Templok

Technical Guide

Armstrong®
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Templok Technical Guide – Table of Contents

INTRODUCTION

Thermal Mass

High-mass materials like concrete and brick can absorb a substantial amount of heat. In buildings, these materials are considered thermally massive because they can dramatically increase a building's thermal 'inertia'. Thermally massive buildings tend to change temperature more gradually, keeping closer to the average of the diurnal temperature variation. This stabilizing effect can delay and reduce the need for mechanical heating and cooling during peak hours, leading to benefits in energy savings, thermal comfort, and sustainability.

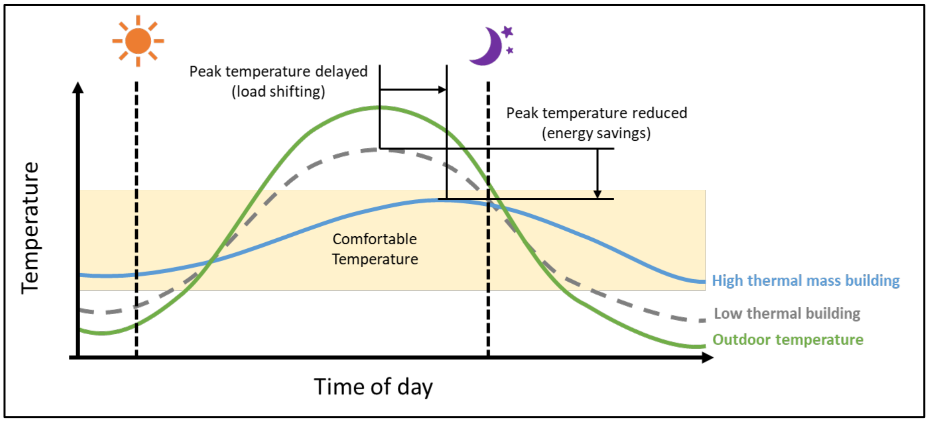
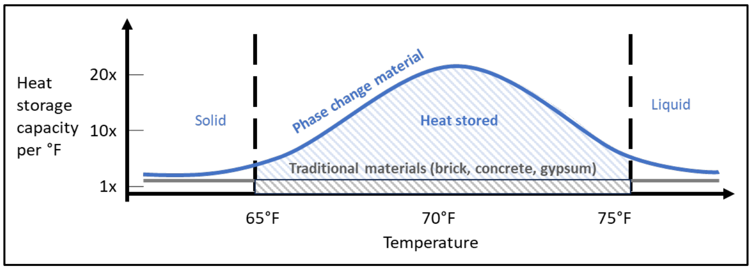


Illustration of temperature variation in thermally massive and light buildings in a climate with warm days and cool nights

Phase Change Materials

When incorporated in buildings, Phase Change Materials (PCMs) increase the thermal mass of the building with minimal added weight and volume, a feature making them effective for transportation and retrofit. PCMs store and release a large amount of heat as they change phase between solid and liquid states. Their peak energy storing capacity is around their melting temperature, where they store latent heat. The term 'latent' means hidden, as this heat does not cause a temperature change but is involved in changing the state of the material. In building interiors, an optimal phase change temperature is typically around 72°F. During phase change the material exhibits high thermal inertia, or resistance to temperature change, as it exchanges heat with its surroundings.

Material	Heat capacity (kJ/m^3 °F)
Brick	1,400
Concrete	2,000
Granite	1,600
Gypsum	800
Acoustical ceiling	240
PCM	20,000



Volumetric heat capacities of traditional thermal mass and a phase change material and illustration of volumetric heat storage capacity of these materials over a range of temperatures.

As a building warms up during the day, the PCM absorbs heat from the air and melts. In a cooling season, the storage of latent heat can help to offset mechanical cooling needs. Later in the evening when temperatures fall, heat releases from the PCM and can be more efficiently removed from the building. In a heating climate, the PCM can retain excess heat from the day to keep the building warmer overnight.

HOW PCM CEILINGS WORK

With its expansive surface area and proximity above heat generating sources in spaces, the ceiling can be an effective building component to store thermal energy. Throughout the day and night, the ceiling absorbs and releases heat in response to changes in air temperature. When the air temperature is warmer than the ceiling, heat flows into the ceiling. When the air temperature falls, heat flows out of the ceiling. In effect, a thermally massive ceiling helps to moderate temperature by absorbing and releasing heat in response to fluctuations in real time.

Passive Cooling

On warm days with cool nights, PCM ceilings can shave peak air conditioning load by providing a passive cooling effect as the building warms up throughout the day. Overnight, as the building's temperature falls, the PCM releases heat and freezes to 'recharge' for the next day.

