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Investigating the Thermal Efficiency of Thermo-foils as a Roof Insulation Material and Developing a New Roof Insulation Material Using Coir Fiber

A. D. Maduranga, H.H. Sumathipala, N.W.K. Jayatissa

Department of Physics, University of Kelaniya, Kelaniya.

ABSTRACT

The thermo-foil is an insulation material which can be used to insulate roofs of residential buildings which causes less energy to accomplish a comfortable temperature inside the building. In this study, an investigation of the efficiency of the thermo-foils in building insulation is performed. The thermal insulation properties and structure of the thermo-foil were analyzed as well as how these properties affect the decrease of temperature inside the residential building. The thermo-foils were tested using miniature building models for a more general conclusion. A heat transfer mechanism for a residential building is also proposed.

A new roof insulation material is designed using an efficient and low cost natural fiber, coconut fiber or coir. The insulation properties unique to the coir fiber are enhanced as an insulation material. The new foil which is called Coir-Foil is tested together with thermo-foil. The Coir-Foil could achieve considerable higher performance than the currently available thermo-foil. The performance analysis for new coir foil and existing thermo-foils was used to conclude how they affect the energy conservation of residential buildings, through reducing the cooling load.

1. INTRODUCTION

Advancing to the modern world from the primitive eras, the human lifestyle has been changed and enormously developed. This growth towards the luxurious life was apparent in agriculture, manufacturing, production, and transportation etc. Henceforth, a rapid increment of energy consumption was apparent and caused “environment loading” [1], the influence on the environment by human beings by means of emission of pollutants, use of resources, threats to the ecosystems and land use changes [1]. The comfort of environment is affected by greenhouse gasses, responsible for global warming; hence the room temperature increases causing discomfort for the building occupants.

Thermal insulation is a method to reduce the heat transfer of the building. An insulated house is more comfortable as the temperature remains consistent over weather changes such as rising daytime temperature [2]. Thermal insulation of exposed roofs is a very effective method for a country like Sri Lanka as throughout the year the solar radiation incidences along the equator and roof is the main surface which absorbs and conducts into the building. Employing an insulation material, the heat transfer can be controlled to attain a comfortable environment inside the building.

Thermo-foils which are widely used in roof insulation can be identified by different names such as heat foils, Aluminium foils, roofing foils etc. Generally, a thermo-foil is a polyurethane or polyethylene foam layer of various thicknesses (3 -12 millimeters) with a reflecting thin Aluminum layer. Thermo-foil is inserted under the roofing material, with the Aluminium layer facing upward, having an air gap between the roof and the foil.

Whenever a temperature difference exists, there exists a tendency to transfer heat. The amount of heat transferred is a function of the temperature difference and of the resistance in the heat-transfer path. When the solar radiation incidences on the roof, the roofing material absorbs (considerably small portion is reflected back though) the energy as heat and then transfers in to the building. When the thermo-foil is inserted in between the roofing material and the building, it is apparently working as a barrier to the heat transmission.

2. EXPERIMENTAL PROCEDURE

2.1. Preparation of Coir-Foil

In this research work, one of the main objectives was to make a new kind of roof insulating material using a natural fiber and to test its performance. After several aspects on other available materials, coconut fiber was chosen as the testing natural fiber for continuing the research. The coconut fiber, extracted from the coconut husk after they are retted in a pit for several weeks/months, is found useful in a variety of industries. Most of those industries are based on bristle fiber which is the primary and most expensive product. Mixed fiber is separated as the secondary product in which coir fiber can be found in different thicknesses along with some impurities.

