Building Performance Energy Assessment

Site Owner: **United States Post Office**

Audit Site: **420 N. Twin Oaks Valley Rd.**
San Marcos, CA 92069

Performed by: **Phase Change**
Energy Solutions
120 East Pritchard Street
Asheboro, NC 27203

Report Date: **June 8, 2018**

Figure 1: United States Post Office Branch, San Marcos, CA 92069

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Figure 2: US Post Office Branch, 420 N Twin Oaks Valley, Rd, San Marcos, CA

Section 1 – Executive Summary

This white paper is intended to help readers understand the impact of introducing bio-based phase change material (BioPCM®) on the HVAC energy consumption in a building. BioPCM was applied to the building envelope in the form of ENRG Blanket™ above the existing T-grid ceiling.

Building specific energy performance data was collected and measured to demonstrate the following:

- HVAC energy consumption prior to the installation of ENRG Blanket.
- HVAC energy savings achieved by the installation of ENRG Blanket.
- Costs associated with the project.
- Economic benefits achieved by introducing BioPCM into the building envelope.
- Observed comfort impact on occupied building space.

Energy Findings

Pre-Installation HVAC energy consumption....................................42,493 kWh/yr

Post-Installation HVAC energy consumption ....27,976 kWh/yr

HVAC energy consumption reduction 34.2%

Economic Outcome

Cost of energy... $0.22 /kWh

Annualized savings (kWh) ....14,517 kWh/yr

Annualized savings ($)..$3,194 /yr

Project Cost:

ENRG Blanket (including freight) $17,591

Installation...$3,318

Total Cost $20,909

Project payback .... 6.5 years

Since the date of this installation, PCES has introduced an improved BioPCM formulation, resulting in about 30% higher thermal storage capacity. This new formulation is now included in all ENRG Blanket products. The projected savings on this project using the new formulation is estimated as follows:

Project payback …………………………………………………….. 5.0 years

*Annualized kWh savings remain static for this comparison. PCES anticipates that future testing will indicate greater savings due to the 30% increase in BTU capacity of the new formulation.

Section 2 - Introduction

Building owners and operators constantly seek measures to reduce the cost of ownership without reducing occupant comfort or increasing tenant turnover. In addition, constant and growing cultural pressure to address growing environmental concerns such as CO_2 emission, carbon footprint and global warming as part of good environmental stewardship requires owners to engage in measures to improve building performance.

HVAC energy consumption is typically the greatest energy cost in a commercial building, accounting for a national average of 35% of the total building energy consumption. Many owners have replaced HVAC systems, optimized controls and engaged in retro-commissioning to reduce the “cost of comfort” in their buildings. These investments represent a significant capital commitment per square foot, and owners are now seeking additional Energy Conservation Measures (ECMs) that can provide incremental savings on a consistent and immediate basis.

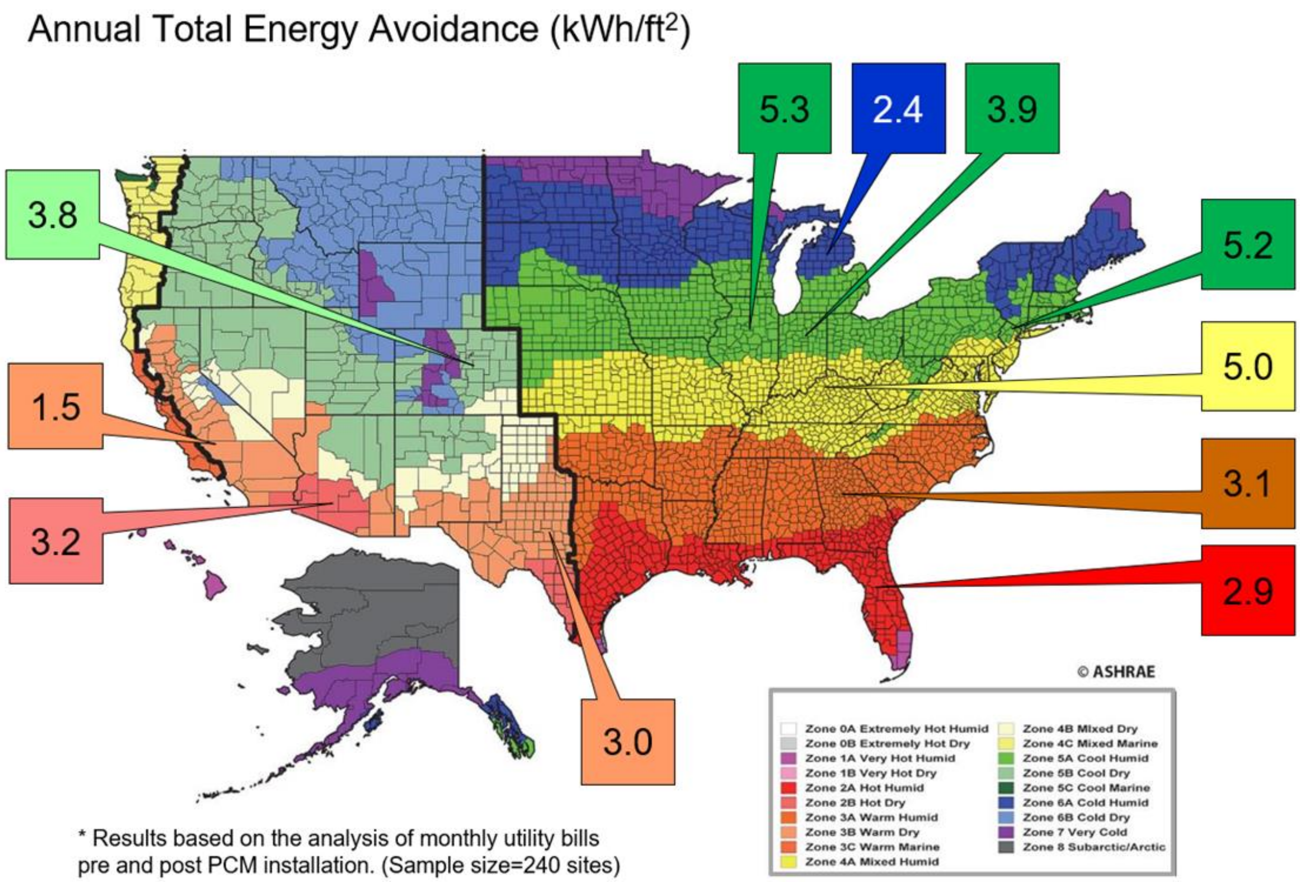


Figure 3: Measured total building energy avoidance (kWh/ft^2)

ECMs have long been available and evolve as technology advances are made. ECMs provide benefits, but implementation often requires an additional investment by building owners. Along with the acquisition cost, most ECMs present an ongoing cost of ownership driven by maintenance and age-related performance degradation. LED Lighting is an example of an ECM that has penetrated the market as economic efficiencies overcame barriers to adoption.

The PCM Solution

Phase change materials (PCMs) have been available for many years.

PCMs are materials which undergo a change of phase, at a useful temperature, for a specific purpose. The term ‘phase change’ refers to three primary thermodynamic modes:

1. Freezing (liquid to solid)
2. Melting (solid to liquid)
3. Boiling (liquid to vapor)

Significant energy is exchanged when undergoing a change in phase. Engineered PCMs absorb and store heat when they melt and release that heat when they freeze or solidify.

