PAE

Beyond Zero Net Energy Buildings Case Studies

SF Symposium on ZNE Buildings and Beyond: Balancing Building and Grid Objectives

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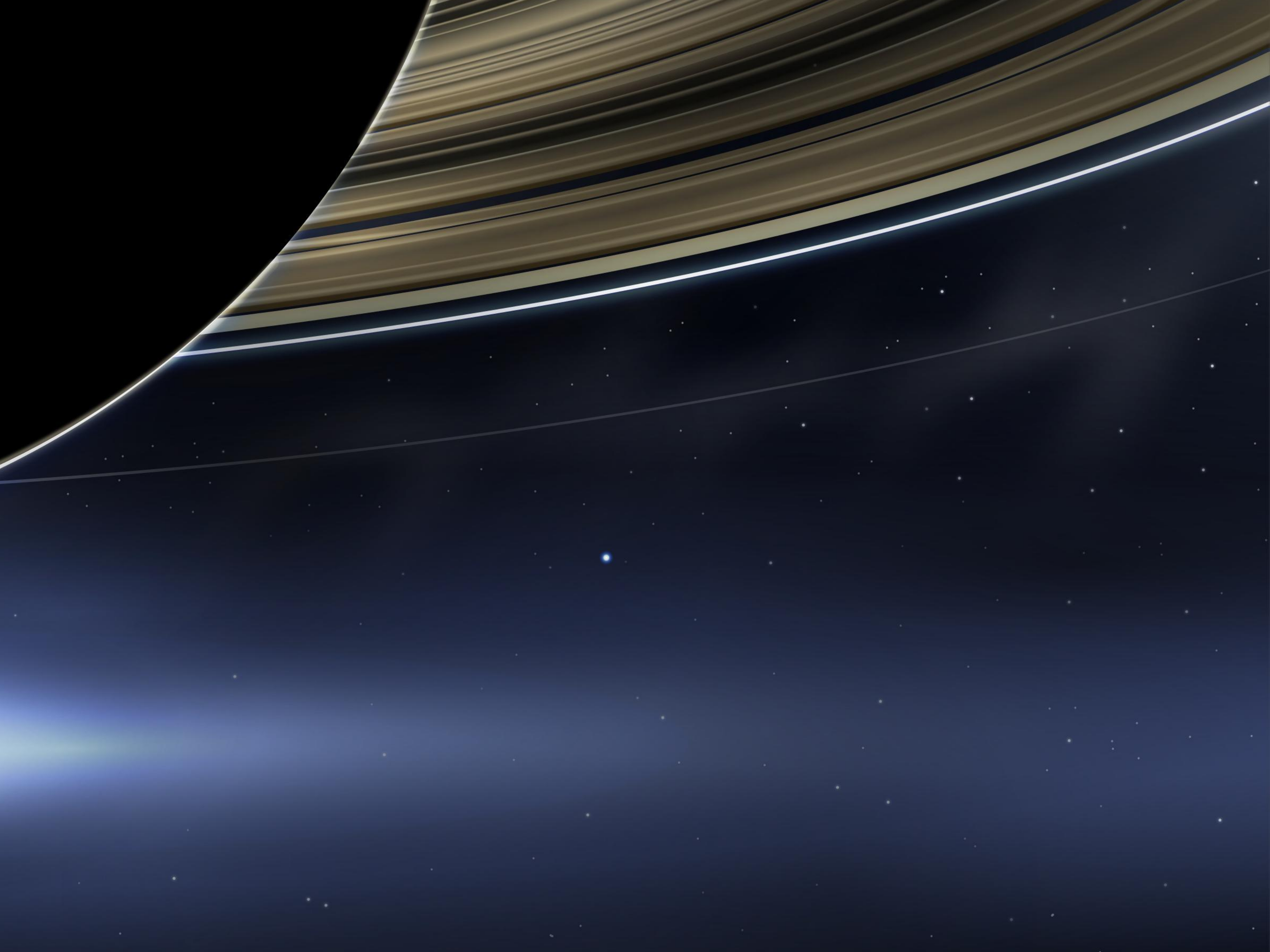
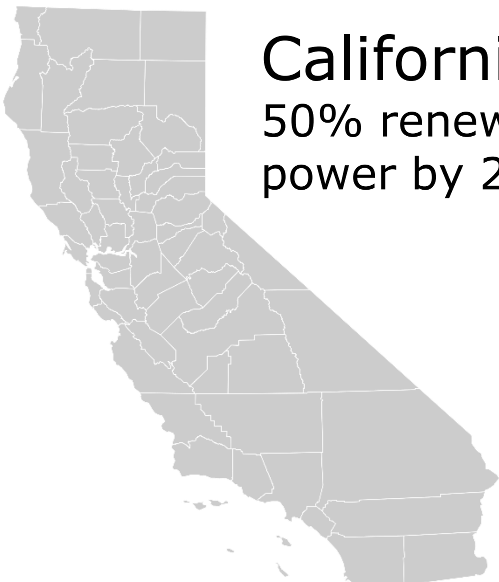
October 25, 2017
Paul Schwer, PE
President

Learning Objectives

1. Beyond Zero Net Energy Case Studies
2. MEETS - Metered Energy Efficiency Transaction Structure
3. Thermal Comfort path to Zero Net Energy
4. The path to a DC powered building