Illustration of a cooling demand profile with diurnal temperature swing

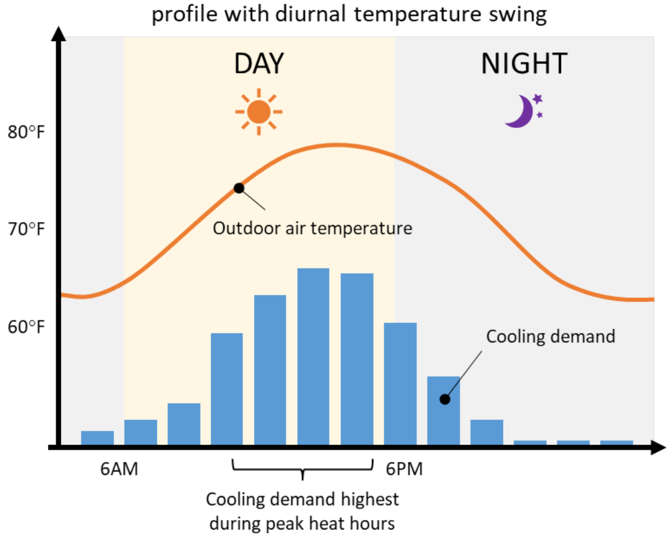
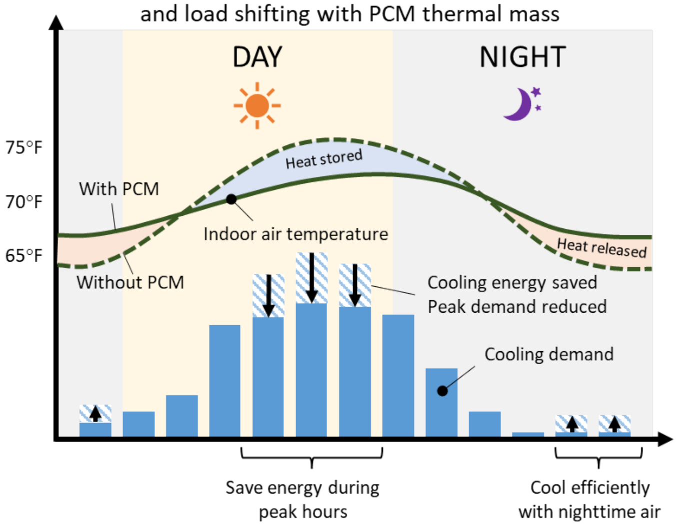


Illustration of peak load reduction and load shifting with PCM thermal mass



When favorable weather conditions allow, automated systems like economizers can induce cool night air to ventilate the building. This 'free cooling' strategy can effectively remove heat from the PCM with minimal energy expenditure. When night ventilation is not possible, the building can be pre-cooled with efficient air conditioning in the cool morning hours. By shifting cooling load to cooler ambient hours, greater efficiency can be achieved. Shifting cooling load can also be cost-efficient as it can lead to lower effective utility rates and demand charges.

Passive Heating

On cool days and in buildings that naturally generate significant heat during the day, PCM ceilings can store excess heat from the day and release it back to the building at night as temperatures fall. This can keep a building warmer at night and reduce the intensity of heating required for morning warmup. The most beneficial applications are in spaces that start the day cool but accumulate a significant amount of heat during the peak hours of the day to an extent that heating is not needed in the afternoon hours. In this case, PCM stores excess heat from the afternoon for 'free' and releases the heat back to the building overnight. Thermal mass is typically less effective in buildings in very cold climates with low internal load and deep nighttime setbacks.

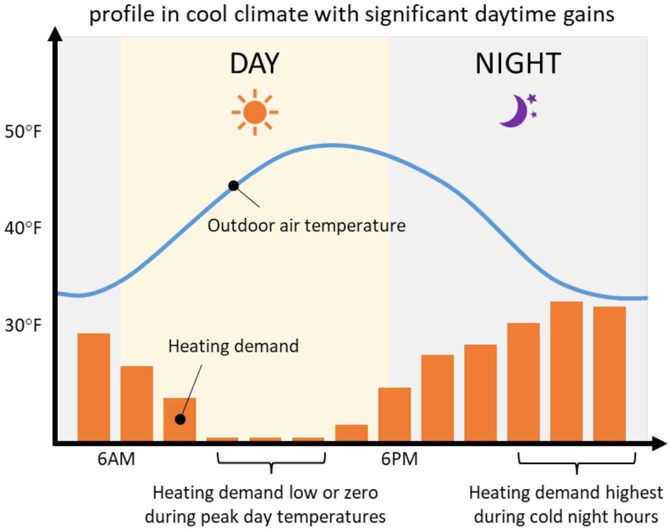


Illustration of a heating demand profile in cool climate with significant daytime gains

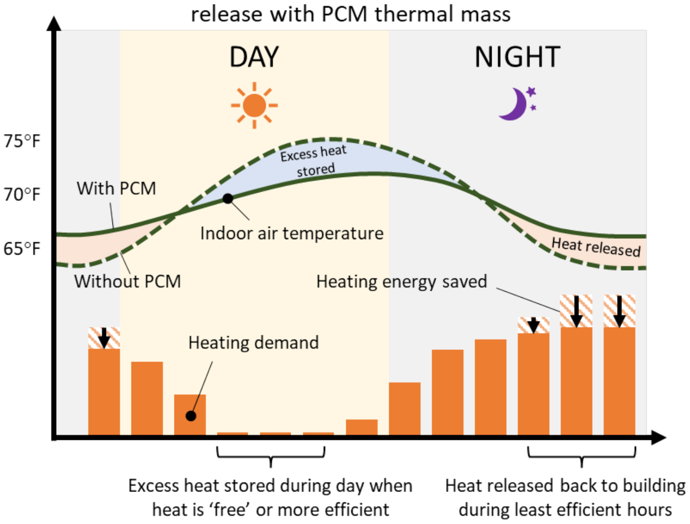


Illustration of excess heat storage and release with PCM thermal mass

Temperature Stabilization

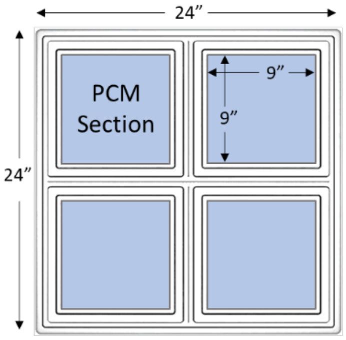
In spaces with intermittent loads throughout the day, thermal mass in the ceiling can help to stabilize the temperature. In spaces like conference rooms or building perimeters with intermittent occupants and solar gains, temperature management can be a challenge. The buffering effect of thermal mass can help reduce overheating or overcooling issues and save energy where such inefficiencies or thermal comfort issues may otherwise occur.

