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Heat Transfer Analysis of Insulation Material for the Reserve Hot Water Tank

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ABSTRACT

A domestic hot water tank represents a significant potential demand-side management asset in energy systems. The selection of insulation materials is crucial for maintaining the temperature of the hot water tank and preventing massive heat loss from the tank. This study aims to analyze the different combinations of insulation material for the reserve hot water tank. Several materials, such as plywood, white bricks, red bricks, plasticine, aluminum foil, styrofoam, fine sand, and glass, were used as the insulation layer in experiments. Seven combinations of insulation layers were made to insulate the mini reserve water tank in the experiment. The insulation layers covered the surface of the water tank, and the initial and final temperature of the hot water was measured. The heat loss from the hot water tank and the thermal resistivity of the insulators were also studied. The experimental results revealed that the combination of plastic, plasticines, styrofoam, and timber yields the lowest heat loss for the hot water tank. This finding indicated that the material with low thermal conductivity is the best insulator for preventing heat loss from the thermal system. Thus, this study is useful in designing and selecting the insulation materials for the reserve hot water tank for domestic and industrial use.

Keywords: Heat transfer, Insulation material, Reserve water tank, Experimental

1. INTRODUCTION

Solar energy is known as a non-polluted fuel source as it would never be exhausted [1]. This gradual increase in demand for technologies that efficiently harness solar energy has encouraged many countries to develop solar power plants. Another plus side for the country would be the increase in favor of alternative energy sources, as it currently depends on non-renewable energy, including fossil fuels [2]. In other words, the carbon footprint can be reduced significantly by supporting renewable energy resources, including solar energy. Harnessing solar energy could not only able to generate a consumable amount of electricity but also produce domestic hot water usage at consumer homes [3]. For this case, energy is described as the flow of water through pipes built inside a solar heater, which would eventually be heated up due to the thermal energy being produced from it. By applying the Thermosiphon principle [4], heated water that remains at the upper portion of the hot water tank due to its lower specific density compared to cold water would be able to be drawn out. A domestic hot water tank represents a significant potential demand-side management asset within the energy systems. Thus, the temperature distribution must persevere throughout its operation to operate effectively as a primary energy storage device. Thus in the conventional method, the heated water that flows from the hot water tank would be used directly for daily usage [5]. This continuous cycle of tank-water-pipe-collector would ensure the water is gradually heated up until it reaches a point where it achieves an equilibrium temperature.

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A new form of energy storage is being researched to replace the usage of lithium-ion and lead acid, which act as a power source in producing thermal energy for domestic hot water and space heating in households [6]. Thus, exploiting the abundant natural resources that could otherwise be obtained through the operation of a fixed-volume hot water tank is easier. As a result, it is considered more economical compared to other conventional sources that produce a similar energy production. The replacement for alternative thermal energy storage is being additionally supported, as such challenges can be seen in other forms of energy storage, including flywheels, super-capacitors, and batteries. According to the range of thickness that was varied for constructing the domestic hot water tank, it is usually between 0.5 and 2.6 mm. However, from the point of view described by Armstrong et al. [6], the inner wall has little known significance to the effect of heat loss compared to the outer regional area that would act as an external insulation for the thermal storage tank. The most frequently used material that shall be built on the outskirt of the wall would be polyurethane.

The thermal performance would reflect the fluid flow rate within the solar domestic hot water (SDHW) system [7]. One would be characterized as a Low-flow SDHW system, and the other is a traditional pump-circulated SDHW system. Both apply a similar principle: the mantle applies a double heat-exchanger rate. The difference can be seen from the data collected, whereby a conventional pump-circulated SDHW system has a flow rate of 1.2 Liter/min collector. A Low-flow SDHW system is estimated to be around 0.2 Liter/min collector. Research studies have shown that a lower flow rate would gradually increase the temperature of the equipped solar collector. Rahman et al. [8] made several discoveries that include its efficiency, which is far greater than the predecessor tank, which is designed to be thoroughly mixed and has a similar dimensional size. This benefit does not end there when applying the principle usage of the dual heat exchanger, as it would only require much lesser maintenance on the tank that has minimal chances of confronting leakage. Its ever-increasing reliability is due to the flow rate that would only occur at a wholly sealed-up coil instead, whereby the double heat exchanger principle is being applied. In other words, it separates the coil with a continuous running fluid and a tank of usable water with zero flow rate. Rahman et al. have decided to conduct computational analysis, which could thereby enable suitable studies towards the effects of variable flow rates that occur during the heat exchanger process, the effects that could be volatile (thickness of the insulation wall) for the source of heat and the buoyancy action that were induced by both location (exit and entrance) and length of a double coil heat exchanger.