When the PCM is engineered to a specific temperature range, it absorbs and releases heat energy when the surrounding temperature rises or falls below its predetermined transition range. Huge amounts of energy are absorbed and released as the material changes phase, while the material stays at a constant temperature.

When applied at the proper temperature in a building application, PCMs fundamentally change the thermal behavior of the building by stabilizing the temperature of the space and reducing both the number of times the mechanical HVAC system cycles and the total amount of time that it runs, as compared to an identical building without PCMs.

System cycling is the primary wear factor on a system as it uses additional energy and works harder during the first few minutes of each new cycle. Reducing the number of cycles and allowing the system to run longer during each cycle has a significant impact on the wear and tear of the system. Reducing wear and tear allows the system to have a longer useful life in the building.

Buildings that are outfitted with BioPCM should have the HVAC systems in good working order and controlled by a programable thermostat or BMS which is resistant to tampering. When integrating a passive energy storage material like PCM into the building, the operation of the active HVAC systems should be altered to maximize energy savings.

We recommend that the building be controlled to the same temperature range as the PCMs latent range, in this case 73.4°F ±3°F, without deep set backs. The building should be controlled to maintain this condition at all times. This consistency mitigates energy consuming pull down/up loads by the HVAC systems after prolonged unoccupied periods. Other viable strategies include incorporation of a pre-occupancy, or nighttime purge to flush the space and allow for recharging of the PCM provided that there is a suitable delta T or hydronic recharging of the material via tubing or panel type heat exchangers using moderate fluid temperatures.

BioPCM

- Made from all natural, renewable, food grade oils
- Environmentally-friendly, non-toxic and non-corrosive
- Non-flammable, meets U.S. fire safety standards
- 100% recyclable and biodegradable
- Formulated and tested for long life, > 100 years

BioPCM is a patented, sustainably-sourced, renewable plant-based PCM material which successfully addresses all of the issues found in traditional PCMs.

BioPCM provides a 'tunable' transition temperature that allows it to be engineered to change phase at a pre-set or 'tuned' transition temperature, anywhere from -58°F to 347°F. This allows the material to be optimized to reflect the temperature profile of a building. The thermo-physical properties such as specific heat, thermal diffusivity, thermal conductivity, enthalpy, viscosity, and density can all be modulated to meet the exact needs of different applications.

This tunability allows owners to benefit from natural diurnal temperature swings and tune their building's environmental system to melt and recharge the material at the most cost-effective temperature and time based on peak demand charges, maximizing energy savings in kWh, therms and dollars.

Many locales charge extra for electricity in periods of peak demand, most often the middle of the day. After the cool night hours charge (freeze) the BioPCM during the night, it offsets the need for some of the daytime HVAC energy demand by absorbing heat from the interior spaces during the hotter daytime hours.

BioPCM provides stable and repeatable performance for the life of the product, demonstrating thermal and chemical stability for a period of more than 100 years through accelerated lifetime testing. This maintenance free solution is fire resistant, non-toxic and 100% biodegradable and recyclable.

Applications in the building envelope

ENRG Blanket is a construction-grade building material developed to apply BioPCM in building spaces. It is designed as a 'blanket' that can be installed conveniently installed above a T-Grid ceiling in a new or existing building to reduce HVAC energy consumption.

Application over the ceiling allows the BioPCM to manage both interior heat leads (people, computers, and equipment) and exterior gains from the roof and walls and windows (solar gain). This building study is based on this type of installation.

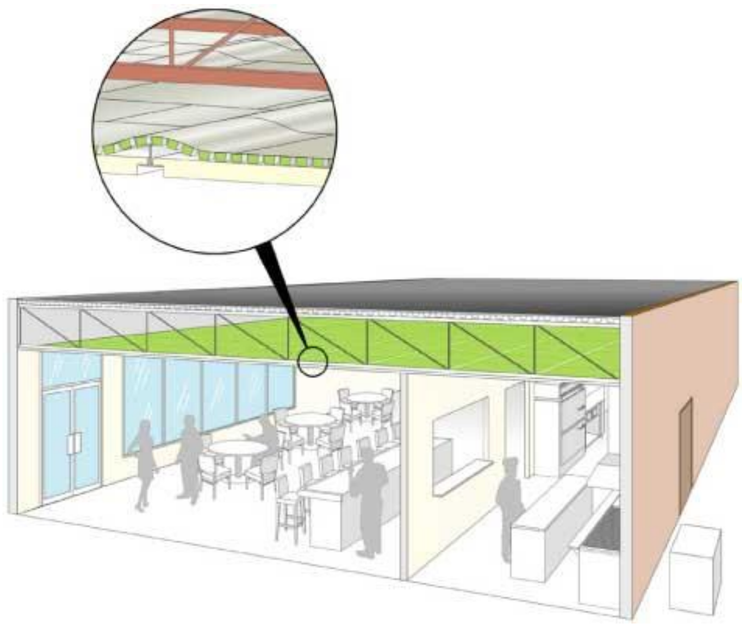


Figure 4: T-Grid Ceiling Application

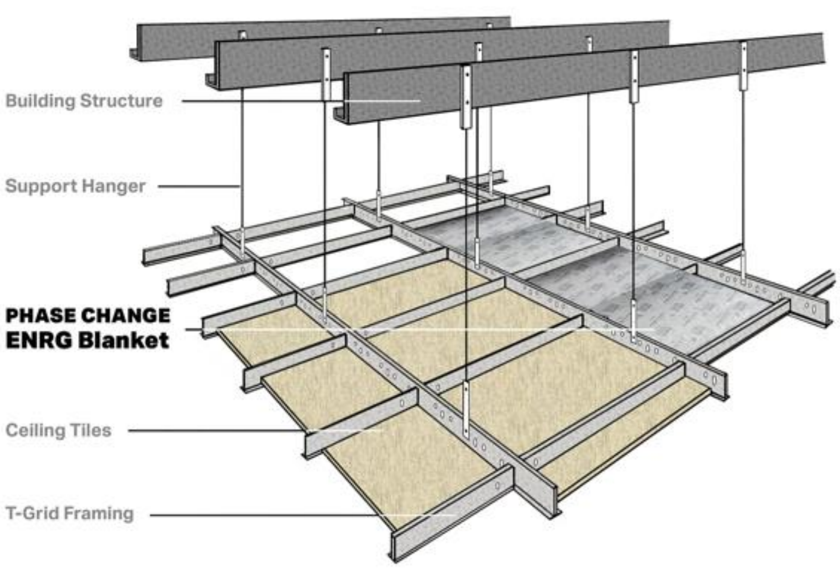
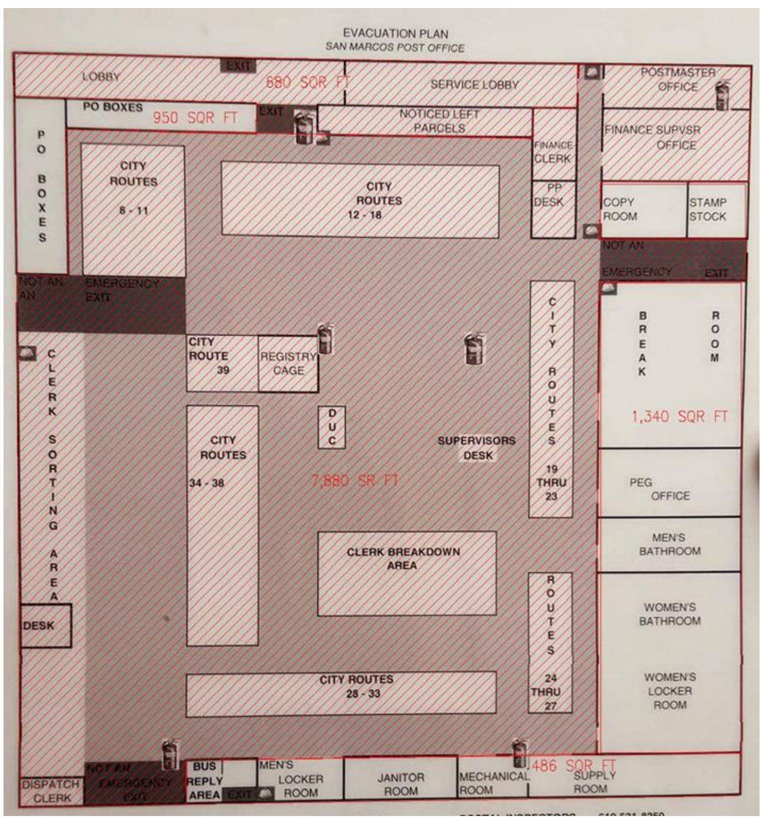