Ultima® Templok® Ceilings

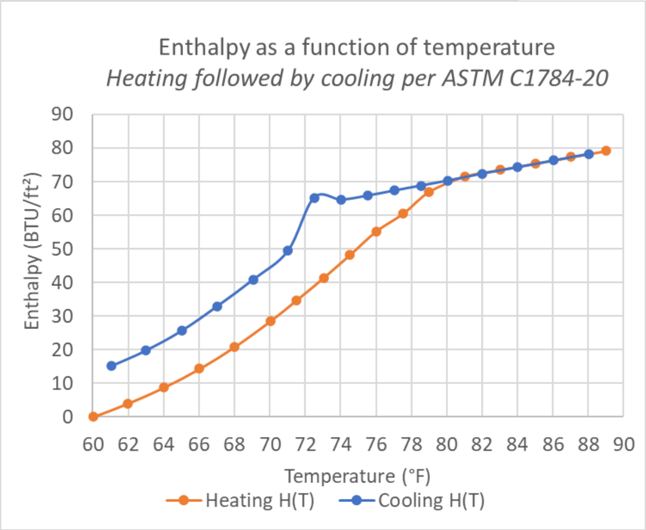
Thermal Properties			
Property	**Value**	**Test Method**	**Notes**
Peak performance range	70-75°F	Heat Flow Meter	Temperature range with highest ΔH per °F
Complete phase change range	66-81°F	Heat Flow Meter	Temperature range of complete phase transition
Phase change enthalpy*	57 BTU/ft²	Heat Flow Meter	Total heat absorbed over complete melting range
Liquid Specific Heat*	0.95 BTU/ft²·°F	Heat Flow Meter	Measured in 81-89°F range for heating and cooling
Solid Specific Heat*	2.52 BTU/ft²·°F	Heat Flow Meter	Measured in 60-66°F range for heating and cooling

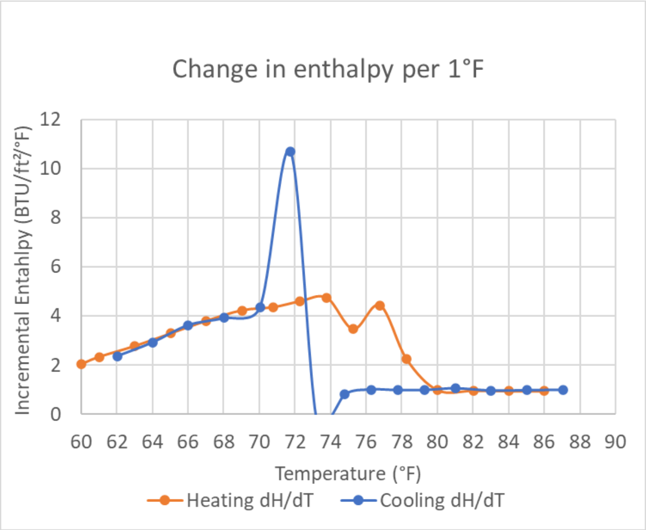
Physical Properties	
Property	**Value**
Templok® tile dimensions	24 x 24 x 0.25”
PCM section dimensions	9 x 9 x 0.25”
PCM sections per tile	4
PCM section areal fraction of tile	0.563
Mass of PCM per section	1.0 LB

*Nominal thermal properties of the PCM section per square foot of PCM section area over the 66-81°F range. Measured by heat flow meter apparatus per ASTM C1784-20. See the test report for actual values.



Templok Tile



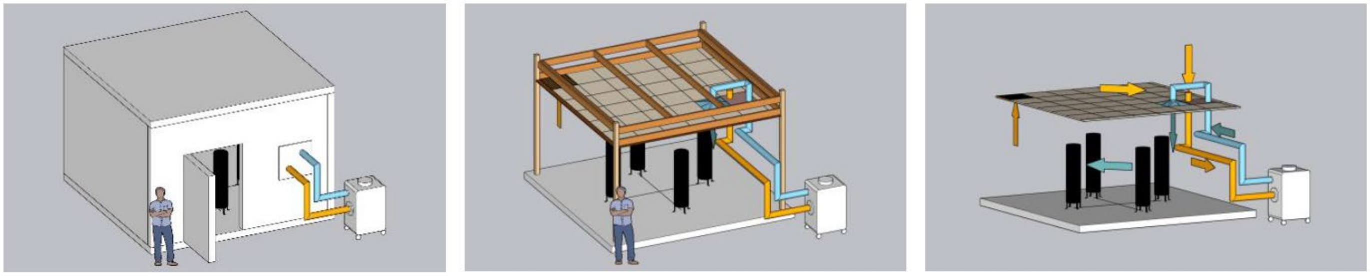


The presented enthalpy data is measured across a temperature range of approximately 60-90°F, wider than typical temperature cycles in buildings. When cooling from a lower starting temperature, such as 78°F, the freezing process occurs more gradually beginning at a higher temperature.

