Evaluation of Aluminum Cans As A Thermal Insulator in Reinforced Concrete Slabs

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ABSTRACT

Thermal insulation is the most effective energy efficient technique of energy conservation available today. The main goal of energy an conscious designer is to condition the interior environment to support a level of climate comfort acceptable to users. From the past 20 years data it is concluded that temperature is at the increase and thus thermal insulation is an immediate need to be considered. Environmental problems have recently expanded due to industrial pollution and manmade products that are found in solid wastes. One of these products are the Aluminum cans. Since the recycling rate of these cans is decreasing. It is therefore the main goal of this study is to evaluate the thermal insulation of these cans through models in insulating reinforced concrete roofs and ceiling and comparing the insulation with that of Thermo-stone blocks and Polystyrene boards which are commonly used in Iraq. Results indicated that Aluminum cans are considered as a good insulator and can withstand a considerable live and dead loads beside it's low construction cost and low weight. Finally the use of Aluminum cans in the thermal insulation will contribute in solving a part of the global environmental problems.

Keywords: Thermal Insulation , Solid wastes, Aluminum cans, Model.

تقييم كفاءة علب الألمنيوم كعازل الحراري للسقوف الخرسانية المسلحة

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الخلاصة

العزل الحراري هو أكثر التقنيات الفعالة المتوفرة هذه الأيام في حفظ الطاقة بكفاءة. إن الهدف الرئيسي لأي مصمم طاقة حريص هو توفير الجو الملائم لمستخدمي المنشأ. أظهرت بيانات درجات الحرارة للعشرين سنة الماضية إن درجة الحرارة في ازدياد، الأمر الذي يؤكد أهمية العزل الحراري. أخذت المشاكل البيئية بالازدياد بسبب التلوث الصناعي والمنتجات الصلبة التي خلفها الإنسان. احد هذه المخلفات هي علب الألمنيوم المستعملة. لقد تبين أن إعادة تصنيع هذه العلب آخذٌ بالنقصان وبالتالي فإن الهدف الرئيسي لهذه الدراسة هو تقييم العزل الحراري لعلب الألمنيوم عن طريق موديل في عزل السقوف الخرسانية المسلحة ومقارنة هذا العازل بالعزل الحراري لكتل الثرمستون وألواح البوليستايرين المستعملة عادة في العراق. بينت النتائج أن علب الألمنيوم ذات عزل حراري جيد وتتحمل أثقالا حية وميتة بدرجة جيدة إلى جانب قلة كلفة الإنشاء وخفة الوزن. أخيرا، إن استعمال علب الألمنيوم في العزل الحراري يساهم في حل جزء من مشاكل التلوث العالمي للبيئة.

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Notations		Unit
Q	Heat Flow	w
T_1-T_2	Thermal potential gradient	^oC
L	Material thickness	m
A	Area	m^2
k	Thermal conductivity	w/m. ^oC
R	Thermal resistance	^oC/w
Rt	Overall thermal resistance	^oC/w
AC	Aluminum cans	
TB	Thermo-stone Blocks	
PB	Polystyrene Boards	
Model A	Model with insulation	
Model B	Model without insulation	
T_1	Temperature reading at the surface of the tile.	^oC
T_2	Temperature reading at the lower face of the reinforced concrete slab.	^oC
T_3	Temperature reading of the inner air space of the model.	^oC
ΔT_{1a}	Temperature gradient of model A, $\Delta T_{1a} = T_1 - T_2$	^oC
ΔT_{2a}	Temperature gradient of model A, $\Delta T_{2a} = T_1 - T_3$	^oC
ΔT_{1b}	Temperature gradient of model B, $\Delta T_{1b} = T_1 - T_2$	^oC
ΔT_{2b}	Temperature gradient of model B, $\Delta T_{2b} = T_1 - T_3$	^oC
ΔNet_1	Temperature gradient, $\Delta Net_1 = \Delta T_{1a} - \Delta T_{1b}$	^oC
ΔNet_2	Temperature gradient, $\Delta Net_2 = \Delta T_{2a} - \Delta T_{2b}$	^oC

1. Introduction:

Thermal insulation is the most effective technique of energy conservation available today. Thermal insulation has the largest impact on reducing fuel cost year after year. The main goal of an energy conscious designer is to condition the interior environment to support a level of climate comfort acceptable to users. Efficient use of energy is important since global energy resources are finite and power generation using fossil fuels (such as coal and oil) has adverse environmental effects. Thermal insulation is a technique that minimizes the transfer of heat energy from inside to outside and vice versa, of a building by reducing the conduction, convection and radiation effects. From the previous on-going 20 years data it is found that the temperature is increasing and thus thermal insulation is an immediate need to be considered for occupant comfort [1], [2].

Environmental problems have recently expanded due to industrial pollution and also due to man made products that are found in solid wastes. One of these materials are the used Aluminum cans. Since 1972, some 594 billion used Aluminum cans have been recycled. If these cans are placed end to end, this would stretch to the moon and back 190 times. Of the 102 billion Aluminum can manufactured in 1999, 63.8 billion of them were recycled. Unfortunately, recycling rate was noticed to be decreasing specially since 1992 (figure 1) [3], [4]. As it is known that these cans are manufactured from aluminum, aluminum is the most abundant metallic element in the earth's crust and, after oxygen and silicon, by mass the third most abundant of all elements in the earth's crust. It constitutes approximately 8% of the earth's crust by mass [4], [5].

There are various thermal insulating materials, commonly used are flexible (mineral wool, glass fiber), loose fill, and spray. In Iraq, the most common insulating materials are Thermo-stone blocks, Polystyrene boards and air gap (Cavity) [6], [7].

