International Journal of Advanced Technology in Engineering and Science
Vol. No.5, Issue No. 07, July 2017
www.ijates.com
ijates
ISSN 2348 - 7550

AEROGEL – THERMAL PERFORMANCE AND ENERGY SAVINGS AS INSULATOR FOR BUILDINGS IN HOT AND DRY CLIMATE

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ABSTRACT

Aerogel, a nano-material, is regarded as one of the most promising materials to be used as thermal insulator in many fields. Due to its low thermal conductivity being as low as 13mW/mK, Aerogel may be the best option to be used as thermal insulator for buildings, as the construction sector consumes a substantial amount of energy. This paper discusses the thermal performance and the resulting energy savings by using Aerogel nano material, as a thermal insulation for buildings located in hot and dry climate. An energy simulation was carried out for a building model after applying Aerogel insulation and located in hot dry climate. The paper highlights the unique thermal properties of Aerogel which surpass those of the other conventional insulation materials used. Aerogel can prove to be a promising thermal insulator, contributing towards making the buildings more sustainable.

Keywords: Aerogel, energy savings, nano materials, polystyrene, thermal insulation

I. INTRODUCTION

The construction industry has always consumed a substantial amount of total energy in the world. A substantial amount of energy in buildings is needed to either heat or cool the building for occupant comfort. India being a tropical country, buildings need more energy to cool rather than to heat. Moreover, if an existing building fails to meet the required comfort temperature, then measures such as insulation or mechanical means of air conditioning are used. Mechanical air conditioning consumes high energy and also causes GHG emissions. Various conventional insulation materials like glass wool, rock wool, polyurethane etc. have been used in buildings. Traditional insulation materials when used are thicker or in multiple layers which results in adverse gross net-to-floor area ratio. Air, as an insulator has reached its limit [1]. Therefore, there is a need for a high performance thermally insulating material having thinner section. Aerogel is one such material that can surpass all the other conventional thermal insulation materials used in buildings till date.

Since the mid 20th Century, the adverse impact of the sectors consuming energy, including the construction industry, came into light. Since then, measures have been taken by many countries to mitigate the adverse effects on environment caused by buildings such as GHG emissions, waste generation, resource depletion and climate change. As sustainable architecture and green building construction practice is on the rise, many new sustainable technologies are being used and researched to reduce the adverse impacts on the environment. One of such technologies being researched on for the construction industry is ‘Nano technology’.

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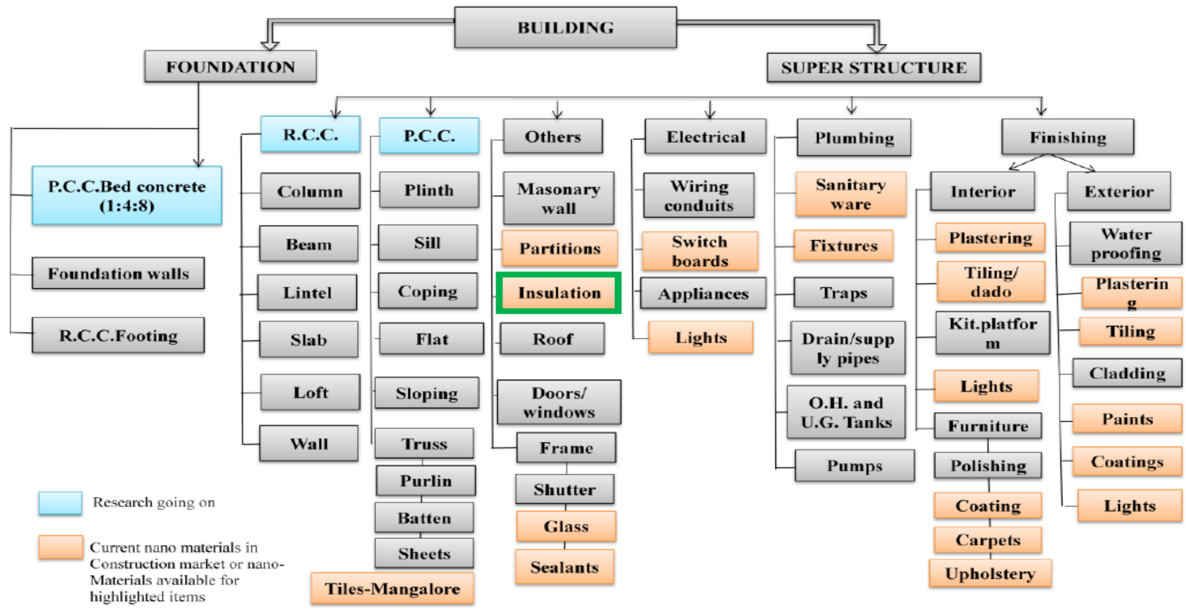
1.1 Nano Material Applications in Buildings

