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ORIGINAL ARTICLE

Possible Usage of Jute Fibre as Sustainable Thermal Insulation Material for Building Construction

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ABSTRACT - Natural fibres can be used in different applications of the building industry and one of the important applications is building insulation. The low value of thermal conductivity and its natural character provide opportunities to consider the jute material for thermal insulation in the building industry. Different blends comprised with natural jute are also an option to get the standard parameters as required. This paper has discussed the possibility of using jute felt as building insulating material. The purpose of this study is to identify the deviation of raw jute's insulation properties by comparing with standard insulation material and introducing the ways that jute could be used for this function, to promote the usage of total eco-friendly insulation material. A simple test result has been provided with this and content accompanies other researched information as well. Insulation test procedures have been discussed, and practically measured values are provided along with the necessary calculations. It is observed that the measured R value of Jute material, 2.386 is within the range of the typical R values for common building insulations. Despite the slightly lower R value than commonly used insulation materials like fiberglass, it is possible to achieve an optimized R-value for Jute felt by using various blends of natural Jute.

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INTRODUCTION

Insulation is an important part of any building construction in North America and many other countries throughout the world [1]. Not only does it retain heat during the winter by restricting airflow, but it also reduces the cost of heating and cooling throughout the year [2; 3]. The resistance value, also referred to as the R-value of a thermal insulator measures its heat flow resistance and crucial in the building industry for evaluating and comparing the thermal performance of different insulation materials, whereby higher R-values mean better insulation [4]. R- value is widely used to identify products in a commercial setting while purchasing insulation [5].

Fibreglass is one of the most common insulation materials in the building and construction industry. For more than a century, most new homes were built with fibreglass insulation. Made mostly from recycled glass, it is used in both commercial and residential buildings. By efficiently weaving fine strands of glass into an insulation material, fibreglass is proficient at reducing heat transfer. Fibreglass is a superb and affordable non-flammable insulation material, with R-values ranging from R-2.9 to R-3.8 per inch [6]. However, it does have many disadvantages. It is potentially harmful to humans and its effectiveness depends heavily on the climatic condition. For example, if there is a significant difference between the outside temperature and the inside temperate, fibreglass insulation is less effective at keeping the heat inside.

Spray foam insulation has been used primarily for home renovations as a way of sealing and insulating in one step. When installed properly, spray foam can help make a house airtight (when first applied); it works as a vapour barrier and it adds a significant level of insulation to a home, further reducing the

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energy needed for heating and cooling. Global Warming Potential (GWP), is a measure of how much heat-trapping potential a substance has, compared to carbon. A GWP of 1430 means that a given unit of a substance is much worse than carbon as a heat-trapping gas when released into the atmosphere. The new HFO (hydro-fluoro olefin) blowing agents that are used recently in spray foam to reduce harmful effect have a GWP of 1. That means that insulating 1,430 houses now with spray foam will do the same atmospheric harm as was done by 1 house in the past. Another biggest problem with spray foam from a sustainability point of view is that it is undeniably made of toxic chemicals, some of which will pollute the indoor air long after owners take occupancy of a home. Furthermore, once it is applied to a substrate, it is extremely difficult to remove it. If it is tried to reclaim wood or other materials that have been coated with spray foam, it can create toxic dust in the process which can be very dangerous to those carrying out such work. Aside from just the health risks, the cost of spray-foamed materials is relatively high and thus it is not a practical and effective solution for eco-friendly home insulation.

Despite the modern trend for sustainable and eco-friendly building constructions, heavy usage of synthetic insulation material is still in common practice [7]. These synthetic materials are formed based on hydrocarbons and are not eco-friendly at all. Due to the volatile quality of those synthetic materials, unhealthy particles are released to the environment. Again, at the time of recycling, those emit poisonous gases into the atmosphere. The most common synthetic foam, namely, Polyurethane foams are fire-resistant and make an effective insulation material. These foams contain non-chlorofluorocarbon (non-CFC) gas, helping to minimize the risks to the ozone layer. These foams have an R-value of R-6.3 per inch. Polystyrene, another synthetic material, is a transparent, waterproof thermoplastic insulation material. Unlike most insulators, polystyrene has a distinctively smooth surface. This insulation product can be cut into blocks, making it an excellent alternative for insulating walls. Because polystyrene is flammable, it will need to be coated with a fireproofing chemical. These more expensive options have an R-value of R-5.5.