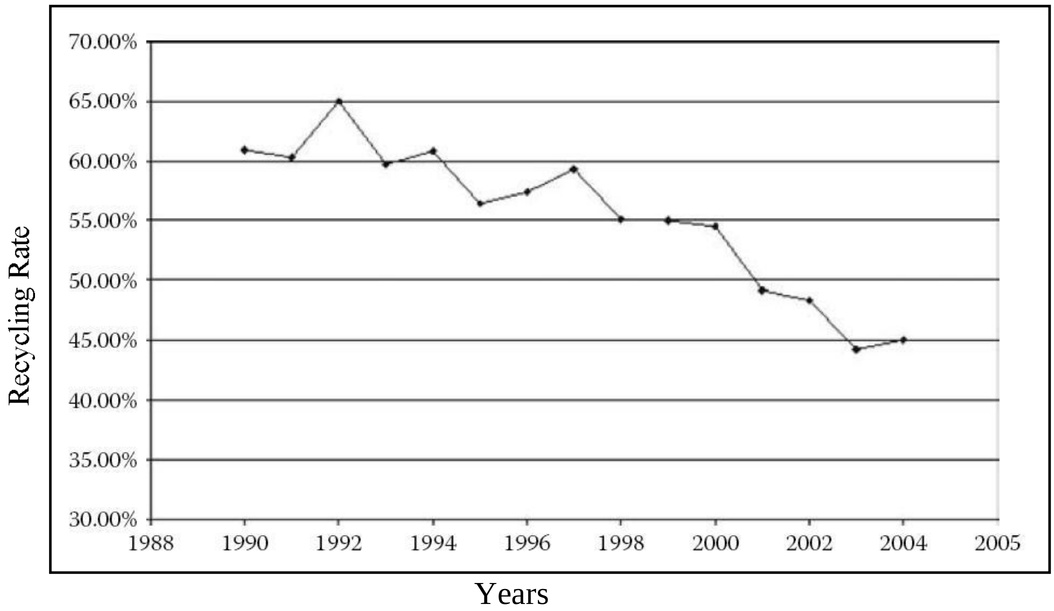


Figure (1): U.S. aluminum recycling rates from 1990 to 2004 (Container Recycling Institute, n.d.), after M. E. Schlesinger.

Insulation material are evaluated in many methods, the most common are U-value and R-value. U-value is the measurement of heat flow, the lower the U-value the better the thermal insulation. R-value is another mathematical expression used to quantify an insulation agent. It indicate the resistance to heat flow. The higher the R-value, the greater insulation effectiveness [8], [9]. In general:

$$Q = \frac{T_1 - T_2}{R} \quad (1)$$

$$R = \frac{L}{A.k} \quad (2)$$

Where:

Q: Heat flow (w)
T_1-T_2: Thermal potential gradient (^oC).
L: Material thickness (m)
A: Area (m^2)
k: Thermal conductivity (w/m.^oC)
R: Thermal resistance (^oC/w)

In many engineering applications, heat transfer takes place through a medium composed of several different layers, each having a different thermal conductivity, k. for composite slabs the heat flow:

$$Q = \frac{T_a - T_b}{R} \quad (3)$$

$$Rt = R_a + R_1 + R_2 + \cdots + R_b \quad (4)$$

Where:
Rt: Overall thermal resistance

The main goal of this study is to evaluate the thermal insulation of used Aluminum cans in insulating reinforced concrete roofs and ceilings and comparing the insulation efficiency with Thermo-stone blocks and Polystyrene boards that are commonly used in Iraq for slabs thermal insulation. The comparison between the selected insulation materials will be based on four aspects, temperature gradient, compressive strength, weight and cost.

2. Materials and Methods:

In order to accomplish the project goals, two identical models were built from local construction materials used in Iraq, this will idealy represent the local boundary conditions of the studied area. The construction site was selected to insure direct sun light on the model ceiling during the day. The site was located in Iraq, Mosul city (36^o 23' 35.41" N and 43^o 08' 38.18" E, elevation: 258m from MSL, Google Earth 2009). One of the models was insulated and the other was kept without insulation to be taken as a reference or as a benchmark.

The construction materials of the two models consisted of a reinforced concrete slab (100x100x15)cm supported by four brick walls of (12)cm thickness and (100)cm height, the four walls were insulated with a clay rendering of (2.5)cm thickness then the last was covered with a (5)cm PB, table (1). The floor was also insulated using a (5)cm dry clay layer covered with Styrofoam board of (5)cm thickness. This procedure was adopted to minimize the heat that would come from the walls and the roof, table (1), figure (2). The reinforced concrete slab was simulated to the local slabs manufactured in Iraq. Usually the slabs in Iraq are covered with tiles that are mostly of white color. The slabs of the two models were covered with tiles plus a cement mortar of (3)cm thick beneath (the insulating agent was installed beneath the tile mortar for the insulated model).

Table (1): Legend of the materials used in model construction.

Legend	Material	Dimension(s) (cm)
	Aluminum cans (AC)	12.5×6 Ø
	Thermo-stone Blocks (TB)	5.5
	Polystyrene Boards (PB)	5
	Clay brick	23×11×7
	Clay rendering	5
	Tile	30×30×15
	Sand mortar (1:3)	3
	Reinforced concrete (1:2:4/0.50)	100×100×15
	Thermometer probe	2.5×0.5

Three digital thermometers were used for each model (range -50 to +70^{o}C, ±0.1^{o}C accuracy). A thermometer was imbedded in the surface of the tile by making a groove that just fit the thermometer probe which was fixed to the tiles using a white cement paste (almost the same color of the tile). Another thermometer was installed at the lower face of the concrete slab similar to the tile's thermometer probe except using an ordinary cement paste. The last thermometer was hanged at the middle height of the model inner space for reading air temperature inside the model. All thermometers were installed during the construction process of the two models, figure (2).

Three types of insulation materials were used in this project, AC, TB and PB. One of the models was treated with insulation (model A) while the other was kept as a reference without insulation (model B). The insulating agent was placed beneath the tiles covering the slab. Each insulation material was tested for one week using the two models. Temperature readings were taken daily at (7:00, 9:00, 11:00, 12:00, 13:00, 14:00, 15:00, 17:00, 19:00 and 21:00), (July-August, 2008).

