Energy and Buildings

October 2013 Journal paper submission draft

Belgian Passivhaus Villa With Advanced bioPCM Envelope

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Abstract

Residential buildings in Belgium do not typically use mechanical cooling systems. "Passivehaus" designs typically use "super" insulation with very high R values and are required to have air tight construction practices. This combination causes high incidence occupant discomfort during the summer months due to overheating. This paper presents bioPCM as a solution to reduce overheating and control temperature fluxions to maintain occupant comfort. This work is the first use of the new dual curve with hysteresis PCM model developed in part by the energy modeler & author of the paper.

Keywords: Phase Change Materials, PCM, BioPCM, Passivehaus, Passive Solar, Energy Plus, Dual Curve Hysteresis

1. Introduction: Four variations of the villa are modeled and analyzed. The first is the actual design where the Villa is fully passive, with natural ventilation cooling, passive solar heating and no heating or cooling systems. The second is typical of USA Passivehaus projects, with a heating system, energy recovery ventilation, natural ventilation and no cooling systems. The third is with heating, cooling and natural ventilation and the fourth is with heating, cooling and no natural ventilation. Both the third and fourth are used to for theoretical comparison of energy consumption. The results of the comfort analysis for the as built villa show BioPCM with natural ventilation to provide comparable cooling comfort control benefits to that of mechanical cooling systems. The results of the energy consumption cases show that bioPCM provides a large reduction in both cooling and heating energy. The results of the design HVAC loads analysis shows bioPCM to provide substantial load reduction. Findings; bioPCM provides substantial benefits for Passivhaus projects in northern Europe.

Nomenclature
PCM: Phase Change Material
BioPCM: Bio-based PCM manufactured by Phase Change Energy Solutions Inc.
Phase Change Heat Absorption: PCM is melting and providing cooling.
Phase Change Heat Rejection: PCM is freezing and providing heating.
Q-Value: Temperature in Degrees Celsius the phase change material is melting at peak heat absorption.
M-Value: Btu/Square Foot of thermal energy storage capacity of phase change material at its Q value.

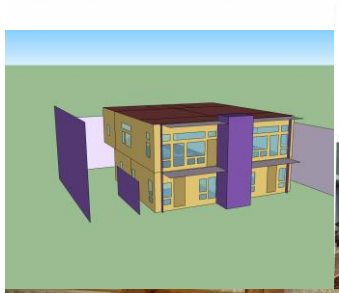
2. Related Work

The Gent Belgium location of the Villa is categorized as ASHRAE Climate zone 4. The Trakhaus located in Portland Oregon USA is also in ASHRAE climate zone 4. This work is related because of its climate zone and because they are both passive house designs that have been modeled in Energy Plus.

The Trekhaus bioPCM project is a built to Passivhaus US standards and is duplex with two residents, one side has NoPCM, while the other side has bioPCM. Both sides where outfitted with detailed measurement sensors monitored by the Portland State University Green Building Research Lab headed up by Dr. David Saylor. Prior to construction the Green Building research lab modeled the Trekhaus Energy Plus version V7. The one year of measurement has been completed and the green building research lab will be publishing their findings and how they correlate to modeling.

The focus of the modelling of the Trekhaus project was to reduce overheating to for passive comfort control.

Modelling results were presented at Proceedings of the ASME International Mechanical Engineering Congress & Exposition November 11-17, 2011, Denver, Colorado, USA. Modelling results were published under the title PHASE CHANGE MATERIALS AS THERMAL STORAGE FOR HIGH PERFORMANCE HOMES by Kevin R. Campbell and David J. Sailor. The summarized findings of their modelling study where that bioPCM is effective at enhancing occupant comfort in multiple climate zones, including the location where the actual Trekhaus is built. Modelling validation based on measured data will be published in the future. The results of the Trekhaus project validate the results of this study for the Villa due to their similar climates.



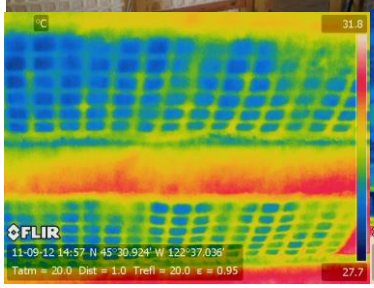
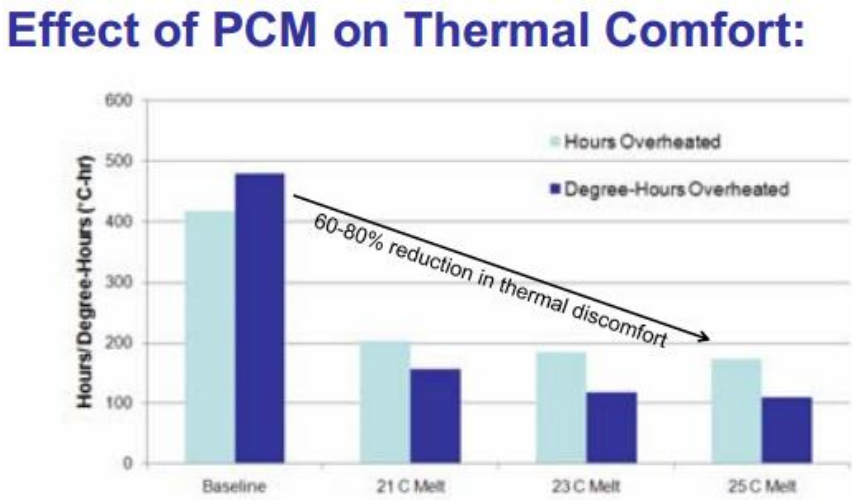


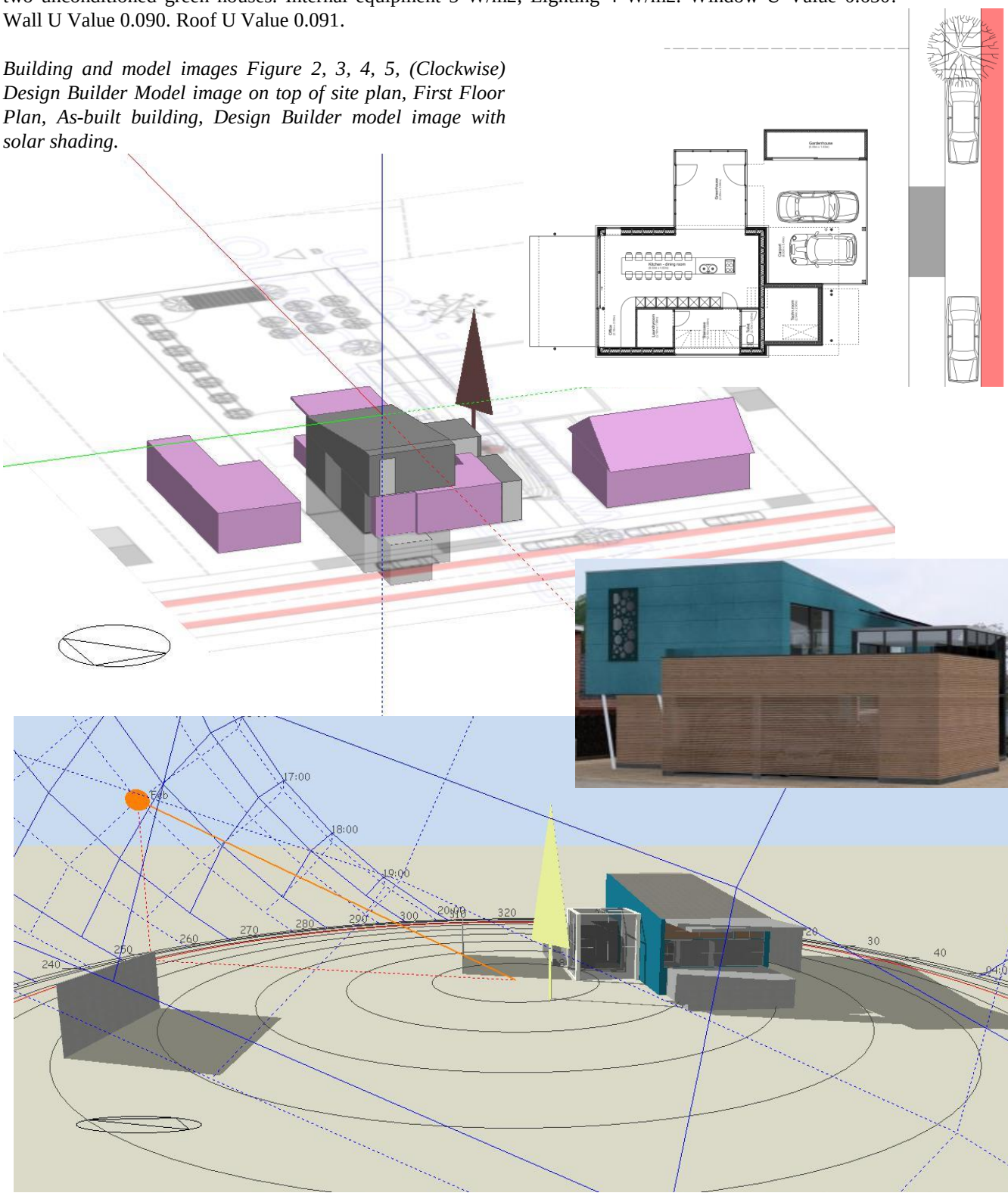
Figure 1, Trekhaus Modelling results

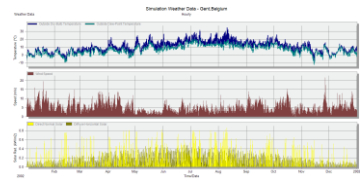


3. Building Energy Model Details

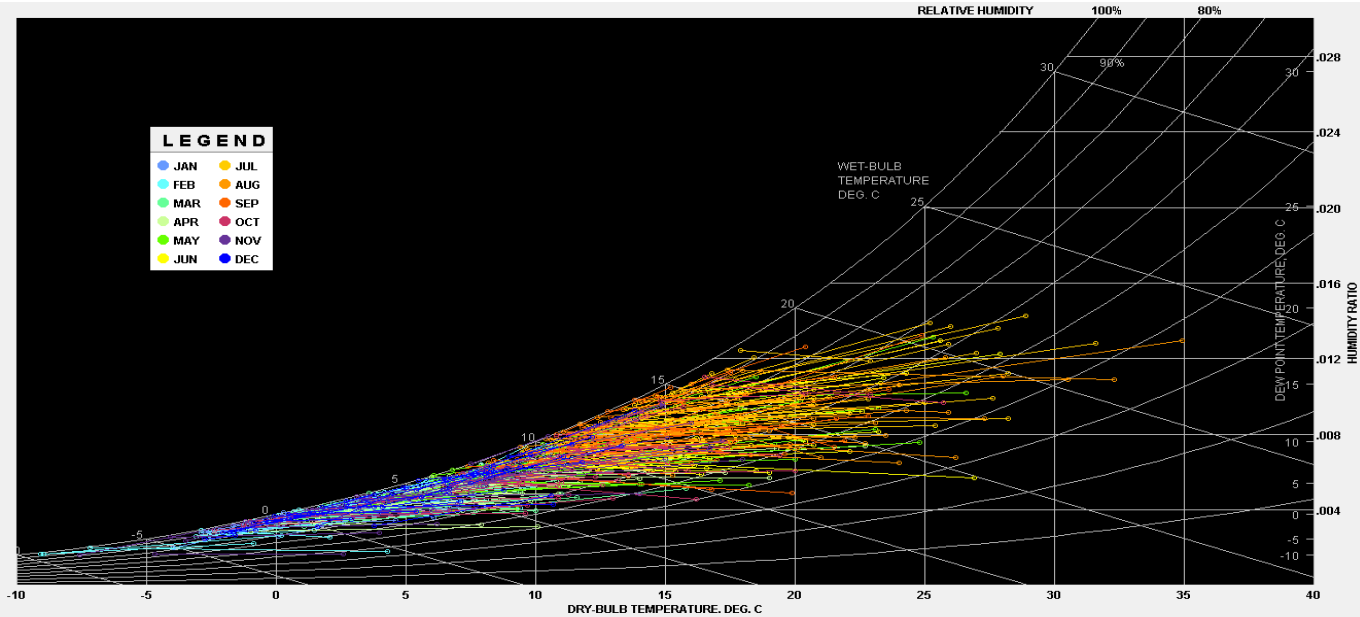
Building description: Two above ground floors, basement, and no attic attached unconditioned garage and two unconditioned green houses. Internal equipment 5 W/m2, Lighting 4 W/m2. Window U Value 0.650. Wall U Value 0.090. Roof U Value 0.091.

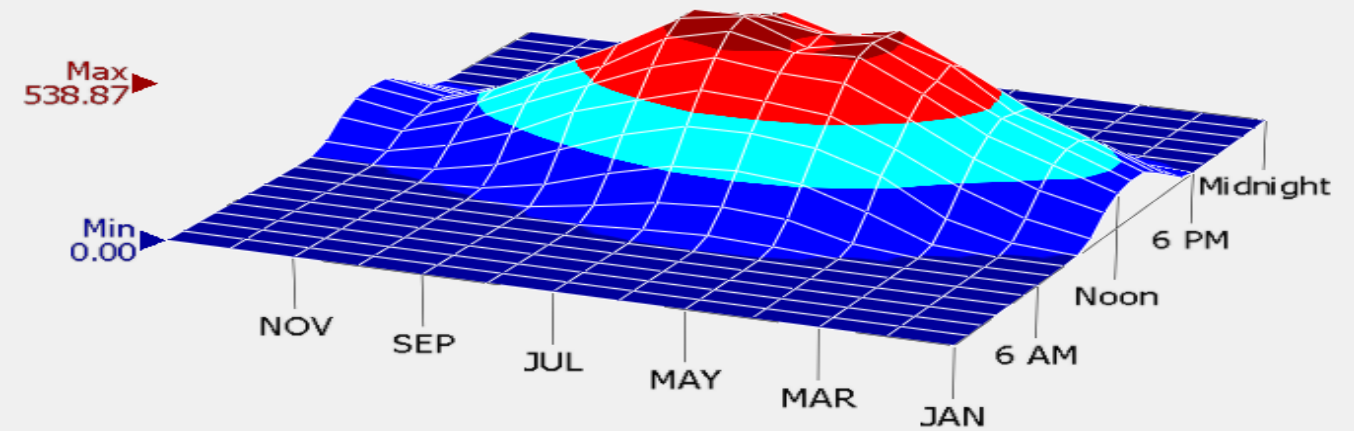
Building and model images Figure 2, 3, 4, 5, (Clockwise) Design Builder Model image on top of site plan, First Floor Plan, As-built building, Design Builder model image with solar shading.