Figure 5: Diagram of installation over ceiling tiles as in San Marcos Post Office

Section 3 – Building Description

A multinational consultancy, engineering and project management company was selected by the US Postal Service (USPS) to help manage its portfolio of over 34,000 facilities. As part of their services, consultant was charged with helping the USPS achieve a federal Energy Policy Act mandate for energy reductions in federal facilities of at least 30%. To date, consultant has been able to achieve 37% energy reductions in facilities where projects have been implemented.

The consultant approached Phase Change Energy Solutions (PCES) to conduct pilot tests on several facilities to test the efficacy of adding phase change materials to buildings in order to reduce HVAC energy consumption. The United States Postal Service building in San Marcos, California 92069, was selected for one of these pilot tests.



Constructed in 1997, this single-story building represented a good test site for the PCES ENRG Blanket solution. This USPS building for 92069 included customer and sorting space and office space. The building has approximately 11,000 ft^2 of conditioned space. Most of the space has a dropped (T-Grid) ceiling. The building was served by 3, 12-Ton Trane packaged air conditioners with gas heat, electric cooling, and economizers.

Figure 6: San Marcos Post Office floor plan, hatched areas indicate ENRG Blanket above T-Grid ceilings.

Section 4 – Pilot Test Process (M&V)

Phase Change Energy Solutions (PCES) provided the client with a detailed Measurement and Verification (M&V) plan for the USPS San Marcos building. The plan provides a systematic procedure for determining the effect of the ENRG Blanket solution on the internal space temperatures and the energy consumption of the building's HVAC systems.

PCES uses the International Performance and Verification Protocol (IPMVP) document to provide a framework for the M&V plan. IPMPV Option B, Isolation Measure Energy Evaluation, has been selected as the approach for this project. ASHRAE Guideline 14-2014 Measurement of Energy, Demand, and Water Savings was used to determine the relationship between HVAC energy use and other independent variables such as weather and occupancy to determine the impact of the applied ECM.

Option B requires the collection of energy consumption data in the building to establish a weather normalized baseline. After the installation of ENRG Blanket, continue to measure and trend the same set of parameters for a minimum of 30-days to establish the post-installation energy use. Option B is used for a single energy conservation measure (ECM) enhancement for which predicted savings can be quantified.

Calibrated portable temperature sensors were installed to record and trend the indoor air temperature at sample locations inside the building at 5-minute intervals.

Electric current transducers (CTs) were installed on the HVAC units to document and trend amperage consumption on a 5-minute interval on the HVAC units. The monitored data was analyzed to determine the performance and characteristics of the building's HVAC system.

The rooftop units use gas for heating and this energy was not measured as a part of this exercise. Weather data was collected from the local NOAA weather station and used to normalize for forecasting full year building energy performance.

Installed temperature data loggers in the area above the ceiling to determine the existing temperature profile in order to optimize the ENRG Blanket material selection and quantity to achieve the best possible energy result.

- ENRG Blanket Q23/M27 – Class A Foil on Poly
- Roughly 70% coverage of the 11,000 ft^2 space
    - 7,790 ft^2 of ENRG Blanket material

Quantity	Part #	Description
1	RX3003-00-01	RX3000 3G Remote Monitoring Station
1	SP-807	US Max-Connect Plan - RX3000 AT&T
1	AC-U30	AC Battery Charger for U30 - 120V, 60Hz
3	T-WNB-3D-240	kWh Xducer 208/240VAC Delta (Pulse out)
9	T-MAG-0400-75	AC Split-Core CT Mini, 75 amp, 333mV out
3	A-WNB-LEADSET	voltage input lead set for use w/ WNB
9	S-UCC-M006	Pulse Input Adapter - Electronic Switch
4	S-THB-M002	Temp/RH Sensor (12-bit) w/ 10m Cable

Table 1: Bill of materials for the data acquisition

Figure 7: Flux sensor above ceiling tile

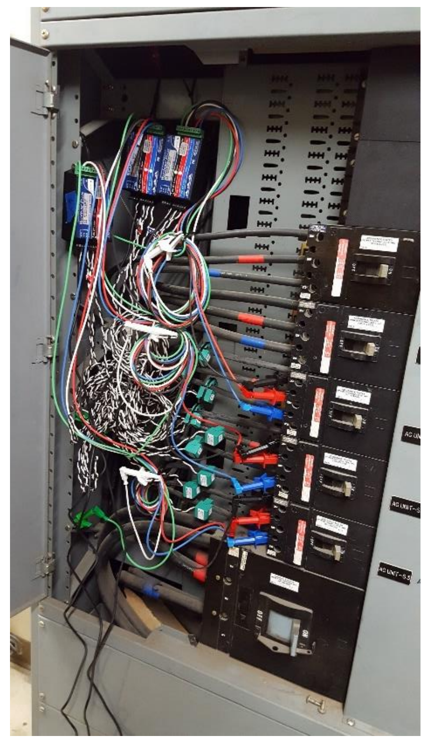


Figure 8: CTs and WattNodes in load center

Section 5 – Building Challenges/Solutions

A data acquisition system was installed June 8, 2016. HVAC energy consumption did not correlate well with weather data nor did it track with normally scheduled building operation. The resultant baseline regression data. Based on these observations, it was apparent that this building had HVAC control issues that had to be addressed before the building could provide a valid result specific to the impact of the BioPCM on HVAC energy consumption.

