

A Comprehensive Review of Thermal Insulation Materials for Energy-Efficient Building Walls

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ABSTRACT

Attention towards the thermal performance of building materials, particularly thermal insulation systems for buildings, has grown in recent years. Thermal insulation of building walls has a significant effect on the reduction of thermal energy consumption in buildings. Making a thermal insulation of a building external wall can in terms of economic aspects be approached as an investment. In this investment the cost is related to the purchase, transport and laying the insulation, whereas the profits are linked to the reduction of thermal energy consumption necessary to heat a building. Objective of this paper is to provide a comparative study of thermal conductivity material for packaging insulation which will hold up over a long period of years over relatively wide temperature ranges and which will prevent the passing of the insulating gas from the package to the exterior of the package and which will also prevent the passage of air into the package.

KEYWORDS: Building walls, Thermal Insulation, Thermal Energy, Insulation materials.

INTRODUCTION

Heat is transferred by conduction, convection or radiation, or by a combination of all three. Heat always moves from warmer to colder areas; it seeks a balance. The greater the temperature difference, the faster the heat flows to the colder area.

Conduction

Conduction is heat transfer by means of molecular agitation within a material without any motion of the material as a whole. If one end of a metal rod is at a higher temperature, then energy will be transferred down the rod toward the colder end because the higher speed particles will collide with the slower ones with a net transfer of energy to the slower ones. For heat transfer between two plane surfaces, such as heat loss through the wall of a house, the rate of conduction heat transfer is

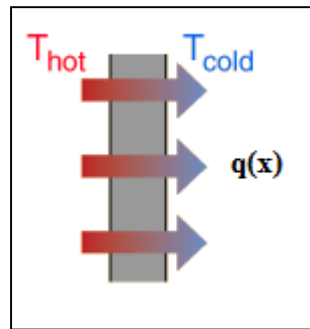


Fig: 1 Heat transfer by conduction

$$q(x) = kA \frac{(T_{HOT} - T_{COLD})}{L}$$

Where,
 k = thermal conductivity,
 L = length,
 A = area,
 T = Temperature,
 q = rate of heat transfer,
 x = location along the length,
 Here (L/kA) is called conductive resistance.

Convection

In liquids and gases, however, the molecules are no longer confined to certain point but constantly change their position even if the substance is at rest. The heat energy is transported along with the motion of these molecules from one region to another. This process is called convection.

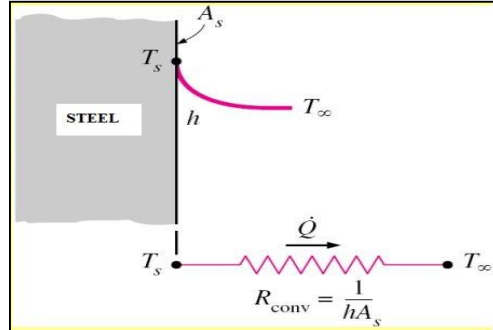


Fig: 2 Heat transfer by convection

The rate of heat transfer through convection is given by

$$q = hA(T_{\infty} - T)$$

Where,

h = convective heat transfer coefficient,

q = rate of heat transfer,

A = area,

T_∞ = ambient temperature,

T_s = surface temperature,

Here (1/hA) is called convective resistance.

THERMAL INSULATIONS

Insulations means using some materials as thermal insulation for reducing the heat transfer in the construction of insulated body. Thermal insulation will help to reduce unwanted heat loss and can decrease the energy demands of heating and cooling system. The effectiveness of insulation is commonly evaluated by the key property of a thermal insulation material—thermal conductivity k (W/m-K), which refers to a material’s ability to conduct heat. Another two corresponded parameters should also be introduced: thermal resistance R-value (m²K/W) and thermal transmittance (or overall heat transfer coefficient) U-value (W/m²K), where thermal resistance is a measure of a temperature difference by which an object or material resist a heat flow per time unit and thermal transmittance refers to the rate of heat transfer through one square meter of a structure divided by the temperature difference across the structure. As good insulation materials, it is needed to achieve as low thermal conductivity as possible, which enables, accordingly, a high thermal resistance as well as a low thermal transmittance.

Moreover, common insulation materials are characterized by light weight, small apparent density, loose and porous, which can barrier the thermal conductivity by the internal non-flow air. Among these, the inorganic insulation materials have non-flammability, a wide temperature range, good resistance to chemical corrosion while the organic materials have high intensity, low water absorption as well as good impermeability.

