The growing role of Phase Change Materials in passive cooling and heating

DR. AMAR RATAN
Research and Development Scientist
Pluss Advanced Technologies Ltd.

Buildings are becoming harder to cool and more expensive to run. Rising temperatures, dense urban development, and growing pressure on electricity networks are forcing designers and operators to look beyond conventional air conditioning. Globally, buildings account for close to 40% of total energy consumption, much of it linked to cooling and heating. In countries like India, where summer temperatures often cross 45°C, this dependence on mechanical cooling is no longer practical in the long term.

Phase Change Materials (PCMs) are increasingly being explored as a passive alternative. These materials store and release heat when they change phase, typically from solid to liquid and back again. For building applications, this phase change usually takes place between 20°C and 28°C, a range that aligns reasonably well with indoor comfort requirements.

When PCMs are integrated into walls, roofs, ceilings or floors, they act as thermal buffers rather than barriers. As indoor temperatures rise during the day, the material absorbs heat and melts, slowing the rate at which spaces warm up. When temperatures fall, the material solidifies and releases the stored heat gradually. The result is a more stable indoor environment and reduced reliance on active cooling or heating systems.

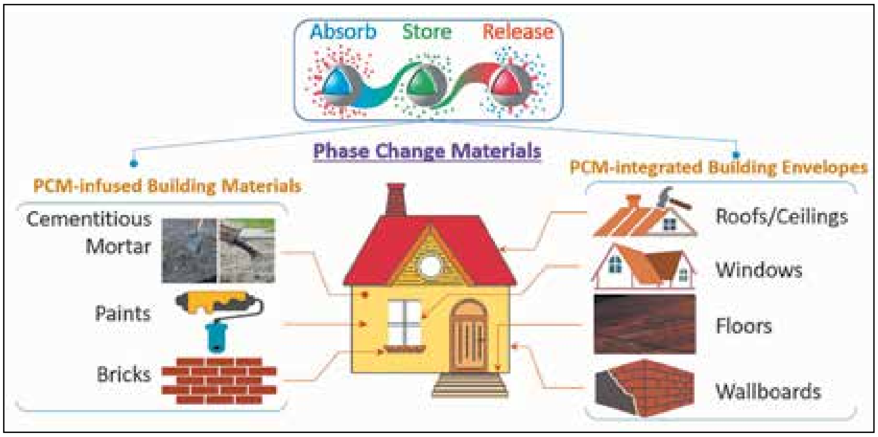
Several types of PCMs are used for such applications. These include organic paraffin waxes, inorganic salt hydrates and, more recently, bio-based formulations. Many of these materials offer latent heat storage capacities of up to 200-kJ/kg. Compared with conventional building materials that rely only on sensible heat storage, this represents a substantial increase in energy storage per unit volume – often five to ten times higher.

In passive cooling applications, PCMs help manage peak heat loads rather than eliminating heat altogether. When incorporated into gypsum boards, false ceilings, roofing systems or green roof substrates, they can delay heat transfer into occupied spaces by four to six hours. Depending on climate and building design, this delay can reduce air-conditioning energy use by 15-40%.

Performance improves further when PCMs are combined with night-time ventilation. Cooler outdoor air at night allows the material to solidify and "reset" for the next day. This approach, often referred to as night-time free cooling, enables PCMs to function without fans or compressors. Studies from hot regions such as Madrid and Phoenix have shown improved indoor temperature stability and better thermal comfort, measured using parameters such as Predicted Mean Vote.

PCMs are not limited to cooling applications. In heating-dominated periods, they can be used to capture and store solar energy. When integrated into south-facing Trombe walls or floors, PCMs absorb heat during the day and release it slowly at night. Salt hydrates with phase-change temperatures below 20°C are commonly used for this purpose, allowing a single system to support both summer cooling and winter heating.

One practical advantage of PCMs is their adaptability. Micro-encapsulated PCMs and shape-stabilised composites can be integrated into prefabricated panels, furniture, window assemblies and ceiling boards. This makes them suitable for retrofitting existing buildings, where extensive structural changes are often not feasible.



PCMs can also improve thermal resilience during power outages. By slowing the rise or fall of indoor temperatures, they help maintain acceptable conditions for longer periods when electricity supply is interrupted.

In India, interest in PCM technology has expanded beyond cold-chain logistics into building and climate-control applications. Companies such as Pluss Advanced Technologies, which have long worked with PCMs in temperature-controlled packaging, are extending these materials into construction-related uses. Improvements in encapsulation and composite design have addressed earlier concerns around leakage and long-term stability. Current PCM-based systems are designed for service lives of 20-30 years.

From a technical standpoint, the energy stored in a PCM system can be expressed using the latent heat relation $Q = m \times L$, where Q is the thermal energy stored, m is the mass of material and L is the latent heat of fusion. When both latent and sensible heat contributions are considered, PCM-based systems outperform conventional materials by a significant margin on a volume basis.

Cost remains an important consideration. PCM integration typically involves higher upfront expenditure than traditional materials. However, lifecycle assessments indicate payback periods in the range of three to seven years, largely due to reduced HVAC energy consumption and lower peak demand. As manufacturing volumes increase and bio-based PCMs derived from agricultural waste become more widely available, costs are expected to reduce further.

At a broader level, PCMs can contribute to more stable electricity demand profiles by reducing daily peaks. This eases pressure on power grids and supports demand-response strategies. Large commercial buildings, in particular, can achieve meaningful reductions in carbon emissions while improving occupant comfort and reducing noise associated with mechanical cooling.

Hybrid systems that combine PCMs with natural ventilation, solar thermal systems or green roofs are also being explored. In such configurations, PCMs help buffer temperature swings, reduce water consumption and improve overall building performance under variable weather conditions.

There are still challenges to address. Selecting the correct phase-change temperature for local climates is critical, as is managing issues such as supercooling in certain salt hydrates. Initial costs can also be a barrier. Ongoing research into bio-based materials and nano-enhanced thermal conductivity is gradually addressing these limitations.

Pluss Climate Technologies is extending PCM applications across energy-efficient buildings, electric vehicles and wearable solutions such as *Brrf*® for heat stress relief. These solutions reduce HVAC energy demand and greenhouse gas emissions by stabilising temperatures during peak fluctuations. Patented PCM-based systems for space heating and solar thermal applications are also being developed to support net-zero energy goals across sectors including healthcare, construction and logistics.

By 2050, nearly 68 per cent of the global population is expected to live in urban areas. In this context, passive thermal management will become increasingly important, particularly in regions facing energy constraints and climate stress. With continued material innovation and supportive building standards, PCMs are likely to play a growing role in how buildings manage heat – quietly, but effectively.

ABOUT THE AUTHOR

Dr. Amar Ratan is a Research and Development Scientist at Pluss Advanced Technologies Ltd., part of the Murugappa Group (CUMI). He works on the development of PCMs for advanced thermal packaging, cold-chain logistics and climate-related applications. He holds a doctorate in chemical sciences and a master's degree in nanotechnology, with experience in nanomaterials, coatings, sensors and supercapacitors. He currently leads the development of PCM-based temperature-controlled packaging under the *Celsure*® brand and is involved in advancing sustainable thermal management solutions across multiple sectors.