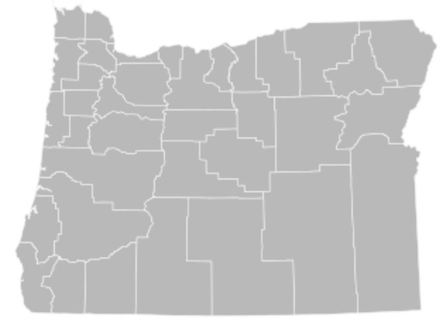


Rise of Renewables - States



California

50% renewable
power by 2030



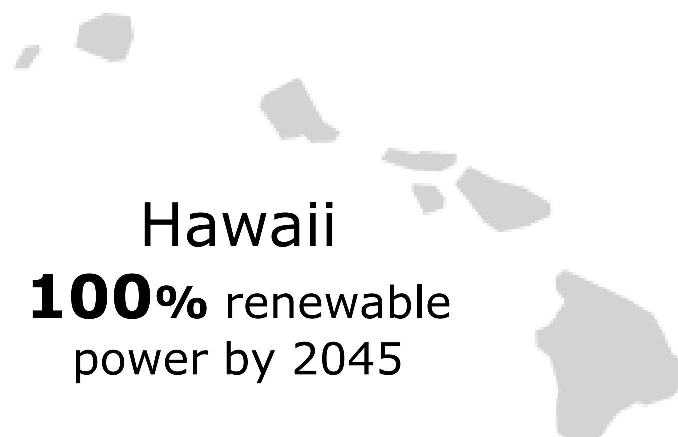
Oregon

50% new renewables by 2040

80% total renewables by 2040

New York

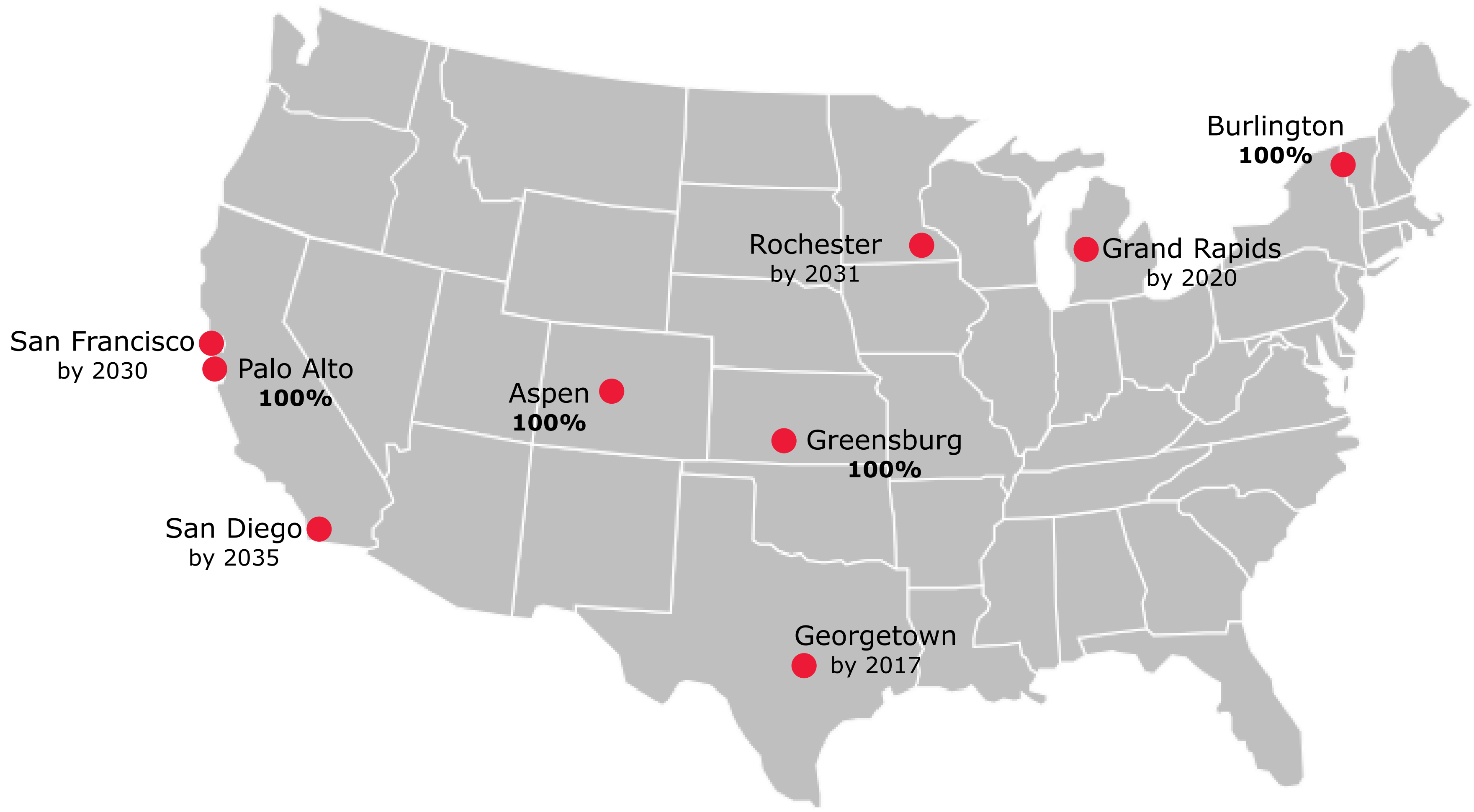
50% renewable
power by 2030



Hawaii

