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Production of Thermal and Sound Insulators from Used Automobile Tires' Fiber

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ABSTRACT

One of the problematic issues with the recycling of used automobile tires is the production of unwanted fiber waste. This waste is considered as a major burden and as an industrial waste which constitutes an extra cost to industries. In this project, thermal and noise insulators were produced from the fiber waste of automobiles. The insulation materials were used in insulating different types of rooms to study their thermal and noise insulation effectiveness (Caravan rooms and brick rooms). Results were also compared to identical rooms without insulation. Results showed that the thermal properties of the obtained sheets are similar to those used currently in construction. The differences between the insulated rooms and the non-insulated rooms were about 2°C and 1-4 dBA for thermal and sound level, respectively, for both construction models during day and night all over the year period.

KEYWORDS: Automobile tires, Fiber, Thermal insulation, Sound insulation.

INTRODUCTION

Waste tires were used in many applications. For example, some researchers used crumb tires as fuel in cement kilns in order to save energy, but this process increased the CO_2 emission to the environment (Abu-Jdayil et al., 2016). This made others recycle waste tires through chemical and/or mechanical processes and obtained fibers, rubber granulates and steel wires. According to the European Tire Recycling Association (ETRA), different researchers have investigated the mechanical properties of rubberized concrete using waste tire crumbs. The addition of the fiber to the crumb rubber has also been studied and found to improve the mechanical properties of concrete more than when using the crumb rubber alone (Sobral et al., 2003). In order to increase the energy absorption of concrete slabs, pillars and paving blocks, rubber-tire granulates and powders have been used as aggregates. Lee and Shang (2013) investigated the thermal behavior of a dry mixture of tire crumbs and mine tailings. Additionally, Abu-Jdayil et al. (2016) changed the rubber concentration from 0 to 40% by volume and used the waste rubber particles as filler in polyester to be used as an insulating material. They discovered that adding rubber particles to polyester can create a good thermal insulator, because the rubber particles lower the composites' thermal conductivity, density and water absorption. The impact of various frequencies on the acoustic characteristics of light-weight concrete with a high volume of recycled rubber aggregates has been examined by Medina et al. (2016). They discovered that when steel and textile fibers are combined with rubber powder, as opposed to regular or rubberized concrete, the sound absorption is increased.

The characteristics of reinforced fibers were studied by Acevedo et al. (2015), who discovered that they are made of three poly amides: rayon, polyester and aramid. Jedidi and Abroug (2022) evaluated the mechanical characteristics of a plaster and *Posidonia oceanica* fiber mixture. They discovered that mixtures with fiber