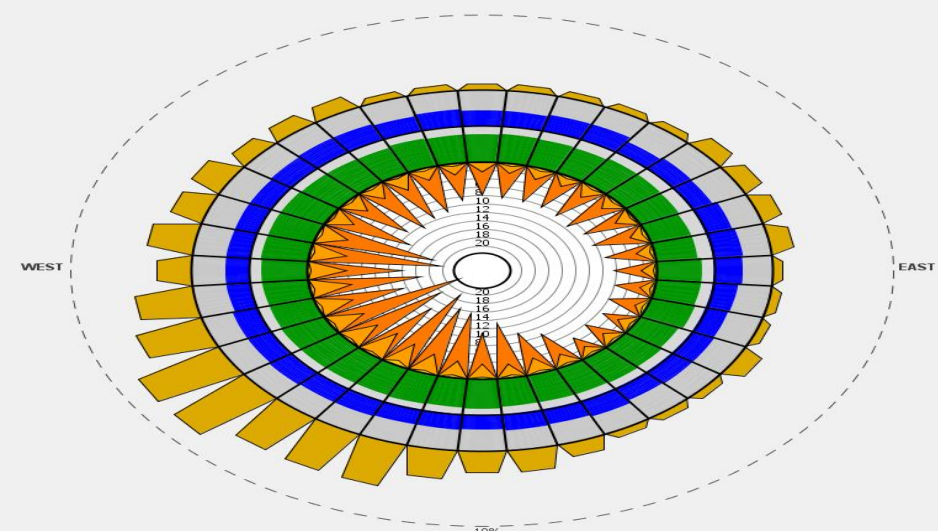


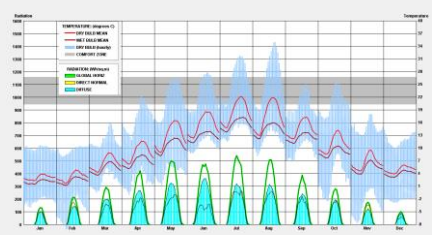


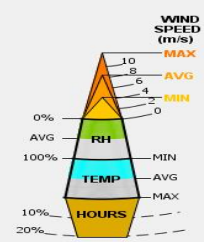
3.1. Simulation Weather Data. Ghent Belgium does not have EPW data, so nearest location of Brussels was used. *Figures, 6, 7, 8, 9 represent the temperature, humidity, solar radiation, and wind speed/direction.*











3.2. Building Energy Modeling Software

This study was modeled in Design Builder, then exported to EnergyPlus V8, then transitioned for use with an enhanced version of EnergyPlus 8.1 that includes a dual curve with hysteresis modeling method developed in part by the modeler.

The model uses polynomial fitting curves to describe the properties of PCM adapted from the Ginzburg-Landau theory of phase transitions. Dependent upon the composition, congruency and if the material is eutectic; PCM's can exhibit discontinuity at the melting temperature (Figure 10 Curve A) thus enthalpy is not a unique function of temperature, or can exhibit enthalpy as a continuous function of temperature (Figure 10 Curve B). This results in a 'mushy' (phase change) region between solid and liquid regions. To address this "mushy region" explicit equations adapted from the work of Egolf and Manz (1994) are used for the enthalpy as a function of temperature that are applicable to PCMs that show different widths of melting region and different specific heats in the solid and liquid phases.

Figure 10, *Discontinuous (A) and continuous (B) functions for enthalpy (Adapted from Egolf and Manz 1994)*

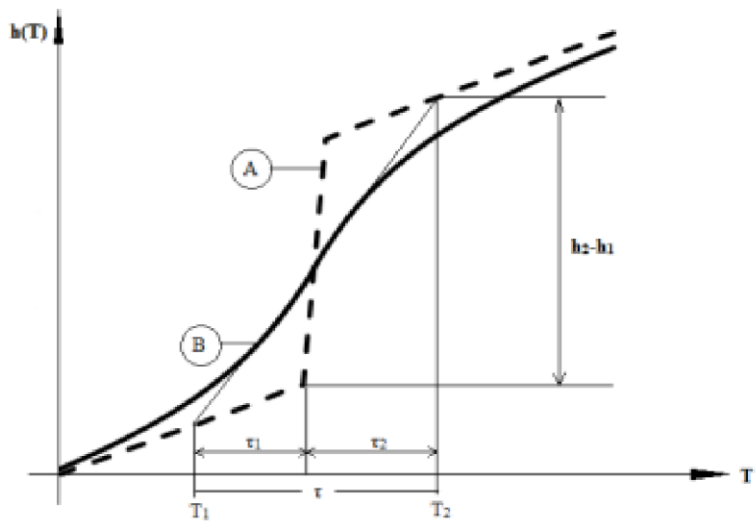


Figure 11, Equations used in Dual Curve PCM model: *Above are the equations for enthalpy as a function of temperature used in the model for both the melting and freezing curves adapted from the work of Egolf and Manz (1994).*

$$h(T) = c_{p,1}T + \eta_1 \qquad \text{if } T \le T_m$$

$$h(T) = c_{p,1}T_m + (h_2 - h_1) + c_{p,2}(T - T_m) - \eta_2 \qquad \text{if } T > T_m$$

$$\eta_n = \left(\frac{h_2 - h_1}{2}\right) e^{\frac{-2|T - T_m|}{\tau_n}}$$

Where

Cp, 1 = specific heat in solid state (J/kg-k)

Cp, 2 = specific heat in liquid state (J/kg-k)

Tm = Melt (Or Freeze) temperature (°C)

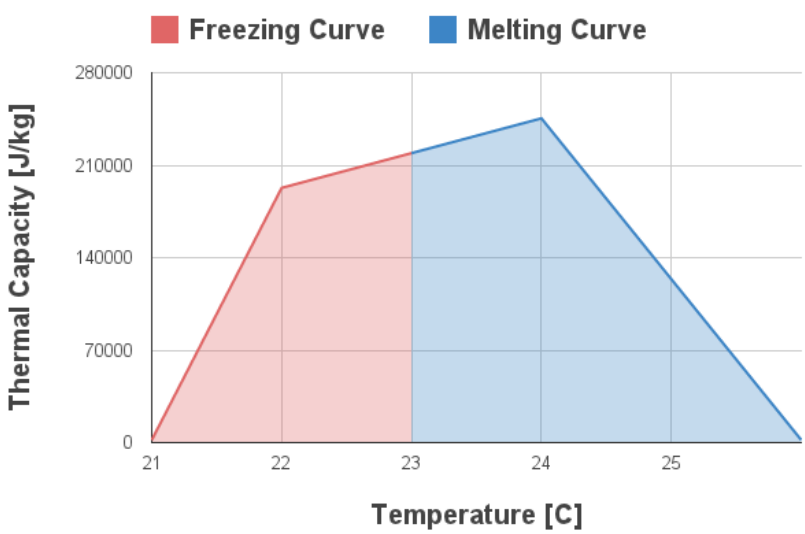
h2-h1 = Latent Heat stored (J/kg)

Tn = Melt (Or Freeze) range

3.3. BioPCM Product configurations

Figure 12, is an image illustrating the thermal capacity chosen for the Villa of M27. This was chosen for all external wall and roof assemblies. This thermal capacity was chosen because of the relatively small internal loads in the building, and also because it is specified to cover all external surfaces rather than for a load targeted application.

Figure 13, is a chart representing the Q-Value chosen for the Villa of Q23. This was chosen due to the mild cooling season of Belgium and due to the design goal of both cooling and heating BioPCM benefits.



4. Model Results

Model result are segmented into the following cases:

- Heating cooling and mixed mode natural ventilation
- Heating and cooling
- Passive natural ventilation, heating and energy recovery ventilation.
- Fully passive with natural ventilation
- Comparisons of cases

4.1 Heating, cooling and natural ventilation. Heat from October 1st to May 31st with a 21C set point and cooling on from April 1st to September 30th with a 25C set point and mixed mode natural ventilation. This illustrates a scenario where the HVAC is used to condition the building for comfort and windows are opened when outdoor conditions are above 17C and indoor conditions are above 21C. This model is most realistic for an average residential dwelling that has mechanical cooling that is used when outdoor temperatures are too hot for comfort. The dramatic cooling load reduction shows that a home with mechanical cooling could downsize their mechanical cooling system to 35% of the size they would need without bioPCM.

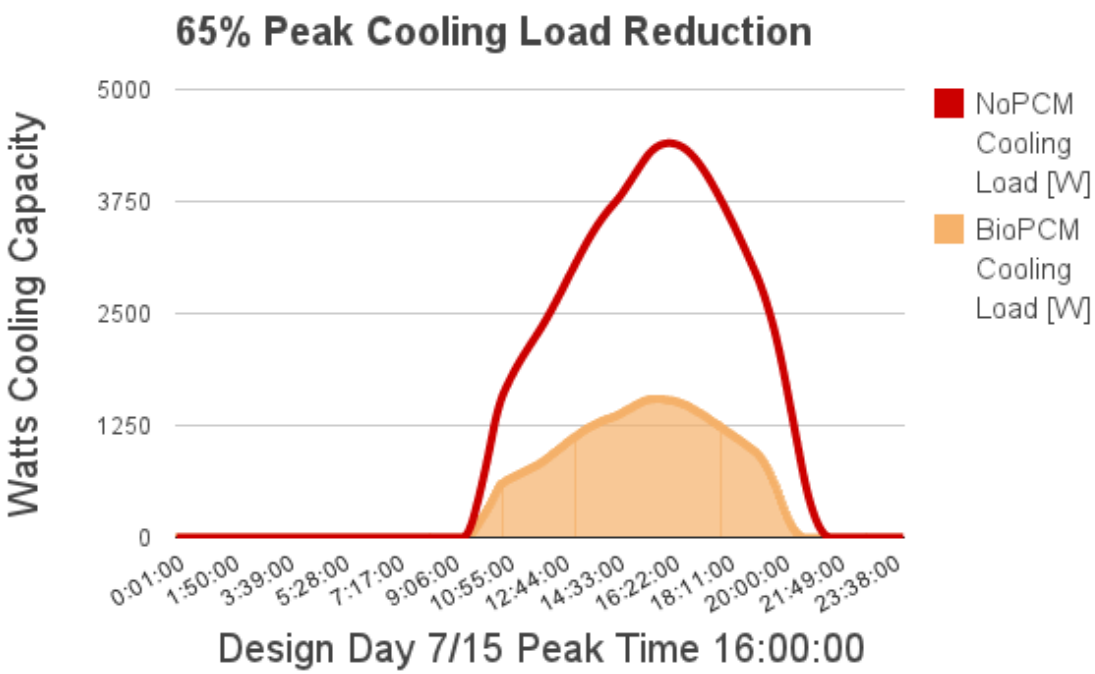


Figure 14, peak cooling load reduction

NoPCM Cooling Load [W]	BioPCM Cooling Load [W]	Reduction [W]	Percent Reduction [%]
4,401	1,547	2,854	65%

Figures 15, and 16, cooling energy comparison

NoPCM Cooling Energy [kWh]	BioPCM Cooling Energy [kWh]	Cooling Energy Reduction [kWh]	Percent Cooling Energy Reduction [%]
3,011	1,026	1,985	66%