One of the challenges of the widespread use of solar energy is its ability to reduce or declination in energy production due to the blockage of clouds during which the sun sets [9]. Without a reserve water tank that collects the thermal water resources, the solar heater would be less effective when using it at times or weather unsuitable for producing the energy required. Besides, from previous research, stainless steel wall specification is costly for consumers to obtain an additional reserve water tank [10]. Several authors have proposed the usage of motor pumps in order to drive the heat exchanger process within a storage tank [11]. However, the purchasing power for a tank should be a priority; as such, it must be affordable for all consumers, besides achieving more fantastic performances for a proposed design. Specific gaps within the research could be addressed; as such, they can be identified through several conducted experimentation methods.

This work aims to analyze the heat loss in the conduction process and examine the suitable insulation materials. In the experiment, the water that is being drawn out from the primary energy storage device or also known as a hot water tank would eventually be filled up at an additional reserve water tank instead or also known as a secondary tank, before consumers can then make use of the hot water provided. The reason would be its ability to maintain and preserve the temperature of the water high for a more extended time. This is due to its wall specification and larger volume size design compared to the hot water tank assembled towards the solar heater. Thus, the reserve tank is equipped with several layers of various materials within a wall to improve the energy storage capability of hot water.

2. MATERIAL AND METHODS

Several materials were used during the fabricating process or for experimental purposes within the thermal storage tank design. The selected and studied materials could influence the overall result throughout the experimentation period. The material that is being selected is affordable and is commonly found within available stores. Another point that would dictate the selection of material is its thermal conductivity. Thermal insulation will work best if the material conductivity has a low measurable value [12]. Table 1 summarizes the materials with the thermal conductivity value and their functionality used for either experimentation or fabrication purposes. The thermal conductivity values identified for every material aspect were taken from several reference tables that are valid for average room temperatures. Thus, the temperature between 273 and 343 K (0 -70° C) would not differ much.

Table 1: Materials used in the fabrication and experimental work.

Material Type	Thermal Conductivity, (W/m.k)	Thickness for left and right side wall (m)	Thickness for top and a bottom wall (m)	Functionality
Plastic	0.22	0.011	0.011	Fabrication
Timber	0.147	0.017	0.017	
Plywood	0.13	0.015	0.015	Experiment
White bricks	0.6	0.09	0.09	
Red bricks	1.61	0.046	0.046	
Plasticine	0.65	0.012	0.012	
Aluminum foil	235	0.0002	0.0002	
Styrofoam	0.033	0.059	0.059	
Fine Sand	0.15	0.05	0.05	
Glass	0.8	0.001	0.001	

Timber and Polypropylene plastic would be preferred fabricating materials. Overall, both materials chosen for the fabrication process were known to be good insulators, as they have minimal thermal conductivity value. Besides, both materials are considered to manufacture from recyclable materials. Thus, both plywood and polypropylene plastic is considered to be environmentally friendly. Timber was considered economical compared with other materials, including steel. Thus, obtaining a high-grade panel is possible, as various types of wood are available on the market. Besides, the use of timber would be its available size. Due to its dimensional limitation, it is much easier to obtain a uniformly thick plywood sheet of size from the market than other uncommon materials found. Thus, the required dimensional shape can be achieved otherwise by using commonly found power tools. Lastly, it would ease undergoing several fabrication processes, reducing the need to use complex machines to construct an experimental thermal storage tank design.

For polypropylene plastic, however, its use would be its ability to withstand high-temperature changes produced during which a hot amount of water is kept for a long time since its melting point is set at 160 °C. This required water temperature to be maintained at about 60 °C. Another point that can be highlighted by using Polypropylene plastic is its chemical resistivity [13]. Its properties would not allow the deterioration caused by bacteria, which in this case, Legionella pathogens [14]. The thickness described in the table above would help to insulate a certain amount of heat within a tank. Figure 1 shows the thickness location of the experimental setup.

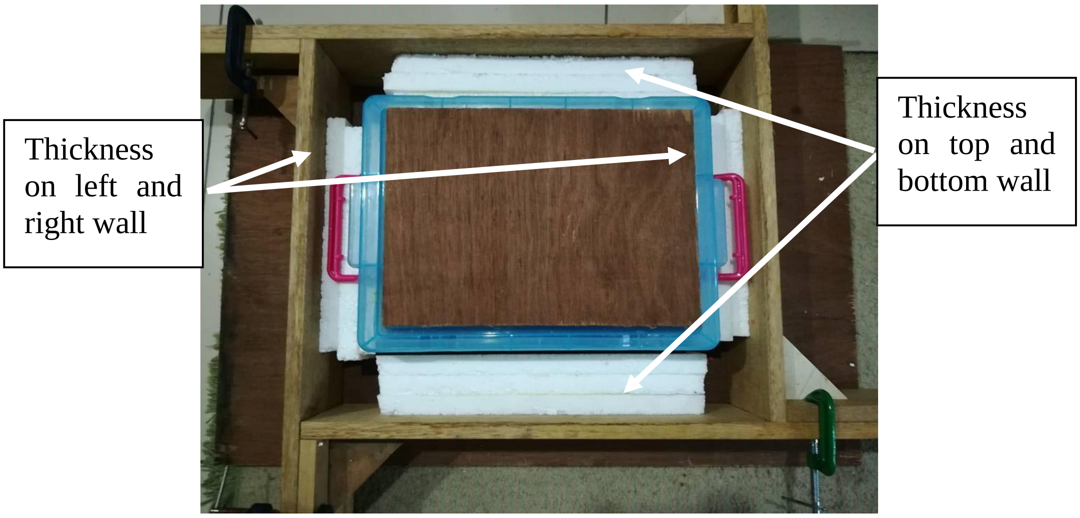

Figure 1: The described location sides that have their specified thickness in the experimental setup.

