Phase Change Material in a New Construction Training Center

Project ID: ET15SDG10151

Prepared by:

Emerging Technologies Program
San Diego Gas & Electric

[November 2017]

A Sempra Energy utility

Acknowledgements

San Diego Gas and Electric's Emerging Technologies (SDG&E's ET) group is responsible for this project. It was developed as part of SDG&E's ET Program under internal project number ET15SDG1051. Both RMS Energy Consulting and MWE2 conducted this technology evaluation with overall guidance and management from Matt Smith. Contact ETinfo@sdge.com.com for more information on this project.

Disclaimer

EXECUTIVE SUMMARY

The purpose of this Emerging Technology (ET) Field Assessment is to study the impacts of installing phase change material (PCM) in a new construction commercial building and recommend how appropriate modelling strategies may be used for a Savings by Design (SBD) or residential new construction program.

PCM is a thermal energy storage product and has evolved over the years. Early PCM versions were either toxic or flammable and posed potentially unsafe conditions and possible health risks in buildings. However, some newer PCM materials incorporate non-toxic micro-encapsulation bio-based organic materials and propose to save energy by absorbing and releasing heat within pre-defined temperature ranges in order to maintain a targeted air temperature within a space.

Despite decades of prior research, the effect of PCM on energy consumption within various commercial buildings is still not well understood. Consequently, several field assessments have been recently conducted to determine the PCM's potential energy savings in different commercial buildings (see **Table 2 on page 8** of the report).

The bio-based PCM material, assessed in this ET field study, is encapsulated in flame retardant, super-engineered polyfilm. The manufacturer indicates that the material is engineered around a fundamental property of nature where materials transfer heat more effectively during a phase change. Materials absorb heat when they melt (phase change from solid to liquid) and release heat when they solidify (phase change from liquid to solid). This field assessment was conducted at a new construction training center located in Chula Vista, California. The Training Center was built with the intent to meet the highest possible standards of LEED Certification, sustainability, and energy efficient design and was originally designed and built with PCM in the walls and roof.

Because the newly constructed training center already installed PCM, the International Performance Measurement and Verification (IPMVP) Option D was used to estimate potential savings due to the PCM. IPMVP Option D involves the use of computer simulation software to predict baseline facility energy use. Thereafter, a post simulation model must be "calibrated" so that it predicts an energy pattern that approximately matches the actual metered energy data from the facility. Annual energy savings estimates were arrived at by taking the difference between the baseline predicted model and the post calibrated model.

Relying on the EnergyPlus Simergy Interface, the autosized baseline and post calibrated model runs showed **annual energy savings at the heat pumps of 19,746 kWh** with **peak demand savings of 14.98 kW** due to the installation of the PCM. An additional 124,148 kWh of annual energy savings were shown at the fans in the facility. However, these results are questionable because the software produced a large number of simulation warnings and errors related to the simulation of the fans. It is not entirely clear what caused these warnings and errors. However, it can be reasonably inferred that the complexity of the building design and the newness of the mechanical HVAC VRF system models caused the issues within the EnergyPlus software. Despite potential energy savings, the savings in new construction applications are inconclusive and not easily quantifiable using the software tools available. Therefore, if energy and peak demand savings estimates are claimed, it should be limited to the heat pumps only until the EnergyPlus software warnings and errors are resolved.

ABBREVIATIONS AND ACRONYMS

CAPFT	Capacity Function of Temperature Curve
CFD	Conduction Finite Difference
CFM	Cubic Feet per Minute
CPUC	California Public Utilities Commission
DX	Direct Expansion
EIRFT	Electric Input to Cooling Output Factor for Temperature Function Curve
EIRFPLR	Electric Input to Cooling Output Factor for Part-Load Function Curve
ET	Emerging Technologies
FC	Fan Coil
HP	Heat Pump
IPMVP	International Performance Measurement and Verification Protocol
PCM	Phase Change Material
SBD	Savings By Design
SDG&E	San Diego Gas & Electric
TMY	Typical Meteorological Year
VRF	Variable Refrigerant Flow
ZNE	Zero Net Energy

CONTENTS

FIGURES

TABLES

INTRODUCTION

Phase change material (PCM) is a thermal energy storage product and proposes to save energy by absorbing and releasing heat within pre-defined temperature ranges in order to maintain a targeted air temperature within a space. Despite decades of prior research, the effect of PCM within various commercial buildings is still not well understood. Consequently, several field assessments have been recently conducted to determine the PCM's potential energy savings in various commercial buildings. (Please refer to **Table 2 on page 8**).

This Emerging Technology (ET) Field Assessment studied the impacts of installing PCM in a new construction commercial training center located in Chula Vista, California. PCM was installed in the stud cavities of the training center's interior walls, exterior walls and underneath the roof sheeting at the time of construction. This new construction training center was selected because the City of Chula Vista has desirable temperature swings appropriate for a PCM field assessment.

The training center is also unique in that the HVAC variable refrigerant flow (VRF) mechanical system is newer relative to other HVAC mechanical systems. Thus, many of the software tools available on the market may not have the algorithms needed to simulate the impacts of PCM on the VRF mechanical system. With tighter building energy codes and standards on the horizon, the combination of installing PCM in a new commercial building with a newer HVAC mechanical system has not been studied, and the potential energy savings is of high interest because the HVAC energy savings in commercial buildings may be significant.

BACKGROUND

The 2013 Title 24 Buildings Energy Efficiency Codes and Standards, Part VI Section 120.7, outlines mandatory insulation minimum efficiency and placement requirements within roof/ceiling, walls and floors within non-residential new construction buildings. These minimum efficiency insulation requirements ensure that new buildings align with California's efficiency goals and strategies.

However, new and emerging technologies are needed to support one of California's Big Bold Strategies of achieving zero net energy (ZNE) in all commercial new construction buildings by 2030 because the current minimum efficiency requirements will likely fall short of achieving that 2030 ZNE goal. Therefore, phase change material (PCM) products are of significant interest because the materials propose to save energy by releasing and absorbing unusually large amounts of heat compared to traditional insulation technologies that merely serve as a thermal barrier to slow down heat transfer.

EMERGING TECHNOLOGY/PRODUCT

PCM is a thermal energy storage product. PCM materials have evolved over the years starting from macro-encapsulation, eutectic salts, paraffin wax and petroleum-based materials. These early PCM versions were either toxic or flammable and posed potentially unsafe conditions and possible health risks in buildings.[1]

Some newer PCM materials incorporate non-toxic micro-encapsulation bio-based organic materials.[2] These newer bio-based PCM products on the market propose that their material transforms buildings into energy neutral structures with recycle thermal gains that would normally need to be removed using costly HVAC systems into useful thermal loads. These newer bio-based PCM products propose to save energy by absorbing and releasing heat at pre-defined temperature ranges in order to maintain a targeted air temperature in the space.

Despite decades of prior research, the effect of PCM on energy consumption within various commercial buildings has improved but is not well understood. Consequently, several field assessments have been conducted to determine the PCM's potential energy savings in various commercial buildings. **Table 2** (pg. 8) lists the field assessments conducted on newer bio-based PCM products from 2012-2016.

The bio-based PCM material, assessed in this ET field study, is encapsulated in flame retardant, super-engineered polyfilm. The manufacturer indicates that the material is engineered around a fundamental property of nature where materials transfer heat more effectively during a phase change. Materials absorb heat when they melt (phase change from solid to liquid) and release heat when they solidify (phase change from liquid to solid).The PCM material proposes to save energy by absorbing heat during the day and releasing heat at night typically at or near room temperature. **Figure 1** illustrates how PCMs work and save energy. **Figure 2** exhibits PCM being installed within a wood framed roof.

---

[1] SDG&E ET Study Project ID: ET16SDG1061 and DR15SDGE0003 Phase Change Material and Controls, page 10.

[2] SDG&E ET Study Project ID: ET16SDG1061 and DR15SDGE0003 Phase Change Material and Controls, page 2.

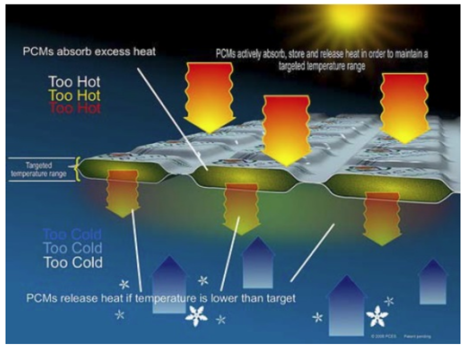


FIGURE 1: PHASE CHANGE ENERGY SOLUTIONS' MARKETING MATERIAL: HOW PCMS WORK AND SAVE ENERGY

FIGURE 2: PHASE CHANGE ENERGY SOLUTIONS' MARKETING MATERIAL: PCM INSTALLED WITHIN WOOD FRAMED ROOF

SITE DESCRIPTION

This PCM ET field assessment was conducted at a new construction training center, herein training center, located in Chula Vista, California. As shown in **Figure 3**, the training center is located in Climate Zone 10, constructed on an 11.37 acre site, and opened on October 22, 2015 (**Figure 4**). The training center was built with the intent to meet the highest possible standards of LEED Certification, sustainability and energy efficient design, and is used for training, competition and research. The building was originally designed and built with PCM in the walls and roof.

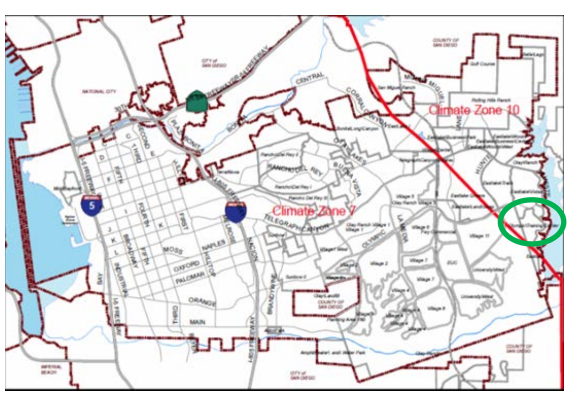
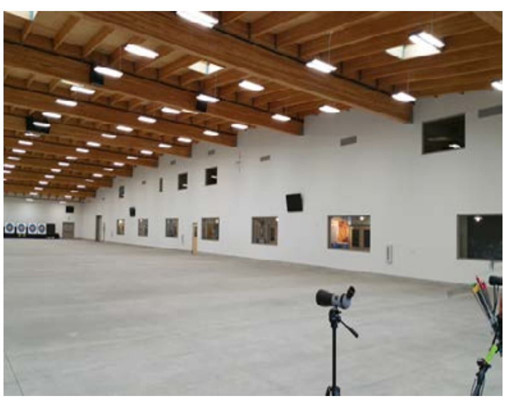


FIGURE 3: CHULA VISTA TRAINING CENTER IN CLIMATE ZONE 10

FIGURE 4: BIRD'S EYE VIEW OF TRAINING CENTER ON 11.37 ACRE SITE

The training center comprises of a two story 43,874 square foot archery center building and consists of an indoor archery range and support spaces. The 70 meter long indoor range is approximately 22,846 square feet. The remaining 21,028 square feet consist of support space including viewing, conference, office and administration space, training and research rooms, lockers, restrooms and storage space. The left photo in **Figure 5** shows the underside of the 1-1/8" plywood within the indoor range. The right side of the **Figure 5** shows that PCM installed above the 1-1/8" plywood.



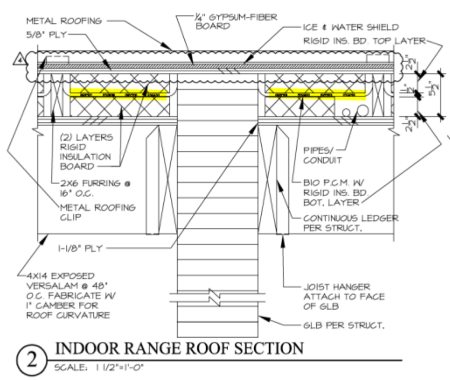


FIGURE 5: INDOOR ARCHERY RANGE

BUILDING CONDITIONS

BUILDING ENVELOPE

The building envelope components such as insulation, fenestration, operable windows, doors, and PCM were chosen to enhance comfort for the building occupants. Insulation within the training center's roof includes a rigid foil-backed polyisocyanurate foam board.

Based on engineering and architectural spec sheets, the insulation within the training center's walls include fiberglass batt insulation. The exterior wall substrate includes an under plaster 5/8" sheathing board. In addition to the batt and foam insulation, the 2015 newly constructed training center installed bio-based PCM below the roof sheeting and in the stud cavities of the interior and exterior walls.

HVAC SYSTEM

At the time of construction, the training center installed a variable refrigerant flow (VRF) multi-zone split heat pump system. The mechanical system consists of:

- VRF heat recovery outdoor units (heat pumps);
- direct expansion (dx) fan coils with one fan coil for each zone; and
- high efficiency inverter type variable speed compressors.

HEAT RECOVERY OUTDOOR UNITS (HEAT PUMPS) AND DX FAN COILS

The heat recovery outdoor units in combination with the dx fan coils allow zones to be independently controlled whenever there is a simultaneous demand for both heating and cooling. This setup allows for one fan coil on the system to cool and one fan coil on the same system to heat. The heat absorbed in the cooling zone is rejected into the heating zone and not to the outside. Zones were chosen based on function, occupancy and building orientation allowing for control of indoor temperature by the building occupants.

VARIABLE SPEED COMPRESSORS

The VRF and variable speed compressors provide appropriate load matching and reduce the number of compressor starts. The proprietary integrated factory digital control system optimizes the system for the most efficient operation possible.

FIGURE 6: TRAINING CENTER VRF MECHANICAL HVAC SYSTEM

TABLE 1: MAKE & MODEL NAMEPLATE INFORMATION, COOLING CAPACITY AND VRF MODELING SYSTEM DESIGNATION

ID	Make	Model	Cooling Capacity (MBH)	VRF System Designation for Modeling
1	Mitsubishi	PURY-P96TKMU-A-BS	96	VRF-1
2	Mitsubishi	PURY-P96TKMU-A-BS	96	VRF-1
3	Mitsubishi	PURY-P96TKMU-A-BS	96	VRF-2
4	Mitsubishi	PUHY-P120TKMU-A-BS	120	VRF-2
5	Mitsubishi	PUHY-P120TKMU-A-BS	120	VRF-2
6	Mitsubishi	PURY-P144TKMU-A-BS	144	VRF-4
7	Mitsubishi	PURY-P144TKMU-A-BS	144	VRF-4

ASSESSMENT OBJECTIVES

The objectives of this ET field assessment are:

- to establish the total annual energy consumption (with the PCM installed) using the building's 12 month billing data;
- to confirm the building's HVAC operational characteristics (with the PCM installed) by collecting 12 months of hourly measurement data through the building's metering system and redundant sub-metering;
- to calibrate energy models to the building's 12 month billing data;
- to calibrate HVAC system (heat pump) to the sub-metering data;
- to simulate a baseline energy model without the PCM in the roof and walls;
- to determine the energy savings potential due to the PCM installation within the wall stud cavities and below the roof sheeting in a new construction building;
- to identify challenges and lessons learned from the energy modeling; and
- to recommend how modelling strategies would fit into a Savings by Design or residential new construction program.

