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Performance Evaluation of Nano Based Materials for Energy Optimization in Buildings

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Abstract

The increasing demand for sustainable and energy-efficient buildings has prompted the exploration of newly developed, innovative materials and technologies that can enhance energy optimization.

Nanotechnology is one of the fastest growing industries in the world in recent years. It will have a profound impact on building materials and their properties. The use of nanotechnology results in the creation of Nano-based materials. These materials offer great potential for enhancing energy efficiency and performance in building envelopes and systems. By precisely controlling materials at the nanoscale, properties such as durability, strength, insulation, and resistance can be optimized.

The research methodology involves a systematic review of the literature to identify the most commonly used Nano-based materials in the field of energy optimization in buildings. These materials are expected to benefit the construction industry, including traditional materials like cement, concrete, and steel. Advances in nanotechnology have led to the creation of insulating materials such as Nano foams, Nanostructured aerogels, Nansulate insulated coating, and vacuum insulated panels etc.

This research focuses on the application of four major Nano-based materials (viz. Aerogel panels, Vacuum insulated panels, Nansulate insulated coating, and Double glazed with aerogel granules) for energy efficiency in buildings. The research employs computer simulation using Ecotect Analysis 2011 to evaluate the performance of these materials in various prototype modules.

Keywords: Nanotechnology,; Nano coatings; Insulation materials; Thermal insulation; Energy efficiency; Building materials.

Introduction

In today's world, ever increasing population has caused crisis on energy consumption. Building constitutes a lot of energy consumption which is a serious issue in developing countries. Today, nanotechnology is presented as an innovative research field in modern technology, various industries and highly efficient buildings. Using nanotechnology as a flexible phenomenon and its application in the construction industry has given more stability, decreased energy consumption, and improved construction material performance. [1]

Nanotechnology, also called "nanotech", is the study of controlling matter at the atomic and molecular level. In general, nanotechnology deals with structures with at least one dimension less than or equal to 100 nanometers and involves the development of materials or devices within that size. Etymologically, "nano" means dwarf in Greek. A nanometre is one billionth of a meter, or 10-9m. [2]

It is the technology of the future which deals with nanoparticles. These nanoparticles like carbon, nitrogen, hydrogen, oxygen, silicon, etc. are derived from nature i.e. earth, air, water and they can manipulate the properties of conventional materials at nanoscale and desired materials can be achieved of required specific properties.

Integration of nanotechnology in the building and construction industry through the use of nano-products developed from nanoparticles, nano-materials, nano-composites and even nano-forms. It can devise faster, cheaper and smaller materials, using less raw materials and consuming less energy. Through nanotechnology we can achieve reliable sustainable environment by creating durable, lightweight, energy efficient and cheap materials and also by this we can build faster, flexible and robust buildings. As Concrete can be made stronger and glass can be made self-cleaning.

It also has ability to achieve a minimum thermal conductivity in a building's facade with very thin insulation materials. It has many benefits on the environment but the risks and drawbacks like health hazards and mass production needs to be identified and controlled. It is one of today's emerging technologies as a result of international interest in nanoscience. This technology has made it possible to manipulate matter on an atomic basis. This should change the way we live and revolutionize. [2]

In the construction industry, nanotechnology will have a major impact on building materials and their properties. Materials behave in different ways because their properties can be more precisely controlled at the nanoscale.

Methodology

Application of nanotechnology in building construction materials

Nanotechnology allows the development of materials with improved properties or the creation of entirely new materials. In recent years this technology gaining popularity in the field of architecture as well as in building construction materials. This can be done either by

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using nanoparticles, nanomaterials, nanocomposites or even Nano-shapes. For example, a photo chromatic glass changes its colour according to the outdoor temperatures, changing its appearance and properties. Also, by the application of nanotechnology, conventional materials properties can be improved. As a glass protected by a Nano cover doesn't let infrared radiations to permit inside the building spaces. [3]

Nanoparticle: Nanoparticles are atomic particles whose size is measured in nanometers (nm). When nanoparticles are introduced into bulk materials, they can significantly affect the mechanical properties such as stiffness and elasticity of the materials. In addition, while reducing weight, it also increases stability and improves functionality. Two nano-sized particles that stand out for their application in building materials are titanium dioxide (TiO2) and carbon nanotubes (CNT). [3]

Nanocomposites: Nanocomposites integrates new nanomaterials with the conventional materials like steel, concrete, glass, and makes it much stronger than conventional materials and it also improves the performance, durability and strength-to-weight ratio of these materials. For example, Nano-silica, Carbon nanotubes, Nanofibers, etc. [3]

There are number of nanomaterials and Nano products that can be applied to various construction materials in view of improving their properties, both physical and chemical.