The drawing aspect would consist of various dimensional terms, including an experimental thermal storage tank's length, width, and height. However, the dimensions being set and proposed on the drawing would only coincide with an inner tank with 20 L. Thus, if the inner tank were to have a much more significant volumetric size proportion, dimensional changes can be made otherwise on the outer layer wall design. The changes would be acceptable if the following criteria were considered, including a suitable range of thickness gap and its practicality in inserting an inner volumetric tank that holds a certain amount of hot water. Figure 2 shows a 3D model from different views.

However, several presumptions were made otherwise when uncovering the results left to be discovered from the fabricated, designed thermal storage tank used for experimental purposes. The radiated heat source from the sun's broad daylight is neglected by placing the experimental thermal storage tank in an adequately closed room with a similar characteristic that replicates a sealed environment. This is because the heat source traveling in the form of light would decline gradually; as such, it would either be absorbed or reflected from insulating materials constructed within the modern household.

The chosen materials for their insulation credibility were placed between an experimental tank's internal and external walls (Figure 3). Based on the thickness combination of several selected insulated materials, the timber that acts as an external wall could be adjusted freely. Therefore, enabling the materials to fit perfectly between the walls of a tank. Once the outer tank wall has been fixed, four sets of G clamps are used to hold four pieces of timber that make up the external wall of a tank. The clamps are capable of preventing slight movements that were caused by minor thermal expansion. Thus, ensuring that the thickness being measured would remain the same from the beginning till the end of the experiment.

The internal tank would then be filled with water that was warmed up by 60 ◦C. This marked temperature is necessary, as it would act as an initial temperature for each experimental case that has been tested. Thus, a thermometer was used to test the initial water temperature. Once the water condition meets a given necessity, the experimental tank would be left in a room for an hour. The final temperature reading was then taken and recorded. To ensure that the readings were accurate, the insulation materials were tested for two days; each day consisted of 4 different periods (morning, afternoon, evening, and night). The experimental procedure would then be reused or repeated for the chosen materials.

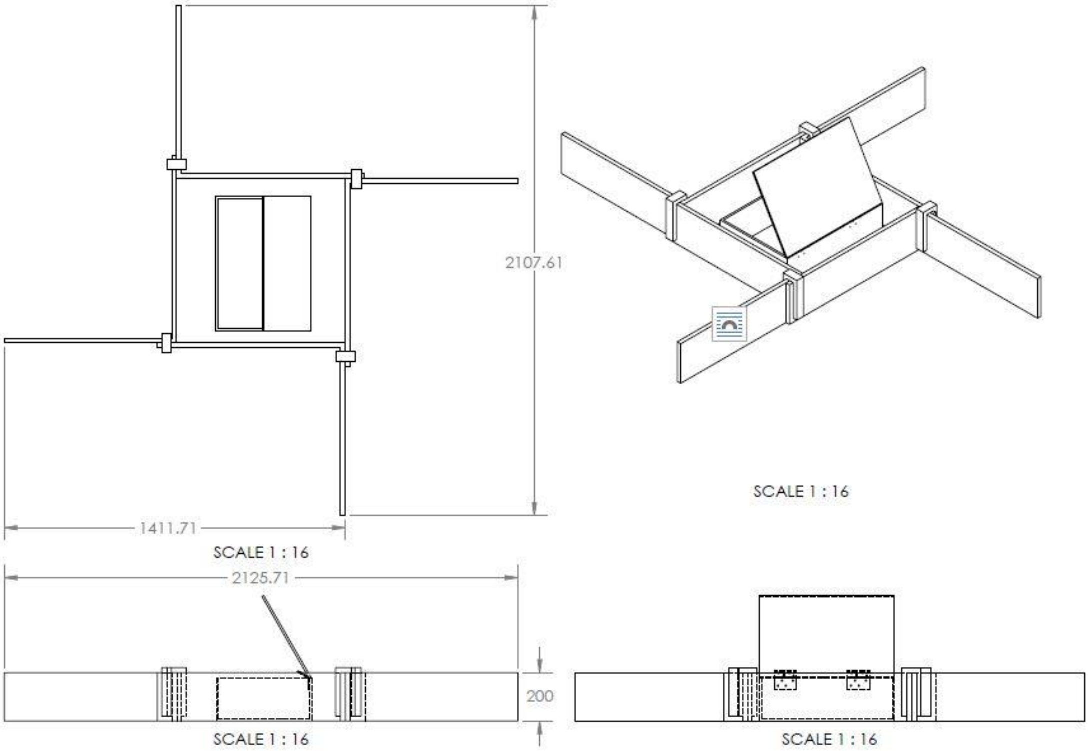

Figure 2: Overall design of the outer layer tank wall with the dimensions (mm).