TECHNOLOGY/PRODUCT EVALUATION

This ET Field Assessment studied the impacts of installing PCM in a new construction commercial training center located in Chula Vista, California. This site was selected because the City of Chula Vista has desirable temperature swings appropriate for a PCM field assessment.

As indicated in **Table 2**, prior field assessments targeted non-residential retrofit installations where both baseline and post PCM data were available. Unlike the prior field assessments, baseline data did not exist for this ET Field Assessment because the training center was designed and built as a new facility with PCM already installed in the walls and roof. Thus, one primary objective of this ET Field Assessment is to recommend effective modelling strategies that would fit into a savings by design or residential new construction incentive program via a calibrated post energy model.

TABLE 2: PHASE CHANGE MATERIAL FIELD ASSESSMENT STUDIES

Entity	ET Project Number	Project Description	Sector	Report Date	Energy Savings
SCE	ET11SCE1260 Phase Change Materials for Building Cooling Applications	Assessing the technical potential of PCMs for reducing the cooling load in commercial buildings.	Commercial Office Space	December 2012	2-14% Savings
SCE	ET15SCE1050 Analysis of Energy Performance in a Quick Service Restaurant	Evaluating the energy saving capabilities of the PCM used in the attic space of a quick service restaurant	Commercial –Fast Food Restaurant	April 2016	1.8% Savings 1,708 kWh
SDG&E	ET16SDG1061 Phase Change Material and Controls Study	Evaluating the energy saving, demand shifting, and demand response applications of the passive PCM and control system across two different walk-in freezers.	Commercial Walk-in Freezers in Cafeteria Kitchens and Warehouse	October 2016	30-38% Savings 59,030 kWh

MV Automation, Inc.	Repair By Upgrade Building Envelope of Augmentee Barracks	Determining the energy savings and thermal comfort impacts on occupants for installing PCM and other efficiency measures.	Military Base Barracks and Admin Buildings	July 2016	34.7% Savings 106,187 kWh
Sustainability Matters	Measurement & Verification Report FINAL Phase Change Material	Monitoring the energy performance of PCM in portable classroom buildings.	Commercial Education Secondary	July 2016	26% Savings

TECHNICAL APPROACH/TEST METHODOLOGY

INTERNATIONAL PERFORMANCE MEASUREMENT AND VERIFICATION PROTOCOL

The International Performance Measurement and Verification Protocol (IPMVP) is a guidance document describing common practice in measuring, computing and reporting savings achieved by energy or water efficiency projects at end user facilities. The IPMVP provides standardized protocols, methods and tools to quantify and manage the performance risks and benefits associated with end-use energy-efficiency, renewable energy, and water efficiency business transactions. The IPMVP presents a framework and four measurement and verification options for transparently, reliably and consistently reporting project savings.

IPMVP OPTION D CALIBRATED SIMULATION

IPMVP Option D, Calibrated Simulation, involves the use of computer simulation software to predict facility energy. A simulation model must be "calibrated" so that it predicts an energy pattern that approximately matches actual metered data.

Option D may be used to assess the performance of individual systems within a facility where the system's energy use must be isolated from that of the rest of the facility by appropriate meters. Option D is useful where baseline energy data does not exist or is unavailable. Such situations may arise for a new construction project or a facility expansion needing to be assessed separately from the rest of the facility.

IPMVP OPTION D FOR A NEW CONSTRUCTION TRAINING CENTER

As indicated above, IPMVP Option D is useful where baseline energy data does not exist. Here, no baseline data existed because the training center was newly constructed with the intent to meet the highest possible standards of LEED Certification, sustainability, and energy efficient design including adding PCM material in the walls and roof. Therefore, the technical approach and field test methodology leveraged IPMVP Option D to assess energy savings potential associated with the PCM installation.

IPMVP OPTION CHALLENGES

Measuring energy data, via accurate computer modeling and calibration, is a major challenge associated with Option D. IPMVP indicates that building types not easily modeled include:

- unusual exterior shapes,
- a large number of distinct zones of temperature control, and
- complex HVAC systems.

The training center presents all three of these challenges. The building has an unusual exterior shape as there are two different shapes to the roof. The roof for the administrative office space has a different shape from the roof over the indoor archery range.

Secondly, the training center has a number of distinct temperature zone controls. As indicated, the HVAC mechanical system includes heat recovery outdoor units in combination with the dx fan coils. This setup allows zones to be independently controlled whenever there is a simultaneous demand for both heating and cooling. This setup also requires data to be collected in the applicable zones to ensure space temperatures are accurately captured and calibrated in the energy model.

Lastly, the HVAC system presents unique challenges to software tools readily available on the market because the VRF mechanical system is newer relative to other HVAC mechanical systems. Thus, many of the software tools may not have the algorithms needed to simulate the impacts of PCM on a VRF mechanical system. Therefore, to control costs all while maintaining accuracy, IPMVP recommends the following considerations:

- input data should represent the best available information including actual performance data from key components in the facility;
- simulation inputs need to be adjusted so results match both the demand and energy consumption data from utility bills within acceptable tolerances (i.e. calibrated);
- simulation printouts, survey data and the metering or monitoring data used to define input values and calibrate the simulation model should be kept in paper and electronic files; and
- modeling efforts can be streamlined by retaining the building energy modeler that created the "as-designed" model to create the calibrated "as-built" and adjusted baseline model for new construction projects.

FIELD TESTING OF TECHNOLOGY

FIELD ASSESSMENT SITE SELECTION

The PCM technology evaluated in this ET Field Assessment proposed to save energy and reduce energy costs on the HVAC system by absorbing heat during the day and releasing heat at night typically at or near room temperature. The criterion to yield unbiased field test results required selecting a site that had some temperature swings to capture the PCM's potential energy savings from its ability to absorb and release heat.

The training center met this criterion because it is located in Climate Zone 10 where warmer inland temperature conditions are typical but also boarders Climate Zone 7 where cooler coastal conditions are typical.

DATA COLLECTION REQUIREMENTS

As shown in **Figures 7, 8** and **9**, PCM was installed in the stud cavities of the training center's interior walls, exterior walls and underneath the roof sheeting at the time of construction. The PCM proposes to save energy and reduce energy costs on the HVAC system by absorbing heat during the day and releasing heat at night.

To align with the goals of IPMVP Option D, this ET Field Assessment needed to collect the best available information including billing data and actual performance data from key components in the facility especially data from the HVAC heat pumps. Thus, to measure HVAC energy savings impact potential, the heat pumps, internal space temperatures, and occupancy needed to be tracked as described in the next section: Monitoring Plan.

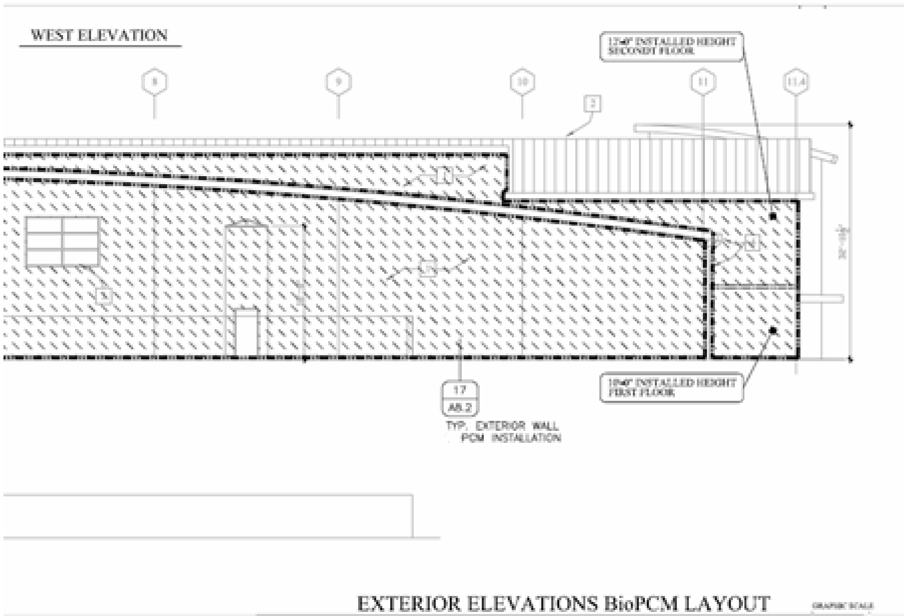


FIGURE 7: PCM INSTALLED IN THE EXTERIOR WALLS OF THE NEWLY CONSTRUCTED TRAINING CENTER

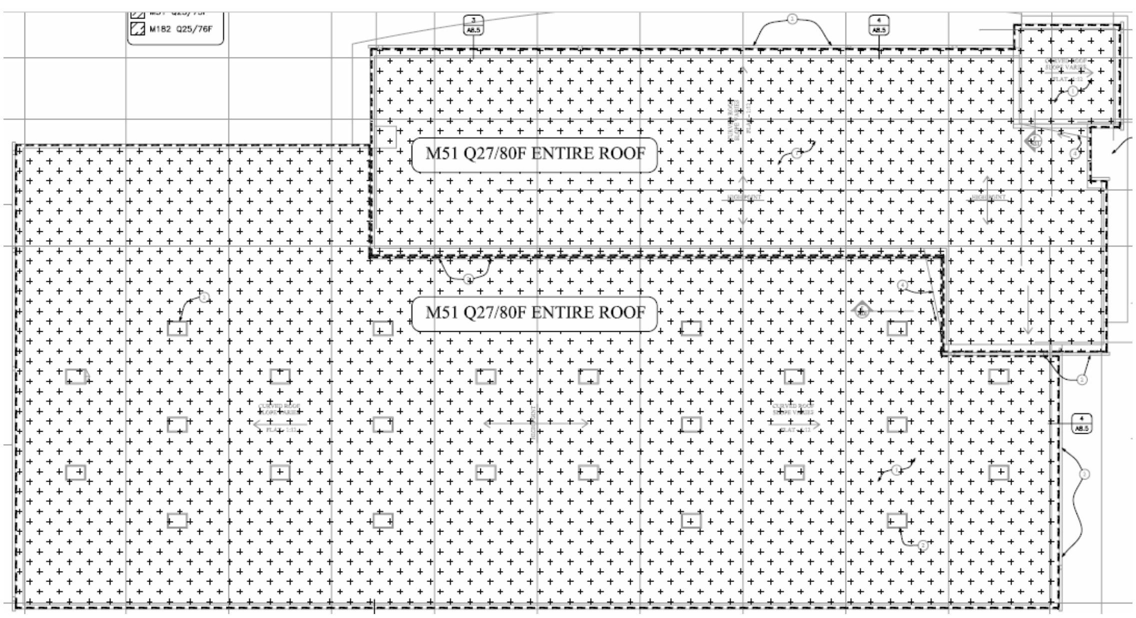


FIGURE 8: PCM INSTALLED UNDERNEATH THE ROOF SHEETING IN THE NEWLY CONSTRUCTED TRAINING CENTER

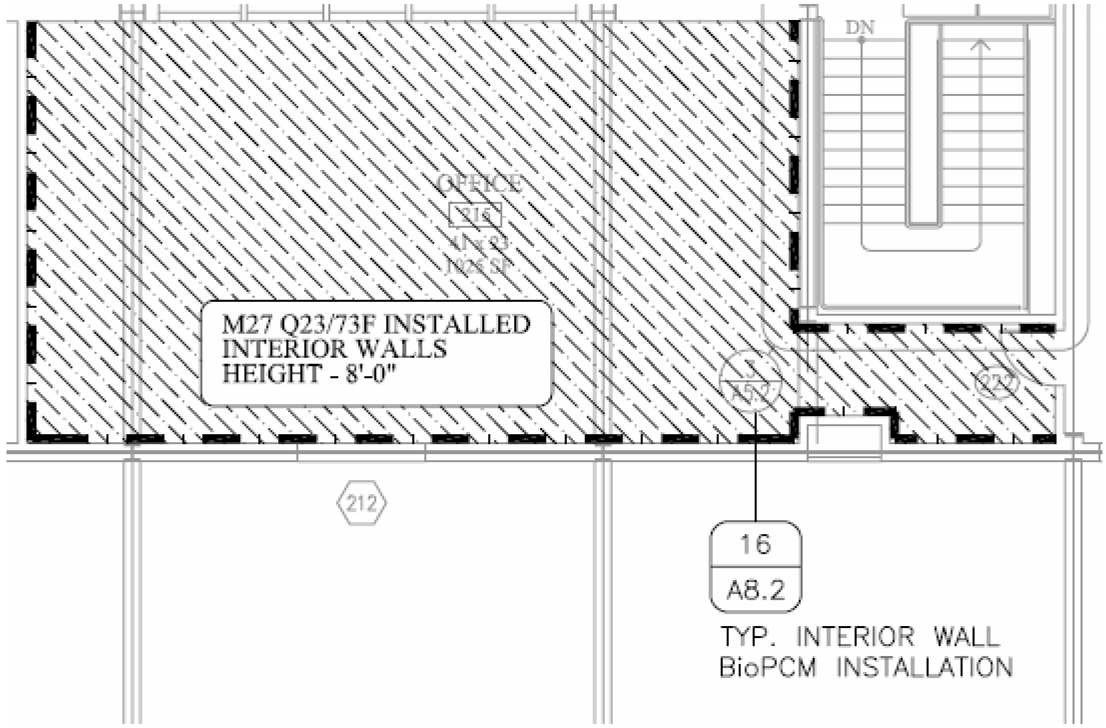


FIGURE 9: PCM INSTALLED IN THE INTERIOR WALLS OF THE NEWLY CONSTRUCTED TRAINING CENTER

MONITORING PLAN

Since the HVAC system load profile is affected by weather conditions, the monitoring plan required 1) gathering energy consumption data from monthly utility bills, and 2) gathering data representing the best available information including actual performance data from key components in the facility to achieve the IPMVP Option D goals.

12 MONTHLY BILLING DATA

The first objective of this ET Field Assessment was to establish the total annual energy consumption (with the PCM installed) using the building's 12 month billing data. **Table 3** exhibits the training center's annual energy consumption with the PCM installed. This information was taken directly from the 12 month billing data. As shown in **Table 3**, the training center consumed a total of 166,152 kWh from 2016 to 2017.

ACTUAL HVAC EQUIPMENT 12 MONTHS OF HOURLY MEASUREMENT DATA

In addition to collecting the 12 month billing data, IPMVP Option D requires collecting actual performance data from key components in the facility. In this ET Field Assessment, this meant collecting HVAC performance data and usage. Thus, to confirm the building's HVAC operational characteristics (with the PCM installed), the monitoring plan required collecting 12 months of hourly measurement data through the building's metering system and redundant sub-metering data on relevant equipment, occupancy and space temperatures.