Vacuum Insulated panel

A vacuum insulated panel(VIP) [5] is a form of thermal insulation consisting of a nearly gas-tight enclosure surrounding a rigid core, from which the air has been evacuated. VIP are regarded as one of the most upcoming high performance thermal insulation solutions. At delivery, thermal conductivity for a VIP can be as low as 0.002–0.004 W/mK depending on the core material. VIPs have been utilized with success for applications such as freezers and thermal packaging.

A VIP consists of a porous core enveloped by an air and vapour tight barrier, which is heat sealed. The core is of an open pore structure to allow all the air to evacuate, and create a vacuum. The envelope needs to be air and vapour tight for the panel to uphold its thermally insulating properties over initial pristine thermal conductivity of the core is normally around 0.004 W/m-K, however increasing with elapsed time due to air and moisture diffusion through the barrier envelope and into the time

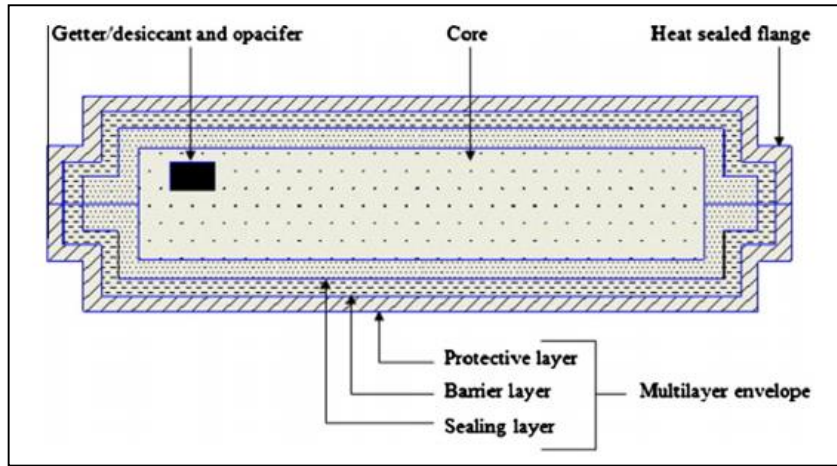


Fig: 3 Vacuum Insulated Panel

The purpose of the core material is to provide the VIP’s insulating and mechanical properties. Various requirement of core material are listed below

1. The core material’s pore diameter needs to be small. In materials with large pores, the pressure has to be very low to obtain a low thermal conductivity. By using a nano-porous material the pressure is not required to be as low, and a low thermal conductivity can be reached with a higher pressure. The relation between effective thermal conductivity of different potential VIP core materials as function of the internal gas pressure is shown in Fig. 3.
2. The pore structure needs to be 100% open so all the gas in the panel can be easily evacuated.
3. The core material needs to withstand compression. The normal range of the initial internal pressure in VIPs is between 0.2 and 3 mbar. The external pressure on the panel is around 1 atm, or about 101 kPa.
4. The material has to be impermeable to infrared radiation, which will reduce the radiative heat transfer in the panel.

Effective thermal conductivity of different potential VIP core materials as function of internal gas pressure.

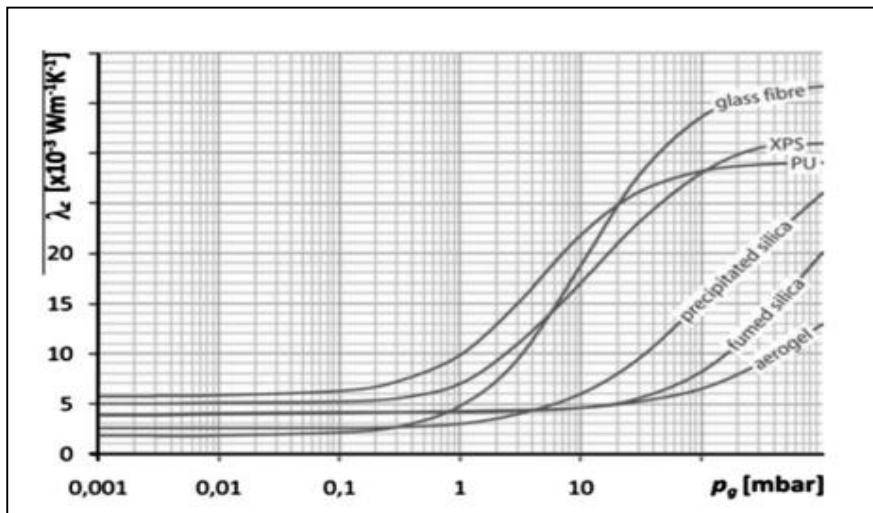


Fig: 4 Thermal Conductivity versus Pressure for different material

Aerogel

Aerogels [3] are dried gels with a very high porosity, high specific surface area, low apparent density and a low refraction index. The pore volume of aerogel may vary from 85 up to 99.8%. This gives the material a bulk density as low as 3 kg/m³, making it the lightest solid state material known. For building applications the density is in the range of 70–150 kg/m³. At ambient pressure the thermal conductivity may be as low as 0.0135 W/m-K, which can be reduced down to 0.004 W/m-K at a pressure of 50 mbar.

