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Thermal insulations under concepts of green building in China

Lingqi Chen[1,†],Yufan Wang[2, 3,4,†]

[1]Wuhan Britain-China School, Wuhan, China
[2]Shenzhen Zhengde Senior High School, Shenzhen, China
[3]Corresponding author

[4]15030340242@xs.hnit.edu.cn
†These authors contributed equally

Abstract. In order to protect the environment in present-day society, green buildings are seen as an effective and logical solution. Insulating materials are frequently widely used in green buildings to reduce their energy dissipation. China, as a global power, is at the forefront of ecological development. This paper will focus on the study of thermal insulations in the context of green concepts, a specific analysis of their properties and examples of their application in China. It is found that most of the green developments lack economic support and therefore, insulation materials need to be developed in the direction of low cost and high efficiency and effectively reduce their harmful effects on the environment. Furthermore, the development of insulation materials in China should pay attention to geographical differences, i.e. the insulation materials that can be applied in different regions in the North and South are different. This study will facilitate the application of insulating materials in China's ecological development, reducing related energy losses and protecting the surrounding environment.

Keywords: thermal insulation, green building, energy, material.

1. Introduction

The environmental problems of the planet are becoming increasingly serious in the twenty-first century. The need for sustainable development has prompted governments to increase their commitment to the green development process. For example, the EU adopted the Packaging and Packaging Waste Directive in 2008 to decrease the environmental impact of materials, and the US enacted the Consumer Product Safety Improvement Act of 2008 (CPSIA 2008) to control lead and phthalates in products, thus promoting green development [1]. In the international community of the 21st century, green development refers to reducing carbon emissions, reducing energy and material losses and avoiding environmental damage, with green buildings aiming to ensure economic, social and environmental sustainability [2]. As one of the top five countries in the world in terms of land area, China has seen urbanization in all regions of the country over the past decades, with more and more buildings being erected and urban coverage increasing. The high speed of construction has brought about rapid economic development and an increase in the number of non-compliant buildings in China. Many "tofu-dreg projects" do not comply with engineering regulations and also have a high energy consumption due to the lack of building science. As a world power and a major carbon emitter, China should play a leading role in green development and lead the world in sustainable development. Therefore, in its future development, China should focus on low-carbon green development in all aspects. Among them, thermal insulation materials are effective in promoting the green development process in the construction industry. This study examines green materials in the context of green development, encompassing the nature of different types of insulation materials and the appropriate direction of application development for different insulation materials in China.

This article investigates some typical thermal insulations including aerogel, polystyrene foam and natural fiber insulations in terms of their thermal attributions and environmental impact. Aerogel as an example of nanoporous material has an excellent thermal attribution, which makes it expected to use as a space material. Polystyrene foam also does well in insulating and skills producing it is developed. Natural Insulation fibers are the most eco-friendly for it can be produced from agricultural waste are easy to be recycled [3].

The study also discusses the applications of existing insulation materials in China: PCM windows, silica aerogel windows and polystyrene insulated walls. In the application study, there is also a comparison of the different materials in terms of price, insulation capacity and energy efficiency, with polystyrene being an excellent option [4]. And finally, the comparison of the studies revealed that China's green development faces: lack of capital, imperfect technology and a small market. As a result, China's insulation materials should be developed in the direction of low cost, high efficiency and low pollution, with aerogel being the ideal option [5]. The results of this study will help to promote the prospect of thermal insulation materials in China.

2. Thermal Insulation under concepts of green building

Green building is a kind of building that is environmentally friendly with resources and energy effectively used. Aspects required consideration includes site selection, construction, design, operation, renovation, maintenance. Silica aerogel can provide the thermal insulation, fireproofing, soundproofing, and waterproofing requirements of the construction industry. The significance of green building includes the following two main points: Saving energy loss and protecting the environment. Overall, the green building concept means constructure with the minimum harmful influence on the environment [6]. Furthermore, since the early 1990s, green buildings, it has garnered considerable attention. It is a targeted expression of sustainability in the architectural field and an necessary part of the continuance development of human society. Green building is not only on environmental sustainability but also on questions of economic and social sustainability [2].

Insulating materials can effectively reduce heat loss from a room and thus reduce energy emissions. It is used extensively in green buildings to achieve green building objectives. Thousands of materials could be used for the insulation function. Good thermal insulation has low thermal conductivity, high fire resistance, and good waterproof. When it is concerned to the green building concept, low environmental impact is also a significant attribution.