TABLE 3: TRAINING CENTER'S ANNUAL ENERGY CONSUMPTION FROM 12 MONTH BILLING DATA

Billing Year	Billing Month	Billing Monthly Usage (kWh)
2017	January	11,525
2017	February	12,091
2017	March	16,762
2016	April	15,556
2016	May	11,992
2016	June	15,651
2016	July	15,531
2016	Aug	15,320
2016	Sept	12,802
2016	Oct	13,065
2016	Nov	14,545
2016	Dec	11,314
Total 12 Month Energy Use		**166,152**

MONITORING AND INSTRUMENTATION APPROACH

TRAINING FACILITY'S BUILDING METERING SYSTEM

The training center's building metering system monitors two electrical panels. The electric panels monitor the HVAC system's compressors, heat pump and fan coil usage. The metering system measures kW, kWh, PF, amps, and voltage for each panel. **Figure 10** illustrates one of the two electrical panels that interface with the training center's metering system.

FIGURE 10: TRAINING FACILITY'S BUILDING METERING SYSTEM ON THE TWO ELECTRICAL PANELS

REDUNDANT ELECTRICAL POWER SUB-METERING DATA AND MONITORING LOCATIONS

To ensure accuracy of the building's metering system, redundant electrical sub-metering equipment was installed on both electrical panels to capture heat pump (HP) and available fan coils (FC) data throughout the 12 month monitoring period. Additionally, these two electrical monitoring points were captured because it was anticipated that any potential savings resulting from the PCM would impact both of these HVAC equipment loads. **Table 4** exhibits the electrical monitoring points and metering instruments used.

TABLE 4: REDUNDANT ELECTRICAL SUB-METERING EQUIPMENT AND MONITORING LOCATIONS

Instrument Serial #	Instrument Channel	Unit	Voltage	Location
10898062	1	FC 3.13	240	Panel 1M, outside
	2	FC 3.14	240	Panel 1M, outside
10898065	1	HP 4-1 (144A)	240	Panel 1M, outside
	2	HP 4-2 (144A)	240	Panel 1M, outside
	3	HP 1-1 (96A)	240	Panel 1M, outside
10898064	1	HP 3 (120)	240	Panel 1M, outside
	2	HP1-2 (96)	240	Panel 1M, outside
	3	HP 2-2 (120)	240	Panel 1M, outside
	4	HP 2-1 (96)	240	Panel 1M, outside
10898063	1	FC 4.21, 4.20, BC-4B	208	Interior Panel / Circuit 14-16
	2	FC 1.2, 1.4	208	Interior Panel
	3	fan 3	208	Interior Panel
	4	fan 4	208	Interior Panel

REDUNDANT TEMPERATURE AND OCCUPANCY SUB-METERING DATA AND MONITORING LOCATIONS

Redundant temperature and occupancy sub-metering equipment were placed in various spaces within the training center including the administrative office spaces, storage and equipment rooms, the indoor archery range and the exercise room to ensure accuracy of the building's metering system.

Table 5 exhibits the temperature and occupancy monitoring points and metering instruments used. These two monitoring points were captured because internal space temperatures and occupancy could trigger an HVAC event. It was anticipated that internal space temperatures and occupancy were needed for the calibrated energy model. Thus, internal space temperatures were collected to ensure building's monitoring system accuracy.

TABLE 5: REDUNDANT TEMPERATURE AND OCCUPANCY SUB-METERING EQUIPMENT AND MONITORING LOCATIONS

Instrument Serial #	Instrument Data Logger	Location
10885426	Occupancy	Admin Office: above side door
10899615	Supply temp	Admin Office: Velcro to unit on FC 4.21
10885423	Occupancy	Bow Storage/Athlete Equipment Room (Lower Level): on duct by door
10899620	Return Temp	Bow Storage/Athlete Equipment Room (Lower Level): Corner of Room
10899618	Supply Temp	Bow Storage/Athlete Equipment Room (Lower Level): Middle of Room
10885425	Occupancy	Loophole Range: on ceiling electric outlet
10899616	Return Temp	Loophole Range: on return air by Doug's A... Shop
10899617	Supply Temp	Loophole Range: on duct facing supply air
10885427	Occupancy	Exercise Room: electrical box by door
10899619	Return Temp	Exercise Room: above sink
10899621	Supply Temp	Exercise Room: on grill by window
10899623	Return Temp	Indoor Archery Range: West Side
10899622	Return Temp	Indoor Archery Range: East Side (nearest lobby)
10899624	Supply Temp	Indoor Archery Range: West Side
10899614	Supply Temp	Indoor Archery Range: East Side (nearest lobby)
10885424	Occupancy	Indoor Archery Range: on first light fixture by lobby door

TEST PLAN

The test plan for this ET Field Assessment used IPMVP Option D because the training center is a new construction building that installed PCM into the stud cavities of the interior and exterior walls and underneath the roof sheeting.

MONITORING PERIOD

The monitoring period for this ET Field Assessment occurred over the course of 12 months from April 15, 2016 to April 21, 2017 with the PCM. Redundant electrical, occupancy and temperature submetering data was recorded and collected every two months to allow the data loggers to clear.

MONITORING DATA POINTS

Measuring space temperatures, occupancy and relevant HVAC electrical equipment are of interest because the PCM proposes to offset HVAC energy costs by absorbing and releasing heat. Thus, a key success to this project is to get these data points and ensure that an accurate and calibrated post energy model is produced. Thus, as outlined in IPMVP Option D, the test approach assessed the HVAC heat pumps, occupancy and both return and supply air temperatures within the training center.

FIGURE 11: TRAINING CENTER'S BUILDING MONITORING SYSTEM SPACE TEMPERATURES BY ZONE

FIGURE 12: TRAINING CENTER'S SUPPLY AIR HANDLER UNIT IN EXERCISE ROOM

FIGURE 13: TRAINING CENTER'S INSIDE ELECTRICAL PANEL

SIMULATION MODELING

WHAT IS SIMERGY?

Simergy is a building energy modeling simulation tool developed by Digital Alchemy. Simergy is the front-end to the US Department of Energy's (DOE) EnergyPlus simulation engine (version 8.6). The Simergy tool allows users to

- create models from scratch,
- create them based on DWG/DXF drawings, or
- import and extend models already developed in architectural design applications like Revit™, ArchiCAD™, Bentley Architecture™, and other applications that are able to export either IFC or gbXML BIM file.

WHY SIMERGY?

When the project began in late 2015, other readily available building energy modeling simulation tools did not have the capabilities to simulate PCM. The Simergy modeling tool incorporated a more user friendly front-end to the EnergyPlus engine. Simergy also used EnergyPlus as its modelling back-end, which is a code compliant software tool. Finally, Simergy was the building energy modeling software tool used in prior SCE ET Field Assessments of PCM materials, which meant that some of the modelling challenges associated with PCM had already been identified and fixed.

IPMVP OPTION D CALIBRATED SIMULATION MODEL

Because this building was newly constructed with the PCM material installed, the calibrated simulation IPMVP Option D was chosen for this project and a calibrated model was created for the training center using the Simergy tool.

As indicated, Simergy was chosen because the project involved PCM, and the Simergy tool had incorporated heat transfer algorithm choices that accounted for the different temperatures and enthalpy properties of PCM. The EnergyPlus software included California Title 24 weather file "SAN-DIEGO-GILLESPIE_722907_CZ2010.epw" which is located in climate zone 10 at an airfield located approximately 20 miles from the site.

The Gillespie weather data was chosen over the Otay Lake weather data because the Otay Lake weather station is located in Climate Zone 7, which typically has a cooler climate compared to Climate Zone 10. Thus, Climate Zone 10 was used in the modeling effort to comply with CPUC weather data requirements.

PRINTOUTS AND DRAWINGS USED IN CALIBRATED MODEL

CAD drawings were obtained, which included the building geometry, windows, schedules, equipment specifications, wall assemblies, roof assemblies, and locations of the PCM material. Information provided in the CAD drawings was verified through site visits and/or discussions with site personnel.

Building Geometry

The building geometry was entered into the Simergy tool by drawing the floorplan over the CAD drawings. Although the algorithms for PCM treatment are built into the Simergy software, users have to manually create PCM materials and then add the algorithm to the PCM material within the Simergy library. Library entries were created for the site's six (6) different PCM types within different building locations including the roof, exterior walls and some interior walls. The PCM library entries included 16 temperature and 16 enthalpy data points that were imported from Design Building Software, which is an alternative EnergyPlus user interface. The wall and roof assemblies were then created in EnergyPlus in accordance with **Figure 14**.

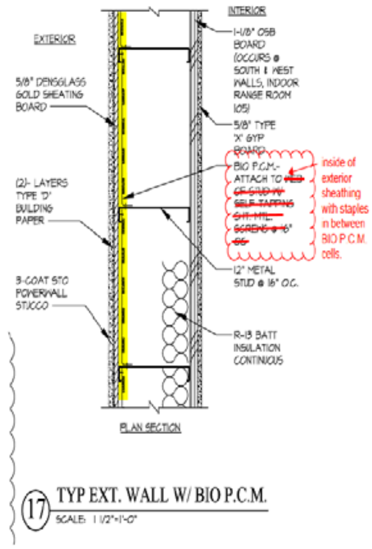


FIGURE 14: CAD DRAWING OF PCM IN EXTERIOR WALLS

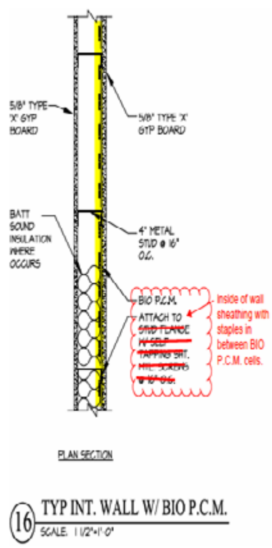


FIGURE 15: CAD DRAWING OF PCM IN INTERIOR WALLS

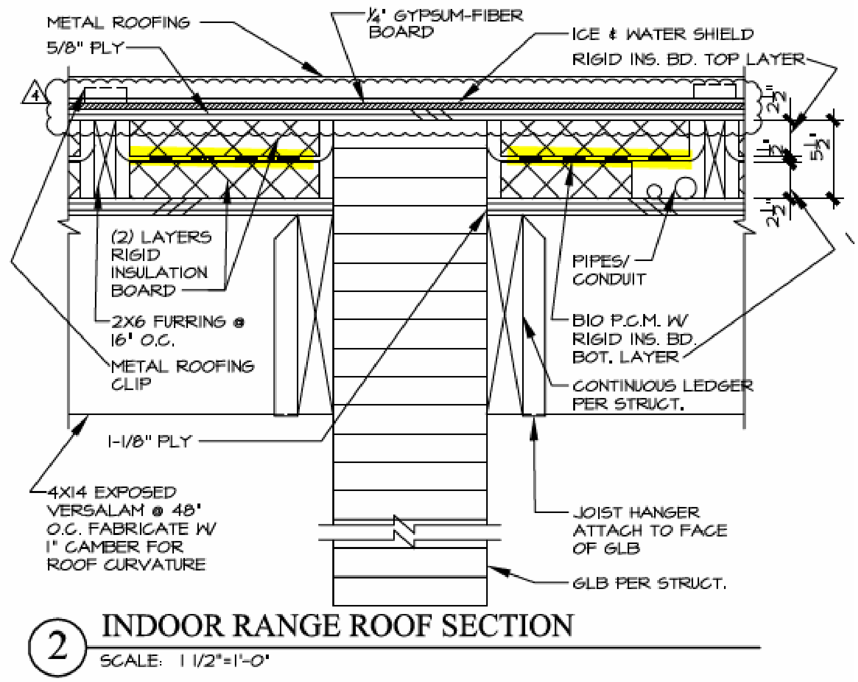


FIGURE 16: CAD DRAWING OF PCM IN THE INDOOR RANGE ROOF

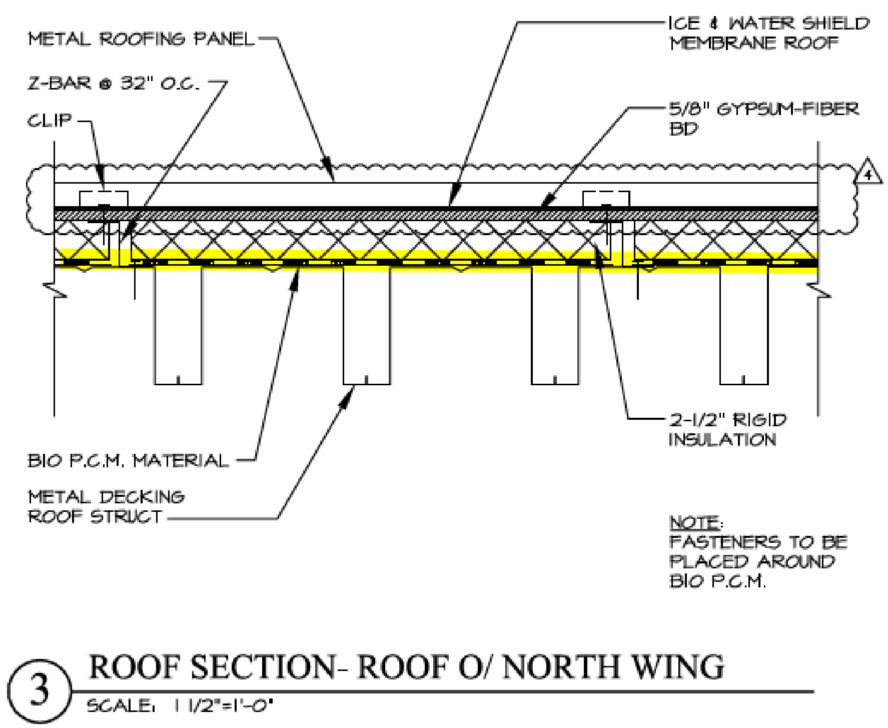


FIGURE 17: CAD DRAWING OF PCM IN THE NORTH WING ROOF

MODELING LIMITATIONS

The newly created library entries for the walls and roofs were assigned to the appropriate locations in the tool's building geometry. However, some limitations were encountered with the modeling software because the training center has a unique and custom architectural design.

Some of the limitations experienced with the tool included not being able to model barrel vault roof assemblies and difficulty modeling double height spaces. Discussions with the Simergy software developers revealed that modeling the roofs as flat roofs and using the average elevation of the barrel-vault would be sufficient.

Additionally, the double height spaces were modeled as stacked spaces, which when simulated are treated as single zones. The indoor range and one storage room were modeled in this manner. However, due to the difficulties with modeling double height spaces, the elevator shaft was not included in the energy model.

COMPLETION OF THE BUILDING SHELL

Once the building geometry was set, doors and windows were added to the training center model to complete the shell of the building. As the training center is a unique and custom designed building that does not match typical commercial building types, and calibrating a model is an iterative process, the starting point was to leverage a commercial office building shell and associated schedules. **Figures 18** and **19** exhibit the completed building shell from the Simergy tool.