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reinforcement are more resilient to compression and bending. Additionally, they discovered that adding *Posidonia oceaqnica* fibers significantly decreased the thermal conductivity and thermal diffusivity of the different mixtures. Sugarcane bagasse waste was used by Mehrzad et al. (2022) to create fibrous materials for sound absorption and thermal insulation. They discovered that the thermal conductivity ranged from 0.034 to 0.042 W/m K, the average level of sound absorption was 0.26 to 0.64 and the noise reduction coefficient ranged from 0.27 to 0.62. With the addition to a small amount of waste synthetic zeolite, Fornes et al. (2022) produced thermal and sound insulators from phosphogypsum matrix reinforced with either waste wood fiber or natural wood fiber. They discovered that the waste wood fiber significantly increased the mechanical properties and decreased thermal conductivity, but did not affect sound pressure level. The thermal insulation for insulators made from cardboard waste and plant fibers was studied by Benallel et al. (2021). They discovered that the thermal conductivity increased as the fiber content increased, rising to a maximum of 0.98 W/m K from 0.072 W/m K for 40% alfalfa and 60% cardboard waste. Multiple diagnostic methods were also used by Parres et al. (2009) to describe and identify the fibers. Their thermal analysis methods identified polyamides 6 and 6.6 in the sample. As a new sound-absorbing material, Maderuelo-Sanz et al. (2012) used fluff (a textile byproduct from grounded end-of-life tires) both with and without resin. They discovered that significantly more sound is absorbed when a second layer of fibrous material is added to the perforated panel that has traditionally been used as a reflective surface. Van de Lindt et al. (2008) looked into the technical viability of replacing conventional fiberglass insulation in light-frame wood residential construction with an innovative fly ash-scrap tire fiber composite. Vasconcelos et al. (2015) created a composite material system by combining recycled textile fibers, thermally activated flue gas desulfurization gypsum and granulated cork. There has been extensive research on the acoustic characteristics of fibers (Allard et al., 1993). For the purpose of sound insulation, recycled polyester fibers have undergone testing to measure their absorption coefficient. The work of Lou et al. (2005) investigated the acoustic characteristics of composites made from non-woven selvages made of polyester and polypropylene blends and examined the impact of thickness and density on the sound-absorption coefficient. According to some studies, recycled polymeric granulates and fibers can be formed into materials with desirable acoustic and physical characteristics (Vitamvasova et al., 1996). These studies demonstrated that high-performance acoustic materials are achievable through a better understanding of the materials’ microstructure, physical strength parameters and the impact of the manufacturing process. The acoustic characteristics of "fluff" heated to temperatures between 130 and 220°C and made up of 27% fibers and the remaining 73% ground tire rubber were studied by Maderuelo-Sanz et al. (2012). The results showed that even at lower thicknesses, there was excellent sound insulation.

To the best knowledge of the investigators, no literature was found on utilizing used tire fibers alone for the purpose of sound and thermal insulation. Therefore, this study is considered the first to use the fiber waste itself for thermal and noise insulation.

Experimental Setup and Procedure

Sample and Insulation Sheet Preparation

Fibers obtained from the shredding of used auto tires were collected from the industrial free zone in Zarqa city in Jordan. Styrene butadiene rubber was used as an adhesive due to its high quality, low cost and availability in the local market. The ratio of adhesive to fiber and pressure values were investigated to determine the optimum ratio that provides the best thermal conductivity and tensile strength.

The fiber is mixed with the adhesive to bind the fiber and produce a coherent insulation sheet. The mixture is placed in a rectangular mold of steel measuring 25 cm x 25 cm x 2 cm and compressed under 15 bar for 24 hours in a hydraulic press to produce fiber sheets. Then, the sheets are removed from the mold and allowed to dry at room temperature for 24 hours in order to become ready for use as insulating sheets.

Measurements of Temperature and Sound Levels

Two identical rooms made from bricks were built (one non-insulated; used as a control room and the other insulated with the fiber sheets) with the dimensions of 1m*1m*1m, as shown in Figure 1a. The walls of the rooms are made of two layers of 10-cm bricks with 2 cm of space between the bricks. In one room, the space is filled with the produced insulation sheets, while being kept empty for the other.

(a) (b)

Figure (1): a) Construction of two rooms built from bricks
b) Construction of two caravan rooms made from rigid polymer

Another model called caravan, as shown in Figure 1b, has been built with two rooms (one of them was insulated with the fiber and the other was kept as it is. The actual temperature measurements and sound-level measurements were carried out during the whole day and night for both systems shown in Figures 1a and 1b over a one-year period.

RESULTS AND DISCUSSION

Properties of the Manufactured Sheets

Using experimental design parameters as shown in Table1, the chosen range of each parameter was based on the cost-optimization rational, since the objective of this project is to produce an insulation material from waste at a low cost. This cost should be competitive to the normal construction insulation materials.

Table 1. Experimental design of the parameters studied

Parameter	Lowest Value	Highest Value
Binder Ratio	10%	30%
Compression Load	10 tons	20 tons
Fiber Ratio*	40%	80%
Binder material is chosen from styrene butadiene rubber.		