100% renewable
power by 2045

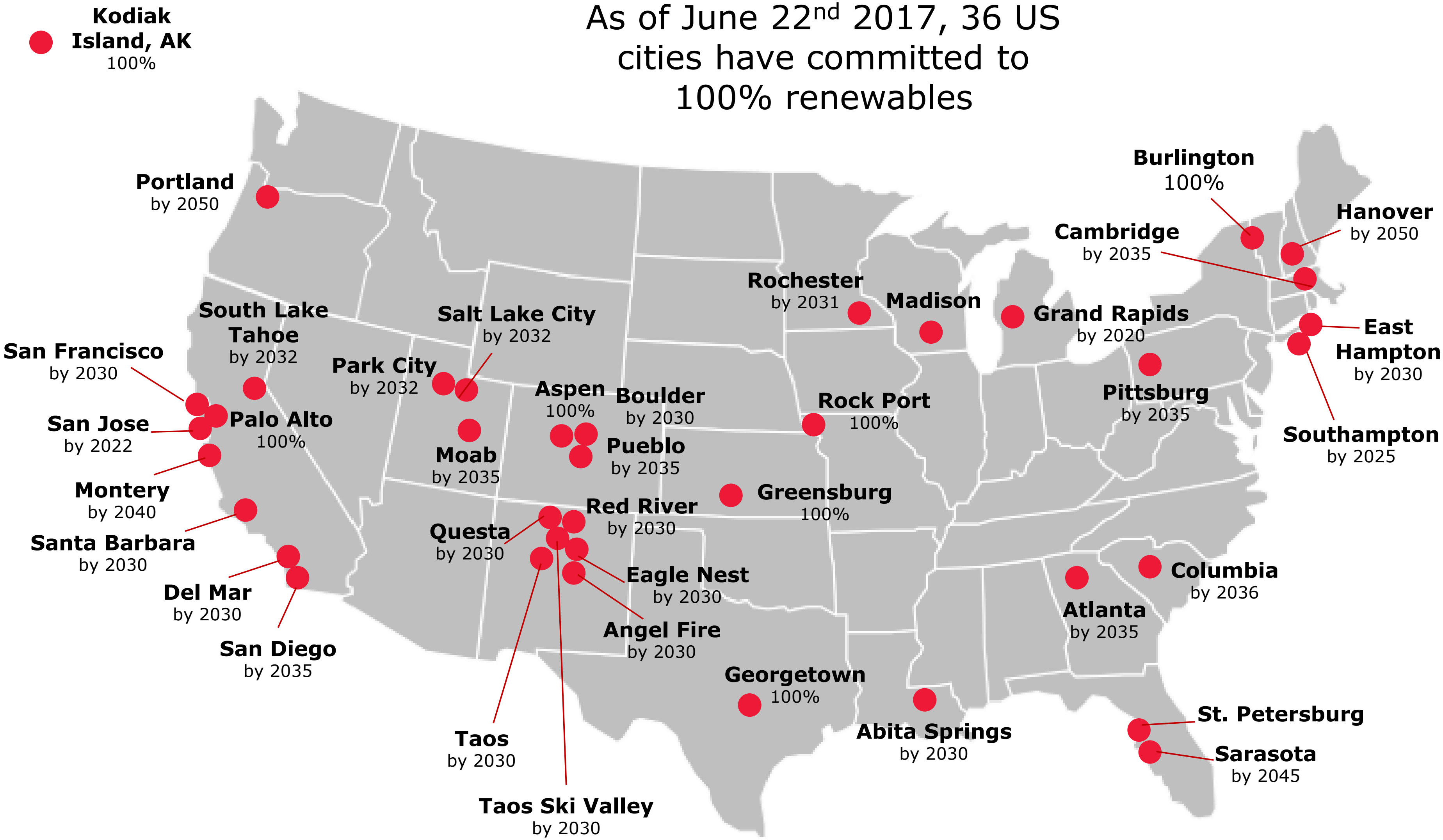
Cities with Renewable Pledges in 2016



Source: Business Insider

Cities with Renewable Pledges in 2017

As of June 22nd 2017, 36 US cities have committed to 100% renewables



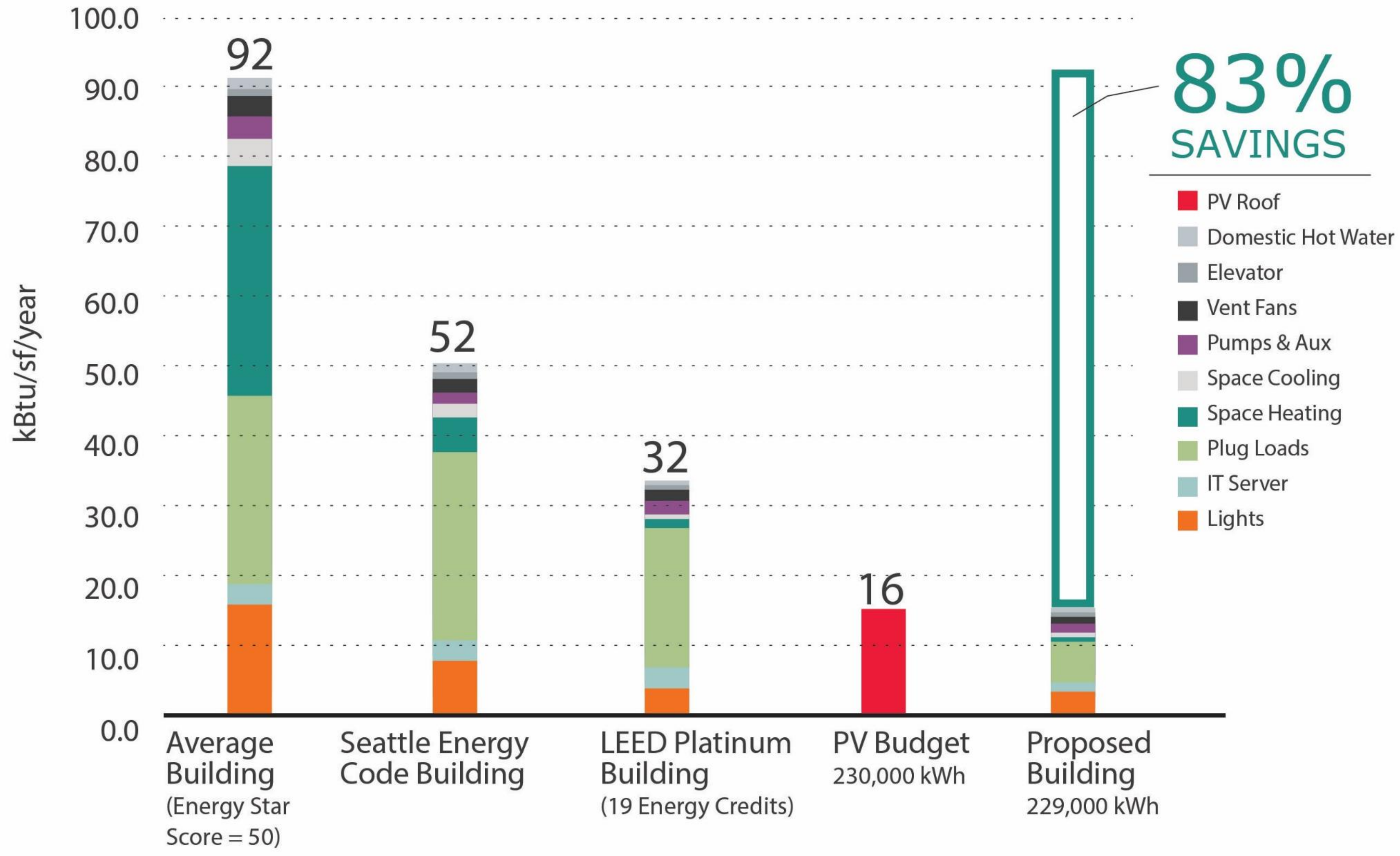
Source: Business Insider