Table 1: Properties of Mixed Fiber (Source: Coconut Research Institute - Lunuwila)

Parameter	Value
Average Diameter	0.22 ($x10^{-3}$m)
Fineness	31.84 (g/km)
Tensile Strength	123.5 (N/mm^2)
Breaking load	4.5 (g)
Impurities	6.5 (%)

This mixed fiber was used to make a fiber matt and the polyethylene layer of the thermo-foil was replaced with it. The new foil with Aluminimum layer and the coconut fiber matt will be called *Coir-Foil* from this point forward. A sample of a known weight was taken from the separated mixed fiber (Figure 1.A). Then that was layered on the clean floor having a thickness of 2-3 inches. The layer was prepared such that it has a approximately equal thickness and covering an area of 15 (3 **x** 5) square meters (Figure 1.B). One litre of rubber field latex (a composition of rubber latex and several other chemicals that catalyze the vulcanizing process) was poured through a filter into the sprayer and the air compressor was turned on(Figure 1.C). The rubber composition was sprayed on the fiber layer evenly and the layer was dried under sun. The same process was performed on the other side of the layer. The fiber mesh was then placed inside the heated press(Figure 1.E). The temerature controller of the press was adjusted to 100 °C and using the hydraulic jack, pressure was applied on the layer unitl the layer was pressed to have a thickness about 0.5 centimeters and, kept under the heat for about 10 minutes for the proper vulcanization(Figure 1.H). Then the layer was removed out of the heated press and the edges were cut off. A thin Aluminimum layer (similar to the Aluminimum layer in the commercially available thermo-foil) was placed on the top of the coir mesh and the new Coir-Foil was completed (Figure 1.K).

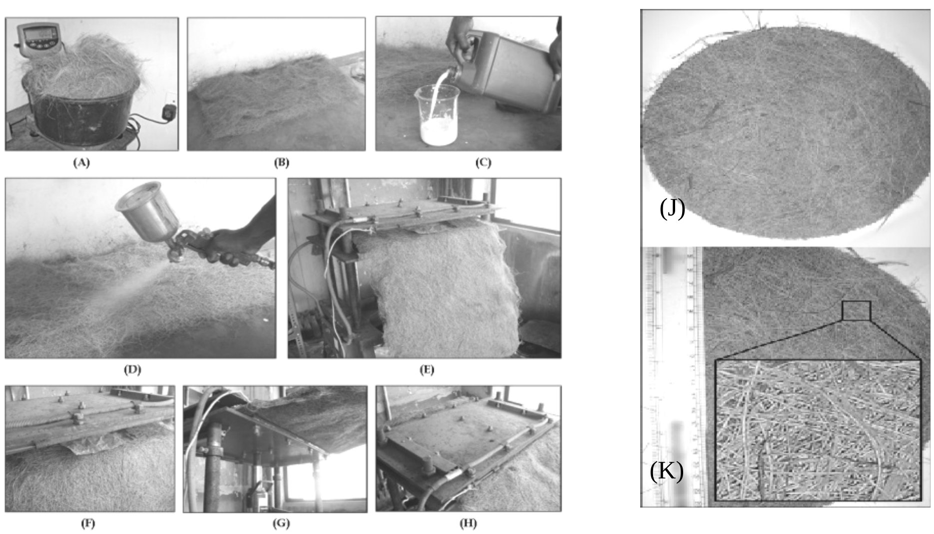


Figure 1 (A-H): Making the coconut fiber matt (Coir-Foil), **(J):** Completed Coir-Foil, **(K)** Enlarged view of the completed Coir-Foil

2.2. Reflection Measurement

The apparatus was setup as shown in the Figure 2. The light source, diaphragm and collimator were adjusted to lie in a straight line to give a parallel beam spot on the material. Then the light sensor was connected to the Lab Pro interface, the lux range switch was set to 600 lux point. The mirror plate was inserted into the material holder and it was angled to the incident beam such that the incident angle was 50 degrees and a good distribution of the reflection intensity was obtained within the range of light sensor. The Lab Pro interface was connected to the computer using USB port and Logger Pro 3.2, data collection and manipulation software, was loaded. Data collection was started and the reflection intensity of the glass plate was detected and noted down for the detector angle from 30 to 130 degrees. The same procedure was repeated for the other samples also.