FIGURE 18: SIDE BY SIDE COMPARISON OF COMPLETED BUILDING SHELL IN SIMERGY AND ACTUAL BUILDING

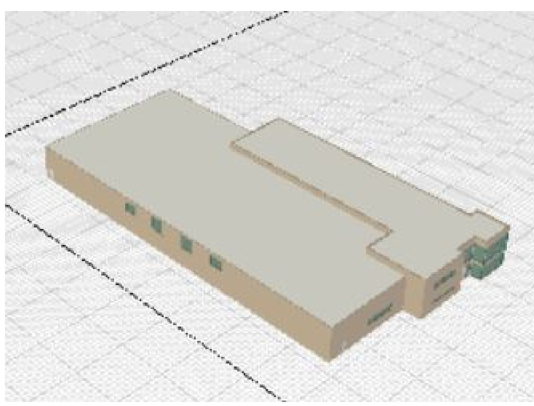


FIGURE 19: BIRD'S EYE VIEW OF COMPLETED BUILDING SHELL

ADDING THERMAL AND HVAC ZONES FOR VARIOUS SPACE TYPES

The various space types were added into the training center energy model as unique thermal zones. The two exceptions included the two ranges and storage areas. The thermal zones were then grouped into seven zonal groups, which allowed the user to assign specific zone loads and associated conditions. Thermal zones served by the same fan coil unit were all grouped together into an HVAC zone. HVAC Zones were then associated with corresponding heat pumps. A summary of this process is shown in **Table 6**.

TABLE 6: SUMMARY OF ADDING AND GROUPING THERMAL LOADS INTO HVAC ZONES FOR VARIOUS SPACE TYPES

Area	Floor	Zone Type	Simergy Thermal Zone	Simergy zone group	Simergy HVAC Zone	Heat Pump	Fan Coil
Hallway 109	1	Conditioned	1-7	6	zone 1	VRF System 1 - HP-1	1.1
Storage 106	1	Conditioned	1-2	6	zone 1	VRF System 1 - HP-1	1.1
Fitness 108	1	Conditioned	1-3	4	zone 1	VRF System 1 - HP-1	1.1
Men's Locker 113	1	Conditioned	1-6	3	zone 2	VRF System 1 - HP-1	1.2
Women’s Locker 119	1	Conditioned	1-6	3	zone 2	VRF System 1 - HP-1	1.2
Athletes Lounge 118	1	Conditioned	1-6	3	zone 2	VRF System 1 - HP-1	1.2
Men’s Rest 117	1	Conditioned	1-8	3	zone 2	VRF System 1 - HP-1	1.2
Women’s Rest 121	1	Conditioned	1-9	3	zone 2	VRF System 1 - HP-1	1.2
Hallway 108/Stairs 2	1	Conditioned	1-4	3	zone 2	VRF System 1 - HP-1	1.2
Women’s Res 122	1	Conditioned	1-11	3	zone 2	VRF System 1 - HP-1	1.2
Men’s Rest 116	1	Conditioned	1-10	3	zone 2	VRF System 1 - HP-1	1.2
Restroom 115	1	Conditioned	1-20	3	zone 2	VRF System 1 - HP-1	1.2
Testing Workshop 123	1	Conditioned	1-12	2	zone 3	VRF System 1	1.3

						- HP-1	
Women's Rest 127	1	Conditioned	1-22	6	zone 4	VRF System 1 - HP-1	1.4
Men's Rest 126	1	Conditioned	1-21	6	zone 4	VRF System 1 - HP-1	1.4
Archery Equipment Storage 125	1	Conditioned	1-13	6	zone 4	VRF System 1 - HP-1	1.4
Hallway 109	1	Conditioned	1-7	6	zone 4	VRF System 1 - HP-1	1.4
Indoor to Outdoor Shooting Area 124	1	Conditioned	1-14	6	zone 4	VRF System 1 - HP-1	1.4
Coaches Office 128	1	Conditioned	1-15	2	zone 5	VRF System 1 - HP-1	1.5
Office 130	1	Conditioned	1-23	2	zone 5	VRF System 1 - HP-1	1.5
Lobby/Gallery/ Stairs	1	Conditioned	1-26	5	zone 6	VRF System 1 - HP-1	1.6
Meeting/Office 103	1	Conditioned	1-17	2	zone 7	VRF System 1 - HP-1	1.8
Coaches Office 104	1	Conditioned	1-18	2	zone 8	VRF System 1 - HP-1	1.9
Mechanical 112/Elec 111	1	Un-conditioned	1-5, 1-19 and 1-25		n/a	n/a	n/a
Elevator Equip RM 129	1	Un-conditioned	1-24		n/a	n/a	n/a
Elevator 132	1	Un-conditioned	n/a		n/a	n/a	n/a
Indoor Shooting Range west end 4511 ft^2	1	Conditioned	1-1	4	zone 9	VRF System 2 - HP-2	2.1
Indoor Shooting Range, 5583 ft^2	1	Conditioned	1-1	4	zone 9	VRF System 2 - HP-2	2.11
Indoor Shooting Range, 4514 ft^2, near balcony	1	Conditioned	1-1	4	zone 9	VRF System 2 - HP-2	2.12
Viewing	1	Conditioned	1-1	4	zone 9	VRF	2.12

balcony						System 2 - HP-2	
indoor shooting range, SW 3897 ft^2	1	Conditioned	1-1	4	zone 9	VRF System 3 - HP-3	3.13
indoor shooting range, SE, 3906 ft^2	1	Conditioned	1-1	4	zone 9	VRF System 3 - HP-3	3.14
Office 215	2	Conditioned	2-3	2	zone 10	VRF System 4 - HP-4	4.15
Conference Room 217	2	Conditioned	2-5	1	zone 11	VRF System 4 - HP-4	4.16
Storage 220	2	Conditioned	2-7	2	zone 12	VRF System 4 - HP-4	4.17
Office 218	2	Conditioned	2-6	2	zone 12	VRF System 4 - HP-4	4.17
Office 219	2	Conditioned	2-6	2	zone 12	VRF System 4 - HP-4	4.17
Conference Room 221	2	Conditioned	2-8	1	zone 13	VRF System 4 - HP-4	4.18
IT Equip Room 210	2	Conditioned	2-18	7	zone 14	VRF System 4 - HP-4	4.19
Lunch Room 222	2	Conditioned	2-9	1	zone 15	VRF System 4 - HP-4	4.2
Storage 225	2	Conditioned	2-12	2	zone 16	VRF System 4 - HP-4	4.21
Facilities Manager Off 224	2	Conditioned	2-11	2	zone 16	VRF System 4 - HP-4	4.21
Janitor 226	2	Conditioned	2-12	2	zone 17	VRF System 4 - HP-4	4.22
Office 207	2	Conditioned	2-15	2	zone 17	VRF System 4 - HP-4	4.22
Office 206	2	Conditioned	2-14	2	zone 17	VRF System 4 - HP-4	4.22
Men's 208	2	Conditioned	2-16	6	zone 17	VRF System 4 - HP-4	4.22

RR 213	2	Conditioned	2-22	6	zone 17	VRF System 4 - HP-4	4.22
Storage 214	2	Conditioned	2-23	6	zone 17	VRF System 4 - HP-4	4.22
Office 212	2	Conditioned	2-21	2	zone 17	VRF System 4 - HP-4	4.22
Office 211	2	Conditioned	2-20	2	zone 17	VRF System 4 - HP-4	4.22
Storage 210	2	Conditioned	2-20	2	zone 17	VRF System 4 - HP-4	4.22
Hallway 205	2	Conditioned	2-24	6	zone 17	VRF System 4 - HP-4	4.22
Women's 209	2	Conditioned	2-17	6	zone 17	VRF System 4 - HP-4	4.22
Meeting/Office 203	2	Conditioned	2-13	2	zone 18	VRF System 4 - HP-4	4.23
Coaches Office 204	2	Conditioned	2-25	2	zone 19	VRF System 4 - HP-4	4.24
Lobby 101	2	Conditioned	2-24	5	zone 20	VRF System 4 - HP-4	4.25
Upper Lobby 201	2	Conditioned	2-24	5	zone 20	VRF System 4 - HP-4	4.25
stairs 216	2	Un-conditioned	2-4			n/a	n/a
Mechanical Mezzanine, 1548 ft^2	3	Un-conditioned	3-1			n/a	n/a

HVAC Equipment Schedule and Heat Pump Software Autosizing

The HVAC equipment schedule was the next item inputted into model. This included heat pump capacity and efficiency and fan coil CFM specifications. The indoor archery range had unique geometric design characteristics requiring a large double height space with fan coil units on both the north and south walls.

Due to the indoor archery range's unique configuration, heat pump 2 (north) and heat pump 3 (south) had to be combined and autosized in the baseline model in order to allow the software to complete a simulation. Autosizing is the process of automatically adjusting heat pump size within the software algorithms based on internal loads. This approach was discussed with Simergy's software developers and was deemed reasonable because aggregation of the heat pumps had no negative impact on the simulation results. The model was validated using Simergy's built in validation tools before initial simulations began.

CALIBRATION POST MODEL APPROACH

To properly simulate PCM material, a new simulation configuration was created using the Conduction Finite Difference (CFD) algorithm, which allows for differing temperature and enthalpy properties as provided by PCM material. The default heat transfer algorithm is a conduction transfer function and completes a simulation in 20 to 30 minutes. Using the CFD algorithm typically completes a simulation within 4.0 to 6.5 hours.

The billing history for this training center was obtained from April 2016 through March 2017. The billing data indicated that the training center experienced a peak demand of 83.2 kW and annual energy consumption of 166,152 kWh. Gas usage billing data at the facility totaled 351 therms/year.

As indicated, the training center is equipped with a building metering system that monitored all of the heat pumps and fan coil units 3.13 and 3.14 on one channel and many of the remaining fan coil units on the other channel. The heat pump data indicated that the four (4) VRF systems used 59,234 kWh for the same time period as the billing history.

The 59,234 kWh HVAC VRF heat pump energy consumption value includes the energy use for fan coils 3.13 and 3.14. As it was not possible to determine the energy use of the VRF's alone, electrical submeter data was used to determine the heat pump's contribution to the training center's annual energy use. The submeter data indicated the heat pump annual consumption totaled 55,717 kWh. **Table 7** shows the electrical submetered HVAC VRF heat pump annual energy consumption data breakdown.

TABLE 7: ELECTRICAL SUB-METER HVAC VRF HEAT PUMP ANNUAL ENERGY CONSUMPTION DATA BREAKDOWN

VRF System	Annual kWh Consumption	Location Served
HP1	6,073	1st Floor, non-range
HP 2 and HP 3	8,146	Range
HP 4	41,498	2nd floor and IT room
Total	55,717	-

CALIBRATION STEPS

As seen in **Table 7**, the primary HVAC energy usage at the training center occurred on the second floor (2nd floor), which included a server room and was mapped to VRF heat pump system 4. Both the total heat pump energy consumption and the overall building energy use dictated the following calibration steps.

- Lighting density for all spaces was dropped from the default of 1W/ft^2 to 0.6 W/ft^2.
- Zone Group 7 was added and only included the IT server room. Additional zone loads were added including a 1000W process load (server). The model was then modified to 3,000 ft^2/person from the default value of 149.9 ft^2/person.
- Temperature set point for HVAC Group 14 (IT server room) was modified to 72°F for weekdays (M-F) and 75°F for weekends using a 24/7 schedule.
- All other HVAC zone cooling set points and schedules were modified to the weekday schedule as shown in **Figure 20** and the weekend schedule as shown in **Figure 21**. The average space temperature of 72 F was obtained from the submeter data and confirmed through viewing of the EMS control panel. The set point was adjusted in the early morning and evening hours to allow the HVAC energy use to calibrate to the submetered data.

- Zone Groups 1-4 include all 1st floor spaces and was modified to 2,500 ft^2/person from the default value of 149.9 ft^2/person.

StartingxPoint	EndXPoint	Value
Midnight	8:00 AM	74
8:00 AM	9:00 AM	73
9:00 AM	4:00 PM	72
4:00 PM	5:00 PM	73
5:00 PM	Midnight	74

FIGURE 20: SIMERGY HVAC SCHEDULING FOR WEEKDAYS

StartingxPoint	EndXPoint	Value
Midnight	8:00 AM	74
8:00 AM	9:00 AM	73
9:00 AM	2:00 PM	72
2:00 PM	3:00 PM	73
3:00 PM	Midnight	74

FIGURE 21: SIMERGY HVAC SCHEDULING FOR WEEKENDS

Once these modifications were saved, a new simulation configuration was created using the CFD algorithm, which allows for differing temperature and enthalpy properties as provided by PCM material. As indicated earlier, the default heat transfer algorithm is conduction transfer function and completes a simulation in 20 to 30 minutes while using the CFD algorithm typically completes a simulation within 4.0 to 6.5 hours.

RESULTS

CALIBRATED MODEL RESULTS COMPARED TO MEASURED DATA

The post calibrated model final results produced a peak demand of 81.9 kW and annual energy consumption of 165,711 kWh. Furthermore, the annual energy consumption of the heat pumps was 761 kWh (heating) and 56,608 kWh (cooling) for a total of 57,369 kWh. Gas usage billing data at the facility totaled 351 therms/year.

Because the heating system is all electric and because the gas use is small, the model was not calibrated to account for gas usage. However, the model predicted annual gas use of 78.32 therms.

A comparison between the billing history/submeter data and the calibrated energy model results are shown in **Table 8**. Based on the results in **Table 8**, the model is considered to be calibrated on an annual basis within reasonable limits and no further changes were made to the post calibrated model.

TABLE 8: BILLING HISTORY AND SUB-METER DATA AND CALIBRATED ENERGY MODEL RESULTS COMPARISON

	kW	Heat Pump kWh	Total kWh
Actual	83.2	55,717	166,152
Calibrated Model	81.9	57,369	165,711
% Error	1.6%	3.0%	0.3%

Energy End Use Summary

	Electricity (kWh)	Gas (kBtu)	District Cooling (kBtu)	District Heating (kBtu)	Other Utilities (kBtu)	Site Energy (kBtu)
Heating	761	.0	.0	.0	.0	2,595
Cooling	56,608	.0	.0	.0	.0	193,007
Fans	27,883	.0	.0	.0	.0	95,069
Pumps	0	.0	.0	.0	.0	0
Heat Rejection	0	.0	.0	.0	.0	0
Humidification	0	.0	.0	.0	.0	0
Heat Recovery	0	.0	.0	.0	.0	0
Water Systems	0	.0	.0	.0	.0	0
Interior Lighting	71,697	.0	.0	.0	.0	244,452
Exterior Lighting	0	.0	.0	.0	.0	0
Interior Equipment	8,761	7,832.4	.0	14,215.8	.0	51,919
Exterior Equipment	0	.0	.0	.0	.0	0
Refrigeration	0	.0	.0	.0	.0	0
Generators	0	.0	.0	.0	.0	0
Grand Total	**165,711**	**7,832**	**0**	**14,216**	**0**	**587,042**

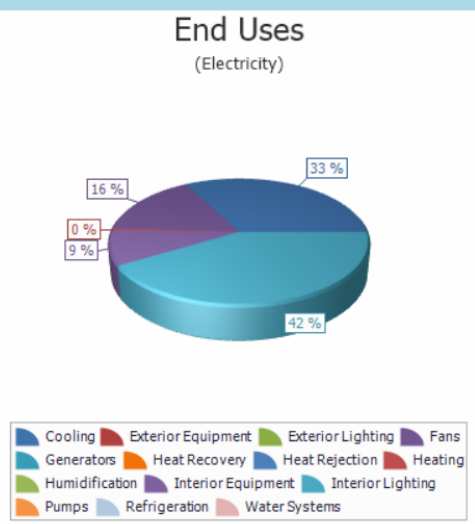


FIGURE 22: SIMERGY CALIBRATED POST MODEL RESULTS

DATA ANALYSIS

As shown in **Table 8**, the calibrated energy model was within 1.6% of the annual billing data for the whole building, within 3% of the actual peak demand, and within 0.3% of the submetered heat pump data.