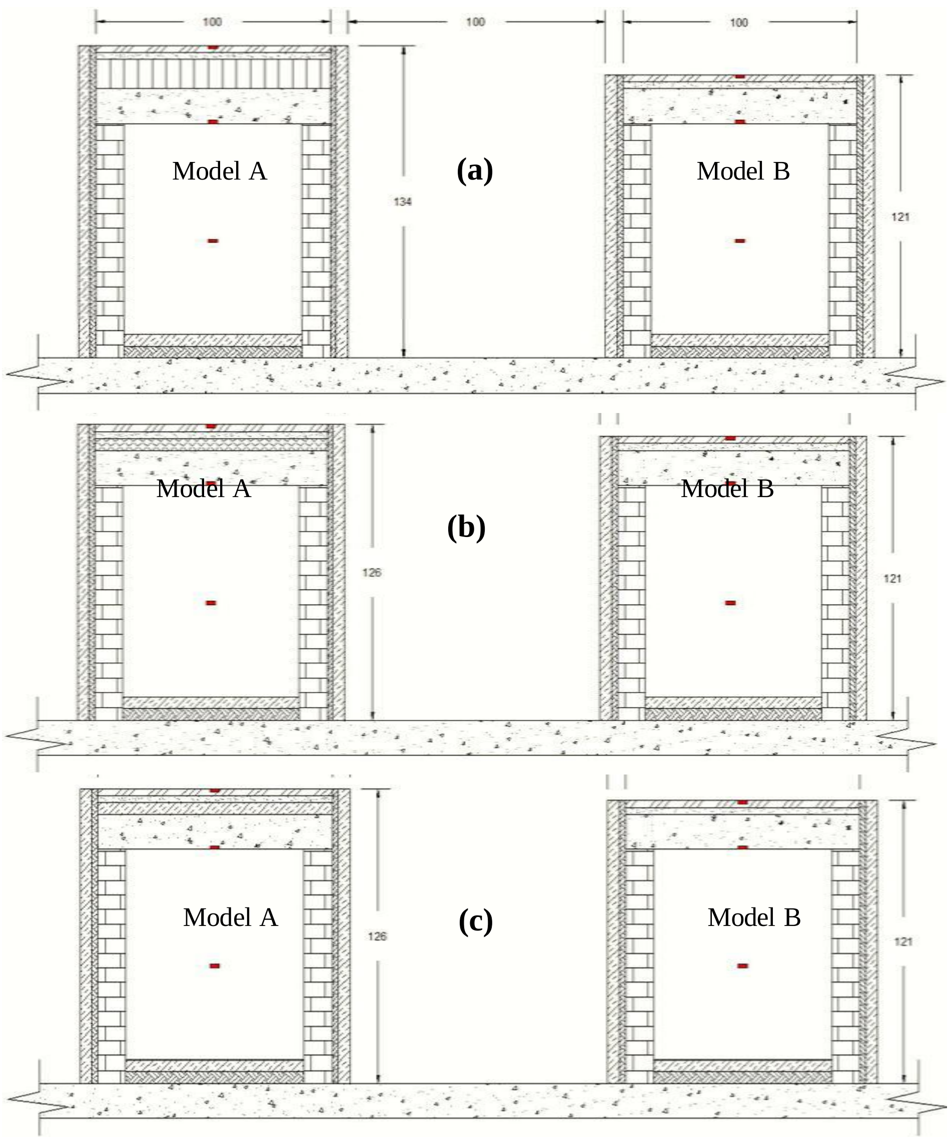


Figure (2): Schematic diagram of Model A and Model B, (a): AC. (b): TB. (c): PB.

The compressive strength of the AC must be obtained. A group of cans were arranged in a hexagonal shape that consists of seven cans, figure (3). Three groups were tested in the unconfined compression machine with a slow rate (0.35 mm/min.). A single can was also tested in the same machine with the same loading rate. The compressive strength of TB was taken as referred in the literature

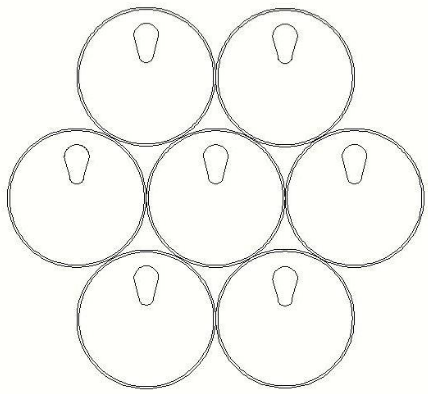


Fig. (3): Hexagonal arrangement of AC for compressive strength evaluation.

3. Results and Discussion:

In order to evaluate which insulation material is better among the selected, the comparison was based on four aspects, temperature gradient, compressive strength, weight and cost. The following paragraphs will discuss these aspects.

3.1 Temperature Gradients:

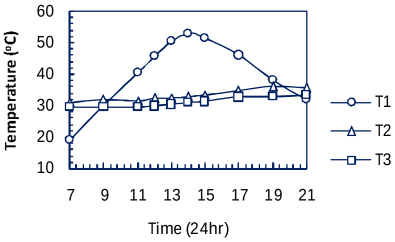
Temperature readings were taken at the same time for model (A) and model (B). There was a thermal gradient between tile temperature (T_1), concrete slab (T_2) and air space (T_3), this is clear in figures (4, 5, 6) for AC, TB and PB respectively. It is obvious from these figures that T_1 was higher than T_2 and T_3 for all insulation materials.
In order to make an accurate comparison, the mean temperatures readings of one week were plotted against time for T_1, T_2 and T_3, figures (7, 8, 9) for AC, TB and PB respectively. The mean maximum temperature recorded of (T_1) was (52.2, 54.4 and 54.3^{o}C) for AC, TB and PB respectively.
Temperature gradients between model (A) and model (B) were adopted to show the better insulation. The algebraic gradient was calculated on the basis of the time that corresponds to the maximum T_1 reading of model (A), table (2), figures (10, 11, 12)

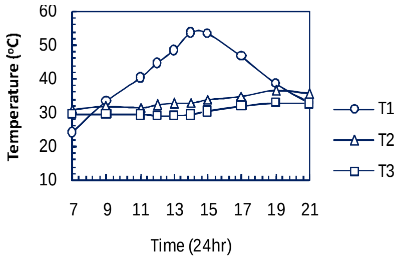
3.1 .1 Temperature gradient between (T_1) and (T_2); (ΔT_1):

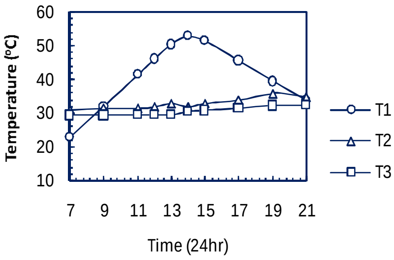
The algebraic difference between T_1 and T_2 is equal to ΔT_1, table (2). From the data listed, the mean value of ΔT_{1a} for AC is 20^{o}C while the mean value of ΔT_{1b} was 9.6^{o}C. The algebraic difference between ΔT_{1a} and ΔT_{1b} is equal to ΔNet_1, this value for AC was equal to 10.4^{o}C. The value ΔNet_1 was adopted in the comparison among the selected insulation materials. The value ΔNet_1 for TB and PB were 7.6^{o}C and 7.3^{o}C respectively. It is clear that the AC showed a greater value of ΔNet_1 than those for TB and PB.

