Thermal and sound performance of new PVC prefabricated wall panel for log-home-style-building

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Abstract

This article suggests an opportunity to utilize Polyvinyl Chloride (PVC) pipes—a kind of lightweight material that is convenient for transportation and building assembly. Thermal and acoustic performance of the developed wall panel made of 3-inch-diameter PVC pipes for prefabricating a log-home-style building was evaluated and compared with an autoclaved aerated concrete (AAC) block, a single fiber cement panel, and a double fiber cement panels with air cavitation core. Heat transfer properties were tested using hot box; and sound proofing properties were tested using sound box. Both hot box and sound box utilized in this study were developed by the researchers. The test results showed that the PVC wall panel can insulate heat as effective as the AAC block can; both panels hold the temperature difference at 25.4°C. Whereas, the heat transfer properties of the PVC wall panel is better than what the single fiber cement panel and double fiber cement panels are. The temperature differences of the single fiber cement panel and double fiber cement panels are 11.3°C and 27.2°C respectively. Its sound proofing properties are better than those of the single fiber cement panel and the double fiber cement panels, except AAC block. The sound differences of the PVC wall panel range between 17.4 – 30.9 decibels (dB), at the sound source of 65, 75, 85 and 95 dB, and at the frequency of 100, 600 and 1200 Hz. According to aforementioned propertied confirm the potential of the PVC pipe in being utilizing as wall panels.

Keywords: lightweight panel, thermal transfer, shelter, prefabricated wall, thermal test box

1. Introduction

In the past, natural wood was commonly used as a construction material for houses such as log houses, Thai-style wooden houses, Asian-style house, etc. However, most of the wood sold in Thailand is imported from abroad because the domestic forests have decreased. Thai Government has enforced logging and wood processing controls of which causing higher timber prices. Consequently, synthetic materials such as fiber cement sheets, Unplasticized Polyvinyl Chloride (UPVC) sheets and Polyvinyl Chloride (PVC) sheets, etc., have become alternatives for construction materials in place of the natural wood.

Materials play an important role in the development of building construction. This article focuses on the construction materials that would specially serve the society's awareness about the environmental concerns: thermal and sound comforts. The material development through this study will consequently enable log-style vernacular lifestyle and economical positivity to the occupants in that building.

The developed material of this study is PVC wall panel. PVC pipes were selected because of their 1) standardized, precise and mass production, 2) air cavity in the middle—an insulating property, 3) light weight characteristic, 4) easy to clean characteristic, 5) scratch and chemical resistance, 6) non-flammability property, 7) re-usability and recyclability and 8) log-like shape. In tackling the thermal comfort, or referring to thermal insulation, the PVC wall panel was tested with an applied thermal transfer method. As for the tackling of sound transmission reduction, the panel was tested in a sound test box. From the design and production of ready-to-assemble emergency shelter from PVC pipe (Figure 1) of Sangrutsamee and Khamput (2018) to assess the cost and the production-assembly, transportation and installation procedures. This prototype building can be assembled within 1 day. It consists of a prefabricated set of components which were concrete base plates, steel structure frames, floor sheets, window-doors, ceiling, roof sheets and PVC pipe wall panels. However, the performance of heat transfer and noise protection has not yet been assessed. Therefore, it was the propose of this study.

The knowledge regarding cost, production-assembly, transportation and rapid installation procedures of a ready-to-assemble emergency shelter from PCV pipes (Figure 1) was suggested by Sangrutsamee and Khamput (2018). The shelter consists of a prefabricated set of components: concrete base plates, steel structure frames, floor sheets, window-doors, ceiling, roof sheets and PVC pipe wall panels. However, the novelty regarding the thermal and the acoustic properties of a building built from PVC pipes were still lacking. Therefore, the objectives of this study were formulated to 1) test the thermal and the acoustic properties and 2) compare the test results with an AAC block, a single fiber cement panel and a double fiber cement panel. The AAC block was selected due to its lightweight property and common usage for both wet and dry construction process; and the single and double fiber cement panels were selected because of their commonality in dry construction process.