However, the simulation results also include an error log, which details 370 potential errors within the model. The errors primarily relate to the fan coil unit sizing and in all cases potential remedies to the errors are included to be: "*Resolution being developed. Should be in next update*." These errors were discussed with the software developer. The software developers indicated that these errors likely have no significant impact on the overall simulation results.

MODELING TRAINING CENTER'S ENERGY SAVINGS & BASELINE ENERGY USE

In order to determine energy savings resulting from the PCM installations, the calibrated model must be modified to estimate energy usage without PCM installations. The simplest approach is to change the heat transfer algorithm for the PCM to not use the CFD algorithm. Additionally, since HVAC sizing parameters of the calibrated model are based on actual equipment, the baseline model was allowed to autosize all components. These components include

- cooling supply flow,
- no cooling supply flow,
- heating supply flow,
- no heating supply flow,
- cooling outside air (OA) flow,
- heating OA flow,
- no load OA flow,
- fan on/off,
- heat pump cooling capacity, and
- heating cooling capacity.

This is not typical because in retrofit scenarios as actual HVAC equipment and associated usage would be accounted for in the baseline simulation run. The baseline energy model was simulated using the post model as a starting point and then allowed Simergy to autosize all the components. The baseline model with no PCM installed results are shown in **Figure 23**.

Energy End Use Summary

	Electricity (kWh)	Gas (kBtu)	District Cooling (kBtu)	District Heating (kBtu)	Other Utilities (kBtu)	Site Energy (kBtu)
Heating	18,400	.0	.0	.0	.0	62,735
Cooling	58,733	.0	.0	.0	.0	200,252
Fans	152,031	.0	.0	.0	.0	518,350
Pumps	0	.0	.0	.0	.0	0
Heat Rejection	0	.0	.0	.0	.0	0
Humidification	0	.0	.0	.0	.0	0
Heat Recovery	0	.0	.0	.0	.0	0
Water Systems	0	.0	.0	.0	.0	0
Interior Lighting	71,697	.0	.0	.0	.0	244,452
Exterior Lighting	0	.0	.0	.0	.0	0
Interior Equipment	8,761	7,832.4	.0	14,215.8	.0	51,919
Exterior Equipment	0	.0	.0	.0	.0	0
Refrigeration	0	.0	.0	.0	.0	0
Generators	0	.0	.0	.0	.0	0
Grand Total	**309,622**	**7,832**	**0**	**14,216**	**0**	**1,077,708**

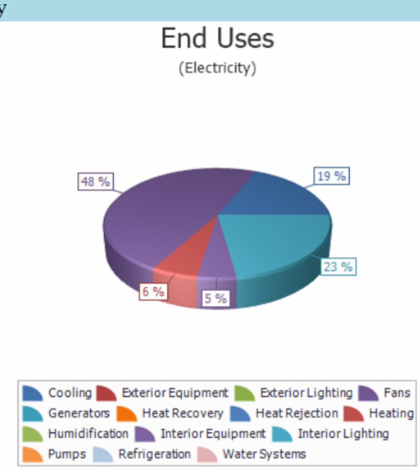


FIGURE 23: SIMERGY BASELINE SIMULATED MODEL RESULTS

ANNUAL ENERGY SAVINGS AND PEAK DEMAND REDUCTION

ANNUAL ENERGY SAVINGS

In summary, the post retrofit model was calibrated within acceptable percent error on an annual basis and is likely a good representation of the actual building. Relying on the Simergy tool's autosized baseline and calibrated post model runs, the annual energy savings at the heat pumps equated to 19,746 kWh (25.6%), and 124,148 kWh annual energy savings at the fans for a total annual energy savings of 143,894 kWh.

Given that actual annual energy consumption with PCM amounted to 166,152 kWh, annual fan savings of 143,894 kWh would result in more than 46% savings from the estimated baseline consumption (309,622 annual kWh as shown in Figure 23) due to the PCM. This result combined with the simulation errors and warnings raise concerns that the fan savings are overestimated.

PEAK DEMAND REDUCTION SAVINGS

Although the actual summer peak period for Climate Zone 10 varies annually, the CPUC DEER peak demand period for this climate zone occurs on September 1-3. However, the Simergy simulation results for this model only show the peak monthly demand. Therefore, the closest entry to the DEER peak demand period occurred on August 19, which was 94.38 kW for the baseline simulation run. The corresponding peak demand period of the calibrated post model simulation run for August 19 was 79.4 kW. Based on the above information, the estimated peak demand savings amounted to 14.98 kW.

ADDITIONAL BASELINE SIMULATION SCENARIO RUNS

Additional baseline simulation scenarios were conducted including:

1) PCM in the roof only,

2) PCM in the exterior walls only, and

3) PCM in the interior walls only to confirm baseline usage was reasonable.

Unexpectedly, the simulation results for all three simulation runs produced no difference in the baseline consumption including heat pump, fans or overall building use. Consequently, additional simulations were conducted for the baseline scenario to assess the reasonableness of the simulation results.

In these additional simulation runs, the PCM layer was replaced with an air gap of equal dimensions. Full year simulations were also conducted and similar results to the prior baseline simulations were reported. In these scenarios, the PCM in the exterior walls did produce a small amount of energy savings of approximately 1,000 kWh, while PCM in the roof and interior walls did not produce any savings.

DISCUSSION

ESTABLISHING TOTAL ANNUAL ENERGY CONSUMPTION USING 12 MONTH BILLING DATA

Before a post calibrated model was created to meet the IPMVP Option D goals, the first assessment objective was to establish the total annual post energy consumption for the training center using the building's 12 month billing history. **Table 9** exhibits the training center's monthly billing usage from 2016-2017. This monthly billing use accounts for the installation of the PCM in the walls and roof, which totals 166,152 annual kWh. This annual energy use number was used to establish the post calibrated model boundary.

TABLE 9: TRAINING CENTER'S ANNUAL ENERGY CONSUMPTION FROM 12 MONTH BILLING DATA

Billing Year	Billing Month	Monthly Billing Usage (kWh)
2017	January	11,525
2017	February	12,091
2017	March	16,762
2016	April	15,556
2016	May	11,992
2016	June	15,651
2016	July	15,531
2016	Aug	15,320
2016	Sept	12,802
2016	Oct	13,065
2016	Nov	14,545
2016	Dec	11,314
Total 12 Month Energy Use		**166,152**

CONFIRMING BUILDING'S HVAC OPERATION

The next objective was to confirm the building's HVAC operational characteristics (with the PCM installed) by collecting 12 months of hourly measurement data through the building's metering system and redundant submetering. **Table 10** exhibits the HVAC usage from all heat pumps and fan coils 3.13 and 3.14, which account for the majority of the HVAC usage on the 2nd floor where the IT server room is also located. Based on this building monitoring system data, HVAC usage accounts for approximately 34% (55,717 kWh) of the building's total energy usage (166,152 annual kWh).

TABLE 10: TRAINING CENTER'S ANNUAL ENERGY CONSUMPTION FROM 12 MONTH BILLING DATA

Year	Month	Building's Metering System Monitored HVAC Usage for Heat Pumps and Fan Coils 3.13 and 3.14 (kWh)
2017	January	3,004
2017	February	2,929
2017	March	4,618
2016	April	4,691
2016	May	3,709
2016	June	6,059
2016	July	7,660
2016	Aug	7,991
2016	Sept	6,030
2016	Oct	5,540
2016	Nov	4,248
2016	Dec	2,755
Total 12 Month Monitored HVAC Energy Use		**59,234**

REDUNDANT TEMPERATURE AND OCCUPANCY SUB-METERING

Temperature readings were taken from over a 12 month period from April 15, 2016 to April 21, 2017. The purpose of collecting this data was to confirm space temperature and occupancy rates. **Table 11** illustrates the data loggers captured minimum, maximum and average temperature and relative humidity readings in the administrative office space. Similar readings for the other areas within the training center can be seen in the Appendix section of this report. **Figure 24** graphs the annual temperature and humidity data points for the same administrative office space.

However, the model uses temperature set points rather than space temperatures. Therefore, the submetered space temperature and occupancy data collected would have been used in the event further calibration was needed in the model based on the temperature profile; however, the data was ultimately not needed because of the temperature set point configuration in the energy modeling software.

TABLE 11: TEMPERATURE AND RELATIVE HUMIDITY READINGS OF ADMINISTRATIVE OFFICE

Logger	Min	Max	Average
Temperature	57.59°F	87.13°F	71.66°F
Relative Humidity	16.75%	81.50%	52.27%

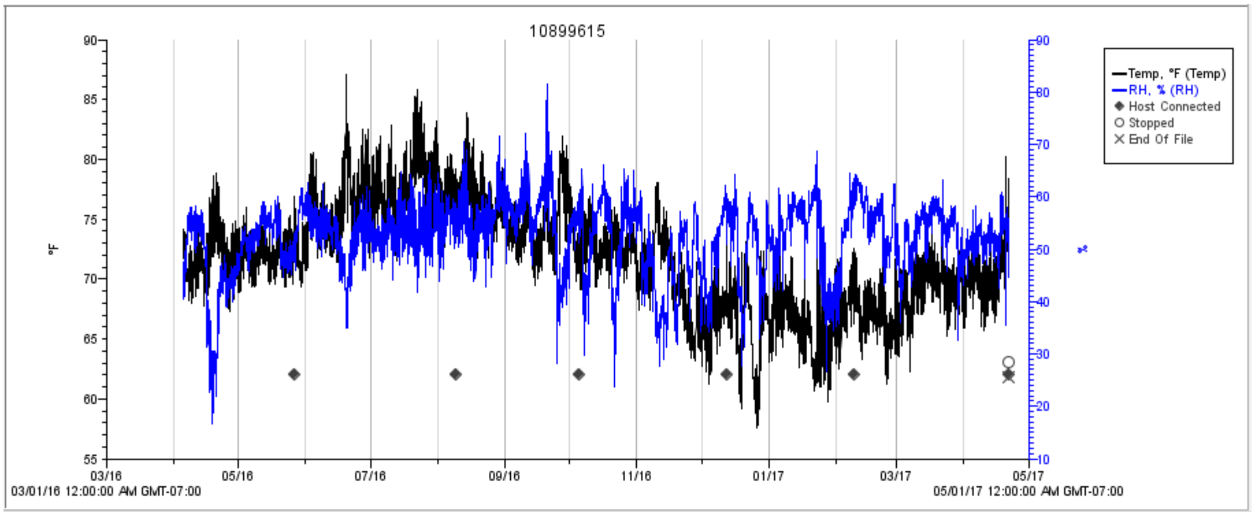


FIGURE 24: ANNUAL TEMPERATURE AND RELATIVE HUMIDITY GRAPH OF ADMINISTRATIVE OFFICE SPACE

The graph in **Figure 25** illustrates when the administrative office space was occupied throughout the year. Based on sub-metered data collected, the lights were on 37.87% percent of the time and off 62.13% of the time. Additionally, the data indicated that the administrative office space was occupied 5% of the time and unoccupied 95% percent of the time throughout the year. Similar readings for the other areas within the training center can be seen in the Appendix section of this report.

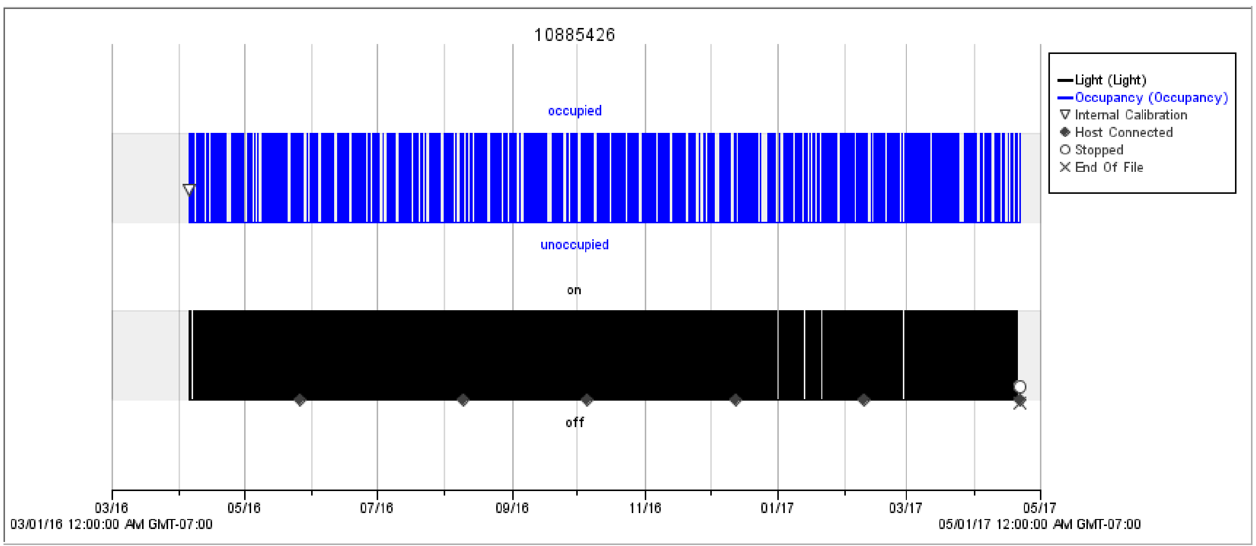


FIGURE 25: OCCUPANCY GRAPH OF ADMINISTRATIVE OFFICE SPACE

CALIBRATE ENERGY MODELS TO BUILDING'S 12 MONTH BILLING DATA

The next objective was to calibrate energy models to the building's 12 month billing data. A comparison between the billing history/submeter data, and the calibrated energy model results are shown in **Table 12**. Based on the results in **Table 12,** the model is considered to be calibrated on an annual basis within reasonable limits and no further changes were made to the post calibrated model.