Net Zero Energy: PAE Projects


The Bullitt Center
Seattle, WA
Architect: The Miller Hull Partnership

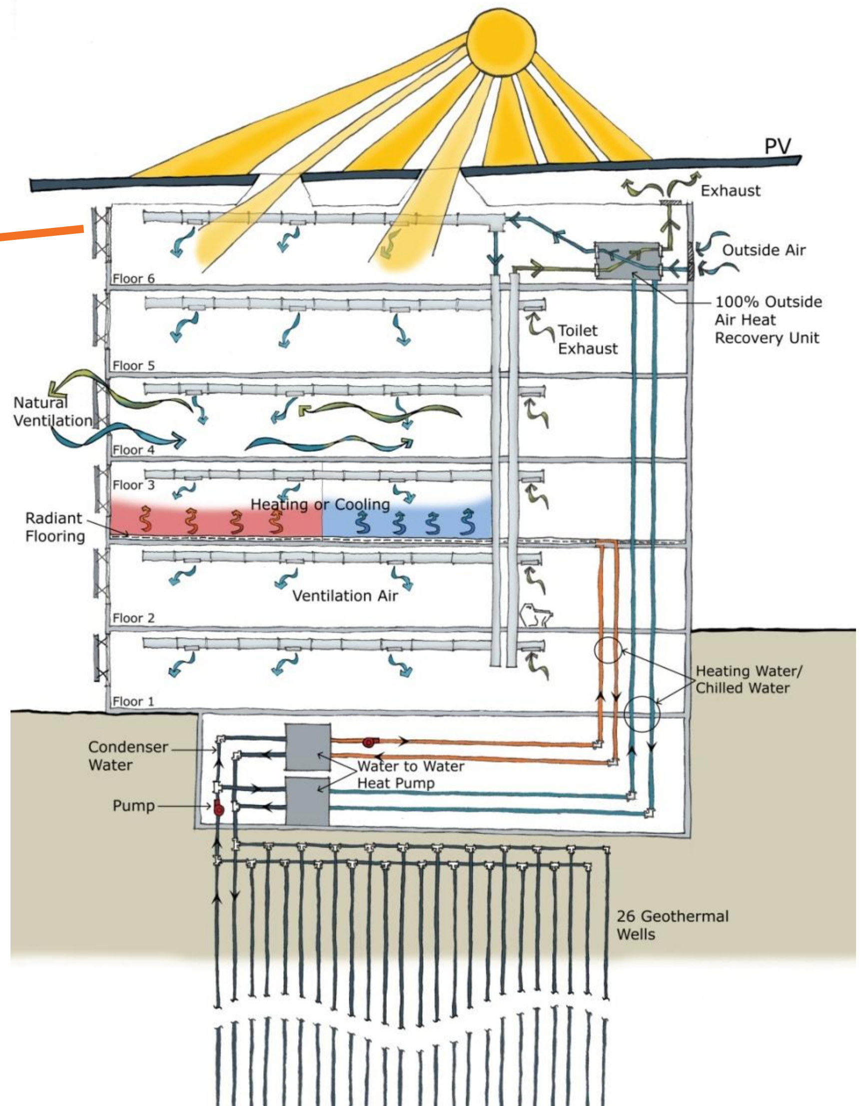

DELL
DELL
Daniel Link

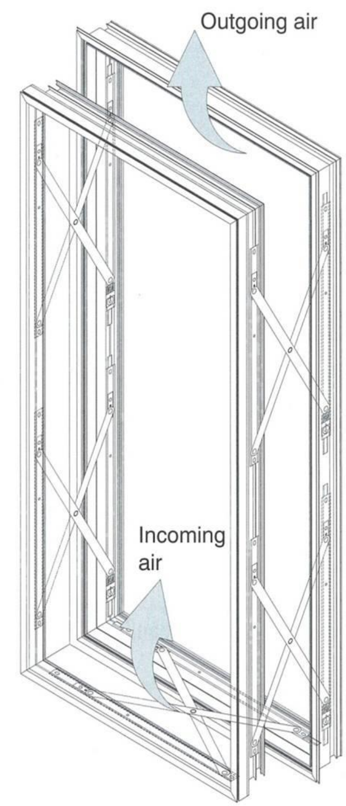
Net Zero Energy in Seattle



Bullitt Center

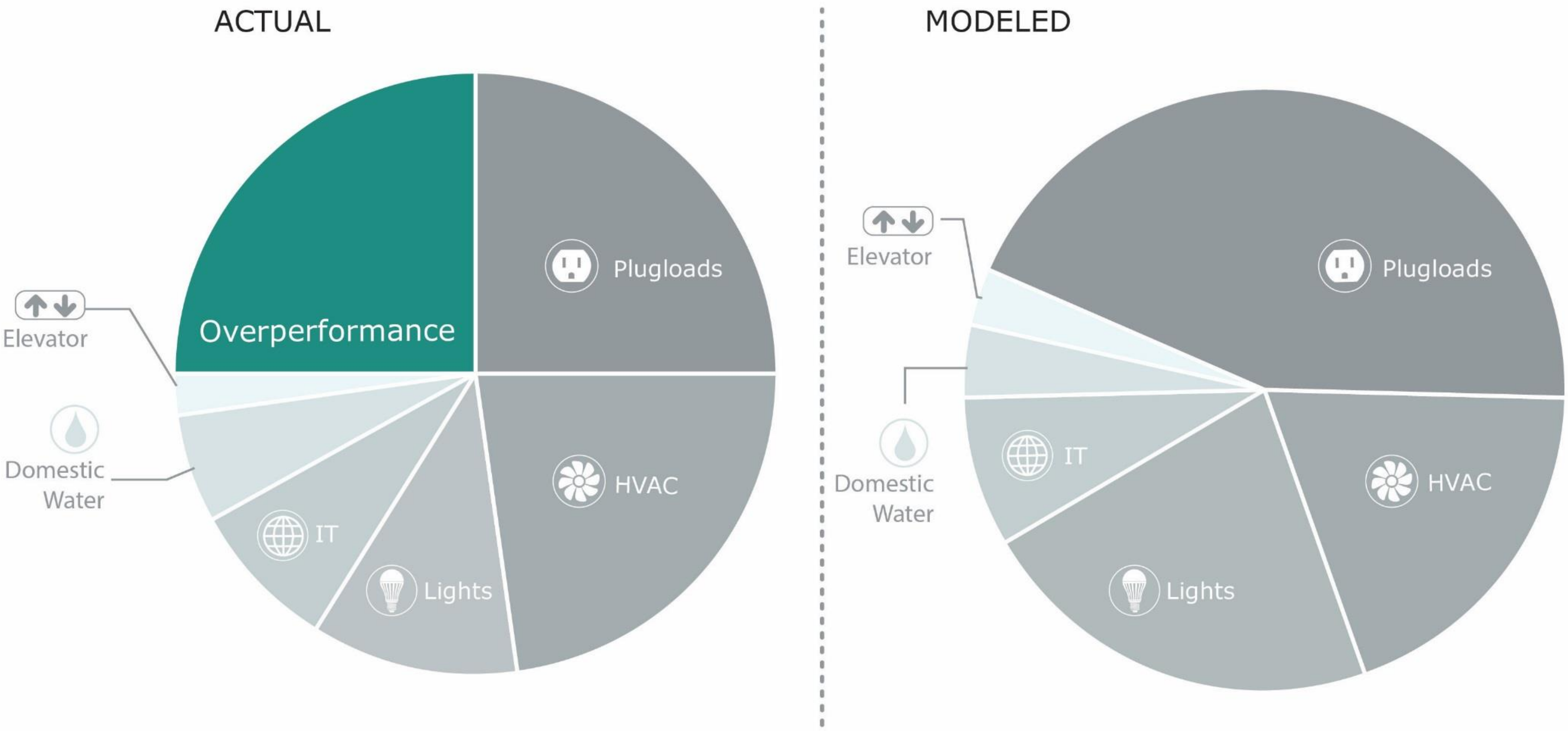