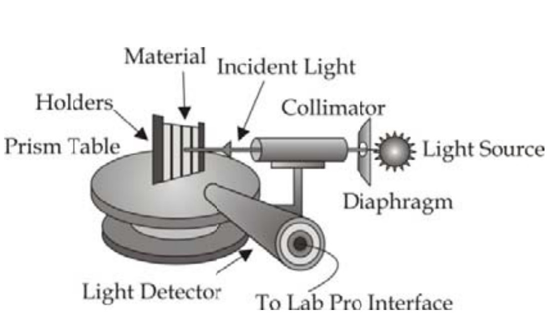


Figure 3 *:* Experimental setup for reflectance measurement

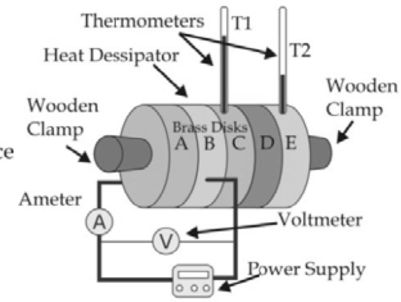


Figure 2*:* Experimental setup for heat resistance measurement

2.3.Heat Resistance Measurement

Apparatus was setup as shown in Figure 3, the block ***B*** (heat generator) was inserted in between brass disks ***A*** and ***C***. The insulation material ***D*** was prepared to have the same cross sectional area equal to the brass disks and inserted in between block ***C*** and ***E***. The thermo-foil was clamped to the apparatus such that it has a good thermal contact with the disks and without a deformation to its shape and dimensions. Thermometers were inserted into the thermometer holes of disk ***C*** and ***E*** and the holes were half filled with mercury liquid for good thermal contact. Voltmeter was connected in parallel and a milli-ameter in series, to the heat generator. The power supply and the stop watch were turned on. The temperatures of T1 and T2 thermometers were measured minute by minute until they get steady values.

2.4. Testing Thermo-foil with Building Models

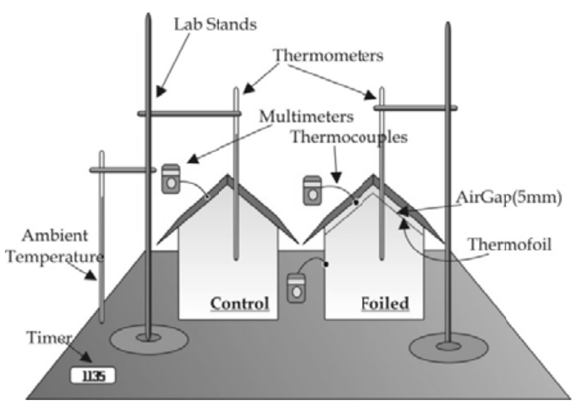


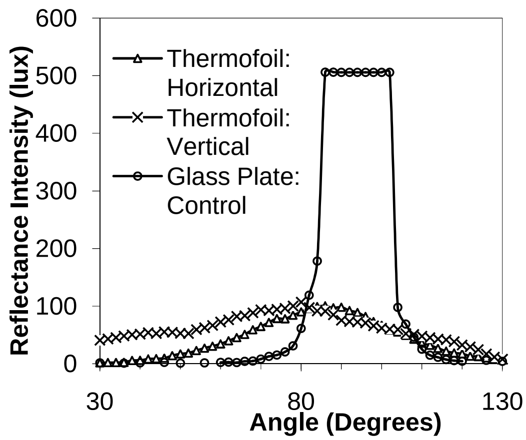
Figure 4*:* Experimental setup for testing the thermo-foils with building models

The two models were placed on the table in the ground as shown in the Figure 4. Two thermometers were inserted into the model through the holes made in the roof and they were leveled to be in the approximate center of the model using the lab stands. The third thermometer was held at the same level as the above thermometers, up on the table surface, using the lab stands. Two thermocouples were placed as in the figure, to measure the temperature near the roof of the control and temperature of the air gap of the foiled model. Another thermometer was used to measure the wall temperature of the foiled model. The ambient temperature, control's thermometer and thermocouple readings and that of the foiled model were noted down with the time. The above procedure was repeated for each 5 minutes for about two hours. Above steps were repeated for the selected insulation materials. The dimensions of the two models were measured and noted down.

