Capacity (kJ/m^2K)	Time (s)
4x3x3m, Lightweight, 0.35 m	33.93	4.93 x 10^{-7}	754.9	1881.6	248513

Table 2. *Cooling Load*

Cube	Cooling Load (W)	Thermal Diffusivity (m^2/s)	Thermal Effusivity ($W/m^2Ks^{0.5}$)	Heat Capacity (kJ/m^2K)	Thermal Time (s)
3x3x3m, Lightweight, 0.3 m	1120.36	4.93 x 10^{-7}	754.9	1612.8	182581
Cube + Window	Cooling Load (W)	Thermal Diffusivity (m^2/s)	Thermal Effusivity ($W/m^2Ks^{0.5}$)	Heat Capacity (kJ/m^2K)	Time (s)
3x3x3m, Lightweight, 0.35 m	1688.11	4.93 x 10^{-7}	754.9	1881.6	248513
Cube + window + slope roof	Cooling Load (W)	Thermal Diffusivity (m^2/s)	Thermal Effusivity ($W/m^2Ks^{0.5}$)	Heat Capacity (kJ/m^2K)	Time (s)
3x3x3m, Lightweight, 0.35 m	1688.16	4.93 x 10^{-7}	754.9	1881.6	248513

DISCUSSION

Every case shown that lightweight concrete materials have a better performance in indoor temperature and cooling load. After the comparison, the cube model have the lowest indoor temperature and cooling load among the others type of buildings. The thermal mass parameters of cube model has been analyzed and was found that time thermal more represent thermal mass than the others parameters. Figure 4 and 5 will explain the correlation about cooling load and indoor temperature as the performance, and thermal time as thermal mass parameter.

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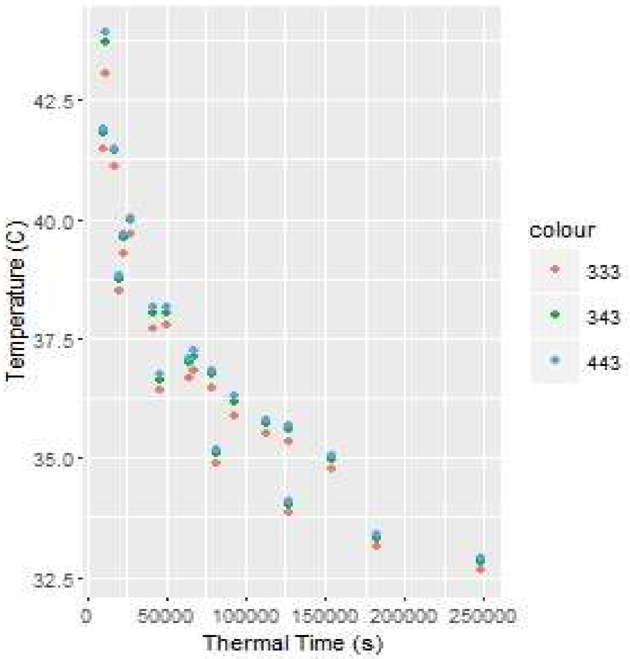

Figure 4. *Thermal Time vs Temperature*

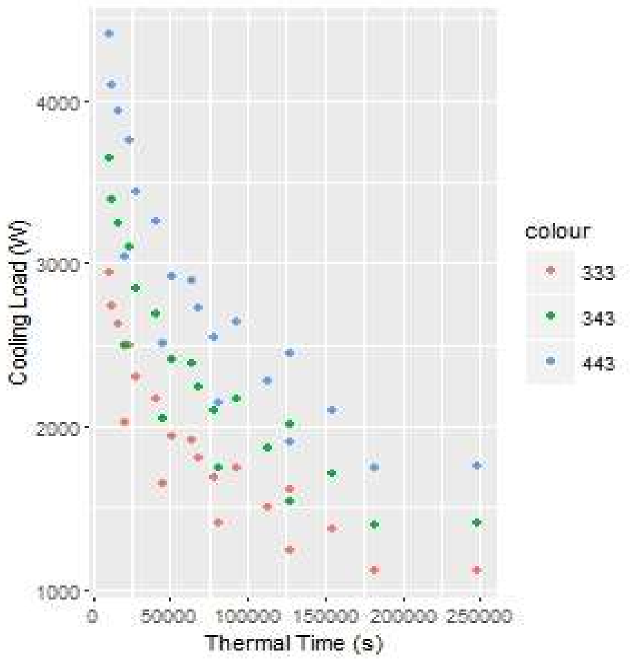

Figure 5. *Thermal Time vs Cooling Load*

The indoor air temperature and thermal time are shown in figure 4, it tell that the lowest indoor air temperature was reach when the thermal time is 248513 s (62 h), its mean that by that time of thermal time was capable to endure the heat flux from outdoor to the indoor and keep the indoor air temperature still comfort. The cooling load and thermal time are shown in figure 5, it tell that the lowest cooling load was reach when the thermal time is 182581 s (50 h), its mean that by that time of thermal time was capable to endure the heat flux from outdoor to the indoor, and it was enough to reduce the cooling load.

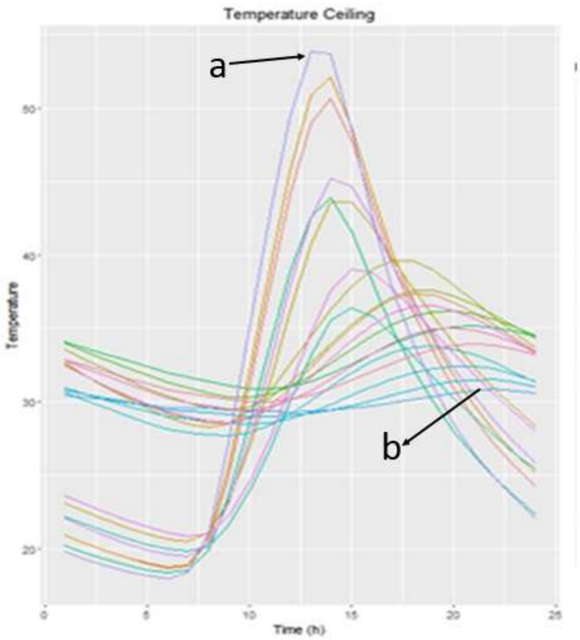

Figure 6. *Time vs Temperature Ceiling*

Figure 6 shown that correlation of ceiling surface indoor temperature and time (24h) of all the combination building. The highest peak temperature (a) was found in building with value of thermal mass is 12584 s and the lowest peak temperature (b) was found in building with value of thermal time is 248513 s (62 h). It is proved by that value of thermal time could be delay the heat flux from the outdoor to the indoor through the envelope of building, also can make the building more stable in temperature fluctuations during a whole day.

CONCLUSION

The aim of this study was to obtain optimum value of thermal mass parameters for use in the tropics. Determining the optimum value of the thermal mass parameters based on the achievement of the ideal performance in building. The ideal conditions were indoor air temperature and the cooling load is reach the optimum thermal comfort while saving energy for cooling. The results showed that the cube type of building dimensions 3x3x3 m with a lightweight concrete material thickness of 0.35 m have the most ideal of indoor air temperature, while the box type of building dimensions 3x3x3 m with a thickness of 0.3 m produce the lowest cooling load among the others combination. Both of the case have been determined their optimum thermal mass which the thermal time is 182581 s (50 h) for case with AC and 248513 s (62 h) for case without AC. By that thermal time will help to maintain the fluctuations of indoor air temperature for more stable.

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