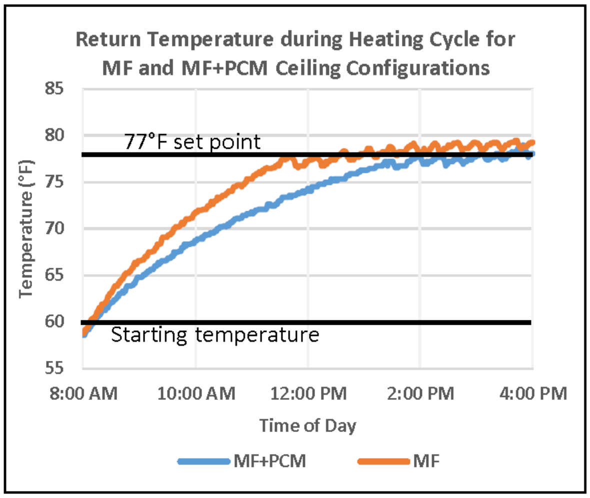
LABORATORY ASSESSMENT OF ULTIMA® TEMPLOK® CEILING TILE PERFORMANCE

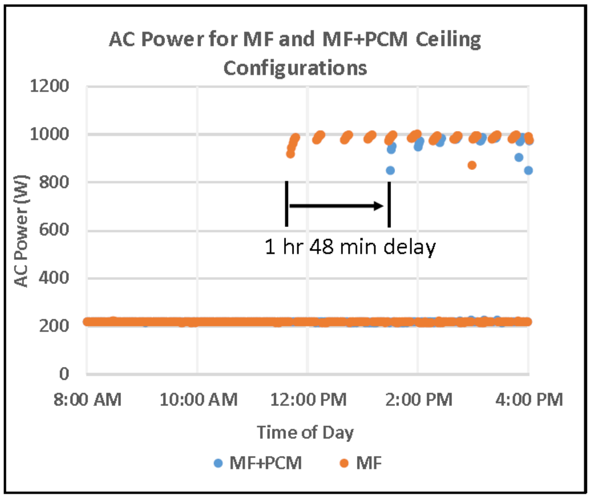
Overview: This study focuses on the thermal storage capacity of Phase Change Material (PCM) ceiling tiles, specifically the Ultima® Templok® ceiling tile, and its impact on load shifting and energy savings. The study assesses the performance of installed PCM ceiling tiles by isolating their effect on air temperature and air conditioning (AC) energy through a sequence of simulated days and nights.

Experimental Setup: A controlled test room was constructed resembling an office room, equipped with extensive temperature, power, and heat flow monitoring equipment. This setup included 22 thermocouples and eight heat flux sensors distributed across all interior surfaces of the chamber and both sides of the ceiling. The chamber was maintained with a constant airflow of 100 CFM (Cubic Feet per Minute) or 5 Air Changes per Hour (ACH) and power to a heat source in the room and AC unit cooling the room was logged. In the experiment, set points were varied to simulate night ventilation with 'free' cool ambient air and heat sources were turned on inside in the day to simulate occupant load.

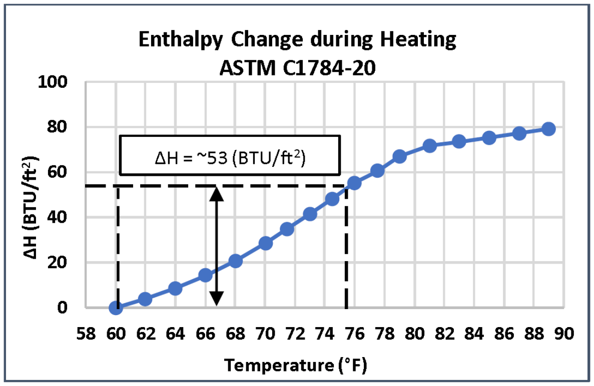


Passive Cooling and AC Delay: The experiment compared two scenarios: one with Ultima Templok ceilings (MF+PCM) and another with standard Ultima mineral fiber ceilings (MF). The test sequence involved pre-cooling the chamber to 60°F in the early morning, followed by a set point increase to 77°F at 8AM and the internal heat load turning on. The AC in the MF+PCM scenario kicked in about two hours later than in the MF scenario. This delay correlated with a slower increase in air temperature, as the air was moderated by the thermally massive PCM ceiling.





Quantifying Energy Flows and Savings: Notably, the AC in the MF+PCM setup removed 4080 BTU less heat during the day than in the MF setup. The heat absorbed by the ceiling in the MF+PCM case was significantly higher, by 3815 Wh, suggesting the PCM was responsible for the reduced heat removal needs. Furthermore, the estimated heat stored by the PCM, based on temperature changes throughout the day and the looked-up enthalpy properties of the PCM was about 53 BTU/SF or 3935 BTU total, a third point of agreement.



Energy Savings Discussion

The measured daytime energy savings by the AC in the MF+PCM setup was 20%, predominantly due to reduced compressor energy from 8am to 4pm as the PCM melted. With strategies like 'free cooling' through open windows or efficient economizer operation, the full 20% daytime savings could be realized with minimal energy expenditure at night. In typical climates with a narrower diurnal temperature range, a more realistic savings was estimated to be up to 15%.

CASE STUDY

HEATING SAVINGS IN NEW HAMPSHIRE HIGH SCHOOL

Introduction

This case study estimates the impact of Phase Change Material (PCM) through Templok ceiling tiles in a New Hampshire high school, with a focus on heating energy during Winter and Spring.

Study Overview

Multiple modeling techniques were used to evaluate power and temperature data collected in a wing of classrooms before and after treatment with Templok ceiling tiles. The primary objective was to estimate the effect of Templok ceiling tiles in reducing heating energy during Winter and Spring nights. In a cool climate in spaces with significant daytime heat gains, like classrooms, the working principle of energy-savings is illustrated in Figure 1. The thermal mass of the ceiling stores heat during the day when the building naturally warms and mechanical heating is efficient, and releases heat back to the space overnight, moderating the air temperature and offsetting the need for nighttime mechanical heating. This principle was investigated in the case study.