Aerogel at ambient pressure has thermal conductivity values 2–3 times lower than conventional insulation, and unlike VIPs, it can be cut and adjusted at the building site. However, Aerogel has a very low tensile strength, making the material very fragile.

Microsphere insulation

Microsphere insulation [1], typically consisting of hollow glass bubbles, combines in a single material the desirable properties that other insulations only have individually. The material has high crush strength, low density, is noncombustible, and performs well in soft vacuum. Microspheres provide robust, low-maintenance insulation systems for cryogenic Transfer lines and dewars. They also do not suffer from compaction problems typical of perlite that result in the necessity to reinsulated dewars because of degraded thermal performance and potential damage to its support system.

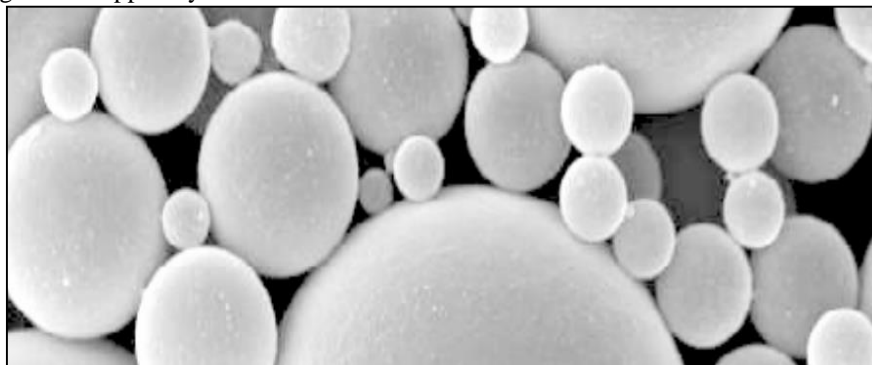


Fig: 5 Microspheres magnified 500x

The 3M Type K1 microspheres are manufactured from soda-lime-borosilicate glass and is the most economical 3M microsphere product at about \$0.40 per liter.

Table .1 Thermal performance of 3MType K1 microspheres

COLD VACUUM PRESSURE (torr)	APPARENT THERMAL CONDUCTIVITY (mW/m-K)	COMPARATIVE THERMAL PERFORMANCE
1×10^{-3}	0.7	7.0 times worse than MLI
1×10^{-1}	1.4	3.3 times better than perlite
760	22	1.5 times better than polyurethane

Rice husk has insulation

S. R. Bello, and T.A. Adegbulugbe [2], they made a Comparative Study on Utilization of Rice husk alone Charcoal and Sawdust as an insulation material and reported that rice husk has better insulating properties in terms radiation and conduction losses with respective time.

