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THE EFFECTS OF FOAM BEADS AND KAOLIN ON PHYSICAL AND THERMAL PROPERTIES OF CONCRETE BLOCKS

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ABSTRACT

It is widely use of air-conditioning systems in Thailand due to its location. It is located in a tropical zone with relatively high temperatures all year round, with high humidity and high intensity of sunlight. In order to save electrical energy for air-conditioning systems, preventing heat transfer into the building is required. The objective of this study is to investigate the physical and thermal properties of concrete blocks. An attempt is made to increase heat resistance of concrete blocks. Foam beads (0–0.30% by weight) and kaolin (0–70% by weight) were added in concrete block mixture to increase discontinuous voids in concrete. Compressive strength and water absorption of concrete blocks were tested. The testing results indicated that compressive strength decreased when foam beads and kaolin were added. Water absorption increased when foam beads were added. In contrast, the more kaolin added the less water absorption. The thermal conductivity coefficient of concrete blocks was also investigated. The results confirmed that the higher the amount of foam beads or kaolin added, the higher the thermal resistance of concrete blocks. Thermal time-lag behavior was also investigated. The results indicated that concrete block with kaolin took the longest time in heating and took the shortest time in cooling. These properties are good for heat prevention in hot climate regions. These concrete blocks which were developed and tested in this research conform to the Thai Industrial Standard. Finally, it can be concluded that because of its thermal behavior, concrete block with kaolin is a suitable energy-saving concrete block for hot and humid climates.

Keywords: Concrete blocks; Foam beads; Kaolin; Physical properties; Thermal properties

1. INTRODUCTION

Thailand is located in a tropical region although it is considered being in a comfort zone based on ASHRAE (2009). As a broad generalization, people living or working in hot or cold climates have lost their sense of productivity, while people working in a comfort zone in a temperate climate generally have higher productivity (Srinavin & Mohamed, 2003). Because of the hot and humid weather, electrical power has been increasingly used for air conditioning, which brings about comfort for people using or living in buildings to improve their productivity. Since air conditioners require a lot of electrical power to run, many surveys have indicated that electricity consumption for air conditioning is about 60 to 70% of the total electricity consumption in a building (DEDE, 2005). Total electrical consumption in Thailand in 1994 was 62,558 million units (kW-hr) (Karnchana, 2008) and 132,492 million units in 2007 and recently 179,201 million units in 2013 (DEDE, 2014). This statistic shows that electricity consumption

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has risen to above 186% within 19 years. To conserve electrical energy, this study, therefore, is aimed towards developing Energy-saving concrete blocks, which are commonly used as materials to construct building walls. The properties of common concrete blocks used today allow rapid heat transfer into buildings. Moreover, owing to their high heat capacity, much of the heat is retained in these walls.

In order to develop heat resistant, energy-saving concrete blocks, low thermal conductivity materials should be added into the mixture of concrete blocks. Different materials have different properties, such as foam beads and kaolin, which are light-weight, having high porosity and good insulation. They have been used generally to produce construction materials (Ugheoke et. al., 2006; Campo, 2008). Adding these materials into the mixture of conventional concrete blocks can potentially produce more voids and lower thermal conductivity. In order to save electrical energy, those kinds of energy-saving concrete blocks developed in this research should have more discontinuous voids than conventional one. The main objective of this study is to investigate physical and thermal properties, including thermal behavior of the already-developed energy-saving concrete blocks.

Kaolinite is the proper name of the mineral, but in industrial terminology the mineral is known as kaolin. Kaolin is used in many industries, such as ceramic whiteware products, insulators, and refractories. Kaolin is lightweight, low in thermal conductivity, and yet sufficiently resistant to temperature (Ugheoke et. al., 2006). Mixing kaolin with concrete block could produce a highly porous concrete block, which is a good insulator (Avallone & Baumeister, 1996). Foam beads have high heat resistance, low density, and are light in weight. One of the objectives of this research is to investigate physical and thermal properties of those already-developed energy saving concrete blocks.