Many nano materials are being researched on for use in buildings due to their unique properties such as hydrophobic nature, photo catalysis, easy-to-clean, air purifying, anti-fogging, UV protection, anti-reflection etc.

Table 1.Areas of application of nano-materials in buildings



From the above table 1, it is clear that the major sector in buildings where nano materials can play a role in energy savings is insulation. Aerogel is one of the nano materials, having distinct properties for thermal insulation, which will benefit the buildings in terms of energy savings, thermal comfort of occupants as well as providing higher gross net-to-floor area ratio.

II. AEROGEL

Aerogel, also called as “frozen smoke” is the lightest known solid material on earth. It was developed in 1931 by Steven Kirstler. It is a synthetic porous ultra light material derived from a gel, in which the liquid component of the gel has been replaced with a gas. It holds 15 entries in Guinness Book of Records for properties such as the lowest density solid and the best insulator. It is a silica-based substance, consisting of a loose dendritic network of the atom silicon. It is 99% air and 1% silica and has thermal conductivity as low as 13 mW/mK at 273K. The first application of Aerogel as thermal insulation was in NASA space suits. Now, flexible fibre-reinforced Aerogel composites are studied for use as insulation materials for future Moon and Mars exploration. Underwater insulation for oil pipelines is another current application of Aerogel insulation [2]. Aerogels can be used for temperatures ranging from -200ºC to +650ºC.

III. BUILDING SIMULATION

3.1 Objective

The objective of building simulation of a building model is to analyse the effective of Aerogel insulation in terms of thermal performance and the resulting energy savings.

3.2 Methodology

Energy simulation was carried out in Autodesk Ecotect software. For simulation, a typical office building, fully air-conditioned during working hours, located in Bikaner, Rajasthan was considered. Bikaner has hot and dry climate. Such climate was purposely selected to measure the thermal performance and savings in energy consumption by Aerogel insulation at extreme temperatures. The building was modeled and three cases were considered for simulation. In the first case, a building having no insulation was simulated. In the second case, a building with Polystyrene insulation was simulated and the third model had Aerogel blankets as insulation.

3.3 Basic design parameters

The basic design parameters common to the three models are as follows:

3.3.1 Location and climate

Location: Bikaner, Rajasthan, India Lat.28º08' N, 73º18'E

Altitude- 224m above Mean Sea Level Situated in the middle of Thar Desert

Climate: Hot and dry

3.3.2 Building model

Type of building: A typical office, fully air conditioned during operating hours

Structure: Ground+2

Dimensions: 10m X 20m

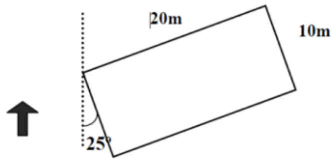
Area of the building: 600 sq.m.

Operating hours: 9am to 6pm

Working days: Monday to Friday (5 days a week)

Holidays: Saturday and Sunday (weekends)

Orientation: Longer axis along North-South, Building is tilted 25ºtowards East from normal.