With the fast-growing housing and building construction industry in Canada, the natural material applications for insulations will support the fully eco-friendly concept. Constructed from recycled paper products, cellulose is one of the top eco-friendly insulation materials in the industry today [8]. Among insulating materials, cellulose fibre insulation has the lowest embodied energy per kilogramme [9]. This insulator contains almost no oxygen, making it a champion at lowering potential fire damage. Cellulose's R-values range from R-3.1 to R-3.7. Mineral wool can be broken down into two insulation material categories; rock wool, made from basalt, and slag wool, manufactured out of slag from steel mills. Mineral wool is non-flammable and doesn't require additives to make it fire-resistant. This environmentally friendly insulation material has an R-value ranging from R-2.8 to R-3.5.

The compressed sheep wool fibres form millions of tiny air pockets, and the outer layer is resistant to water while the inner layer absorbs moisture. This helps it generate heat while preventing condensation, and thus it can keep the home warm in the winter and cool in the summer. Eco-friendly insulation helps in reducing pollutants in a home, it protects the environment, a Canadian survey has shown that 86% of people in Canada would choose an energy-efficient eco-friendly home and in that sense, it increases the value of the home and due to the radiant heat exchange, it makes a more comfortable atmosphere [10].

This work is focused on analyzing the potential application of 'jute felt' material as an alternative for synthetic building insulation material. Jute is one of the oldest cultivated fibre crops and 'jute sacks' are used in many applications as thermal insulating material [11]. Apart from these, it is the cheapest fibre crop available commercially in bulk quantities as of today. This fibre is a mesh-like structure that provides good coverage, good tensile strength, provides toughness and durability, less elongation at break, ensures dimensional stability, and natural colour. Apart from these properties, 'jute felt' materials have also properties like thermal, sound, and electrical insulation, out of which thermal insulation area is more popular [11; 12]. The thermal insulation-related properties mainly depend on the availability of the number of air pores in the textile structure. The static air trapped in fabric pores makes the fabrics act as thermal insulating media [12; 13].

Jute fiber has emerged as a promising sustainable material for thermal insulation applications. Studies have shown that chemically treated jute fiber quilts exhibit lower thermal conductivity compared to cotton and polyester alternatives [14]. Jute-based nonwoven fabrics, including blends with recycled polyester, demonstrate favorable insulation properties due to their low mass density and cellular structure [15]. Layered Jute felts have been developed as eco-friendly insulators, with thermal insulation values comparable to synthetic materials like glass wool and polystyrene [16]. The study focused on structural parameters of jute fibers such as pore size, bulk density and gas pocket in fibrous structures for correlation with thermal insulation property. Hence, the thermal performance of Jute is attributed to its inherent lumen structure, polymer chain anisotropy, and the presence of tiny gas pockets within the felt structure. Additionally, hybrid composites combining Jute with other natural fibers, such as coir and polyurethane foam binders, have shown promising thermal resistance properties, offering environmentally friendly solutions for automotive applications [17].

This paper provides practically measured values, test arrangements, technical calculation methods/standards, and supportive well-recognized scientific literature to prove the feasibility of Jute, as a natural insulation material. Resistance (R) value is considered the main attribute of jute fiber in this study concerning its building insulation purpose.

EVALUATION OF THERMAL INSULATION

Important measures for an insulation

The effectiveness of a material in thermal insulation is significantly influenced by its thermal conductivity, which refers to the ability of a given material to conduct/transfer heat. It is generally denoted by the symbol k but can also be denoted by lambda, λ and kappa, κ and is affected by the material's density, porosity, moisture content and mean temperature difference [18]. The lower the thermal conductivity of a material, the slower the rate at which temperature differences transmit through it; hence it is more effective as an insulator.

The R-value of insulation is a value that is used to measure how well a specific type of insulation can resist heat flow. The higher the R-value, the more effective the material is at preventing heat transfer. R-value is short for Resistance value and is closely related to the metric unit of RSI. Different insulating materials each have their unique R-value per unit length. R-values enable the comparison of the thermal performance of different materials. The thicker the material the more it resists heat transfer, so values are listed per inch (and then multiplying the value by the thickness of the insulation gives the R-value).

