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A Review of Performance of Insulating Material in Buildings

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ABSTRACT:
Today India is a fast developing economy; its GDP is increasing so the per capita income is also increasing. To meet the comfort requirements, especially in scorching summer and chilling winter in one form or other, we need modern amenities like air-conditioners and room heaters. Both need energy (electricity) as a fuel to perform their function, so at individual level or at national view point, energy saving has to be done. The phrase will not be wrong: *"Let the energy be saved, though the heaven falls"*. In this paper, a review of insulation materials along with their properties has been presented. The information given is relevant and useful for architects and engineers. This paper also has glimpses of past and future of insulating materials.
Keywords: Thermal insulation, Vacuum Insulation, Heat losses, Cooling in buildings, Insulation practice

I. INTRODUCTION

The man knowingly and unknowingly using the different material to increase the insulation of its hutment e.g. constructing a thick adobe wall or using a reed based roofing called *chappar* in northern India; it was having a less useful life but was giving good comfort to the occupants. This practice was continuing upto 17th century. After the industrial revolution in 1726, engineers realised the importance of insulation. Table 1 presents the chronological evolution of insulating materials.

Cities are growing at a fast rate, so land has become costly in the cities. One of the very basic solution to conserve the energy is to provide good thermal insulation in the buildings. The challenge is how to reduce the thickness of the insulation, the higher thickness of insulation encroaches the carpet area of the building thus per square foot cost of carpet area is increased.

As 21^{st} century is called the century of materials; new insulating materials like vacuum insulation materials (VIMs), nano insulation materials (NIMs), gas insulation materials (GIMs), dynamic insulation materials (DIMs), etc. are readily available in the market and can be used optimally to provide desired thermal insulation in buildings.

II. EVOLUTION OF INSULATING MATERIALS

Unknowingly or knowingly man was interested in searching a material which will reduce the energy consumption. This aspect of human nature of energy saving can be observed even in today's society that purchase of fuel is a tweaking purchase whether in form of fire wood or coal or electricity. Table 1 shows evolution of insulating materials.

Whatever insulating material one develops, the following requirements have to be achieved if not in totality, then partially:

1. It should be cost effective.
2. Its useful life should be between 5-30 years.
3. The insulation should be thin.
4. Machineability with minimum performance disturbance.
5. Low transportation cost.

Table 1: Evolution of insulating materials

Period of time	Lifestyle	Ongoing Searches	Popular Insulation materials
12000 years ago	Hunter and food gatherer	Materials for covering the body	Animal skins, fur, wool, plant leaves etc.
5000 years back	Settled lifestyle	Durable materials	Earth, wood, straw, eelgrass, reed, vegetable fibres (gossypium and linen fibres)
1750 - 1940	Beginning of Industrial revolution, Heat loss thought process (conduction, convection and	Refining of available insulating materials and process of factuation of insulating materials	Fire brick (magnesium bricks) and refractory materials, Ash-filled bricks, hollow bricks, Autoclaved Aerated Concrete (AAC), Asbestos, rock wool, fibre-glass, foam glass, dross, expanded

	radiation) commenced		clay and perlite
1940-2000 (World War I and World War II)	Polymer revolution	Development of techniques and processes to exploit polymerisation process	Polystyrene, Polyurethane, Polyester, Polyethylene, Polycarbonate, Perspex, Phenol, Formaldehyde and Melamine foam
2000 till date	Environmental health consciousness occupied paramount importance	Revival of the natural materials. Fresh thought and experimentation on new materials began	Cellulose insulation, cork, straw bale, wood, glass wool, sheep wool. Transparent thermal insulation, dynamic thermal insulation, nana-cellular insulation, vacuum insulation panels, gas filled panels, aerogels, phase change materials and many more.

III. RESEARCHES IN INSUALTING MATERIALS

Historical evidences show that industrial research is always directed towards those products which have expanding market i.e. sale of this product will increase with the passage of time. In turn any research effort in that area will give dividend in future. Following table shows consumption of energy appliances in the present and future projection:

Table 2: Population of consumer durable electrical goods (millions) (Source: World Bank Report, 2008)

Appliances	Demography	2006	2011	2016	2021	2026	2031
Refrigerator	Urban	26.0	41.4	59.4	76.1	88.8	101.1
	Rural	7.3	16.2	32.6	57.0	81.0	100.3
	Total	33.3	57.6	92.0	133.1	169.8	201.4
Air-Conditioner	Urban	1.7	4.0	8.9	17.5	28.5	40.0
	Rural	0.3	0.6	1.3	2.6	4.8	8.0
	Total	2.0	4.6	10.2	20.1	33.3	48.0
Electric Water Heater	Urban	27.0	38.9	55.7	78.1	103.9	132.4
	Rural	0.0	0.0	0.0	0.0	0.0	0.0
	Total	27.0	38.9	55.7	78.1	103.9	132.4