Building materials developed with Nanotechnology

Nano based materials majorly used in buildings are:

Aerogels

Vacuum insulated panels

Nansulate insulated coating

Phase change Glasses (Glass with salts hydrate or aerogels, photo chromatic glass)

Nansulate insulated coating

Phase change Glasses (Figure 1)

(Figure 2)

Aerogels

Aerogel is an open-pore, high-performance insulation that can be used for very thin building insulation. It consists of silica nanoparticles separated by Nano pores and is composed mainly of air, making it an excellent insulator. For example, if this material were used instead of conventional insulation, the insulation in the walls of the building would be about one-third as thick. [4]

Figure 1: (Left to right) Aerogels blanket, Aerogel granules & Aerogel panels.

Figure 2: Left to right) Vacuum insulate panel, Nansulate coating & Phase change glasses.

Aerogel concrete is an ultralight concrete system based on aerogel granules or powder. It offers high compressive strength with comparable thermal conductivity, making it suitable for the construction of exterior walls of high-rise buildings without the need for additional insulation.

Double-walled cavities for insulation can be easily filled with these loose aerogel granules. (Figure 3)

Aerogel-filled bricks conduct only about 12.5% less heat than standard bricks, offering even greater energy savings potential. [4]

Aerogel Insulation panels results in more than 15% on energy consumption reduction and tariff savings can be achieved. [4]

Vacuum insulated panels

An evacuated foil encapsulated open porous material as a high-performance thermal insulating material. The Nanomaterial used in its core fill is fumed silica and envelope is basically used as a metalized laminated sheet. It has a very low thermal conductivity. [4]

(Figure 4)

(Figure 5)

As compared to conventional insulation such as Styrofoam, polystyrene etc. these panels have up to 10 times lower thermal conductivity. This means that maximum heat transfer resistance can be achieved with minimum insulation thickness. VIP has a very low thermal conductivity of only 0.005 W/mK. [5]

(Figure 6)

Nansulate insulated coating

Nasulate is a water-based translucent original insulating coating that integrates a nanocomposite called Hydro-NM-Oxide, a product of nanotechnology.

(Figure 7)

This material has one of the lowest thermal conductivity values recorded. It composed of approximately 70% Hydro-NM-Oxide and 30% acrylic resin and performance additives. The low thermal conductivity of Nasulate and the nanomaterials it contains make it an excellent insulator.

Nasulate Thermal Insulation Coatings allow building and factory owners to easily coat windows, skylights, interior or exterior walls, ceilings and ducts with translucent, paint-compatible insulation to significantly reduce energy consumption. [6]

(Figure 8)

The typical energy savings reported by Nansulate for building envelope applications is between 20%-40 %. [6]

Phase change materials (PCM's)

Phase change materials (PCM) are considered a possible solution to reduce energy consumption in buildings. By storing and releasing heat within a certain temperature range, it increases the inertia of the building and stabilizes the indoor climate.

(Figure 9)

Aerogel		
S. No.	Materials specifications	Description
1	Products available	Aerogel blankets, Aerogel granules,aerogel panels etc.
2	Market Cost	₹3500-4000/Sq. m. (Insulation panel) ₹3500-4000/Sq. m. (Aerogel granules)
3	Available Thickness	3mm, 5mm, 6mm & 10 mm
4	Max. withstanding temperature	650 Degree celcius
5	Used in buildings	Insulation over wall Aerogel granules in window glazing Aerogel sheeting in roof Used in thermal bridging Aerogel bricks Aerogel concrete blocks
6	Energy saving	Aerogel bricks results about 12.5% energy consumption than standard bricks Aerogel panels results about 15% energy consumption
7	Major Indian operating market	Aerogel Insulation India pvt. Ltd. – Vadodara Gujarat JLMOil & Gas LLP – Mumbai,India PBM Insulations Pvt. Ltd – Uttar Pradesh, India BASF India limited – Mumbai, India Kalkis Inc. – Bengaluru, Karnataka, India

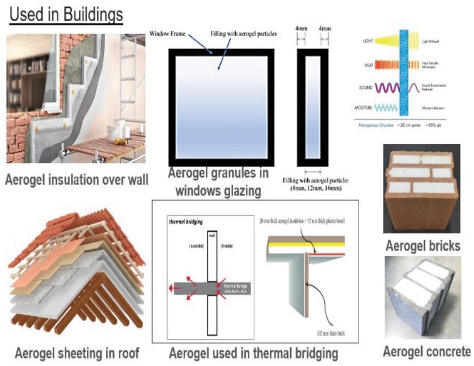

Figure 3: (Left to right) Materials specification & Use of Aerogel in buildings.

