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A Comparative Study of Advantages of using Phase-Changing Materials over Conventional Building Materials for Achieving Thermal Comfort

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ABSTRACT

Recent advancements in building materials and technology have led to the improved thermal performance of the new materials, which is one of the important factors in contributing to energy conservation in the building sector. There are various types of advanced building materials available now that can positively contribute toward achieving energy efficiency in a building. Low-energy building materials, Nano-materials, Green materials, and Phase-change materials are some of the major players as energy-saving materials. Out of which, Phase change materials (PCM) have a tremendous capacity to store energy and release it when temperature variation occurs in or outside the building. A wide range of Phase change materials is available according to the purpose and application in a building component. This research illustrates how the PCM helps in reducing the cooling and heating load of a building, thereby saving energy.

Keywords- Green materials, Heating load, Insulation, Nanomaterials, Phase change material

INTRODUCTION

Advancement in technology has led to a tremendous increase in the energy load of a building. The major share of the energy load of a building depends on the heating and cooling load. This energy is mostly generated by burning fossil fuel (which converts the resultant heat energy to electrical energy). Due to this generation process energy bills in the form of electricity, services, and maintenance of equipment have become costly and polluting. Various strategies have been applied such as solar passive architecture, green building strategies, facade treatment, bio-climatic design, vernacular architecture, etc., in order to achieve energy efficiency in a building. The implementation of these strategies and services in the initial construction phase is becoming a growing costly upfront, in order to get a payback period after 7-8 years.

There are various types of advanced building materials that can contribute toward achieving energy efficiency in a building, namely:

1. Low energy building material
2. Nano-materials
3. Green materials
4. Phase-change material

Low Energy Building Material

The amount of energy used in extraction/ manufacture/ production and associated transportation is known as embodied energy. The material which has low embodied energy should be used for construction to encourage energy-saving and resultant pollution. The material which is locally sourced and used in unprocessed form can be widely termed as low-energy material (Table 1). The main benefits of low-energy materials are-

1. They minimize the energy required to run the building.
2. Low-energy building material can be recycled, reused, and recovered.
3. This material can be used in unprocessed form.
4. They contribute to healthy indoor environments.
5. The overall energy usage of buildings can be decreased drastically.

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Table 1: *Embodied energy in various walling and floor/roofing systems [1].*

Type of Building Element	Embodied Energy Per Unit (GJ)
Burnt clay brick masonry (m3)	2.00–3.40
SMB masonry (m3)	0.50–0.60
Fly ash block masonry (m3)	1.00–1.35
Stabilized rammed earth wall (m3)	0.45–0.60
Un-stabilized rammed earth wall (m3)	0.00–0.18
Reinforced concrete slab (m2)	0.80–0.85
Composite SMB masonry jack-arch (m2)	0.45–0.55
SMB filler slab (m2)	0.60–0.70
Un-reinforced masonry vault roof (m2)	0.45–0.60

Nano-Materials

Nanomaterials are the material created by changing the property through reaction, combustion, and specialized engineering at the nanoscale [1-100 nanometer (nm) at one of its dimensions] [2]. The technology involved in designing and improving the performance of nanomaterials is nanotechnology. The property of nanomaterials gives the best performance when implemented in building materials or technology. The property of nanomaterial positively Strength; Hardness; Elasticity; Plasticity; Brittleness; Fatigue; Impact strength; Abrasion resistance and also depends on application and usage as a building element (Table 2) [3]. The benefits of Nanomaterial's are

1. Due to the size of a nanomaterial, it offers more advantages as compared to other bulk materials. In manufacturing, adding on other materials and benefits according to the requirement of nanomaterials led to increasing demand in various building industries [4].
2. Nanomaterial has contributed to more advancement in energy generation methods, such as solar panels becoming more efficient and cost-effective when carbon nanotubes have been introduced.
3. In the electronics and building appliances industry, nanomaterials has increased the accuracy of circuits at the atomic level which lead to the advanced development of all electronic products [5].
4. In the medical industry, nanomaterial has increased the likelihood and combating the disease of medicines.

Table 2: *Use of nanomaterial in existing building materials and their prospects.*

Sr. No.	Materials	Nanomaterial	Prospects
1	Cement	Carbon nanotubes Polypropylene nanofiber	improve strength Resistance against fire
2	Concrete	Carbon nanotubes SiO_2, Fe_2O_3	Sufficient reinforcement Fraction prevention
3	Steel	Copper nanoparticles	Improve oxidation resistance Improve weld quality
4	Tints/coating	TiO_2 Silver nanoparticles	Anti-dirt Bacteria and bug-killing ability
5	Solar cells	Cover shade / TiO_2 Carbon nanotubes & C60 CdSe quantum dots	More efficient application of solar energy
6	Sensors	Carbon nanotubes	On-time structure safety evaluation

Green Materials

The aim of using green building materials is to construct energy-efficient structures and to build those structures; awareness should be generated of different green building materials, their properties and how they contribute to saving energy (Table 3) [6].