2.1. Aerogel

Aerogel are a typical example of nano-porous insulation materials, which means the thermal insulations have a bore diameter within nanometers. They are normally extracted from silica gels through supercritical drying. The chemical component of silica aerogels is mainly SiO_2-chains placed in a cross-linked system. Among the chains, there are dense pores with air filling them. Thus, aerogels have excellent attributions in terms of thermal [7]. As Figure 1 shown, aerogel has a quite low thermal conductivity, which is lower than most of the insulations that are now widely used including EPS and XPS.

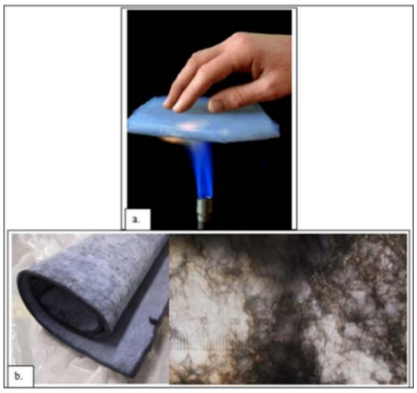

Figure 1. a. Aerogel above an alcohol lamp, b. Aerogel rug (left) and a micrograph of the rug (right) [8].

However, the leakage of aerogel is its mechanic properties: low-temperature resistance, brittleness and low strength, but combining Al_2O_3 or combining Ceramic tile fiber can strengthen aerogel.

2.2. *Polystyrene foam board*

Polystyrene is a petrochemical product. It is a synthetic aromatic polymer derived from ethylene and benzene. Polystyrene is no colour and transparent, which can form good insulation boards by pressed or expanded. When polystyrene is expressed, it can be made as extruded polystyrene foam board. It can also be foamed to shape polystyrene expand board, which is loose with small beads full of it [9]. Expanded polystyrene (EPS) and Extruded polystyrene insulation are the two most widely used insulations. They are produced by different methods. For EPS, it is produced by expanding spherical foam beads and fusing them together at high temperatures and pressure. XPS is produced using a process of extrusion. The attributions of EPS and XPS are shown in Table 1.

Table 1. Performance of several insulations [9-11].

	Thermal Conductivity W/(m·K)	Density (kg/m^3)	Water vapor diffusion resistance factor	Fire Class	EC (kg $CO_2e \cdot kg^{-1}$)
EPS	0.029-0.041	18-50	20-100	E	6.3-7.3
XPS	0.025-0.035	20-80	80-170	E	7.55
Aerogel	0.13-0.021	70-150	2-5.5	A1/C	4.3

EPS and XPS have low thermal conductivities. The water vapor diffusion resistance factor is high, which means it is hard to be affected by water vapor in the atmosphere and so is more durable. However, the Environmental impact of polystyrene foam boards is relatively high and they cannot be degraded, which causes much undegradable waste. It is the same for other plastic insulations including phenolic foam and polyurethane foam.

2.3. *Natural fiber insulations*

As manifested above, thermal attributes of EPS and XPS perform well. However, they are accompanied by heavy environmental impact and the flammability. Possible solutions to this problem may come from natural fibers. Natural fibers show a better prospect and can be used to produce many building materials and they are usually the byproducts and residues of agricultural products which mean there are a lot of resources from local places. Although NFIs are still not used widely, it is worth expecting the development of them.