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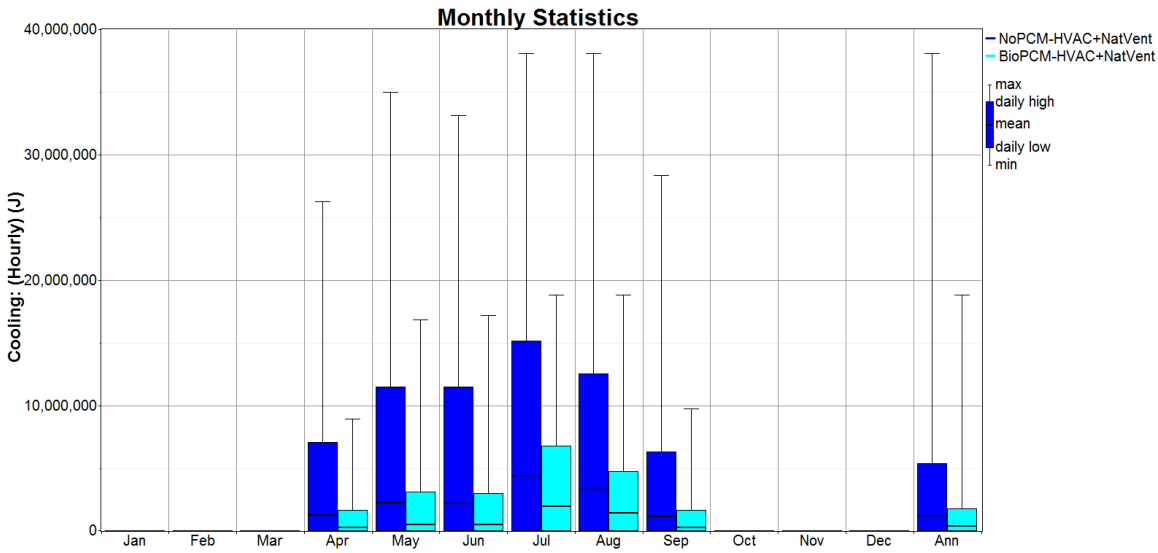
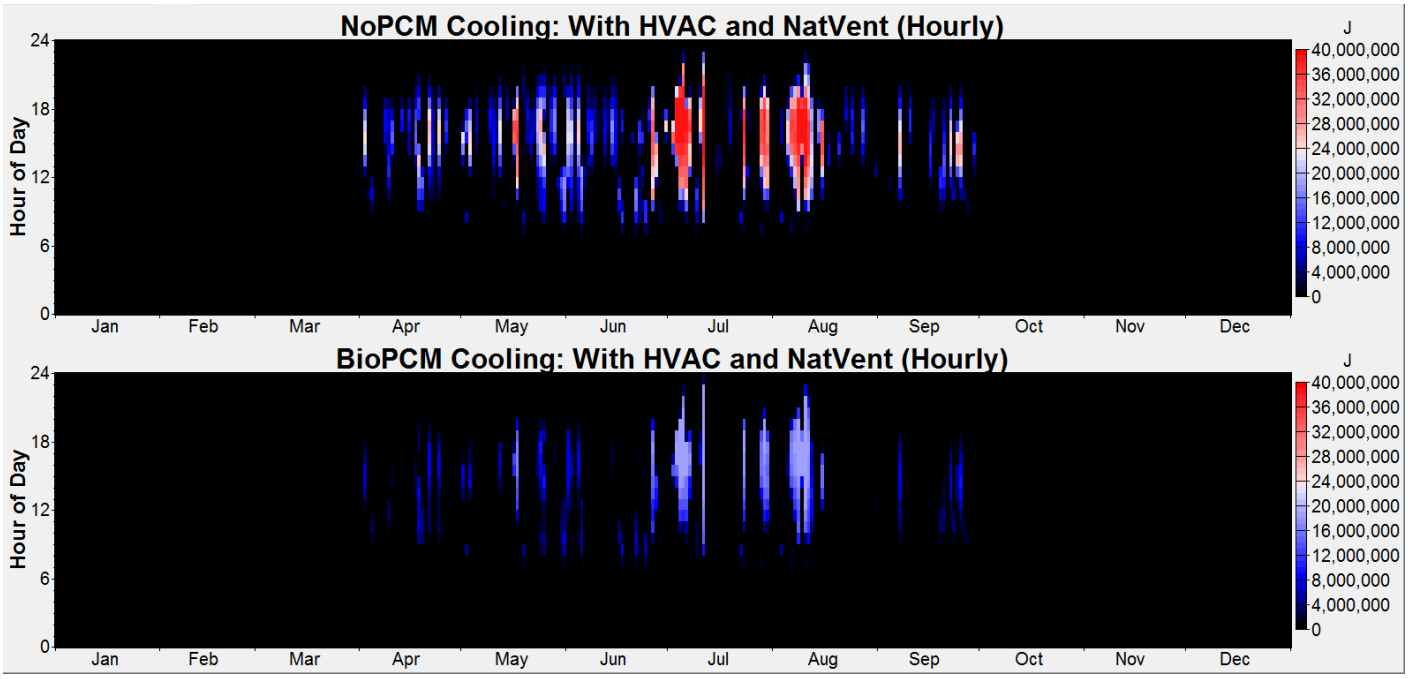
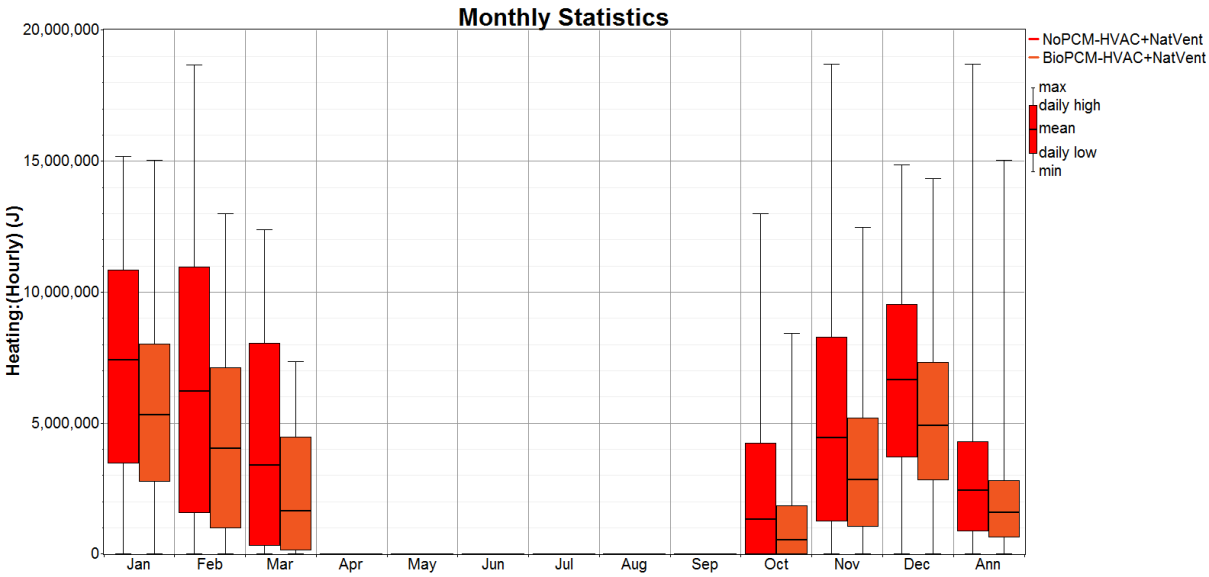
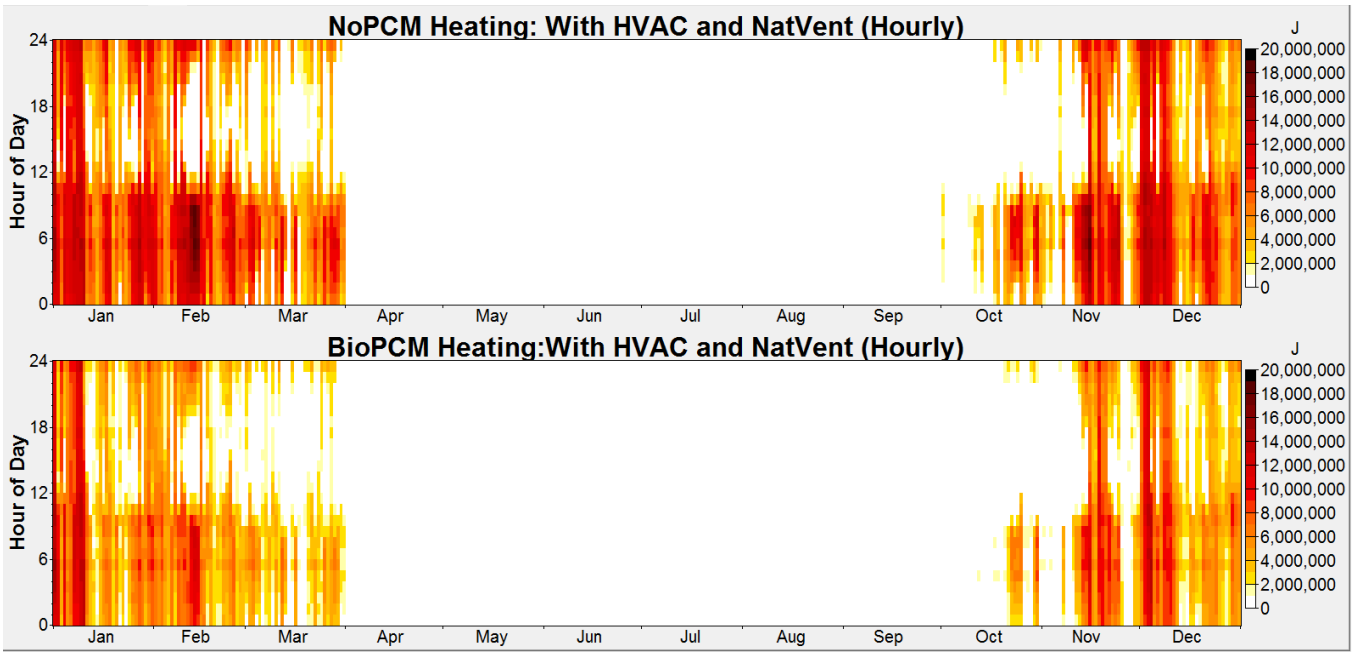




Figures 17 and 18, Heating Energy comparison

NoPCM Heating Energy [kWh]	BioPCM Heating Energy [kWh]	Heating Reduction Energy [kWh]	Percent Heating Energy Reduction [%]
5,941	3,903	2,038	34%





4.2 Heating and cooling, no natural ventilation. This illustrates a scenario where the HVAC is used to condition the building for comfort and windows are never opened. It is the least realistic for the actual occupants, but is the model that is most realistic for calculating theoretical return on investment based on energy savings. Even with heating and cooling running year round bioPCM provides substantial comfort enhancement benefits.

NoPCM HVAC Energy [kWh]	BioPCM HVAC Energy [kWh]	HVAC Energy Savings [kWh]	HVAC Energy Percent kWh Reduction [%]
14,636	8,623	6,013	41%
NoPCM ASHRAE 55 Time Not Comfortable [hr]	BioPCM ASHRAE 55 Time Not Comfortable [hr]	ASHRAE 55 Time Not Comfortable Savings [hr]	Percent ASHRAE 55 Time Not Comfortable Reduction [%]
2,388	870	1,518	64%

Figure 19, annual energy consumption savings, Figure 20 cooling set point hours not met

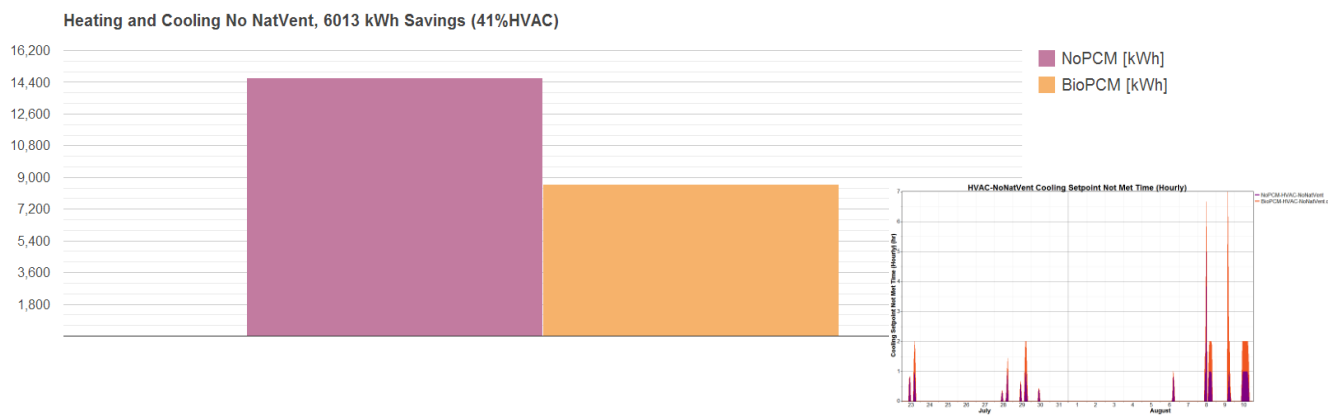
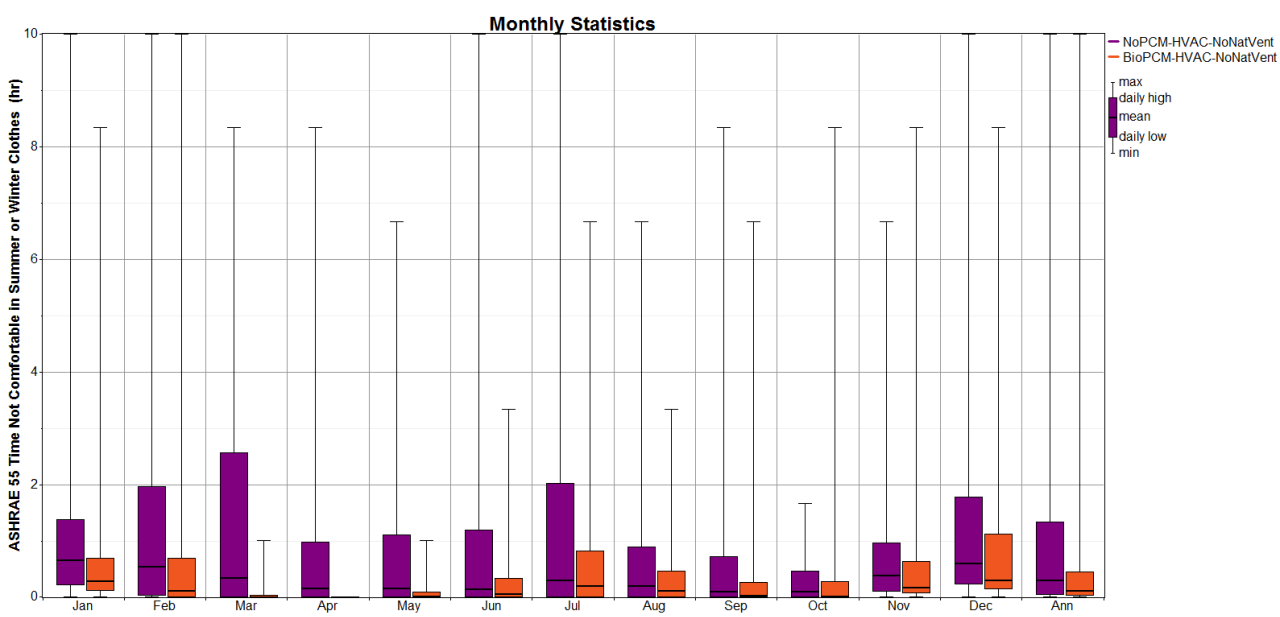


Figure 21 ASHRAE 55 hourly time not comfortable in summer or winter clothes.



4.3 Heating with Energy Recovery ventilation, and natural ventilation.

This is the typical Passivhaus configuration for USA Passive house projects. The table below illustrates the envelope load reduction and ASHRAE 90% discomfort time reduction and eating energy consumption are significantly reduced.

**Envelope Peak heat gain is same in fully passive no heating or cooling case.	BioPCM	NoPCM	Reduction	Percent Reduction
Heating Energy [kWh/m2]	13.2	21.8	8.6	40%
*Roof Peak Heat Gain [W]	939,805	3,154,244	2,214,438	70.21%
*Walls Peak Heat Gain [W]	20,901,902	40,287,332	19,385,431	48.12%
ASHRAE55 90% Limits Discomfort Hours [Hr]	577	1,475	897	60.86%

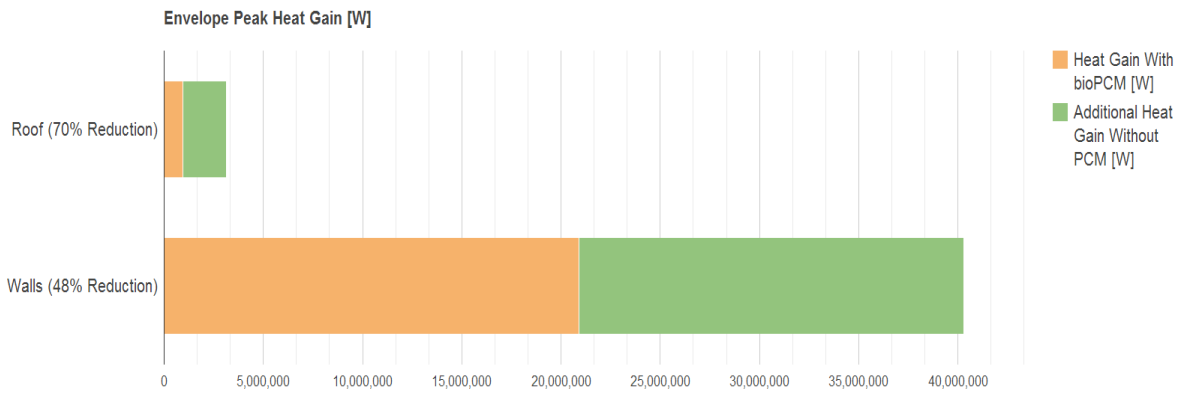
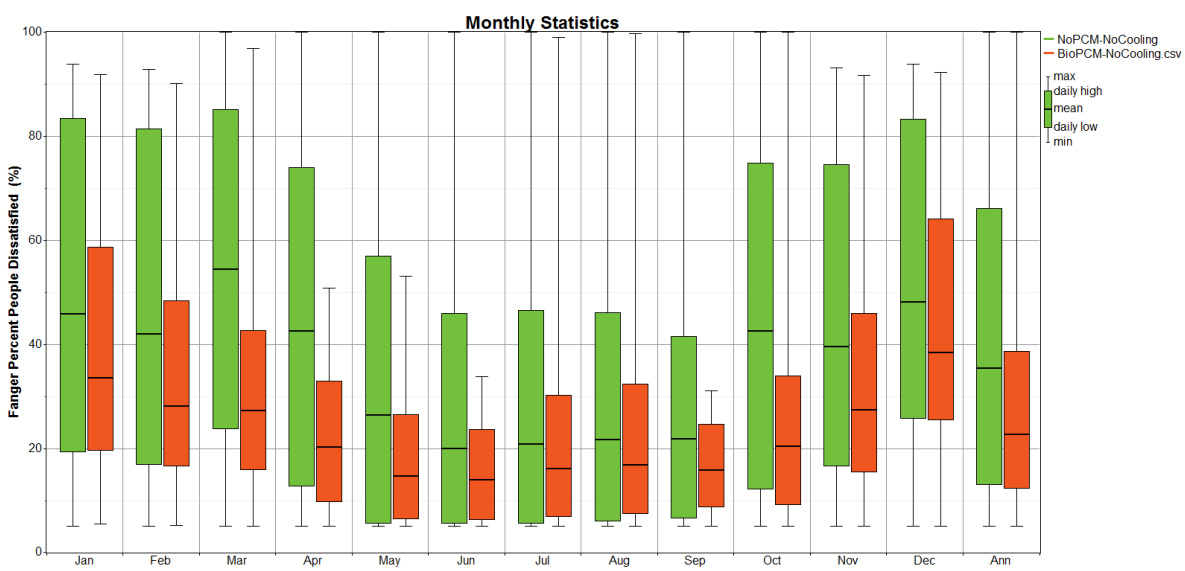