The following HVAC system deficiencies were addressed:

- Repair of AC-1 (6/8/16 – 8/14/16) and AC-3 (6/24/17 – 8/21/17). All units running Aug 21, start of good baseline data.
- Remove T-Stat defeat device, paperclip, 8/2/16.
- Install programmable T-Stats with tamper-proof covers 2/3/17
- The thermostats were original, non-programable type with the following characteristics:

	Schedule	Cooling setpoint	Cooling Setback	Heating Set Point	Heating Set back	Mode
Baseline	n/a	74 but varied	n/a	68 but varied manually	n/a	Manually set – Fan On
Post install	M-Sat 0200-1600, Sun 0800-1700	74	78	70	64	Auto – Fan On during occupied

Table 2: Thermostat characteristics

Figure 9: Thermostat defeat device

Figure 10: Programmable thermostat with tamper-proof cover

Once the deficiencies were addressed and repaired and an acceptable baseline with good correlation to weather data could be developed, PCM installation was completed September 30, 2016.

Section 6 – Results

ASHRAE Guideline 14-2014 defines the methodology for multiple variable regression analysis to calculate annual energy savings. The multiple variable regression analysis method used in this effort uses four independent variables as they relate to a single dependent variable, providing a robust mathematical determination of predicted energy savings. The multiple variable regression analysis was performed using 39 days pre and post installation HVAC energy data to develop the regression model and used TMY3 (30-year average weather data) to determine a projected annual energy usage for cooling energy above 65F ambient.

The variables are defined as follows:

- HVAC electricity usage (kWh) → Dependent Variable
- Ambient (dry bulb) temperature
- Wet bulb temperature
- Relative humidity
- Occupancy

Independent Variables

Based on the multiple variable regression analysis, this facility saves 34.2% of the annual baseline HVAC energy consumption. This does not include savings that may result from avoidance of demand charges, gas usage, reduced maintenance and increase equipment life.

TMY3 Multi Variable Regression Analysis	kWh	R^2
Annual Pre-Install HVAC Energy	42,493	0.88
Annual Post Install HVAC Energy	27,976	0.77
Total Cooling Savings	14,517	
Total Percent Savings	34.2%	

Table 3: Multi-variable regression analysis

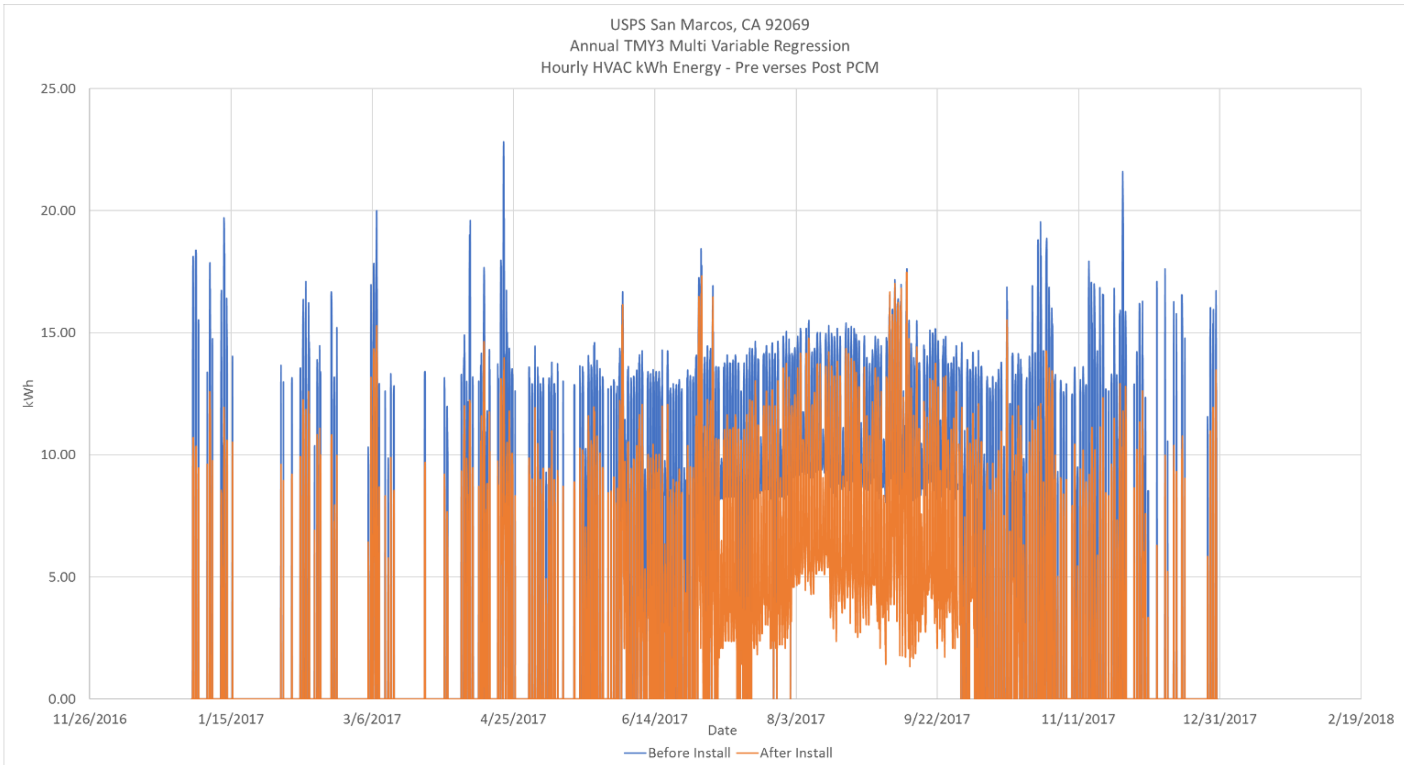


Figure 11: Annual HVAC energy consumption comparison

As an additional measurement we also compared actual measured HVAC energy from the same period of time in 2016 to same period of time in 2017 and the results are as follows.

Measured HVAC Energy for Aug 2017 - Sept 2017 compared to Aug 2018 - Sept 2018

Aug - Sept 2017 HVAC Energy (kWh)	15,575
Aug - Sept 2018 HVAC Energy (kWh)	10,427
Total Cooling Savings (kWh)	5,148
Total Percent Savings	33.1%