Figure 1 Sangrutsamee and Khamput's (2018) shelter from prefabricated PVC pipe panels

2. Methodology

2.1 The making of the studied panels

Four types of material (Figure 2) were used for making each wall panel. The list is as follows:

1. PVC pipes with the specifications of being Class 5, 3-inch diameter and 75-mm thickness were exploratively used for making wall panels. The researchers prepared the pipes by heat extrusion to reshape them (Figure 3a) before assembling as a panel. During the assembly, 3 rebars were threaded through the assembled pipes at each end and at the middle (Figure 3b). Next, silicone caulk was used to seal the seamlines between each stacked pipes.

The thermal properties of the PVC panel are not specified nor calculated in this article because such properties can be altered from the specifications stated in Table of Thermal Conductivity, Specific Heat Capacity and Density (Announcement of the Ministry of Energy (2021) on Criteria, Methods of Calculation and Certification of Assessment Results for Building Design for Energy Conservation for Each System Total Energy Consumption of the Building and the Use of Renewable Energy in Building Systems B.E. 2564). The variation of the thermal properties can affect 3 factors being raw materials, the formula, and the manufacturing process that each manufacturer uses. A slight alternation can further affect the accuracy of calculations in determining the values of the Thermal Resistance (R) and the Heat Transfer Coefficient (U).

2. Off-the-shelf fiber cement board, with a thickness of 8 mm, and k= 0.397 W/m °C was modified. One layer is assembled and attached to a galvanized steel frames (Figure 2b).

3. Off-the-shelf fiber cement board, with a thickness of 8 mm, and k= 0.397 W/m °C was modified differently than the one above. The board was made into 2 layers, with an air cavitation of 82 mm in the middle. The wholes layers were attached to a galvanized steel frame. Its total thickness was 98 mm (Figure 2c).

4. An AAC block with a thickness of 70 mm (k= 0.303 W/m °C) sat between plaster (k= 0.72 W/m °C) on both sides. The total thickness was 100 mm (Figure 2d). Each panel was in the size of 300x500 mm, wrapped by 3-inch-thick foam on its 4 edges. All of the panels were painted in white.

2.2 Testing Methods

2.2.1 Physical properties and workable evaluations

Physical properties evaluation includes 1) weight, 2) density and 3) dimension of the panels; these properties were measured by a scale and a measuring tape. Workable evaluation covers the convenience in cutting, trimming, assembling and priming and finishing; these were conducted through observations and photograph annotations.

a) PVC pipes panel b) Single fiber cement panel c) Double fiber cement panel d) AAC block

Figure 2 The panels made for testing.

a) Pipe preparation by heat extrusion method | b) Rebar threading | c) Frame attachment | d) Surface finishing the surface and preparing to assemble the building

Figure 3 Assembly of prefabricated wall panels from PVC pipes

2.2.2 Heat transfer testing and the heat transfer test box

Laboratory testing was selected over the field heat transfer testing due to the controllable factors. Field heat transfer testing refers to outdoor testing using solar radiation is of various interferences (e.g., daily and monthly solar orbital and directional changes) and uncontrollable weather conditions (e.g., the amount of cloud, rain, dust and humidity). For this study, the researchers applied the methods conducted by (Soubdhan et al., 2005) and (Somi, 2011). Their methods were based on the principle of heat transfer from a spot with high temperature to the one with a lower temperature. The test material was used as a barrier between these two temperature spots. All test box walls were equipped with thermal insulating materials so that the temperature inside the box and at the surfaces of the material could be kept and measured.

Soubdhan (2005) designed the box in the size of 1220 x 1220 x 500 mm. Five sides of the tested wall consisted of plywood and polystyrene foam, except the top where installed the tested roof sheet. Thermal sensors were installed in various locations. The obtained results were calculated to identify conductive heat flux and radiative heat flux.