Figure 22, Peak heat gain comparison

Figure 23, Fanger Percentage People dissatisfied with thermal conditions (PPD)



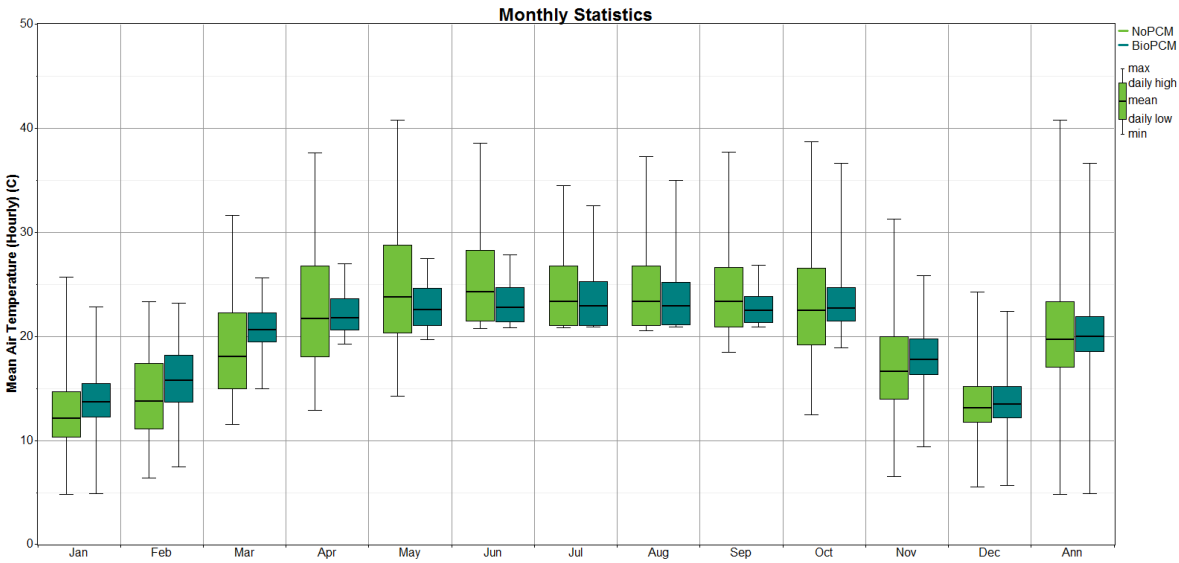
4.4 Fully passive/as designed. Relying on natural ventilation to keep the home cool and a combination of internal and solar gains to keep the home warm. This is how the building is actually designed and will be built. The other cases in this study are used for comparison only.

Several comfort models are used to quantify bioPCM benefits. Each can be referenced in the literature. In general comfort is modeled as an expression from the metabolic rate, dynamic clothing insulation and environmental conditions of humidity, air velocity, mean air temperature (MAT) and mean radiant temperature (MRT). MAT and MRT are averaged to produce the operative temperature. Operative temperature is combined with metabolic rates to deduce clothing surface temperature. ASHRAE55, and CEN15251 use these and count hours of modeled discomfort. Fanger PPD rates the percent people who would be dissatisfied with thermal conditions based on a thermal sensation scale that also uses these variables

	ASHRAE55 90% Acceptability Limits [Hours]	ASHRAE55 80% Acceptability Limits [Hours]	CEN15251 Category I Acceptability Limits [Hours]	CEN15251 Category II Acceptability Limits [Hours]	CEN15251 Category III Acceptability Limits [Hours]
NoPCM	1,565	1,196	2,458	1,514	988
BioPCM	576	335	1,157	447	222
Savings	989	861	1,301	1,067	767
%	63%	72%	53%	70%	78%

	NoPCM ASHRAE 55 TIME NOT COMFORTABLE SUMMER OR WINTER CLOTHES [HOURS]	BioPCM ASHRAE 55 TIME NOT COMFORTABLE SUMMER OR WINTER CLOTHES [HOURS]	REDUCED DISCOMFORT TIME [HOURS]	%
January	732	651	82	11%
February	642	591	51	8%
March	615	204	411	67%
April	399	39	359	90%
May	230	25	205	89%
June	181	40	141	78%
July	173	140	33	19%
August	130	64	66	51%
September	112	18	95	84%
October	380	102	278	73%
November	580	435	145	25%
December	734	713	21	3%
Annual Sum or Average	4,908	3,020	1,888	50%

Figure 24, and 25, mean air temperatures (MAT)



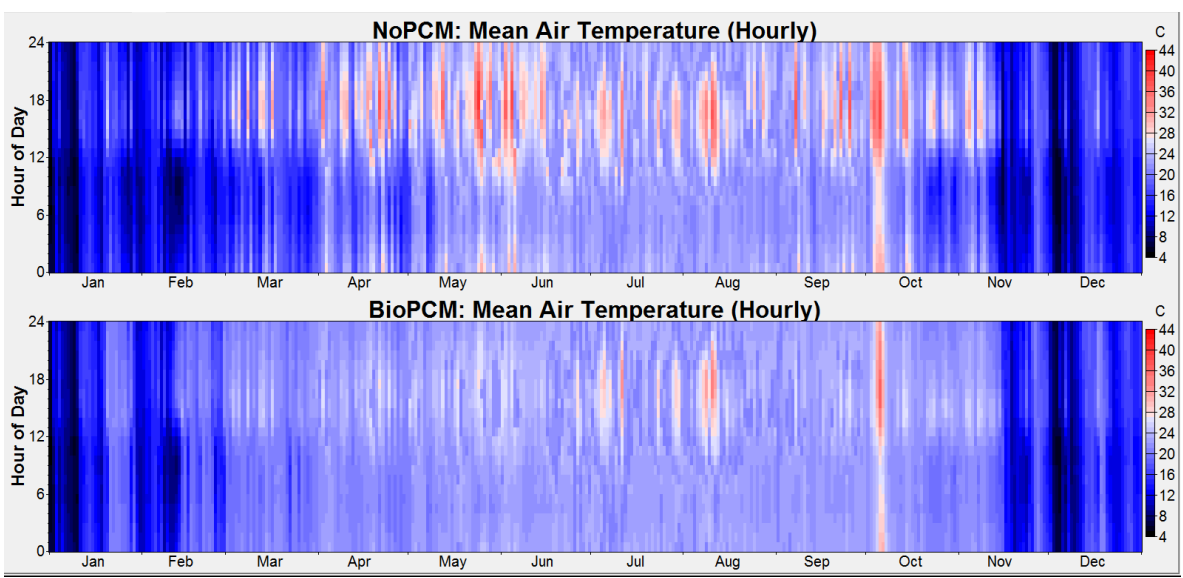
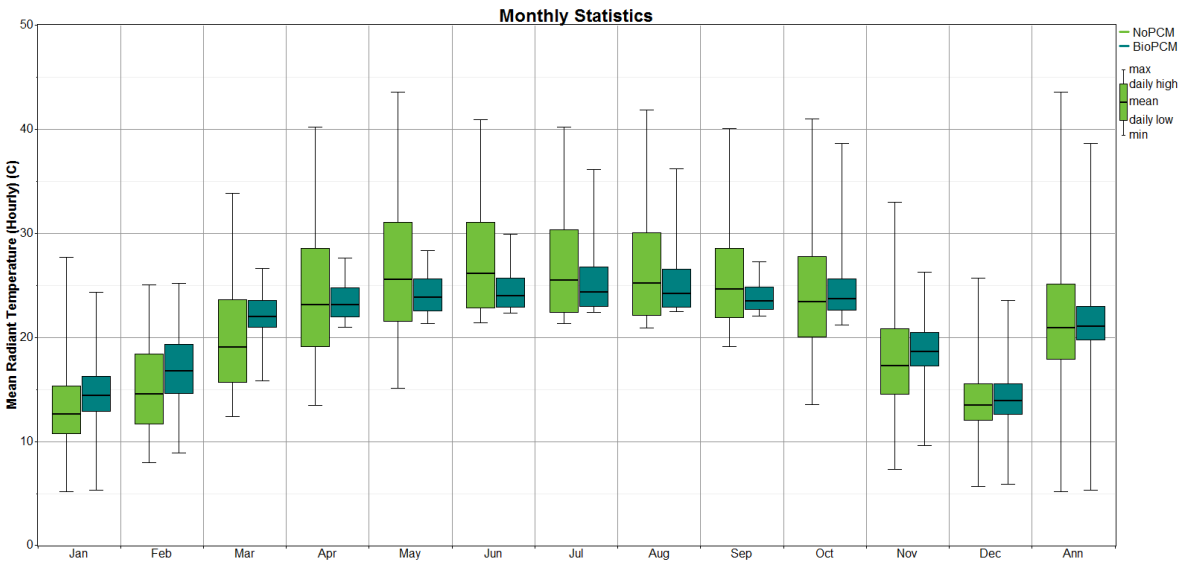


Figure 25 and 26, mean radiant temperatures (MRT)



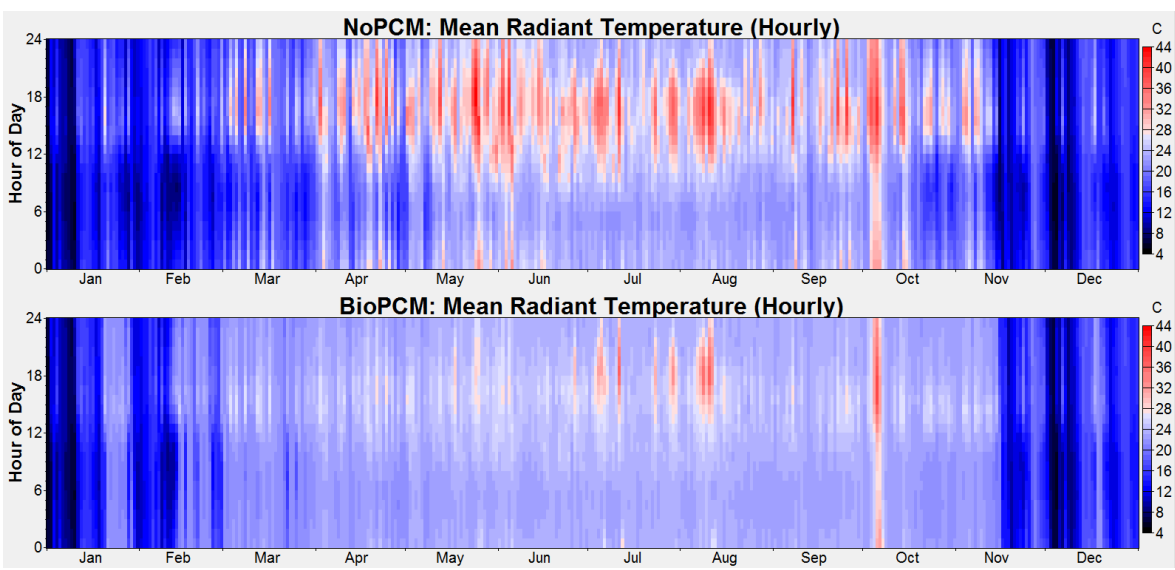
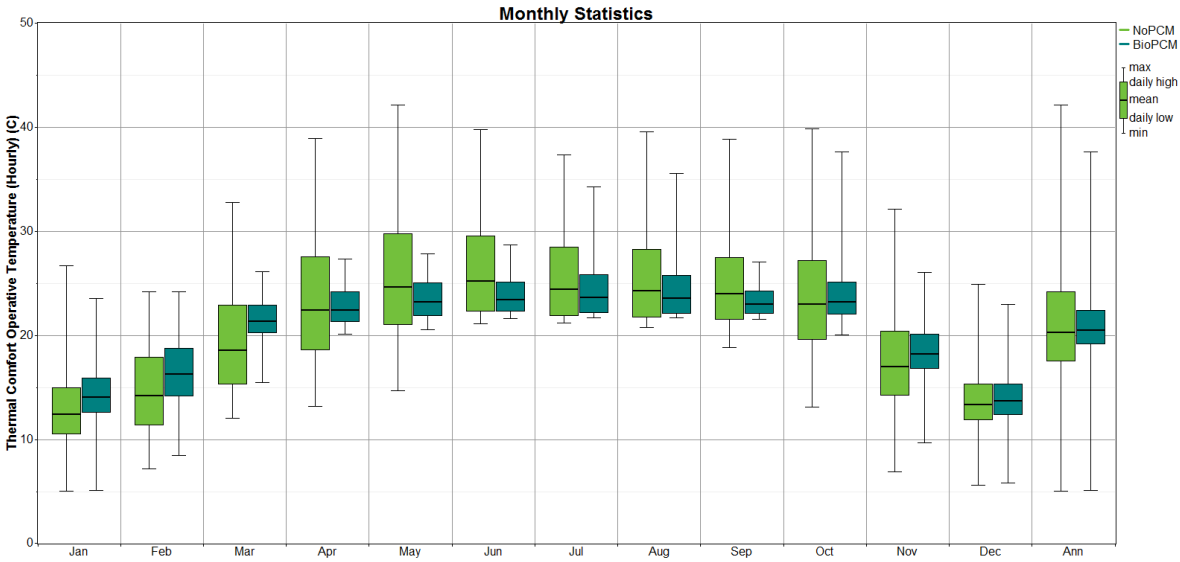


Figure 27 and 28, operative temperatures (MAT x MRT / 2)