Table 4: Measured HVAC Energy

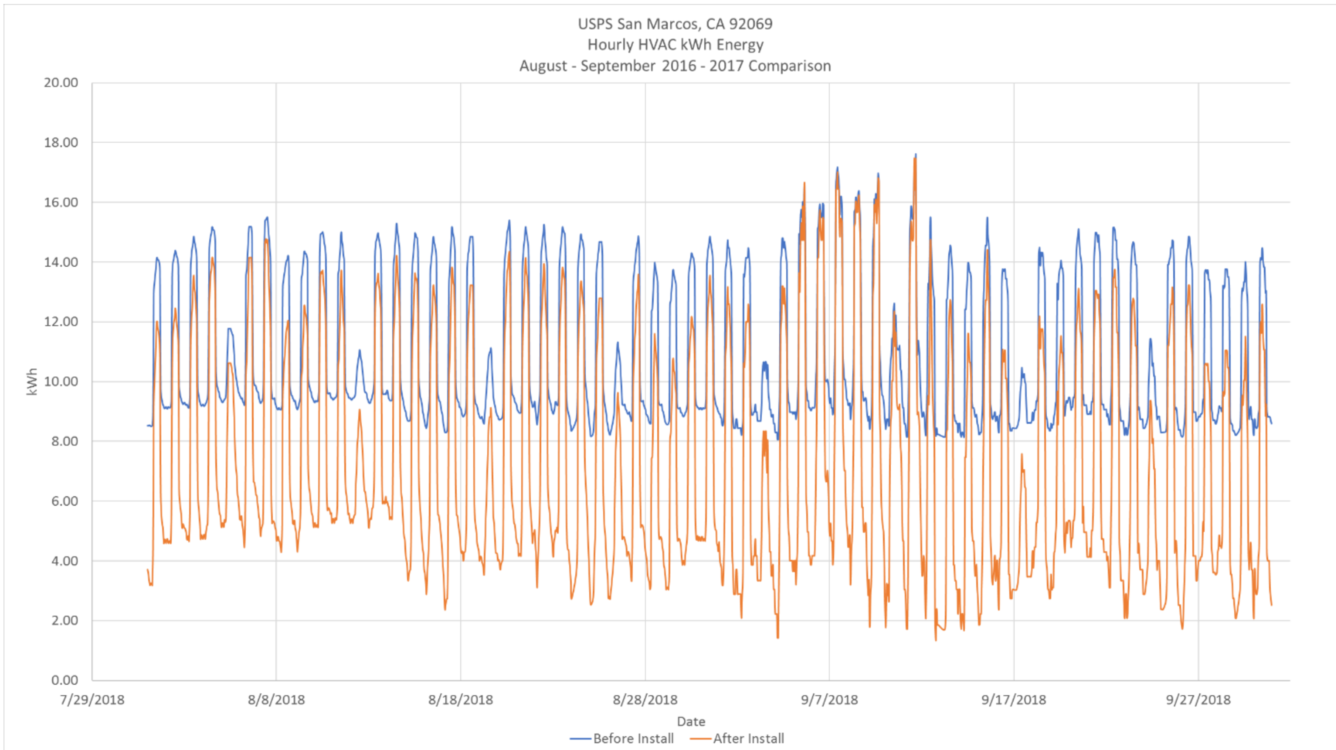


Figure 12: Comparison of HVAC energy consumed during the pre-installation period in 2016 and the same period in 2017, post-installation

Both the regression analysis and measured year over year HVAC energy data are very close to the same result, within 1% of each other which indicates a very strong data set.

Another analysis was done to compare the year over year monthly utility energy data. We determined HVAC only energy consumption by taking the total building energy data and removed 90% of the lowest month from the other months in the date range.

Utility Month	Total Bldg kWh	HVAC kWh	CDD60	HDD60	TDD60	Calc'd Total kWh	Calc'd HVAC kWh
Pre Period							
Oct-15	14465	5947	356	0	356	18743	10649
Nov-15	9778	1260	93	79	172	12267	4173
Dec-15	12523	4006	31	178	209	13569	5475
Jan-16	11143	2625	18	143	161	11880	3786
Feb-16	9857	1339	118	75	193	13006	4912
Mar-16	9464	946	44	66	110	10084	1991
Apr-16	9672	1154	100	28	128	10718	2624
May-16	11851	3334	70	9	79	8993	899
Jun-16	15435	6917	190	0	190	12900	4806
Jul-16	19578	11061	314	0	314	17265	9171
Aug-16	19791	11273	310	0	310	17124	9030
Sep-16	19061	10543	279	1	280	16068	7974
Post Period							
Oct-16	16414	7382	210	2	212	12868	3579
Nov-16	10727	1695	145	56	201	12602	3312
Dec-16	11575	2543	31	132	163	11680	2390
Jan-17	11309	2278	21	166	187	12262	2973
Feb-17	10035	1004	12	119	131	10904	1614
Mar-17	11246	2214	56	81	137	11049	1760
Apr-17	10761	1729	94	35	129	10855	1566
May-17	11143	2111	83	24	107	10321	1032
Jun-17	12810	3778	150	74	224	13159	3870
Jul-17	15843	6811	323	0	323	15561	6271
Aug-17	15196	6164	305	0	305	15124	5835
Sep-17	14379	5347	300	2	302	15051	5762

Non Normalized	Total kWh	HVAC kWh
kWh Pre	162619.2	60404.6
kWh Post	151437.1	43057.0
% Savings	6.9%	28.7%