2. METHODOLOGY

Energy-saving concrete blocks were produced by the plant in Khon Kaen province using the same process as the ordinary concrete block based on Thai industrial standard (TIS 58-2533, 1990) with the size of 70×190×390 mm. Portland Cement Type 1 and well balanced crushed dust (Sieve Analysis: Cu = 5.69, Cc = 1.51) were weighed, according to the proportions shown in Tables 1 and 2. These were blended in a concrete mixer. Then white round 1–2 mm foam beads No. 1 (Figure 1) with a density of 0.026 g/cm^3 or kaolin (Figure 2) (XRF: 64.04% SiO_2, 23.81% Al_2O_3, 1.93% Fe_2O_3, 1.12% MgO, 4.32% LOI @ 900°C, and Mesh 2,800), were added in the designed proportion (shown in Tables 1 and 2, respectively) until the mixture had a consistent color of cement. Next, clean water was added at the designed amount. Then the mixture was transferred on the conveyor belt to the molds. A shaker agitated the mixture so that it settled in the molds. Concrete blocks were then pressed by a pressing machine. After pressing, they were taken out of the molds and let dry under a shed roof. They were marked and then cured for 28 days.

Figure 1 Foam bead no.1

Figure 2 Kaolin

Table 1 Concrete block mixture: 1–2 mm foam beads no. 1

Mix No.	Foam beads No. 1 (% wt. instead of dust)	Foam beads No.1 (kg)	Dust (kg)	Cement (kg)	Water (kg)
Control CB-1	0.00	0.000	90.000	14	5.5
CB-1-1	0.10	0.090	89.910	14	5.5
CB-1-2	0.15	0.135	89.865	14	5.5
CB-1-3	0.20	0.180	89.820	14	5.5
CB-1-4	0.25	0.225	89.775	14	5.5
CB-1-5	0.30	0.270	89.730	14	5.5

Table 2 Concrete block mixture: kaolin

Mix No.	Kaolin (% wt. instead of cement)	Kaolin (kg)	Dust (kg)	Cement (kg)	Water (kg)
Control CB-2	0%	0.0	7	1.0	0.4
CB-2-1	30%	0.3	7	0.7	0.4
CB-2-2	40%	0.4	7	0.6	0.4
CB-2-3	50%	0.5	7	0.5	0.4
CB-2-4	60%	0.6	7	0.4	0.4
CB-2-5	70%	0.7	7	0.3	0.4

The developed energy-saving concrete blocks of both types were tested for compressive strength, water absorption, thermal conductivity, and thermal time-lag. In order to test the thermal time-lag, the energy-saving concrete blocks were laid and plastered to form a tested wall with a dimension of 100×100 cm^2. A tested wall was then inserted into a designated insulated chamber as shown in Figure 3 for testing.