3. RESULTS AND DISCUSSION

3.1. Reflection Measurement:

The Aluminimum layer of the thermo-foil/Coir-Foil was subjected to the reflection measurement. The reflection data was recorded for the horizontal and vertical orientations of the corrugated pattern with respect to the prism table of the measuring aparatus and incoming light beam. The procedure was repeated for a sample asbestos ceiling sheet and a mirror plate to infer a proper comparison. The asbestos sheet does not properly reflect the incident beam as the thermo-foil. It demonstrates a flat curve with respect to the thermo-foil.



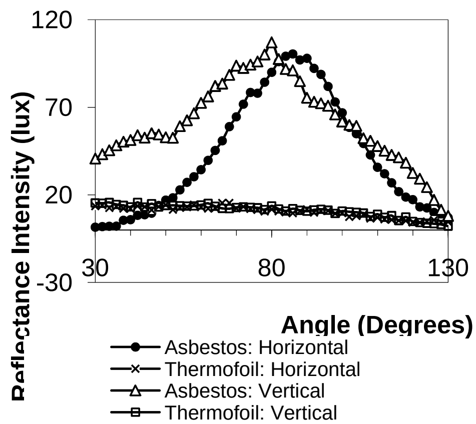


Figure 6: Graph of reflection - intensity vs. angle of rotation for Aluminimum layer (Thermofoil/Coir-Foil) with compared with glass plate.

According to the graphs above, the asbestos sheet seems to be absorbing more radiation and heat than it reflects. In contrast, the thermo-foil/Coir-Foil reflects more heat than it absorbs. The curves of the thermo-foil/Coir-Foil smoothly obey the Gaussian distribution. The cumulative intensity that the asbestos sheet reflects is 2153 lux and is about 20% of the reflection of the mirror plate. The Cumulative sum of the reflection of the thermo-foil is 10449 lux and is about 98% of the mirror plate (10680 lux).

3.2. Heat Resistant Measurement:

The efficiency of the polyethylene foam layer can be defined in terms of its ability to resist the heat transfer through it. The polyethylene layer is a porous medium with irregular inner structure. The tiny bubbles inside the material are filled with air, disturbing the proper heat transfer by means of conduction. Therefore the heat transfer through this layer will occur by both conduction and convection and a large measuring process with assumptions should be taken place to estimate the effective thermal conductivity [05]. As specified by the manufacture (whose products which were used in the experiment), the thermal conductivity of the thermo-foil was 0.0384 $Wm^{-1}K^{-1}$. Three thermo-foil samples with three different thicknesses were tested for their thermal resistances.

The Coir-Fiber matt too has a porous and irregular inner structure. The coconut fiber has got a very low thermal conductivity 0.05 $Wm^{-1}K^{-1}$ as a raw material. The layers of coir fiber one on another, occupies air gaps inside them which work as a barrier to the transfer of heat similar to the polyethylene foam layer described above. The Coir-Fiber matt was then subjected to the same test as polyethylene foam layer.

The samples were clamped to the apparatus such that they had a good thermal contact with the disks and without a deformation to its shape and dimensions. At the steady state of the heat flow through the samples, the thermometer readings were noted down. Temperature difference of thermometers was analyzed for 3 commercially available thermo-foils and the Coir-Foil.

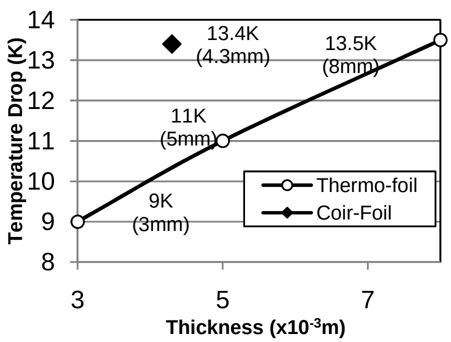


Figure 7: Temperature drop vs. thickness of the thermo-foil (Coir-Foil's temperature drop is also

The temperature drop through thermo-foil increases with the thickness. The temperature drop that can be attained by the thicker foils will be higher. The Coir-Foil attains a temperature drop of 13 K which is fairly near to the 8mm thick thermo-foil at a thickness of 4.3 millimeters. This is illustrated in the Figure 7.