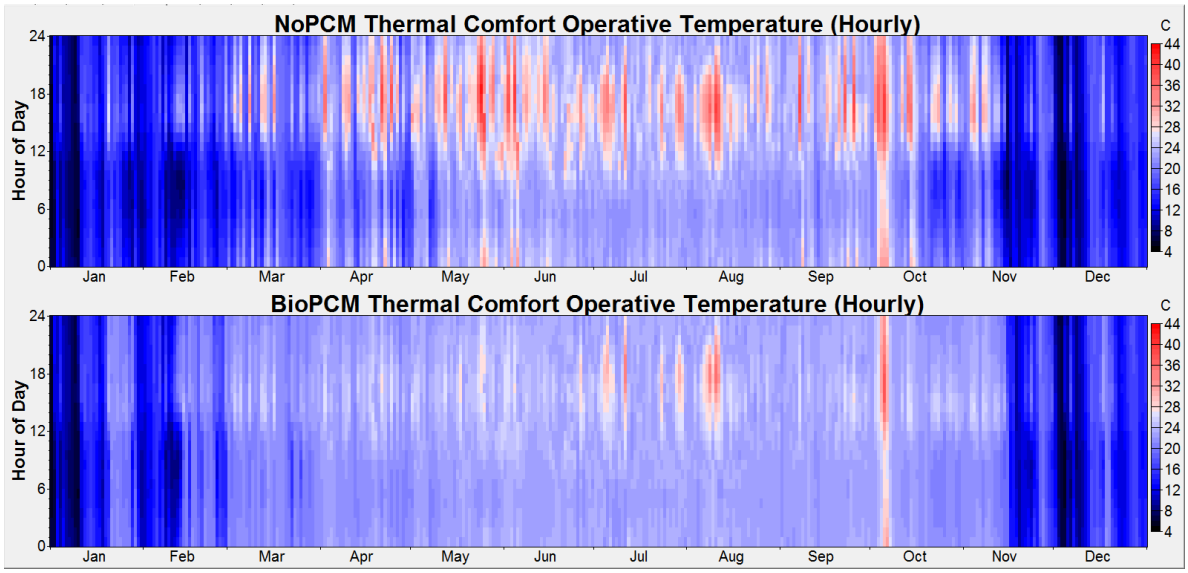


Figure 29 and 30, clothing surface temperatures

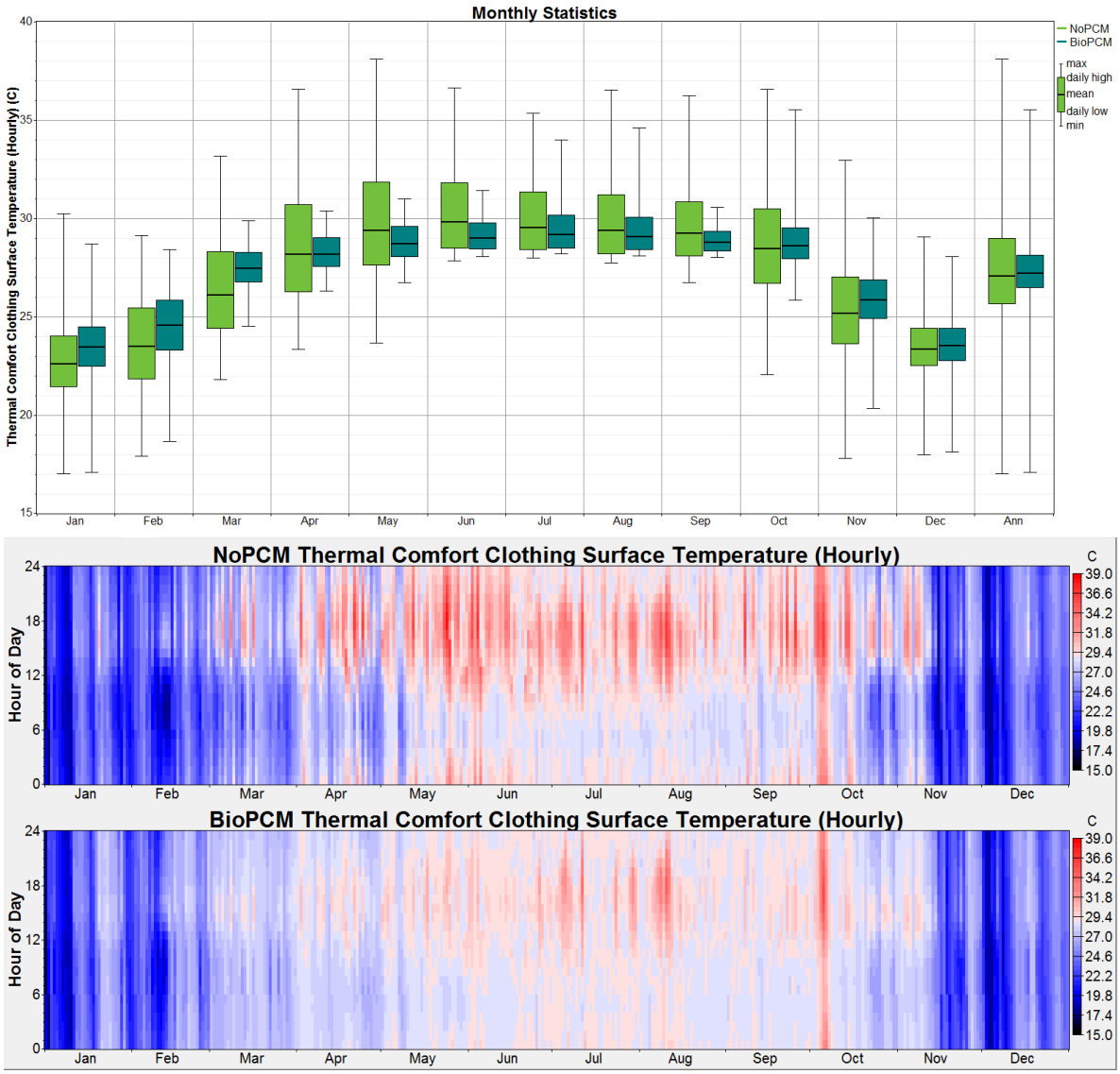
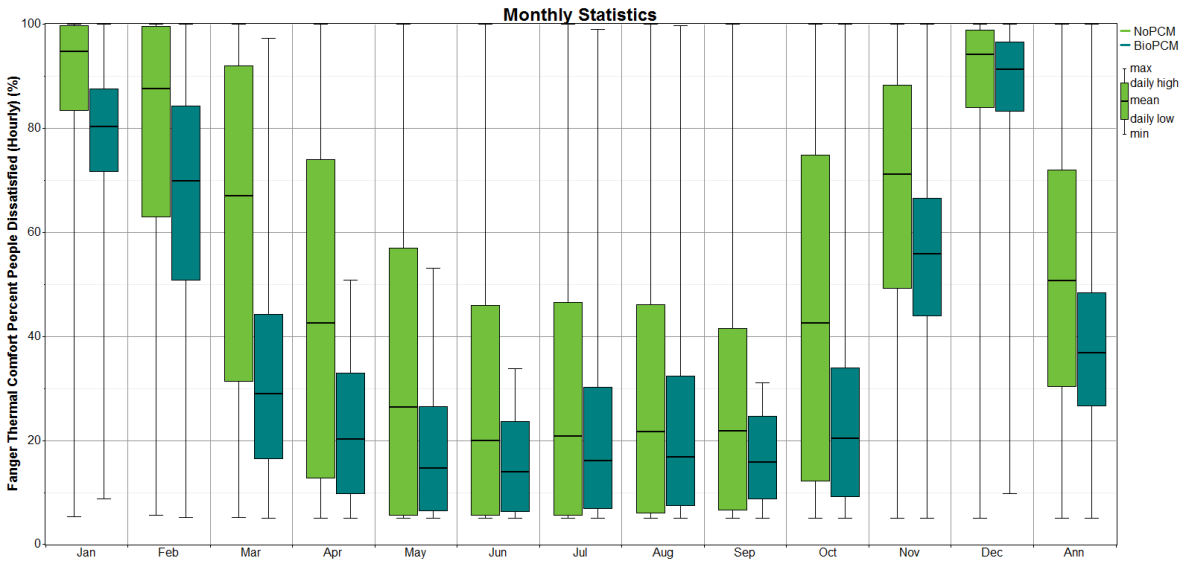
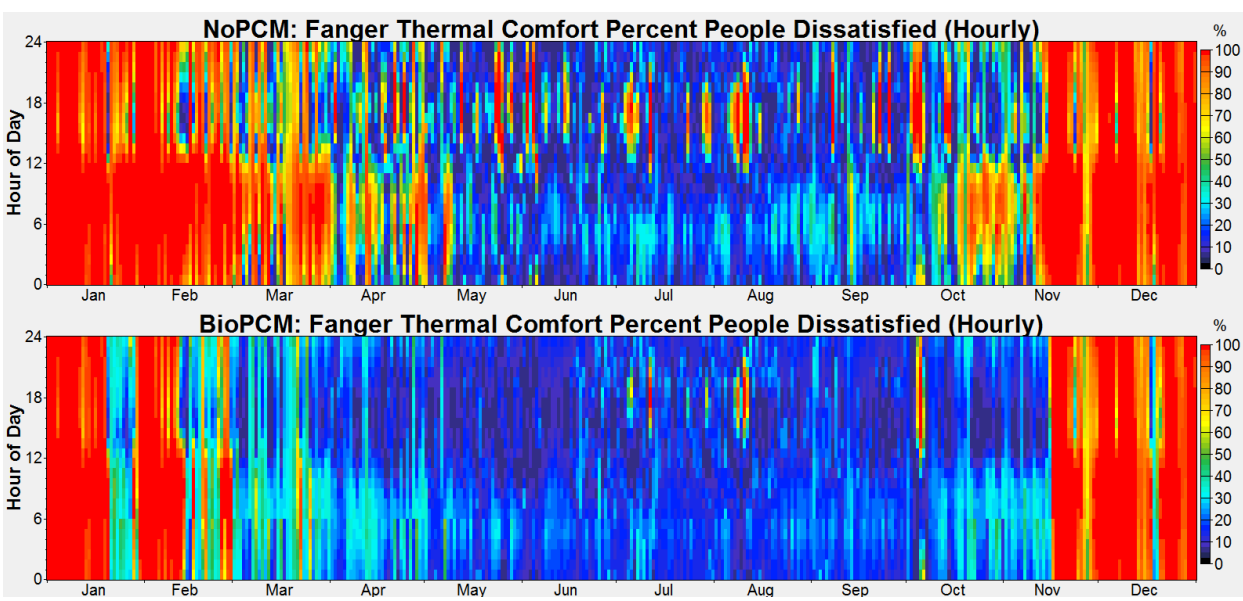


Figure 31 and 32 Fanger percent people dissatisfied with thermal conditions





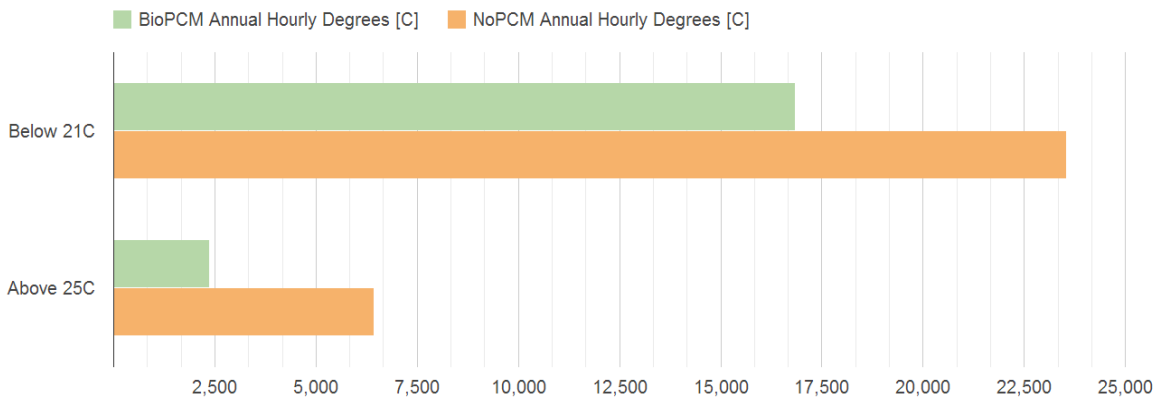
Comparison A: temperature analysis
The fully passive/as designed building with and without bioPCM operative temperatures where compared.

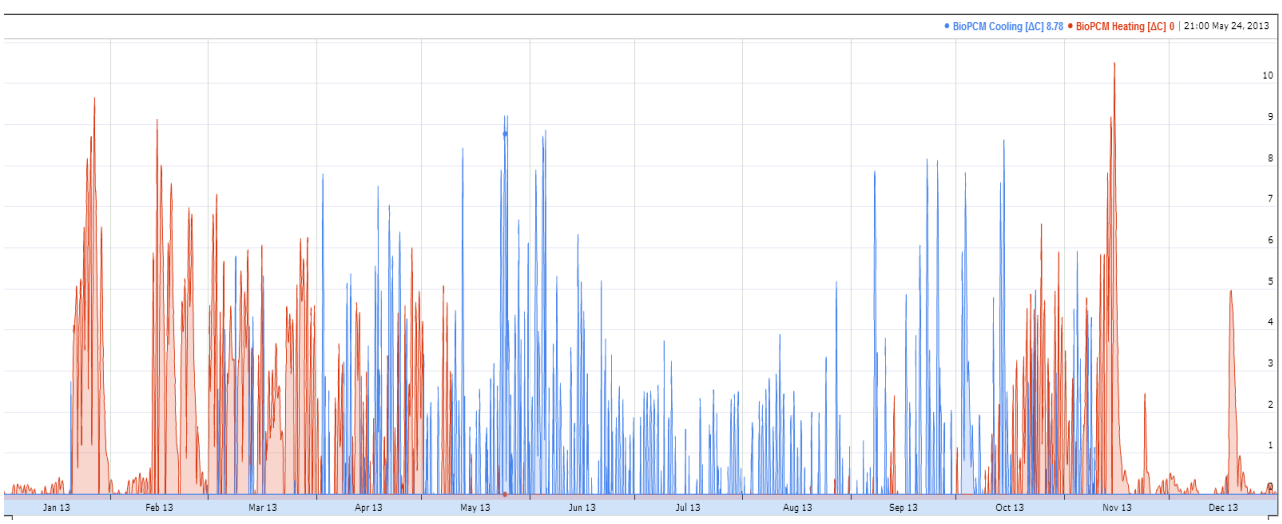
- For heating 21C was assumed as the benchmark, the temperature difference (ΔT) below the set point was calculated for each hour of the year. Then the BioPCM case was subtracted from the NoPCM case. The result shows the heating effect of the BioPCM in degrees C.
- For cooling 25C was assumed as the benchmark, the temperature difference (ΔT) above the set point was calculated for each hour of the year. Then the BioPCM case was subtracted from the NoPCM case. The result shows the cooling effect of the BioPCM in degrees C.