Calculating the R-Value of the material is a major factor here and it provides an idea about the comparison of two materials regarding thermal performance. The apparatus for that is well described by Schumacher et al. [19]. The requirement of thermal conductivity & specific heat considerable characteristics of a thermal insulation material and being the thermal resistant has been discussed by Fazli [20]. Investigations of in-situ thermal properties are essential for comparison purposes. The related code standards are described by Ahmad et al. [21]. ASTM C177 [22] explains many other options of calibration procedures and explanation of necessary formulas, besides providing the procedures to follow if the tests are going to be followed on a regular basis like in a laboratory. The research by Oushabi et al. [23] provides a complete test scenario which was done to determine the potential ability of using Date Palm waste as thermal insulation material. The research paper provides a closer set of steps that can be followed by other similar types of material, such as the Jute material in this current study.

The overall or effective thermal conductivity of fabric can be calculated by Fourier's law of conduction, where Q is the heat flow, A is the surface area, ΔX is the thickness of fabric and ΔT is the temperature difference:

$$k = \frac{Q.\Delta X}{A.\Delta T} \qquad \text{Eq. (1)}$$

The insulation property of the fabric is measured by thermal resistance. The thermal resistance (R-value) of fabric is defined as the ratio of temperature difference to the rate of heat flow per unit area. The thermal resistance of fabric can be expressed by electrical analogy according to Ohm's Law, where Q is the heat flow, A is the surface area, ΔT is the temperature difference:

$$R = \frac{\Delta T}{Q/A} \quad (\mathrm{m^2.K/W}) \qquad \text{Eq. (2)}$$

Thermal resistance can also be calculated by the effective thermal conductivity of fabric:

$$R = \frac{\Delta X}{k} \quad (\mathrm{m^2.K/W}) \qquad \text{Eq. (3)}$$

Test method using steady-state heat flux through the specimen

Various methods are used for measuring the thermal-insulating values of fabric materials. Generally, three different methods have been used in the determination of the thermal insulation of fabrics [24; 25]. The first is the cooling method in which a hot body is surrounded by a fabric whose outer surface is exposed to the air, and the rate of cooling of the body is determined. Second is disc method, where the fabric is held between two metal plates at different temperatures, and the rate of flow of heat is measured, and third is constant temperature method, where the fabric is wrapped around a hot body and the energy required to maintain the body at a constant temperature is found. Among these methods, the constant temperature method may be considered as the best for obtaining thermal insulation of fabrics and it gives the most accurate results [26]. The main advantage of this method lies in the fact that the measurement of heat is replaced by those of electrical energy and can, therefore, be used more easily and more accurately.

In general, the heat transport properties can be divided into two groups [5]: steady-state thermal properties such as thermal conductivity and resistance which provide the information on the warmth of a fabric; and transient-state thermal properties such as thermal absorptivity which provides the information of warm-cool feeling when fabric handled first. In practice the measurement of the rate of heat flow in particular direction is difficult as a heater, even when supplied with a known amount of power, dissipates its heat in all directions. Most success full heat transport measuring instruments are: Togmeter [27], Guarded hot plate [28; 29] and Alambeta instrument [30]. However, the accuracy of various methodologies used to evaluate thermal conductivity and other related thermal characteristics is a subject of extensive dispute across several areas, since it is considered a fundamental property. Due to the diverse thermal characteristics of insulating materials, there is no universal measuring technique for all thermal conductivity tests [31].

In this research, an in-house experimental setup was developed to measure the thermal conductivity of fabric by using the constant temperature method. The setup was based on the guarded hot plate and Jute felt was wrapped around the heating source. Guarded hot plate is standardized in United State (US) through ASTM C 177. The method and standard were employed by Charca et al. [32] to study thermal properties of natural fibers. However, the guarded hot plate method requires specimen of flat plate with dimensions as specified in the standard. Meanwhile, a cylindrical arrangement was adopted in this study. Research by Morris [33] proved that conventional guarded hot plate method and cylindrical specimen apparatus measure thermal conductivity with a high correlation, hence validating the latter as an effective method of thermal conductivity measurement. Figure 1 shows the dimensions and test arrangement of the Jute felt.