Two known limitations were imposed when experimenting; as such, it would be difficult to overcome those barriers. The weather that frequently changes within a two-day experimental test would produce slight temperature differences when comparing the recorded data. The weather could not be controlled as it acts as a noise factor. The gaps unoccupied with the materials being selected and placed between the tank's internal and external walls would lead to a slight heat loss. The gaps created are due to the size of materials that were smaller than the overall length of timber. Thus, hollow spaces exposed to the surrounding air would further influence the gradual drop in water temperature. The control of the material thickness is challenging. However, materials like fine sand and plasticines would experience another level of difficulty. Thus, the need to adjust an equal thickness on all sides of a tank was seen to be too complicated as these given materials are not in the form of a compact solid like bricks and others.

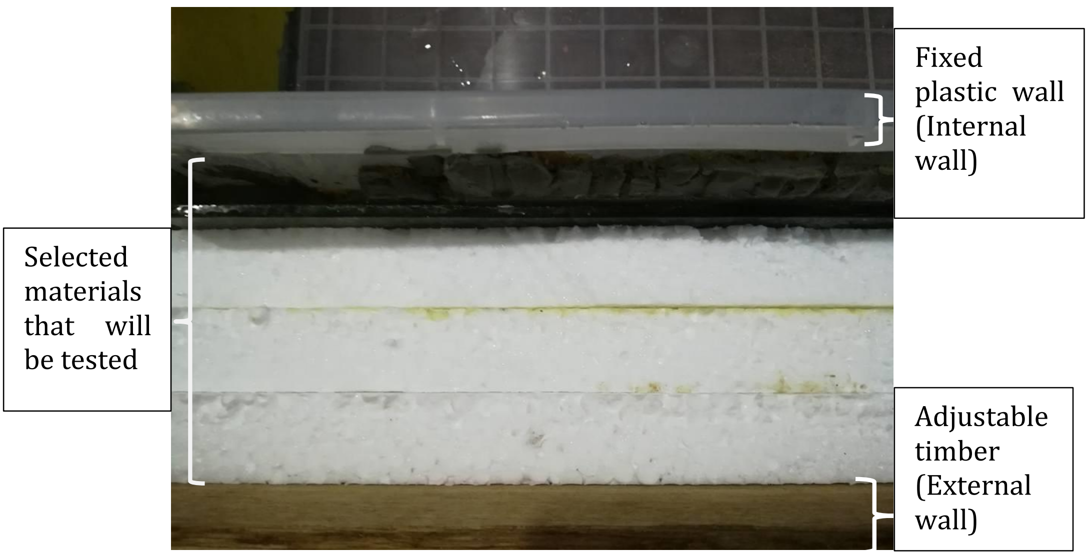

Figure 3: Chosen materials were placed between the internal and external walls.

3. RESULTS AND DISCUSSION

This section identifies and discusses several factors and responses based on the inputs taken. The factors would include thickness, surface area, and type of materials that could be related to several responses. Four different sides of a thermal storage tank are accounted for the given surface area when collecting and analyzing the experimental data. The location and labeling on all four thermal storage tank sides are depicted in Figure 4. Besides, heat loss, thermal resistivity, drop in the percentage of heat, changes in temperature over two days, and scale ratio are among the responses. The overall best material combinations that can be fabricated onto a thermal storage tank will be discussed and proposed in the last section. Therefore, it would conclude the main objectives for this given project.

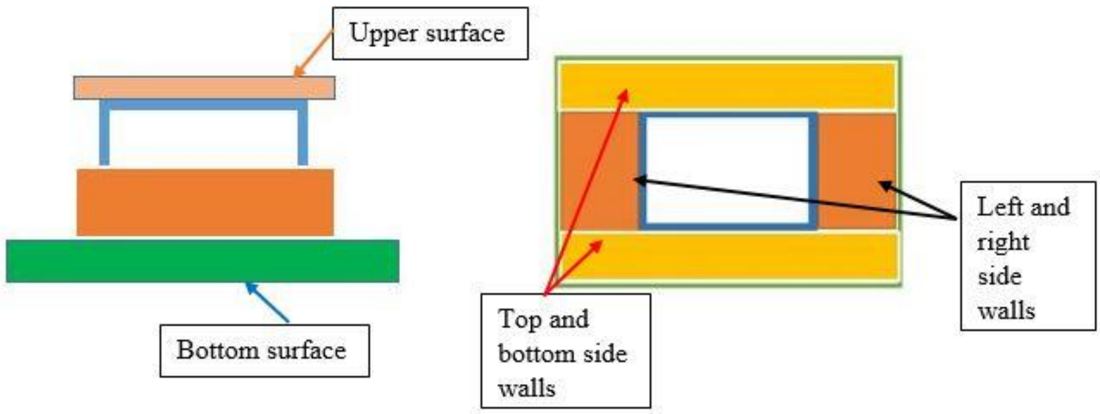

Figure 4: The described location for each surface area labeled for every chart result.