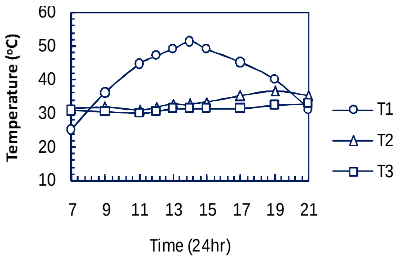
Table(2): Temperature reading gradients of the insulation materials.

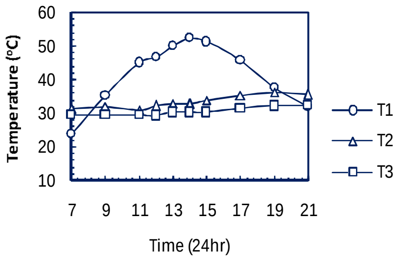
Day	Time (Hours)	Model A		Model B			
		ΔT_{1a} (^{o}C)	ΔT_{2a} (^{o}C)	ΔT_{1b} (^{o}C)	ΔT_{2b} (^{o}C)	ΔNet_1 (^{o}C)	ΔNet_2 (^{o}C)
AC data analysis							
1	3:00	20.4	22.1	10	15.2	10.4	6.9
2	3:00	20.7	24.3	10.3	16.3	10.4	8
3	2:00	21.2	22.4	9.5	14.4	11.7	8
4	3:00	18.6	19.7	8.5	10.1	10.1	9.6
5	3:00	19.6	20.9	9.6	14	10	6.9
6	3:00	20.2	22	10.5	15.9	9.7	6.1
7	3:00	19.3	22	9.1	14.3	10.2	7.7
Mean		**20.0**	**21.9**	**9.6**	**14.3**	**10.4**	**7.6**
TB data analysis							
1	2:00	17.1	20.3	10.7	14.8	6.4	7.2
2	2:00	18.1	21	9.3	15.7	8.8	7.3
3	2:00	19	21.5	11.1	16.5	7.9	7.9
4	2:00	19.7	21.1	11.9	15.1	7.8	6.9
5	2:00	19.2	21.1	12	15.3	7.2	5.9
6	2:00	18.6	21.4	11	16	7.6	7
7	2:00	19.9	20.9	12.4	16.2	7.5	6.5
Mean		**18.8**	**21.0**	**11.2**	**15.7**	**7.6**	**5.3**
PB data analysis							
1	2:00	18.8	19.8	11.7	15	7.1	4.8
2	2:00	19	19.7	11.4	13.6	7.6	6.1
3	2:00	17	17.8	9.5	13.3	7.5	4.5
4	2:00	18.5	19.5	11	14.8	7.5	4.7
5	1:00	18.2	19.1	11.8	14.3	6.4	4.8
6	1:00	16.9	19.1	9.4	15.1	7.5	4
7	1:00	17.7	20	10.3	15.6	7.4	4.4
Mean		**18.0**	**19.3**	**10.7**	**14.5**	**7.3**	**4.8**

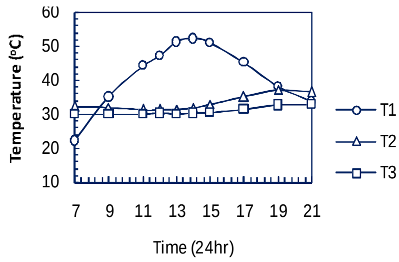


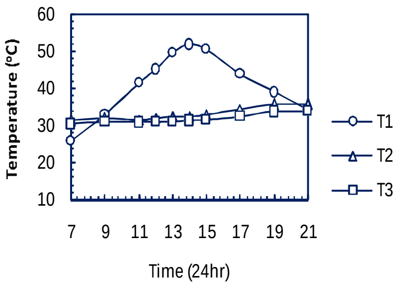






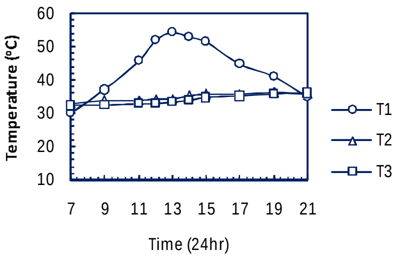


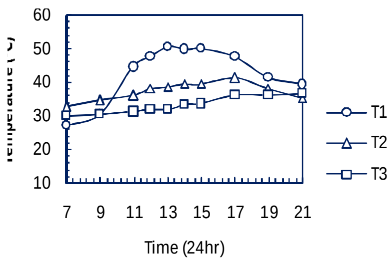


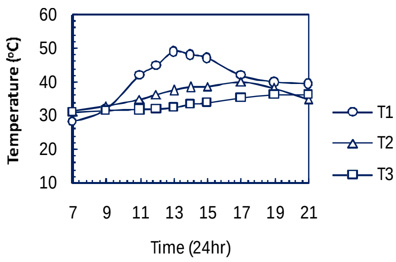


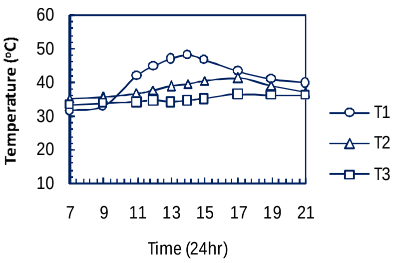
Group (a)

