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THE EFFECT OF THERMAL RESISTANCE OF CEILING LAYER ON THE PERFORMANCE OF AN AIR CONDITIONER AND ROOM TEMPERATURE DISTRIBUTION

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Abstract

The effectiveness of an air conditioner does not only depend on the design of the air-conditioner solely. Several factors affect the effectiveness of the cooling process of a room. One of the main factors in obtaining optimal results in the cooling process of a room is the rate of heat flow that enters a conditioned space. The amount of heat flow that enters a conditioned room affects the final temperature of the room. The ceiling is a part of the room that has a immense heat-flow rate. That is because the air temperature above the plafond is relatively high, and the thickness of the room plafond is relatively compact. It is necessary to analyze the room plafond material thermal resistance in increasing the heat absorption efficiency of household air conditioners. The thermal resistance of the material effect on the average room temperature, room temperature map, and the energy consumption is examined experimentally. The result shows that by occupying the plafond with a Styrofoam layer, the average room temperature decreases by 1.3ºC, the air conditioner cooling capacity decreases by 0.402 kW, electric current decreases by 0.006 A compared to the existing room condition.

Keywords: *Effectiveness of Cooling, Thermal Resistance, Thermal Conductivity, Temperature, Air Conditioning System.*

1. RESEARCH BACKGROUND

Nowadays, a room air conditioner is a necessity in tropical climates such as Indonesia. That is because the average ambient air temperature is above the thermal comfort level. Thermal comfort level is the temperature in a region where people feel comfortable for daily activities [1, 2]. The ambient air temperature is higher than the thermal comfort temperature resulting in a reduced concentration of a person in their daily activities. This condition reduces a person's productivity [3]. Decreasing the room air temperature and adjusting it to the thermal comfort condition; can be done using an air conditioner. Room air conditioner is the equipment that absorbs heat and moisture from the room and releases it to the surrounding environment [4]. The heat absorbed by the air conditioner's evaporator from inside the room is released through the air conditioner's condenser. As the air conditioner is on, the room temperature decreases until the air conditioner reaches the maximum heat absorption capacity. Besides the air conditioner cooling capacity, several factors influence the final room temperature. These factors are the outside air temperature, the room volume, the heat source within the

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room, and the ability of the walls to withstand the rate of heat flow into the room, which is determined by the thermal resistance of the walls and ceiling of the room [5, 6].

This study examines the use of passive techniques to increase the effectiveness of an air conditioning machines. The heat transfer process is optimized not only by the active technic but also by the passive technic [7]. The passive technic in this case, is not to treat the air conditioning system but by a room modification so that the process of heat flow into the room can be slowed down [8, 9]. The heat-load was reduced by 31.5% by using the passive technique. The passive technic used fiberglass reflective material for the roof, double-glazed windows, adding trees around the room along with an overhang roof model [10]. The research activity is to analyse the wall ability to resist the rate of heat flow into a conditioned space. This research focuses on the ceiling of the house. Most of the heat flow occurs in this area compared to other areas of the wall [11]. That is because the space above the ceiling being directly adjacent to the house roof. The roof house temperature has the highest temperature because it withstands direct sunlight. The roof temperature can reach 61^{O}C. The rate of heat flow is different during the day; it depends on the position of the sun [12]. However, the other study found that 14.30 – 16.30 is time range when the sun's heat has the maximum effect [13]. As usual, the the room plafond are plywood, gypsum, or GRC. As is known, the plafond is usually compact for safety reasons.

Previous research on the use of insulating materials as ceilings for example, the Styrofoam as a GRC maker blend. The results obtained by adding Styrofoam to the GRC (Glass Fiber Reinforced Concrete) is that the speed of water permeation increases, but the compressive strength of the GRC decreases [14]. The ability of ceiling/wall materials to withstand heat flow was analyzed by Fauzie and Veranika [15]. The results of their research show that each material has a different ability to withstand the heat flow rate.