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Table 3: *Types of Green materials and their use.*

Sr. No.	Green Building Material	Use	Feature
1.	Recycled Steel	Steel Beam	Recycled steel from scrap parts can be used to make beams that can be used in an earthquake-prone area.
2.	Insulating Concrete Forms	Between Two Insulation Layers	Binding material and most durable form of work.
3.	Plant-Based Polyurethane Foam	Insulation	It offers high resistance to moisture and heat and protects against mould and pests. It insulates better than fiberglass or polystyrene.
4.	Straw Bales	Roof and Wall as Insulating Material	They can last for hundreds of years, and they bond well to plaster and external render.
5.	Cool Roof	Roof	It will improve heat dissipation and will considerably lower temperatures in your home during summer, which in turn decreases the air conditioning load
6.	Structural Insulated Panels	Foam Insulation Sandwiched Between Plywood or Cement Panels	It is fire resistant and suitable for floors, basements, foundations as well as load-bearing walls
7.	Plastic Composite Lumber	Cladding Material	The manufactured from waste plastic and wood fiber, it is more durable and less toxic than conventionally treated wood.
8.	Low-E Windows	Window	They reduce heat during summer and block infrared radiation. They have a clear coating of metal oxide. It also helps keep the heat in during the winter. They can reduce heat flow by up to 50%.
9.	Vacuum Insulation Panels	Commercial Refrigeration Units	They comprise a textured silver rectangle that encloses a core panel in an airtight envelope. All of this means heat loss will be reduced to a minimum.
10.	Earth	Wall, Floor	Walls made from the earth provide an excellent thermal mass, and it is up there with other renewable sources of building materials

Phase-Change Material

Enhancing the thermal energy storage capacity of the building envelope by incorporating PCM is one of the sustainable methods of regulating indoor temperature [7]. Phase change material (PCM) has a tremendous capacity to store energy and release it when temperature variation occurs in or outside the building [8]. PCM has the property to prevent loss of energy when particles change from solid to liquid or liquid to solid. The main advantage

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of PCM is that the material itself organizes the structure where there is a new thermodynamic phase.

NECESSITY OF PHASE CHANGE MATERIAL

Buildings account for 40% of global energy consumption and greenhouse gas emissions and play a pivotal role in global warming [9]. Over the last two decades, it is observed that there is wide research being done in energy conservation in the building sector. Building material as a major component in a building contains high embodied energy (like Aluminium, steel, copper, composites, etc.). In order to reduce the embodied energy phase change material can be preferred over other high-energy building materials (Table 4).

Types of Phase Change Materials

Phase Change Material		
1. Organics	**2. Inorganics**	**3. Eutectics**
• Paraffin • Non-Paraffin	• Salt Hydrate • Metallic	• Organic-Organic • Inorganic-Organic • Inorganic-Inorganic

Table 4: *Types, Characteristics and building components of PCMs [2].*

Sr. No.	PCM Types	Advantages	Building Component
1.	Organics (Paraffin wax, fatty acids, and vegetable oils)	Availability in a wide temperature range • High heat of fusion • No sub-cooling • No segregation • Stable after many cycles • Chemically and physically stable • Compatibility with a wide range of containers • Corrosiveness materials • Environmentally safe, nonreactive • Recyclable	Organic PCM is used as Insulation in roof
2.	Inorganic (Salt hydrates)	• High thermal storage capacity • Good thermal conductivity • Low cost • Available easily • Sharp melting points • Low vapor pressure • Non-flammable	Inorganic PCM is used as insulating material in exterior glass in facade treatment.
3.	Eutectic	Sharp melting and boiling points • Higher volumetric storage density than the organic PCM	Eutectic PCM can be used in false ceilings, interior walls and also embedded as ceiling material

Application of PCM in a Building

Some major applications of PCM in buildings are given here (Fig 1 a), b), c), d)):-

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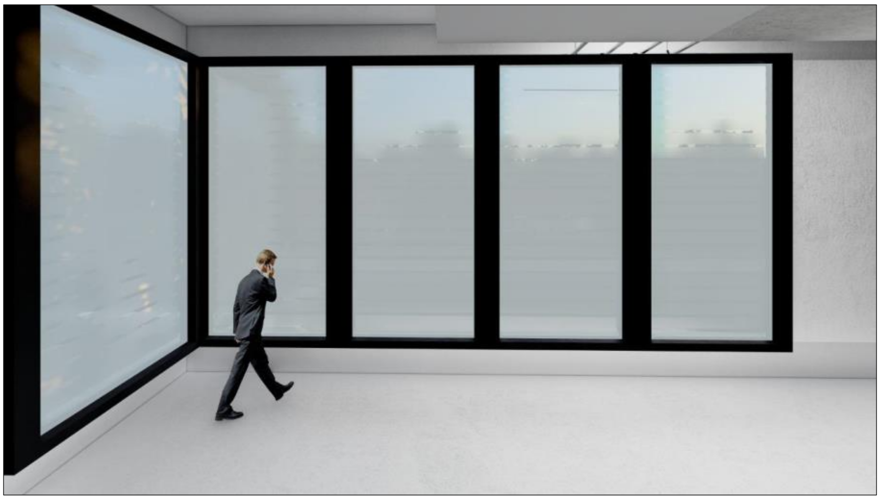