HVAC System Overview





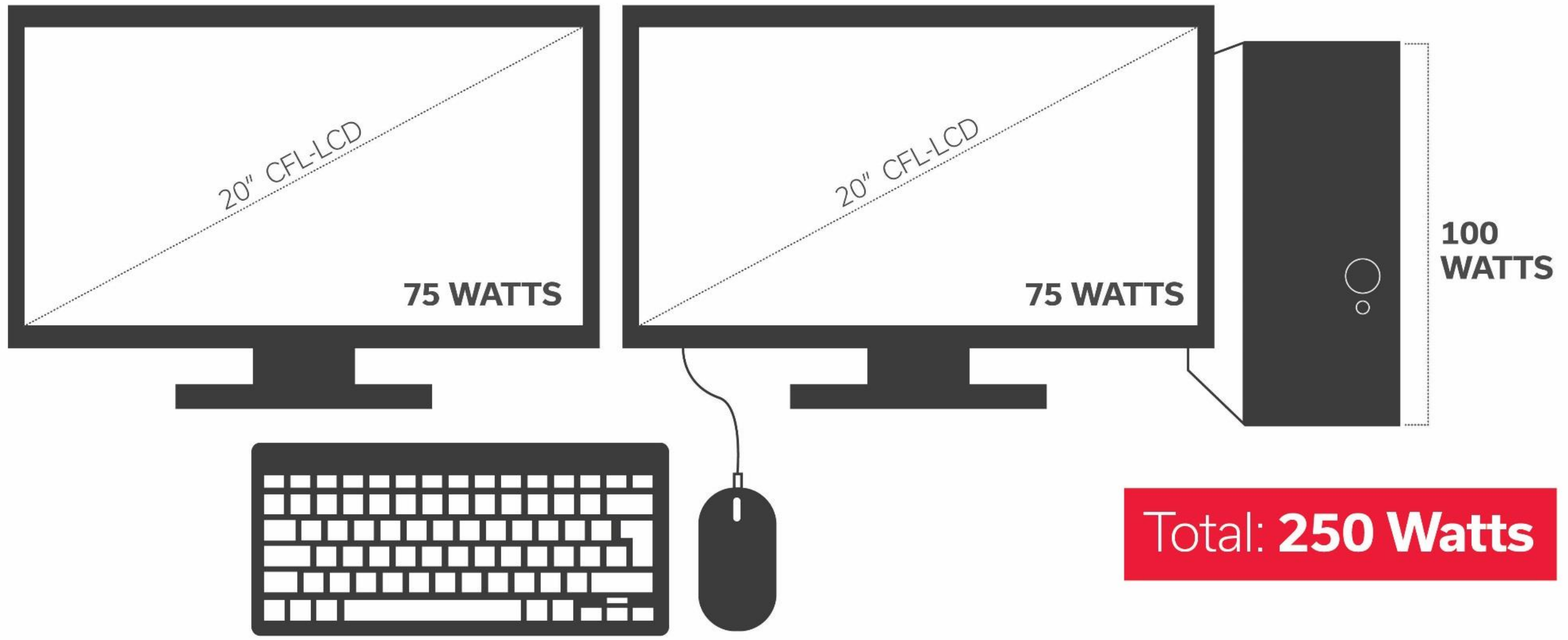
Bullitt Center Performance

Actual EUI ~ 12 kBTU/SF/yr, lower than Modeled EUI of ~ 16



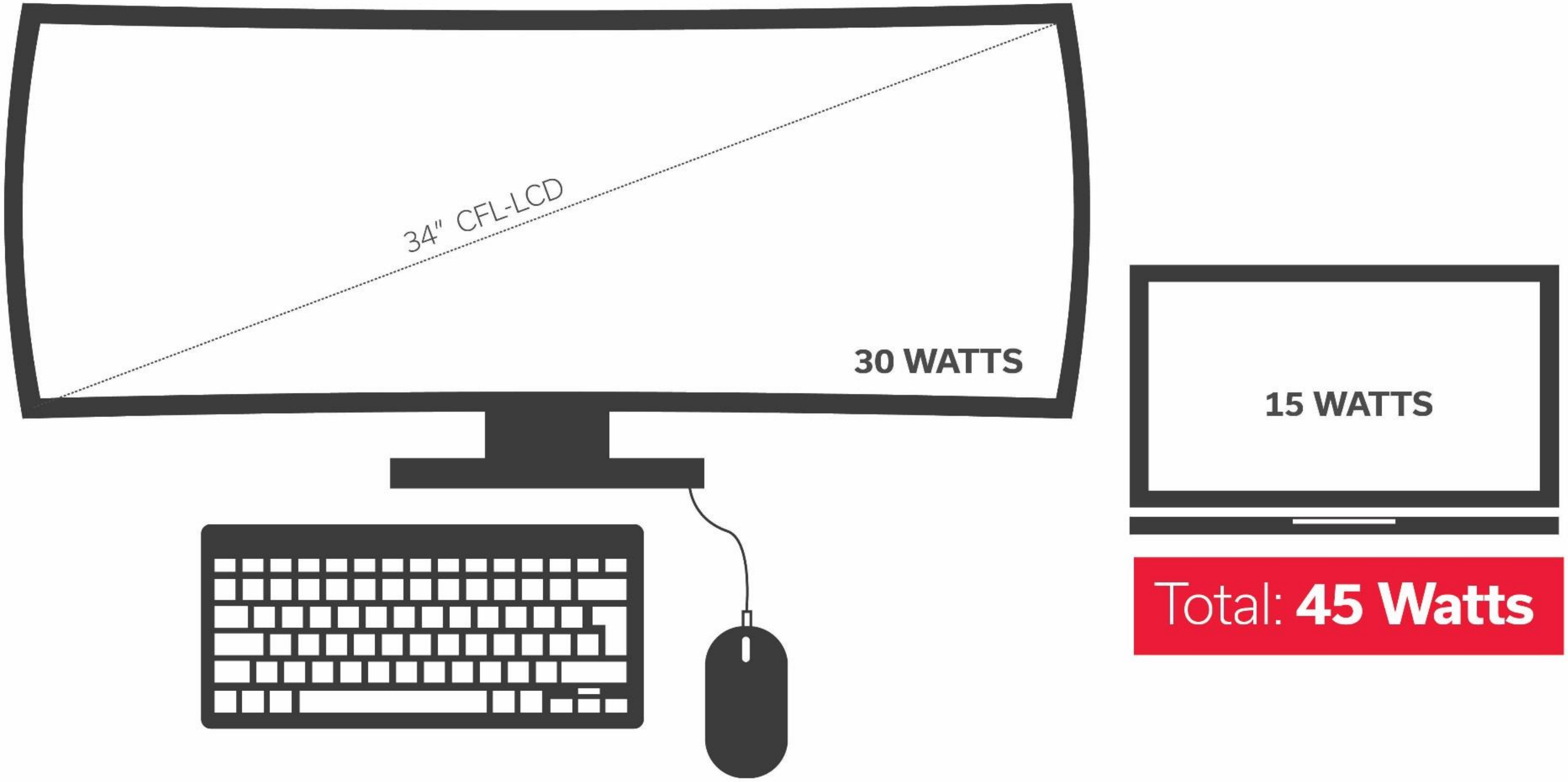
Reduction Plug Loads

2007



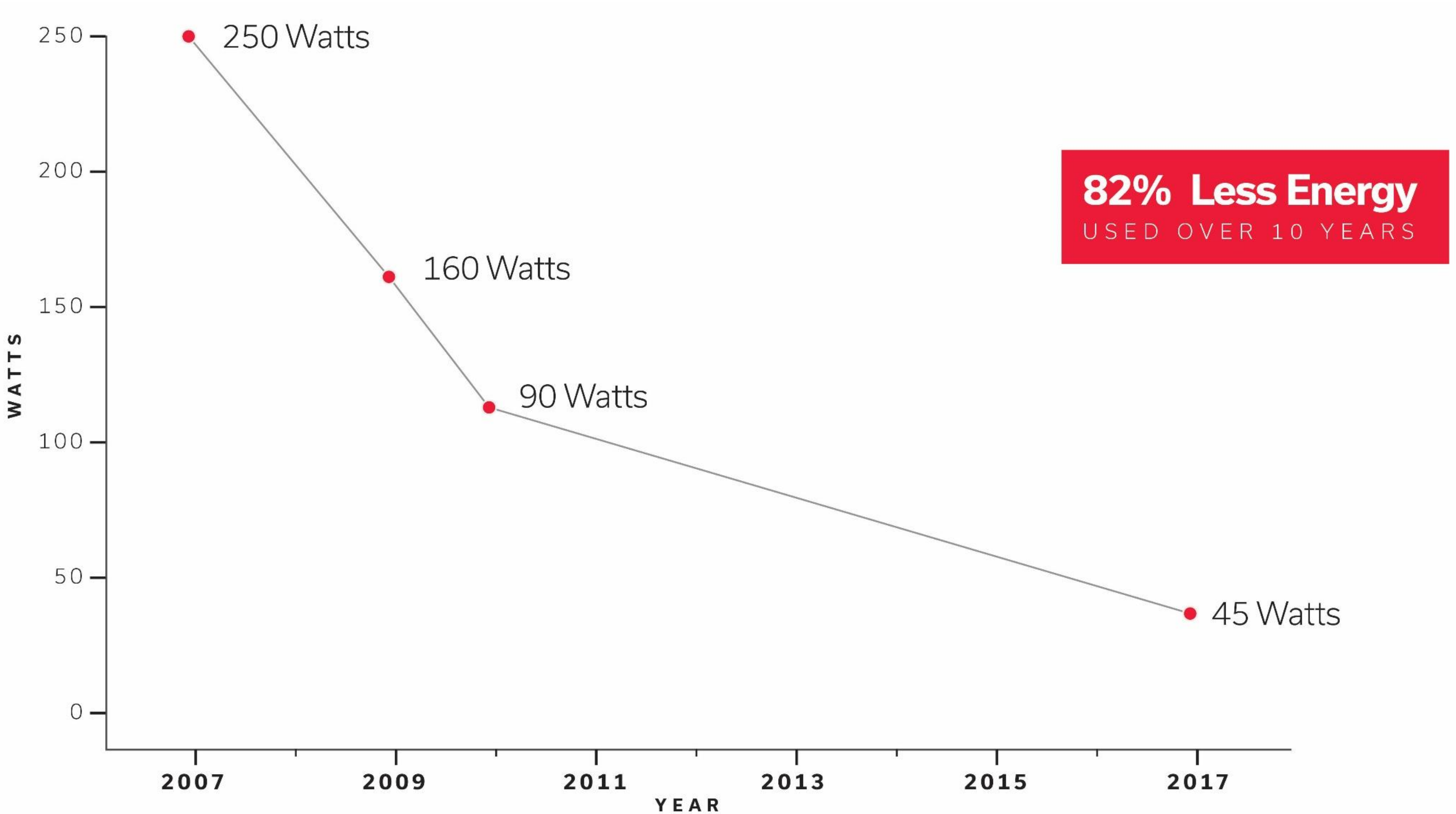
Reduction Plug Loads

2017



Plug Loads