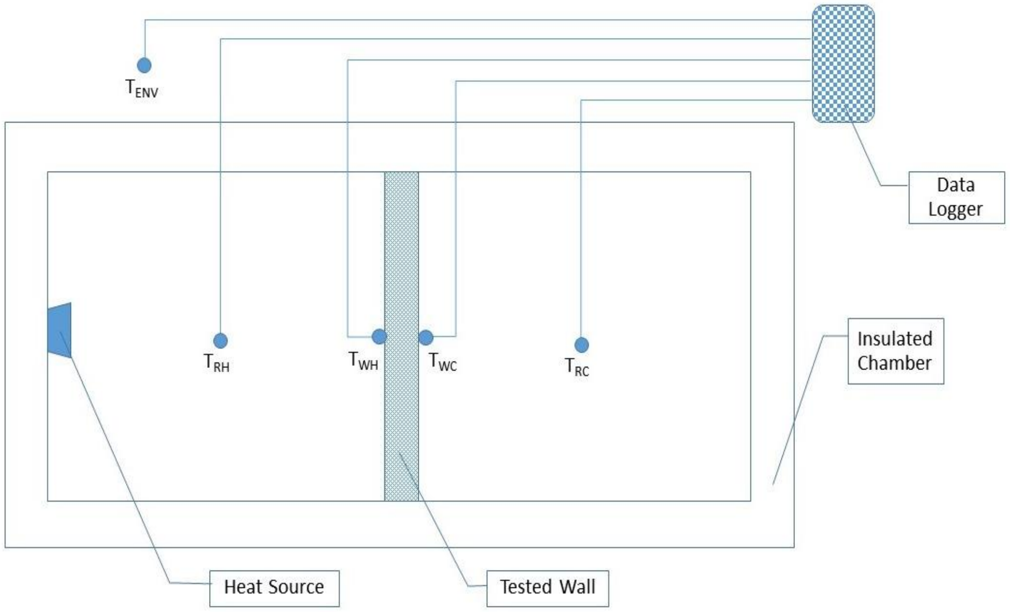

Figure 3 Thermal time-lag testing chamber (section view)

2.1. Compressive Strength

Energy-saving Concrete blocks were tested for compressive strength according to ASTM C140-70 (1970) and TIS 58-2533 (1990). The compressive strength can be calculated using Equation 1.

$$fc' = \frac{P}{A} \quad (1)$$

where *fc'* is the compressive strength (ksc), *P* is the maximum load (kg), and *A* is the compression area (cm^2).

2.2. Water Absorption

Energy-saving concrete blocks were tested for water absorption according to the ASTM C140-70 and TIS 58-2533. The water absorption can be obtained using Equation 2.

$$\text{Absorption} = \frac{W_{wet} - W_{dry}}{W_{dry}} \times 100 \ \% \quad (2)$$

where W_{wet} is wet weight (g), W_{dry} is dry weight (g).

2.3. Thermal Conductivity

The ASTM C177-10 (2005) steady state method was applied to test thermal conductivity of the energy-saving concrete blocks. The thermal conductivity coefficient can be calculated using Equation 3.

$$k = \frac{QL}{A(t_1 - t_2)} \quad (3)$$

where k is thermal conductivity coefficient (W/m•K), Q is heat energy (W), L is specimen thickness (m), A is heat flow area (m^2), t_1 is hotplate temperature (K), and t_2 is specimen surface temperature (K).

2.4. Thermal Behavior: Time-lag

Since the energy-saving concrete blocks with the maximum amount of additive i.e. 0.30% foam beads or 70% kaolin have passed the TIS standard for compressive strength and water absorption, therefore, it was selected for the thermal behavior testing. The concrete blocks were laid with mortar and plastered on both sides to form a test wall with a size of 100cm×100cm. The test wall was inserted into the custom made apparatus (Figure 1) to test for time-lag. After installation of the test wall, a heat source was turned on until the room temperature (T_{RH}) was equal to wall temperature (T_{WH}) and steady, then the heater was switched off. The room temperature and wall temperature were still monitored for 24 hours until it was steady. The environment temperature (T_{ENV}) was monitored and kept constant at 25°C. The room temperature and wall temperature on cool side (T_{RC} and T_{WC}) were also monitored.

3. RESULTS

Energy-saving concrete blocks had similar appearance compared to the conventional concrete blocks.

3.1. Compressive Strength

The findings show that compressive strength of the Energy-saving concrete blocks decreases where the amount of foam beads or kaolin increases, as shown in Figure 4. This is because foam beads and kaolin have a high porosity and are relatively easy to crush.