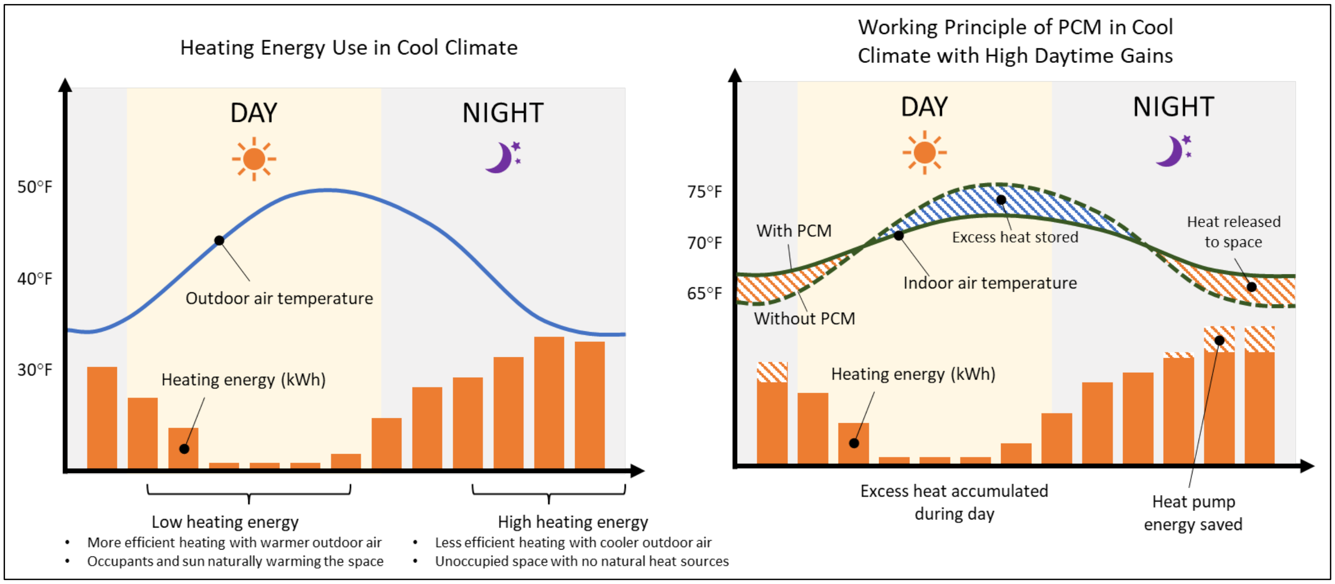


Figure 1. Illustration of energy saving mechanism of thermal mass in a cool climate in a building with high daytime gains.

Study Design

A wing of classrooms of similar size and use were selected to identify a suitable set of classrooms for control and PCM treatment cases. Each classroom was primarily heated by an individual split heat pump system inside the classroom. While real-world experiments are difficult to control, the uniformity of repeating classrooms heated by individual systems offered a conducive framework to isolate the effect of the PCM ceiling. The study was conducted in stages as follows:

1. **Baseline Energy Collection:** This phase involved the monitoring and selecting a group of classrooms with comparable heating energy usage over several months leading up to the heating season.
2. **PCM and Sensor Deployment:** In this phase, Templok tiles were installed in half of the selected classrooms. Simultaneously, temperature sensors were placed in each classroom, in the air below the ceiling, on the back of the ceiling surface, in the plenum air above the ceiling, and in the unit ventilator along the exterior wall.
3. **Multivariate Analysis:** In this analysis, a multivariate model was developed to predict heat pump power from several measured variables, including the PCM treatment.

4. **Difference of Differences Analysis:** This analysis compared the difference in energy usage in PCM-treated classrooms before and after the treatment date to the energy usage difference in 'control' classrooms that did not receive PCM before and after the treatment date.

Baseline Energy Data

Current transducers and a data logging system recorded power to the heat pumps in 14 classrooms beginning on September 8th. Figure 1a depicts the general layout of each ~800 square foot classroom. A heat pump is located within each classroom near the ceiling that heats and recirculates the air. Each room also has a unit ventilator that provide tempered outdoor air in the mornings for ventilation. Temperature loggers were added inside the unit ventilators at the time of PCM deployment to include as a variable in the multivariate model. Figure 1a depicts the basic classroom layout. Figure 1b highlights the classrooms that were monitored for baseline on the first and second stories, as well as the set of four classrooms that were selected for treatment and control in the next phase.