Previous research did not present the use of insulation material as an addition to the ceiling board. This research aims to analyse the effect of insulation material addition on the ceiling on: the room temperature characteristic, the cooling capacity of the air conditioner, and electricity consumption will be analyzed based on this gap in the literature,. A styrofoam insulating material is being tested. Based on the mass of this material, a styrofoam sheet is light material with a density of 30 – 120 kg/m^3 and has a fine heat-insulating capability. Additional load on the ceiling frame is neglected due to its light density. As a comparison, densities of the materials used for house plafonds such as GRC has a density of 1380 kg/m^3, gypsum with a density of 754 kg/m^3, and plywood of 350 – 560 kg/m^3 [16]. One of the things needed from heat insulation materials is the material thermal conductivity. For example, the thermal conductivity of plywood is 0.12 W/m K, GRC = 0.58 W/ m K, and gypsum 0.48 W/m K. The thermal conductivity of Styrofoam is 0.042 W/m K [17]. From the thermal conductivity data above, Styrofoam is able to use as a heat-insulating material on the ceiling of the house.

2. LITERATURE REVIEW

In this study, conduction heat transfer is the focus of the study. As is known, the heat transferred by conduction is directly proportional to the thermal conductivity, the heat transfer surface area, and the temperature difference. The rate of heat transfer by conduction is inversely proportional to the wall thickness through which heat is transferred [18]. Conduction heat transfer is a heat transfer process that propagates through a material that is not accompanied by the movement of molecules that make up the material [19].

2.1. Thermal Conductivity

As described above, one of the variables that affect the heat transfer process is the thermal conductivity of the material. Thermal conductivity of a material is the ability of a material to conduct heat through a solid object [20, 21]. The greater the value of the thermal conductivity is the greater the heat transferred by conduction through a solid object.

2.2. Heat transfer surface area

As with thermal conductivity, the heat transfer surface area is directly proportional to the amount of heat transferred by conduction. The larger the heat transfer surface area, the greater the heat transferred [22].

2.3. Temperature difference of heat transferred surface area

The direction of heat propagation in conduction heat transfer is from the surface of a solid object that has a higher temperature and propagates through the solid to another surface that has a lower temperature. The greater the temperature difference, the greater the heat transfer rate [23].

2.4. Temperature difference of heat transferred surface area

The thickness of the conduction heat transfer wall is the distance between the surface of an object with a high temperature and another surface in a perpendicular direction that has a lower temperature. The greater the distance between the walls, the lower the heat transfer rate. Mathematically, conduction heat transfer based on Fourier's law is formulated as shown in Eq. (1) [19].

$$Q = k\ A\ \frac{\Delta T}{\Delta x} \qquad (1)$$

Where: Q, is heat transfer rate (W); k is thermal conductivity (W/m K); A is heat transfer surface area (m^2); ΔT is temperature difference (K) and Δx is wall thickness (m)

3. STATE OF THE ART

Previous research has proven that Styrofoam can be used as an insulator in the cooling room of fishing vessels [24]. Fishing vessel insulation materials have been studied. Styrofoam insulation has a lower price compared to other insulation materials [25]. The use of Styrofoam in buildings has been used as a layer under the roof and has been shown to reduce solar heat that enters the room [26]. The addition of insulating material on the walls of a refrigerated room reduces the cost of using an air conditioner [27]. The final temperature of a room is relatively constant in the same room conditions with different cold air duct positions [28].

4. RESEARCH METHOD

4.1. Research Design

This research was conducted experimentally. The heat flow variation into the room was obtained from two conditions of the ceiling, the first condition of the room is the room with existing ceiling material, and the second is by adding insulation material to the plafond. In the first step of this research, the room temperature, speed-and-temperature of airflow over the evaporator coil, wall, and plafond temperature were measured at the condition of the existing ceiling material. The plafond's outside temperature is assumed similar to the air temperature above the plafond because there is no air movement. After data recording for the first condition of the room, Styrofoam sheets were added to the ceiling, and the latter data recording was performed similarly to the first step. Analysis of the data recorded under two different conditions is then carried out to conclude the research outcome.

4.2. Research Variable

This research was carried out with variations in the type of ceiling used, namely the original ceiling (GRC) and added a layer of Styrofoam with a thickness of 1.5 cm (Figure 1). Ambient air temperature was measured under the same conditions (estimated the hottest sunlight around 12.00 – 14.00).