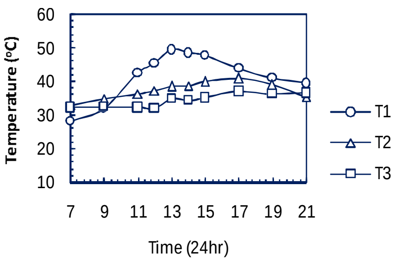
From to left to right (1 – 7) Days

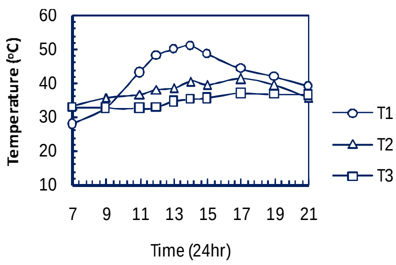


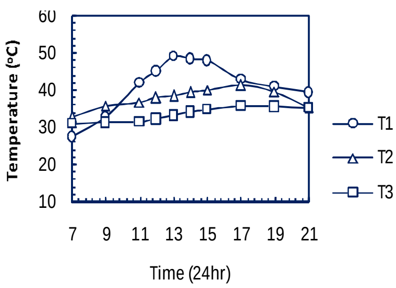








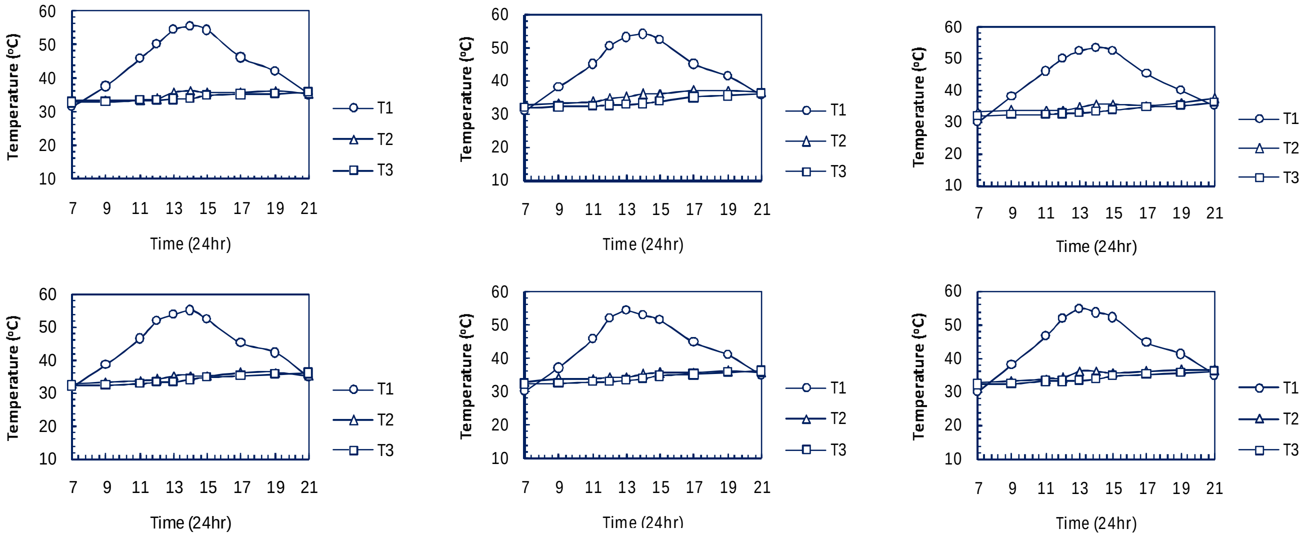


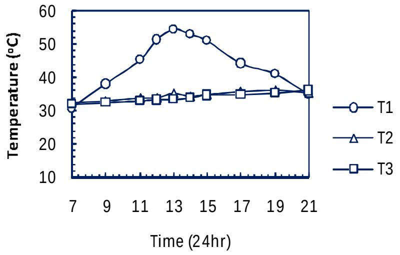


Group (b)

From to left to right (1 – 7) Days

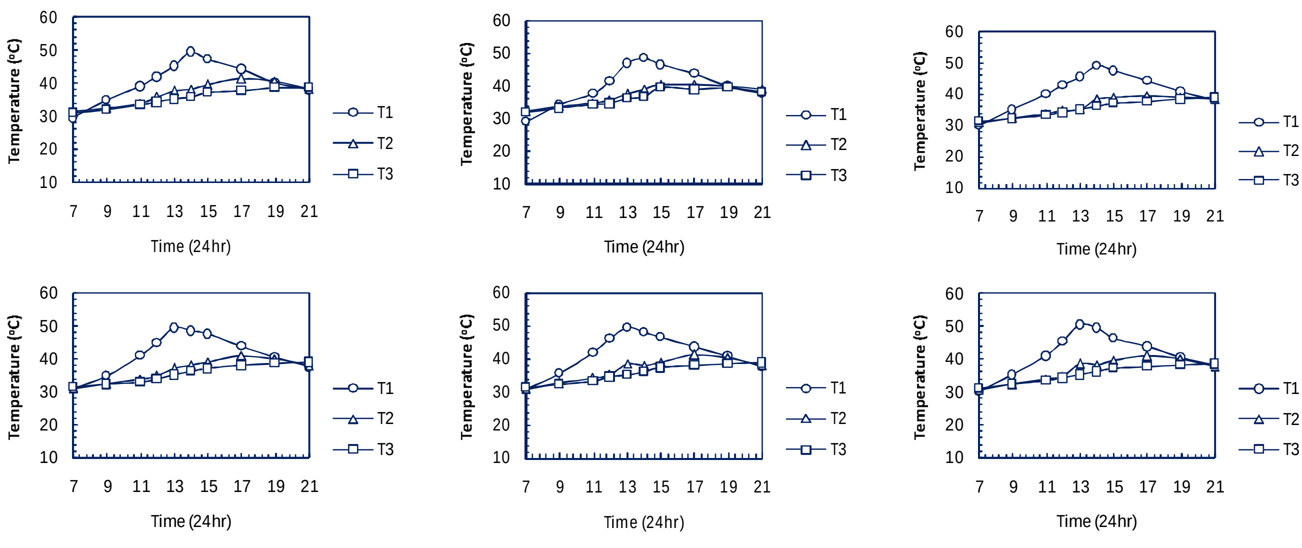
Figure (4): Temperature readings of AC for one week, (a) Model A, (b) Model B.

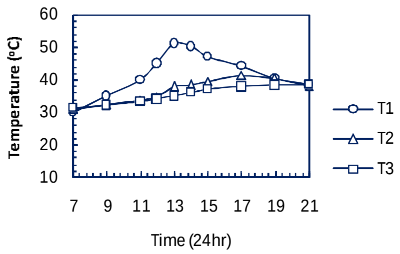




Group (a)

