International Research Journal of Education and Technology
Peer Reviewed Journal
ISSN 2581-7795

INVESTIGATION ON INTEGRATION OF PHASE CHANGE MATERIALS AND HEAT PUMP IN THE ROOF OF A BUILDING FOR BUILDING EFFECTIVE COOLING.

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ABSTRACT:

This research seeks to synthesize a hybrid radiant cooling system which not only cools the space but also heats water. The system employs Phase Change Materials (PCMs) to improve performance and heat pumps to reduce energy and enhance sustainability. PCMs capture and release thermal energy so that temperatures are maintained indoors while heat pumps control the thermal transfer. Uniform temperature and thermal comfort is ensured with aluminum and copper pipes. PCMs incorporated in the roof can capture excessive heat in the daytime and release this at night in order to reduce the need for cooling. Heat pumps are able to control off peak cooling and peak demand efficiently and hence energy costs and load on the grid are brought down. Among the key ingredients to designing this integrated building are PCM selection, its structural integration and control algorithms. Life Cycle Assessment shows a significant potential for energy saving, emissions reduction and improvement in thermal comfort. The present study outlines a novel approach which is highly relevant for sustainable building design.

KEYWORDS:

Phase Change Materials (PCMs)
Latent heat storage
Off-peak cooling
Peak load demand reduction
Life Cycle Assessment (LCA)
Structural integrity
Sustainable building design

1. INTRODUCTION:

Today the world is still heating up, but people are more fond of air conditioning units despite their expensive energy costs. What can be achieved in such a case? This research addresses a radiant cooling element coupled with a heat pump system that uses PCM and The Point Of its temperature for melting. 18C degree PCM is assimilated in the building roofs and used for thermal energy storage. Heating, when implemented in this manner, avoids reliance on active cooling strategies in most cases. Heat pumps utilize PCM cooling in low demand periods and PCM charging in peak demand periods leading to reduced load on the grid and energy consumption. The load on the system is strategically controlled to maintain safety and allow for real time performance modification. The high latent heat storage of PCM allows it to be used in energy efficient cooling which decreases the amount of pollution produced. Organic, inorganic, or eutectic PCM types are used and tempered with such specifications including melting points, stability, thermal conductivity to support the construction and renewable energy systems. This novel strategy reveals huge promise for the future of sustainable building solutions.

2. OBJECTIVE:

The aim of this project is to fabricate the radiant building cooling system with and without PCM for hot water from a single hybrid system. The main objective of integrating PCM with heat pump is to increase the performance of the heat pump radiant building cooling System. This helps to reduce the power consumption at home. This allows space cooling and hot water from a Single Hybrid System. This system helps to provide a sustainable energy solution for building cooling and hot water.

3. PROBLEM IDENTIFICATION:

The use of heat control building material systems has become important in facets of design considering the increasing demand for energy- efficient cooling in buildings . In a much wider context, high performance building systems address the same energy problem in a holistic way instead of losses related to energy emittance. Maximising the use of passive heat retention and natural ventilation becomes feasible with the use of biophilic designs with phase change materials (PCM) integrated into the walls and ceilings. This integration focuses on minimising indoor temperatures and energy usage, thereby offering an environmentally friendly cooling solution. Investigating this area of study will help understand the prevailing gaps in building designs towards the ultimate goal of minimization of energy consumption in the buildings’ heating and cooling systems. This research will evaluate thermal energy retention PCM materials to reduce energy costs while increasing indoor thermal comfort for heating-dominated buildings.

4. METHODOLOGY:

4.1. Design and Engineering:

Utilize computer-aided design (CAD) software: To model and optimize the system's performance, ensuring efficient heat exchange, proper airflow distribution, and effective utilization of PCM materials. Develop detailed design specifications: For the radiant cooling system, including component selection, system layout, and integration of PCM-based thermal energy storage with refrigeration technology.

4.2. Prototyping and Modelling:

Construction: Build prototypes of the radiant cooling system to validate design concepts, functionality, and performance under controlled laboratory conditions.

Smart Monitoring Systems: Integrate sensors and DAQ technology to monitor the cooling capacity, power output.