TABLE 12: BILLING HISTORY AND SUB-METER DATA AND CALIBRATED ENERGY MODEL RESULTS COMPARISON

	kW	**Heat Pump kWh**	**Total kWh**
Actual	83.2	55,717	166,152
Calibrated Model	81.9	57,369	165,711
% Error	1.6%	3.0%	0.3%

CALIBRATE HVAC SYSTEM (HEAT PUMP) DATA

The next objective was to calibrate HVAC system (heat pump) to the electrical sub-metering data. As shown in **Table 12**, the post calibrated model HVAC heat pump usage was within 3% of the actual submetered data. Based on these results, the model is considered to be calibrated on an annual basis within reasonable limits and no further changes were made to the post calibrated model.

SIMULATE BASELINE ENERGY MODEL WITHOUT PCM

The baseline energy model required the removal of the PCM from the walls and roof since PCM was included in the calibrated run. As indicated, there were many issues experienced with the Simergy tool producing many output errors. More specifically, the errors primarily relate to the fan coil unit sizing and in all cases potential remedies to the errors are included to be: "*Resolution being developed. Should be in next update*." These errors were discussed with the software developer and indicated that these errors likely have no significant impact on the overall results.

However, given this experience, there are several potential issues with modeling the impacts of PCM in this particular case including:

1. With the number of errors being produced by the fans in the model, and the resolution being supplied by Simergy of a fix will be supplied in a subsequent update, the output related to the fans is questionable.

2. The internal space temperatures may not have varied enough within the model itself to allow the PCM to properly change phase; hence, leading to no difference between the different PCM installations (roof, exterior, interior).

3. VRF systems are relatively new to EnergyPlus and may still contain bugs that do not allow for proper simulation.

4. Autosizing all components in the base case may not accurately reflect what would have been installed in lieu of the PCM.

5. The length of time to simulate each run may be as little as 10 minutes but may take up to several hours. Therefore, simulating a post calibration model with PCM can be time consuming.

DETERMINE POTENTIAL SAVINGS OF PCM

ESTIMATING POTENTIAL SAVINGS BY REMOVING PCM IN THE BASELINE SCENARIOS

Unexpectedly, the simulation results for all three simulation runs produced no difference in the baseline consumption including heat pump, fans or overall building use. Consequently, additional simulations were conducted for the baseline scenario to assess the reasonableness of the simulation results.

In these additional simulation runs, the PCM layer was replaced with an air gap of equal dimensions. Full year simulations were also conducted and similar results to the prior baseline simulations were reported. In these scenarios, the PCM in the exterior walls did produce a small amount of energy savings of approximately 1,000 kWh, while PCM in the roof and interior walls did not produce any savings.

ESTIMATING POTENTIAL SAVINGS USING SIMERGY'S AUTOSIZE FEATURE

As with all ET field assessments, one primary objective of this field study was to determine the energy savings potential due to the PCM installation within the wall stud cavities and below the roof sheeting in a new construction building. In summary, the post model was calibrated within acceptable percent error on an annual basis and is likely a good representation of the actual building. However, because removing the PCM in the baseline run yielded little to no savings, the only other feasible option to estimate the baseline use was to rely on the tool's autosize feature.

Relying on the Simergy tool's autosized baseline and calibrated post model runs, the annual energy savings at the heat pumps equated to 19,746 kWh (25.6%), and 124,148 kWh annual energy savings at the fans for a total annual energy savings of 143,894 kWh (46.4%). For Climate Zone 10, the DEER peak demand period is September 1-3. However, the Simergy simulation results for this model only show the peak monthly demand. Therefore, the closest entry to the DEER peak period occurred on August 19, which was 94.38 kW for the baseline simulation run. The corresponding peak demand period for the calibrated post model simulation run for August 19 was 79.4 kW. Based on the above information, the estimated peak demand savings amounted to 14.98 kW.

An additional 124,148 kWh of annual energy savings were shown at the fans in the facility. However, these results are questionable because the software produced a large number of simulation warnings and errors related to the simulation of the fans. It is not entirely clear what caused these warnings and errors. However, it can be reasonably inferred that the complexity of the building design and the newness of the mechanical HVAC VRF system models caused the issues within the EnergyPlus software. Despite potential energy savings, the savings in new construction applications are inconclusive and not easily quantifiable using the software tools available. Therefore, if energy and peak demand savings estimates are claimed, it should be limited to the heat pumps only until the EnergyPlus software warnings and errors are resolved.

BIN SIMULATION ANALYSIS TO CHECK REASONABLENESS OF SOFTWARE RESULTS

As indicated in the prior section, relying on the Simergy tool's autosized baseline and calibrated post model runs resulted in significantly high energy savings associated at the fans. A temperature bin simulation analysis was performed to check the reasonableness of the software energy savings results. The temperature bin simulation used relevant data from manufacturer VRF spec sheets. The outcome of the temperature bin simulation effort is discussed In the next section.

OUTCOMES OF BIN SIMULATIONS

1. CALCULATING FAN CFM USING RECORDED TEMPERATURE DATA

Calculating the cfm on the fans using the recorded temperature data was challenging because average supply temperature was higher than the cooling set point temperature (72°F). This is apparent in **Table 13** where the recorded average supply temperature data is higher than the cooling set point (72°F) for almost all temperature bins for heat pump 1 located on the 1st floor. Thus, making it difficult to determine which hours are impacted by the PCM especially because most of the heat pumps do not have any use in the highest temperature bins.

TABLE 13: WEATHER BIN DATA COMPARED TO HEAT PUMP 1 RECORDED AVERAGE SUPPLY AND RETURN TEMP DATA

Bin	Bldg. Op. Hours	Wet Bulb Temp	Avg. Supply Temp	Avg. Return Temp
101	2	65	77	79
99	9	62	75	76
97	11	65	75	76
95	10	66	75	76
93	19	67	77	78
91	59	64	75	75
89	59	65	76	76
87	63	66	76	76
85	87	66	75	75
83	129	67	76	76

81	198	65	75	75
79	246	64	74	75
77	137	64	74	74
75	299	63	73	74
73	578	62	73	73
71	444	61	73	73
69	504	61	73	74
67	659	60	73	73
65	751	59	73	73
63	843	57	72	72
61	717	56	70	70
59	313	55	70	70
57	722	54	69	69
55	940	52	68	67
53	498	50	67	66
51	230	48	66	65
49	125	45	66	65
47	59	43	65	64
45	37	41	64	63
43	12	40	64	63

2. San Miguel Raws (MIGC1) Weather Station Data

The San Miguel Raws (MIGC1) Weather Station data was used as part of the temperature bin simulations. The temperature bin simulations for both the post and baseline model scenarios were separated by 2 degree temperature bins. Although the post model showed similar results to both the Simergy model and the recorded data collected, using the MIGC1 weather station data resulted in odd kW/ton and VRF percent full capacity system values.

a. kW/Ton Values

Using the MIGC1 weather station and relevant VRF manufacturing spec sheet data, the temperature bin simulation yielded kW/ton information shown in **Table 14**. Oddly, the temperature bins (51°F to 101°F) showed kW/ton values lower than 1.0. For AHRI conditions, the rating temperatures are 95°F dry bulb and 75°F wet bulb for VRF systems. At those temperatures, it was expected that the bin temperatures should produce a kW/ton value similar to the rated heat pump value of 0.96 kW/ton. However, the temperature bin showed a 0.58 kW/ton.

As a sanity check, capacity function of temperature (CapFT), electric input to cooling output factor for temperature function (EIRFT) and electric input to cooling output factor for part-load function curve (EIRFPLR) curves were verified to ensure VRF manufacturing spec sheet data was correctly used. Equations from EnergyPlus were also verified to confirm correct data use.

However, EnergyPlus uses a few additional correction factors for both heat recovery and fraction of run time errors. Because the VRF manufacturer's coefficient correction factors could not be obtained, the temperature bin simulation model over predicts the cooling tons at the condenser, which makes the kW/ton value skew lower. EnergyPlus uses the same equations but iteratively adjusts the cooling capacity based on run time fraction and heat recovery impact. Furthermore, the issue is further compounded because heat pumps 1 and 4 are heat recovery units where simultaneously heating and cooling occurs. Thus, it is difficult to model the potential energy savings impact of the PCM in a temperature bin simulation when only post data is available.

Table 14: kW/Ton Values in Bin Simulation Using Manufacturing VRF Spec Sheet Data

Bin	Bldg. Op. Hours	Wet Bulb Temp	kW/ton
101	2	65	0.64
99	9	62	0.59
97	11	65	0.59
95	10	66	0.61
93	19	67	0.59

91	59	64	0.56
89	59	65	0.54
87	63	66	0.53
85	87	66	0.52
83	129	67	0.51
81	198	65	0.50
79	246	64	0.49
77	137	64	0.48
75	299	63	0.48
73	578	62	0.48
71	444	61	0.48
69	504	61	0.48
67	659	60	0.48
65	751	59	0.48
63	843	57	0.49
61	717	56	0.50
59	313	55	0.49
57	722	54	0.51
55	940	52	0.53
53	498	50	0.63
51	230	48	0.82

49	125	45	1.19
47	59	43	1.54
45	37	41	2.25
43	12	40	8.32

b. HEAT PUMP 3 OVER 100% FULL CAPACITY

Using the MIGC1 weather station and relevant VRF manufacturing spec sheet data, the temperature bin simulation also yielded VRF system full capacity information shown in **Table 15**. Oddly, heat pump 3 had full capacity percentages exceeding 100% full capacity in approximately one third of all the temperature bins.

TABLE 15: TEMPERATURE BIN SIMULATION RESULTS: HEAT PUMP 3 VRF SYSTEM PERCENT FULL CAPACITY

Bin	Bldg. Op. Hours	Wet Bulb Temp	Percent Full Capacity
101	2	65	0%
99	9	62	0%
97	11	65	131%
95	10	66	97%
93	19	67	124%
91	59	64	98%
89	59	65	111%
87	63	66	112%
85	87	66	108%
83	129	67	107%
81	198	65	100%

79	246	64	110%
77	137	64	106%
75	299	63	113%
73	578	62	108%
71	444	61	110%
69	504	61	95%
67	659	60	99%
65	751	59	88%
63	843	57	82%
61	717	56	71%
59	313	55	81%
57	722	54	83%
55	940	52	75%
53	498	50	71%
51	230	48	45%
49	125	45	0%
47	59	43	0%
45	37	41	0%
43	12	40	0%

TYPICAL METEOROLOGICAL YEAR (TMY) OR AVERAGE DATA AND MAXING HEAT PUMP 3 CAPACITY TO 100%

Due to the odd kW/ton and percent full capacity VRF system values, TMY3 or average weather data (DEER 2013 for Climate Zone 10) was used to see if that would help alleviate both issues. Many of the over 100% capacity temperature bins for heat pump 3 go away using the new TMY3 weather data. However, some of higher temperature bins required greater than 100% capacity, which is likely related to the kW/ton value discussed above. EnergyPlus provided similar warnings for heat pump 3 stating that it was undersized. For these higher temperature bins, the percent capacity was limited to 100% capacity.

BIN SIMULATION ASSESSMENT TAKEAWAY

Although the temperature bin simulation is applying the data and formulas correctly as the results are similar to EnergyPlus, there are lots of unknowns about the VRF system and whether EnergyPlus is modeling correctly because it is unlikely that the VRF system is only using 0.58 kW/ton. Therefore, it is difficult to pinpoint if any energy savings can be associated from PCM because EnergyPlus uses more iterations and correction factors to model the VRF system. However, disregarding the EnergyPlus results in favor of the BIN sim is not necessarily a better option as discussed in the prior sections.

IDENTIFY CHALLENGES AND LESSONS LEARNED FROM THE ENERGY MODELING

Much of the time spent on this project was debugging, troubleshooting and calibrating the models due to the software bugs. Some of the main hurdles experienced in this project were the back and forth coordination between the software development team and the project team. Software product updates were routinely released during the late stages of the project while the 12 month submetered data was being collected. Some of the issues experienced with the software bugs include:

- Inability to model this building (as designed) including VRF system in the initial software version releases;
- Training center became the “guinea pig” project for future software update releases to support multiple profiles;
- Although Simergy supports gable roof assemblies, the ridge always follows the long axis, so modeling this configuration was not possible;
- The bearing elevation and height of the barrel vault roof over the offices was higher than the archery range, and extended 5+ feet above the office ceilings, so the attic space was assigned the average height (3 feet) and was modeled as a 3rd story so that it would have a separate roof;
- If dimensions are not precise, it causes error for air gap distances;
- Virtually all wall and slab construction had to be changed;
- The Simergy tool models stacked spaces (one each for first and second story). This follows the convention that is used in the international IFC standard for building models. Simergy then puts the pair for each space into a single zone. Since only the zones are sent to EnergyPlus, it looks like double-height spaces in the simulation; and
- Debugging the model takes a minimum of 10 minutes per run and up to several hours. This occurs because the software tool fixes the errors reported by EnergyPlus and runs all the way through the simulation.

RECOMMEND HOW MODELING STRATEGIES FIT IN A NEW CONSTRUCTION INCENTIVE PROGRAM

- As with all ET Assessments, a primary objective of this field study is to help mobilize new and emerging technologies into the rebate and incentive programs. More specifically, this final assessment objective is to recommend how modeling strategies fit in a New Construction Incentive Program given that the PCM technology was installed in a new construction application.

- As identified in the IPMVP Option D monitoring guidelines, a calibrated post energy model is essential to achieving the goal of getting the PCM adopted in a new construction incentive program because the PCM material was installed at the time of construction. The critical item to ensure that the calibrated post model is accurate requires collecting enough billing history and HVAC submetered data. This allows the post model to accurately calibrate to building usage in the post PCM scenario.

- Additionally, when using the Simergy tool, it is important that the correct heat transfer algorithm is used to model the PCM. More specifically, the Conduction Finite Difference (CFD) algorithm must be used correctly.

- To correctly simulate the baseline usage scenario, it is important to check the fan savings because the Simergy tool fan savings numbers appear to be suspect. There were errors produced relating to the fan usage in the base case model, which led the fan savings results to be questioned. Therefore, claiming fan energy and peak demand savings related to the PCM installation is not advisable.

- Since many custom new construction projects aim at the whole building performance based approach, modeling the savings to compare against incumbent code compliant insulation requirements for the prescriptive approach was not warranted.

- The post model was calibrated within acceptable percent error on an annual basis and is likely a good representation of the actual building. Relying on the Simergy tool's autosized baseline and calibrated post model runs, the annual energy savings at the heat pumps equated to 19,746 kWh. Additionally, the annual fan energy savings amounted to 124,148 kWh for a total annual energy savings of 143,894 kWh. However, these results are questionable because the software produced a large number of simulation warnings and errors related to the simulation of the fans. It is not entirely clear what caused these warnings and errors. However, it can be reasonably inferred that the complexity of the building design and the newness of the mechanical HVAC VRF system models caused the issues within the EnergyPlus software.

