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Mechanical and Acoustic Properties of Composite Material in a Secondary Roof to Reducing the Cooling Load

Abstract- *The present investigation aims to perform experimental study to show the feasibility of application composite materials as secondary roofs, as well as their capability for reducing cooling load in building. Moreover, compare some of their mechanical properties and acoustic insulation with conventional secondary roofs. Three basic models, which are common, were chosen for the construction of buildings' roofs in Baghdad (concrete and concrete tiles as basic components of the first model, brick and clay tiles as basic components of the second model and brick and normal tiles as basic components of the third model). In addition, three composite materials were used in present work (fiber glass+ Nylon 66, fiber glass+ one layer of date palm cortex and fiber glass+ two layers of date palm cortex). The gypsum plates have been selected as a conventional secondary roofs when performing calculations and comparison. The results show that using proposed composite materials leads to significant reduction in cooling load by about 69.56 %, 65.3 % and 65.5 % respectively for the three models. In addition, the comparison of acoustic insulation shows that the proposed materials offer good acoustic insulation. Moreover, these materials able to afford external shocks better.*

Keywords- *Secondary Roofs, Cooling Load, Composite Materials, Acoustic Insulation.*

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1. Introduction

In the summer season, temperatures are increased in Iraq, thus increasing the cooling load rates away from the principles of saving energy and rationalizing its consumption. The reason for this is due to the presence of buildings that do not deal intelligently with the harsh climatic conditions of Iraq [1]. Therefore, it is necessary to find alternatives and solutions for reducing thermal loss through the walls and ceilings of buildings, thus enhancing energy performance of building through reducing energy consumed by the air conditioners. Therefore, studying the thermal performance of the building during its design or implementation stages, and selecting structural materials or packaging and insulating materials that have good mechanical and acoustical performance and reduce the thermal loss of buildings is necessary now. In this context, many studies that dealt with studying the use of different kinds of insulating materials or using smart ways in order to raise energy performance level in buildings. For example, reducing (24.97%) of cooling load by making buildings adapts itself to the harsh climatic conditions of Baghdad using intelligent systems named "Ecotect" [2]. Increasing the value of thermal resistance for roof through covering the roof by white paint or using plastic tiles over the roof [3], or, by covering the building roof by grasses or by a layer of water in order to reduce the heat that transfer through roof [4]. Using composite materials as an insulators are now a research growing interests, some of these research interest in inorganic based materials such as using composite materials that consist of fiberglass and polyester resin as thermal insulators for roofs [5], and others interest in using organic based materials such as using sunflower stalks particles and chitosan as an insulating composite material [6], using corn stalk particles with epoxy resin as insulation composite material [7], using hemp fiber with polyurethane composite [8] or using straw and sunflower with clay for thermal insulation [9]. The present investigation aims to show the possibility of using composite materials as secondary roofs, through studying and comparing their mechanical, acoustical and thermal behaviors with conventional secondary roofs.

2. Experimental Part

In this study, three basic models as shown in Figures (1a-c) that are common in the construction of the buildings roofs in Baghdad were selected for the comparison of thermal

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behavior (concrete and concrete tiles as basic components of the first model, brick and clay tiles as basic components of the second model and brick and normal tiles as basic components of the third model). Furthermore, gypsum plates have been selected in order to compare their thermal performance, acoustic insulation and mechanical properties with the proposing materials. The details and specifications of the three models have been included in Table 1. In addition, three specimens of composite materials have been made: the first specimen consists of eight layers of fiber glass and one layer of nylon 66 as a reinforcement layer (4 layers of fiber glass + 1 layer of nylon 66 +4 layers of fiber glass), the second specimen consists of eight layers of fiber glass and one layer of date palm cortex as a reinforcement layer (4 layers of fiber glass + 1 layer of date palm cortex +4 layers of fiber glass) and the third specimen consists of six layers of fiber glass and two layers of date palm cortex as a reinforcement layers (2 layers of fiber glass +1 layer of date palm cortex +2 layers of fiber glass +1 layer of date palm cortex + 2 layers of fiber glass) and Figure 2 shows the three samples with gypsum sample. The thermal properties of samples have been specified by using thermal constants analyzer (**TPS 500**) which is available in Materials Engineering Department- University of Technology. In addition, laboratory tests have been carried out in order to specify the mechanical specifications, including tensile test and impact test to determine the ability of samples to withstand shocks and overloads. Moreover, the acoustic insulation test was done for all samples by using acoustic insulation instruments **ASTM E-336** {which are consisting of sound wave generator (UNIT 092812), sound amplifier (TNG, Type: AV 298), sound source (speaker) and sound wave meter (30-130 dB)} that available in Materials Engineering Department, University of Technology. The results of all laboratory tests were listed in Tables 2-5.