3.3.Testing Thermo-foil and Coir-Foil with Building Models:

The ability of the thermo-foil to minimize the heat transfer into the building is tested as a whole using some miniature building models, each model having the same dimensions, appearance and properties. The roof of a model, made of asbestos ceiling sheets, was insulated with a thermo-foil/Coir-Foil having an air gap between the roof and it about 5 millimeters and the shiny Aluminum layer facing the roof. Another similar model was taken as the control experiment without installing the thermo-foil/Coir-Foil.

The two models were placed in a lawn such that the shadows do not interfere while the experiment was being done. The models were placed on a wooden surface about 1 meter above the ground, so as to keep the surrounding environment of the models similar. The ambient temperature, thermometer and thermocouple readings of the control model and that of the foiled model were noted down with the passing time. This was repeated for the thermo-foils with different thicknesses which are available in the market.

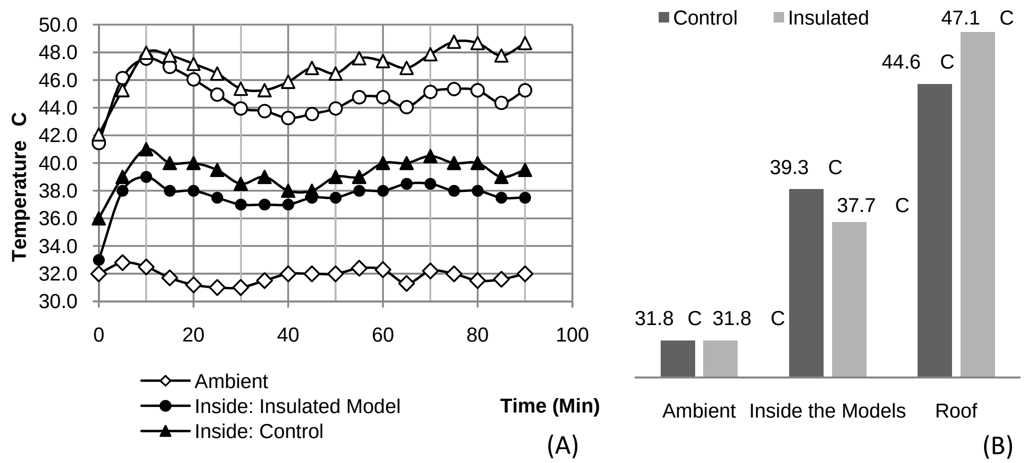


Figure 8: (A) The temperature variation with time (B) Average values of the temperature (Insulated with 3 mm thermo-foil)

According to the readings, temperature at the roof of the control model holds a lower value compared to that in the air gap provided in between the roof and the foil of the insulated model. This is because the heat circulates in the air gap provided, as the thermo-foil resists the heat to transfer through it. The average values of temperature variation inside the two building models can be compared together as follows (Figure 8.A). When the average of the temperatures were considered after 35 minutes where the variation shows some stability and an equilibrium, the temperature drop inside the building when the roof is insulated by 3 millimeter thermo-foil is 1.6 °C (Figure 8.B). The temperature difference between the inner side of the roof of the control and the air gap of the insulated model is 2.6 °C. The thermo-foil with a thickness of 8 millimeters was tested using the same experimental procedure as above. The temperature variation was plotted (Figure 9.A). The pattern of the temperature curve shows consistency with the temperature variation of Figure 8.A. The temperature inside the insulated model doesn't show a rapid variation with the temperature inside the control model instead it illustrates a stable temperature variation with the control.