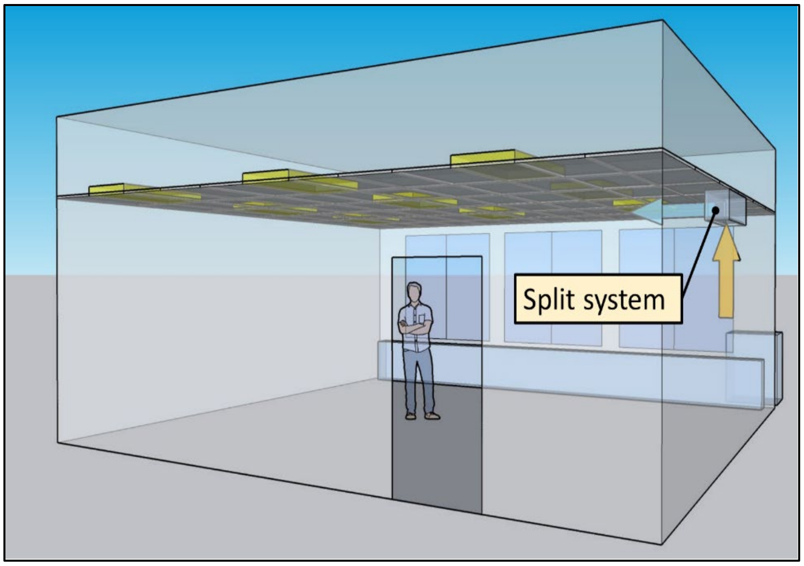


Figure 1a: Classroom layout

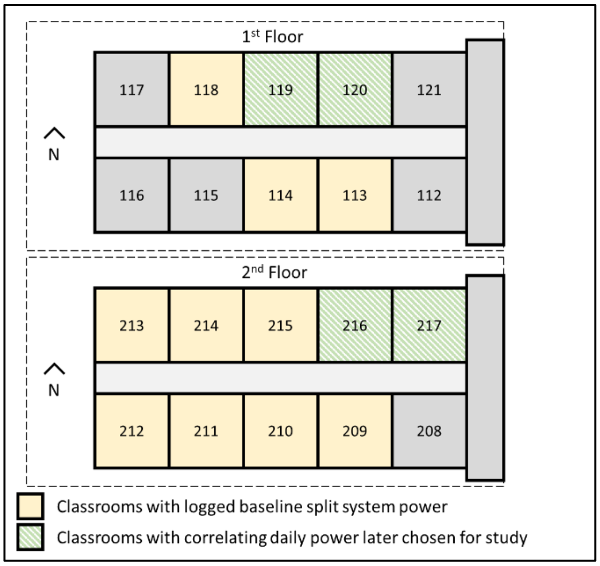


Figure 1b: Classroom wing showing monitored rooms

Power to each heat pump was recorded in 15-minute intervals to estimate heating energy by each system over time. Correlations between the power data in most of the classrooms began to strengthen in February as the heat pumps were routinely heat. In Figure 2, the power data was binned into daily sums and displayed for the month of February. Neighboring classrooms 119, 120, 216, and 217 on first and second stories showed strong correlations in February and were selected for the study.

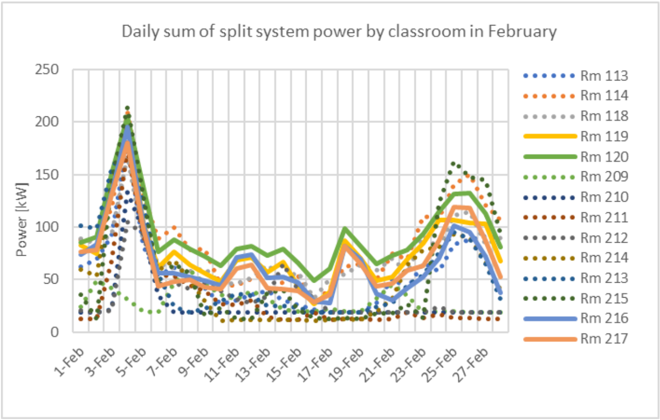
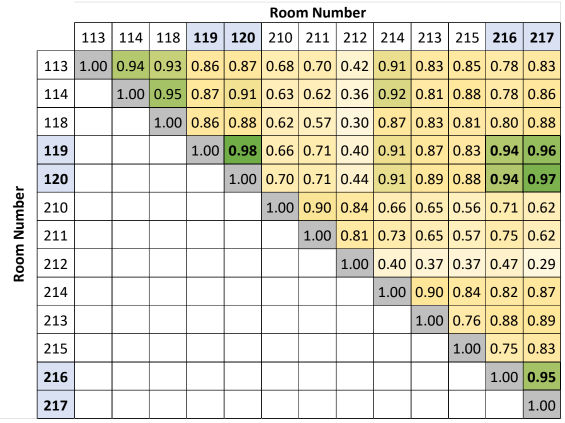


Figure 2a: Daily heat pump power sums in monitored classrooms in February.



	Room Number												
Room Number	113	114	118	**119**	**120**	210	211	212	214	213	215	**216**	**217**
113	1.00	0.94	0.93	0.86	0.87	0.68	0.70	0.42	0.91	0.83	0.85	0.78	0.83
114		1.00	0.95	0.87	0.91	0.63	0.62	0.36	0.92	0.81	0.88	0.78	0.86
118			1.00	0.86	0.88	0.62	0.57	0.30	0.87	0.83	0.81	0.80	0.88
119				1.00	**0.98**	0.66	0.71	0.40	0.91	0.87	0.83	**0.94**	**0.96**
120					1.00	0.70	0.71	0.44	0.91	0.89	0.88	**0.94**	**0.97**
210						1.00	0.90	0.84	0.66	0.65	0.56	0.71	0.62
211							1.00	0.81	0.73	0.65	0.57	0.75	0.62
212								1.00	0.40	0.37	0.37	0.47	0.29
214									1.00	0.90	0.84	0.82	0.87
213										1.00	0.76	0.88	0.89
215											1.00	0.75	0.83
216												1.00	**0.95**
217													1.00

Figure 2b: Correlation coefficients between daily heat pump power sums of each classroom pair.

PCM and Sensor Deployment

On March 1, Templok tiles were installed above the ceiling tiles in rooms 120 and 217. In all four rooms, 119, 120, 216, and 217, thermocouples were installed in the ceiling to measure the room and plenum air temperature and the back of the ceiling tile temperature, as depicted in Figure 3a. An example air temperature thermocouple is shown in Figure 3b. In the classrooms that did not receive PCM tiles, the back of ceiling thermocouple was positioned on the acoustical tile. Data loggers recorded temperature measurements from each thermocouple. A thermocouple was also installed in the unit ventilator of each classroom to give an indication of when the unit ventilator was adding heat to the space, which tended to occur briefly in the mornings as outdoor air was tempered during morning ventilation.

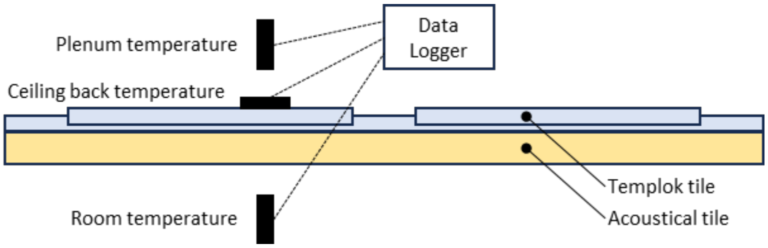


Figure 3a: Ceiling sensor schematic

Figure 3b: Room air temperature sensor.