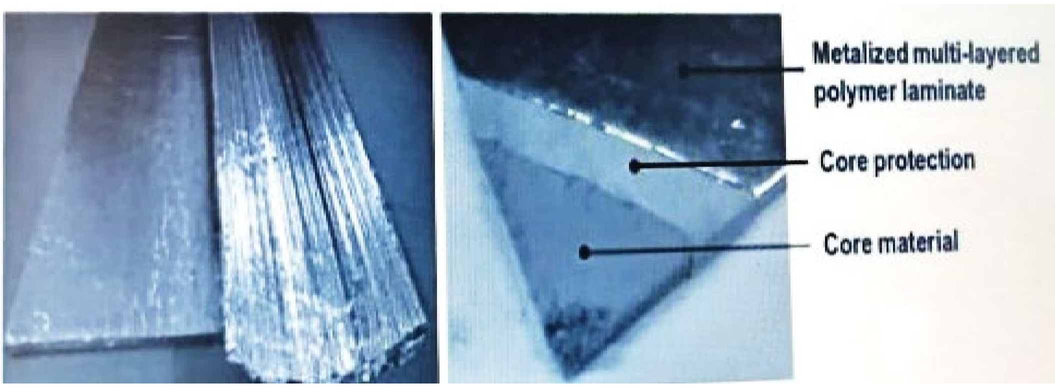

Figure 4: Vacuum insulation panels.

Vacuum Insulated panels		
S. No.	Materials specifications	Description
1	Products available	VIP sheetings, VIP panels etc.
2	Market Cost	₹ 850-1000 /unit (Insulation panel)
3	Available Thickness	6mm to 25 mm
4	Max. withstanding temperature	100 Degree celcius
5	Used in buildings	Insulation over walls Floor & roof insulation Aerogel sheeting in roof Used in thermal bridging uses in Dormer windows Door insulation
6	Energy saving	VIP panels results about 10 times more energy efficient as compared to conventional materials
7	Major Indian operating market	Morgan Vacupor NT Vacuum Insulation Panel – Chennai, Tamil Nadu, India Galleria Tower DLF Phase 4 – Gurugram, Haryana, India Switch Build Engineers India Pvt. Ltd. – Maharashtra, India Gromax Engineering Private Limited – Uttar Pradesh, India

Figure 5: (Left to right) Materials specification & Use of VIP in buildings.

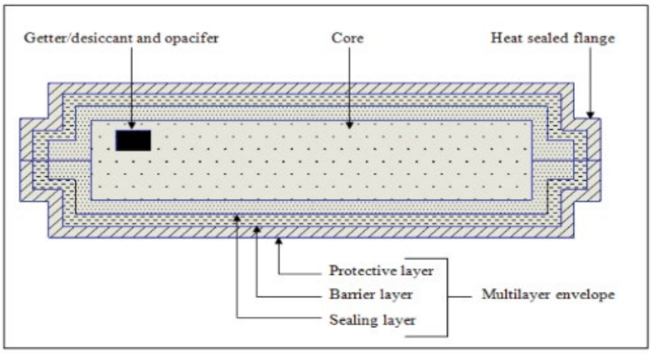

Fig.4. Schematic of a VIP

Figure 6: Schematic of VIP.

Figure 7: Types of Nansulate insulate

These used where summers and winters prevails equally, these PCM's are used. These can be used for both heating and cooling as well. [7]

Phase change material in concrete is the most used building material in the world can help in reducing energy consumption for buildings. Several uses of PCMs already exist in building materials, such as in Drop ceilings, metal roofs, windows glazing, Doors and stud walls etc.

Used in Buildings

Concrete phase change materials are the most widely used building materials in the world and help reduce energy consumption in buildings. There are already several applications of PCM in building materials. Such as suspended ceilings, metal roofs, glazing, doors, stud walls, etc.

(Figure 10)

Phase change glasses

Different types of nanotechnology-treated glass were 75% more energy efficient, with a solar heat gain coefficient (SHGC) of less than 0.25. This reduces the heat load transferred by indoor solar radiation and reduces the HVAC load by 20%. This glass has high light transmission and is energy efficient. This is because sunlight reduces the need for artificial lighting and reduces energy consumption. [8]

Solar control window film (low reflectance, high transparency or high emissivity, smart glass for solar control with significant heat reduction. Reflects 80% of all infrared rays and 99% of ultraviolet rays)

Sun Control Window Films (smart glass for solar control with low reflectivity, high clarity or emissivity and high heat reduction; it reflects 80 % of the total infrared radiation and 99 % of UV light)

(Figure 11)

Nansulate insulated coating

S. No.	Materials specifications	Description
1	Products available	**Nano insulate Energy protect** for walls, ceilings, windows etc. , **Nano insulate crystal** for roofs
2	Market Cost	₹ 6000-7000/gallon (4.5 litre approx.)
3	Coverage area per gallon	150 sq. ft. per gallon
4	Typical applied coat	Thickness 3-5 wet mils (76.2-127 microns) per coat.
5	Used in buildings	Coating over walls Floor, ceilings & roof insulation Aerogel sheeting in roof Used in thermal bridging used for coat windows used for coat Skylights
6	Energy saving	Nansulate coating results about 20- 40 % more energy saving or efficient.