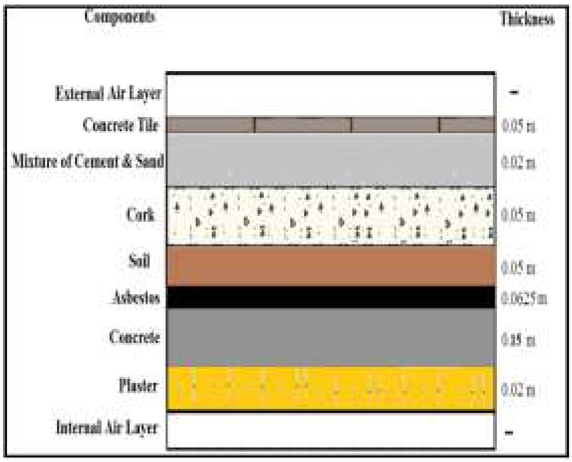


Figure 1a: Details and specifications of first model

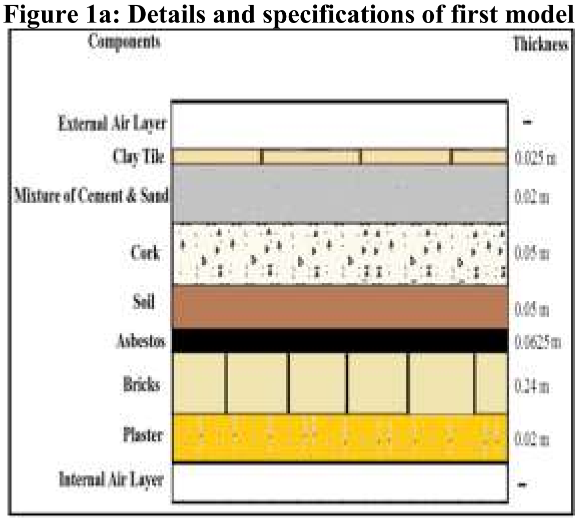


Figure 1b: Details and specifications of second model

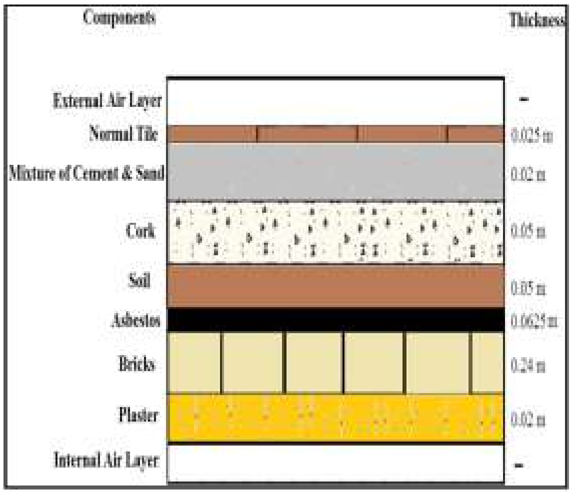


Figure 1c: Details and specifications of third model

Table 1: Details and specifications of three models [10]