- Despite potential energy savings, the savings in new construction applications are inconclusive and not easily quantifiable using the software tools available. Therefore, if energy and peak demand savings estimates are claimed, it should be limited to the heat pumps only until the EnergyPlus software warnings and errors are resolved

CONCLUSIONS

As IPMVP Option D outlines, a calibrated model is needed to assess the energy savings potential for installing PCM in the stud cavities of the walls and underneath the roof sheeting in new construction buildings. IPMVP Option D also outlines certain challenges to consider including:

- input data should represent the best available information including actual performance data from key components in the facility;
- simulation inputs need to be adjusted so its results match both the demand and energy consumption data from utility bills within acceptable tolerances (i.e. calibrated);
- simulation printouts, survey data and the metering or monitoring data used to define input values and calibrate the simulation model should be kept in paper and electronic files; and
- modeling efforts can be streamlined by retaining the building energy modeler that created the “as-designed” model to create the calibrated “as-built” and adjusted baseline model for new construction projects.

Following these guidelines, the project team ensured that the calibrated post model was within acceptable tolerances by collecting enough billing history and HVAC submetered data to support the model and comparing it to actual building usage.

When evaluating PCM in new construction projects, it is important to consider the energy model tools capabilities as the savings in this new construction application are inconclusive and not easily quantifiable using the software tools available. Therefore, if energy and peak demand savings estimates are claimed, it should be limited to the heat pumps only until the EnergyPlus software warnings and errors are resolved.

RECOMMENDATIONS

Although the PCM technology installed in this new construction application achieves energy savings and should be considered in a customized new construction incentive program, it is recommended that Simergy tool users attend the free software training sessions provided by the developer. Additionally, Simergy tool users need to work closely with the Simergy software development team because frequent software updates are released before a customized project is initiated and submitted for utility incentive consideration.

As indicated in the Conclusion section of this report, when evaluating PCM in new construction projects, it is important to consider the warnings and errors produced by the tool to assess the reasonableness of the baseline model. Although it is not clear as to what exactly is causing these warnings and errors, it could be reasonably inferred that it was triggered by the complexity of the building design and the newness of the mechanical HVAC VRF system in the EnergyPlus software.

Despite potential energy savings, the savings in new construction applications are not easily quantifiable using the software tools available. Therefore, if the EnergyPlus energy models are used to estimate energy savings for similarly situated buildings and HVAC systems, it is recommended that energy and peak demand savings estimates associated with the fans are not advisable and should be limited to savings at the heat pump energy until the EnergyPlus software warnings and errors are resolved.

For retrofit projects, where baseline conditions and data are captured, that baseline information could be used to help inform future new construction energy models to ensure baseline usage and energy savings estimates are accurate.

Program Administrators need to be aware of software energy modeling tools' capabilities and challenges so that future customers applying for a PCM custom incentive in new construction applications can anticipate the challenges identified here in this report. Additionally, this project was isolated to a commercial customer in Climate Zone 10 with a unique building design. Thus, results may vary depending on occupancy, internal space temperatures and HVAC equipment.

APPENDICES

4-CHANNEL ANALOG LOGGERS

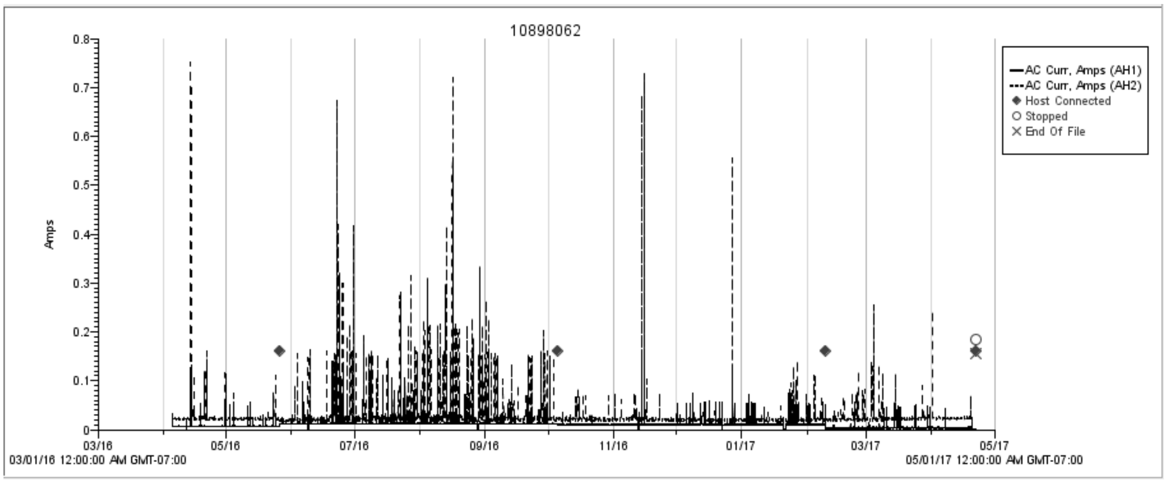


FIGURE 26: 4-CHANNEL ANALOG LOGGERS ON 2 FAN COILS

4/15/16 to 4/21/17:

- AH1 Max: 0.14 A, Min 0.0012 A and Ave 0.010
- AH2 Max: 0.75 A, Min 0.0009 A and Ave 0.029
- Fan3 Max: 1.87A, Min 0.1169 A and Ave 0.32
- Fan4 Max: 1.55A, Min 0.0024 A and Ave 0.36

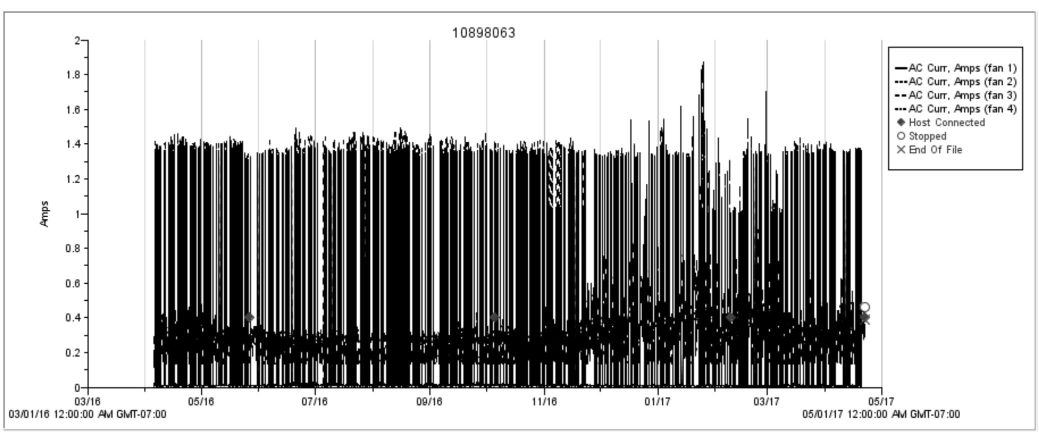


FIGURE 27: 4-CHANNEL ANALOG LOGGERS ON FAN COILS 2 FANS AND 5 FAN COILS

4/15/16 to 4/21/17:

- Fan1 Max: 1.43 A, Min 0.0009 A and Ave 0.20
- Fan2 Max: 1.49 A, Min 0.0009 A and Ave 0.20
- Fan3 Max: 1.87A, Min 0.1169 A and Ave 0.32
- Fan4 Max: 1.55A, Min 0.0024 A and Ave 0.36

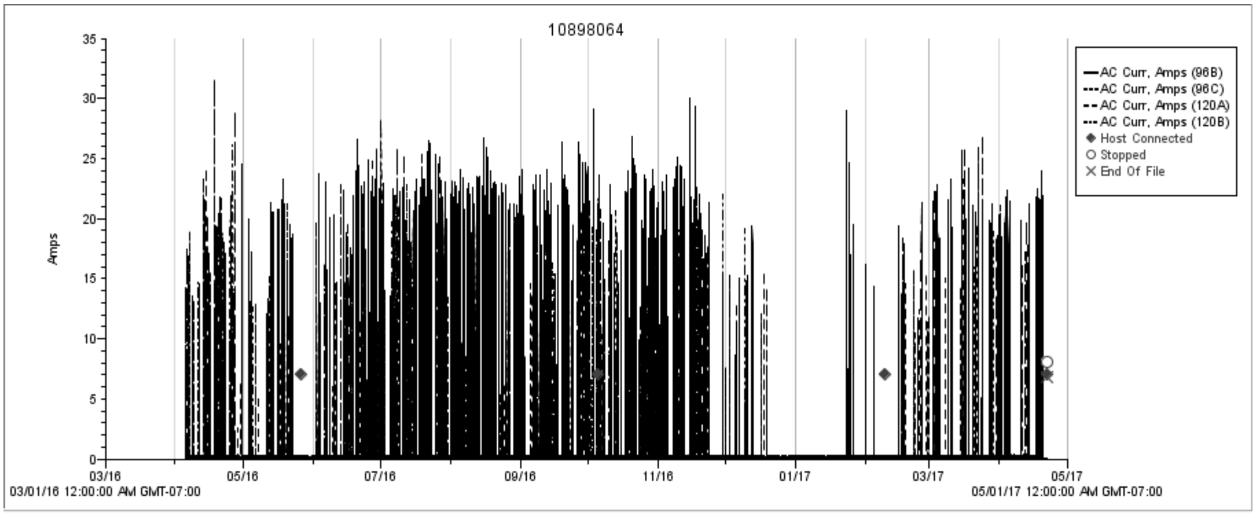


FIGURE 28: 4-CHANNEL ANALOG LOGGERS ON 4 HEAT PUMPS

4/15/16 to 4/21/17:

- 96B Max: 28.95 A, Min 0.0023 A and Ave 1.49
- 96C Max: 25.08 A, Min 0.0023 A and Ave 0.51
- 120A Max: 31.59A, Min 0.0015 A and Ave 1.32
- 120B Max: 28.25A, Min 0.0015 A and Ave 1.25

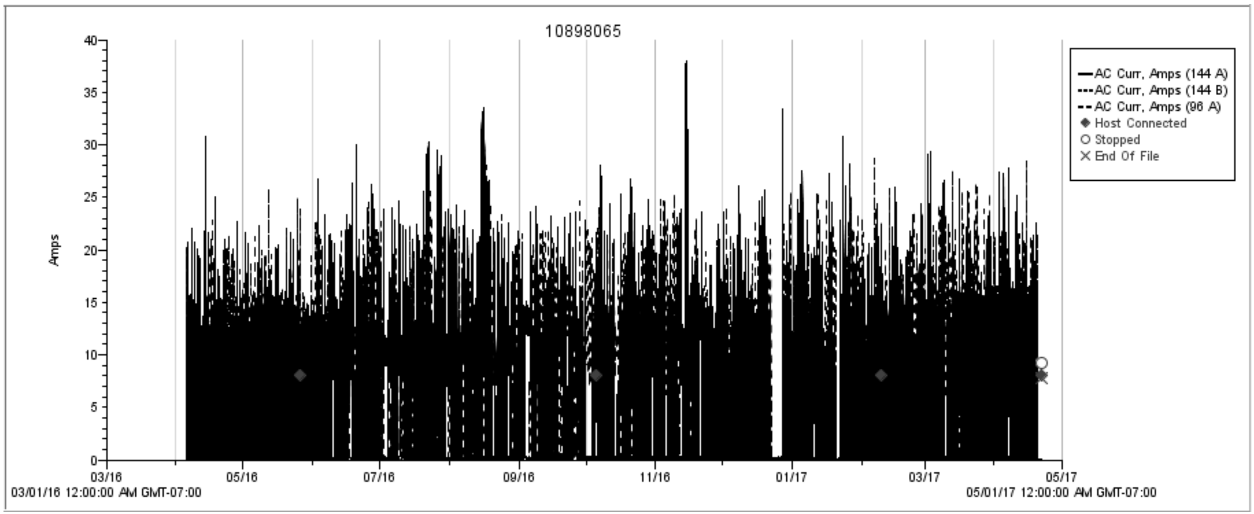


FIGURE 29: 4-CHANNEL ANALOG LOGGERS ON 3 HEAT PUMPS

4/15/16 to 4/21/17:

- 144A Max: 38.02 A, Min 0.0046 A and Ave 6.82
- 144B Max: 33.53 A, Min 0.0031 A and Ave 6.39
- 96A Max: 27.41A, Min 0.0015 A and Ave 0.61

Light Sensor Loggers

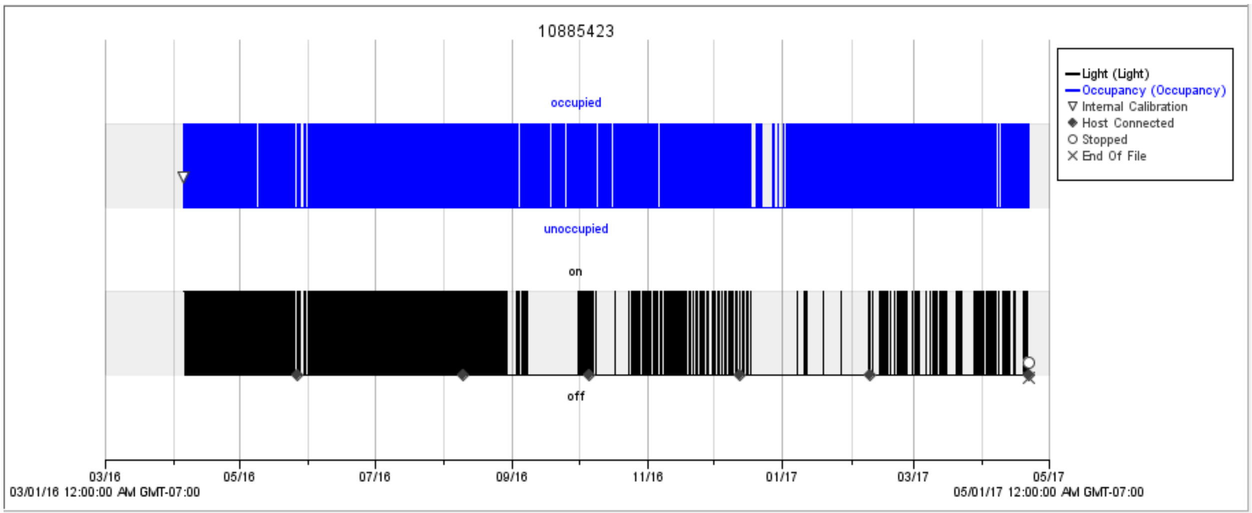


Figure 30: Occupancy Light Sensor Logger in Athletic Room

Based on data, 19.20% percent light time on and 80.80% percent light time off
Based on data, 7.74% occupied and 92.26% unoccupied