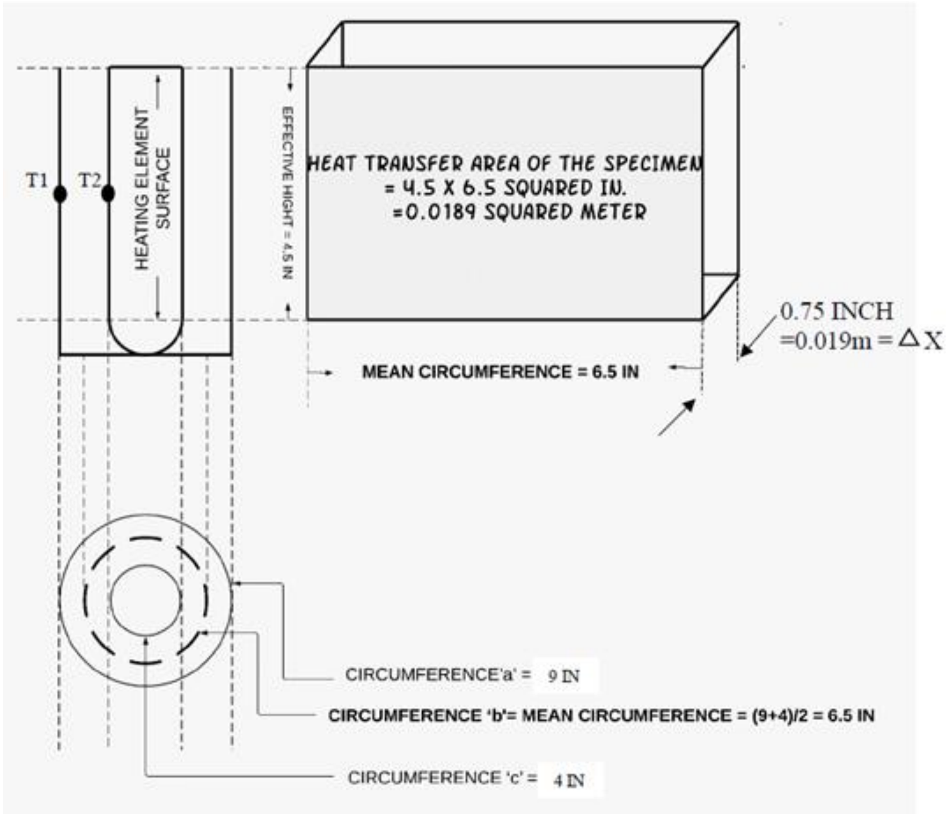

Figure 1. Test Arrangement Diagram

Possible attempts have been taken In this experiment study to comply with the ASTM C 177 by maintaining the steady-state heat flux through the specimen (i) and arranging the hot plate end and cold wall (room temperature) end at the opposite sides of the specimen (ii) and with the cylindrical arrangement used as illustrated, it eliminates the need of "guarded" setting as per ASTM C 177, since no ends are provided there, for any heat loss (iii). Instead, all the heat does transfer through the specimen. Moreover, due to the cylindrical arrangement, there is only one surface (Figure1), that transmits heat outwards, so that only one specimen has been used [31].

A specimen sample of natural Jute felt was used in this study to test for R value, whereby, first the thermal conductivity was tested, and the R value was calculated based on the experimental thermal conductivity value. Two thermo couples have been used with its digital reader to get accurate temperature readings. A cylindrical arrangement as shown in Figure 1 and Figure 2, was used to pack jute fiber to control any heat loss for the surrounding. With this arrangement all the heat generated by the element passes through the material. In that way, it helps with the accuracy of the calculations. The heat output corresponds to the electrical power supplied to the heating. The maximum wattage of the heat source was 75W and it was selected 1/30 of it (2.5W) to leave the temperature below the auto-ignition temperature of the Jute material.