No. of Model	Components	Thickness m	Thermal Conductivity W/m.^{0}C
1	External air layer	-	-
	Concrete Tile	0.05	1.785
	Mixture of cement & sand	0.02	0.721
	Cork	0.05	0.045
	Soil	0.05	0.788
	Asbestos	0.0625	0.115
	Concrete	0.15	1.775
	Plaster	0.02	0.81
	Internal air layer	-	-
2	External air layer	-	-
	Clay Tile	0.025	0.49
	Mixture of cement & sand	0.02	0.721
	Cork	0.05	0.045
	Soil	0.05	0.788
	Asbestos	0.0625	0.115
	Bricks	0.24	0.72
	Plaster	0.02	0.81
	Internal air layer	-	-
3	External air layer	-	-
	Clay Tile	0.025	0.758
	Mixture of cement & sand	0.02	0.721
	Cork	0.05	0.045
	Soil	0.05	0.788
	Asbestos	0.0625	0.115
	Bricks	0.24	0.72
	Plaster	0.02	0.81
	Internal air layer	-	-

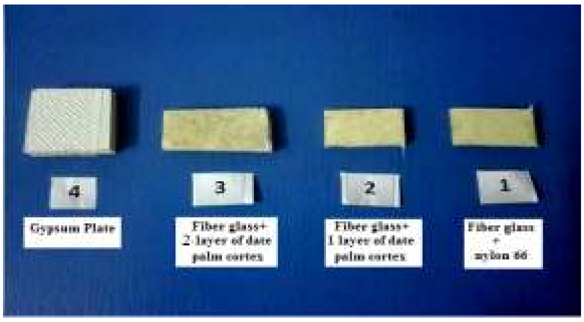


Figure 2: Samples of proposing composite materials & gypsum plate

Table 2: Outcomes of thermal test

Samples type	**Thermal conductivity W/m.^{0}C**
Sample No.1 (Fiber glass+ Nylon)	0.26
Sample No.2 (Fiber glass+ one layer of date palm cortex)	0.12
Sample No.3 (Fiber glass+ two layers of date palm cortex)	0.1
Sample No.4 (Gypsum plate)	0.295

Table 3: Outcomes of mechanical properties (Impact test)

Samples type	**Impact test Reading (kJ/m^2)**
Sample No.1 (Fiber glass+ Nylon 66)	32
Sample No.2 (Fiber glass+ one layer of date palm cortex)	56
Sample No.3 (Fiber glass+ two layers of date palm cortex)	63
Sample No.4 (Gypsum plate)	27

Table 4: Outcomes of mechanical properties (Tensile test)

Samples type	**Tensile test Results (Mpa)**
Sample No.1 (Fiber glass+ Nylon 66)	88
Sample No.2 (Fiber glass+ one layer of date palm cortex)	108
Sample No.3 (Fiber glass+ two layers of date palm cortex)	135
Sample No.4 (Gypsum plate)	61

Table 5: Outcomes of acoustic insulation test

Frequency	Air without sample	Sample No. 1 Fiber glass+ Nylon 66	Sample No. 2 Fiber glass+ one layer of date palm cortex	Sample No. 3 Fiber glass+ two layers of date palm cortex	Sample No. 4 Gypsum plate
(Hz)			(dB)		
100	114.7	95.2	94.4	94.1	93.7
200	114.8	95.3	94.4	94.2	93.7
300	114.9	95.3	94.5	94.2	93.7
400	115.0	95.4	94.7	94.3	93.8
500	115.0	95.5	94.8	94.3	93.8
600	115.1	95.6	94.9	94.4	93.9
700	115.1	95.7	95.0	94.4	94.0
800	115.2	95.8	95.0	94.5	94.1
900	115.3	95.8	95.0	94.6	94.1
1000	115.4	96.2	95.2	94.7	94.2
2000	115.6	96.3	95.2	94.9	94.3
3000	115.7	96.4	95.3	94.9	94.3
4000	115.8	96.5	95.4	94.9	94.4

3. Theoretical Part

I. Thermal analysis

A computer program in Matlab language has been built to calculate the overall heat transfer coefficient and the heat that transfer through roof model before and after using the secondary roof. In addition, the cooling load temperature difference method ($CLTD_r$) has been selected in calculations, where the cooling load of roof can be calculated from the following equation [10]:

$$q_r = u_r . A_r . CLTD_r \quad (1)$$

Where

the overall heat transfer coefficient u_r can be calculated by calculating the thermal resistances of roof components as follows [10]:

$$u_r = 1/\left(\frac{1}{f_{in}} + \frac{x_a}{k_a} + \frac{x_b}{k_b} + \cdots + \frac{x_n}{k_n} + \frac{1}{f_{ex}}\right) \quad (2)$$

Where

(x_a, x_b and x_n) represent the thickness of roof layers, and (k_a, k_{bn} and k_n) represent the thermal conductivity of structural materials for roof. While, (f_{in} and f_{ex}) represents the thermal resistance of air layers on both sides of roof.