Somi (2011) tested the thermal conductivity of materials to determine their insulating properties by constructing a test box measuring 1200 x 1200 x 1200 mm. The box consisted of 3 main parts: 1) hot area using a heater to produce the heat at 40°C, 60°C and 70°C, 2) cold area, and 3) the test material placed in the middle between the hot and the cold areas.

The researchers of this study adapted the methods, including the building of the heat transfer test box above. The dimensions of the box were deviated due to the availability of the materials in Thailand. The heat transfer test box of this study, shown in Figure 4, consisted of 3 parts:

1. The hot box, where installed a heat source, was in the size of 500 x 300 x 300 mm for the inner. A steel plate structure with 1.2-mm thickness were lined with 3 inches thick expandable polystyrene (EPS) foam all around, except on the side that the test panel was installed. One 500-watt infrared lamp and one temperature control device (thermostat) 50-100°C.

2. Each test panel was 300 x 500 mm. Its thickness varied between 5 - 100 mm, according to the material use for assembling the test panel.

3. The cold box what in the size of 500 x 300 x 300 mm at the inside. It was lined with a 1.2-mm-thick wooden frame, and covered with 3-inch-thick EPS foam. However, the foam did not cover the side of the cold box that a test panel was installed.

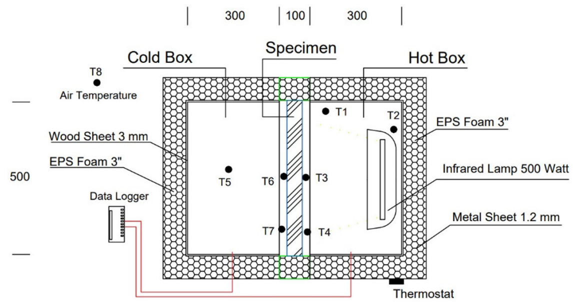


Figure 4 The heat transfer test box

a) Plan section of the heat transfer test box

b) Preparation and installation of the heat transfer box

The equipment and instruments used for recording the temperatures inside the test box included 1) data logger (Yokogawa model MX100) for recording temperature every 5 minutes and 2) type-K thermocouple wire that can measure the range of 0-800 °C (+/- 2.2 °C (36.5 °F) or +/- 0.75% accuracy), including 8 temperature sensors. The position at which these sensors were installed are as described in Figure 4, together with additional texts below.

• Two air temperature sensors: front (T1) and back (T2) were installed inside the hot box.

• Two temperature sensors: T3 and T4 were installed onto the surface of the test panel inside the hot box.

• One air temperature sensor: T5 was inside the cold box.

• Two temperature sensors: T6 and T7 were installed onto the surface of the test panel inside the cold box.

• One air temperature sensor: T8 was installed outside the test box. The box was place in a shaded area during the test.

Heat transfer value test procedures
Six procedures were proceeded for the heat transfer value test. Their details can be described as follows:

1) Preparation of the materials and equipment according to the prescribed format,

2) Installation of the temperature sensors and the test panel at their specified positions and creating an airtight condition using silicone caulking and tape masking at all joints,

3) Input of heat throughout using a 500-watt infrared lamp into the box and controlling of the temperature within the range of 50 - 100 °C for a period of 570 minutes (9 hours and 30 minutes) using a thermostat,

4) The record of temperature in different locations of the box using the data logger at every 5 minutes,

5) The record the temperature after switching of the heat source using the data logger for another 570 minutes (9 hours and 30 minutes),

6) Data analysis and comparisons of temperature differences between the test panels.

2.2.3 Sound test box

Somi's (2011) method for testing acoustic performance of wall panels was applied in this study. One test box in the overall size of 700 x 850 x 600 mm was built as a research instrument. Its chamber was made of two steel plates, filled with lightweight material, and plastered with gypsum mortar to insulate noise. One speaker controlled by a computer was installed as a sound source inside the box. Since this method was determined to identify the loss of sound transmission as each test panel was put in place, the measurements of the sound levels both inside and outside the box were required. As such, a plastic funnel and a sponge were placed at a small opening to allow the measurements at the outside of the box. The sound levels were tested between 55.4 - 87.5 dB.