Progression of PAE Computer Energy use

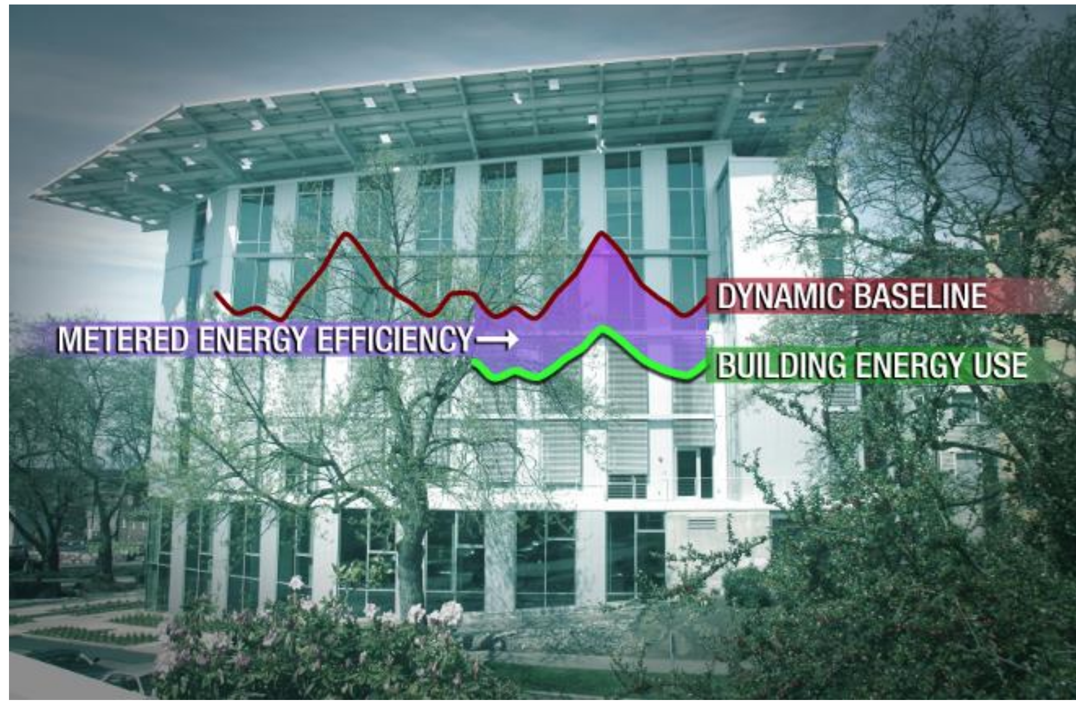


“Negawatts”

MEETS Concept

Metered Energy Efficiency Transaction Structure

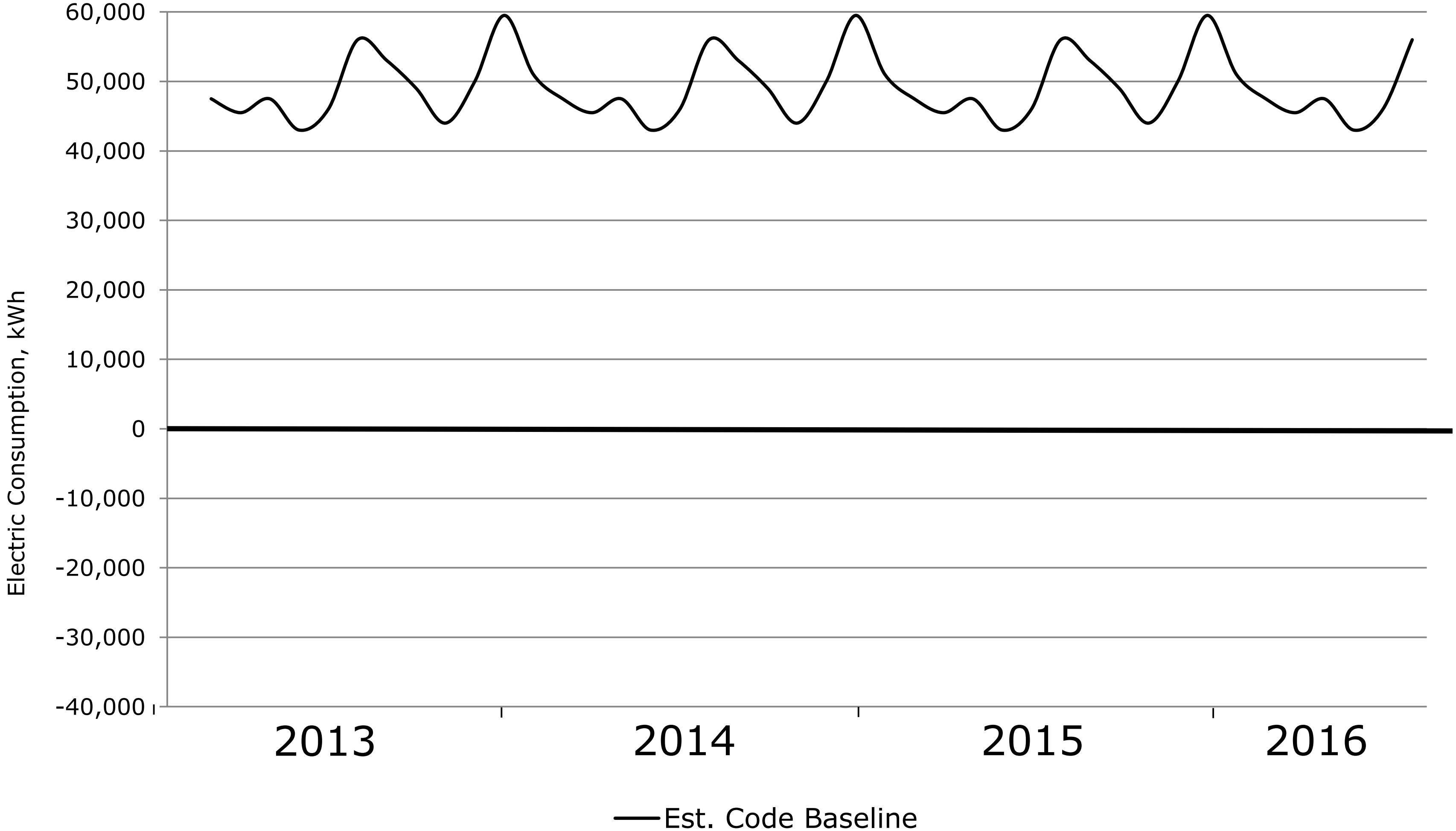
1. Tenants pay for Baseline
2. Measure the saved energy with a meter
3. Buy and sell it through PPA *just like generation*