The ($CLTD_r$) can be determined by the external design temperature and the difference of daily change of the external temperature, where the rate of daily change is divided into three rates according to the [11 & 12]:

1- Little change rate (the difference less than 9 ^{0}C).

2- Medium change rate (the difference from 9 ^{0}C to 14 ^{0}C).

3- High change rate (the difference more than 14 ^{0}C).

The values of ($CLTD_r$) were selected depending on [10-12] and were listed in Table 6.

Table 6: Values of (CLTDr) with respect to direction

Direction	North (N)	North-East (NE)	East (E)	South-East (SE)
($CLTD_r$) ^{0}C	17	19	24	24
Direction	South (S)	South-West (SW)	West (W)	North-West (NW)
($CLTD_r$) ^{0}C	21	29	31	25

The reduction in cooling load can be calculated from the following equation:

$$R_c = \frac{C_{without} - C_{with}}{C_{without}} \times 100\% \quad (3)$$

II. Acoustic insulation analysis

In acoustic insulation analysis, three parameters have been selected (sound level, equivalent sound absorption area (A) and sound absorption coefficient ($\boldsymbol{\alpha}$). The reason behind selecting these parameters is that the sound level and the other two parameters have reverse relationship with acoustic insulation. Therefore, it is important to know the sound level values to estimate the level of acoustic insulation of materials that used in construction or in packaging. The following equations were used for determining equivalent sound absorption area (A) and sound absorption coefficient ($\boldsymbol{\alpha}$) [13]:

$$A = \frac{0.921 \times V \times d}{c} \quad (4)$$

$$\boldsymbol{\alpha} = \frac{A}{S} \quad (5)$$

The range of frequency which was used in tests between 0 up to 4000 Hz, because this range is common using in construction field for estimating acoustical performance [14].

4. Results and Discussion

Recently, materials which are used in building construction and finishing are expected to meet multiple functions such as thermal, structural and acoustical functions [15]. Therefore, the present study investigated these functions for proposed materials as follows:

I. Thermal behavior test

The outcomes of thermal test have been presented in Figures (3-5). It can be observed that in all three models there is a considerable reduction in cooling load when using both the gypsum plate and the proposing composite materials, where in first model, the reduction rates {(69.56) % for the sample that consists of nylon layer, (69.644) % for the sample that consists of one layer of date palm cortex and (69.717) % for the sample that consists of two layers of date palm cortex and (69.58) % for the gypsum plate while in second model the reduction rates were {(65.195) % for the sample that consists of nylon layer, (65.280) % for the sample that consists of one layer of date palm cortex and (65.36) % for the sample that consists of two layers of date palm cortex and (65.219) % for the gypsum plate}, and finally in third model, the reduction rates were {(65.356) % for the sample that consists of nylon layer, (65.441) % for the sample that consists of one layer of date palm cortex and (65.519) % for the sample that consists of two layers of date palm cortex and (65.380) % for the gypsum plate}. This behavior can be attributed to that the suggested materials have approximately close values of thermal conductivity but the lowest value for the sample that consists of two layers of date palm cortex. Therefore, this sample presents maximum reduction in cooling load compared with other samples in the three models.