2.3.1. Thermal attributions

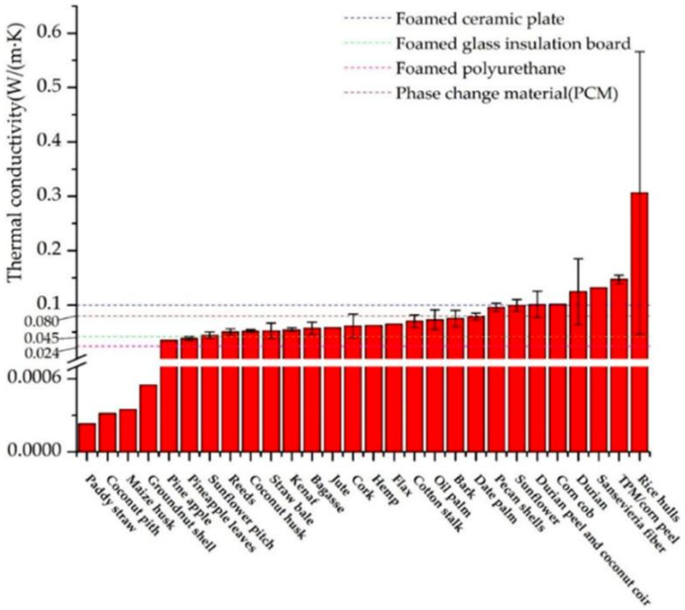

Figure 2. Thermal conductivity of different NFIs [11].

Most thermal insulations in normal buildings have thermal conductivity between 0.02 $W \cdot m^{-1} \cdot K^{-1}$ and 0.06 $W \cdot m^{-1} \cdot K^{-1}$. As Figure 2. shown, four materials including coconut pitch and paddy straw have the smallest thermal conductivity among NFIs which are lower than 0.024 W/(m·K), that of foamed polyurethane. Two kinds of fiber from pineapples have thermal conductivity below that of foamed glass insulation board (0.045 W/(m·K)). Twenty natural materials have thermal conductivity lower than 0.080 W/(m·K), that of most phase change materials. The Thermal conductivity of most NFIs is lower than 0.1 W/(m·K). In Figure 3, NFIs also performs well in aspect of density. Densities of hemp, flax, and jute are the lowest -less than 50 kg/m^3. Most of NFIs have a density lower than 600 kg/m^3. The thermal distribution of many NFIs is eligible for using in buildings (See Figure 2-3).

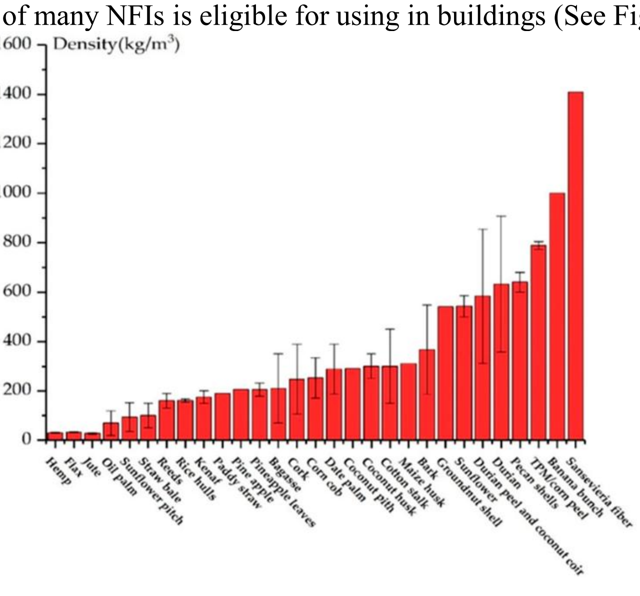

Figure 3. *Density* of different NFIs [11].

2.3.2. Recyclability. NFIs are always produced from agricultural situations, so reusing waste from agriculture during its production is in line with concept of green building. Natural fibers for thermal insulations like cork, date palm wood powder, hemp and straw bale, etc. could be recycled. They can be reused in hempcrete, wood-based concrete blocks, flax wool, cellulose wadding and so on.

2.3.3. Durability. Furthermore, in general, natural insulation such as hemp, cork, and coconut pith has better durability than plastic insulation. Natural insulation materials have a more stable and resilient chemical structure, whereas synthetic chemistry structures easily cause shrinkage. With proper storage, cork and hemp can be used lasting over fifty years.

2.3.4. Drawbacks. Firstly, in the current market, price of NFIs is relatively high limiting its use. The high cost from both gathering and processing is the main cause of the high price. The cost is even higher in areas with fewer plantings. Secondly, although some NFIs such as natural tannin-based foams and cellulose have little fire risk, most of them are of high flammability. In this aspect, NFIs are even less advantageous than EPS and XPS. Thirdly, all NFIs are hygroscopic. Even if NFIs can collect water vapor when humidity is higher and relieve water when humidity is relatively low to adjust the humidity indoor, water vapor may make thermal attributes of NFIs change and probably make NFIs swell.