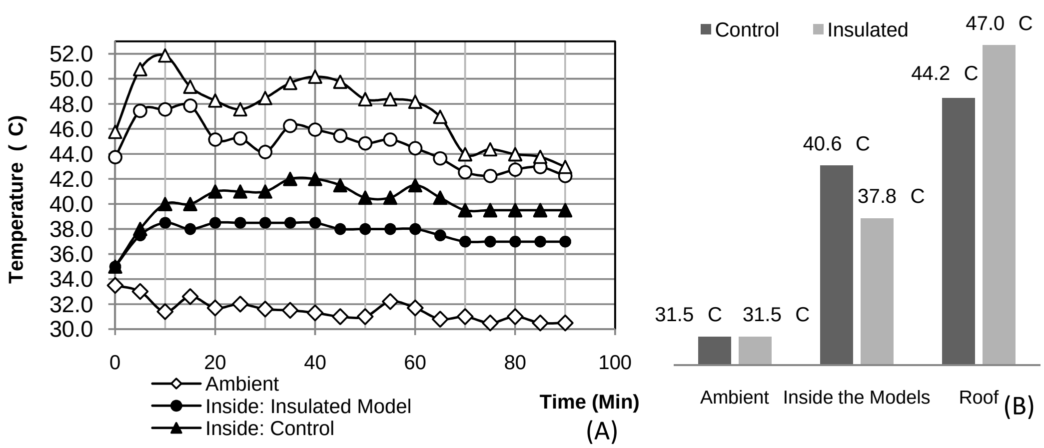


Figure 9: (A) The temperature variation with time (B) Average values of the temperature (Insulated with 8 mm thermo-foil)

The average temperature drop inside the building when the roof is insulated by 8 millimeter thermo-foil is 2.8 °C (Figure 9.B). The temperature difference between the inner side of the roof of the control and the air gap of the insulated model is 2.8 °C.

The Coir-Foil was used as the insulating material of the building model replacing the thermo-foil and the same experiment was repeated under the similar physical conditions. The temperature readings were plotted as shown in the Figure 10.A. The temperature readings show a slight variation at the beginning but inside the insulated model, the temperature variation obeys a smooth and stable curve without rapid temperature variation.

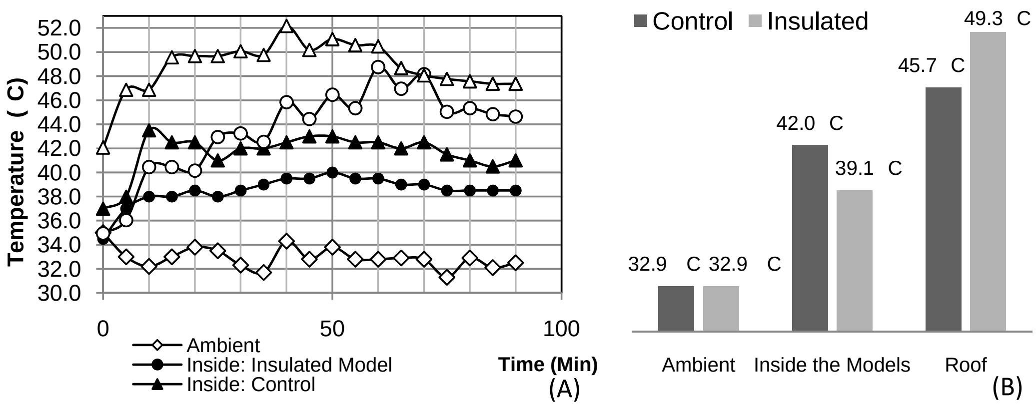


Figure 10: (A) The temperature variation with time (B) Average values of the temperature (Insulated with Coir-Foil)

The average temperatures were calculated from the 35 minutes onwards when the temperatures show a stable variation. The average temperature drop inside the insulated model compared to that of the control model, for that portion of data, is 2.9 degrees in Celsius while the temperature difference between the inner side of the roof of the control and the air gap of the insulated model is 3.6 °C. The cumulative results for the three building models can be compared together as follows.