Normalized		
TDD HVAC	Pre kWh	87922.0
	Post kWh	57921.6
% Savings		34.1%

Table 5: Year over Year Monthly Utility Bill Comparision

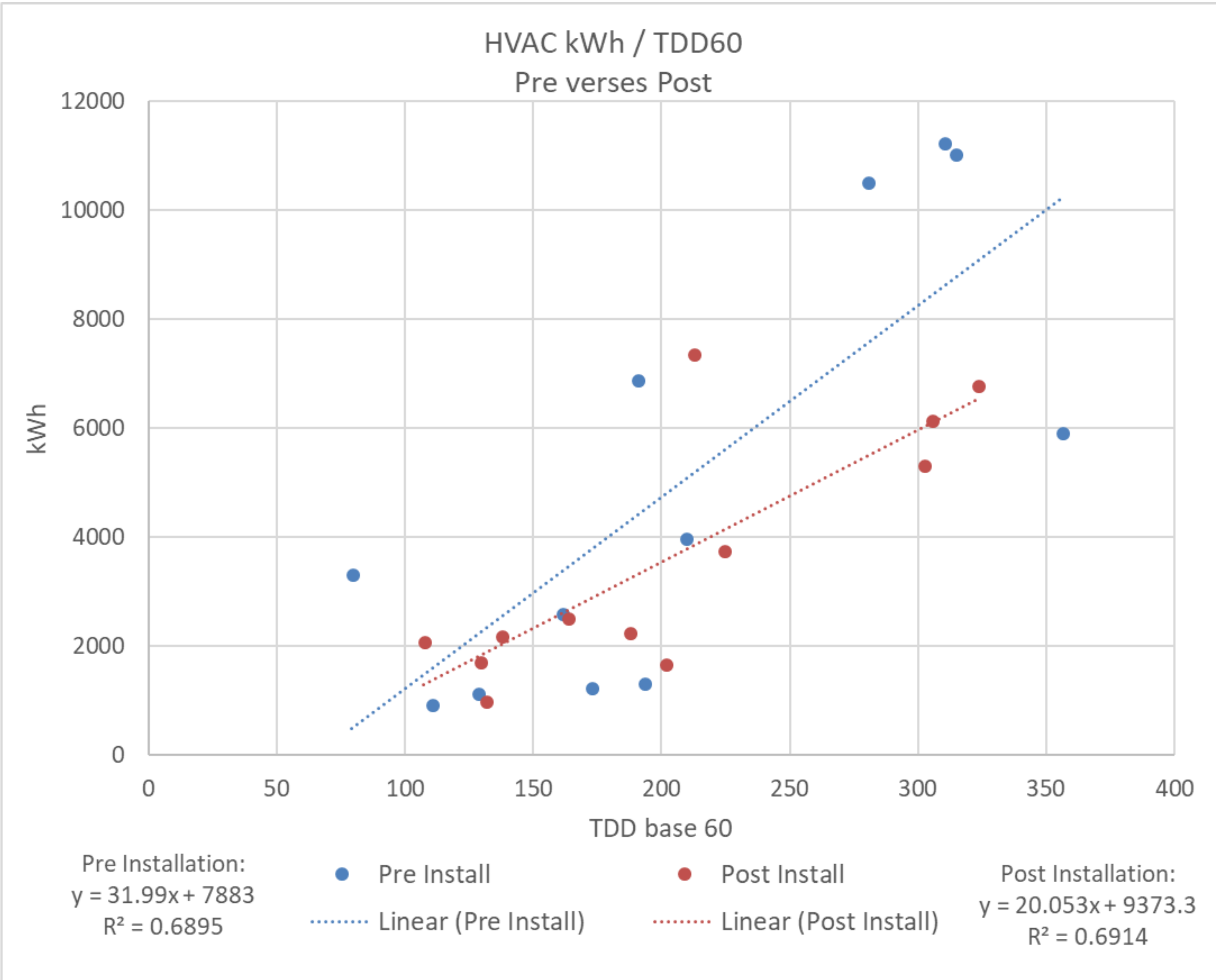


Figure 13: Regression for Monthly Utility Bill Data Pre verses Post Installation

A deeper measurement of the energy flux through the ceiling assembly into and out of the ENRG Blanket was also made. Using energy an energy flux sensor we were able to measure energy flux at the interface between the ceiling tile and the ENRG Blanket.The flux data logger also meaures temperature above and below the assembly. Energy flux measurements indicate the magnitude and the direction of energy flow. This illustrates the absorption and rejection of heat energy by ENRG Blanket.

Figure 14: Energy Flux Sensor deployed between the ceiling tile and the ENRG Blanket

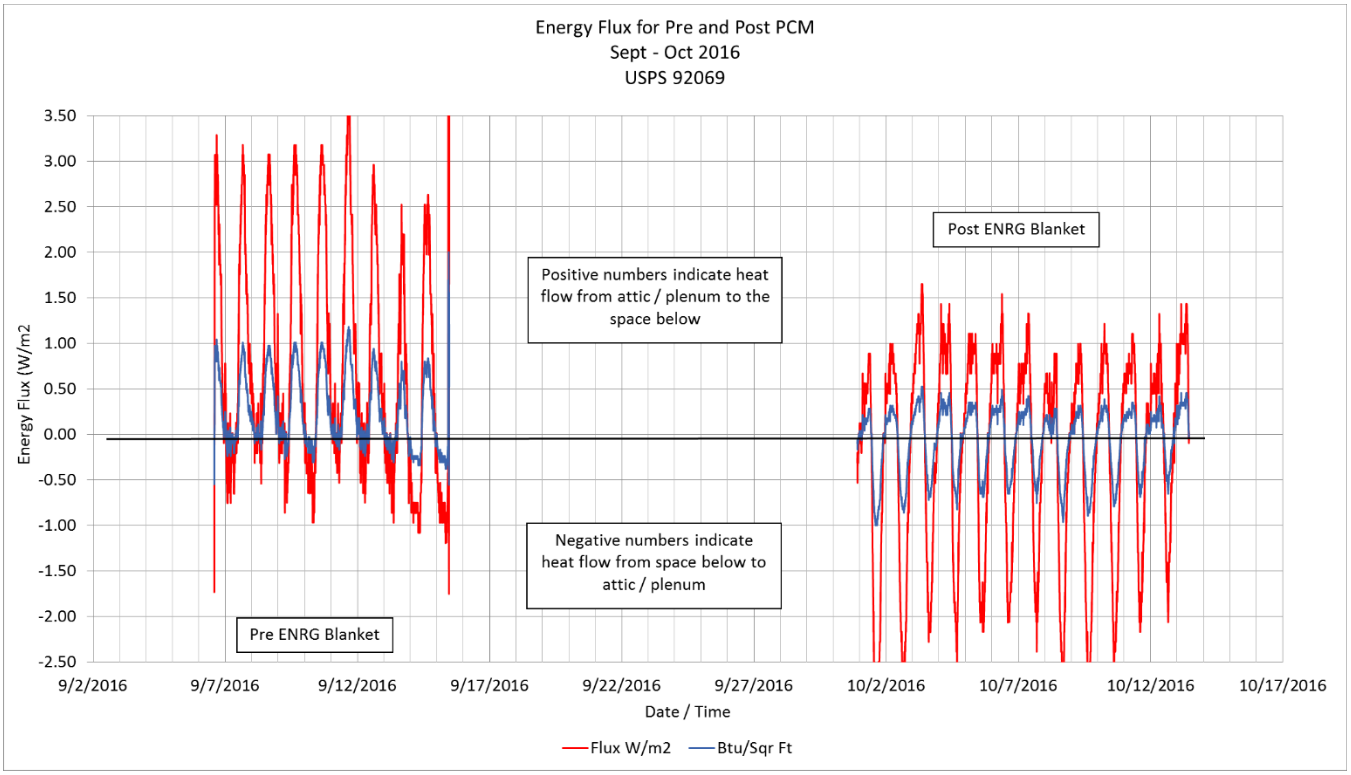


Figure 15: Measured energy flux at the interface between the ceiling tile and the ENRG Blanket.

There is a significant effect on the ceiling assembly by adding the ENRG Blanket above the ceiling. Note that on Figure 15 the lines shift down to below the 0 axis post installation. This indicates that heat flux is more evenly regulated from the ENRG Blanket. Energy flux before installation showed heat transfer from the attic to the space below much more often compared to after the period after PCM installation. Figure 16 shows the temperatures above ENRG Blanket and below the ceiling. Post installation measurements demonstrate that the PCM is within its latent range most of the time, providing benefit to the building.