3. Development direction of thermal insulation materials in China

3.1. Application of thermal insulation materials in green buildings in China

3.1.1. Insulating material glass window. Insulating material glass could use PCM and silica aerogel. By increasing heated and cooled loads and reducing energy depletion, PCM can enhance a building's energy efficiency and internal thermal comfort [1]. Silica aerogel material is lightweight, low thermal conductivity, long life and has good hydrophobic properties. Silica aerogel can provide the thermal insulation, fireproofing, soundproofing, and waterproofing requirements of the construction industry. The good light transmission, thermal insulation and noise reduction capabilities of silica aerosols give them a distinct advantage in the construction sector, particularly in architectural glass. The application of aerogel on the glass not only reduces the thermal dissipation of the glass, but also responds to the demand for light. China has a distinctive continental monsoon climate and a mostly cold climate in northern China. In China's chilly climate, silica aerosol helps to improve the comfort conditions of the enclosed spaces by lowering temperature differences on the internal surfaces of windows. The use of silica aerosols in combination with PCM is even more effective. The way of adding silica aerogel insulation material to the PCM-glass window could solve the problem that the PCM cannot effectively exploit latent heat under a cold climate of China.

3.1.2. Polystyrene wall. Exterior walls, roofs, etc. as a building maintenance structure, the use of insulating materials in indoor design can save energy and thus achieve energy efficiency in inter design can save energy and thereby improve energy efficiency [3]. Polystyrene can be used in a wide range of applications for internal wall insulation, external wall insulation and roof insulation. The construction process of external wall insulation is: firstly, the inner surface of the interior wall is brushed with an interface agent and then leveled with cement mortar; then the construction of the thermal insulation layer is carried out; finally, the construction of the decorative layer of the exterior walls is carried out. When using polystyrene foam panels to insulate walls, the panels are used as the basis for constructing insulation on their interior surfaces. The application of insulation in the wall has the advantages of easy operation and time-saving. However, it can produce the phenomenon of a "thermal bridge", which affects the service life of the insulation material and the insulation effect. However external insulation of the wall solves the problem of "thermal bridges. In the external thermal insulation of the wall, the polystyrene foam plastic board as a part of the wall can effectively play its thermal insulation performance. Furthermore, there are two types of polystyrene foam insulation panels in roof insulation projects: positive and inverse. The orthotropic type is the construction in

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which the insulation board is first laid on the roof structure; Then the slope is found, leveled and the protective layer is laid; finally, the waterproofing treatment is carried out and the surface layer is laid, while the inverted type is the opposite of this.

There is an experiment in Sichuan China. In the course of the experiment, the experimenter measured and calculated the thermal insulation capacity of the materials used in the building in Sichuan, resulting in the following tables. The table clearly demonstrates the role of polystyrene in green buildings in terms of energy efficiency and environmental protection(See Table 2) [4].

Table 2. Insulation material information [4].

Material	Thermal conductivity λins [W/(m K)]	Material cost C(CNY/m³)	Density
Gypsum plaster	0.76	/	ρ(kg/m³)
Clay	0.76	/	1500
Phenolic foam (PF)	0.034	400	1600
Polystyrene foam (PU)	0.024	550	60
Extruded polystyrene (XPS)	0.030	472	35
Expanded polystyrene (EPS)	0.039	442	35

Table 3. Insulation material thickness optimization, energy savings, and economic evaluation [4].

Insulation material	SW	XPS	PU	PF	EPS
Optimum thickness/Xop(m)	0.105	0.098	0.081	0.113	0.114
Thermal resistance of insulation/Rins (m²K/W)	2.56	3.25	3.38	3.32	2.91
Overall heart transfer coefficient of wall/U(W/m²K)	0.346	0.279	0.269	0.273	0.308
Heating load (kWh/ m²)	33.27(54.8%)	31.93(56.7%)	31.77(56.9%)	31.83(56.8%)	32.52(55.9%)
Cooling load (kWh/ m²)	2.61(82.3%)	2.39(83.7%)	2.36(83.9%)	2.35(84%)	2.49(83.1%)
Total loads (kWh/ m²)	35.88(59.4%)	34.32(61.2%)	34.13(61.4%)	34.18(61.3%)	35.01(60.4%)
Payback period (year)	8.0	8.0	7.8	7.9	8.7
Economic benefits during Ne(CNY/ m²)	292.1	301.1	306.7	304.6	283.2

From the above, it is clear that there is a reasonable use of insulation in green buildings in China (See Table 3).