3.3.3 Building elements

a. Windows

Size: 1.2m X 1.2m

Window wall ratio: 0.24 (i.e. 24.3%)

Glass: Double glazed- two layers of 6mm thick flint glass having 30mm air gap between them

Frame: Low e-Aluminium frame

U-value: 2.68 W/m2K (Maximum U-value is 3.3 W/m2K as per Energy Conservation Building Code (ECBC) 2007 for hot and dry climate)

Admittance: 0.54 W/m2K

Solar heat gain: 0.1 (Maximum Solar Heat Gain Co-efficient (S.H.G.C.)is 0.25 as per ECBC 2007 co-efficient for hot and dry climate)

Visible transmittance: 0.64 (Minimum VLT is 0.27 for Window to Wall ratio (WWR) 0-0.3 as per ECBC 2007)

b. Door

Size: 3m x 2.1m

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Frame: Low e aluminium frame

Shutter: 40mm thick Polystyrene foam sandwiched between 5mm thick plywood

U-Value: 0.19 W/sq. mK

c. Floor

100mm thick R.C.C. slab

d. Ceiling:

10mm suspended plaster board ceiling, plus 50mm insulation, with remainder (150mm) joists as air gap.

3.3.4 Internal heat gains

Occupancy: 17 persons per floor (Typical office=12sq.m.area/person as per Ecotect)

Sensible heat gain: 9.15 sq.m./Person (as per National Building Code 2007)

Latent heat gain: 2 W/sq. m

Activity: Clerical- 70W

3.3.5 Infiltration rate

Air change rate: 0.5 air changes per hour *(acph)* (well-sealed)

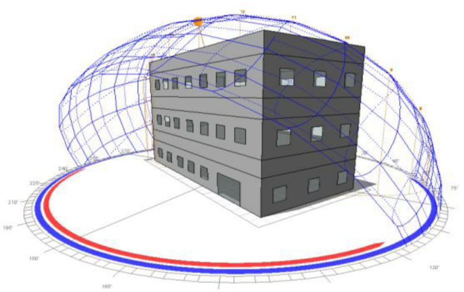
Wind sensitivity: 0.25 acph (reasonably protected)

3.3.6 HVAC

Type of system: Mixed mode ventilation, split system

Efficiency: 95%

Thermostat range: Lower band: 18ºC, Upper band: 25ºC



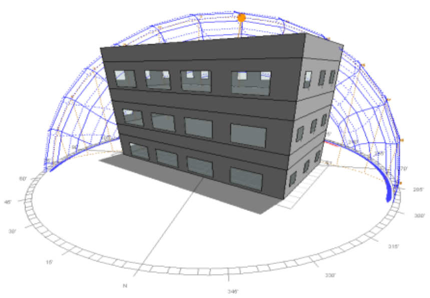


Fig.1 Model of G+2 office building in Ecotect (South view) Fig.2 Model of office building in Ecotect (North view)

3.3.7 Wall sections

The wall sections of the three models to be simulated are as follows:

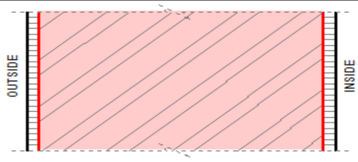
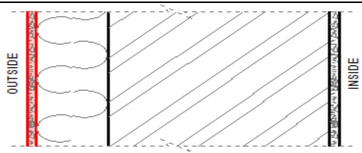
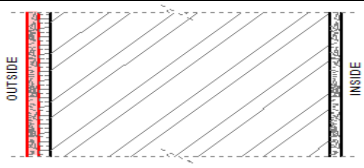
Case 1: 230mm thick brick masonry wall with 10mm cement sand plaster external and internal

Case 2: 230mm brick with 75mm external Polystyrene insulation

Case 3: 230mm brick with 10mm external Aerogel insulation

Thermal simulation of Case1 is done so that results of buildings in Case 2 and 3 can be compared with Case 1 to find out the reduction in heat gain and annual energy consumption. Thermal simulations for whole building for the day of 10th May were carried out for the three models, as the month of May is critical for summer season. The thermal simulation results gave the monthly heating and cooling loads, annual energy consumption by whole building as well as break up of each floor energy consumption. The type and properties of wall section and insulation used is as follows:

Table 2 Materials layers of wall section

Sr.no.	Material properties	Wall section
1	Case 1: 230mm thick brick masonry wall with 10mm cement sand plaster external and internal U- value of wall section: 1.83 W/sq.m.K	
2	Case 2: 230mm brick with 75mm external Polystyrene insulation U-value of wall section: 0.1 W/sq.m.K	
3	Case 3: 230mm brick with 10mm external Aerogel insulation U-value of wall section: 0.77 W/sq.m.K	