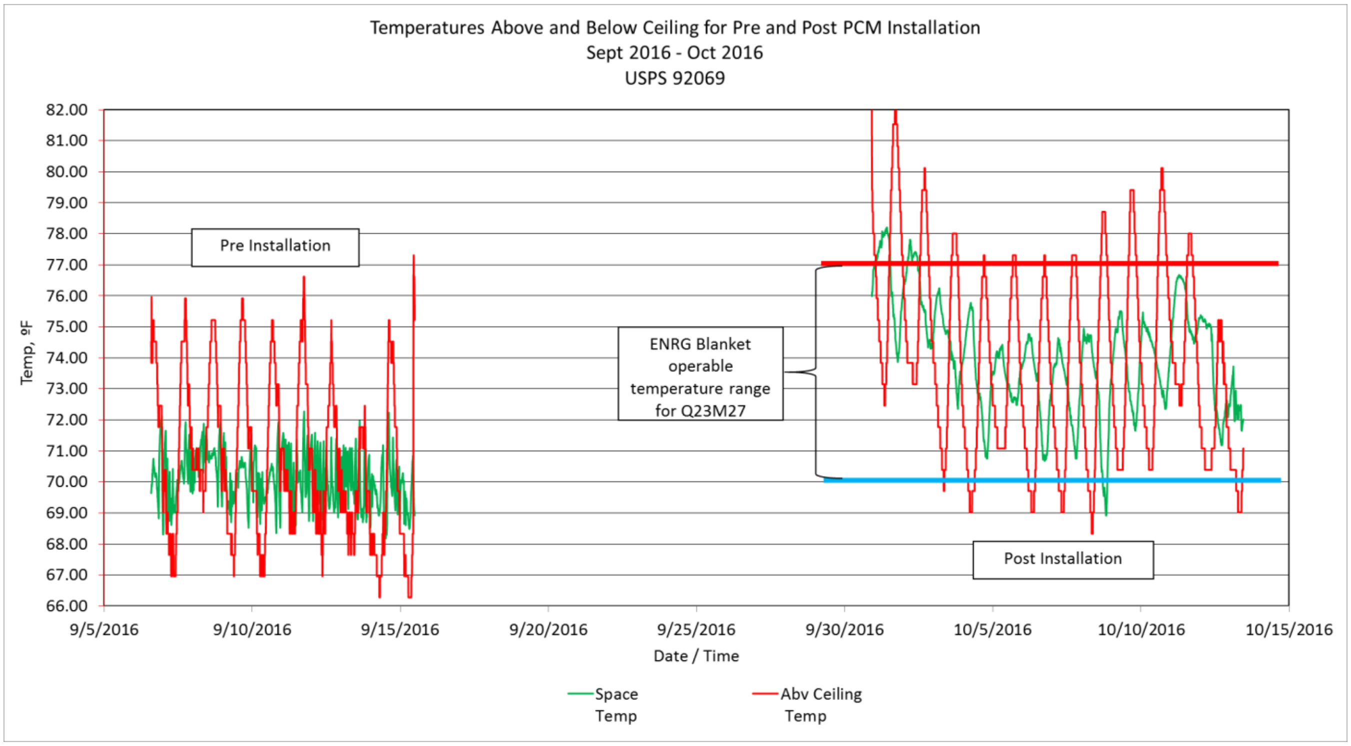


Figure 16: The temperature profile above and below the ceiling before and after the ENRG Blanket installation.

Other comparisons were made for HVAC energy usage. We compared same degree day energy use profiles pre and post ENRG Blanket installation for two different degree day values for a hot (higher degree day) and mild day (lower degree day).

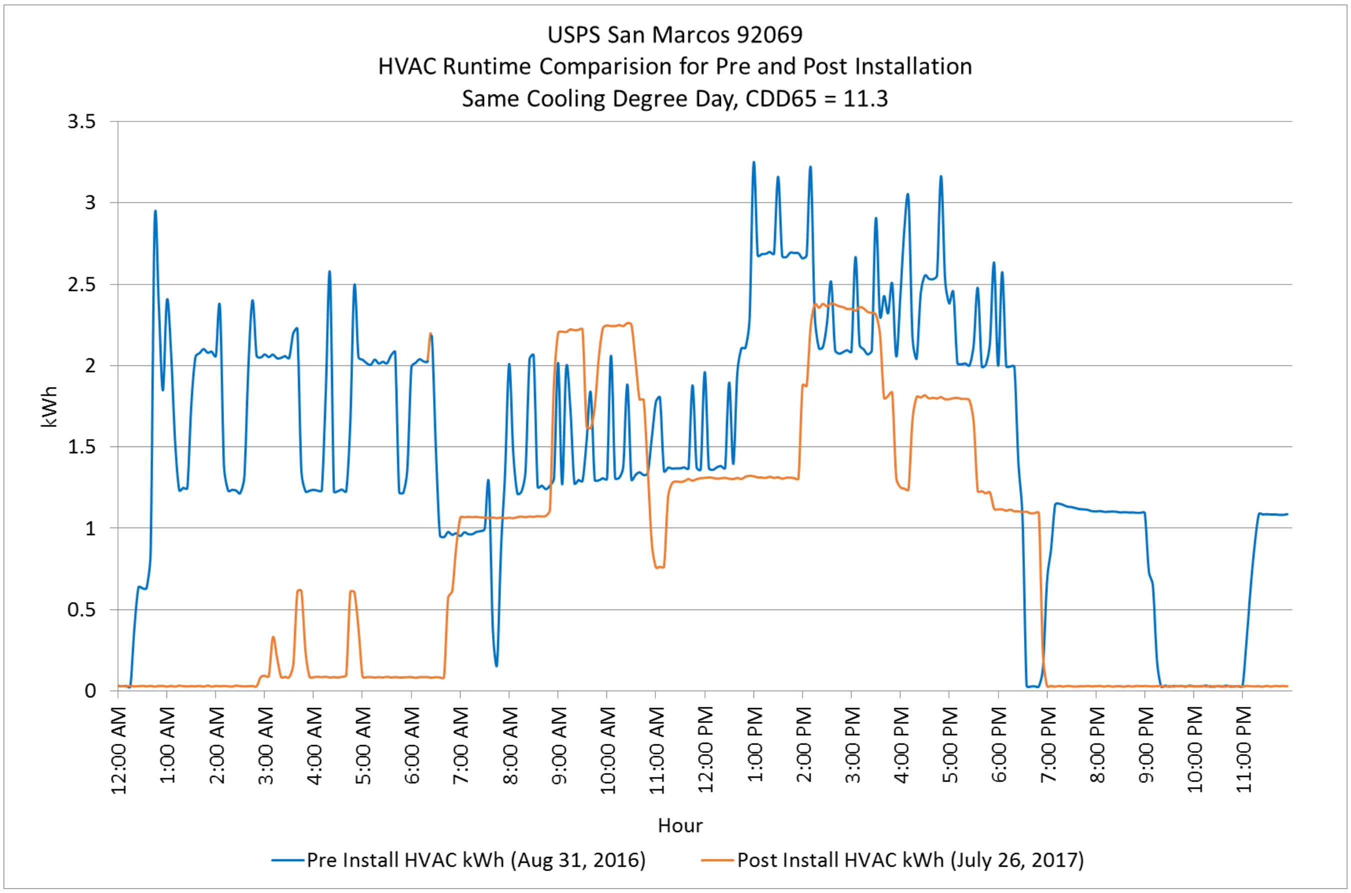


Figure 17: HVAC runtime for a same degree day pre and post PCM installation.

Figure 17 shows the comparison of HVAC energy use for an 11.3 degree day during summer. During occupied periods the energy use is stabilized and units run longer once on, and less frequently overall. This shows a **15.4%** HVAC savings for the day during occupied hours 6:30am – 7:00pm.

For the 24 hour period the savings is **53.8%**.