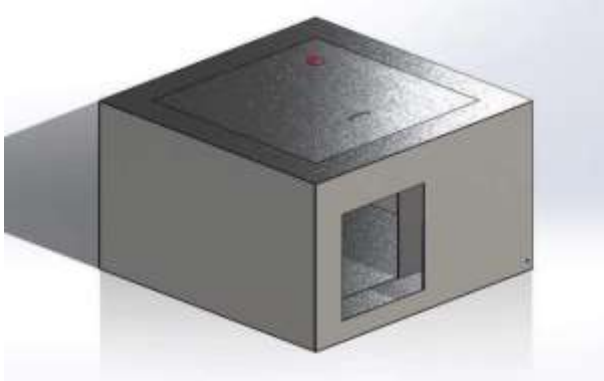

Fig-1: Isometric view of the system

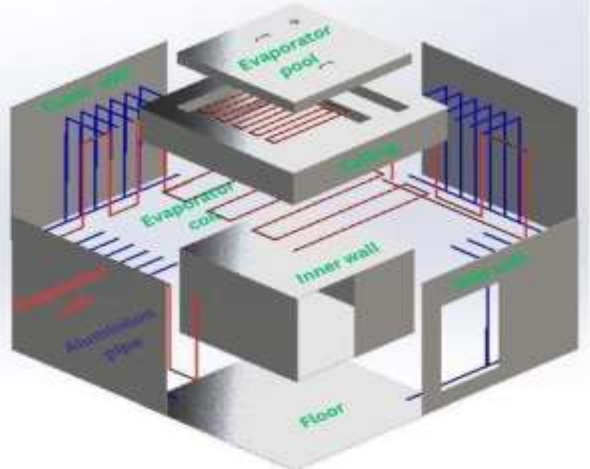

Fig-2: Exploded view of the system

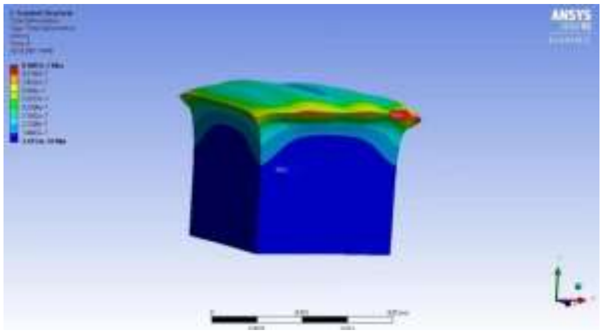

Fig-3: Thermal analysis of the system

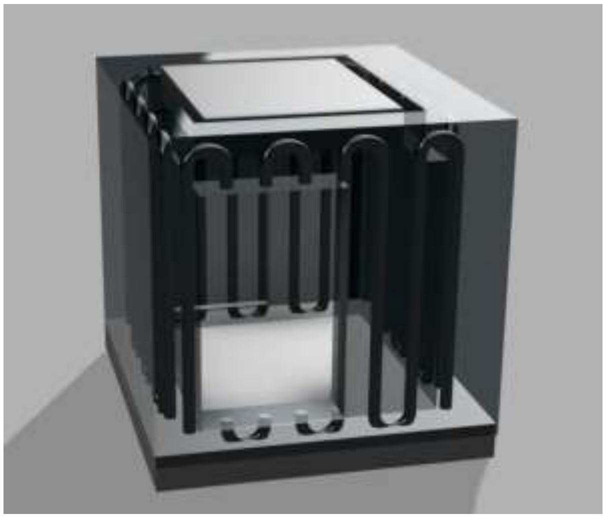

Fig-4: Cross sectional view of the system

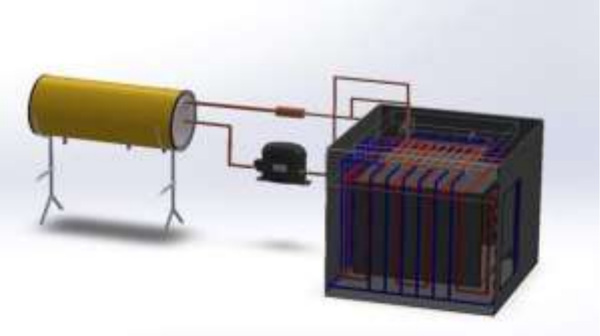

Fig-5: Complete view of the system

5. PROPOSED METHODOLOGY:

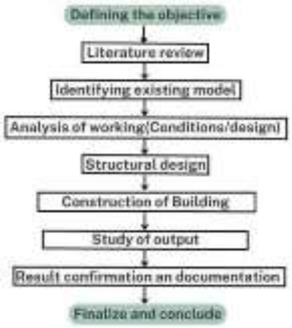

Fig-6: Workflow diagram

Fig-7 : Flow chart

TOPCS	WITHOUT PCM	WITH PCM
Daily Energy Consumption	Daily Energy (kWh)=0.746 kW×24 hours=17.904 kWh	Daily Energy (kWh)=0.746 kW×12 hours =8.952 kWh
Monthly (30 Days) Energy Consumption	Monthly Energy (kWh)=17.904 kWh/day×30 days=537.12 kWh	Monthly Energy (kWh)=8.952 kWh/day×30 days=268.56 kWh
Bimonthly (60 Days) Energy Consumption	Bimonthly Energy (kWh)=17.904 kWh/day×60 days=1,074.24 kWh	Bimonthly Energy (kWh)=8.952 kWh/day×60 days=537.12 kWh
Semiannual (6 Months or 180 Days) Energy Consumption	Semiannual Energy (kWh)=17.904 kWh/day× 180 days=3,222.72 kWh	Semiannual Energy (kWh)=8.952 kWh/day×180 days=1,611.36 kWh
Annual (365 Days) Energy Consumption	Annual Energy (kWh)=17.90 kWh/day×365 days=6,537.96 kWh	Annual Energy (kWh)=8.952 kWh/day×365 days=3,267.48 kWh
Monthly Cost	Monthly Cost=537.12 kWh×6.75 ₹/kWh=₹3,623.06	Monthly Cost=268.56 kWh×6.75 ₹/kWh=₹1,812.78

Semiannual (6 Months or 180 Days) Energy Consumption	Semiannual Energy (kWh)=17.904 kWh/day×180 days=3,222.72 kWh	Semiannual Energy (kWh)=8.952 kWh/day×180 days=1,611.36 kWh
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Table-1: Cost Analysis

WITHOUT PCM	WITH PCM
1 Month: ₹3,623.06 2 Months: ₹7,246.12 6 Months: ₹21,738.36 1 Year: ₹44,628.73	1 Month: ₹1,812.78 2 Months: ₹3,623.06 6 Months: ₹10,869.18 1 Year: ₹22,555.49

Table-2: Summary of cost.

6. CHOICE OF COMPONENTS:

6.1. Reciprocating Compressor:

The Max Flow Rate (CFM) of the compressor is 501CFM. The Power Consumption Capacity is approximately 80 to 120 watts. The capacity depends on factors like desired cooling temperature and the efficiency of refrigerator insulation. The Voltage and Frequency is typically designed for 220-240V and 50-60 Hz for residential use. Common refrigerants include R134a or R600a, chosen based on environmental regulations and energy efficiency.

6.2. Refrigerant:

Refrigerants are used in various applications to transfer heat and create cooling effects. The primary use of refrigerants is in refrigeration and air conditioning systems.. The most common refrigerants in use today are hydrofluorocarbons (HFCs) and hydrofluoroolefins (HFOs).R-134a, also known as 1,1,1,2-Tetrafluoroethane, is a hydrofluorocarbon (HFC) refrigerant. It is commonly used in various cooling and air conditioning applications.

6.3. PCM:

During the daytime when ambient temperatures rise, the PCM absorbs excess heat from the environment and undergoes a phase change from solid to liquid. This absorption of heat helps to keep the indoor temperature lower and prevents overheating of the building. When temperatures drop, the PCM releases the stored thermal energy as it changes back from liquid to solid. This process helps to cool the indoor environment when external temperatures are cooler, contributing to energy savings. Paraffins are a type of organic PCM commonly used in building applications.

6.4. Copper Pipe:

Copper pipes are commonly used in cooling systems for several reasons, primarily due to the beneficial properties of copper in heat transfer and its resistance to corrosion. Up to 1 ton: Suction line is 1/2,Liquid line is 1/4. Copper is compatible with various refrigerants commonly used in cooling systems. It does not react adversely with refrigerants, ensuring the efficiency and longevity of the cooling system.

6.5. Condenser:

The condenser in this system is where the high-pressure, high-temperature refrigerant gas from the compressor releases heat to 100 Litre tanks. It is used to absorb the heat from the refrigerant. This process causes the refrigerant to condense into a liquid state.

6.6. RTD Sensor:

Resistance Temperature Detector sensors to monitor and control temperatures within buildings. They help maintain comfortable and energy-efficient indoor environments. RTDs are known for their high precision and stability over a wide temperature range. They provide a reliable and repeatable output proportional to the temperature. RTD sensors are based on the principle that the electrical resistance of certain materials, such as platinum, changes predictably with temperature. The measuring range of an RTD is -200* to 500* C.

6.7. Capillary:

The primary function of a capillary tube is to act as a flow restriction device in a refrigeration or air conditioning system. It helps control the flow of refrigerant between the high-pressure side (condenser) and the low-pressure side (evaporator).This pressure drop helps in reducing the pressure of the refrigerant, allowing it to expand and absorb heat efficiently in the evaporator.