Based on the bar graph extracted from the experimental data, the overall thickness range on the left and right sides and the top and bottom walls for all selected materials varied from 0.086 m to 0.13 m (Figure 5). Thus, by combining the materials that obtain the highest thickness value, the efficiency in insulating the warm water for a time is ever more significant. The combination of plastic, plasticine, white bricks, and timber have been considered the thickest among every other assembled material. In this case, the walls have a similar thickness, making them equally insulated on all sides when water that is heated at a specific temperature has been filled and must be maintained for a certain amount of time. It is beneficial when combining layers of material that possibly provide the most considerable possible thickness, as it would improve the thermal insulation process. Nonetheless, there is also a downside for its size whereby the cost of fabricating that amount of thickness would be higher than the other.

However, the small thickness would be a combination of plastic, plasticine, aluminum foil, styrofoam, and timber. The sides on the left and right, as well as the top and bottom wall thicknesses measured at 0.086 m and 0.096 m, respectively, were considered to be the most minimalistic thickness range in this experiment when assembling several layers of material upon one another. According to the previous study [6], the average thickness for constructing a domestic hot water tank is 0.05 m. Therefore, the pros and cons were the opposite of a much thicker size range in this case. The construction cost would be slightly cheaper, but with the price of having its insulation system working less effectively than the others. However, the combination of plastic, plasticine, styrofoam, and timber was considered to have an average or a medium-range thickness insulated layer. It is determined by initially adding both the minimum and maximum thickness size and eventually dividing it by 2. Thus, the thickness values that were based on its sides were closer to the average value that has been calculated, as explained above. Overall, these given assembled materials have achieved an optimum thickness range size. This is because it solved the cons on both assembled materials cases that resulted in a maximum or minimum thickness range.

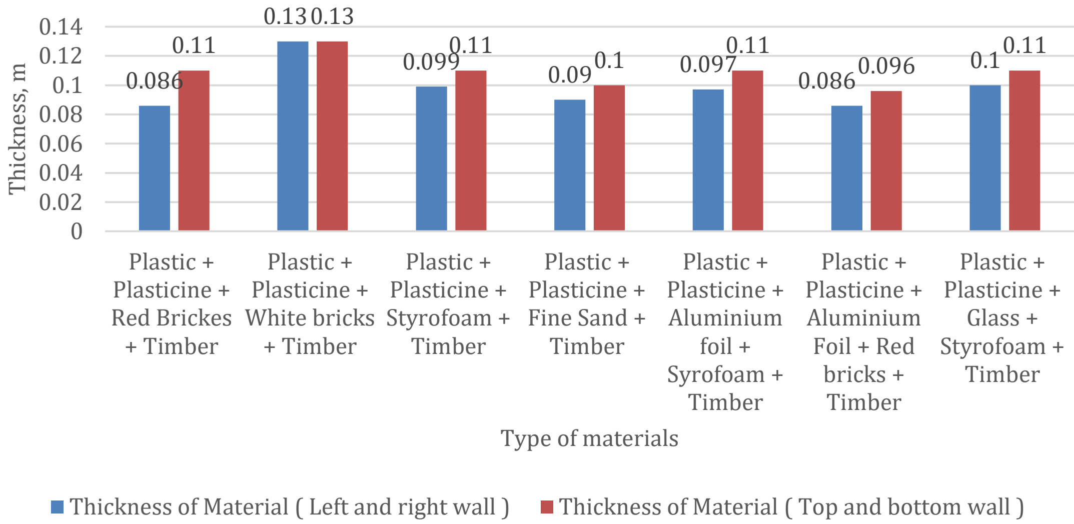

Figure 5: Thickness of both specified walls for each case that combined materials.

The tabulated bar graph in Figure 6 has accounted for the heat loss that occurred on all selected materials that were likewise being tested; thus, its results are recorded. The heat loss value ranges from the least at 0.13 W to the highest at 1.90 W. The highest heat loss can be seen when combining plastic, plasticine, aluminum foil, red bricks, and timber. This massive leap in heat loss could be due to the combination of ceramic materials like white and red bricks. The situation described above could be proven when comparing other experimental cases that use ceramics as the main driving force for controlling the thermal insulation process. The main reason would be that the permeable material moisturizes the environment, making it less efficient in trapping the heat needed to keep the warm water at an optimum temperature. Thus, it results in heat loss that was seen to have exceeded 1W. Other experimental cases, including the combination of plastic, plasticine, fine sand, and timber, have similar reasons for their high heat loss.