From to left to right (1 – 7) Days

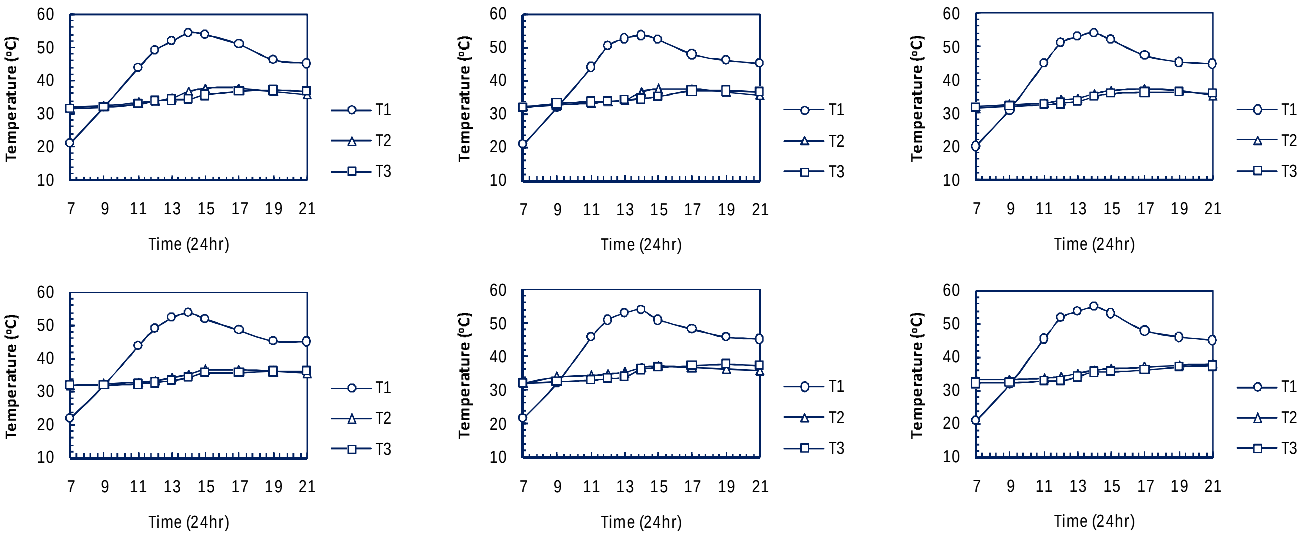


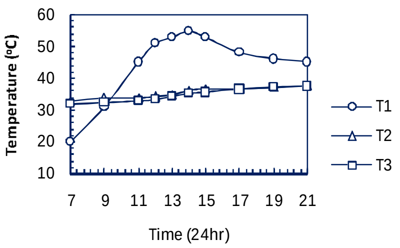


Group (b)

From to left to right (1 – 7) Days

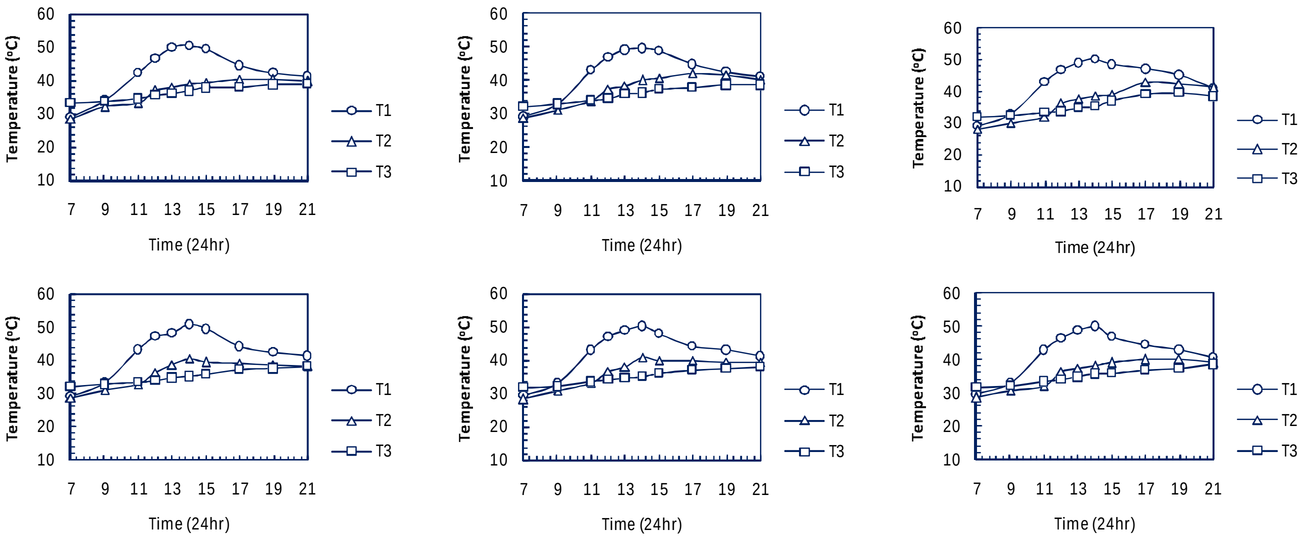
Figure (5): Temperature readings of TB for one week, (a) Model A, (b) Model B.

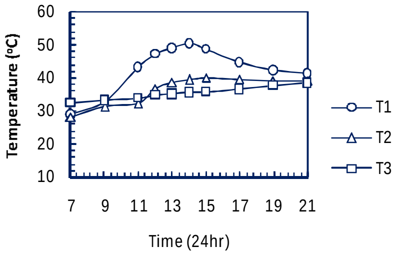




Groap (a)

From to left to right (1 – 7) Days

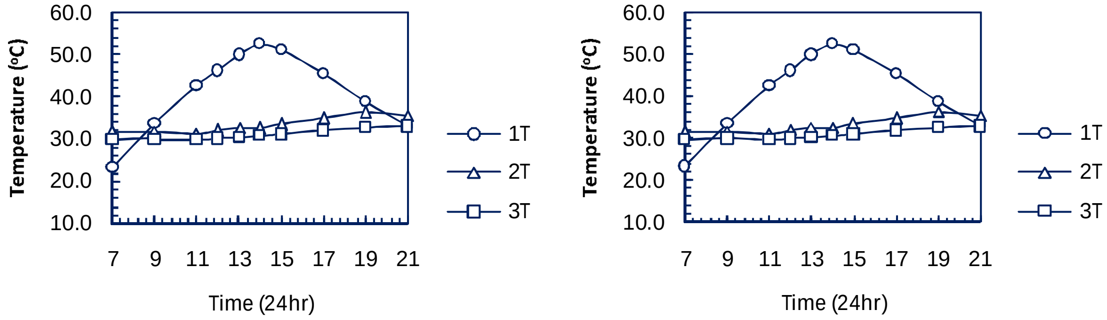




Groap (a)