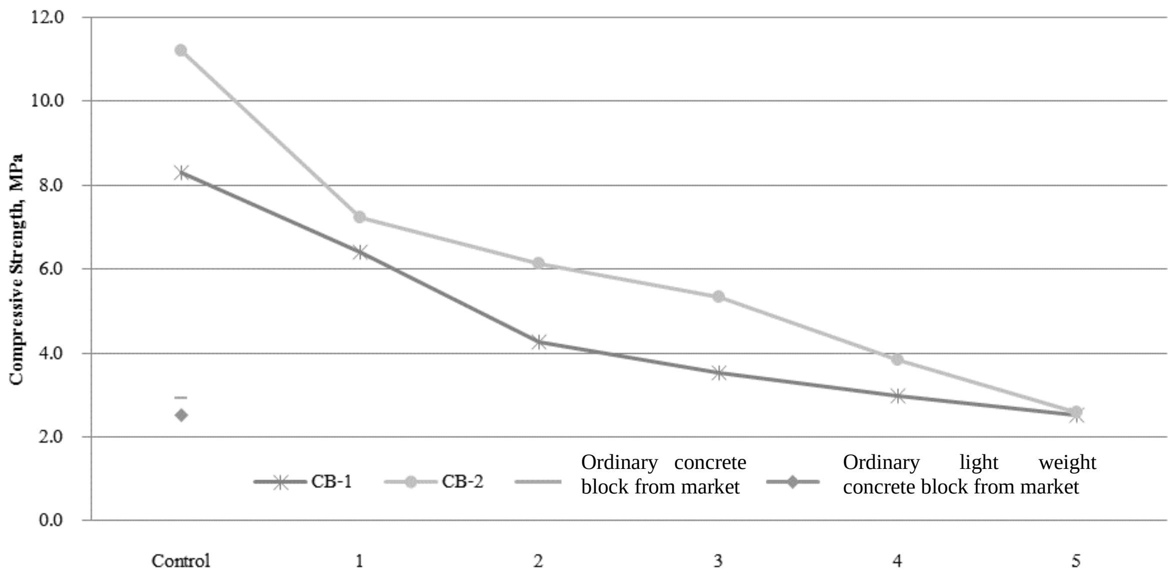

Figure 4 Compressive strengths of energy-saving concrete blocks

Concrete blocks mixed with kaolin give higher compressive strength than concrete blocks mixed with foam beads. This may be because foam beads are too soft, therefore, cracks may produce between the foam beads and bindings under load.

However, all proportions of mixtures of energy-saving concrete blocks show an average compressive strength higher than specified in the TIS 58-2533 (1990) standards, in which compressive strength of concrete blocks must be higher than 2.5 MPa. It should be noted that ordinary concrete blocks and ordinary light weight concrete blocks obtained from the market had similar compressive strength compared to those of energy-saving concrete blocks (at 0.30% of foam beads or 70% of kaolin).