Materials that have achieved minor heat loss would be a combination of plastic, plasticine, styrofoam, and timber. Unlike ceramics, styrofoam was constructed with a rigid insulated foam-like structure that could resist the moisturized surrounding. Thus, using styrofoam, which occupies most of the combined materials spaces in any experimental case, has caused the heat loss on both sides to reach below 20 W. The thickness on the upper roof and bottom surface have identical thicknesses measured at 0.026 m and 0.02 m, respectively (Figure 7). For each experimental case that has been conducted, the type of materials that were situated on either side of a roof has been similar all the time. Thus, the materials assembled upon the roofs include plywood and plastic. When comparing the upper roof and bottom surface with a specified wall, the thickness has been considered shallow.

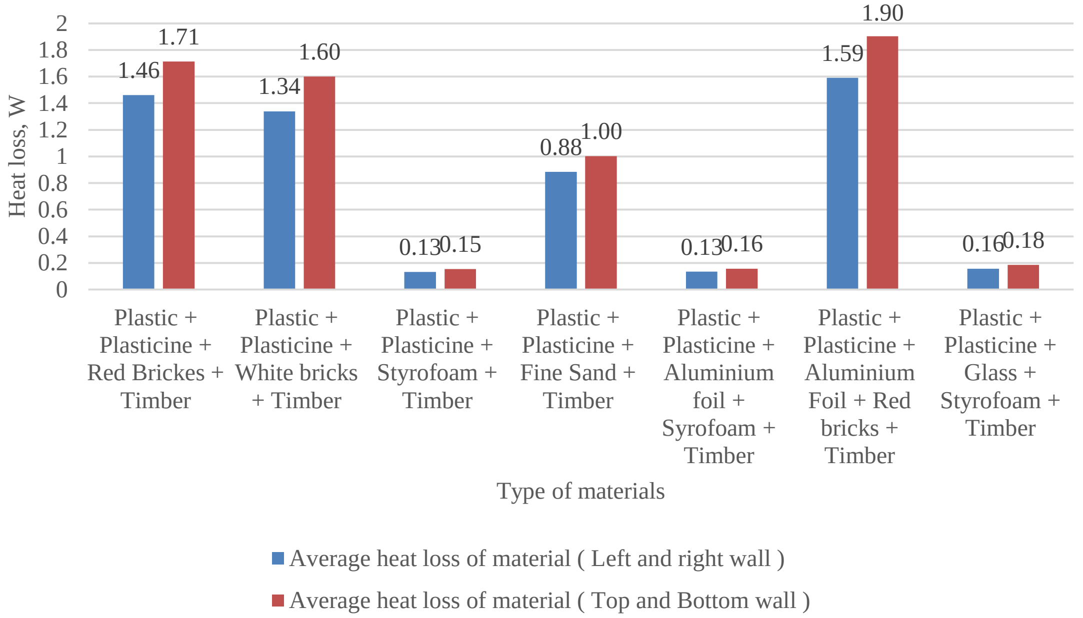

Figure 6: Average heat loss against the type of materials.

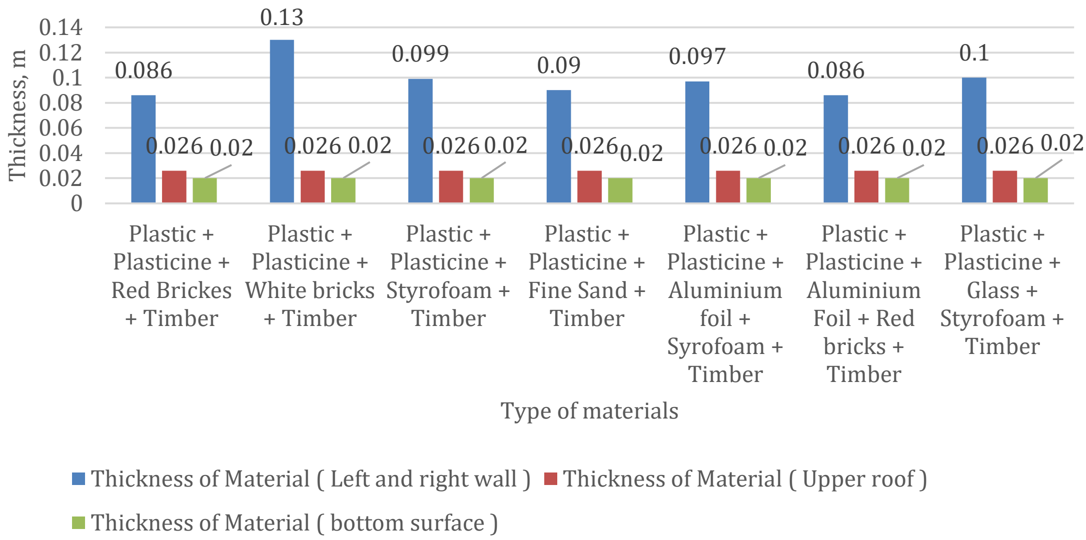

Figure 7: Thickness of the upper roof, the bottom surface, and the specified wall for each case that combined materials