	BioPCM Annual Hourly Degrees [C]	NoPCM Annual Hourly Degrees [C]
Below 21C	16,845	23,545
Above 25C	2,359	6,442

BioPCM Heating ΔT	6,700
Reduction of "too cold" conditions	28%
BioPCM Cooling ΔT	4,083
Reduction of "too hot" conditions	63%

Figure 32, Annual sum of hourly degrees above 25C or below 21C, Figure 33, hourly degrees above 25C or below 21C





Comparison B: energy analysis

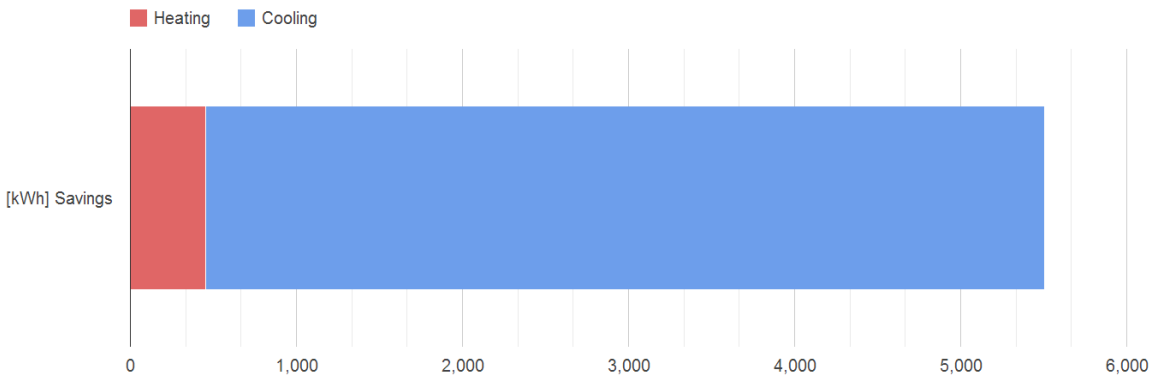
BioPCM NoHVAC heating and cooling Set Point Hours Met multiplied by the energy consumption of the NoPCM HVAC NoNatVent case. Both models have a heating set point of 21C and cooling set point of 25C. The NoPCM HVAC, NoNatVent case is used because it has heating and cooling on all year round. The premise of this comparison is if the bioPCM no HVAC building meets the thermostat set points then it is performing the same work as the HVAC system. There are some issues with this method of comparison:

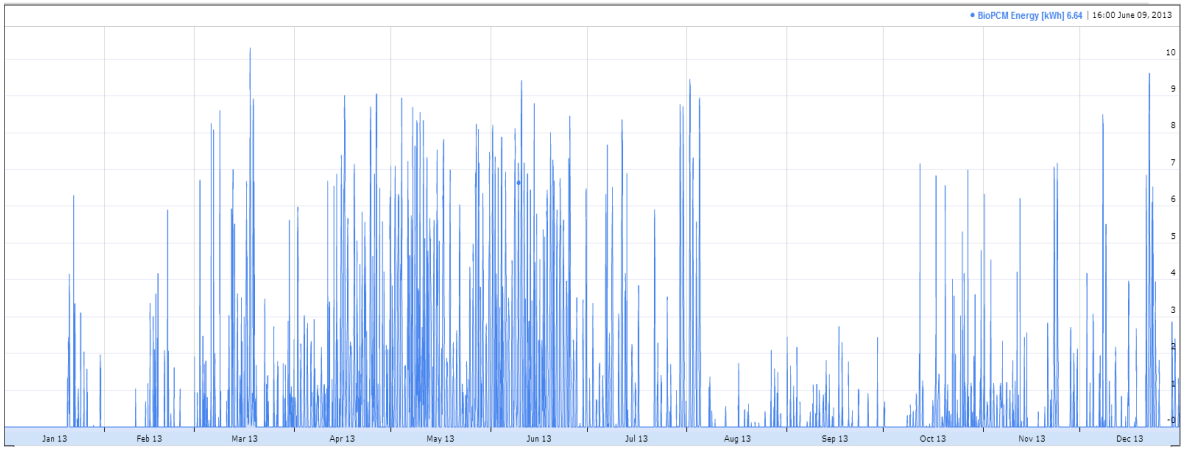
- The 59 hours that the building with HVAC does not meet cooling set point. (This is illustrated in the tiny chart in the HVAC no NatVent section) It would take more energy to meet the set point then is calculated with this method.
- BioPCM provides heating benefits below the set point, (This is illustrated in comparison A) however this is not counted with this method.

The issues with this energy analysis method for comparing a building with phase change materials and no heating or cooling indicate that the method will slightly under predict benefits, however it is estimated that the error is minor. It is noteworthy that energy savings are primarily during shoulder season. This makes since the because of less extreme temperatures and higher diurnal swings.

	Heating	Cooling	Total
[kWh] Savings	451	5,055	5,506

Figure 34, Annual sum of heating & cooling energy savings, Figure 35 hourly total energy savings

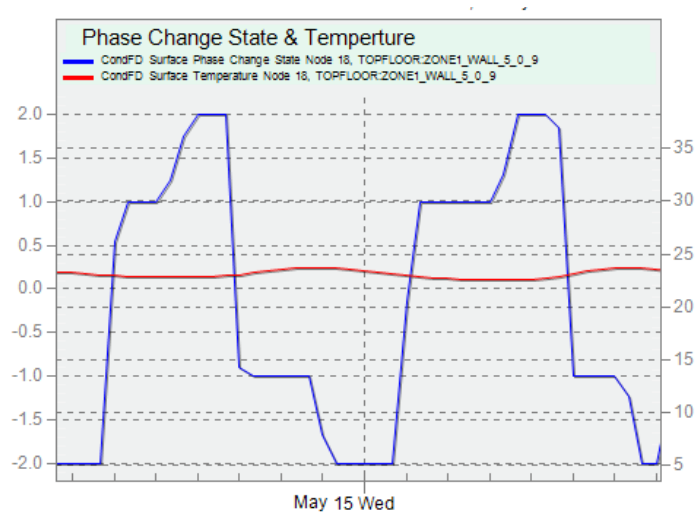


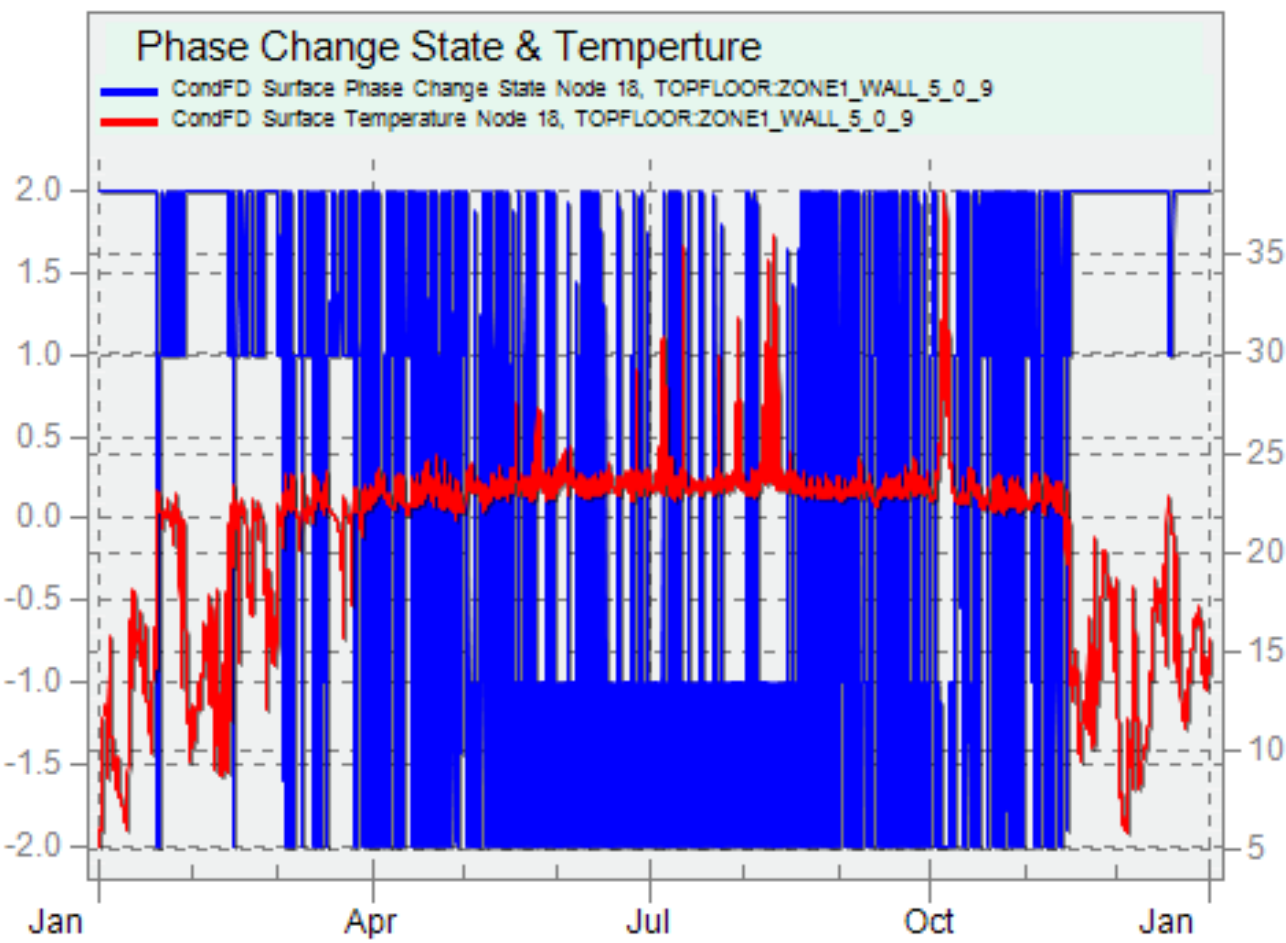


Phase Change State and Temperature agree with other model results.

- *CondFD Surface Phase Change State Node <X> []* -2: Liquid, -1: Melting, 0: In Transition 1: Freezing, 2: Crystalized.
- *CondFD Surface Temperature Node <X> []* Nodal temperature of the PCM. Construction specifications

Figure 36, change temperature and state May 15th phase change temperature and state, Figure 37, Annual hourly phase change temperature and state

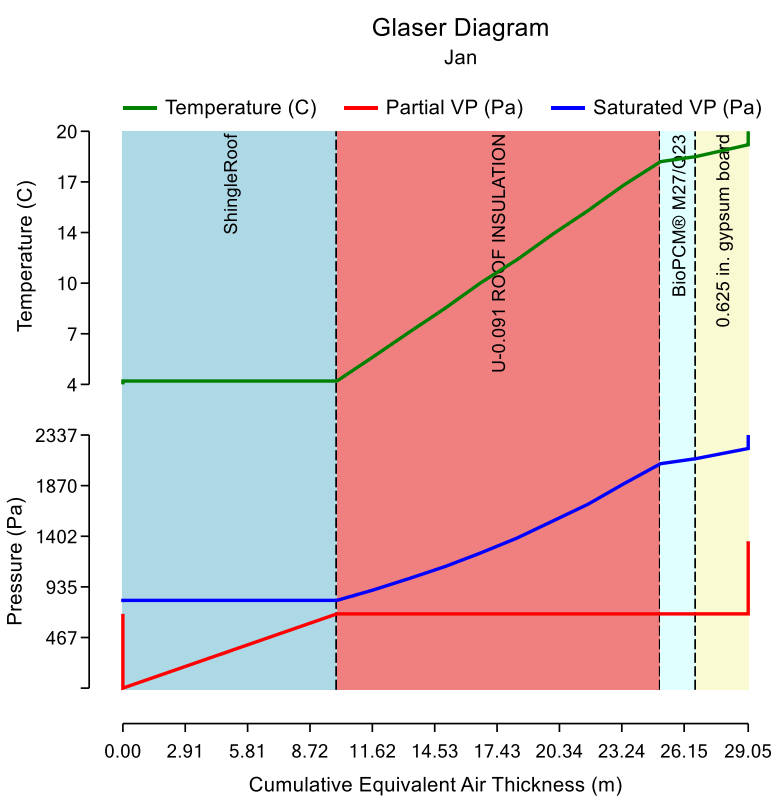




BioPCM Applied interior of insulation for the entire top floor roof. Cost estimate: **€9367.30**

Figure 38, Roof Assembly

Figure 39, Roof Condensation analysis.



Condensation Analysis Report

Interstitial Condensation

Structure is free of condensation.

Condensation Interfaces

Number of condensation interfaces: 0

Surface Condensation

Thermal quality Good. Mold growth unlikely.

BioPCM Applied interior of insulation for the all external walls on top and bottom floors. Cost estimate**: €18082.98**

Figure 40, Wall Assembly

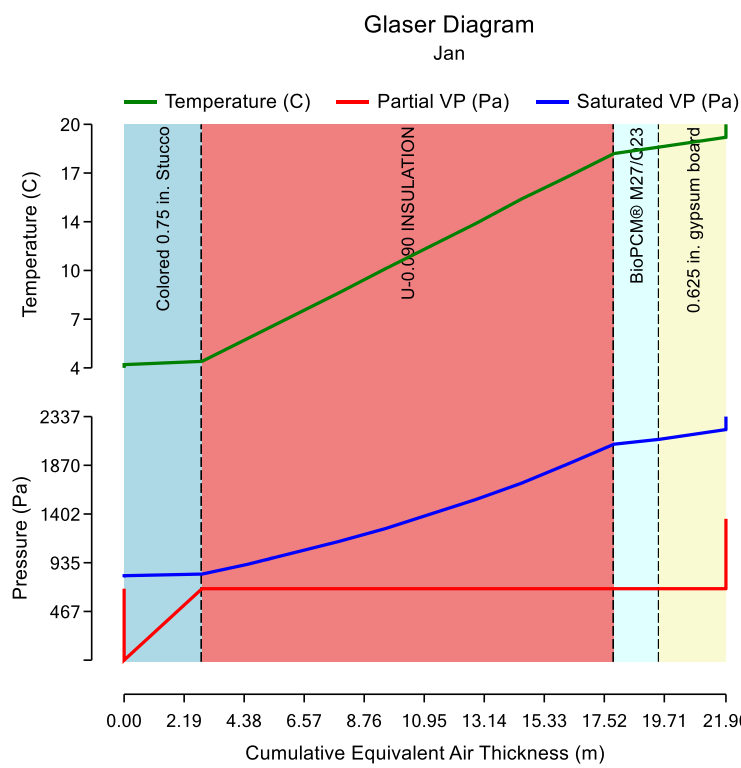


Figure 41, Wall Condensation analysis.

Condensation Analysis

Report

Interstitial Condensation

Structure is free of condensation.

Condensation Interfaces

Number of condensation interfaces: 0

Surface Condensation

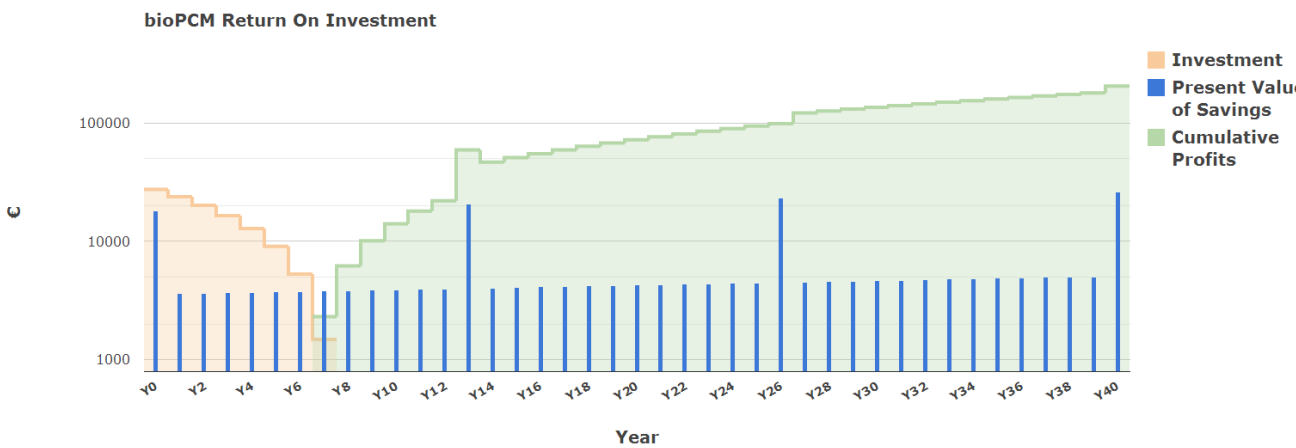
Thermal quality Good. Mold growth unlikely.