3.4 Properties of Wall sections

3.4.1 230mm thick brick masonry wall with 10mm cement sand plaster external and internal

Table 3 Properties of wall section-Case1

Sr.no.	Material assembly	U value in W/m2K	Width in m	Density in Kg/m3	Specific heat in J/kg.K	Conductivity in W/m.K	Thickness in m
1	Plaster building (moulded dry)		0.10	1250	1088.0	0.431	
2	Brick masonry		0.23	2000	836.8	0.711	
3	Plaster Building (moulded dry)		0.10	1250	1088.0	0.431	
		1.83					0.25

3.4.2 230mm brick with 75mm external Polystyrene insulation

Table 4 Properties of wall section-Case2

Sr. no.	Material assembly	U value in W/m2K	Width in m	Density in Kg/m3	Specific heat in J/kg.K	Conductivity in W/m.K	Thickness In m
1	Cement plaster, sand aggregate		0.10	1860.0	840	0.72	
2	Polystyrene foam (high density)		0.075	46.0	1130.0	0.008	
3	Brick masonry medium		0.23	2000.0	836.8	0.711	
4	Gypsum plasterboard		0.10	1100.0	840.0	0.650	
		0.10					0.325

3.4.3 230mm brick with 10mm external Aerogel insulation

Table 5 Properties of wall section-Case3

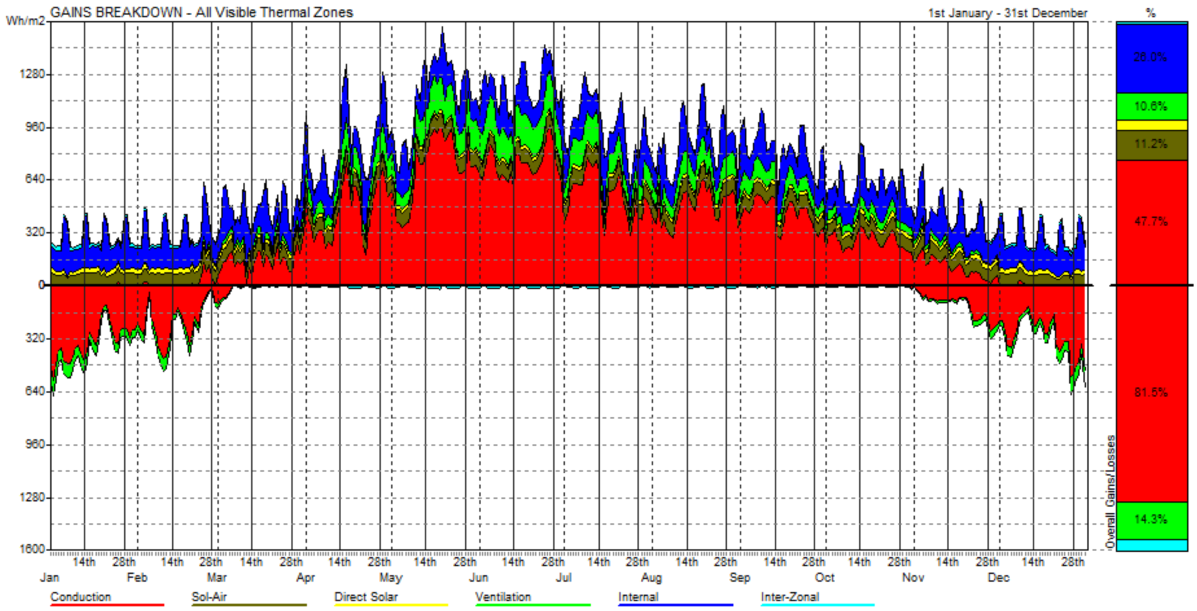
Sr. no.	Material assembly	U value in W/m2K	Width in m	Density in Kg/m3	Specific heat in J/kg.K	Conductivity in W/m.K	Thickness In m
1	Cement plaster, sand aggregate		0.01	1860.0	840	0.72	
2	Aerogel		0.1	109.0	1.046	0.013	
3	Brick		0.23	2000.0	836.8	0.711	
4	Gypsum plasterboard		0.10	1100	840	0.65	
		0.77					0.26