Figure 8: Nano insulated coating.

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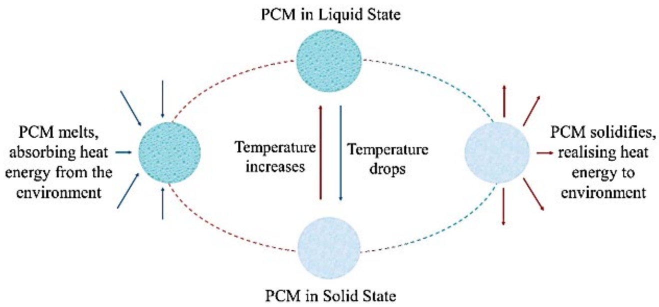


Figure 2. Phase change processes taking place in phase change materials (PCMs).

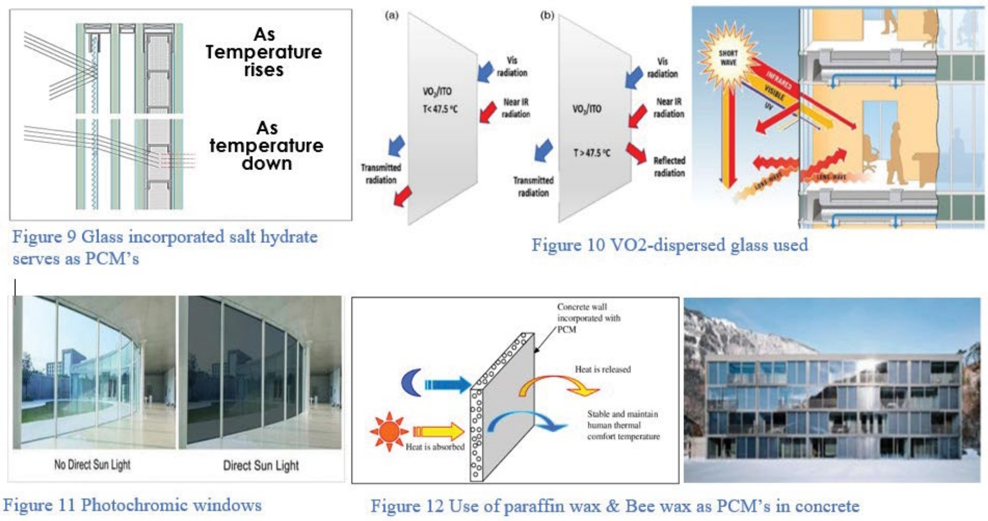


Figure 9: (Left to right) Materials specification & Types of Nansulate insulate. Concrete phase change materials.

Phase Change switchable glasses

S. No.	Materials specifications	Description
1	Products available	Sun control window films, Smart switchable glasses for windows and glazings, Dichroic film,paint protection film etc.
2	Market Cost	₹ 1500-5000/sq. ft.
3	Coverage area per gallon	150 sq. ft. per gallon
4	Typical applied coat	Thickness 3-5 wet mils (76.2-127 microns) per coat.
5	Used in buildings	Used in windows, skylights
		Used in curtain walls
		Used as glazing over facade
6	Energy saving	It reflects 80% of infrared radiations and 99% UV light. And results upto 40 % energy saving.
7	Major Indian operating market	Max Inc. – Mumbai , India
		Glassto India Private Limited – West Bengal India
		Smart Glass India – Faridabad, Haryana
		Satguru Smart Switchable Glass – Hyderabad, Telangana

Figure 10: Sun Control film pasting over glasses.

Comparative Analysis of nanotechnology based materials from conventional materials				
S. No.	**Materials**	**Thermal conductivity of conventional materials (W/m K)**	**Thermal conductivity nanotechnology based materials (W/m K)**	**Energy efficiency (%)**
1	Aerogel filled bricks	0.5 – 1.0 W/m K	0.01– 0.02 W/m K	12.5%
2	Aerogel insulation panel	0.1 – 0.2 W/m K	0.013 W/m K	15%
3	Vacuum insulated panels	0.1 – 0.2 W/m K	0.005 W/m K	10%
4	Nansulate insulated coating	0.2 W/m K	0.25 x 10^{-3} W/m K	20%
5	PCM glasses	1.0 W/m K	0.2 W/m K	30%
6	Nano gel filled polycarbonate sheets	0.19 – 0.22 W/m K	0.018 – 0.020 W/m K	Up to 50%

Figure 11: Comparative Analysis of Nano based materials.