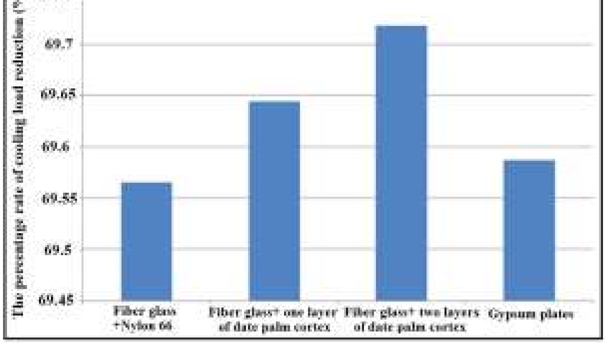


Figure 3: Reduction rates in cooling load for model-1

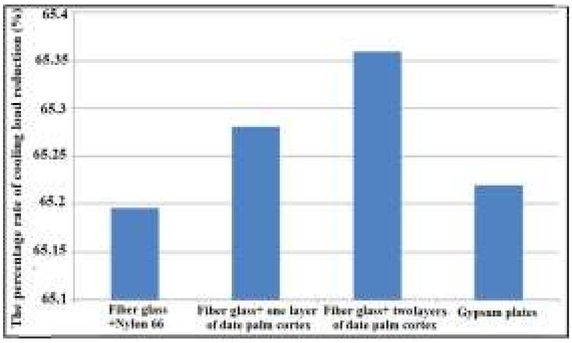


Figure 4: Reduction rates in cooling load for model-2

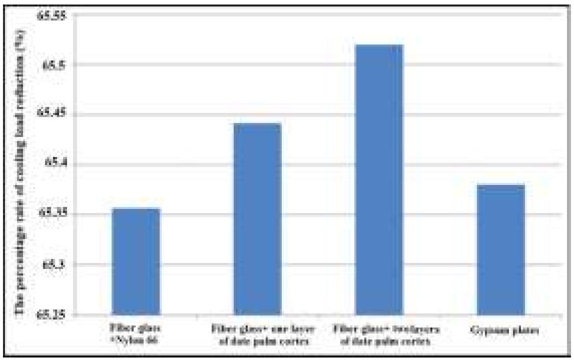


Figure 5: Reduction rates in cooling load for model-3

II. Mechanical properties tests

The results of tensile and impact tests are given in Figures (6 &7). It can be seen from these figures that the composite materials have better mechanical properties than conventional material (gypsum plates). The reason for this can be attributed to the presence of the reinforcing layer, which acts as a supporting layer in the composite material, in addition to the adhesive that binds the layers of the composite material to each other. Hence, it can be demonstrated that the proposing materials have the ability to withstand the external mechanical factors that cause damage such as shocks, overloads, etc. more than the conventional materials. In addition, the composite material that reinforced by double layers of date palm cortex presents best mechanical properties comparing with the conventional gypsum plates and other proposing materials.

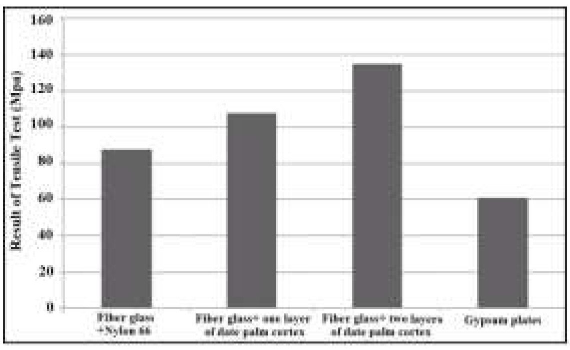


Figure 6: Results of tensile test for all samples

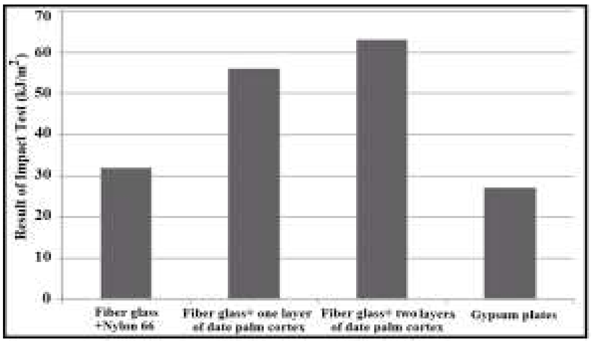


Figure 7: Results of impact test for all samples

III. Acoustic insulation test

Acoustical performance for building materials can be evaluated by using three major parameters (sound level, equivalent sound absorption area (A) and sound absorption coefficient (**α**)) which were represented in figures (8-10). These figures reveal that all samples that were tested have close acoustical performance, as well as offer good acoustic insulation property.