3.2. Requirements for thermal insulation materials for green buildings

Firstly, the thermal bridge effect should be avoided in the application of thermal insulation materials. The thermal bridge effect refers to the phenomenon, in late autumn and early winter, due to poor ventilation, frequent contact between hot and cold air, uneven thermal conductivity of the wall insulation layer and wide temperature variations between inside and outside the house, leading to condensation, mould and even dripping water on the interior walls. The thermal bridge phenomenon will lead heat losing, which violate the requirement of green building. Therefore, the ventilation effect should be fully considered when using thermal insulation materials. Reduce the use of heat insulation materials with higher density, and use polystyrene foam. Avoid the thermal bridge effect caused by the poor indoor air circulation due to excessive pursuit of thermal insulation.

Secondly, thermal insulation materials should pay attention to environmental impact. As a result, attention must be paid to the recyclability of thermal insulation materials to prevent environmental damage during construction and use. As an example, the rubber fiber contained in the tyer waste is turned into aerogel. Due to its low thickness (20-91), high multihole, low thermal conductivity (0.035-0.049) and high adsorption coefficient, it is in fact an ideal choice for a broad application [5] (See Table 4). As a comparison, it can be seen from the following chart that the thermal insulation coefficient of rubber aerogel is higher.

Table 4. Thermal insulation with rubber aeroglomerates and various materials [5].

Material	Density (mg cm^{-3})	Thermal conductivity ($Wm^{-1} K^{-1}$)
Rubber aerogels	20 - 91	0.035 – 0.049
Silica aerogel	3 - 350	0.012 – 0.022
Polyethylene	35 - 40	0.041

3.3. Cost and economic benefits of thermal insulation materials

The economic cost is one of the decisive factors of material application. In China, the material cost should be considered when building green buildings. As a result, high-quality and cheap thermal insulation materials often have more room for development. For example, polystyrene foam board, due to its high production cost, is difficult to put into large-scale use, resulting in limited application prospects.

3.4. Development direction of thermal insulation materials in China

In China, the development of green buildings faces low economic efficiency, a poor market environment and a lack of technical support. Insulation materials also face the same problem. For green building reasons, insulation materials should be developed towards low cost and high efficiency. The cold winters in northern China have led to the widespread use of thermal insulation, especially for walls. Walls with an insulated core retain heat better in cold conditions and maintain indoor temperatures, thus reducing the use of electrical appliances such as air conditioners, thereby reducing the associated carbon footprint and thus achieving a green building. In southern China, where the weather is hot, the use of porous materials such as PCM can be called for to enhance airflow under the premise of thermal insulation to avoid thermal bridging effects, which can cause damage to the environment. All in all, there is a more promising future for insulation in China. The production and use of insulation materials should be reasonable in different regions. At the same time, insulation materials should be produced at the lowest possible cost, on a larger scale and with a wider scope of application

4. Conclusion

This article searched some commonly used thermal insulations in green buildings and their use situation in China. Aerogel, polystyrene foam and natural fiber insulations (NFIs) all present a good performance in the aspect of thermal attributions. Among them, polystyrene foam has a higher environmental impact and can lead to heavy plastic pollution. Aerogel and NFIs have a better performance in eco-friendliness for their lower environmental impact. Furthermore, raw materials of NFIs are waste from agriculture and they are degradable. However, for high price derived from technological barriers, aerogel can’t be widely used in lower-reach market. The collection of raw materials and production of NFIs are rudimentary, so cost of NFIs is high. And for its flammability few people are willing to use it. In China, application of insulations includes insulating material glass window and polystyrene wall. They are eligible for the two requirements-good thermal attributions and low carbon footprint. Although thermal insulations used in China now can restrict heat transfer well, the production of them still causes much carbon emission. If NFIs can take place of some polystyrene foam board, plastic pollution may be alleviated and buildings may be greener. This article points out the importance of thermal insulations in green buildings, compares several thermal insulations and searches the development of thermal insulations under the concept of green building in China. It is clearer to learn about the limitation and development targets for Chinese green buildings in terms of thermal insulations. However, the lack of solutions to problems about a technique to advance thermal insulations needs to be supplemented. In the future, with answers to them found, green buildings can be developed widely.

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