In this study, the researchers applied the methods and the research instrument as suggested by Somi (2011) in terms of materials for building the test box, sound source, and the measuring technique using a plastic cone and a sponge insulation. However, box size and replacement of an insulation material for gypsum mortar, including the sound levels and frequencies for test had to be deviated due to the availability of the materials and sound control equipment in Thailand. The details of the sound test box are as follows:

• The test box was built with an internal size of 300 x 500 x 500 mm. It was built from 2-mm steel plates and lined with 75 mm (or 3 inch) thick foam on five sides, with a gap on one side for inserting a test panel. The panel was in the size of 300 x 500 mm.

• The inside of the box consisted of 1) one of 3-watt speaker, 2) one Sound Check Generator (SCG) (with the dBs at 65, 75, 85 and 95 and the tested frequencies at 100, 600 and 1,200 Hz), 3) one temperature and humidity sensor (Brand: CE Model AZ8829, ±0.6 °C, between 20 - 100 °C, and humidity deviation ±3%) and 4) one digital sound level meter as the sound source (Brand: CE Model AZ8922, ±0.1 dB, sound range 30-130 decibels dB). A computer program was used to control frequency and volume through the speakers.

• The outside of the box was installed with one sound measuring device placed inside a plastic cone that padded with a piece of sponge. The sponge acted as an insulator to prevent interfering noises from the outside while the measurements were conducted.

• The test panels were in the size of 500 x 300 mm. The thickness of the panel differed according to the material used for assembling the panel. Three-inch-thick foam was lined at all edges of the test panel. The test panel was adhered to the inside of the box by silicone caulking, plus masking tape to prevent the noises from the speaker that might interfere the measurement of the digital sound level meter.

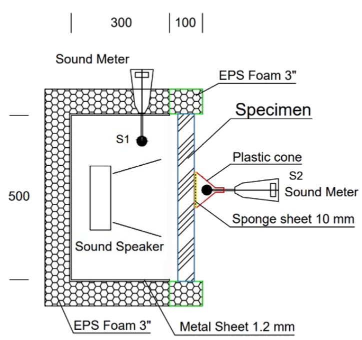
Four procedures for testing the soundproofing performance were proceeded as follows:

1) Preparation of equipment, test boxes, and tools and installation of each test panel in the designated position,

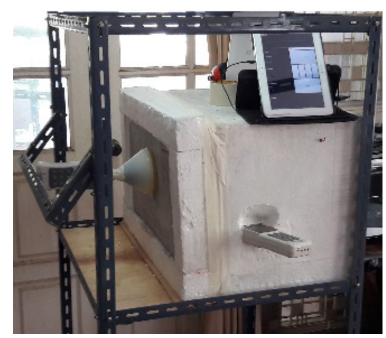
2) Measurements and records of the temperature and humidity inside the test box,

3) Inputting the frequency into the test box by using a trustworthy and open-access SCG program and adjusting the frequency generator at 100, 600, and 1,200 Hz, plus at 65, 75, 85 and 95 dB per stated Hz (see Table 2), including 3 times of measurements and loudness records per stated Hz at the inside and the outside the sound test box,

4) Data analysis and synthesis.



a) Plan and test box equipment



b) Sound test photo

Figure 5 Sound test box

3. Results and discussions

3.1 Evaluation regarding the physical and workable properties

Physical properties evaluation includes 1) weight, 2) density and 3) dimension of the panels. The total weight of each assembled panels that included its frame structure was compared. The panels made of 3-inch-diameter PVC pipes, the single fiber cement, the double fiber cement and the AAC block were found with the weight and density as follows:

- The 3-inch-diameter PVC pipes, size: 1000 x 1000 x 76 mm, including its frame structure, and weighing 25 kg,
- The single fiber cement panel, size: 1000 x 1000 x 8 mm, including its frame structure, and weighing 15 kg,
- The double fiber cement panel, size: 1000 x 1000 x 98 mm, including its frame structure, and weighing 23 kg,
- The AAC block, size: 1000 x 1000 x 100 mm, including its construction mortar and plaster, and weighing 26 kg.