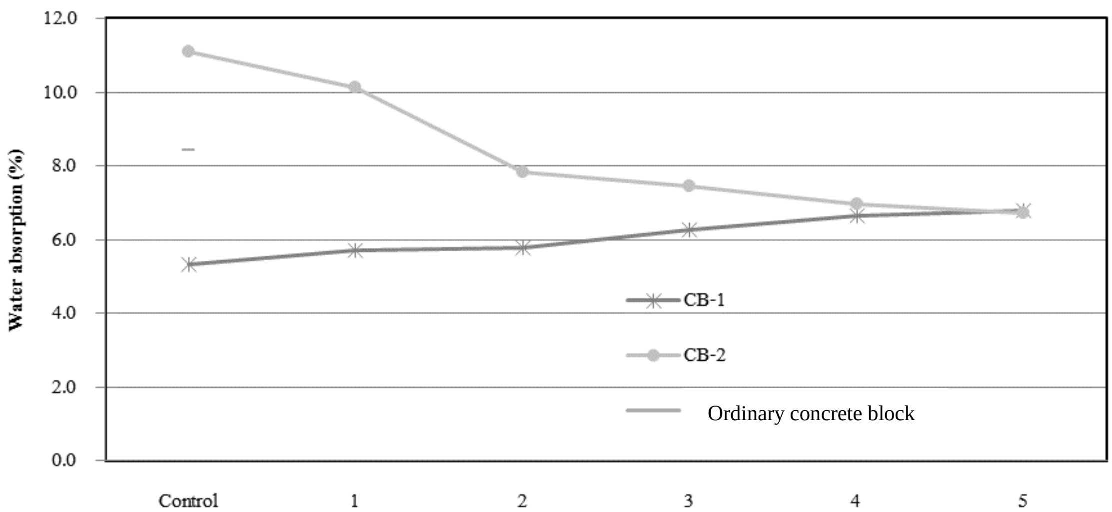

Figure 5 Water absorption of energy-saving concrete blocks

3.2. Water Absorption

Figure 5 shows all proportions have an average of water absorption within the range specified in the TIS 58-2533 standard (not more than 20%). Concrete blocks with foam beads had higher water absorption when more foam beads were added. However, concrete blocks with kaolin showed an opposite condition, the water absorption reduces when the amount of kaolin increases.

3.3. Thermal Conductivity

Thermal conductivity coefficients of all Energy-saving concrete blocks were lower than conventional concrete blocks. The calculated thermal conductivity coefficients were plotted and shown in Figure 6. Energy-saving concrete blocks had lower heat conduction when more foam beads or kaolin were added. Concrete blocks mixed with foam beads had a higher thermal conductivity coefficient than concrete blocks mixed with kaolin.

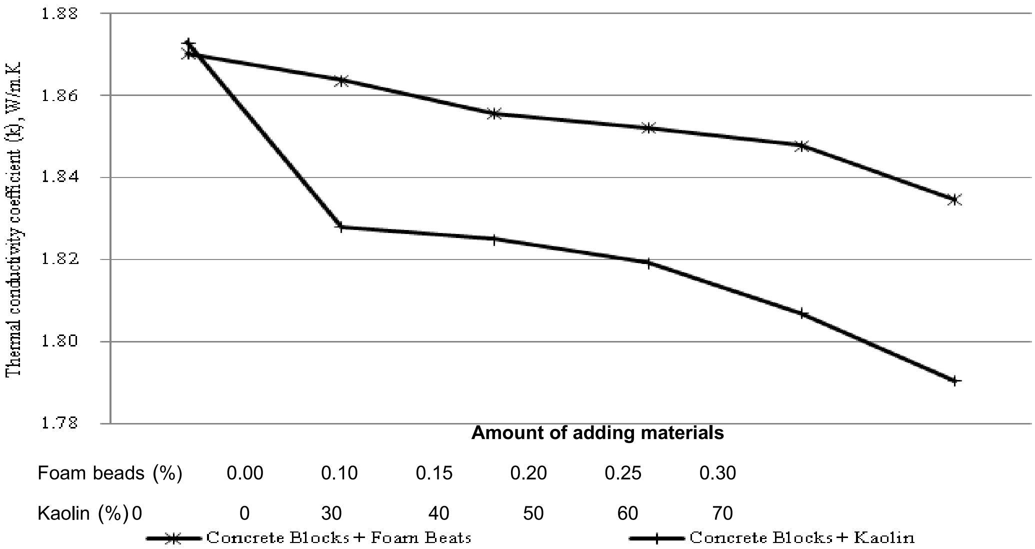

Figure 6 Bricks' Thermal conductivity coefficients of concrete blocks

3.4. Thermal Behavior: Time-lag

Thermal behavior of concrete blocks can be explained using Figures 7–9, in which are shown all the temperatures monitored for each type of the energy-saving concrete blocks versus time lapse. T_{RH} rises rapidly after the heater is turned on, passing the heat to the wall so that the wall become hotter (T_{WH}). When the wall facing the heater becomes hotter, it passes the heat to the other side (T_{WC}), then T_{WC} begins to rise. However, T_{WC} is lower than T_{WH} for all types of concrete block tested. T_{WC} took 420 minutes to reach 40°C for concrete block with 0.30% foam beads, whereas concrete block with 70% kaolin took 540 minutes and 450 minutes for the ordinary concrete block. After T_{WH} equals to T_{RH} and steady, the heater was turned off. T_{WC} of concrete block with 0.30% foam beads took 240 minute (3120–2880) to cool down to 40°C, as seen in Figure 7.