* The third parameter (water ratio) is determined based on the balance of the binder and fiber ratio.

After conducting few experimental trials, the best cost-optimized formulation of fiber, adhesive and water was determined. As shown in Table 2, it was found that the sample (74F-13W-13A-15B) with the formula of 74% fiber, 13% water and 13% adhesive under a pressure of 15 bar was found to be the best formula due to the good adhesion of the sheet, the lowest amount of adhesive and thus the lowest cost. A total of more than 240 (Figure 2) of the optimized insulation sheets were produced (approximately 16 square meters) at the optimum conditions to be used for insulating a structure in order to characterize the thermal and sound insulation capabilities of these sheets in a real construction.

Figure (2): Produced insulation sheets

Table 2. Results of the experimental design of the parameters studied

Sample	Fiber Waste %	Water %	Adhesive %	Pressure (bar)	NOTES
80F-10W-10A-20B	80%	10%	10%	20	Failed at 20 bar.
60F-20W-20A-20B	60%	20%	20%	20	Failed at 20 bar.
55F-25W-20A-20B	55%	25%	20%	20	Failed at 20 bar.
55F-10W-10A-15B	55%	10%	10%	15	Few cracks noticed.
55F-10W-10A-10B	55%	10%	10%	10	Few cracks noticed.
40F-30W-30A-10B	40%	30%	30%	10	Few cracks noticed.
40F-30W-30A-20B	40%	30%	30%	20	Successful
40F-30W-30A-15B	40%	30%	30%	15	Successful
74F-13W-13A-15B	74%	13%	13%	15	Successful

Different compression pressures were used in this study to determine the minimum pressure that would produce suitable coherent sheets. It was found that a pressure of 240 tons/m^2 is suitable. It is important to mention here that the duration of compression used is 24 hours in a hydraulic press.

Thermal Conductivity Measurements

The thermal conductivity of produced sheets was measured using a thermal constant analyzer (TPS 2200) made by Hot Disk Co. as per the ISO 22007-2:2015 standard. The thermal conductivity values of the samples obtained are presented in Table 3.

Table 3. Thermal conductivity of samples prepared

Sample	Thermal Conductivity (W/m. K)	NOTES
80F-10W-10A-20B	0.110	Failed at a pressure of 20 bar.
60F-20W-20A-20B	0.100	Failed at a pressure of 20 bar.
55F-25W-20A-20B	0.100	Failed at a pressure of 20 bar.
55F-10W-10A-15B	0.110	Resulted samples with cracks
55F-10W-10A-10B	0.120	Resulted samples with cracks
40F-30W-30A-10B	0.060	Resulted samples with cracks
40F-30W-30A-20B	0.080	Successful sample
40F-30W-30A-15B	0.070	Successful sample
74F-13W-13A-15B	0.090	Successful sample (optimized sheet)

The thermal conductivity of the optimum parameters was determined as 0.090 W/m.K for the sample (74F-13W-13A-15B), which is in the same order of magnitude of known excellent insulation materials such as 0.04-0.07 W/m.K for *Posidonia oceanica* fibers (Kudo et al., 2018). Although the samples (40F-30W-30A-20B and 40F-30W-30A-15B) showed lower thermal conductivity values (0.08 and 0.07 W/m.K, respectively), they were not chosen due to the high binder contents which would be reflected on the cost of the produced sheets.

Tensile Tests

The tensile strength of the successful optimized insulation sheets was determined using a 2-kN load cell computer-controlled electromechanical universal testing machine made by Testing Equipment IE Co. The tensile strength measurements of the produced sheets were determined as per the ASTM D638 standard and are shown in Table 4. From the tensile test measurements, it is clear that some samples failed, such as (80F-10W-10A-20B, 60F-20W-20A-20B and 55F-

25W-20A-20B), due to the weak structure, while samples, such as (55F-10W-10A-15B, 55F-10W-10A-10B and 40F-30W-30A-10B), showed very low tensile stress values, due to the presence of some cracks in their structures. The rest of the samples (40F-30W-30A-20B, 40F-30W-30A-15B and 74F-13W-13A-15B), showed reasonable tensile stress values and good coherent structures. Therefore, the best sample (74F-13W-13A-15B) was chosen for further works, because it showed a high tensile stress, a low thermal conductivity, a good coherent structure and the lowest binder quantity.