IV. RESULTS AND DISCUSSION

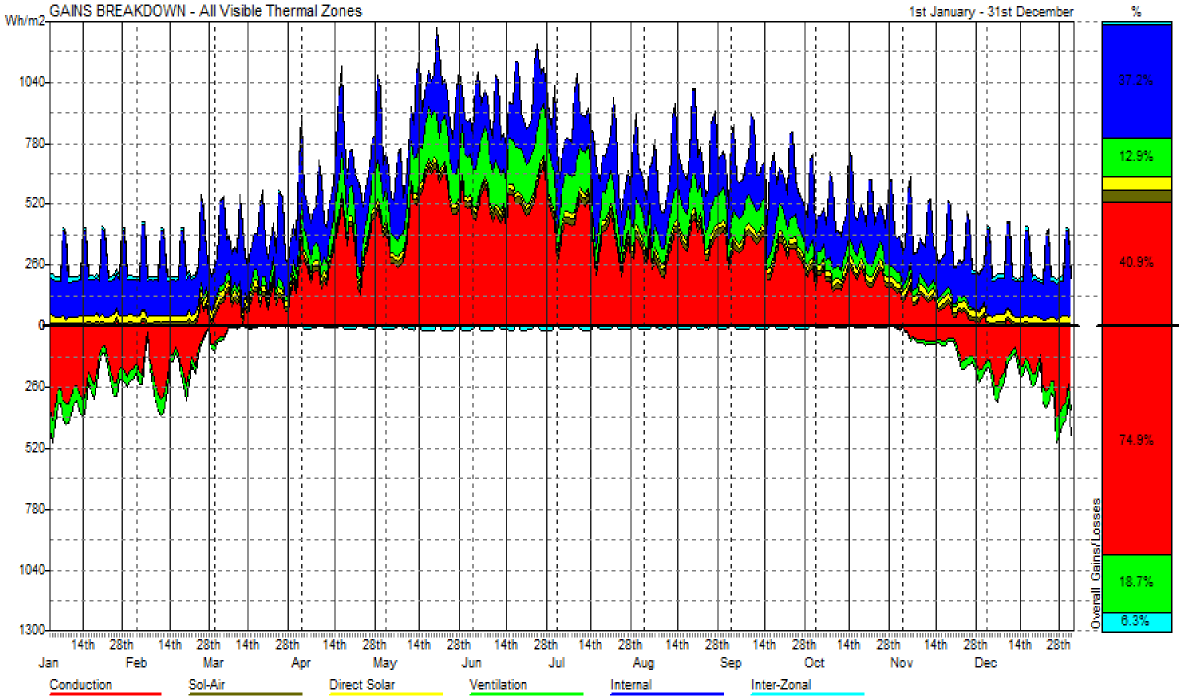
The thermal simulation results can be broadly divided into two categories. First category includes the heat gain in the building due to the different insulation. The second category includes reduction in annual consumption of energy by the building after using Polystyrene and Aerogel insulation.

4.1 Thermal results

The results of the thermal simulation showed that the heat gain in the building was minimum in the building Aerogel insulation. The following graphs show the gains breakdown of the two cases of Polystyrene and Aerogel insulation after thermal simulation.



Graph 1. Gains breakdown for building with Polystyrene insulation applied



Graph 2. Gains breakdown for building with Aerogel insulation applied

The heat gain reduced by 4.8% when Polystyrene insulation was applied to walls and the heat gain further reduced by 11.6 % when Aerogel blanket was used for simulation. Aerogel is 6.8% more efficient than Polystyrene insulation.

Table 6 Results showing heat gains and losses through conduction or building fabric

Sr.no.	Type of wall section	Category fabric conduction	
		Losses	Gains
1	Case 1: Brick masonry without insulation	85.9%	52.5%
2	Case 2: Polystyrene insulation applied externally	81.5%	47.7%
3	Case 3: Aerogel blanket insulation applied externally	74.9%	40.9%

The thermal simulation results showed that the heat gain through sol air temperature reduced by 2.9% using Polystyrene insulation and 10.4% by Aerogel blanket.