The presence of heat capable of transferring onto different roof spots is seen to lose quickly when combining plastic, plasticine, fine sand, and timber. The heat loss is significant for both roof sections compared to the specified side walls. The discovery has pointed out the use of sand for this given experiment. Sand is composed of tiny particles formed from massive rocks that have otherwise been weathered or processed to produce much smaller fragments and, finally, sand particles. As a result, developed grains would create microscopic porous spaces that block a certain amount of heat from flowing out of the solid material [15]. This barrier within porous gaps was created by air, which consists of low thermal conductivity properties (0.024 W/mK). Figure 8 compares sand particles in contact with one another and separated by a gap in the air. Thus by combining the fact that styrofoam has low thermal conductivity, heat loss would be distributed at a much equal level compared to fine sands. The presents of heat loss could never be prevented for any material, including the use of styrofoam. However, its properties explained above could somehow reduce the unequal heat distribution towards the walls and roofs.

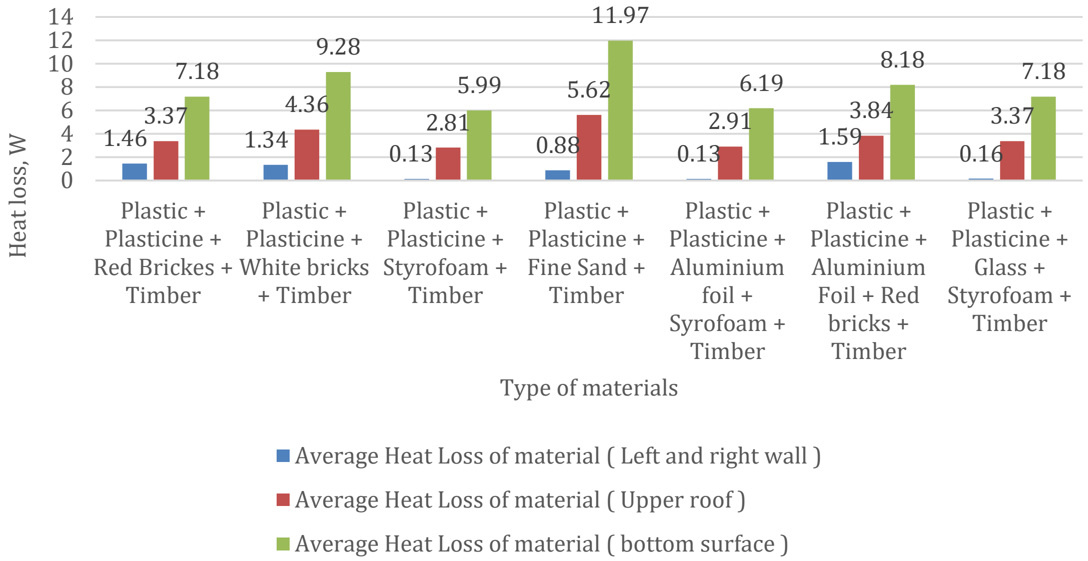

Figure 8: Heat loss on the upper roof, bottom surface, and specified wall for each case that combined materials.

Figure 9 compares thickness on the top and bottom surfaces and other surfaces. The comparison in thickness with both roof locations and a specified side wall was similar to the previous explanation in Figure 5. The wall thickness described for the top and bottom sections has been far greater than the specified roofs, which are equally similar in each experimental case.

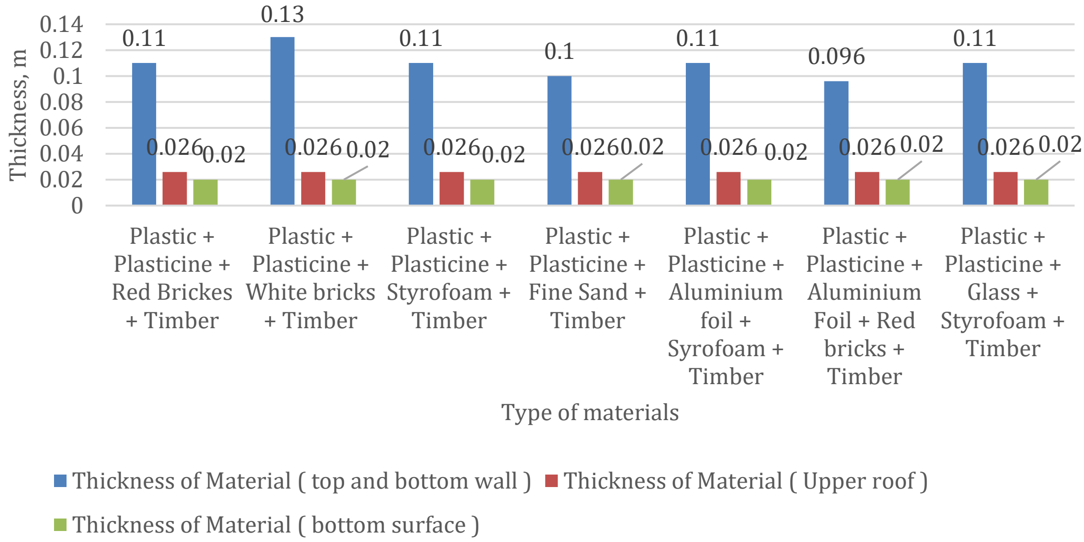

Figure 9: Thickness on the upper roof, bottom surface, and specified wall for each case that combined materials.

