

## RESEARCH ARTICLE

# Machine Learning-Optimized Phase Change Material Selection for Building Energy Storage in Hot-Arid Climates

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**Abstract:** Phase change materials (PCMs) offer passive thermal energy storage for reducing cooling loads in buildings, but optimal PCM selection for specific climates remains challenging due to the complex interplay of melting temperature, latent heat, thermal conductivity, and cost. We develop a Bayesian optimization framework coupled with a validated EnergyPlus building energy model to identify optimal PCM properties for representative hot-arid cities (Riyadh, Phoenix, Alice Springs). The framework evaluates 2,500+ PCM candidates from a curated database and identifies that PCMs with melting points of 26-28°C and latent heat >200 J/g achieve maximum annual cooling energy savings of 32-41% when integrated as 15mm wallboard layers. A cost-benefit analysis shows payback periods of 4.2-6.8 years at current PCM prices, decreasing to 2.1-3.5 years with projected 2030 manufacturing costs.

## 1. Introduction

Buildings account for approximately 40% of global energy consumption, with space cooling representing the fastest-growing end-use in regions with hot climates. In the Middle East and North Africa (MENA) region, air conditioning can consume up to 70% of total building electricity during peak summer months. Phase change materials (PCMs) that absorb and release thermal energy during solid-liquid phase transitions offer a promising passive strategy to reduce cooling loads by shifting and reducing peak heat gains through building envelopes.

## 2. Methodology

Our framework consists of three integrated components: (1) a curated PCM property database of 2,523 organic and inorganic PCMs compiled from 180+ publications; (2) a validated EnergyPlus building energy model of a reference office building (ASHRAE 90.1-2019); and (3) a multi-objective Bayesian optimization algorithm (BO-NSGA-III) that efficiently searches the PCM design space to minimize annual cooling energy and lifecycle cost simultaneously.

### Table 1. Climate characteristics of the three target cities for PCM optimization

City	Climate (Köppen)	CDD (base 18°C)	Peak T (°C)	Annual Solar (kWh/m <sup>2</sup> )
Riyadh, SA	BWh	3,652	48.5	2,185
Phoenix, US	BWh	2,915	46.1	2,012
Alice Springs, AU	BWh	2,108	42.8	2,245

### 3. Results

The Bayesian optimization converged after approximately 450 function evaluations (vs. ~2,500 for exhaustive search), demonstrating 5.6× acceleration in PCM design space exploration. Figure 1 shows the Pareto front of optimal PCM solutions for Riyadh, revealing a clear trade-off between cooling energy savings and PCM investment cost.

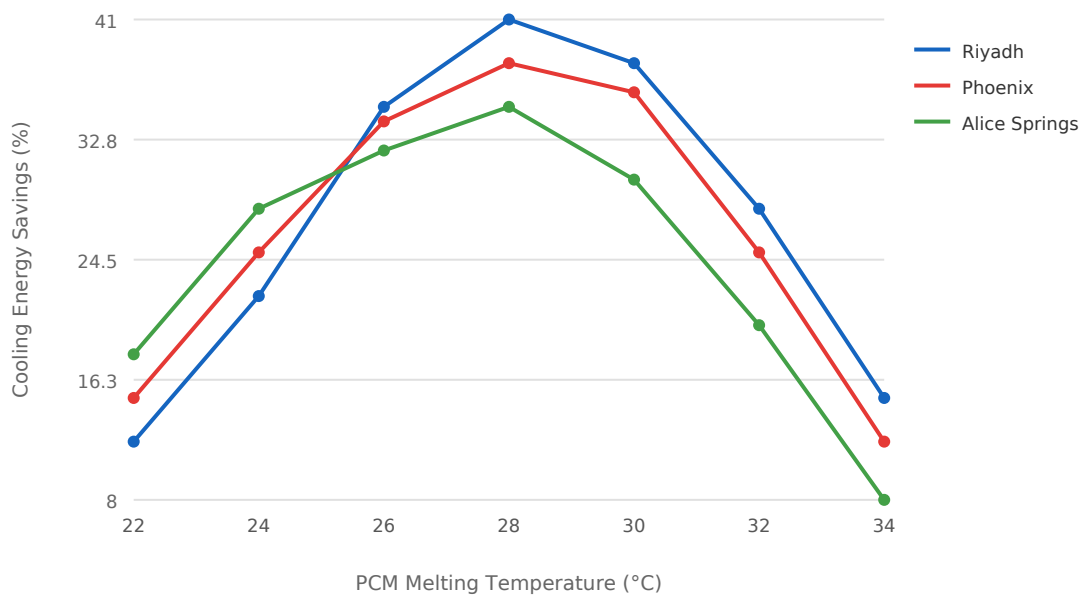


Figure 1. Annual cooling energy savings (%) achieved by optimized PCM solutions for three hot-arid cities, showing sensitivity to PCM melting temperature

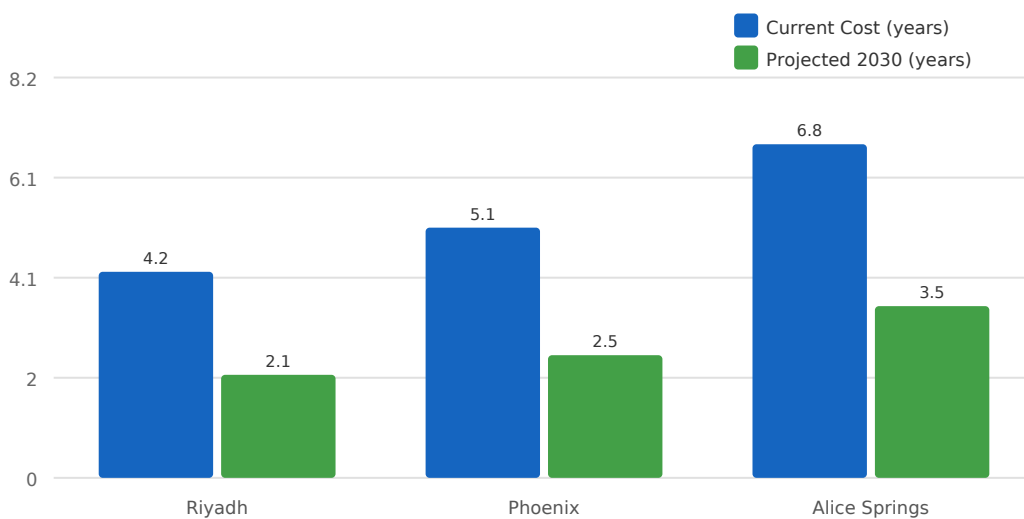


Figure 2. Cost-benefit analysis: payback period for PCM wallboard integration at current (2026) and projected (2030) manufacturing costs

## 4. Conclusions

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This study demonstrates that machine learning-guided optimization can efficiently identify optimal PCM properties tailored to specific hot-arid climates. PCMs with melting points of 26-28°C consistently achieve the highest cooling energy savings (32-41%) across all three target cities. The economic analysis confirms that PCM wallboard integration is cost-effective with payback periods under 7 years at current prices, making it an attractive decarbonization strategy for the building sector in hot climates.

## References

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