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Prospect of Adopting Kapok Fibre as Roof Insulation

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Abstract. Interest on building insulation has started to develop among the research community in recent years. Kapok fibres have the potential to become a roof insulation material because of its low thermal conductivity. This paper reviews studies on kapok fibre as insulation material. It is revealed that there were no reported findings on the application of kapok fibre as roof insulation.Thorough study is highly recommended in this area since kapok fibre has good thermal and acoustic properties.

Introduction

Building occupants desire indoor thermal comfort for optimum productivity and contentment. Under hot climates, heat from direct sunlight flows into buildings through the roof and heats up the living space. As a result, indoor temperatures increase and occupants experience thermal discomfort. Consequently, occupants respond to the thermal discomfort by turning on fans or air-conditioners (AC). However, prolonged use of fans and AC leads to increased electricity consumption, which negatively affects the building owners economically and the whole country environmentally.

The roof is heavily exposed to direct sunlight throughout hot days. Therefore, improving the thermal performance of roofs is a vital strategy that should be adopted to make buildings energy-efficient. Roof insulation can block the flow of heat from direct sunlight into buildings through the roof structures. As a result, use of fans or AC to achieve thermal comfort is significantly reduced, leading to economic benefits for building owners and significant environmental benefits for the whole country if implemented at a large scale. Despite the benefits, factors such as lack of awareness and preparedness to make the initial investment to install roof insulation hinder its implementation [1, 2]. Figure 1 shows roofs that are exposed to direct sunlight.

Figures 1. Roofs that are exposed to direct sunlight, taken from [3]

Interest on building insulation has started to develop among the research community in recent years. However, the majority of research in this area focused on buildings under cold climates. Furthermore, research on wall insulation is more popular than roof insulation due to the location of the research institutes involved [1]. Wall insulation discussed in previous researches consists of installation of insulation materials in the wall structure and enhancement of the wall structure itself such as the adoption of new materials that reduces the thermal conductivity of cement paste used for the wall construction [4]. On the other hand, there are some researches carried out to develop new materials that can be adopted as roof insulation that consist of materials with high reflectivity [5] and low thermal conductivity. Interest in roof insulation is present in the research community and further developments in this area can produce significant benefits to many parties economically and environmentally.

Kapok Fibre

Kapok fibres have the potential to become a roof insulation material because of its low thermal conductivity. The kapok tree or also known as *Ceibapentandra (L.)*Gaertn. (Malvales: Malvaceae) can be found mostly in Southeast Asia, East Asia and Africa. Fruits obtained from kapok trees(Figure 2) are extracted to produce kapok fibres[6, 7]. Kapok fibres can be obtained directly from kapok trees since it is anatural cellulosic fibre [8]. Kapok trees can live up to 60 years. It becomes productive after four to five years and the yields will continue to grow within eight years. A kapok tree can produce 330 to 400 fruits per year [9]. Each fruit contains 200 seeds and each tree produces 1000 to 2000 pods yearly[10]. It has beenreported that kapok fibres consist of a hollow structure with a thin fibre wall with a diameter of 16.5 ± 2.4 μm, a large lumen with a diameter of 14.5 ± 2.4 μm and a structure that is cylindrical and non-twisted[11-13]. Even though it is made of unicellular fibres similar to cotton, its density is seven (7) times less than cotton [14].In addition, kapok fibres (Figure 3) are hydrophobic, resilient to fungi and bacterial attacks, and the texture is very soft owing to the presence of cuticle wax [12]. Due to its buoyancy, it has been used as a survival material such as safety jacket. Hollow structure of kapok fibre makes it the best insulation material among other natural fibres and competitive to synthetic fibres like polyester. Apart from that, the seeds are beneficial for human and livestock as a foodstuff[15]. Other properties of kapok fibre are shown in Table 1. Although it has many advantages, it is inflammable[12]. Currently, kapok fibres are mainly used in pillows, mattresses, quilts, soft toys, upholstery and thermal and acoustic insulation owing to its low density and insulation properties [16-19]. However, there is a lack of research on kapok fibre as insulation material. This paper reviews studies on kapok fibre as insulation material.

Table 1. Physical properties of Kapok fibre

Property	Kapok
Bulk density [8]	0.29 g/cm^3
Thermal conductivity [12]	0.03-0.04 W/mK
External wall diameter [13]	16.5 ± 2.4 μm
Internal wall diameter [13]	14.5 ± 2.4μm
Thickness of cell wall [20]	0.5 - 2.0 μm
Average length [20]	20.0 mm
Porosity [27]	84-99%
Specific surface area [28]	0.23 m^2/g
Hollowness [28]	73.08%

Figures 2. Kapok plant, taken from [21]

Figures 3. Kapok fibre, taken from [22]

Literature Search

All articles on kapok fibre published from 2009 to 2013 were retrieved from Scopus. Scopus is used because it is the largest online database of conference papers and peer-reviewed journals[23]. Articles in languages other than English are not included. "Kapok fibre"was used as the keyword. Documents other than articles such as reviews, letters, editorials and notes were excluded. The papers were categorized into five (5) groups according to different research areas, which are insulation, oil absorption, biodiesel, characterization and others. Articles grouped under the insulation research area were utilized in this review.