Table 3: Average operating per-unit power consumption (Source: World Bank Report, 2008)

Appliances	Unit	2006	2011	2016	2021	2026	2031
Refrigerator	kWh/unit	705	568	473	431	417	418
Air-Conditioner	W/hr	1,973	1,883	1,834	1,817	1,811	1,809
Electric Water Heater	kWh/unit	609	591	575	566	562	561

Table 2 shows that population of consumer durable electrical appliances are increasing with time. Power consumption of any device can be reduced by two ways; one way is by improving the technology and another way is by preventing losses and that too at minimum possible cost and minimum encroachment of the space by insulating material. By improving the technology per refrigerator/A.C/Electric water heater, energy consumption will be reduced but overall consumption in this sector will increase because of the rising standard of living and with the passage of time, any luxury today becomes the necessity after sometime e.g. in middle-income group, refrigerator and computer today has become a necessity, with A.C as well.

By sifting of data given in the table above, one can conclude that overall energy consumption is on rise, so a strategic energy planning is the need of the hour. Any developing country should embark on this problem in two ways; one is the production strategy and another is the conservation strategy. So emphasis on insulation technology helps in prevention approach if insulation of any device like refrigerator or a building is poor then the energy losses are like energy drain, throughout useful life of the structure or machine amenity. Before using any insulating material, it is obligatory upon the decision maker to have through knowledge of inherent and desired properties of insulating material along with the cost.

IV. MECHANICAL AND CHEMICAL PROPERTIES OF INSULATION

Other than the thermal properties, few more properties must be considered while choosing the insulating materials for specific applications, few are as under:

1. **Alkalinity (pH) or acidity**: Significant, when moisture is present e.g. coastal areas. The material should not promote the corrosion of the system e.g. encased steel structures building.
2. **Appearance:** Important in exposed areas and for coating purposes.
3. **Breaking load:** Insulation must have some bridging property when applied at the discontinuities.
4. **Capillarity:** Must be considered when material may come in contact with liquids e.g. failure of cooling system of a refrigerator i.e. instead of making snow, vapour is being converted into water or vapour condensation on refrigeration ducts.
5. **Chemical reaction:** Its oxidation properties should not promote the fire hazards.
6. **Chemical resistance:** Insulation should be inert towards the chemical under use in the building.
7. **Coefficient of expansion and contraction:** This property becomes important when multilayered insulation is used e.g. Cold storage. If this property is not considered then due to change in ambient temperature leads opening of the joints in turn loss of energy.
8. **Combustibility:** The material should not be combustible.
9. **Compressive strength:** A minimum compressive strength is always desirable atleast to support self weight and handling forces.
10. **Density:** It is an important parameter for commercial classification of insulating material.
11. **Volumetric stability:** Due to large changes in the ambient temperature of the building, stresses are caused in the in-built insulation system. The material should have sufficient endurance to resist the dimensional changes or reversal of stresses. In short wide gaps, cracking should not happen because of thermal changes.
12. **Fire resistance:** An ideal insulating material should never burn under fire but it should give smoke and fume for safety reasons.
13. **Resistance to ultraviolet light:** Ultraviolet rays are destroyer of any synthetic insulating material so outdoor exposure of such materials should be avoided.
14. **Resistance to fungal or bacterial growth:** Fungal and bacterial growth both requires food and water and warmth. Thereby insulating material should never be hygroscopic.
15. **Shrinkage:** Significant on applications involving cements and mastics.
16. **Sound absorption coefficient:** Acoustic property of the material is important factor in case of radio station, ICU of a hospital or wherever noise or decibel reduction is required.
17. **Sound transmissivity loss value:** It is significant factor for row housing, hotel rooms or meeting rooms of confidential nature.
18. **Toxicity:** This factor becomes important when material has to come in human touch, animal touch or any medicinal vegetation.

As a matter of fact the performance of the building should always be considered on the basis of life cycle costing because of the maintenance factor and initial fixed cost and operational cost of the building. On the basis of fixed cost, useful life and in present scenario sustainability parameter, guides the selection of right insulation material for the right place of the building.