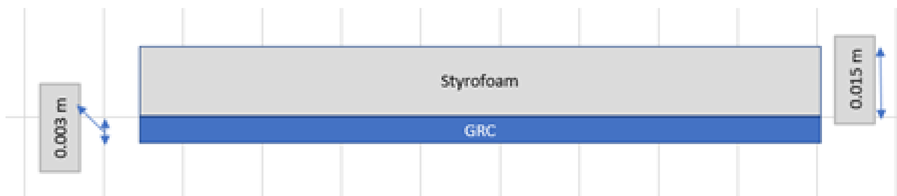
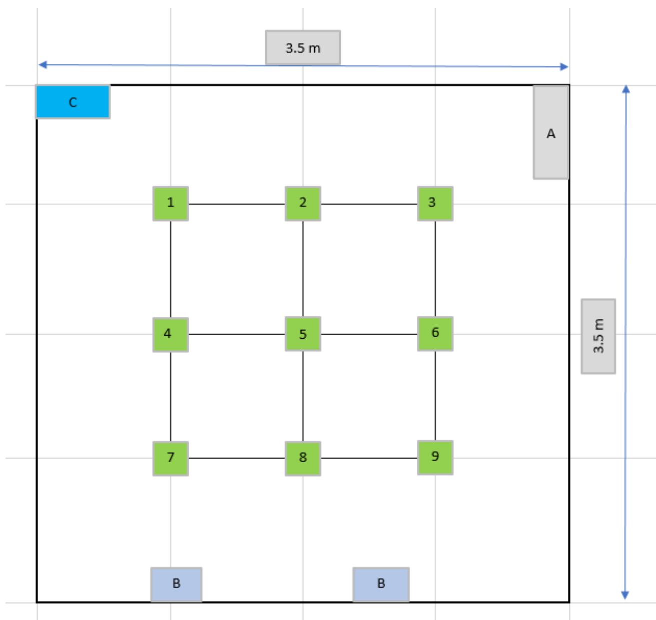


Figure 1. Ceiling and Styrofoam insulation layer

To be able to illustrate the variation in temperature of the room, a temperature-distribution-image was generated. The steady-state condition was assumed for temperature distribution within the conditioned space. Figure 2 shows the schematic-diagram of the conditioned space and the location of temperature measurement points to determine the room temperature distribution. The temperature was measured at 9 points at a height of 2.0 m from the floor.



Description

1 – 9 : Temperature point measureent

A : Door

B : Window

C : Indoor air conditioning unit

Figure 2. Schematic diagram of conditioned room and location of temperature measurement points

Distribution temperature of the room is depicted using 7 x 7 nodes. Temperature at each node was calculate using formulae of interior node [29; 30] as shown in Figure 3:

$$T_{m,n+1} + T_{m,n-1} + T_{m+1,n} + T_{m-1,n} - 4T_{m,n} = 0$$

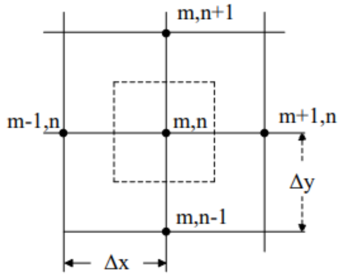
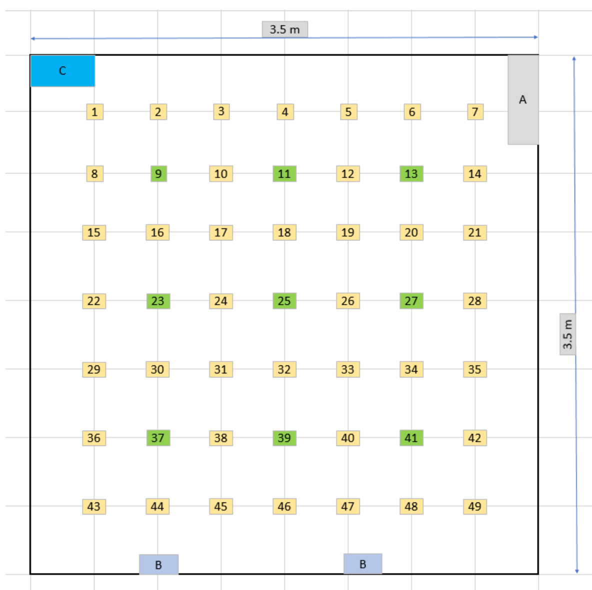


Figure 3. Interior node

Gauss Seidel method was applied to find unknown temperature [31]. The temperature of each wall and ceiling were average temperatures. Figure 4 shows the 7 × 7 nodes for temperature distribution.