Power and temperature data from each classroom was recorded from March 1 through May 5. Figure 4 shows the temperature and heat pump power trends during a weekday in Room 217. Heating intensity is highest at night during the coldest hours. Heat pump power is lower in the afternoon when classroom is occupied, and ambient temperatures are warmer. The small power measured in the afternoon when room air temperatures are in the upper 70s°F is likely to be predominately fan energy with little or no heating. The change in temperature of the ceiling over time indicates the daily heat storage and release pattern. The PCM in the ceiling is storing heat during the day as it warms and melts, and releasing heat back to the building at night as it cools and freezes.

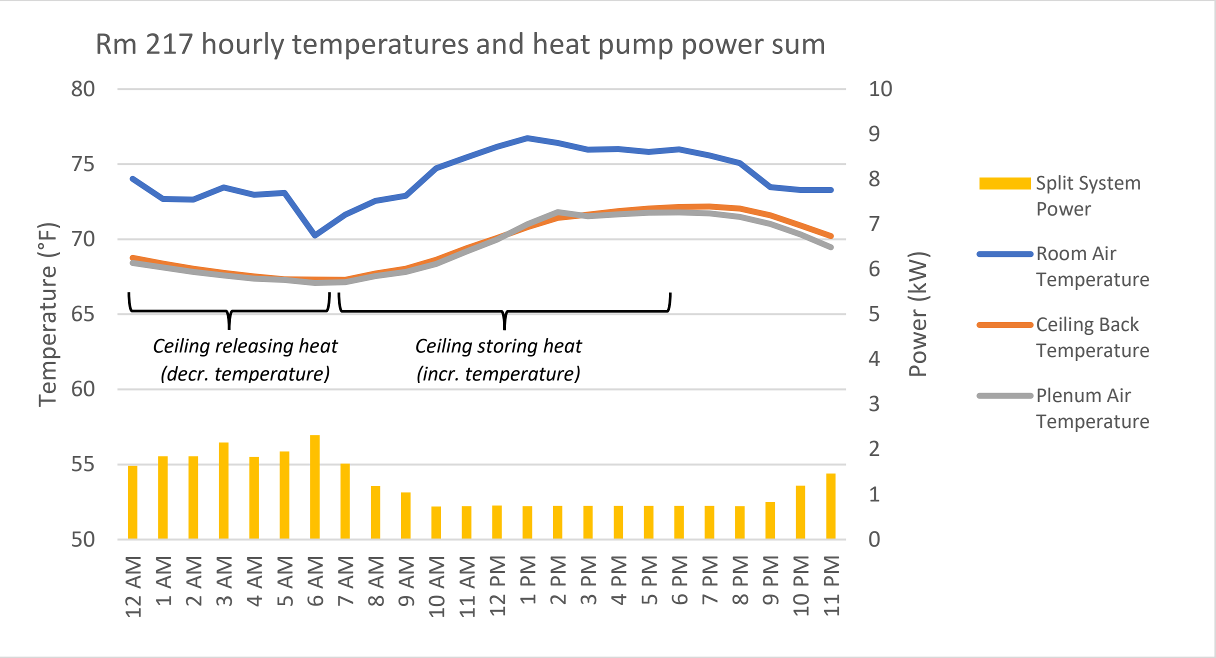


Figure 4: Diurnal room, ceiling and plenum temperatures and hourly split heat pump system power intensity.

Multivariate Analysis

The dataset was stratified by season (Winter, Spring) and hour (Day, Night) for analysis. A generalized additive model (GAM) was then constructed, including measured variables anticipated to influence heat pump power. The model included true/false status of unit ventilator heating, outdoor and room air temperatures, floor level, timestamp, and true/false status of PCM in the ceiling.

Table 1 shows an analysis of both floors in the Winter. In night hours, a 5% reduction in heating power was estimated by isolating for the PCM variable. The result was statistically significant ($P<0.05$), and the model had strong predictive power ($R^2 = 0.81$). In day hours, no significant change in the heating power was estimated, suggesting a significant heating penalty was not incurred during the day as the PCM was melting.

Condition	Estimate	P-value	Adjusted R^2	% Reduction
Winter (3/13-4/4) - Day Hours (8 a.m. - 8 p.m.)	0.000 (P > C)	> 0.05	0.77	--
Winter (3/13-4/4) - Night Hours (9 p.m. - 7 a.m.)	**-0.032 (P < C)**	**< 0.05**	**0.81**	**5%**

Table 1: Estimated reduction in heating power due to the PCM variable (Both floors, Winter).

Some anomalies in the kW data in Room 119 after 4/4 led to refocusing the Spring analysis on the second floor only. Table 2 shows an analysis of the second floor during Winter and Spring days and nights. The model predicted a 7% and 9% reduction in heating power in Winter and Spring, respectively. Both results were statistically significant with good predictive power. Daytime heating energy was not estimated to be significantly impacted by the PCM treatment, although the model was less predictive in Spring Days due to other variables not included in the model.

Condition	Estimate	P-value	Adjusted R^2	% Reduction
Winter (3/13-4/4) - Day Hours (8 a.m. - 8 p.m.)	-0.001 (P < C)	> 0.05	0.72	--
Winter (3/13-4/4) - Night Hours (9 p.m. - 7 a.m.)	**-0.032 (P < C)**	**< 0.05**	**0.71**	**7%**
Spring (4/5-5/5) - Day Hours (8 a.m. - 8 p.m.)	-0.001 (P<C)	> 0.05	0.59	--
Spring (4/5-5/5) - Night Hours (9 p.m. - 7 a.m.)	**-0.018 (P<C)**	**< 0.05**	**0.78**	**9%**

Table 2: Estimated reduction in heating power due to the PCM variable (Second floor, Winter and Spring).

