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REVIEW OF THE EFFECT OF MOISTURE CONTENT ON THE THERMAL CONDUCTIVITY OF NATURAL FIBER INSULATING MATERIALS

ABSTRACT

The demand for thermal insulators from natural materials, energy efficiency and sustainable power strategies has been rising significantly in recent decades. The thermal performance of a building depends on the thermal characteristics of its envelope, which is mainly determined by its thermal conductivity. However, the λ-values can be greatly affected by the presence of moisture which is determined by relative humidity in the surroundings. This paper presents the effect of moisture content factor on the thermal conductivity coefficient of some common natural fibrous insulation materials used in building construction such as sheep's wool, hemp, jute, and flax, etc. Natural fibers-based construction materials are the most promising for buildings due to various benefits such as environmental protection, low embodied energy, and low health impact compared with conventional insulation, which is made from foam polystyrene or inorganic materials. Because the thermal performance of insulation materials derived from natural fibers changes due to its sensitivity to moisture percentage, it is essential to know the relationship between thermal conductivity and moisture levels.

Keywords: thermal conductivity, moisture content, natural fiber insulation materials

1. Introduction

Since the energy consumption of buildings accounts for a considerable part of the global total energy, there is a strong demand to improve the energy efficiency in buildings and constructions. According to Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010, on the energy performance of buildings, new construction will have to consume nearly zero energy and that energy will be to a very large extent from renewable resources [1]. This is because the construction sector has been identified as the largest energy consumer, generating up to 1/3 of global annual greenhouse gas emissions, contributing up to 40% of the global energy, and consuming of 25% of the global water worldwide [2, 3]. The increased consumption of natural resources for lighting, refrigeration, ventilation, recycling, heating and cooling system in commercial buildings due to the acceleration of urbanization, results in the enormous expenditure for used energy. As energy becomes more precious and the global demand is predicted to increase by 55% in the next decade [4], the use of thermal insulation materials is being enforced in buildings and constructions. Therefore, it is necessary to develop new advanced insulation materials, especially from natural and agricultural resources with high thermal resistance values to achieve better energy efficiency and to enhance sustainable energy strategies.

The main objective of this work is to present some common alternative insulation materials based on natural fibers and evaluate the effect of moisture content on their coefficients of thermal conductivity.

2. Natural fibrous insulation materials

A wide range of fibers can be used in the production of insulation materials, both natural fibers (plants, farm wastes, and minerals) or artificial fibers (natural polymers, synthetic polymers, and non-polymers). The most beneficial effect of the insulation based natural fibers is not only its low value of thermal conductivity but also the natural character of these fibers. Another advantage is that it is a renewable material which has no strong impact on the environment and health. When compared with conventional materials such as foam polystyrene or mineral wool, they have sometimes even better thermal performances. Some disadvantages are their high wettability and absorbability due to their open pore structure as well as being flammable. Besides, they are easily attacked by biological fungi and parasites [5]. Nevertheless, they can be used as a potential insulation material in construction they are modified properly by chemical treatment.

3. Thermal conductivity coefficient

The main role of thermal insulation materials in a building envelope is to prevent heat loss and provide thermal comfort for the occupants of a building. The thermal performance of a building envelope depends to a great extent on the thermal effectiveness of the insulation layer which is mainly determined by its thermal conductivity. This is the time rate of steady-state heat flow through a unit area of a homogeneous material in a direction perpendicular to its isothermal planes, induced by a unit temperature difference across the sample [6-8]. A series of practical experiments concluded the thermal conductivity coefficients of conventional materials including mineral wool, and foam polystyrene range from 0.02 to 0.04 W/mK. While the thermal conductivity values of alternative insulation materials made from natural fibers vary from 0.04 to 0.09 W/mK as shown in table 1. According to the DIN 4108, “Thermal insulation and energy economy in buildings”, materials with a λ-value lower 0.1 W/mK may be classed as thermal insulating materials. Most insulating materials with thermal conductivity ranging from 0.03 to 0.05 W/mK can be regarded as good [9, 10].