Table 7 Results showing heat gains and losses through sol air

Sr.no.	Type of wall section	Category Sol air	
		Losses	Gains
1	Case 1: Brick masonry without insulation	0%	14.1%
2	Case 2: Polystyrene insulation applied externally	0%	11.2%
3	Case 3: Aerogel blanket insulation applied externally	0%	3.7%

Therefore, from the above results it is clear that Aerogel insulation is more efficient than Polystyrene insulation as it has low thermal conductivity. The reduction in heat gain factor in the building using Aerogel insulation will definitely affect the HVAC energy consumption pattern of the building.

The following table 8 shows that conductance reduces by 10.35% when Aerogel insulation is applied than Polystyrene.

Table 8 Conductance values of the wall section with insulation materials

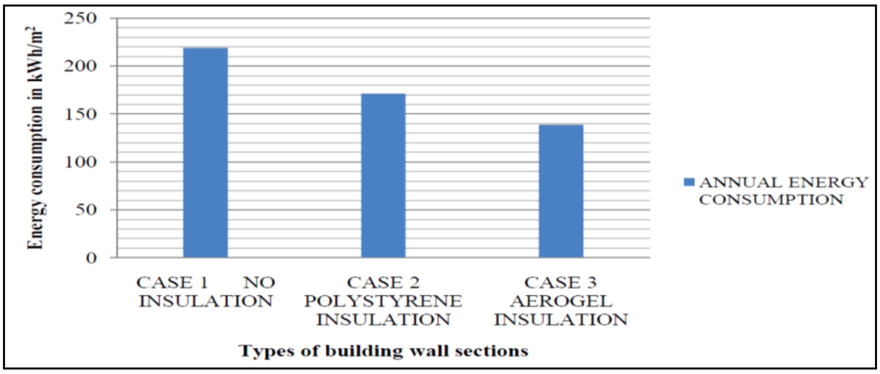
Sr.no.	Type of wall section	Conductance in W/ºK	% Reduction in conductance
1	Case 1: Brick masonry without insulation	0%	14.1%
2	Case 2: Polystyrene insulation applied externally	0%	11.2%
3	Case 3: Aerogel blanket insulation applied externally	0%	3.7%

4.2 Annual energy consumption

The thermal simulation results showed the total annual heating and cooling load required for the three cases. It showed that the reduction in annual energy consumption by using Polystyrene insulation is 21.8%, whereas reduction using Aerogel insulation is 36.6%. Therefore, Aerogel is 14.8% more efficient than Polystyrene.

Table 9 Annual energy consumption in the three cases

Sr. no.	Type of wall section	Annual energy consumption in kWh/m2	Percentage reduction in annual energy consumption
1	Case 1: Brick masonry without insulation	219.16	
2	Case 2: Polystyrene insulation applied externally	171.36	21.81%
3	Case 3: Aerogel blanket insulation applied externally	138.88	36.6%



Graph 3. Annual energy consumption of building using different insulations

V. CONCLUSION

It is clear that Aerogel blankets as an insulation work more effectively in a hot and dry climate as compared to Polystyrene foam (high density), in terms of thermal insulation and annual energy consumption. We also see that where 75mm of Polystyrene is needed, only 10mm of Aerogel can perform better. Such insulation applied internally can save lots of area. Aerogel is relatively sturdy as compared to Vacuum Insulation panels (having thermal conductivity of 4-8 mW/mK) which are fragile and need to be handled with utmost care during transportation and on-site installation. Aerogel, as an insulating material, however, is less popular due to its high cost and less demand in the Indian market. If measures are taken to create awareness about this untapped insulating material, the demand may increase leading to reasonable purchase costs. Aerogel will then play a major role in energy savings and providing effective gross net-to-floor area ratio. As it will reduce the use of mechanical air-conditioning, it will also help to reduce adverse impacts on environment caused by AC equipments such as GHG emissions. Thus, Aerogel, the world's lightest known solid, proves to be one of the best thermal insulating material and needs to be popularized in the Indian construction market. Further research regarding the material, its application in building and means to lower its high capital investment, especially in India, is needed.

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