Difference in Differences Analysis

A difference in difference (DiD) analysis can be used to estimate the effect of a treatment by comparing the outcomes of the control and treatment groups over time (before and after the treatment). In this analysis, DiD estimates the effect installing PCM had on difference in mean power in PCM classrooms before and after installation minus the difference in control classrooms before and after installation. The DiD method relies on a parallel trend assumption which held stronger for the second floor than the first floor. Thus, only the second floor was analyzed in the DiD method. The month immediately preceding and following the PCM intervention (February and March) were analyzed. Controlling for outdoor temperature and average change in power measurements in the control rom between February and March, power measurements during night hours decreased on average by 0.045 kW (6%) after installation of PCM.

Condition	Estimate	P-value	% Reduction
Day Hours (8 a.m. - 8 p.m.)	-0.022	> 0.05	--
Night Hours (9 p.m. - 7 a.m.)	**-0.045**	**< 0.05**	**6%**

Table 3: DiD estimated reduction in average power measurements due to PCM variable (Second floor, February and March)

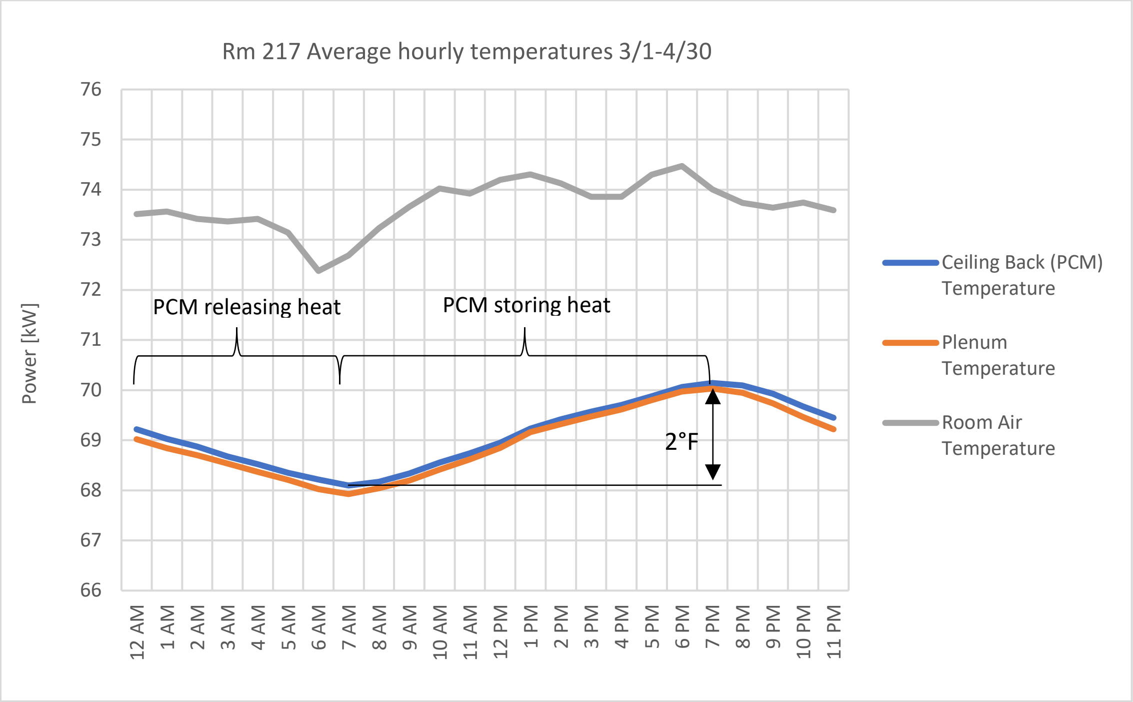
Results

Across several modeling techniques, classrooms with PCM installed saw a 5-9% drop in energy compared to control classrooms during night hours primarily during winter months. While this phenomenon was not ubiquitous, it was relatively consistent across approaches.

Reconciliation of Case Study Result with Laboratory Prediction

The diurnal change in temperature of the ceiling tile and its temperature-enthalpy properties can be used to independently estimate the amount of heat moved by PCM from day to night. In March and April, the average diurnal temperature variation of the PCM ceiling was about 2°F, corresponding closely with the plenum air temperature near the ceiling. Referencing the enthalpy properties of the PCM, cooling from 70°F to 68°F corresponds with a release of about 8 BTU/sqft of heat from the PCM to the building. About 144 Templok tiles were installed per classroom, representing coverage of the PCM-containing portion of Templok of about 324 sqft. Therefore, the predicted daily heat moved by the PCM from day to night is about 2600 BTU/classroom.

In the previous section, the reduction in average nighttime kW was estimated to be 5-9% by various methods. In March and April in Rm 217, the average total energy (kWh) in nighttime hours (9pm-7am) was 4.5 kWh. Assuming a COP of 3 for the heat pump, the 5-9% nighttime energy savings corresponds with about 2300-4200 BTU of heat saved, in general agreement with the estimated 2600 BTU of heat released by the PCM tiles overnight to the building.



Discussion

Even with a modest ceiling diurnal temperature range of approximately 2°F, the study observed a significant reduction in nighttime heating energy usage of 5-9% without a daytime heating penalty. This outcome is encouraging, as it suggests that buildings with greater internal and solar heat gains during the day could potentially achieve even more substantial energy savings at night.

Conclusion

The case study at a New Hampshire high school contributes to the relatively less-established application of PCM in cool climates for saving heating energy. The study estimated a 5-9% reduction in nighttime heating energy during winter and spring nights after retrofitting with Templok ceiling tiles. The result agrees with the estimated amount of heat released by the PCM at night measured by thermocouples and referencing the material's enthalpy properties.