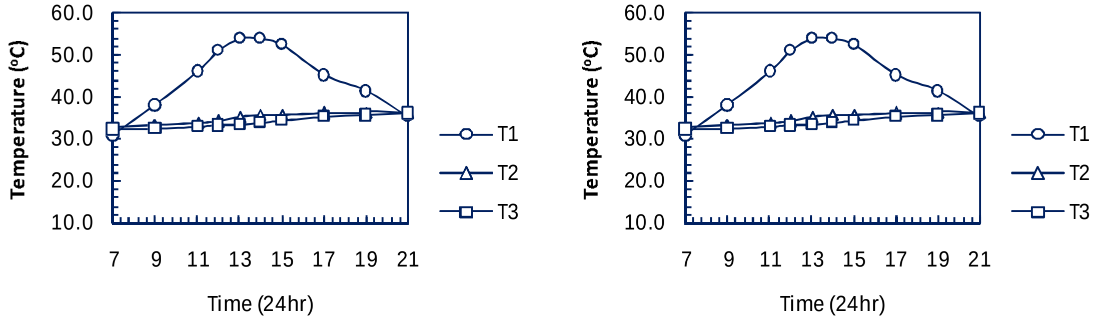
From to left to right (1 – 7) Days

Figure (6): Temperature readings of PB for one week, (a) Model A, (b) Model B.



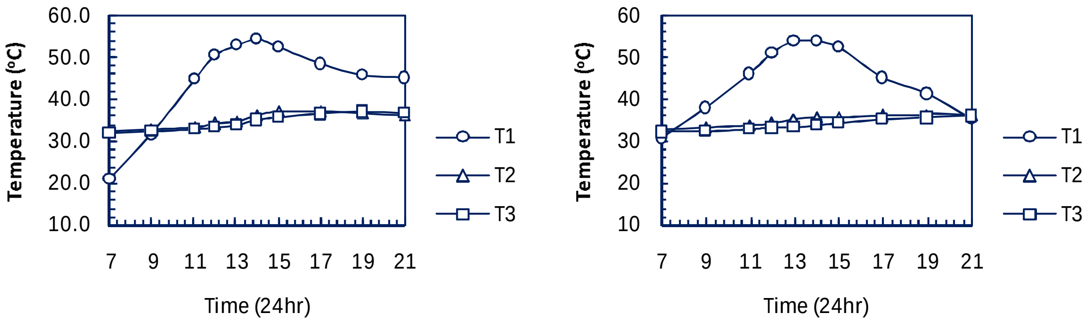
(a) (b)

Figure(7): Mean temperature readings of AC for one week, (a) Model A, (b) Model B.



(a) (b)

Figure(8): Mean temperature readings of TB for one week, (a) Model A, (b) Model B.



(a) (b)

Figure(9): Mean temperature readings of PB for one week, (a) Model A, (b) Model B.

3.1 .2 Temperature gradient between (T1) and (T3); (ΔT_2):

The same calculation procedure considered in the previous paragraph will be applied here to calculate the gradient between T_1 and T_3, this will give ΔT_2 value, table (2). The algebraic gradient between ΔT_{2a} and ΔT_{2b} is equal to ΔNet_2 which was considered in the comparison as had used in ΔNet_1 values. The mean value of ΔNet_2 for AC is 7.6^{o}C, while it is 5.3^{o}C and 4.8^{o}C for TB and PB respectively.

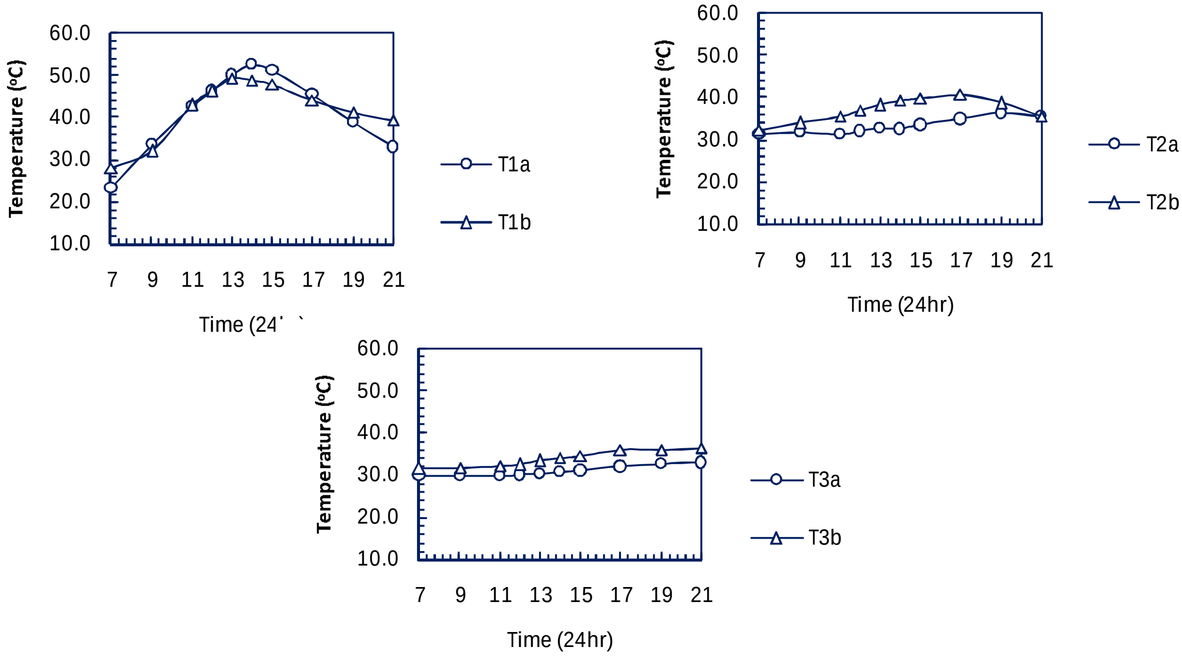


Figure (10): Comparison between mean temperature readings of model A and Model B for AC.