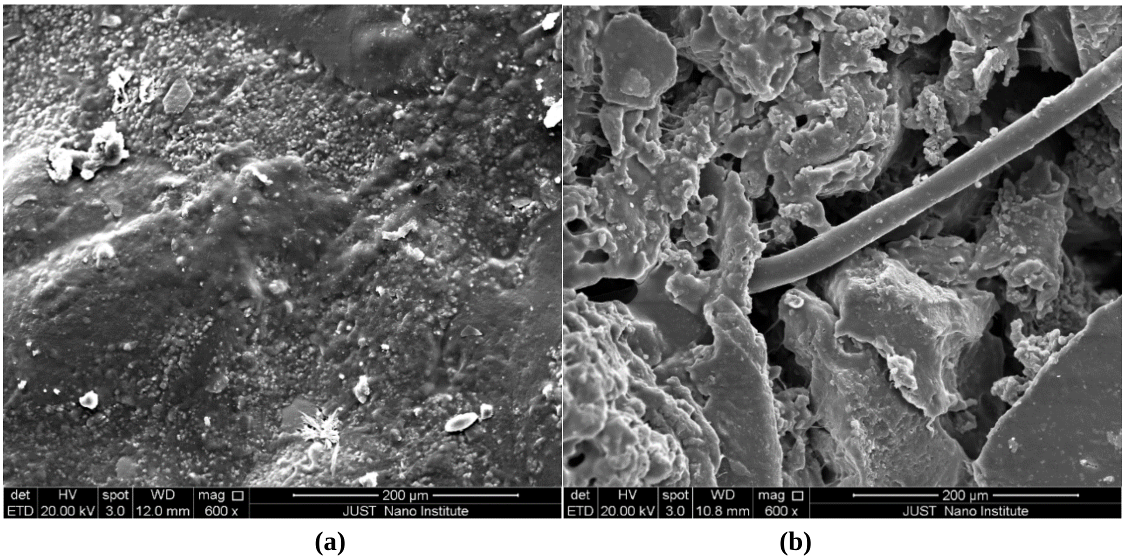
Table 4. Tensile strength of the prepared samples

Sample	Tensile Strength (kN/m^2)	NOTES
80F-10W-10A-20B	0 *	This sample failed after preparation.
60F-20W-20A-20B	0 *	This sample failed after preparation.
55F-25W-20A-20B	0 *	This sample failed after preparation.
55F-10W-10A-15B	8.0	Resulted samples with cracks
55F-10W-10A-10B	6.0	Resulted samples with cracks
40F-30W-30A-10B	10.0	Resulted samples with cracks
40F-30W-30A-20B	46.0	Successful sample
40F-30W-30A-15B	37.0	Successful sample
74F-13W-13A-15B	22.0	Successful sample

* Could not be measured (due to immediate failure).

Scanning Electron Microscopy

SEM images at different magnifications were obtained for the optimized samples and one of the failed samples. Samples were first gold-coated and then placed inside the SEM device. SEM images obtained for the optimized sheet (74F-13W-13A-15B) and one of the failed samples (55F-10W-10A-10B) are shown in Figure 3. It is clear that the bonding of failed samples is very week despite the presence of a significant amount of binder. This is due to the low compression applied during making this particular sheet.



(a) **(b)**

Figure (3): SEM images for (a) the successful sample (left) and (b) the failed sample (right)

Temperature and Sound-level Measurements

Temperature and noise-level measurements were performed in the control rooms that do not have insulation as well as in insulated rooms. Two types of rooms were used; custom-built brick rooms and custom-built caravan rooms with no windows.