The comparison above shows that the weight and density of the PVC pipe panel were on the heavy side, as to being only less heavy than the panel made of the AAC.

As for the workable evaluation, the PVC pipes to assemble prefabricated wall panels can be easily cut, heat treated, drilled, assembled, sealed and painted. Assembling a panel of the PVC pipe require less time than the panel of the AAC block.

Although the PVC pipe panel was evaluated to be better than the AAC block in terms of the physical and workable evaluation, its weight and density are considered inferior to ones of the single fiber cement panel and the double fiber cement panel. The lower the weight and density is the easier to work with will be. Also, the single fiber cement panel and the double fiber cement panel are more durable and stronger than AAC block and PVC pipe panel.

3.2 Heat transfer performance

The relationship between temperature and time of heat transfer through the PVC pipe panel is shown in Figure 6. The graph in red demonstrate that the temperature rises sharply after the heat was inputted into the thermal test box. The average temperature measured the surface of the PVC pipe panel in the hot box is 82.9 °C; this value was captured at 30 minutes before turning off the heater. The graph in black presents 57.5 °C as the temperature on the surface of the PVC pipe panel in the cold box. The temperature difference of the two surfaces of the PVC pipe panel is up to 25.4 °C. After the heaters were switched off for 194 minutes, the temperatures of the surfaces on both sides equalize at 52.3 °C.

The findings above shows that the PVC pipe panel has the heat insulating potential. This is due to the air cavitation inside this tube.

The results of single fiber cement panel testing show that 76.8 °C is the average temperature of its surface in the hot box; and 65.5 °C is the average temperature of the surface in the cold box. These temperatures were measured during Minute 540 – 570—the period in which the heat absorption is fairly constant in the hot wall surface. The temperature difference of the two surfaces of the single fiber cement panel is up to 11.3 °C. After the heaters were switched off for 142 minutes, the temperatures of the surfaces on both sides equalize at 49.7 °C. As shown in Figure 7, the surface temperature of the test panel rises sharply on both surfaces. High and low temperatures shift periodically, as presented by the wave-like curve. These findings led to the understanding that the single fiber cement panel is of a poor thermal insulation property.

Refer to Figure 8, the heater causes the temperature of the double fiber cement panel to rise for both surfaces in the hot and cold boxes. The average temperature of the surface in the hot box is 79.4 °C, and the surface in cold box is 52.2 °C; this value was capture at 30 minutes before turning off the heater. The temperature difference of both surfaces is up to 27.2 °C. After the heaters were switched off for 284 minutes, the temperatures of the surfaces on both sides equalize at 39.3 °C. These findings show that the double fiber cement panel can insulate the heat due to the fact that it has a good thermal insulating air cavitation core between the fiber cement panel on both sides.

The relationship between temperature and time of heat transfer through AAC block is shown in Figure 9. The average temperature at the surface of the AAC block in the hot box is 82.9 °C, measured before the heater was switched off at 30 minutes. At Minute 570, 57.5 °C is the temperature measured at the surface in the cold box. The temperature difference of both surfaces is up to 25.4 °C. After the heaters were switched off for 196 minutes, the temperatures of both surfaces equalize at 52.3 °C. These findings show that AAC block has thermal protection potential. The fact is it is an aerated building material with many small air pockets is an insulator inserted within the material.

A comparison of all test materials, shown in Table 1, indicates that double fiber cement panel performs the best among others. The PVC pipe panel and AAC block possess similar thermal insulation properties. Among these test materials, the single fiber cement panel is of the least thermal insulation properties.