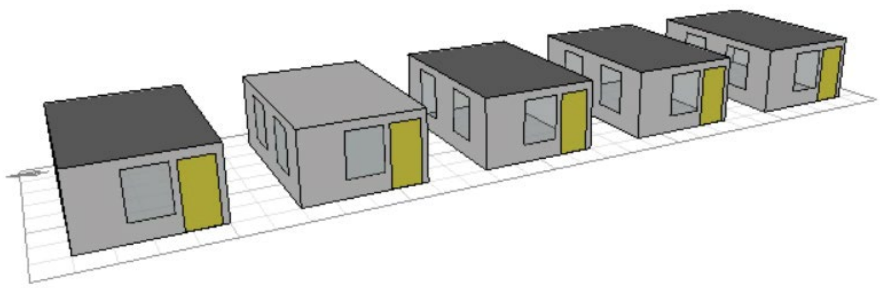


Figure 12: Base model along with four different Nano based models developed over Ecotect software.

Based simulation

Thermal performance analysis of a Nano based materials

A base model of 4x5 m room was made with two windows towards north on longer face on room and one window along with a door on west wall was made on Autodesk Ecotect Analysis 2011.

Base model was made with brick wall single glazed windows and with concrete slab roof and concrete floor above soil base.

(Figure 12)

Four models were made as similar to Model A (Base model) with different nanostructured materials.

Model A: Base Model with conventional materials (Base model with Brick wall, single glazed windows, concrete slab roof and concrete floor above soil base).

Model B: Double glazed with aerogel granules filled in between in windows.

Model C: Aerogel insulation panels over wall as well as underside of slab was used.

Model D: Nansulate paint coating was used walls and roof.

Model E: VIP insulated panels over wall as well as underside of slab was used.

Thermal performance analysis of all the above models is perform/ done by simulation with the help of Ecotect Analysis 2011 software tool.

(Figure 13)

Material details of (model a)

Walls (Figure 14)

Windows (Figure 15)

Roof slab (Figure 16)

Floor' (Figure 17)

Door (Figure 18)

(Figure 19)

Material details

Model B

Windows (Figure 20)

Model C

Walls

(Figure 21)

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Plaster Building (Molded Dry	10.0	1250.0	1088.000	0.431	85
2.	Brick Masonry Medium	95.0	2000.0	836.800	0.711	25
3.	Plaster Building (Molded Dry	10.0	1250.0	1088.000	0.431	85

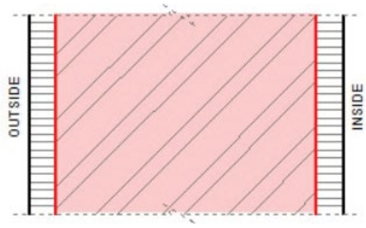


Figure 13: Walls section.

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Glass Standard	6.0	2300.0	836.800	1.046	75

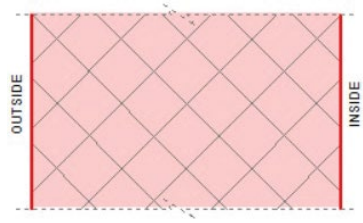


Figure 14: Windows section.

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Plaster Building (Molded Dry	10.0	1250.0	1088.000	0.431	85
2.	ConcreteLightweeight	150.0	950.0	656.900	0.209	35
3.	Plaster Building (Molded Dry	10.0	1250.0	1088.000	0.431	85

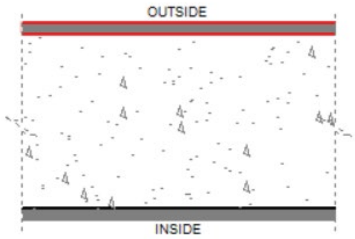


Figure 15: Roof slab section.

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Soil (Avg. Props)	450.0	1300.0	1046.000	0.837	115
2.	Concrete	100.0	3800.0	656.900	0.753	33

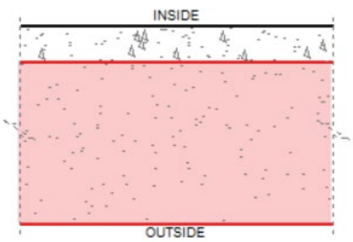


Figure 16: Floor section.

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Wood Oak White Live (Acro	40.0	825.0	2385.000	0.209	91

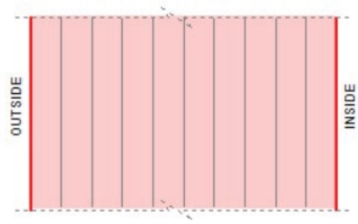


Figure 17: Door section.

Model D

(Figure 22)

Wall

Roof slab (Figure 23)

Model E

Wall (Figure 24)

Roof slab (Figure 25)

(Figure 26)

(Figure 27)

These figures show the graphical results of heat transfer values, thermal lag values and U value in the model A with conventional materials as well as in nanostructured materials model B, C, D and E respectively.