Review of Previous Research

Five (5) articles were found that reported findings on the application of kapok fibre as insulation. It is revealed that there were no reported findings on the application of kapok fibre as roof insulation. Research gaps are highlighted in Table 2.

Cui and Wang (2009) [8]studied the heat transfer through kapok to be used as an insulation material in fabric to minimize heat loss from the human body. Effect of different temperatures at different wind speeds onthe heat transfer through kapok was analysed and compared with cotton. The researcher designed a theoretical heat flow model that combines heat flow by conduction, convection and radiation and used an artificial climate chamber for testing. Experimental results were in line with the theoretical model. Findings also reveal that wind speed does not affect the transient heat loss from the human body because it takes time to penetrate into the fibrous insulation material. In addition, kapok has smaller transient maximum heat flow than cotton. This research proved that kapok can minimize heat losses from the human body better than cotton because it has better heat balance flow.

Yeoup Chung *et al.* (2009) [24] removed the combustible compounds of kapok to convert it into a flame-resistant fibre that can be used for insulation.Hydrophobic compounds were removed from kapok fibre through the exposure to gamma radiation and cleaved the methoxyl group in order to transform it into flame-resistant fibre.The researcher discovered no morphological change after radiation but the methoxyl group in lignin polymer like p-coumaryl alcohol, sinapyl alcohol and coniferyl alcohol was cleaved by irradiation.The chemical composition in kapok fibre was reduced remarkably with decreases of nitrobenzene oxidation products. Therefore, gamma ray treatment is an alternative method to convert kapok into a flame-resistant fibre.

Song and Yu (2011) [25] compared the heat transfer within kapok and other fibre assemblies, which are wool, cashmere, polyester and goose down to assess their potential as insulation materials.Radiative heat properties of assembled fibre and low bulk densities were characterized using Fourier transform infrared (FTIR) spectroscopy. Results showed that bulk density influenced the radiation heat transfer into the fibre assemblies. The radiative thermal conductivity of the fibres decreased as the bulk density was increased. Random was found to be the most suitable arrangement of fibre assemblies as it prevents radiative heat transfer more effectively compared to random ball and parallel arranged fibre assemblies. The increasing of temperature will increase the radiative heat conductivity, which shows that radiative heat conductivity is proportional to the cubic temperature. Experimental radiative heat conductivity result was compared to the theoretical model and some modifications have been done to the existing theoretical model in order to enhance it.

In 2013,Dieng*et al.*[26] conducted an experiment on kapok as thermal insulation material to analyse its heat retention. Results showed that there is an evolution of thermal impedanceas a function of heat capacity. The significant of pulse excitation and depth in the material was visualized in the evolution curves of temperature versus convective heat transfer coefficient. The optimum thermal insulation capacity depends on convective heat transfer coefficient and external pulse excitation.

The potential of kapok fibre as a sound insulating material was investigated by Xiang *et al.* (2013) [27].Based on the results analysed using impedance tube, kapok fibre showed an excellent acoustical performance. Bulk density, thickness and the orientation of assembled kapok fibre gave significant impact to sound absorption coefficient except for fibre length. Same thickness of kapok fibre assemblies with less bulk density were compared with other commercial sound insulating materials, which are glass wool and degreasing cotton fibre, and ended with the same sound absorption coefficient. Hollow structure of kapok fibre gives an advantage to its performance and the experimental acoustical damping performance agrees with the theoretical model. It is proven that kapok fibre can be a good candidate in the future as sound insulating material.

Table 2.Research gap

Reference	**Heat Transfer**	**Flame-resistant**	**Heat Retention**	**Acoustic**	*Roof*
Cui and Wang (2009) [8]	✓				
Yeoup Chung *et al.* (2009) [24]		✓			
Song and Yu (2011) [25]	✓				
Dieng*et al.*(2013) [26]			✓		
Xiang *et al.* (2013) [27]				✓	

Conclusion

It has been found that there is a lack of study done on kapok fibre as an insulation material. Moreover, the review also revealed that there is no research that explores the adoption of kapok fibre as a roof insulation material. Thorough study is highly recommended in this area since kapok fibre has good thermal and acoustic properties. Its application as an insulation material may be extended to the building industry especially in countries that produce kapok fibre.

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