DeltaMeter®

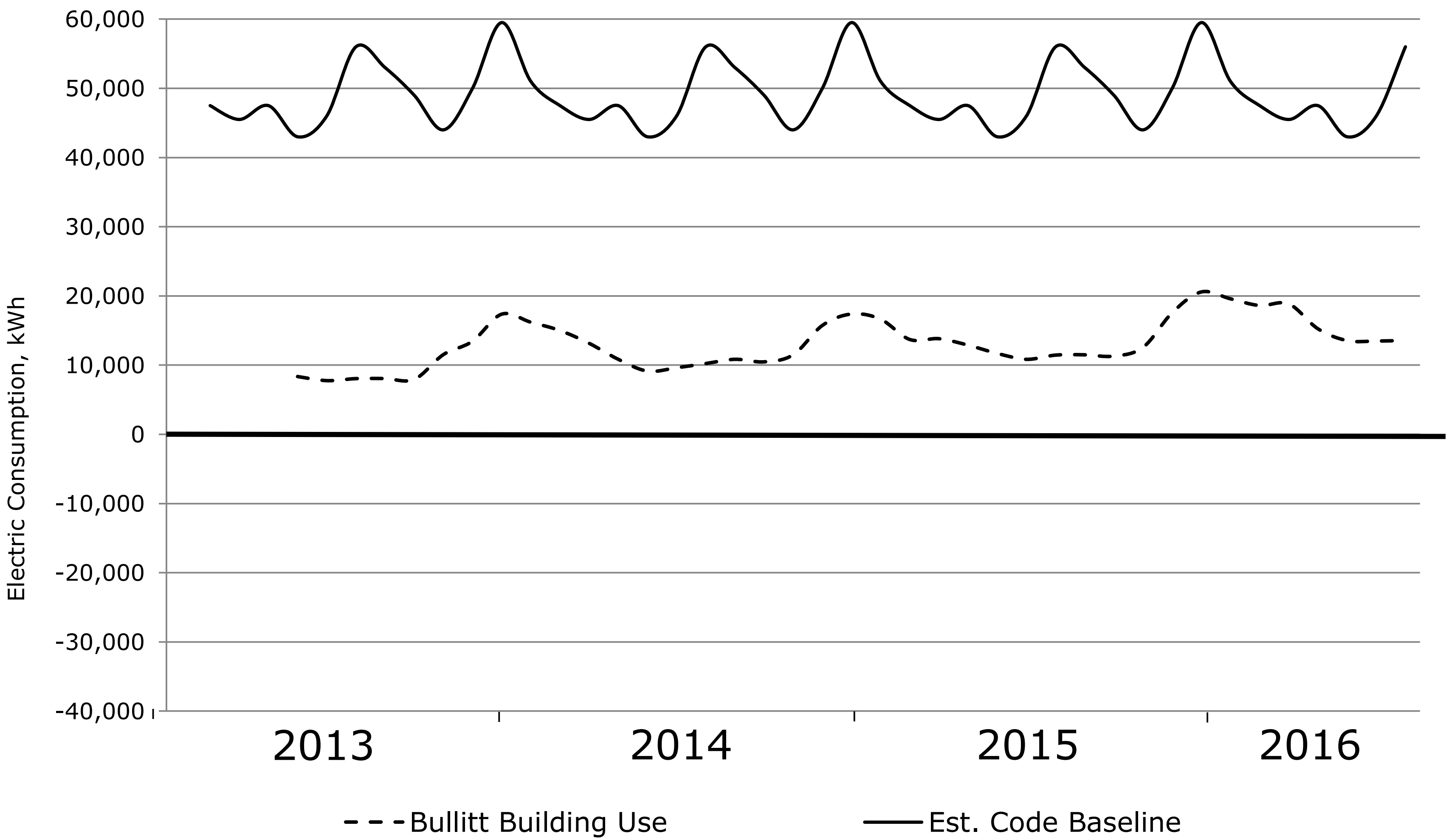
Predicted vs. Actual

Bullitt Center Performance



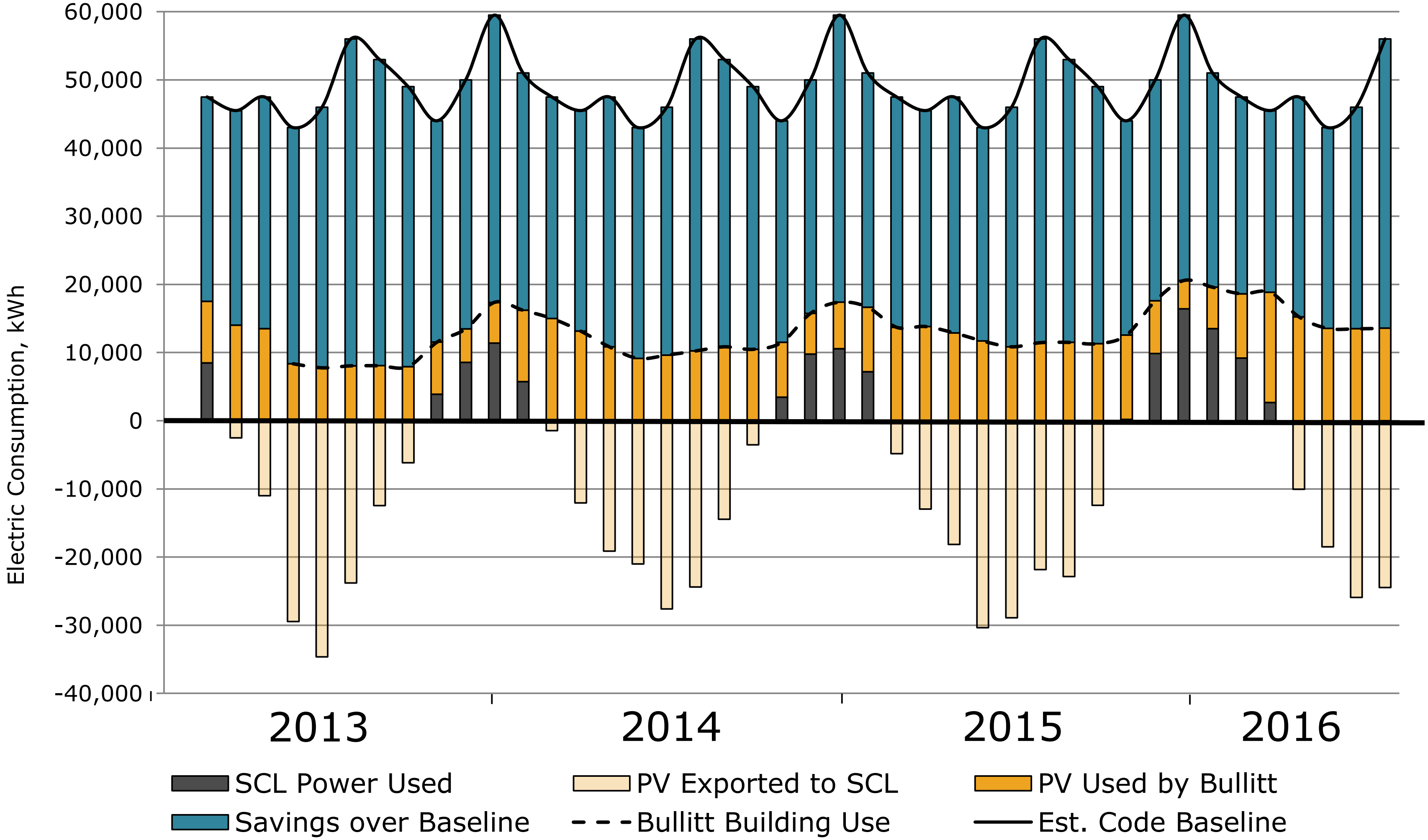
Predicted vs. Actual

Bullitt Center Performance

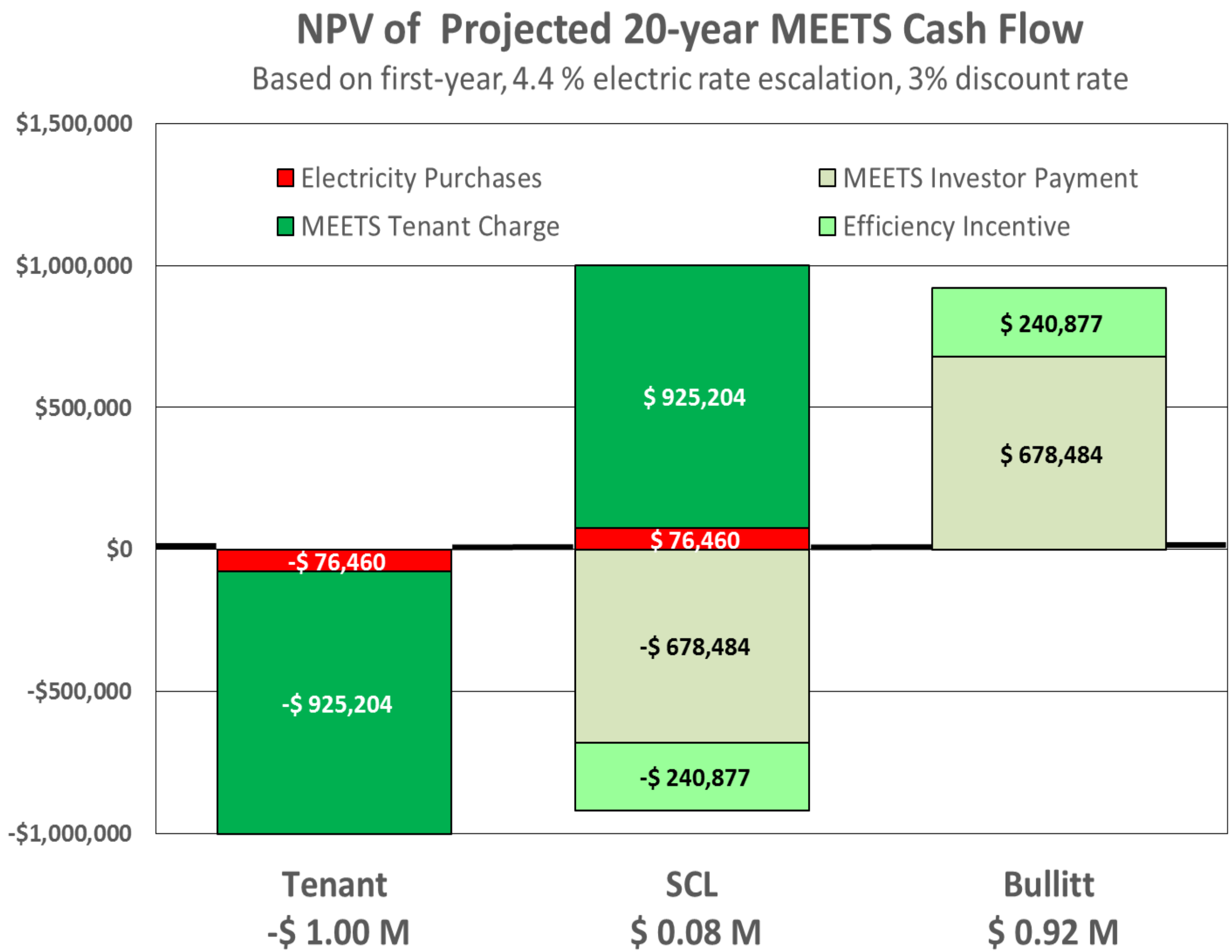


Predicted vs. Actual

Bullitt Center Performance



Results


NPV of Projected 20-year MEETS Cash Flow
Based on first-year, 4.4 % electric rate escalation, 3% discount rate
$1,500,000
$1,000,000
$500,000
$0
-$500,000
-$1,000,000
Electricity Purchases
MEETS Tenant Charge
MEETS Investor Payment
Efficiency Incentive
-$ 76,460
-$ 925,204
$ 925,204
$ 76,460
-$ 678,484
-$ 240,877
$ 240,877
$ 678,484
Tenant
-$ 1.00 M
SCL
$ 0.08 M
Bullitt
$ 0.92 M

MEETS Benefits

Owner

New $ flow

Receive ECM savings

Tenants pay normal rates

Investor

~30 yr return

Increased $ for performance

Like a PPA

Utility

~30 yr fixed revenue