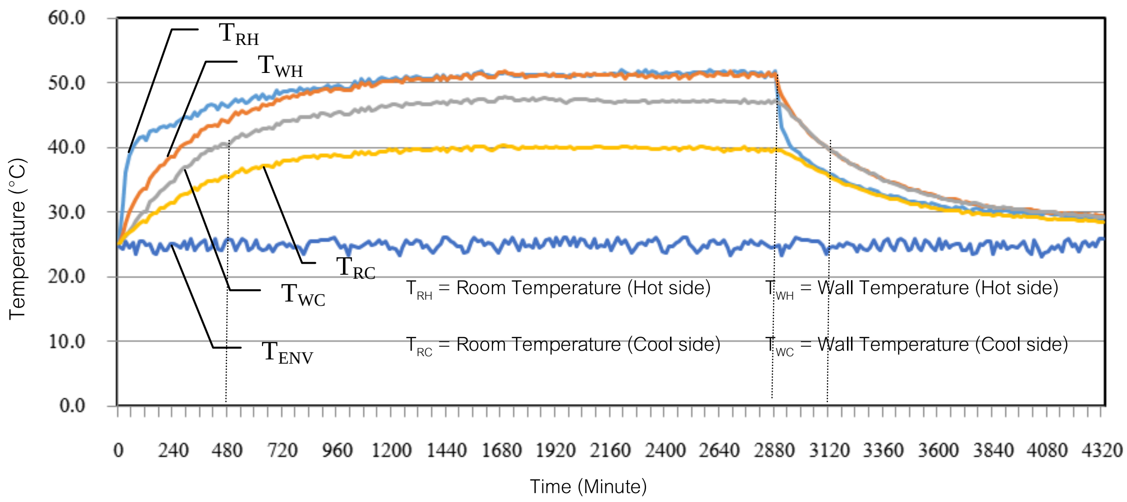

Figure 7 Thermal behavior of concrete block with 0.30% foam beads

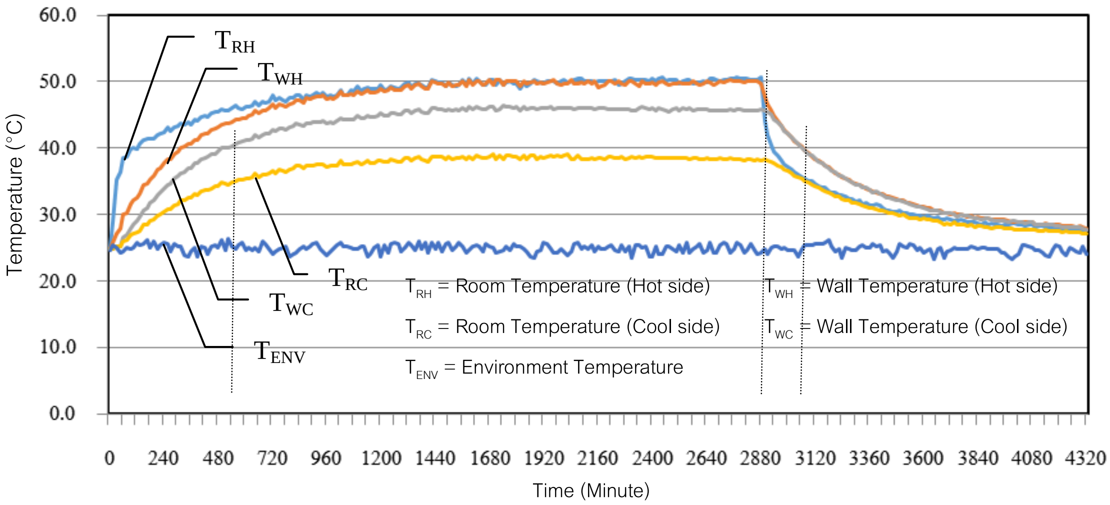

Figure 8 Thermal behavior of concrete block with 70% kaolin

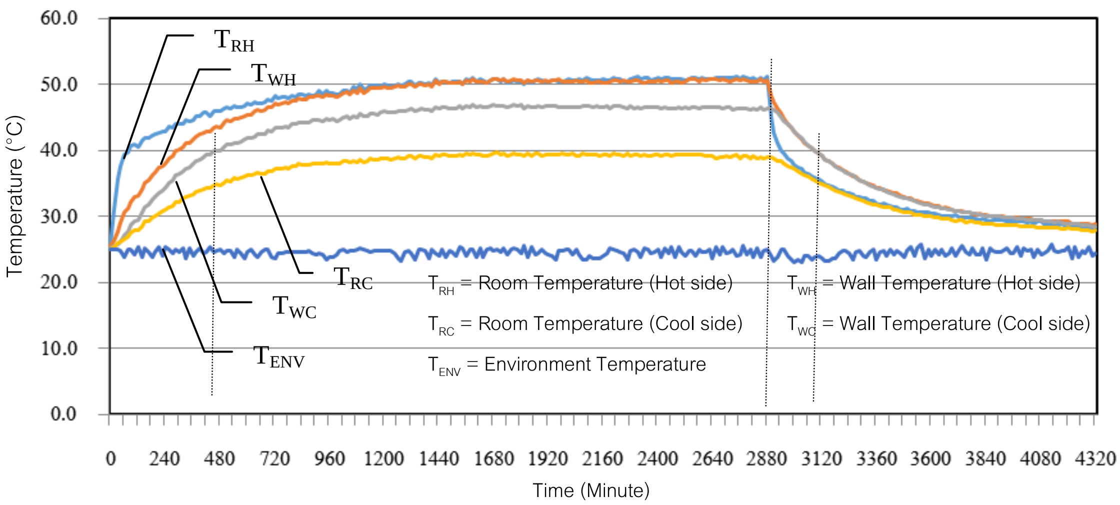

Figure 9 Thermal behavior of ordinary concrete block

The thermal time-lag behavior can be summarized in terms of heating time and cooling time as shown in Table 3. The concrete block with kaolin takes the longest time for heating which means it has the highest heat resistance. In addition, the concrete block with kaolin also takes the shortest time for cooling. It means that the concrete block with kaolin can release heat faster than others.

Table 3 Thermal time-lag behavior

Concrete block type	Heating time, min. (hr.)	Cooling time, min. (hr.)
Concrete block with foam beads	420 (7)	240 (4)
Concrete block with kaolin	540 (9)	180 (3)
Ordinary concrete block	450 (7.5)	210 (3.5)

According to the thermal time-lag behavior, it can be concluded that concrete block with kaolin is a suitable energy-saving concrete block for hot and humid climates.

4. CONCLUSION

The compressive strength of energy-saving concrete blocks tends to decrease with the increase of foam beads or kaolin. However, at a maximum of 0.30% foam beads or 70% of kaolin added, the compressive strengths are higher than 2.5 MPa, passing the TIS 58-2533 Standard.

Energy-saving concrete blocks mixed with kaolin have more water absorption when a higher amount of kaolin is added. Even at the highest amount of kaolin added (70%), water absorption is still lower than ordinary concrete block. However, all absorptions readings are less than 20%, passing the TIS 58-2533 standard.

The heat resistance of the energy-saving concrete block for both types is higher where the amount of foam beads or kaolin are increased.

The heating time of the 70% kaolin energy-saving concrete blocks was of the longest duration among others, whereas heating time of the 0.30% foam beads energy-saving concrete blocks was the shortest. Energy-saving concrete blocks with 0.30% of foam beads take a longer period of time for cooling down compared to both ordinary and 70% kaolin concrete blocks.

It can be concluded that because of its thermal behavior, concrete block with kaolin is a suitable energy-saving concrete block for hot and humid climates.

5. ACKNOWLEDGEMENT

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