Figure 1 a): *Inorganic PCM that contain salt hydrants can be embedded between the glass panel which acts as thermal insulation and helps in reducing the effect of hot and cold air inside the building.*

Figure 1 b): *Eutectic PCM is mixed with a layer of concrete and has excellent thermal storage capacity which is useful to maintain temperature for the entire room throughout the day.*

Figure 1 c): *Eutectic PCM can be incorporated inside the drywall for use in interior walls which makes it less costly and has high thermal storage as compared to conventional walls.*

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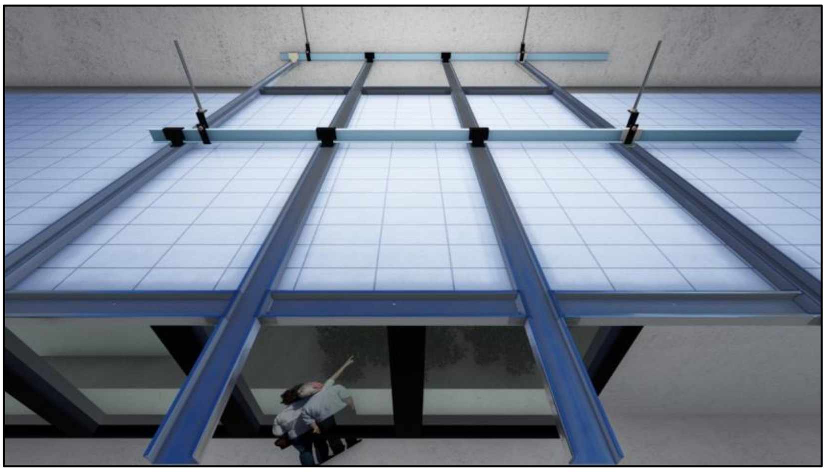

Figure 1 d): *Organics PCM is embedded as ceiling material or false ceiling as it has higher thermal storage capacity.*

Benefits of Phase Change Material over Conventional Materials

1. In the future, Modern architecture will consist of building components that should be attractive, flexible, and light weight. PCM material is an alternative modern building material that is lightweight, low cost, durable, and can be used in attractive interior works.
2. Phase change material can be used as insulation, ventilation [10] interior work, false ceiling, exterior wall finishes, roof insulation, and facade treatment.
3. Phase change material has the capacity to store a large amount of thermal energy per unit mass as compared to common conventional building material [5].
4. It requires less amount of initial embodied energy in the production and manufacture of the material.
5. PCM can store and release energy in the form of latent heat in order to maintain indoor temperature which is required to achieve thermal comfort for occupants living inside the building. PCM is widely used for energy storage applications worldwide [3].
6. PCM material can be used to regulate the temperature throughout the daytime as well as night time. Latent heat storage using phase change materials (PCMs) can be used for free-cooling purposes due to their high storage density [7].
7. PCM material can reduce or omit the usage of the HVAC system which again reduces the electricity bill and cost of installation of AC or HVAC system
8. PCM material is widely used in all elements of building envelope [6, 9] in various types of building such as residential, commercial, and educational buildings.

A comparison is made here to better understand the advantages of PCM in Table 5:-

Table 5: *Comparative analysis of conventional building material with phase change material.*

	LOW ENERGY B.M.	NANO MATERIAL	GREEN MATERIALS	PCM
Embodied energy	★★	★★★	★★	★
Affordability	★	★★	★	★
All-weather suitability	★★★	★★★	★★★★	★★★★
Used in building components	★★★★	★★★	★★	★★★★
Non-polluting	★	★★	★	★

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Sustainability	★★★★	★★★	★★★★	★★★★
Suitable for mass construction	★★★★	★★★	★★★★	★★★★
Durable	★★★	★★★	★★★	★★★★

★-LEAST ★★- LOW ★★★-MEDIUM ★★★★-HIGH

CONCLUSION

The Study conducted in this paper shows how nanomaterial and green materials incorporate less embodied energy and are environment-friendly materials, so can be considered sustainable building materials. The future innovative approach in building material is the PCM which helps in reducing the cooling and the heating load of a building as it is thermal heat storage, which uses latent heat from converting from solid to liquid and vice versa to achieve the required temperature according to the type of building and use of occupant working/living in that building.

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