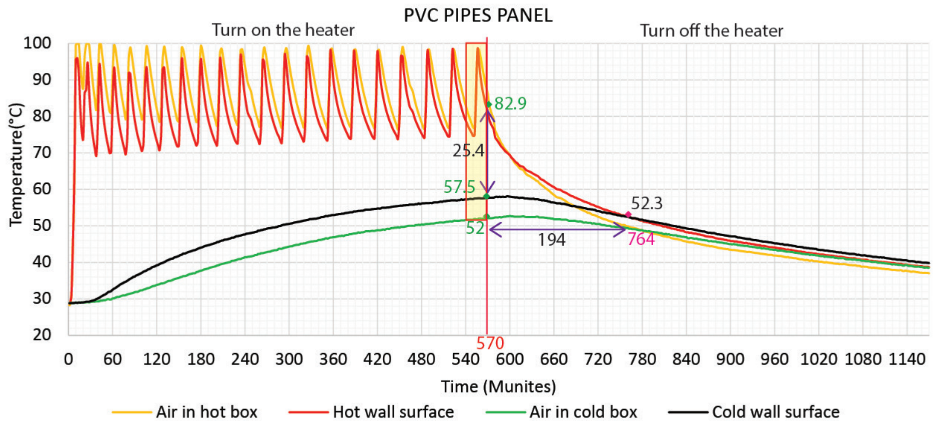


Figure 6 Temperature and time of heat transfer through PVC pipes panel

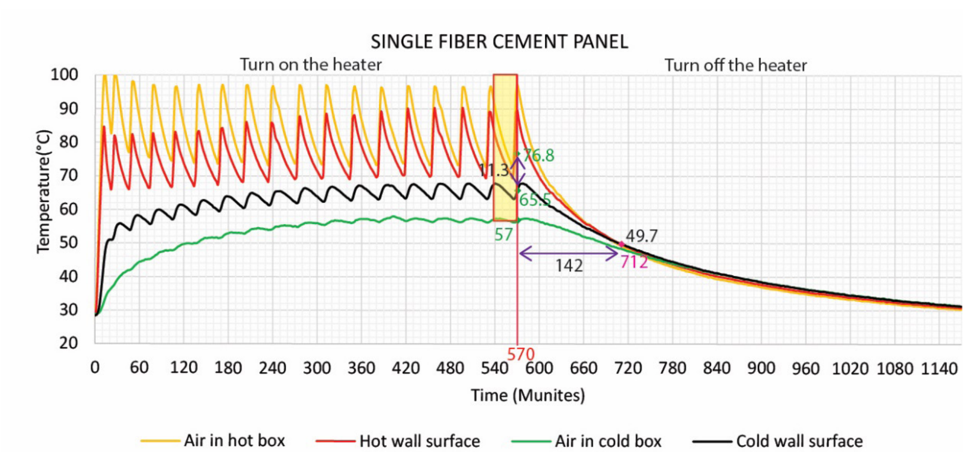


Figure 7 Temperature and time of heat transfer through single fiber cement panel

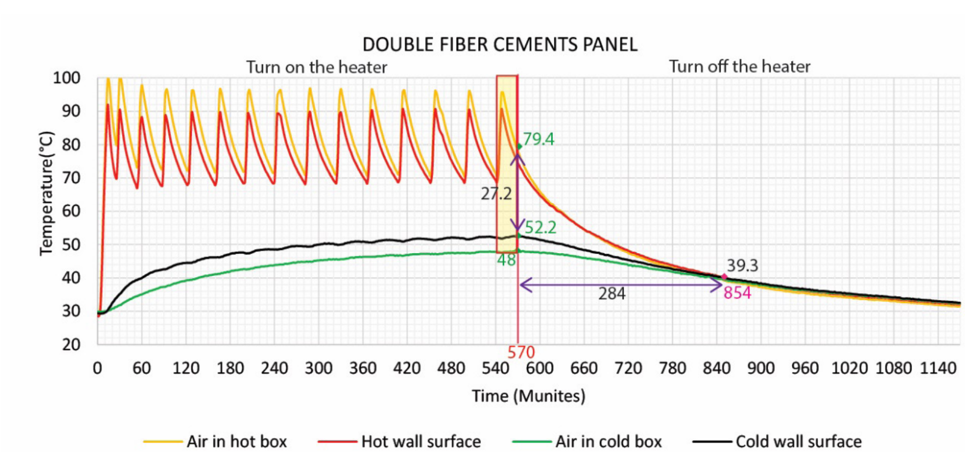


Figure 8 Temperature and time of heat transfer through double fiber cement panel.

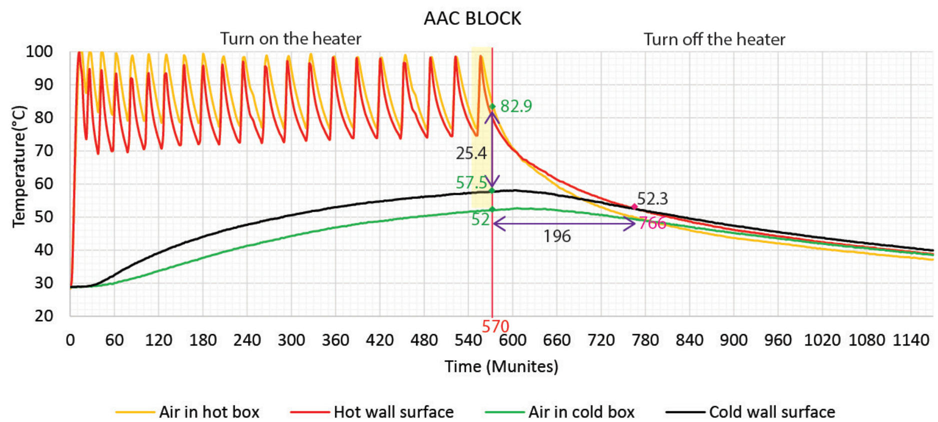


Figure 9 Temperature and time of heat transfer through AAC block

Table 1 Comparison of the different temperatures of all the test samples.

Type	Average temperature 30 minutes before turning off the heater.			The time at the same surfaces temperature on both sides after turned off the heater (minute (°C))
	Temperature on surface (the hot box) (°C)	Temperature on surface (cold box) (°C)	Temperature difference (°C)	
PVC pipes panel	82.9	57.5	25.4	194 (52.3 °C)
Single fiber cement panel	76.8	65.5	11.3	142 (49.7 °C)
Double fiber cement panel	79.4	52.2	27.2	284 (39.3 °C)
AAC block	82.9	57.5	25.4	196 (52.5 °C)