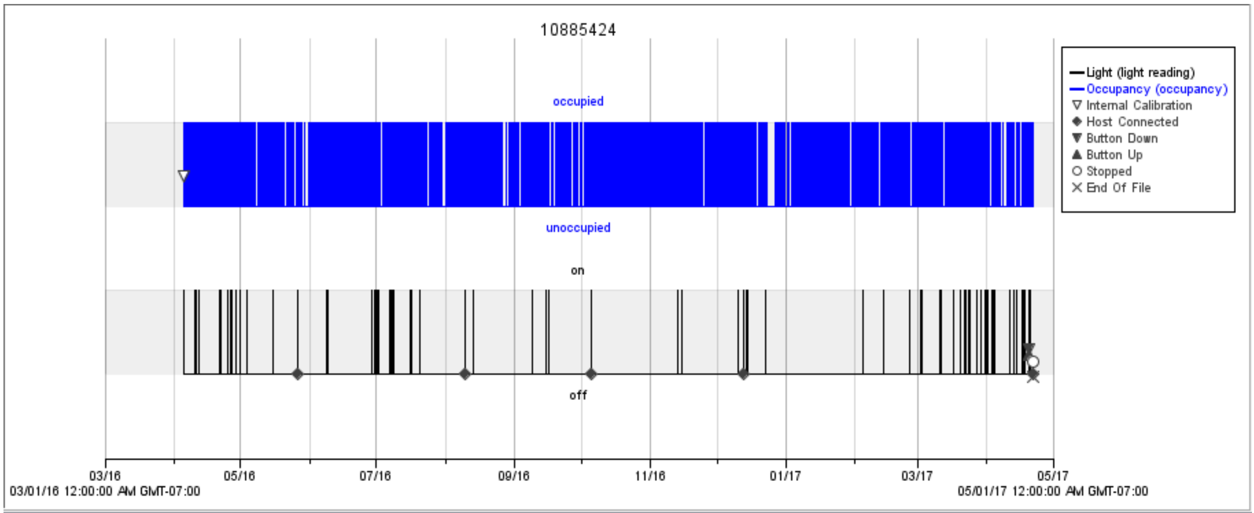


Figure 31: Occupancy Light Sensor Logger in Indoor Archery Range West Side

Based on data, 1.62% percent light time on and 98.38% percent light time off
Based on data, 12.54% occupied and 87.46% unoccupied

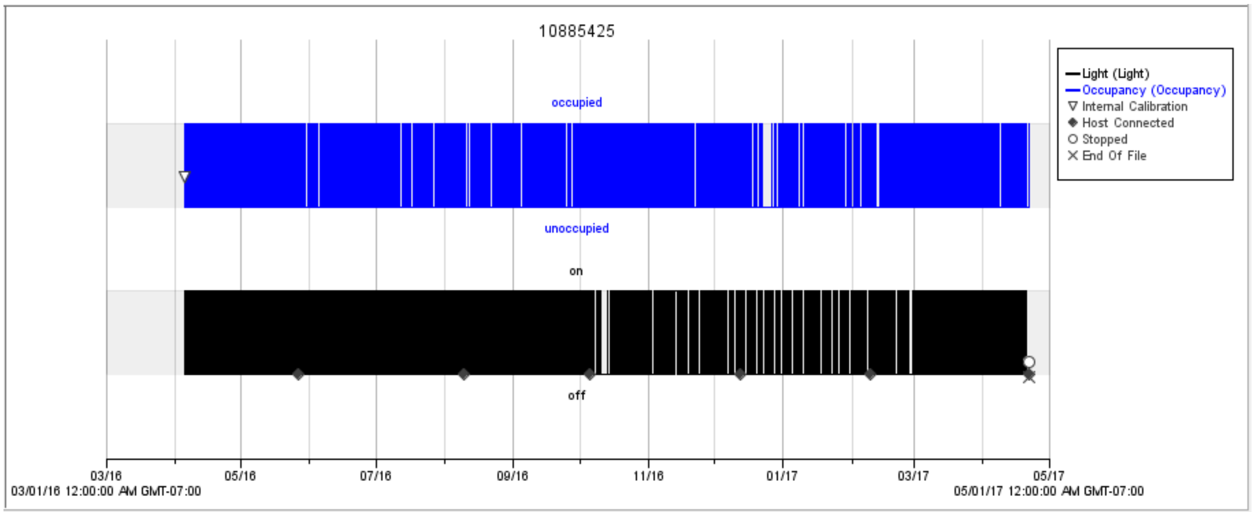


FIGURE 32: OCCUPANCY LIGHT SENSOR LOGGER IN LOOPHOLE RANGE ON CEILING ELECTRIC OUTLET

Based on data, 40.55% percent light time on and 59.45% percent light time off
Based on data, 8.71% occupied and 91.29% unoccupied

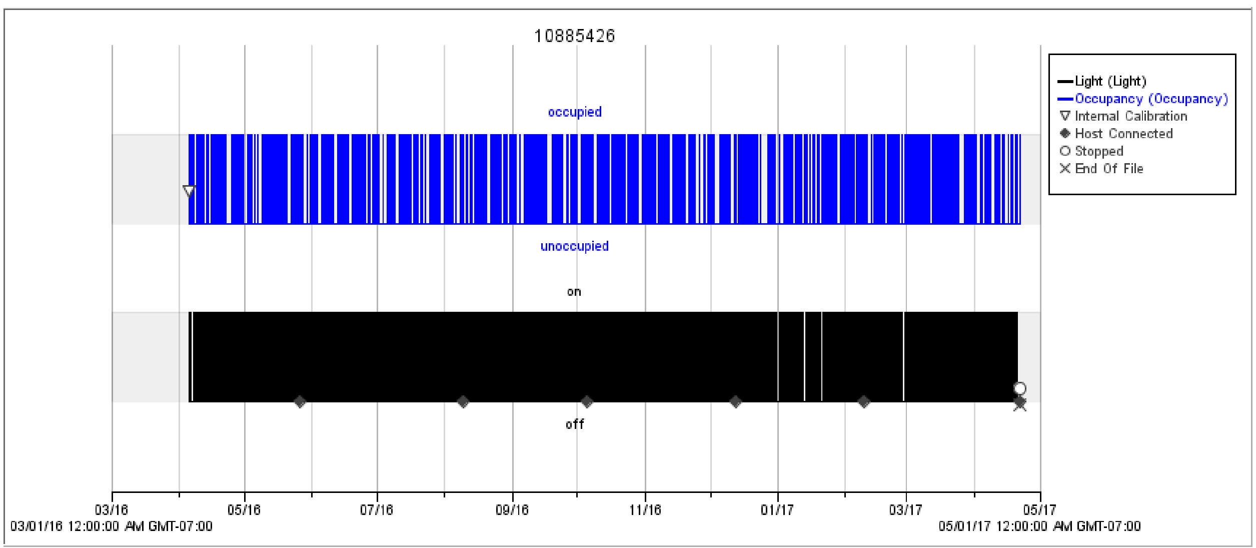


FIGURE 33: OCCUPANCY LIGHT SENSOR LOGGER IN ADMIN OFFICE SPACE ABOVE SIDE DOOR

Based on data, 37.87% percent light time on and 62.13% percent light time off
Based on data, 5.01% occupied and 94.99% unoccupied

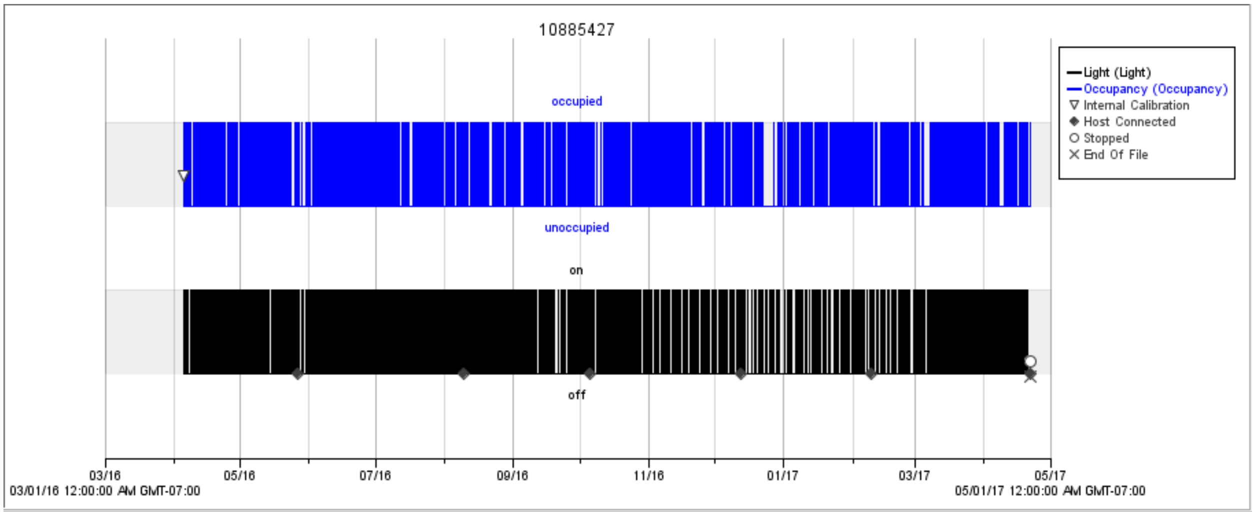


FIGURE 34: OCCUPANCY LIGHT SENSOR LOGGER IN EXERCISE ROOM BY ELECTRICAL BOX BY DOOR

Based on data, 32.27% percent light time on and 67.73% percent light time off
Based on data, 3.93% occupied and 96.07% unoccupied

RELATIVE HUMIDITY SENSOR HOBO LOGGERS

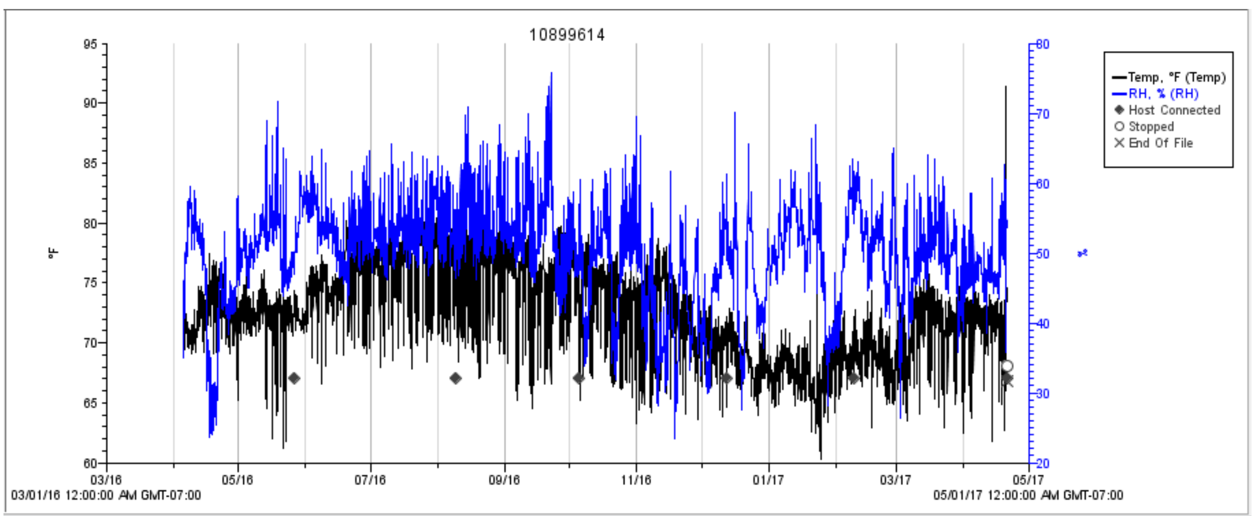


FIGURE 35: SUPPLY TEMPERATURE SENSOR IN INDOOR ARCHERY RANGE

4/15/16 to 4/21/17:

- Temperature
  - Max: 91.41F, Min 60.26F and Ave 72.73F
- Relative Humidity
  - Max: 75.83%, Min 23.39% and Ave 49.47%

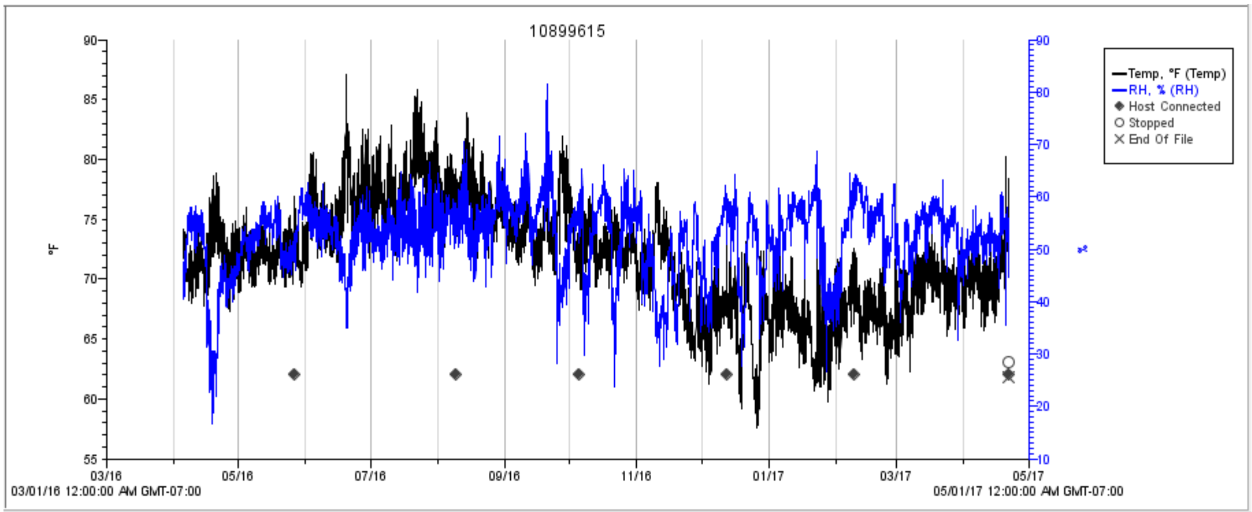


FIGURE 36: SUPPLY TEMPERATURE SENSOR IN ADMIN OFFICE SPACE

4/15/16 to 4/21/17:

- Temperature
  - Max: 87.13F, Min 57.59F and Ave 71.66F
- Relative Humidity
  - Max: 81.50%, Min 16.75% and Ave 52.27%

REFERENCES

1. James, Brian. 2012. “Phase Change Materials for Building Cooling Applications.” Southern California Edison ET11SCE1260/HT.11.SCE.022 Report. Rosemead, California.
2. James, Brian. 2016. “Phase Change Materials for Building Cooling Applications Analysis for Energy Performance in a Quick Service Restaurant.” Southern California Edison ET15SCE1050 Report. Rosemead, California.
3. Baffa, John. 2016. “Phase Change Material and Controls Study.” San Diego Gas & Electric ET16SDG1061 and DR15SDGE0003 Report. San Diego, California.
4. MV Automation, Inc. 2016. “Repair By Upgrade Building Envelope of Augmentee Barracks.”
5. Sustainability Matters. 2016. “Measurement & Verification Report FINAL Phase Change Material Monitoring the energy performance of PCM in portable classroom buildings.”
6. Phase Change Energy Solutions at https://www.phasechange.com/.