Table 1

Thermal properties of some natural fibrous insulating materials

Insulation materials	Density (kg/m^3)	Specific heat capacity (kJ/kg.K)	Moisture content (%)	Thermal conductivity (W/m.K)	Water vapour diffusion resistance factor	Sources
Hemp	20 – 68	1.5 – 2.2	6 – 12	0.04 – 0.05	1 – 2	[10-12]
Flax	20 – 80	1.3 – 1.64	8 – 12	0.037 – 0.045	1 – 2	[10-12]
Jute	35 – 100	2.3	12 – 14	0.038 – 0.055	1 – 2	[10-13]
Sheep wool	25 – 30	0.96 – 1.3	15 – 35	0.034 – 0.045	1 – 5	[10, 12]
Coconut	70 – 120	1.3 – 1.6	11 – 13	0.04 – 0.055	1 – 2	[10, 11]
Cork	100 – 220	1.7 – 2.1	4 – 12	0.038 – 0.07	5 – 10	[9, 12, 14]
Bagasse	70 – 120	1.87	6 – 7	0.046 – 0.068	N.A.	[11, 13, 15, 16]
Cotton	20 – 60	0.84 – 1.3	8 – 25	0.04	1 – 2	[10, 11]
Cellulose	30 – 80	1.7 – 2.15	8	0.04 – 0.045	1 – 2	[10, 12]
Rice straw	154 – 168	1.2	6 – 10	0.046 – 0.057	N.A.	[13, 16]
Reeds	120 – 225	1.2	6 – 8	0.045 – 0.056	2 – 5	[10, 16]
Wood	30 – 270	1.6 – 2.1	3 – 14	0.038 – 0.09	5 – 10	[10]
Wood wool	350 – 600	1.6 – 2.1	13 – 15	0.09	2 – 5	[10]

4. Moisture-dependent thermal conductivity

As natural fibers materials are naturally hygroscopic and have a porous structure, they can accumulate moisture by adsorption from the air. The capabilities of penetrating moisture into the internal open pore system at increased relative humidity significantly affect the temperature distribution and thermal conductivity as well. Results from experimental investigation found that higher moisture content of fibrous insulation is always associated with higher λ-value [17].

Tye and Spinney [18] found that thermal conductivity of loose fill cellulose fiber insulation increased by 15% for each 10% increase in moisture absorption. Sandberg described the moisture-dependent thermal conductivity as a linear function [19]. Another study concluded that an increase in 1% of moisture content can lead to an average increase of 1.2 to 1.5% in λ-values and even when its highest moisture content was reached, thermal conductivity continued to increase from 1.6 to 2% [20]. For a variation of moisture content by weight, the thermal conductivity of concrete-based hemp fibers can increase by 25% from a dry state after it reaches 90% relative humidity [21]. The effect of moisture in the thermal conductivity of bio-based concrete made from hemp, flax, and straw was investigated in the range of temperature from 10 to 40^0C [22]. The thermal conductivity increases since moisture content increases and the effect is more important at high temperatures over 40^0C. The relationship of three bio-based natural fiber samples is also presented as a linear function. Practical results collected from the impact of moisture content on the samples made from natural fibers include hemp, shive, and flax showed a significant increase in thermal conductivity as the moisture content increases from the dry state to 80% relative humidity [23].

The dependence of thermal conductivity of sheep wool on moisture content was investigated [24]. Measurements show that the sample contained sorption humidity around 20% under normal conditions of 15-95% relative humidity and their coefficient of thermal conductivity was significantly affected by moisture content which varied from 20 to 70%. A study on the presence of a small percentage of water showed a significant increase in thermal conductivity of the bagasse sample. When 5% moisture by weight was absorbed in an atomized form, the thermal conductivity increase by about 17% over the test density ranges from 45 to 110 kg/m^3 [25]. A very strong correlation between λ-values and water content was found for kenaf fibers in which a 19% of water content increase leads to a 41% increase of thermal conductivity. The relationship between thermal properties and moisture content of bagasse was examined [26]. Result showed that the thermal conductivity ranged from 0.09 to 0.1 W/m.K and increased with increase in moisture content through the range of 8.52%-28.62%.

5. Conclusions

This investigation presents the effect of moisture content on thermal conductivity of some insulation materials made from natural fibers. Natural fibrous insulation materials can be favorably worked very well in commercial buildings in combination with common building materials to achieve more sustainable solutions to solve the problems of the energy consumption and healthy interior environment. When compare to traditional materials, they can bring advantages in thermal comfort and energy efficiency. The thermal conductivity values vary from 0.03 to 0.09 W/mK and thermal performance is affected significantly by the moisture content.

The investigations showed that the moisture effect can lead to a significant increase of thermal conductivity and the relationship is linear at a given temperature and low range of moisture in the steady state. Due to the high absorption of water into the open-cell structure of natural fibrous materials, it is essential to determine the effect of moisture content on the thermal conductivity to predict the aging of insulation made from fibrous materials over the time.

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