Based on the observation regarding the air cavitation of the PVC pipe, single fiber cement, double fiber cement, and AAC block, it is likely that more the air cavitation is, the better the material will become an insulator. Since the amount of the air pockets in the double fiber cement are more than its counterparts, the air pockets can insulate the heat. As such, its results imply a heat protection property.

3.3 Soundproofing performance

The soundproofing test results of all panels are presented in Table 2.

Table 2 All the soundproof test results

Frequency (Hz)	Sound source (dB)	PVC pipes panel		Single fiber cement panel		Double fiber cement panel		AAC block	
		Sound penetration (dB)	ΔT (dB)	Sound penetration (dB)	ΔT (dB)	Sound penetration (dB)	ΔT (dB)	Sound penetration (dB)	ΔT (dB)
100	65	47.6	17.4	47.5	17.5	45.9	19.1	41.4	23.6
	75	53.8	21.2	57.3	17.7	53.7	21.3	51.2	23.8
	85	63.7	21.3	66.8	18.2	64.8	20.2	59.9	25.1
	95	73.4	21.6	77.6	17.4	73.5	21.5	69.8	25.2
600	65	43.8	21.2	48.2	16.8	45.0	20.0	40.9	24.1
	75	52.0	23.0	58.0	17.0	53.6	21.4	51.6	23.4
	85	60.7	24.3	67.9	17.1	63.0	22.0	61.2	23.8
	95	70.7	24.3	78.0	17.0	72.7	22.3	71.0	24.0
1200	65	40.5	24.5	44.0	21.0	41.5	23.5	36.1	28.9
	75	46.9	28.1	49.2	25.8	47.5	27.5	45.2	29.8
	85	54.3	30.7	58.8	26.2	54.6	30.4	50.3	34.7
	95	64.1	30.9	68.6	26.4	64.5	30.5	59.8	35.2