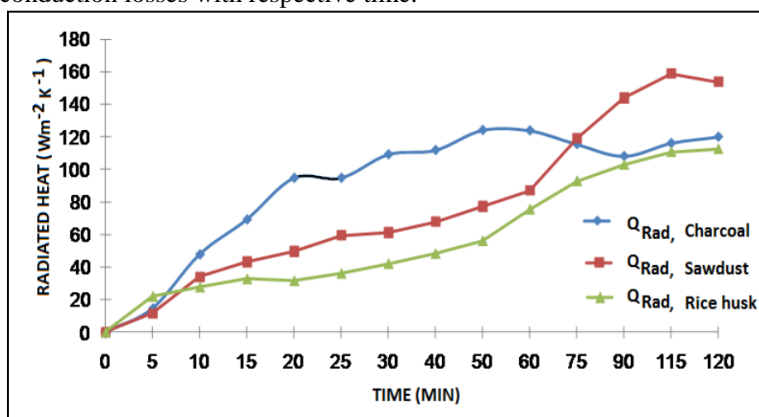


Fig: 6 Radiated heat Vs, Time

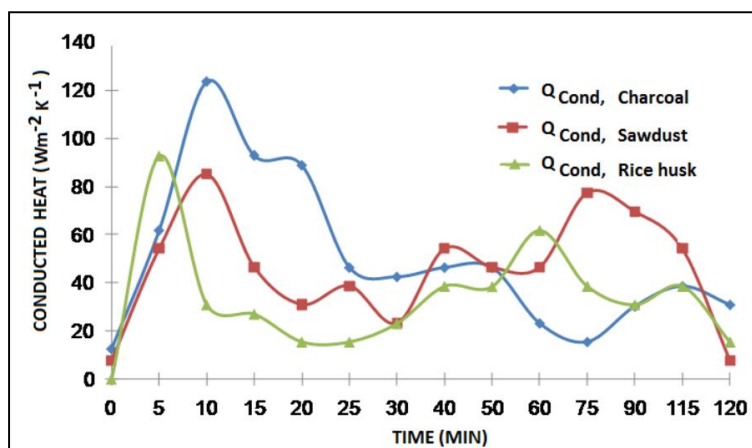


Fig: 7 Conducted heat Vs, Time

RESULTS AND CONCLUSION

This below table has presented a survey of different thermal insulation materials components. With the knowledge of the basic heat transfer mechanisms and the ways to reduce the total thermal conductivity of a material or component, novel thermal insulation materials and components were described. Thermal conductivity is a property of a substance and characterise its ability to transfer heat by conduction. In general, the numerical value of thermal conductivity is highest for solids, the lowest for gases and it has intermediate values for liquids. A summary of the thermal Conductivity of the materials is presented.

Table .2 Thermal conductivity of insulating materials

Insulation matirial	Thermal conductivity(milliW/mK) at 10 °C	Density(kg/m ³)
Glass bubbles	4.7	125
Fumed silica	3	80-200
Mineral wool	30 to 40	30 and 200
ExpandedPolystyrene(EPS)	30 to 40	40
Extruded Polystyrene (XPS)	30 and 40	40
Cork	45	120~200
Polyurethane(PUR)	35	40~60
Cellulose	35	24 to 27.2
Vacuum Insulation Panels (VIP) with fumed silica	4 or higher	Vacuum
Aerogels	13-16	3
Kapok	40	50
Jute	35	50
sugarcane fiber	50	100
coconut fiber	55	50
Rice husk	22	400-600

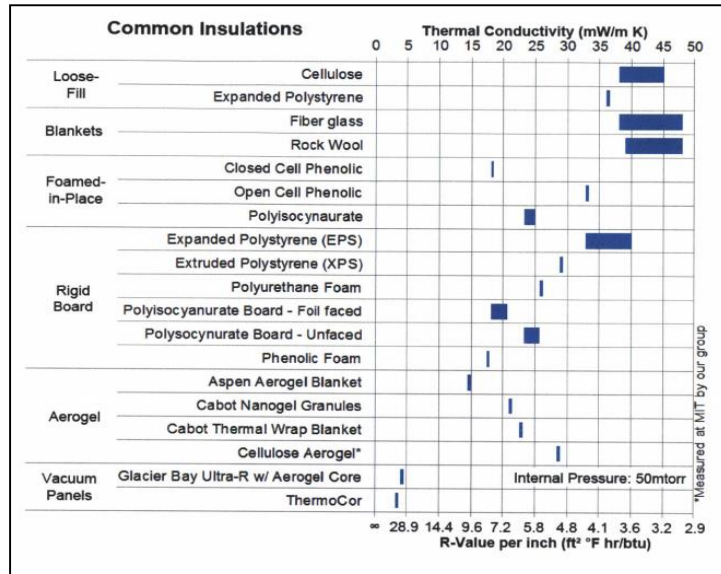


Fig: 8 Thermal Conductivity of Various insulating materials

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REFERENCES

1. Allena.M.S et al. “Advance microsphere insulation” Cryogenic Engineering Conference, 2003
2. Bello.S.R and Adegbulugbe, Comparative Study on Utilization of Charcoal, Sawdust and Rice Husk in Biomass Furnace-Dryer, Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Manuscript 1592, Volume XII, March, 2010.
3. Fesmire.J.E,Sass.J, “Aerogel insulation application for liquid hydrogen launch vehicle tanks” space cryogenics workshop,
4. Gupta.C.P, Engineering Heat Transfer, University of Rookie, Nemchand and bros., 1997
5. Kalnas.S.E, Jelle.B.P, “Vacuum insulation panel products”, Applied Energy 116. 2014 355–375
6. Pandey.S, “Dropwise and film wise condensation”, International Journal of Scientific & Engineering Research Volume 3, Issue 4, April-2012untsville, July 2007.
7. Psychometrics from ASHRAE Fundaments hand books, 2001.