5. Lifecycle assessment

BioPCM has a first cost of €27450.28. For the NoPCM case there is an HVAC replacement cost every 13 years of €15,000 annual maintenance €200, and energy costs of €0.22566 per kWh. The calculation also includes a discount rate 1.5% (European Union Central bank discount rate), inflation 2.4%. (Euro Inflation Rate average from 1991 until 2013) and a 1% escalation rate.

Year	Present Value of Cumulative Savings	Present Value of Cumulative Profits
2014	-€ 9,289.36	-€ 9,289.36
2027	€ 84,265.11	€ 56,814.83
2040	€ 158,408.06	€ 130,957.78
2053	€ 241,567.34	€ 214,117.06

Figure 42, BioPCM return on investment and 40 year profitability



BioPCM service life, using enhanced ageing tests were bioPCM is cycled from crystalized to melting to freezing to crystalized and then tested if energy storage capacity had degraded over time-heat/cool cycles. Observations: Sample shows little to no breakdown over duration of 87.2 years cycling test. We infer from these results that bioPCM will perform well on an ongoing basis and over the 40 years of this lifecycle assessment.

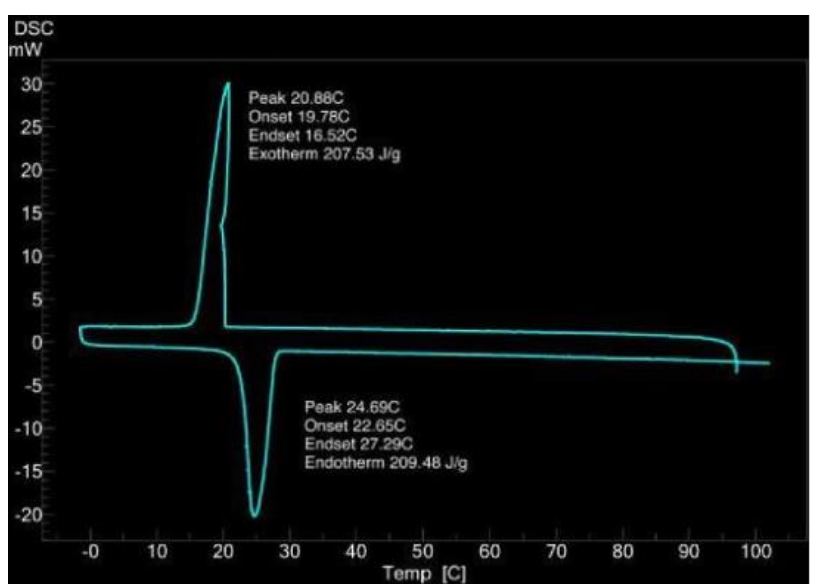


Figure 43, bioPCM lifecycle DSC test results

6. Benefits for Utility electricity providers, site vs. source energy savings & peak demand reduction.

BioPCM provides source energy savings for electric utilities and reduces peak demand. In the case illustrated in figure 45, bioPCM with natural ventilation reduces cooling load over no PCM and no natural ventilation by 62% on the design day of 7/15 at 15:42:00.

	Site Building Energy	Source Energy	
NoPCM [kWh/m2]	115	293	
BioPCM [kWh/m2]	66	208	
	Building Energy Savings	Utility Energy Savings	Total Energy Savings
[kWh/m2]	49	37	86
[%]	42.3%	20.79%	29.21%

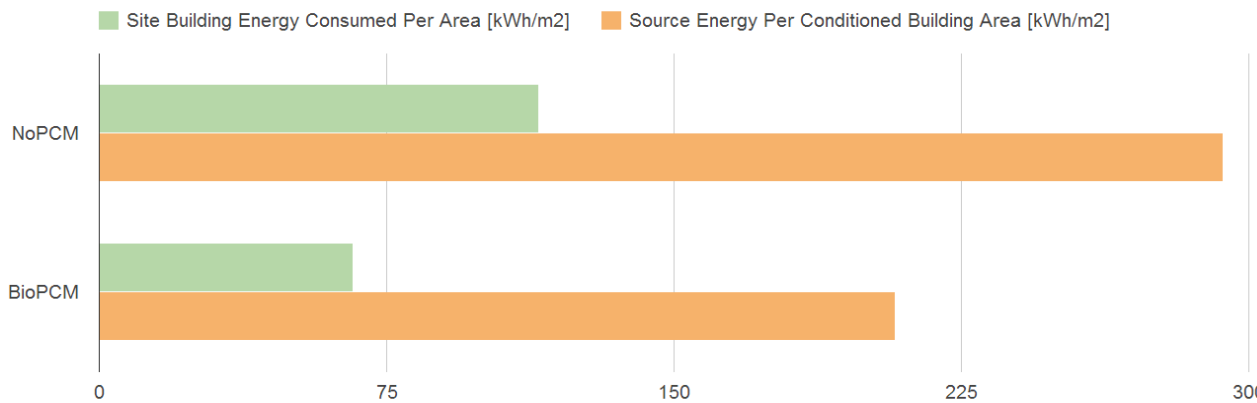
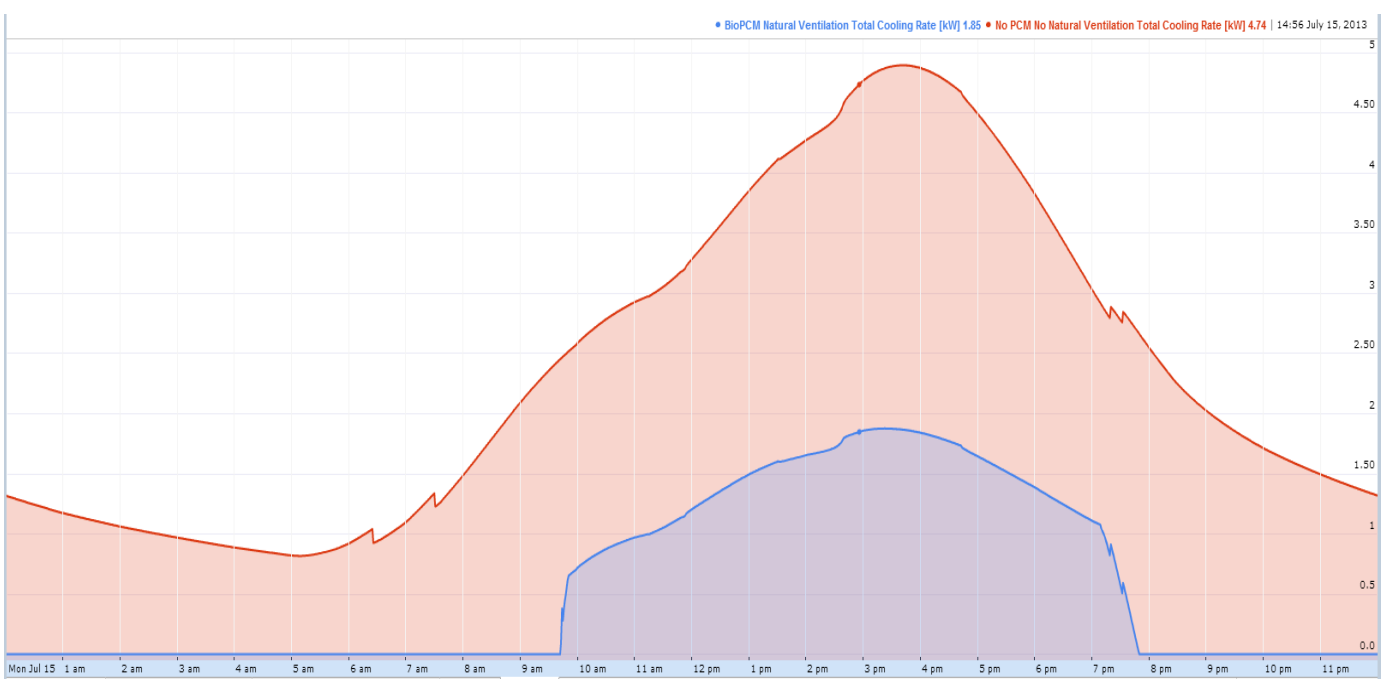
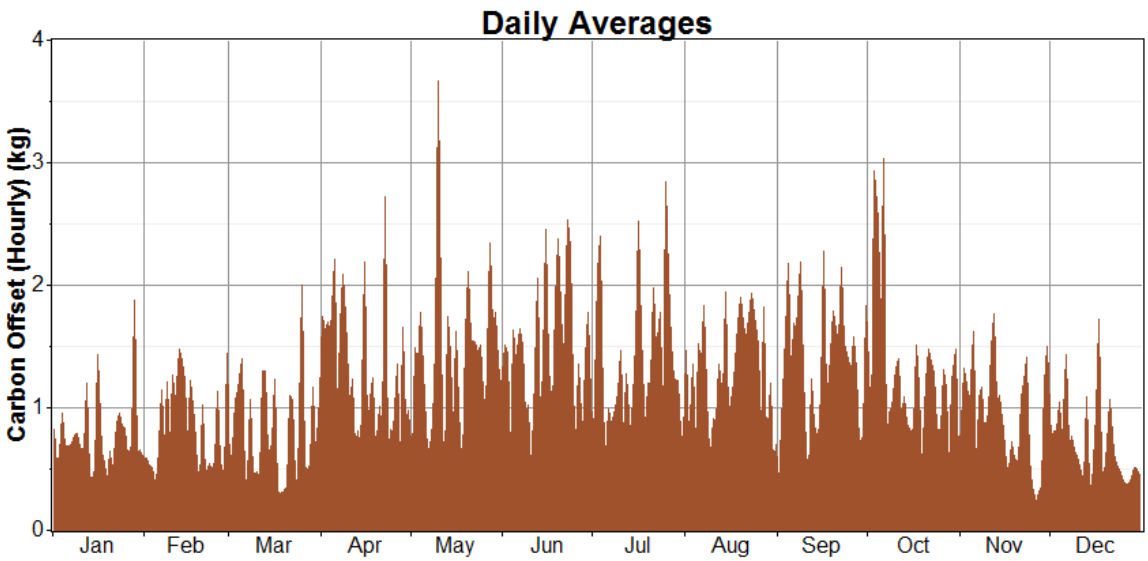


Figure 44, site vs source energy per area, Figure 45 peak demand reduction



7. Carbon offset

Design with no heating or cooling reduces the carbon foot print of the Passivhaus Villa by 2,485 kilograms per year. This is equivalent to the carbon sequestered by 8094m² of mature forest or 63 seedlings grown for 10 years.



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Appendix A. *Dropbox folder links with full model input and output files:*

- As designed full passive: https://www.dropbox.com/sh/d7zblr6b7q0fhxd/6xdJDl2zXH
- Typical passive house, With Heat and ERV: https://www.dropbox.com/sh/u4bdh31hx7se18k/wW50inwjDJ
- Typical house, With hearing and cooling: https://www.dropbox.com/sh/miuil3zrdjlkebp/oET4gj8RyG
- Comparison case, Heating and cooling with no natural ventilation: https://www.dropbox.com/sh/h847x3x3l9158b7/G5j6hhqBXg
- Phase Change State models, https://www.dropbox.com/sh/13gsub2voiw1swz/KseViwc6j0

Appendix B. *Dropbox folder links to tools for further analysis:*

- DVIEW, Hourly .CSV file comparison: https://www.dropbox.com/s/rsw6li7ysj9bcff/DView125.exe
- RESULTS-VIEWER, Hourly .ESO file viewer: https://www.dropbox.com/s/ny031b6prmql7e1/ResultsViewerInstall098.msi
- EP-COMPARE, Annual HTML comparison; https://www.dropbox.com/s/2z3nlpt4jszxnvl/EP-Compare.zip
- ENERGY PLUS V8.1.0.008, Custom version of Energy Plus with dual curve modeling capabilities provided under Jeremiah Crossett's license for personal use for further modeling analysis https://www.dropbox.com/s/zbgmlbnbdi81phd/EnergyPlusV8-1-0-008.zip

Appendix C. *BioPCM Cost Estimate:*

Cost Line Item Details

	Line No.	Item Name	Quantity.	Units	€ per Qty.	SubTotal €
--	1	BIOPCM M27 WALLS COST ESTIMATE	244.63	m2	*73.92	18082.98
--	2	BIOPCM M27 ROOF COST ESTIMATE	126.72	m2	*73.92	9367.30
Line Item SubTotal	--	--	--	--	--	27459.28

*- Study villa special cost/m²

Appendix D. Energy Plus NoPCM Lifecycle report

Report: **Life-Cycle Cost Report**

For: **Entire Facility**

Report: **Life-Cycle Cost Report**

For: **Entire Facility**

Timestamp: **2013-10-28 20:08:19**

Life-Cycle Cost Parameters

	Value
Name	BELGIUM RESIDENTIAL HVAC LIFE-CYCLE COST ANALYSIS
Discounting Convention	EndOfYear
Inflation Approach	CurrentDollar
Real Discount Rate	-- N/A --
Nominal Discount Rate	0.0150
Inflation	0.0240
Base Date	January 2014
Service Date	January 2014
Length of Study Period in Years	40
Tax rate	0.0000

Depreciation Method	StraightLine-40year

Use Price Escalation

	ELECTRICTY
Resource	Electricity
Start Date	January 2013
1	1.009600
2	1.009600
3	1.012700
4	1.009600
5	1.017700
6	1.027900
7	1.034400
8	1.032700
9	1.038200
10	1.045400
11	1.049400
12	1.056400
13	1.058700
14	1.054900
15	1.056600
16	1.063000
17	1.070700
18	1.085700
19	1.095300
20	1.106300
21	1.116500
22	1.122700
23	1.129200
24	1.134900
25	1.141400
26	1.148000
27	1.155000

28	1.161700
29	1.168600
30	1.000000
31	1.000000
32	1.000000
33	1.000000
34	1.000000
35	1.000000
36	1.000000
37	1.000000
38	1.000000
39	1.000000
40	1.000000

Cash Flow for Recurring and Nonrecurring Costs (Without Escalation)

	ANNUALMAINT	HVAC REPLACEMENT YEAR 13	HVAC FIRST COST
	Recurring	Recurring	Nonrecurring
January 2014	0.00	0.00	15000.00
January 2015	204.80	0.00	0.00
January 2016	209.72	0.00	0.00
January 2017	214.75	0.00	0.00
January 2018	219.90	0.00	0.00
January 2019	225.18	0.00	0.00
January 2020	230.58	0.00	0.00
January 2021	236.12	0.00	0.00
January 2022	241.79	0.00	0.00
January 2023	247.59	0.00	0.00
January 2024	253.53	0.00	0.00
January 2025	259.61	0.00	0.00
January 2026	265.85	0.00	0.00
January 2027	272.23	20416.94	0.00
January 2028	278.76	0.00	0.00
January 2029	285.45	0.00	0.00