Description

Highlighted yellow number	: unknown temperature
Highlighted green number	: measured (known) temperature
A	: Door
B	: Window
C	: Indoor air conditioning unit

Figure 4. Conditioner room with 7 x 7 nodes

5. RESULTS AND DISCUSSION

Obtained data on temperature, humidity, and electric current were displayed in the form of tables and graphs to facilitate data analysis as follows:

5.1. Cooling capacity

Based on the data in Table 1, when the plafond is without Styrofoam insulation, the cooling capacity of the air conditioning system is 1.943 kW, while when the ceiling is layered by Styrofoam insulation, the cooling capacity of the air conditioning system is 1.541 kW. Air-cooling capacity calculation is carried out by the changes in temperature and humidity of air flows over the evaporator. This result is supported by previous research [32] that stated that the cooling capacity of the air conditioning system increases as the room air temperature increases. The existence of insulation on the ceiling has a significant effect on room temperature, and it affects the work of the air conditioning system to be adjusted to the heat in the room (Table 3).

Table 1. Temperature, relative humidity and cooling capacity of air flows over the evaporator

Ceiling condition	Temperature (^{o}C)		Relative humidity (%)		Cooling capacity (kW)
	In	Out	In	Out	
No insulation	30.967	22.000	89.067	99.900	1.943
With Styrofoam insulation	29.867	22.167	88.067	99.900	1.541

5.2. Electric current and Volt Ampere

Understanding the existence of the insulation layer at the ceiling effect on the electrical power consumed by the air conditioning system, the compressor electric-current of the air conditioning system was measured. The measurement shows that the electric current of the air conditioning system operating in a room without a ceiling insulation layer is higher (1,503 A) compared to electric-current of the air conditioning system running in a room with a ceiling occupied by an insulation layer (1,497 A). That can happen because the operating air conditioner in a room with an insulation layer to the plafond absorbs less heat from the room compared to another one. Due to the system absorbing less heat from a space and releasing it to the surroundings, the temperature difference between the condenser and the surrounding temperature is less than the higher heat release. As a result, the condenser temperature and pressure should be decreased. At a lower condenser pressure, the system needs a lower electrical current. The long-term effect of this condition is life span of the air conditioner is better because the compressor works lighter when the condenser pressure is lower.

Table 2. Electric current and volt ampere.

Ceiling condition	Electric current (A)	Volt ampere (VA)
No insulation	1.503	330.660
With insulation	1.497	329.340

5.3. Room temperature distribution

The effect of installing the insulation layer on the room ceiling can be seen in Table 2. Table 2 shows that a Styrofoam insulation layer presence on the room ceiling causes the measured room temperatures to decrease generally. At each measurement point, the air temperature reduces as the Styrofoam insulation is added to the room ceiling. On average, the indoor air temperature decreases by 1,304 ^{o}C. This temperature-decreasing is the result of reduced heat entering through the room ceiling. Figure 5 shows the temperatures at the measurement points in the room. Figure 5 shows the temperature rises at points 1 to 3, similar to points 4 to 6 and from points 7 to 9. That is due to the location and direction of AC airflow at points 1, 4, and 7. So at these points, the temperature is lower compared to the other measurement points.

Tabel 3. Room temperature at point of measurements.

Point of measurement	Room temperature (^oC)		Average temperature (^oC)	
	No insulation	With insulation	No insulation	With insulation
1	30.067	28.567	30.467	29.163
2	30.533	29.267		
3	30.767	29.567		
4	30.267	28.667		
5	30.600	29.367		
6	30.633	29.367		
7	30.300	28.933		
8	30.500	29.400		
9	30.533	29.333		

More descriptively, the overall air temperature distribution comparison can be seen in Figure 6a and Figure 6b. The width of the temperature distribution in a room occupied with a ceiling without insulation is 0.6 ^oC with a minimum temperature of 30.1 ^oC and a maximum temperature of 30.7 ^oC. From the room's total area, about 40% of that area has temperature above 30.5 ^oC or 33.3% of the highest temperatures. For a room equipped with insulation on the ceiling, the temperature distribution width is 1.0 ^oC with a minimum temperature of 28.6 ^oC and a maximum temperature of 29.6 ^oC. About 25% of the room area is at 30% of the highest temperature or above 29.3 ^oC.