Temperature Measurements

Temperature measurements were carried out continuously inside the above-mentioned rooms for a complete year using a data-acquisition system. The idea was to measure the performance of the produced fiber sheets through the four seasons. Due to the large number of data points collected for temperature and sound-level measurements, it was decided to choose 3 representative samples for one day in March, one day in October and one day in December.

Figure 4a shows the temperatures of the insulated brick room and the non-insulated brick room in addition to the outside temperature of one day in March. In the brick construction, when the outside temperature is below 20ºC from (00:00:00 AM to 11:00:40 AM and from 18:20:40 PM to 00:00:00 AM), the temperature inside the insulated brick room is higher than both outside and inside the non-insulated temperatures. On the other hand, when the outside temperature is higher than 20ºC from (11:00:40 AM to 18:20:40 PM), the temperature of the insulated brick room is higher than 20ºC, the temperature of the insulated brick room is lower than both the outside temperature and the inside non-insulated brick room temperature. This means that the insulation makes the brick room cold when the weather is hot and keeps it warm when the weather is cold. The difference in temperature between insulated and non-insulated brick rooms is about 2ºC.

Figure 4b shows the temperature measurements for the insulated and non-insulated Caravan rooms in addition to the temperature outside the rooms for one chosen day in March. It is obvious that when the outside temperature is around 15ºC or less (i.e., from 00:00:00AM to 07:00:00 AM and from 18:00:00 PM to 00:00:00 AM), the temperatures inside insulated and non-insulated caravan rooms are higher than the outside temperature and the insulated room temperature is higher than the non-insulated room temperature by about 1-2ºC. On the other hand, from 07:00;00 AM to 18:00:00 PM, where the outside temperature is higher than 15ºC, the insulated caravan-room temperature is lower than that in the non-insulated one by about 1-2ºC, but both are higher than the outside temperature.

The same trends are noticed for March (summer time), October (autumn time) and December (winter time) as shown in Figures 4c to 4f with few differences in the temperature values at specific period times due to changes in the outside temperature. In October and December, the outside temperatures are not shown in the figures due to technical problems with the sensors, because rain water affected and broke the sensor. It is clear that the reduction in temperature between the insulated and non-insulated brick rooms was about 2ºC, while that for the caravan rooms was from 1-2ºC.

Noise-level Measurements

Figures 5a to 5d show the effect of insulation on the sound level for both rooms made of bricks and caravan in different months of the year. Figure 5a shows the sound levels for insulated and non-insulated rooms made from bricks in March, while figure 5b shows the same for the caravan rooms. The same is valid for Figures 5c and 5d for October. All figures presented the same trend and showed that the sound level in the rooms which are insulated are lower than in the non-insulated rooms by about 1 to 4 dBA regardless of the season or the outside temperature, but it depends on the material of construction. The reduction of sound level for the rooms made from bricks was about 1 dBA, while that for caravan rooms was about 4 dBA.