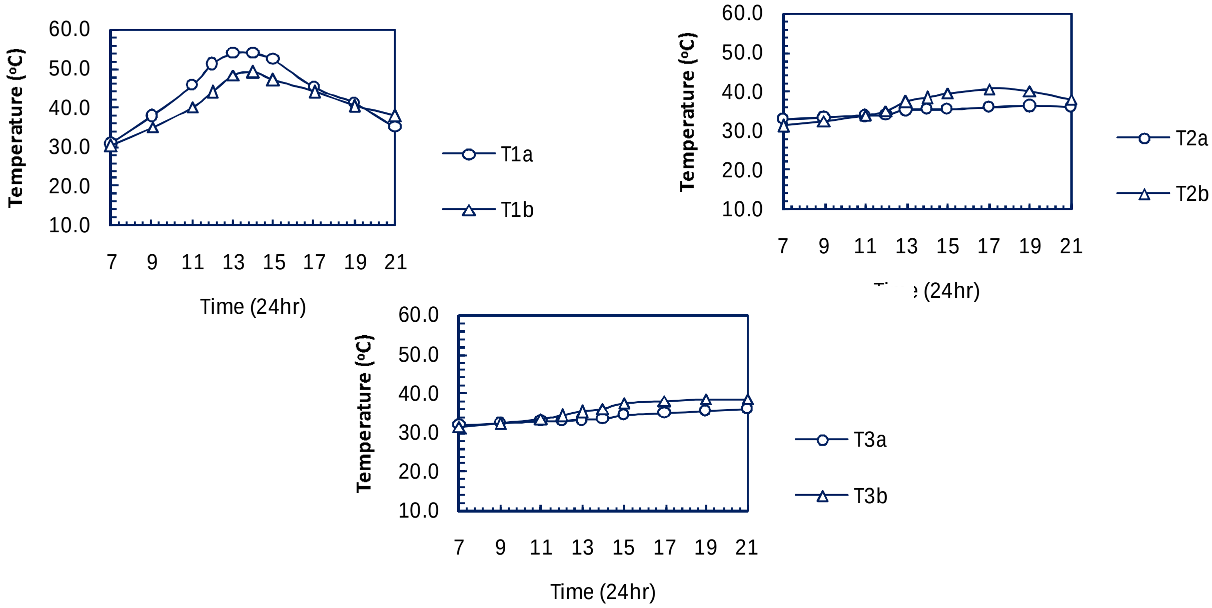


Figure (11): Comparison between mean temperature readings of model A and Model B for TB.

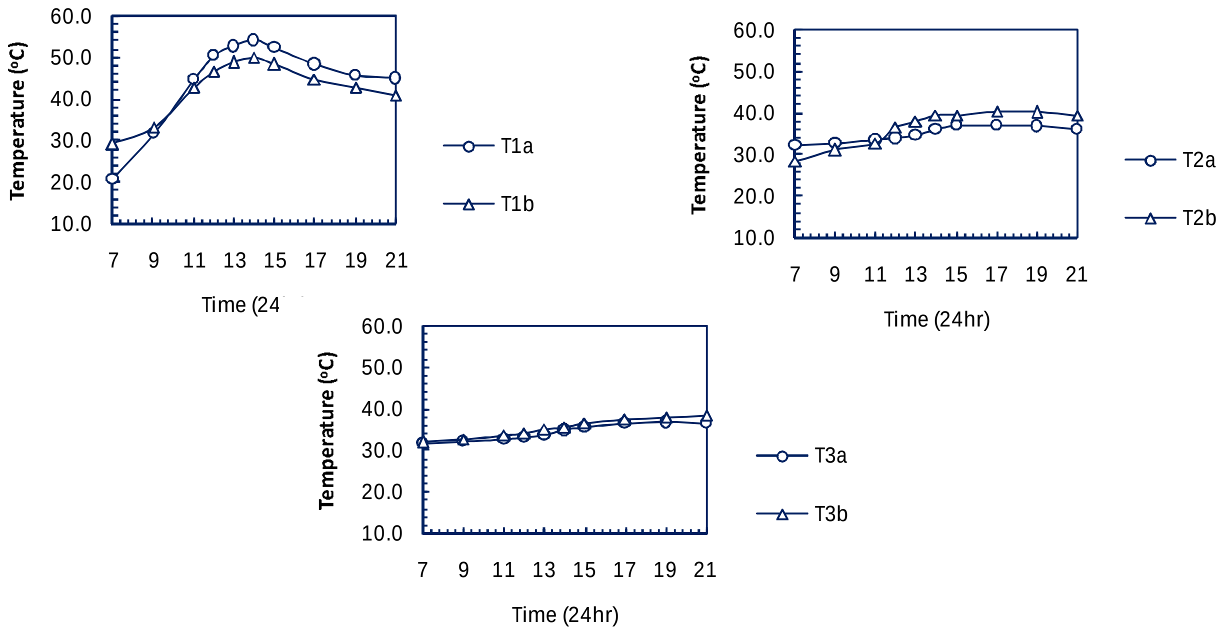


Figure (12): Comparison between mean temperature readings of model A and Model B for PB.

3.1Compressive Strength:

Group AC was found to carry a load of 5.23kN, while a single can carried a load of 0.75kN. The number of cans beneath one tile (30x30cm) consisted at least of fourteen cans, this means that one tile can carry a load of 10.5kN. These results could be calculated roughly for one square meter, which is equal to be 100kN/m^2.

TB was found to withstand 10kN/m^2 according the Iraqi Standard Specifications No. 1441. PB was considered in this paper to carry the minimal compressive strength compared with the AC and the TB, table (3). From these results it can be concluded that AC withstand a load much higher than the TB and PB.

3.2 Weight:

The weight of any insulation material is considered to represent its dead load. Table (3) shows the weight of each insulation material for one square meter. Each can was weighted, the weight range was (20-27)g. It was also found that in order to cover an area of one square meter, a number of (255) cans were required, this will bring the total dead load to (6.5)kg/m^2.

Table(3): compressive strength and weight of the selected insulation materials.

Insulation material	Compressive strength (kN/m^2)	Weight (kg/m^2)
AC	100	6.5
TB	10	20
PB	None	1.0

3.1 Cost:

The cost of any insulation material has the controlling rule for selection, the higher the cost, the better the insulation and the higher the construction cost. In this study, AC was found to meet the minimum cost requirements, since AC could be collected from Aluminum Recycling Agencies, beside the minimal construction cost. AC may also be bought directly from the factory for insulation use. The cost of AC is much lower than the cost of TB and the PB

4. Conclusions:

The tested insulation materials were evaluated through models, AC showed a significant results. Experiments also showed that the cans are a good thermal insulation material and can withstand a considerable live and dead loads, in addition to the low construction cost and low dead weight. From practical side of view, these cans could be packed using nylon sheets with suitable dimensions (100x100cm or 50x50cm) for easy installation process beneath the floor's or ceiling's tiles. As it was stated before that the AC recycling rate is decreasing, the use of these cans is certainly will contribute in solving part of the environmental problems.

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