January 2030	292.30	0.00	0.00
January 2031	299.32	0.00	0.00
January 2032	306.50	0.00	0.00
January 2033	313.86	0.00	0.00
January 2034	321.39	0.00	0.00
January 2035	329.10	0.00	0.00
January 2036	337.00	0.00	0.00
January 2037	345.09	0.00	0.00
January 2038	353.37	0.00	0.00
January 2039	361.85	0.00	0.00
January 2040	370.53	27790.10	0.00
January 2041	379.43	0.00	0.00
January 2042	388.53	0.00	0.00
January 2043	397.86	0.00	0.00
January 2044	407.41	0.00	0.00
January 2045	417.18	0.00	0.00
January 2046	427.20	0.00	0.00
January 2047	437.45	0.00	0.00
January 2048	447.95	0.00	0.00
January 2049	458.70	0.00	0.00
January 2050	469.71	0.00	0.00
January 2051	480.98	0.00	0.00
January 2052	492.53	0.00	0.00
January 2053	504.35	37825.93	0.00

Energy Cost Cash Flows (Without Escalation)

	Cooling	Heating
January 2014	1883.76	1549.57
January 2015	1928.97	1586.76
January 2016	1975.27	1624.84
January 2017	2022.67	1663.84
January 2018	2071.22	1703.77
January 2019	2120.93	1744.66

January 2020	2171.83	1786.54
January 2021	2223.95	1829.41
January 2022	2277.33	1873.32
January 2023	2331.99	1918.28
January 2024	2387.95	1964.32
January 2025	2445.26	2011.46
January 2026	2503.95	2059.74
January 2027	2564.05	2109.17
January 2028	2625.58	2159.79
January 2029	2688.60	2211.62
January 2030	2753.12	2264.70
January 2031	2819.20	2319.06
January 2032	2886.86	2374.71
January 2033	2956.14	2431.71
January 2034	3027.09	2490.07
January 2035	3099.74	2549.83
January 2036	3174.13	2611.02
January 2037	3250.31	2673.69
January 2038	3328.32	2737.86
January 2039	3408.20	2803.57
January 2040	3490.00	2870.85
January 2041	3573.76	2939.75
January 2042	3659.53	3010.31
January 2043	3747.36	3082.55
January 2044	3837.29	3156.54
January 2045	3929.39	3232.29
January 2046	4023.69	3309.87
January 2047	4120.26	3389.30
January 2048	4219.15	3470.65
January 2049	4320.41	3553.94
January 2050	4424.10	3639.24
January 2051	4530.28	3726.58
January 2052	4639.00	3816.02

January 2053	4750.34	3907.60

Operating Cash Flow by Category (Without Escalation)

	Energy	Water	Maintenance	Repair	Operation	Replacement	MinorOverhaul	MajorOverhaul	OtherOperational	Total
January 2014	3433.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3433.34
January 2015	3515.74	0.00	204.80	0.00	0.00	0.00	0.00	0.00	0.00	3720.54
January 2016	3600.11	0.00	209.72	0.00	0.00	0.00	0.00	0.00	0.00	3809.83
January 2017	3686.52	0.00	214.75	0.00	0.00	0.00	0.00	0.00	0.00	3901.26
January 2018	3774.99	0.00	219.90	0.00	0.00	0.00	0.00	0.00	0.00	3994.89
January 2019	3865.59	0.00	225.18	0.00	0.00	0.00	0.00	0.00	0.00	4090.77
January 2020	3958.37	0.00	230.58	0.00	0.00	0.00	0.00	0.00	0.00	4188.95
January 2021	4053.37	0.00	236.12	0.00	0.00	0.00	0.00	0.00	0.00	4289.49
January 2022	4150.65	0.00	241.79	0.00	0.00	0.00	0.00	0.00	0.00	4392.43
January 2023	4250.26	0.00	247.59	0.00	0.00	0.00	0.00	0.00	0.00	4497.85
January 2024	4352.27	0.00	253.53	0.00	0.00	0.00	0.00	0.00	0.00	4605.80
January 2025	4456.72	0.00	259.61	0.00	0.00	0.00	0.00	0.00	0.00	4716.34
January 2026	4563.69	0.00	265.85	0.00	0.00	0.00	0.00	0.00	0.00	4829.53
January 2027	4673.21	0.00	272.23	0.00	0.00	20416.94	0.00	0.00	0.00	25362.38
January 2028	4785.37	0.00	278.76	0.00	0.00	0.00	0.00	0.00	0.00	5064.13
January 2029	4900.22	0.00	285.45	0.00	0.00	0.00	0.00	0.00	0.00	5185.67
January 2030	5017.83	0.00	292.30	0.00	0.00	0.00	0.00	0.00	0.00	5310.13
January 2031	5138.25	0.00	299.32	0.00	0.00	0.00	0.00	0.00	0.00	5437.57

January 2032	5261.57	0.00	306.50	0.00	0.00	0.00	0.00	0.00	0.00	5568.07
January 2033	5387.85	0.00	313.86	0.00	0.00	0.00	0.00	0.00	0.00	5701.70
January 2034	5517.16	0.00	321.39	0.00	0.00	0.00	0.00	0.00	0.00	5838.54
January 2035	5649.57	0.00	329.10	0.00	0.00	0.00	0.00	0.00	0.00	5978.67
January 2036	5785.16	0.00	337.00	0.00	0.00	0.00	0.00	0.00	0.00	6122.16
January 2037	5924.00	0.00	345.09	0.00	0.00	0.00	0.00	0.00	0.00	6269.09
January 2038	6066.18	0.00	353.37	0.00	0.00	0.00	0.00	0.00	0.00	6419.55
January 2039	6211.77	0.00	361.85	0.00	0.00	0.00	0.00	0.00	0.00	6573.62
January 2040	6360.85	0.00	370.53	0.00	0.00	27790.10	0.00	0.00	0.00	34521.49
January 2041	6513.51	0.00	379.43	0.00	0.00	0.00	0.00	0.00	0.00	6892.94
January 2042	6669.83	0.00	388.53	0.00	0.00	0.00	0.00	0.00	0.00	7058.37
January 2043	6829.91	0.00	397.86	0.00	0.00	0.00	0.00	0.00	0.00	7227.77
January 2044	6993.83	0.00	407.41	0.00	0.00	0.00	0.00	0.00	0.00	7401.24
January 2045	7161.68	0.00	417.18	0.00	0.00	0.00	0.00	0.00	0.00	7578.86
January 2046	7333.56	0.00	427.20	0.00	0.00	0.00	0.00	0.00	0.00	7760.76
January 2047	7509.57	0.00	437.45	0.00	0.00	0.00	0.00	0.00	0.00	7947.02
January 2048	7689.80	0.00	447.95	0.00	0.00	0.00	0.00	0.00	0.00	8137.74
January 2049	7874.35	0.00	458.70	0.00	0.00	0.00	0.00	0.00	0.00	8333.05
January 2050	8063.33	0.00	469.71	0.00	0.00	0.00	0.00	0.00	0.00	8533.04
January 2051	8256.85	0.00	480.98	0.00	0.00	0.00	0.00	0.00	0.00	8737.84
January 2052	8455.02	0.00	492.53	0.00	0.00	0.00	0.00	0.00	0.00	8947.54
January	8657.94	0.00	504.35	0.00	0.00	37825.93	0.00	0.00	0.00	46988.21

2053										

Monthly Total Cash Flow (Without Escalation)

	January	February	March	April	May	June	July	August	September	October	November	December
2014	15359.57	287.65	216.98	198.86	281.98	293.86	478.52	387.78	193.27	161.51	244.34	329.02
2015	573.00	294.55	222.19	203.63	288.75	300.91	490.00	397.09	197.91	165.39	250.20	336.92
2016	586.75	301.62	227.52	208.52	295.68	308.13	501.76	406.62	202.66	169.36	256.21	345.00
2017	600.83	308.86	232.98	213.52	302.77	315.53	513.80	416.38	207.53	173.42	262.35	353.28
2018	615.25	316.27	238.57	218.65	310.04	323.10	526.13	426.37	212.51	177.58	268.65	361.76
2019	630.02	323.86	244.30	223.89	317.48	330.86	538.76	436.60	217.61	181.84	275.10	370.44
2020	645.14	331.63	250.16	229.27	325.10	338.80	551.69	447.08	222.83	186.21	281.70	379.34
2021	660.62	339.59	256.17	234.77	332.90	346.93	564.93	457.81	228.18	190.68	288.46	388.44
2022	676.48	347.74	262.31	240.40	340.89	355.26	578.49	468.80	233.65	195.25	295.38	397.76
2023	692.71	356.09	268.61	246.17	349.08	363.78	592.37	480.05	239.26	199.94	302.47	407.31
2024	709.34	364.64	275.06	252.08	357.45	372.51	606.59	491.57	245.01	204.74	309.73	417.08
2025	726.36	373.39	281.66	258.13	366.03	381.45	621.15	503.37	250.89	209.65	317.17	427.09
2026	743.80	382.35	288.42	264.33	374.82	390.61	636.06	515.45	256.91	214.68	324.78	437.34
2027	21178.59	391.53	295.34	270.67	383.81	399.98	651.32	527.82	263.07	219.84	332.57	447.84
2028	779.93	400.92	302.43	277.17	393.02	409.58	666.95	540.49	269.39	225.11	340.56	458.59
2029	798.64	410.54	309.69	283.82	402.46	419.41	682.96	553.46	275.85	230.51	348.73	469.59
2030	817.81	420.40	317.12	290.63	412.12	429.48	699.35	566.74	282.47	236.05	357.10	480.86
2031	837.44	430.49	324.73	297.61	422.01	439.78	716.14	580.34	289.25	241.71	365.67	492.41
2032	857.54	440.82	332.52	304.75	432.13	450.34	733.32	594.27	296.19	247.51	374.44	504.22
2033	878.12	451.40	340.50	312.06	442.51	461.15	750.92	608.53	303.30	253.45	383.43	516.32
2034	899.19	462.23	348.68	319.55	453.13	472.22	768.95	623.14	310.58	259.54	392.63	528.72
2035	920.77	473.33	357.04	327.22	464.00	483.55	787.40	638.09	318.03	265.76	402.06	541.41
2036	942.87	484.69	365.61	335.07	475.14	495.15	806.30	653.41	325.67	272.14	411.71	554.40
2037	965.50	496.32	374.39	343.12	486.54	507.04	825.65	669.09	333.48	278.67	421.59	567.70
2038	988.67	508.23	383.37	351.35	498.22	519.21	845.46	685.15	341.49	285.36	431.71	581.33
2039	1012.40	520.43	392.57	359.78	510.17	531.67	865.76	701.59	349.68	292.21	442.07	595.28
2040	28826.80	532.92	402.00	368.42	522.42	544.43	886.53	718.43	358.08	299.22	452.68	609.57
2041	1061.58	545.71	411.64	377.26	534.96	557.49	907.81	735.67	366.67	306.41	463.54	624.20
2042	1087.06	558.80	421.52	386.31	547.80	570.87	929.60	753.33	375.47	313.76	474.67	639.18

2043	1113.15	572.22	431.64	395.59	560.94	584.57	951.91	771.41	384.48	321.29	486.06	654.52
2044	1139.86	585.95	442.00	405.08	574.41	598.60	974.75	789.92	393.71	329.00	497.72	670.23
2045	1167.22	600.01	452.61	414.80	588.19	612.97	998.15	808.88	403.16	336.90	509.67	686.31
2046	1195.23	614.41	463.47	424.76	602.31	627.68	1022.10	828.29	412.83	344.98	521.90	702.78
2047	1223.92	629.16	474.59	434.95	616.76	642.75	1046.63	848.17	422.74	353.26	534.43	719.65
2048	1253.29	644.26	485.98	445.39	631.57	658.17	1071.75	868.53	432.89	361.74	547.25	736.92
2049	1283.37	659.72	497.65	456.08	646.72	673.97	1097.48	889.37	443.28	370.42	560.39	754.61
2050	1314.17	675.55	509.59	467.02	662.24	690.14	1123.82	910.72	453.91	379.31	573.83	772.72
2051	1345.71	691.77	521.82	478.23	678.14	706.71	1150.79	932.58	464.81	388.42	587.61	791.27
2052	1378.01	708.37	534.34	489.71	694.41	723.67	1178.41	954.96	475.96	397.74	601.71	810.26
2053	39237.01	725.37	547.17	501.46	711.08	741.04	1206.69	977.88	487.39	407.28	616.15	829.70

Present Value for Recurring, Nonrecurring and Energy Costs (Before Tax)

	Category	Kind	Cost	Present Value	Present Value Factor
ANNUALMAINT	Maintenance	Recurring	200.00	9214.00	46.0700
HVAC REPLACEMENT YEAR 13	Replacement	Recurring	15000.00	56018.67	3.7346
HVAC FIRST COST	Other Capital	Nonrecurring	15000.00	14778.33	0.9852
Cooling	Energy	Energy Cost	1862.13	88640.89	47.6019
Heating	Energy	Energy Cost	1534.79	72915.50	47.5084
TOTAL				241567.38	

Present Value by Category

	Present Value
Construction	0.00
Salvage	0.00
Other Capital	14778.33
Energy	161556.39
Water	0.00
Maintenance	9214.00
Repair	0.00
Operation	0.00
Replacement	56018.67
Minor Overhaul	0.00

Major Overhaul	0.00
Other Operational	0.00
Total Energy	161556.39
Total Operation	226789.06
Total Capital	14778.33
Grand Total	241567.38

Present Value by Year

	Total Cost	Present Value of Costs
January 2014	18433.34	18160.92
January 2015	3720.54	3611.38
January 2016	3809.83	3643.40
January 2017	3901.26	3675.71
January 2018	3994.89	3708.30
January 2019	4090.77	3741.18
January 2020	4188.95	3774.36
January 2021	4289.49	3807.82
January 2022	4392.43	3841.59
January 2023	4497.85	3875.65
January 2024	4605.80	3910.02
January 2025	4716.34	3944.69
January 2026	4829.53	3979.66
January 2027	25362.38	20590.43
January 2028	5064.13	4050.55
January 2029	5185.67	4086.47
January 2030	5310.13	4122.70
January 2031	5437.57	4159.26
January 2032	5568.07	4196.14
January 2033	5701.70	4233.35
January 2034	5838.54	4270.88
January 2035	5978.67	4308.75
January 2036	6122.16	4346.96
January 2037	6269.09	4385.50

January 2038	6419.55	4424.39
January 2039	6573.62	4463.62
January 2040	34521.49	23094.38
January 2041	6892.94	4543.13
January 2042	7058.37	4583.41
January 2043	7227.77	4624.05
January 2044	7401.24	4665.06
January 2045	7578.86	4706.42
January 2046	7760.76	4748.15
January 2047	7947.02	4790.25
January 2048	8137.74	4832.73
January 2049	8333.05	4875.58
January 2050	8533.04	4918.81
January 2051	8737.84	4962.43
January 2052	8947.54	5006.43
January 2053	46988.21	25902.83
TOTAL		241567.38