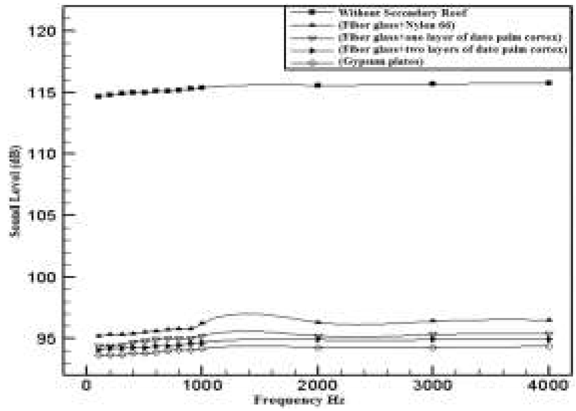


Figure 8: Sound level for the test samples

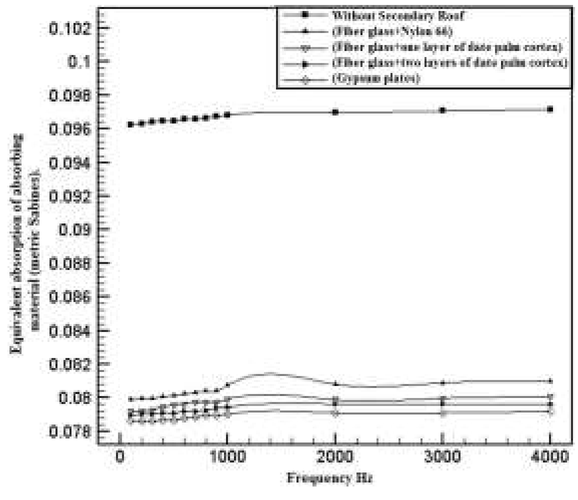


Figure 9: Equivalent sound absorption area for the test samples

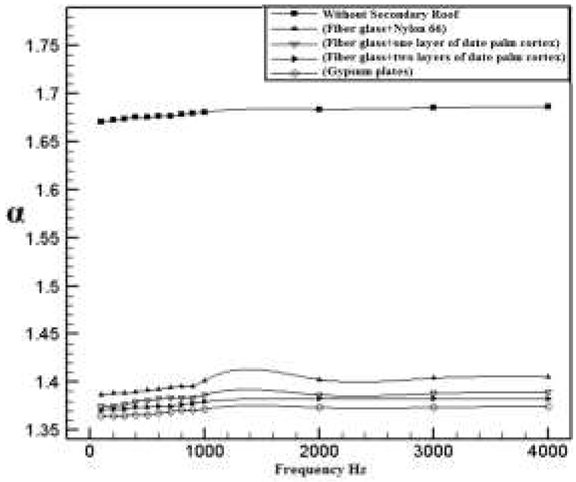


Figure 10: Sound absorption coefficient for the test samples

5. Conclusions

1- The composite materials, which are proposed in this study, have the ability to reduce cooling load by about 65-69.5%.

2- There is a little difference between the proposing materials and conventional material in thermal performance but the pest performance can be achieved by using two layers of date palm cortex.

3- The proposing composite materials have better mechanical properties than the gypsum plates.

4- The proposing composite materials offer good acoustical insulation performance.

5- Depending on thermal, mechanical and acoustical insulation performances of proposing materials, it can be demonstrated that the feasibility of using proposing materials as secondary roofs in building construction for reducing both cooling load as well as noise. Moreover, these materials have low cost and better quality than materials that currently used in markets.

References

[1] A. Kadum, A. Abdulwahab and N. Fadhil, “Compared the thermal behavior for packaging materials natural and industrial for the walls on the cooling load in Baghdad,” Journal of Babylon University/Engineering Sciences, Vol. 21, No. 4, pp.1450-1463, 2013.

[2] W.A. Alaqily and I.J. Al–Yousif, “Reduction Cooling Load Using Intelligent Envelope System,” the Iraqi journal of architecture, Vol. 4B, No. 14-15, pp. 76-96, 2008.