Whatever insulation we use ultimately that insulating material has to conform performance specification as per any standardisation body. ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) has given following recommendations for building envelope requirements as given in Table 4:

Table 4: ASHRAE* Building Envelope Requirements

Opaque Elements (Insulation)	**Non-Residential**		**Residential**	
	Assembly Maximum (W/m^2K)	**Insulation Minimum R value (m^2K/W)**	**Assembly Maximum (W/m^2K)**	**Insulation Minimum R value (m^2K/W)**
Roofs, entirely above deck	U-0.360	R-2.6 ci#	U-0.360	R-2.6 ci#
Roofs, entirely under deck	U-0.720	R-5.2 ci#	U-0.720	R-5.2 ci#
Walls, above grade	U-3.293	-	U-0.857	R-1.6 ci#

[#]ci – continuous insulation

Table 5: Typical thermal properties of common insulation materials:

Name of insulating material	**Thermal Resistivity r-value (mK/mW)**	**Thermal Transmissivity u-value (mW/mK)**
Mineral Wool (Glass Wool, Rock Wool)	0.03-0.04	30-40
Extruded Polystyrene (XPS)	0.03-0.04	30-40
Expanded Polystyrene (EPS)	0.03-0.04	30-40
Cellulose	0.04-0.05	40-50
Cork	0.04-0.05	40-50
Polyurethane (PUR)	0.02-0.03	20-30
Vacuum Insulation Panels (VIP)	0.25-0.125-0.05	4-8-20
Gas-Filled Panels (GFP)	0.04	40
Aerogels	0.08	13

This is obligatory upon the architect or refrigeration engineer to classify the building components/ exterior walls and roofing from thermal insulation view point and then apply his wisdom on Table 5 and then decide the most suitable material for a particular location if over specified insulating material is used it will be shear wastage of money in the form of fixed cost. On the other hand under specified material will give poor performance that will lead to more operational cost, so this will act as an energy drain for the building.

V. Future Thermal Insulation Solutions

Batens (2009), Jelle et al. (2009) and Baetens et al. (2010) have presented a list of advanced insulation materials. Few materials are as under:

Vacuum Insulation Materials (VIM)

A vacuum insulation material is basically a homogenous material with a closed small pore structure under vacuum condition. The thermal conductivity is less than 4 mW/mK in pristine condition. Any intervention on this material of local nature will not result in any loss of thermal conductivity.

Gas Insulation Materials (GIM)

Gas insulation material has a pore structure but pores are filled with noble gases like argon, krypton, xenon etc. The thermal conductivity is less than 4 mW/(mK). The better performance is because of low conductance offered by noble gases.

Nano Insulation Materials (NIM)

This material has closed or open nano pores. In such material the pores are below 40 nm. Overall thermal conductivity is less than 4 mW/(mK). The useful life of such material is atleast 100 years. Such a long lasting useful life is because of the size of the pores which does not allow neither penetration of air nor moisture. This phenomenon is sometimes called Knudsen effect (or nano pore effect).

Dynamic Insulation Materials (DIM)

A dynamic insulation material is that material thermal conductivity of which can be controlled within a desirable range. The solid state thermal conductivity is made up of two components, one is phonon thermal conductivity, and it implies vibration of lattice atoms and the conductivity coming from free electron availability. This is the most advanced insulation technology and the material falls in this category are Electrochromic materials.

Construction Technology with NIMS

The load bearing building envelope requires thin layers of NIM in order to attain satisfactory thermal insulation resistance. The NIMS can be applied as a concrete retrofitting or as a sandwich in the overall building envelope thickness. The application of NIMS reduces with a factor of 10 as compared to mineral wool or expanded or extruded polystyrene having a thermal conductivity of 36 mW/(mK). In physical terms insulation is reduced from 40 cm (mineral wool) to 4 cm thick NIMS.

A Step towards Sustainability

World Business Council for sustainable development, 2002 and Lindstorm, 2009; point towards negative environmental impact through cement production. So the consumption of concrete has to be kept as low as possible for the sustainable development of the society. This problem must be examined in long term perspective.

So today the challenge is to invent a technology which must be sustainable having sufficient structural strength and should have low thermal conductivity as in long run higher thermal conductivity is an indirect encroachment on the energy reserves. So to meet such challenges we can say that a combination of nanotechnology and construction technology in short called NanoCon is desired. Development of the NanoCon will require cross fertilization of physical sciences and engineering technologies e.g. extremely large tensile strength can be obtained by exploiting carbon nanotubes in construction materials. Such thinking is certainly an out of box thinking. It seems such material is almost impossible to manufacture but advance researches in future can bring such thing a reality.

VI. Conclusion

After reviewing the available literature, the authors are of the view that energy planning for developing countries like India, an application based researches are desired in this direction as energy saved is energy generated. The present review in the research area of insulating material is a modest attempt in this direction.

New concepts for the advanced insulating material like VIM, GIM, NIM and DIMS are there and NanoCons have to be developed for construction activity. NIMS have potential to cover all types of buildings like timber, framed and concrete buildings.

The researcher will be failing in their duty if their research benefits are not reached to the poorest of the poor of the country so some thought has to be given to develop an insulating material by using the local materials available in the villages.

At the end authors are constrained to say that an optimal selection of insulating material requires diversified knowledge of building materials, material economics, cost management and life cycle costing. Certainly, such a blend of knowledge and skill rather we can say the engineering wisdom comes with the passage of time.

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