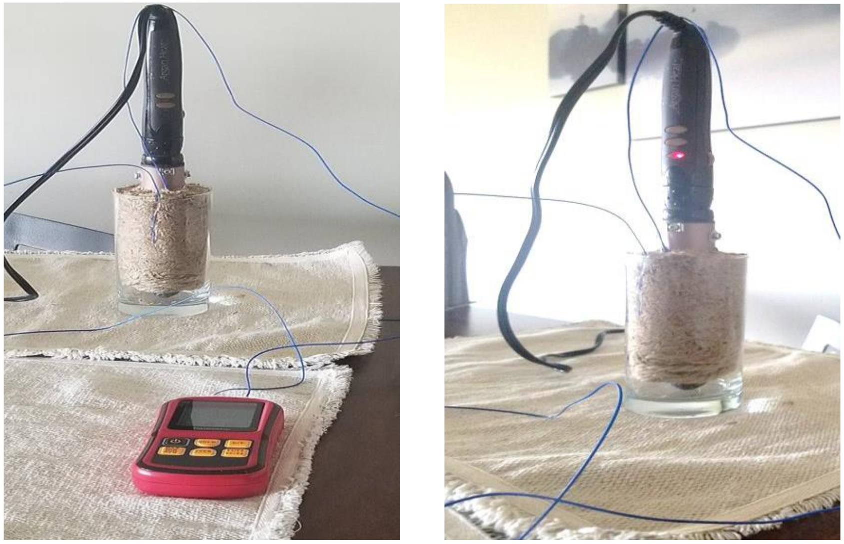

Figure 2. Testing of Jute felt

TEST RESULTS AND DISCUSSIONS

Table 1 shows the average result of the three tests conducted in the laboratory. In each test, a constant heat flow from source of 2.5W (Figure 2) has been used to dynamic heat flow stability through the Jute material. The temperature at location 1 and 2 (see Figure 1) were measured and recorded using the digital meter.

Table 1. Test results

Heat Applied	**Temperature (°C)**	
2.5 W	T1	T2
	50.6	92

Based on the test results, the thermal conductivity (k) and resistance of the Jute felt (R value) are calculated from Equation 1 and Equation 3, respectively as below:

$$k = \frac{Q.\Delta X}{A.\Delta T} = \frac{2.5\ W\ X 0.019\ m}{0.0189 X\ (92 - 50.6)} = 0.0607$$

$$R\ value = \frac{\Delta X}{k} = \frac{0.019}{0.0607} = 0.312\ (\mathrm{m^2.K/W})$$

It shows that the observed R value is for the thickness of 0.75 inch. For 1 inch thickness jute felt the RSI value is 0.312/0.75=0.42 (m^2.K/W) which is equivalent to 2.385 per inch. It is observed that the measured R value is within the range of the typical R values for common building insulations. Although the R value is slightly less than the commonly used insulation materials such as fiberglass, it is possible to obtain an optimized R-value of Jute felt by utilizing different blends of natural Jute. Furthermore, using suitable natural treatment or coating, it is also possible to obtain a satisfactory fire rating for this natural and eco-friendly insulation. In terms of economy, Jute felt is widely available in Asian countries and it is relatively cheaper as compared to other building insulations. Hence, Jute felt has a great potential as an insulation material in building construction.

CONCLUSION

In this paper, the possible usage of natural Jute felt as an insulation building material has been investigated. A simple test has been conducted to identify the R-value of Jute felt. It is concluded from the study that the Jute material has an R-value of 2.385 per inch. The R-value of Jute material is slightly lower than that of fiberglass, deviating from the lower limit of fiberglass's R value by 0.515. This study shows that the observed R-value stays among the typical R-value range of the most commonly used building insulation material. Based on this result, it can be concluded that there is a huge potential for using natural eco-friendly Jute felt material as insulation material for buildings. Further experiments are needed to optimize the R-value using various blends and natural treatments of this natural fiber.

RECOMMENDATIONS

While this experimental study has provided a positive outcome for the starting hypothesis, it is highly recommended to conduct a validation test from a well-equipped laboratory facility for optimal findings. Next, additional tests such as fluid dynamics, wave theory, and acoustical dynamics need to be conducted in a standard laboratory facility. Jute has a high capacity to absorb and retain significant amounts of water without it being easily detectable. It is highly recommended to thoroughly dry the jute before conducting testing in order to get more accurate findings. It is also advisable to consider the mean temperature value of a multi-point sensing arrangement. Further investigations may also include considering bi-component fiber.

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