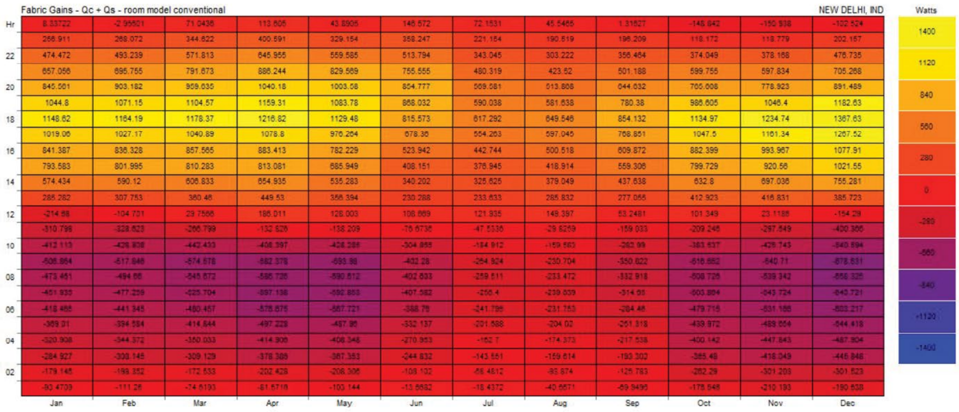
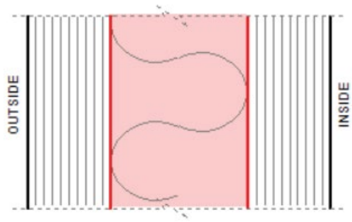


Figure 18: Rate of heat transfer through the envelope of Base model made from conventional materials.

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Glass Standard	6.0	2300.0	836.800	1.046	75
2.	aerogel granules	10.0	120.0	1900.000	0.013	45
3.	Glass Standard	6.0	2300.0	836.800	1.046	75



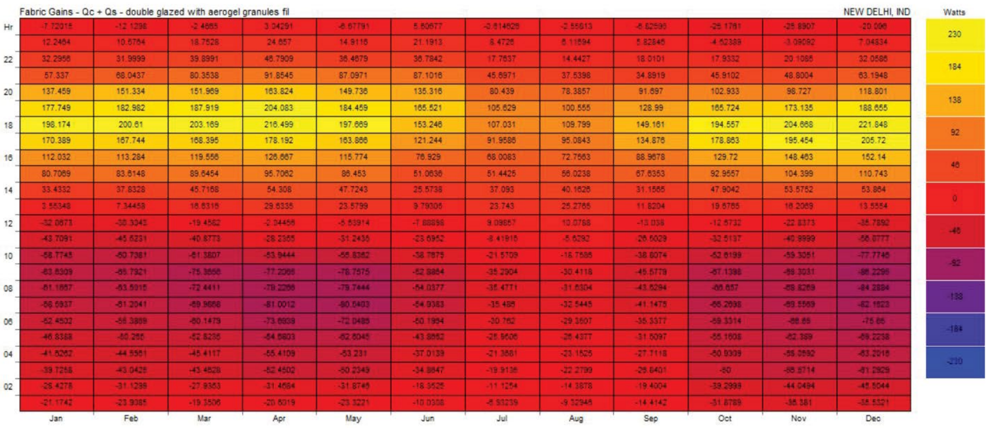


Figure 19: Windows section.

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Plaster Building (Molded Dry	10.0	1250.0	1088.000	0.431	85
2.	Brick Masonry Medium	95.0	2000.0	836.800	0.711	25
3.	Plaster Building (Molded Dry	10.0	1250.0	1088.000	0.431	85
4.	AEROGEL PANEL	10.0	190.0	1900.000	0.013	45

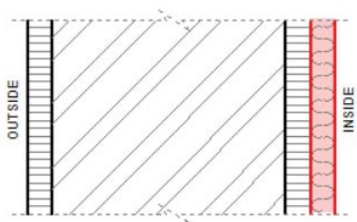


Figure 20: Roof section.

Nanomaterial based models achieves the least amount of heat transfer, highest amount of thermal lag and lowest U value as compared to base model with conventional materials used.

Findings from Simulation Analysis

From all the above models, Model B with double glazed windows with aerogel filled in between glazing (U value 1.040 $W/m^2 \cdot K$) is tested to prove to be a better insulation material among all models.

The results shows of heat transfer values of various models along with base models in ascending order of heat transfer are as follows:

Model B < Model E < Model C < Model D < Model A

where,

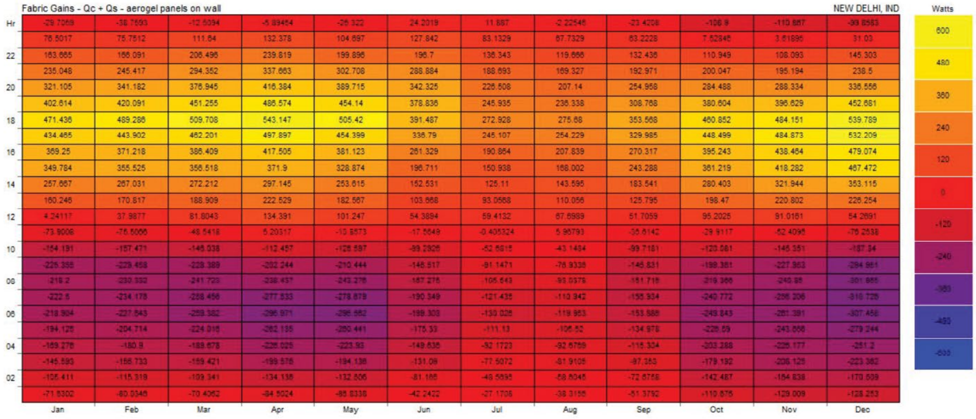


Figure 21: Rate of heat transfer through the envelope of model having aerogel panels over wall.