6.8. Pressure Sensor:

Pressure sensors are employed to monitor the pressure of the refrigerant. This helps in maintaining the appropriate pressure levels for efficient heat exchange, ensuring that the cooling process is effective.

7. RESULT AND DISCUSSION:

In this section, the results from simulations or experimental analyses of integrating phase change materials (PCMs) and heat pumps in roofing systems are discussed in terms of cooling performance, energy savings, thermal comfort, and economic feasibility.

7.1. Cooling Performance:

7.1.1. Temperature Reduction:

The results indicate that there is significant lowering of peak surface as well as interior temperatures of roofs covered with embedded PCMs and attached heat pumps. Heat increase is taken in by the PCM, thus lowering the temperature that is transmitted to the indoors.

7.1.2. PCM Performance:

Wood and paraffin based PCMs were effective on melting point which are a great combination since it has a latent heat capacity. Materials with a melting point equal to or slightly above average daytime temperatures have good performance ratios because they have a long time in latent heat phase transition. Paraffin based PCM exhibits fairly good performance owing to the combination of high latent heat capacity as well as thermal stability.

7.2. Energy Savings:

7.2.1. Reduction in Cooling Load:

Buildings with PCM integrated roofing reported the least cooling loads in the high diurnal temperature range. simulation studies have shown that, on average, electric energy from the HVAC system was reduced by 10-20% with greater savings occurring during peak times often experienced in summer months.

7.2.2. Heat Pump Efficiency:

The integrated system permitted greater efficiency of the heat pump system. Intermediate heating and low power operation further decreases energy consumption as the heat pump was only required when PCM was too hot.

7.3. Thermal Comfort:

7.3.1. Indoor Temperature Variability:

According to the data, there were lower variations of temperatures within the day and during the night which enhanced the comfort of the occupants. The PCMs managed to transfer heat energy at a slow rate which eased the temperatures in the early evenings hours when otherwise the temperatures would have been high.

7.3.2. Humidity and Air Quality:

As the system did not add moisture, there was no such increase in humidity level. This demonstrates that there can be no adverse effects on air quality management with the aid of PCM-heat pump systems.

7.4. Economic Feasibility:

7.4.1. Cost Analysis:

It has to be accepted that the initial outlay for the integration of PCM and heat pumps are more when compared to conventional roofs. However, this investment also has a positive return Was estimated to be within 5-8 years given the energy rates and climate to be normal which is not the case in many areas of the world.

7.4.2. Maintenance Considerations:

PCM portions needed little attention as far as maintenance was concerned but in the case of the heat pump, this was not the case as the system had to be maintained often. This further enhances the economic side as maintenance cost is not big.

7.5. Environmental Impact:

7.5.1. Carbon Emissions:

Decline energy use means lesser emissions and therefore the PCM-heat pump system assists in reducing the amount of greenhouse gases and therefore is a solution for design within green buildings.

7.5.2. Possibility of System’s Integration with Renewable Sources:

The system is compatible with renewable energy sources, thus if it is used along with solar panels or other sources, further reduction in environmental impact is possible.

The obtained results confirm the hypothesis that integration of PCM and heat pumps in roof structures of buildings can be used to lower temperatures in the interior space while saving energy and improving comfort of the occupants.

The combination of passive cooling from PCMs and active cooling with hot pumps makes the building design flexible and suitable especially in areas that experience high temperature day and night differences. Nonetheless, awareness of the effectiveness of PCM, climate and engineering design of the building must be noted. Also, the economic aspect is dependent on energy prices, which has a better return on the investment of regions with expensive electric bills.

The test results imply that PCM-heat pumps systems, which are likely to be more expensive initially, are sound and efficient solutions that advance green building goals and lead to cost savings over the life cycle of the structure. Future work could develop improved PCM formulations and more sophisticated control methods which together would achieve even better energy efficiency and economic performance of the building system.

8. CONCLUSION:

The combination of PCMs with heat pumps into the roofs of buildings may be one of the most promising passive, energy-efficient, and green solutions for cooling. The results presented here are the ability of PCMs to periodically adjust their heat storage capacity by absorbing heat and reducing the need for active cooling during peak daytime hours, which is best complemented by a heat pump that gives additional cooling when required. Together PCMs and heat pumps work to stabilize indoor temperatures, enhancing the comfort of building occupants while reducing energy consumption, especially in regions with high diurnal temperature swings. The results obtained provide at least a general insight into the possibility of reducing the cooling load of a building by up to 20%, thus allowing the potential for significant long-term cost savings and reduced greenhouse gas emissions. Attractive payback periods can be achieved, even though the initial capital cost of investing in a PCM-heat pump system may be relatively high compared to a conventional system.

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