In Figure 10, thermal resistivity values were closely similar in several cases. Table 2 summarizes the highest thermal resistance to identify specific similarities for the given cases. According to Table 2, there is a simple explanation that could be concluded for each case that has been described. Likewise, the similarity in values on both specified wall sides for cases 1, 2, and 3 have highlighted the continuous usage of styrofoam that occupies a more significant portion of the space when combining several other insulating materials. Thus, it comes down to the thermal conductivity of both bricks, which were much higher than materials like glass and styrofoam. This downfall would result from its weakness in resisting the thermal losses during which an optimum warm water temperature has been filled into a plastic box.

Table 2: Thermal resistivity of the wall surfaces.

Case	Combination materials	Thermal resistivity, °C/W (left and right wall)	Thermal resistivity, °C/W (top and bottom wall)
1	Plastic, plasticine, Styrofoam and Timber	28.58	24.35
2	Plastic, plasticine, aluminum foil, styrofoam, and timber	29.0	24.65
3	Plastic, plasticine, glass, styrofoam, and timber	28.59	24.36

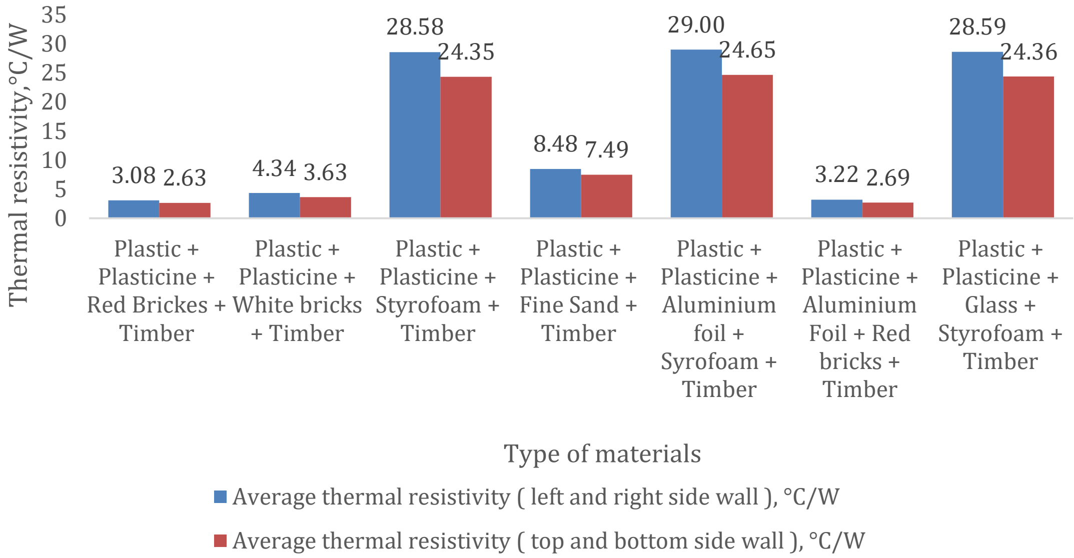

Figure 10: Thermal resistivity against the type of materials.

4. CONCLUSION

The heat transfer analysis of the different insulation materials for the reserve water tank was successfully conducted. Various insulation materials such as plywood, white bricks, red bricks, plasticine, aluminum foil, styrofoam, fine sand, and glass were considered in the experiments. These materials were used to insulate the outer surface of the reserve water tank, and those influences on heat loss were studied. The amount of heat lost due to the conduction process within a reserve tank has been carefully analyzed and explained to the discoveries made over time. It has been confirmed that conduction has been the leading cause of heat dissipating from hot water as the heat source. The experiment revealed that the combination of plastic, plasticine, and styrofoam prevents the heat lost from the hot water. However, other materials are unsuitable to be used as an insulation layer due to low thermal resistivity. The presence of plastic, plasticine, and styrofoam yields higher thermal resistivity for the insulation layer ranging from 28.6 - 29 °C/W. Overall, the best material choice that could be used for thermal insulation would be a combination of plastic, plasticines, styrofoam, and timber. Therefore, these materials could be considered when determining the insulation of any reserve hot water tank. Besides, this project is expected to provide references in determining the most effective method for maintaining the thermal energy stored in water within the reserved tank. It has provided an alternative and affordable solution that could rival the previous research works made for other materials or methods instead.

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