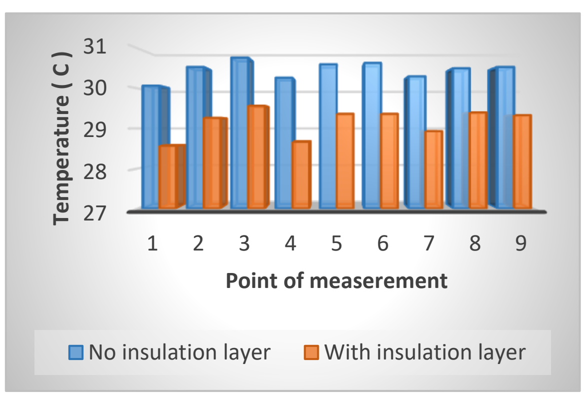


Figure 5. Room temperature at point of measurements

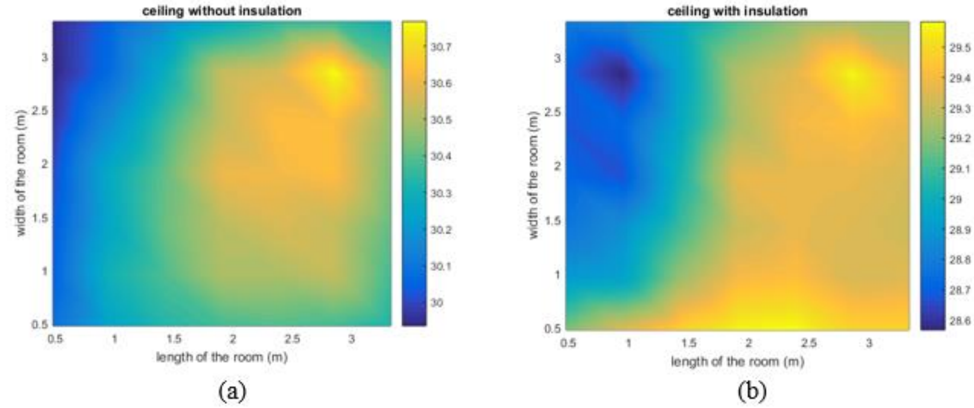


Figure 6. General description of room temperature distribution (a) no ceiling insulation (b) with ceiling insulation.

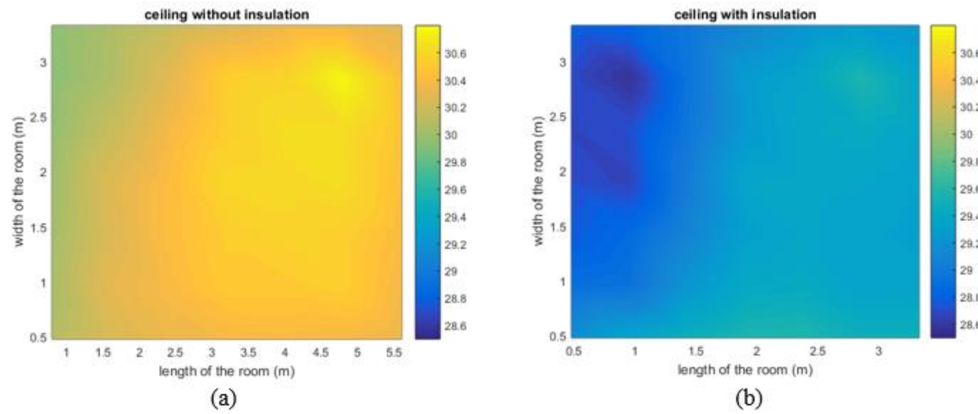


Figure 7. Room temperature distribution with similar scale of temperature (a) no ceiling insulation (b) with ceiling insulation.