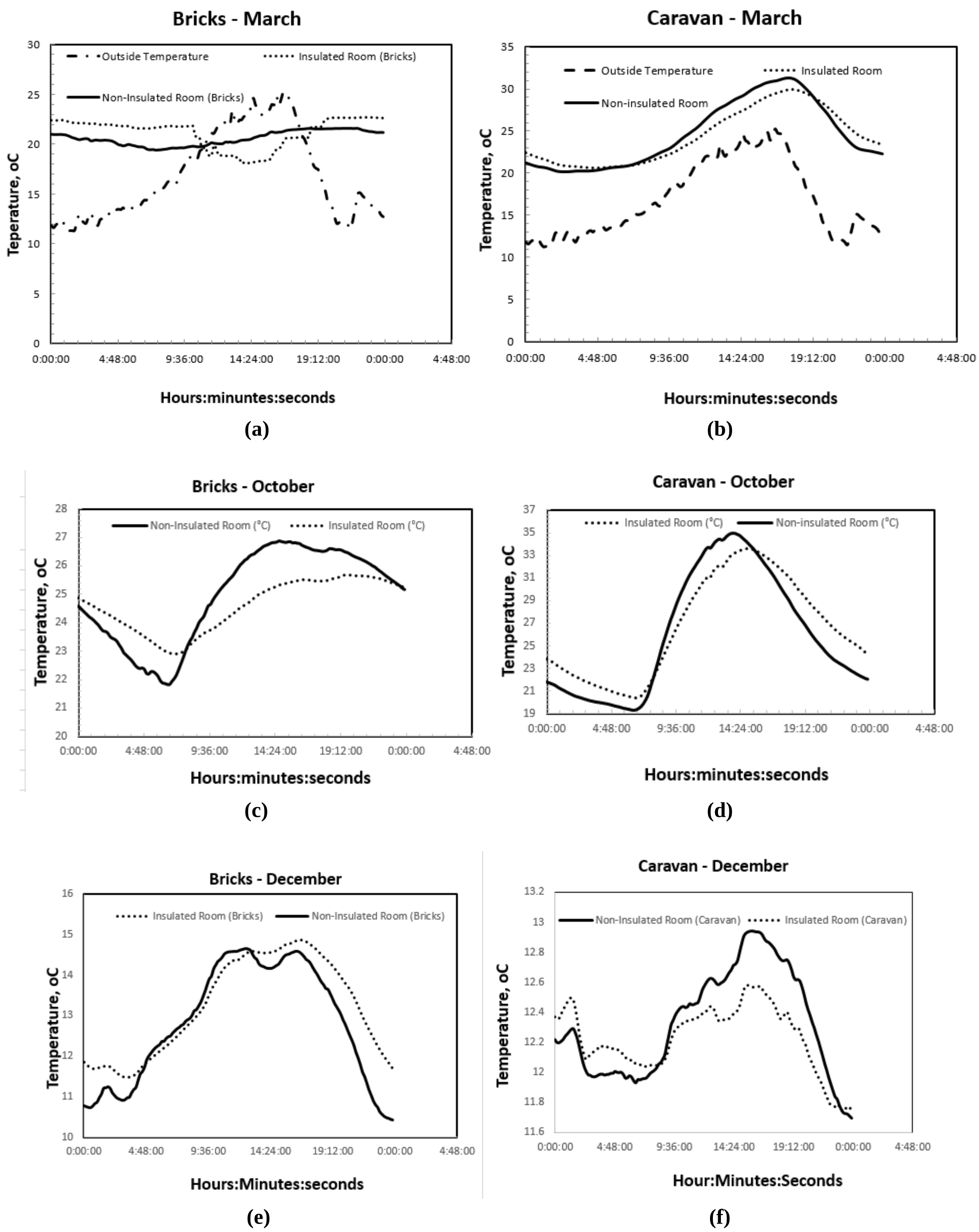


Figure (4): Temperature measurements for bricks and caravan on one day of a, b) March c, d) October and e, f) December