Noted: The frequencies as tested were referenced with the values suggest by SCG.

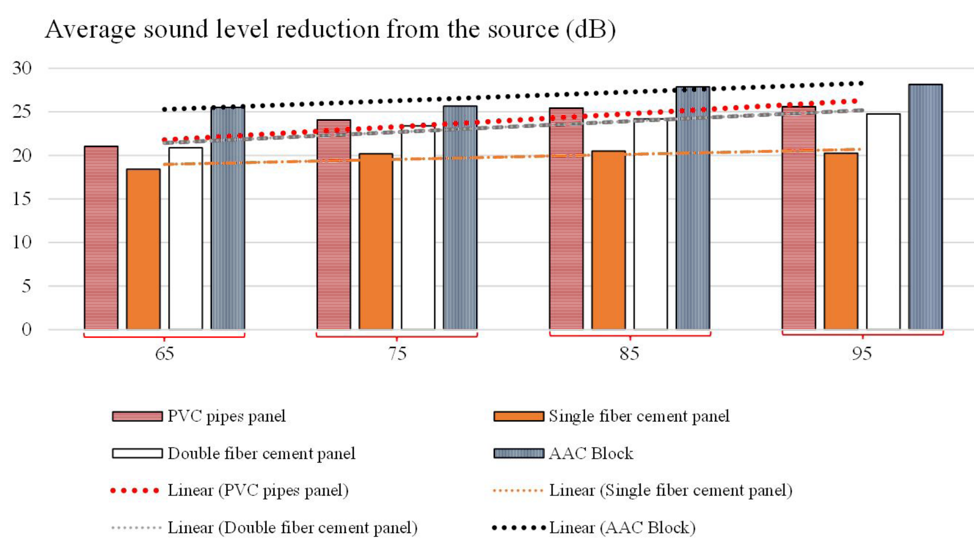


Figure 10 Soundproofing of all the test panels

Figure 10 shows the average difference between the source sound and the sound passing through the test panels from a sound source of 65 - 95 dB. It is due to the fact that the AAC block is of the best soundproofing capability and can reduce sound 26 - 28 dB. The PVC pipe panel can reduce the sound level 21 - 26 dB. Based on these ranges, AAC block has the best soundproofing properties. The PVC pipe panel can reduce the noise slightly better than the double fiber cement panel. Also, they can reduce noise much better than the single fiber cement panels.

4. Conclusion

The results of study serve the research objectives as reformulated. In terms of the physical and workable properties, PVC pipes in a log-like shape are lightweight and are easy to work with during a production. They can be cut, assembled, sealed, painted and decorated without extraordinary procedures. Its thermal and the acoustic properties in comparison with the panels made of single fiber cement, double single fiber cement and AAC block can be concluded as follows:

- Thermal protection: the PVC pipe panel is not as effective as the double fiber cement panel in term of thermal protection. However, it performs effectively in insulating heat as much as the AAC block. Yet, it is better than single fiber cement panel.

- Sound protection: the PVC pipe panel can reduce noises better than both single fiber cement panel and double fiber cements panel. However, it performs less effective than AAC block for sound protection.

Therefore, the novelty of this study is indicating that PVC pipes can be utilized as wall panels. They can be an interesting alternative material for a development toward commercial the prefabricated wall panels for log home style in the time of real wood scarcity in Thailand.

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