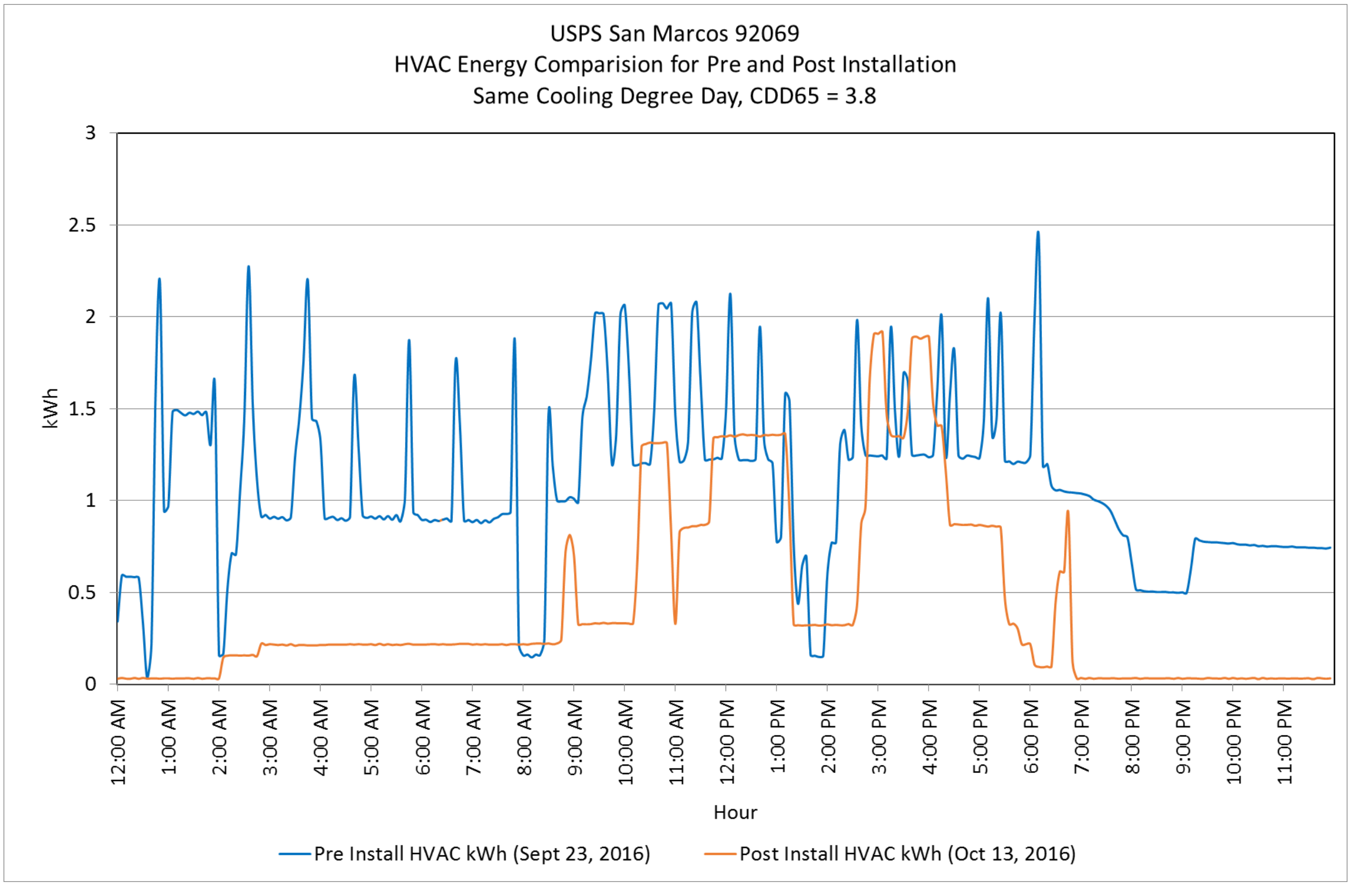


Figure 18: Shows reduced runtime during same cooling degree day pre and post installation.

Figure 18 shows the comparison of HVAC energy use for a 3.8 degree day during fall. During occupied periods the energy use is stabilized and units run longer once on, and less frequently overall. This shows a **41%** HVAC savings for the day during occupied hours 6:30am – 7:00pm.

For the 24 hour period the savings is **60.3%**.

Section 7 – Ancillary Benefits

Many ancillary benefits can be achieved during the evaluation and execution of a building ENRG Blanket retrofit. Other benefits provide an improvement in the financial performance of the building, and are not measured, but merit attention in this document.

- **HVAC System Maintenance Expenses**: The reduction in HVAC system cycling can potentially allow building managers to extend the routine maintenance cycles for their equipment, spreading the cost more effectively over the life of the equipment.

- **HVAC Repair Costs:** As indicated in the "HVAC System Life" section. Reduction in system cycling reduces the wear and tear on the system allowing owners to reduce system failure costs and associated business interruption resulting in a system failure.

- **Reduced/Eliminated Business Interruption:** Reducing or eliminating any factor that interrupts the business conducted in a commercial building has measurable impact on the financial performance of any company. The impact of ENRG Blanket on the HVAC performance outlined in previous sections could have marked impact on the profitability of any commercial building by reducing the potential of business interruption due to a failed or underperforming HVAC system.

- **Improving Long – Term HVAC System Performance:** As mechanical systems age, the design performance of the system begins to degrade as a normal function of wear and tear. Reducing the cycling of any system can slow the normal degradation of performance and allow the system to provide the design performance, maintaining and enhancing the thermal comfort for which it was originally designed. This reduces the need to provide ancillary equipment to maintain building comfort, or total system replacements to achieve design system performance.

- **Occupant Comfort & Productivity:** The primary purpose of most commercial HVAC systems is to provide thermal comfort for occupants. A 2005 study by Lawrence Berkeley National Laboratories (https://indoor.lbl.gov/sites/default/files/lbnl-60946.pdf) compiled the finding of several studies on human comfort and its relationship to productivity. Based on these studies, people are most productive when they are most comfortable, between 69.8°F and 73°F. BioPCM helps maintain a constant comfortable room temperature and buffers the effects of extremes in ambient temperature that may go beyond the HVAC systems capabilities to mitigate.

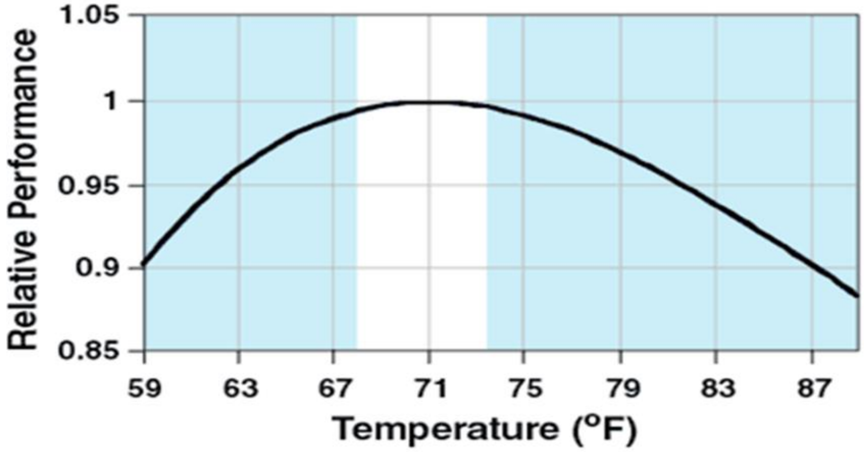


Figure 19: Source Lawrence Berkeley National Laboratories, July 2005

The results on this building are specific to the type of building, geographic location and temperature profile. Costs and payback analysis have a variety of variable factors, including the temperature profile of the phase change material, installation cost, energy costs and diligence in building HVAC operations and control.

Phase Change Energy Solutions can provide a building specific energy calculation to owners and operators who have a need to reduce operating expenses without significant investment and little or no business interruption.