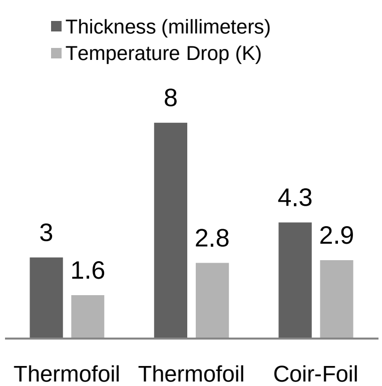


Figure 11: Cumulative Performance of thermo-foil and Coir-Foil

Table 2: *Temperature drop due to two different thicknesses of the thermo-foil*

Thickness ($x10^{-3}m$)		Average Temperature Drop (°C)	Variation (σ^2)	Standard Deviation (σ)
A	3	1.6	0.217	0.465
	8	2.8	0.193	0.440
B	4.3	2.9	0.174	0.417

According to the Figure 11, the thermo-foil which is 3 mm thick cause a temperature drop of 1.6 °C inside the building model. 8 mm thick thermo-foil causes a temperature drop of 2.8 °C. The thicker thermo-foils hence have provided a larger temperature drop inside the building model. Compared to the thermo-foils, the Coir-Foils perform better in insulating the building interior from the heat transfer through the roof. The Coir-Foil having a thickness of 4.3 millimeters attains a temperature drop of 2.9 degrees of Celsius which is a significant value at a considerably low thickness, compared to the 8 mm thermo-foil. These temperature drops may depend on the size of the building model. More over for the thermo-foil, the drop is not linearly proportional to the thickness. The same results are tabulated below for further analysis.

3.4.Proposed heat transfer mechanism:

The radiation energy incoming from the sun is absorbed by the asbestos sheet (roof) and it emits the heat energy as radiation back to the atmosphere and building interior when the insulation material is not installed (control). Therefore the temperature inside the building arises. But when the insulation material is applied, that radiation is blocked by the Aluminium layer and is reflected back scattering it, so that the roof is heated. The convection currents deliver that heat into the air gap between the roofing sheet and the foil. The oscillation of this radiation and convection heat increases the temperature of the air gap to a considerable high value compared to the same point at the control model.

The heat absorbed by the foil after all is transferred through the polyethylene foam layer/coir matt of the thermo-foil/Coir-Foil. The porous irregular inner structure of these materials resists the proper transfer of heat through the foil. Radiation from the surface of the insulation material and convection by the large air inside the building cause the temperature to rise. Heat losses to the atmosphere keep the system in equilibrium.

Today the most of the urban industrial buildings have air-conditioned environment. In that case, a roof properly insulated with developed Coir-Foil will give a temperature drop of several degrees inside the building which can be considered as a considerable saving of energy by the reducing workload of the air-conditioning machines. Moreover, domestic buildings can also be insulated using Coir-Foil to drop the interior temperature by several degrees than usual. This effect is significant to the buildings which use Galvanized roofing sheets and Asbestos related roofing materials. This is because such materials absorbs and radiates back the heat incoming as solar radiation at higher ratios. Therefore, compared to the environmental temperature, that of the building interior is higher and hence is uncomfortable. The developed Coir-Foil as a roofing product will be able to provide a feasible solution for this and it may be a properly suits a tropical country like Sri Lanka.

4. CONCLUSION

There are two major characteristics that the thermo-foil has which minimizes the heat transfer into the residential building. High reflective Aluminium layer works as a barrier to the radiant heat and reflects back most of the radiant heat and heat resistive polyethylene layer which has a very low thermal conductivity value ($0.383Wm^{-1}K^{-1}$

according to the manufacturer) minimizes the heat absorbed by the Aluminium layer being transferred into the building.

Using the thermal insulation properties of coconut fiber, a new effective thermo-foil can be made. The new thermo-foil design (Coir-Foil) consists of a high reflective Aluminium layer to reflect back the radiant heat and a layer of coconut fiber matt which minimizes the absorbed heat to transfer into the building. A Coir-Foil which has a thickness of 4.30 millimeters performs better than the 8mm thick commercially available thermo-foil.

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