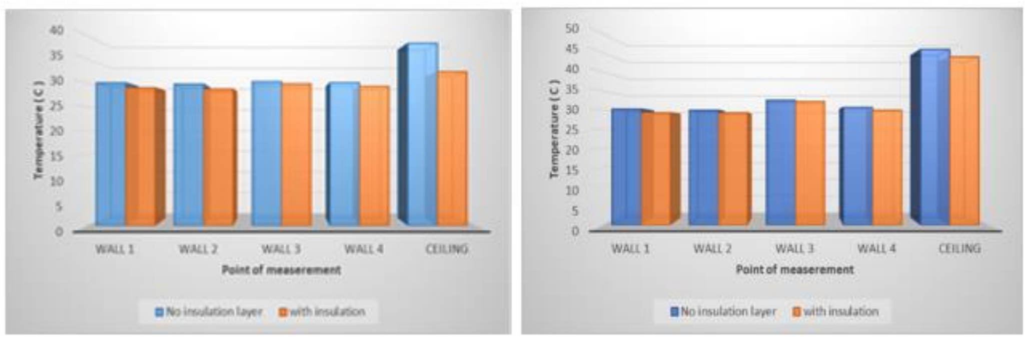
The comparison of the room temperature level between the room without ceiling insulation and with ceiling insulation can be seen in Figure 7. Figures 7a and 7b have the same temperature scale. Figure 7a shows the room is in a temperature distribution above 30 ºC, while Figure 7b shows the room is in a temperature distribution below 29.6 ºC. That indicates that the effect of installing the insulation layer to the ceiling reduces the temperature distribution to below 30 ºC.

5.4. Wall temperature

The inside wall temperature depends on the outside temperature of the wall. Table 3 shows the inside and outside wall temperatures with and without the addition of ceiling insulation comparison. The condition shows a significant difference on the inside of the wall. The temperature of the inner wall equipped with insulation on the ceiling is lower than the inside wall temperature not equipped with insulation on the palate. The most significant difference is, on the inner wall of the palate, the inside wall temperature with ceiling insulation is lower by 6,184 ºC, or when compared to the temperature of the outer wall of the palate, there is a temperature reduction of 4.217 ºC. That is due to the addition of the effect of ceiling insulation causes the thermal resistance of the combined palate with insulation increases. Figure 8 shows the comparison of the wall temperature at two different conditions of the palate.

Table 4. Walls and ceiling temperatures.

Ceiling condition		Wall temperature (^{o}C)				
		1	**2**	**3**	**4**	**ceiling**
No insulation	Inside wall	30.033	29.767	30.267	30.233	38.467
With insulation		29.000	28.733	29.800	29.267	32.283
No insulation	Outside wall	30.300	30.300	32.600	30.733	45.900
With insulation		29.433	29.433	32.267	30.033	43.933



(a) (b)

Figure 8. Temperature comparison of wall and ceiling temperatures (a) inside wall temperature (b) outside wall temperature

5.5. Remote-control temperature setting of the air conditioner

The last discussion of the result is to compare the temperature settings on the remote control under the two conditions mentioned. During the day, the minimum remote-control setting is at a temperature of 28 ºC or the minimum temperature that can be achieved by the air conditioner when there is no insulation to the palate. Meanwhile, when the palate is equipped with insulation, the AC remote-control setting is at a temperature of 27 ºC. That indicates that the retaining heat entering through the ceiling is higher when the palate is occupied by the insulation layer. In the morning, the setting of the AC remote control at ceiling conditions with and without insulation is the same, namely at a temperature of 25 ºC. That can happen because, in the morning, the air temperature above the palate is similar to the palate condition with and without insulation.

Table 4. Air conditioner temperature setting.

	Temperature setting (^{o}C)			
	In the morning		**Mid day**	
Ceiling condition	**No insulation**	**With insulation**	**No insulation**	**With insulation**
	25	25	28	27

6. CONCLUSION

The discussion from discussion of the data measurement, data calculation, and the temperature distribution diagram above, results in a conclusion that the existence of an insulating layer on the ceiling of a room decreases the average room temperature, a different room temperature map, a change-in electric current to the air conditioning compressor and a better operation life of the air conditioning system. A decrease in average temperature causes the retained heat flows through the ceiling by the insulation layer. In this case, the thermal resistance of the combination of the palate with Styrofoam is more than the thermal resistance of the existing ceiling, resulting in a decreased heat flow rate. The difference in temperature map between the room with and without insulation layer brings the different locations and levels of the highest accumulation heat of the room. A lower room temperature improves the thermal comfort level with an insulation layer. By running the AC at a lower pressure, the AC life is better than the existing condition due to lower compressor work. For the same lower temperature levels during the day, an AC running in a room with a palate insulating layer works lighter with less electrical power than the AC running in a room with no insulation palate. That means that there is a reduction in electricity costs. The electric current measurement result also supports the decrease in electrical energy. The negative point of styrofoam is termite destruction.

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