[3] A.A. Hasan, “The Experimental Study for Heat Transferred from Building Roofs and Roof Finishing System Usage,” The Iraqi Journal for Mechanical and Material Engineering, Vol.12, No.1, pp.910-930, 2012.

[4] A.A. Hasan, “The Heat Transferred Reduction from Building Roof Which Exposed to Environmental

by using Grasses and Water (Experimental Study)," Journal of Engineering, Vol. 17, No.6, pp. 311-324, 2011.

[5] Q.S. Mehdi, F.A. Abdulla and A.A. Abdul shaheed,"Experimental & Theoretical Investigation of Composite materials as Thermal Insulation for Resident Building," Journal of Engineering and Sustainable Development, Vol. 14, No. 3, pp.105-123, 2010.

[6] N. Mati-Baouche, H. De Baynast, A. Lebert, S. Sun, C. Lopez-Mingo, P. Leclaire and P. Michaud "Mechanical, thermal and acoustical characterizations of an insulatingbio-based composite made from sunflower stalks particles and chitosan," Industrial Crops and Products, Vol. 58, pp.244–250, 2014.

[7] H. Binici, O. Aksogan and C. Demirhan, "Mechanical, thermal and acoustical characterizations of an insulation composite made of bio-based materials," Sustainable Cities and Society, Vol. 20, pp.17-26, 2016.

[8] S. Sair , A. Oushabi, A. Kammouni, O. Tanane, Y. Abboud, A. El Bouari, "Mechanical and thermal conductivity properties of hemp fiber reinforced polyurethane composites," Case Studies in Construction Materials, Vol.8, pp. 203-212, 2018.

[9] Y. Brouard, N. Belayachi, D. Hoxha, N. Ranganathan, S. Méo, "Mechanical and hygrothermal behavior of clay – Sunflower (Helianthus annuus) and rape straw (Brassica napus) plaster bio-composites for building insulation," Construction and Building Materials, Vol.161, pp196-207, 2018.

[10] I. Salih, "Study to improve heat transfer reduction for exist building's roof by using local available materials," Journal of Babylon University/Engineering Sciences, Vol.19, No.3, pp.1-18, 2015.

[11] ASHRAE, "Hand Book of fundamentals" American society of heating, refrigeration and air-conditioning engineering," 1997.

[12] ASHRAE, "Hand Book of fundamentals" American society of heating, refrigeration and air-conditioning engineering, 2005.

[13] S.A. Kadhum, "Investigation of Tensile, Physical and Microstructure Properties for Chemically Treated Sawdust/UPE Composites," M.Sc. Thesis, Materials Engineering Dept., Univ. of Technology, Iraq, 2015.

[14] N. El Hajj, B. Mboumba-Mamboundou, R.M. Dheilly, Z. Aboura, M. Benzeggagh and M. Queneudec, "Development of thermal insulating and sound absorbingagro-sourced materials from auto linked flax-tows," Ind. Crops Prod, Vol. 34, pp. 921–928, 2011.

[15] P. Glé, E. Gourdon, and L. Arnaud, "Acoustical properties of materials made of vegetable particles with several scales of porosity," Appl. Acoust, Vol. 72, pp. 249–259, 2011.

Nomenclature

A: Equivalent absorption of absorbing material (metric Sabines).

A_r: Surface area of roof (m^2).

c: Sound speed (m/s).

C_{with}: Cooling load with insulation (Kw).

$C_{without}$: Cooling load without insulation (Kw).

$CLTD_r$: Temperature difference for cooling load for roofs (^0C).

d: Decay rate (dB/s).

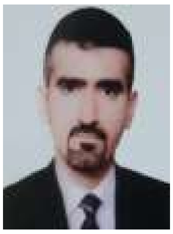
f_{in}: Internal Resistance of Materials on Inner Side of the Roof.

f_{ex}: External Resistance of Materials on Outer Side of the Roof.

k_a,k_b,k_n : Thermal Conductivity of Structural Materials for Roof.

R_c: Reduction rate in cooling load (%).

S: Specimen area (m^2).



u_r: Overall Heat Transfer Coefficient for Roof.

V: Volume of room device (m^3).

x_a,x_b,x_n : Thickness of Roof Components Layers (m).

α: Sound Absorption Coefficient.

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