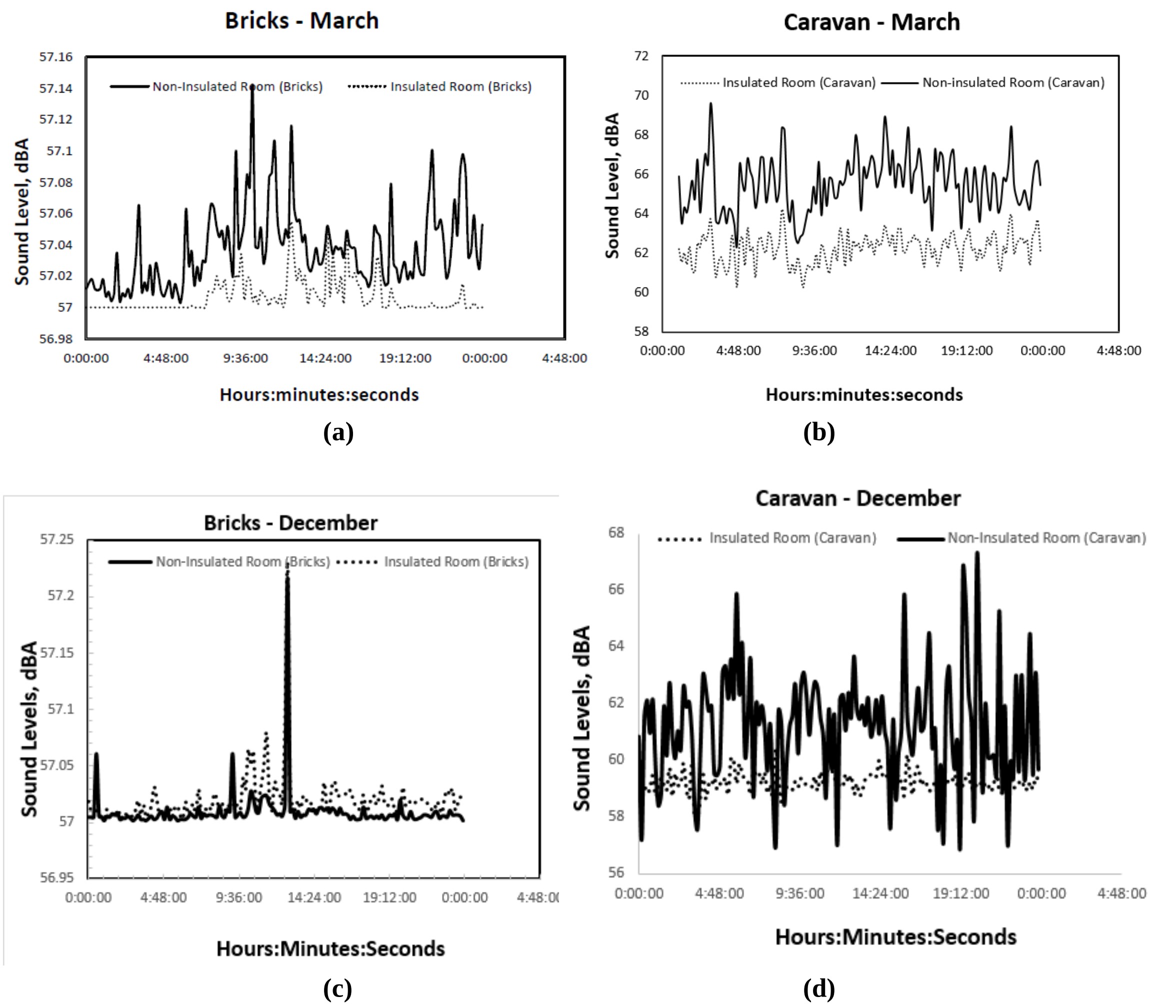


Figure (5): Sound-level measurements for brick and caravan rooms for one day in a, b) March and c, d) December

CONCLUSIONS

Thermal and sound insulator sheets were produced with good physical and mechanical properties from waste fiber of used tires. The study reported the optimum parameters to form workable insulation sheets with acceptable thermal and noise-insulation properties. A real application to measure the effectiveness of these produced sheets was obtained by building two identical rooms from bricks and two identical caravan rooms while insulating one and leaving the other one empty. Temperatures and noise levels were measured throughout a whole year to establish the required effectiveness of these sheets. The results of this real application showed that the temperature difference between insulated rooms and non-insulated rooms was about 2ºC for both brick and caravan models, while the sound-level reduction was about 1 dBA in the brick rooms and 4 dBA in the caravan rooms.

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