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	nansulate coating	1.0	300.0	1300.000	0.000	45
2.	Plaster Building (Molded Dry	10.0	1250.0	1088.000	0.431	85
3.	Brick Masonry Medium	95.0	2000.0	836.800	0.711	25
4.	Plaster Building (Molded Dry	10.0	1250.0	1088.000	0.431	85

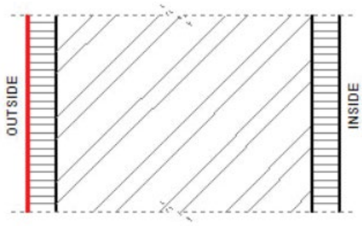


Figure 22: Wall section.

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	nansulate coating	1.0	300.0	1300.000	0.000	45
2.	Plaster Building (Molded Dry	10.0	1250.0	1088.000	0.431	85
3.	ConcreteLightweeight	150.0	950.0	656.900	0.209	35
4.	Plaster Building (Molded Dry	10.0	1250.0	1088.000	0.431	85

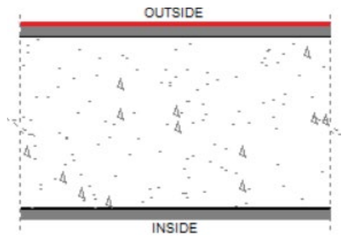


Figure 23: Roof section.

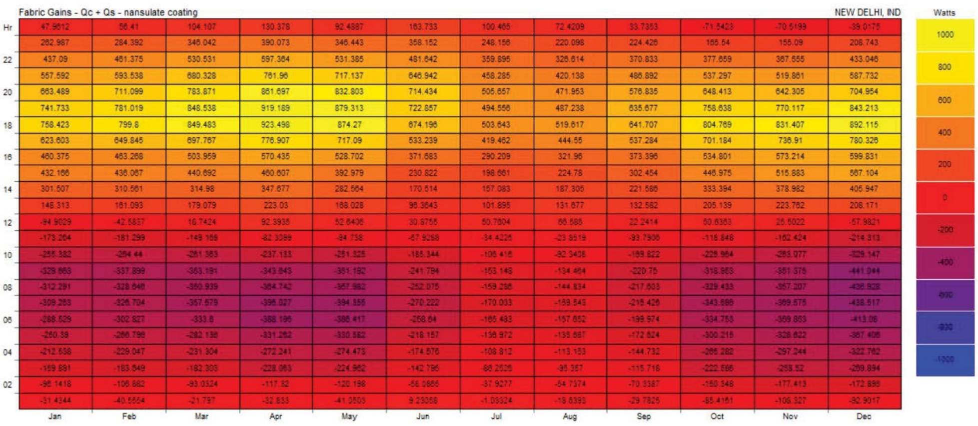


Figure 24: Rate of heat transfer through the envelope of model having Nansulate coating over exterior of wall and roof.

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Plaster Building (Molded Dry	10.0	1250.0	1088.000	0.431	85
2.	Brick Masonry Medium	95.0	2000.0	836.800	0.711	25
3.	Plaster Building (Molded Dry	10.0	1250.0	1088.000	0.431	85
4.	VIP panels	10.0	180.0	800.000	0.007	45

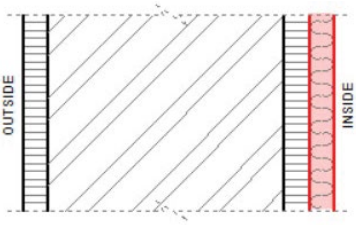


Figure 25: Wall section.

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Plaster Building (Molded Dry	10.0	1250.0	1088.000	0.431	85
2.	ConcreteLightweeight	150.0	950.0	656.900	0.209	35
3.	Plaster Building (Molded Dry	10.0	1250.0	1088.000	0.431	85
4.	VIP panels	10.0	180.0	800.000	0.007	45

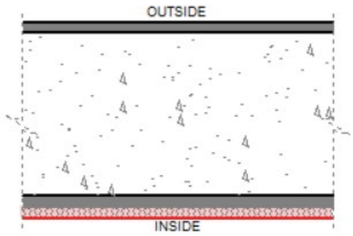
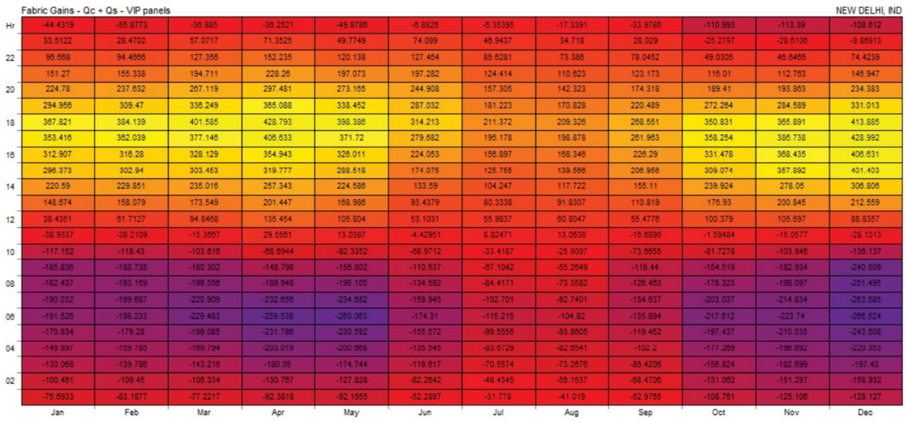


Figure 26: Roof slab section.



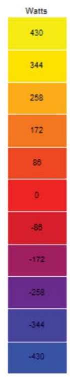


Figure 27: Rate of heat transfer through the envelope of model having VIP panels over interior side of wall.

Model A: Base model with Brick wall, single glazed windows, concrete slab roof and concrete floor above soil base.

Model B: Double glazed with aerogel granules filled in between was used in windows.

Model C: Aerogel insulation panels over wall as well as underside of slab was used.

Model D: Nansulate paint coating was used walls and roof.

Model E: VIP insulated panels over wall as well as underside of slab was used.

CONCLUSION

The world has to move forward with advancement technology and nanotechnology promises to give a better future to the people. The growth of nanotechnology in India is increasing with increase in the economic growth of the country.

Buildings have a significant share in total energy consumed globally. Building materials occupy a great share of this consumption. The incorporation of nanotechnology into the construction industry has served as a groundbreaking research area in modern technology, various industries, and high-efficiency buildings. It is more stable than traditional materials, consumes less energy, and improves the performance of building materials.

Aerogels are the lightest solid material and it reduces the structural load on the building and provide better thermal insulation than other conventional materials.

Vacuum insulation panels serve the best purpose for thermal insulation with the least thickness and increasing the floor area.

Phase change materials such as photo chromatic glasses which changes the color of glass if there is greater heat gain in the building through glass. Better application of insulation in glass has been inferred.

Nasulate translucent PT insulating coating significantly reduces energy consumption and reduces condensation. All wall panels are coated to increase the building's energy efficiency and sustainability. To provide low VOC and anti-mold coatings to improve air quality.

From the simulation analysis with the help of Ecotect Analysis tool 2011, it has become clear that Nano based materials help to reduce the energy consumption in buildings. As Nano based materials provides better thermal insulation which results in reducing the fabric gain/ heat transfer through the building envelope.

This research shows that the maximum heat transfer is achieved by Base model (i.e., Model A) with conventional materials, as it results the maximum fabric gain inside the building is 1400 watts. While the model B with double glazed with aerogel granules filled in between used in windows has resulted in the minimum heat transfer i.e. 230 watts.

In the models C, D & E the fabric heat gain/transfer is minimum in model E then in model C and maximum in D. From all the above models, Model B with double glazed windows with aerogel filled in between glazing (U value 1.040 $W/m^2{\cdot}K$) is tested to prove to be a better insulation material among all models.

So, the final results show of heat transfer values of various models along with base models in ascending order of heat transfer are as follows:

Model B < Model E < Model C < Model D < Model A

The application of Nanotechnology in building materials has made it possible to reduce significant amount of reduction in energy consumption in buildings as well as achieving greater floor area by reducing the thickness of insulation material along with increasing its energy efficiency which overall results in the reduction of the cost of the building.

This is a particularly important perspective given that a high percentage of all energy consumed is consumed by commercial and residential buildings (including heating, lighting and air conditioning). However, the drawbacks in production are the intensive energy consumption and the huge costs.

In research and development sector that improves the properties of building materials and introduces high-performance, state-of-the-art insulation materials based on nanotechnology. The outcomes of this research provide valuable insights and guidance for architects, engineers, and policymakers involved in sustainable building design and construction. The integration of advanced nano-based materials can play a pivotal role in achieving energy-efficient and environmentally friendly buildings. As well as the advancements in nanotechnology and ongoing research in nano-based materials hold the potential to revolutionize the construction industry, leading to the development of innovative, energy-efficient, and sustainable building solutions for a greener future.

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