Helps meet regulatory requirements

Financial Considerations

Direct Construction Costs

$350 / SF

Includes City infrastructure improvements and costs associated with the PV array.

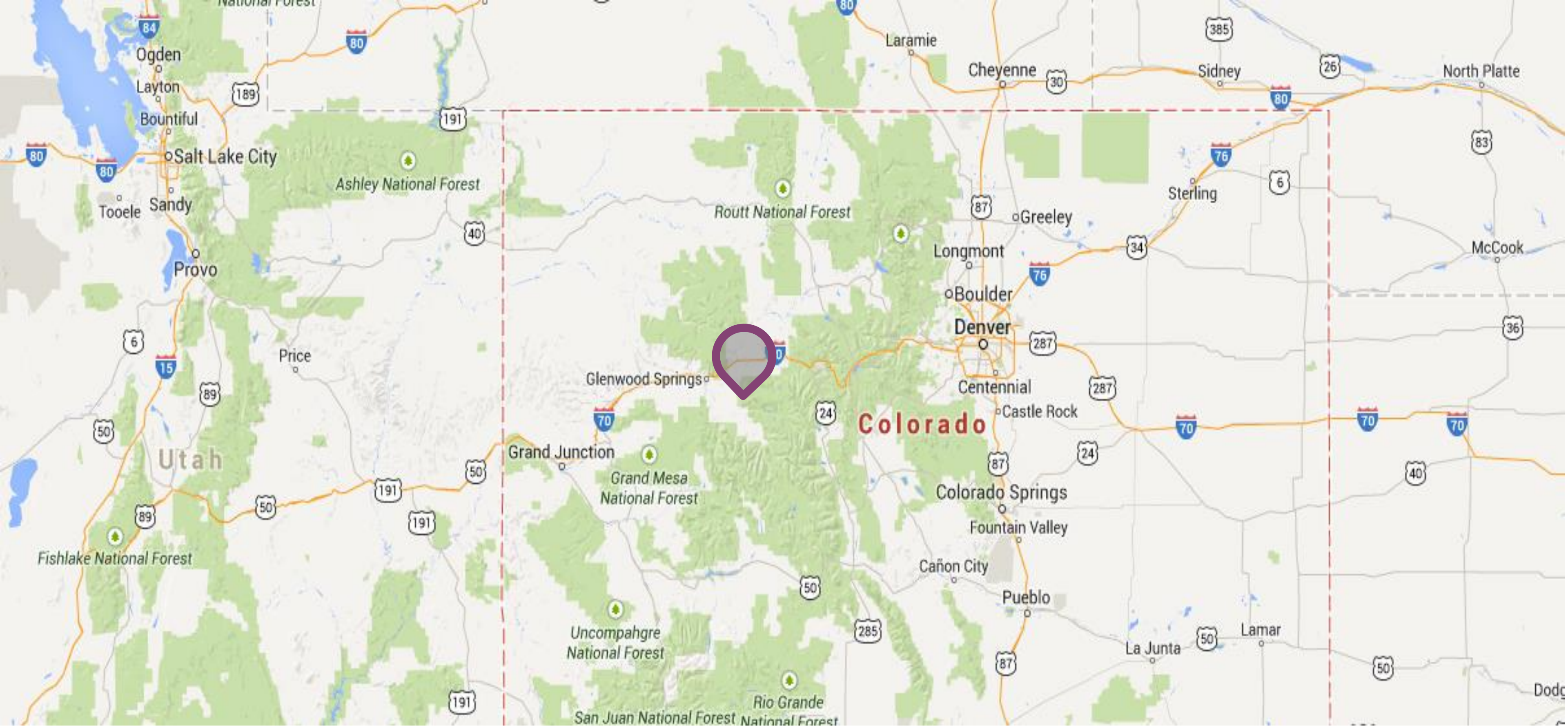
$265 / SF

Does not include PV, water system, or city infrastructure improvements.

RMI Vision

ROCKY MOUNTAIN INSTITUTE®

RMI's vision is a world thriving, verdant, and secure, for all, for ever.



Laramie
Cheyenne
Sidney
North Platte
Ogden
Layton
Bountiful
Salt Lake City
Ashley National Forest
Routt National Forest
Sterling
Greeley
Tooele
Sandy
Provo
Longmont
McCook
Boulder
Denver
Price
Glenwood Springs
Centennial
Castle Rock
Colorado
Grand Junction
Grand Mesa National Forest
Utah
Colorado Springs
Fountain Valley
Fishlake National Forest
Cañon City
Pueblo
Uncompahgre National Forest
Lamar
La Junta
Rio Grande National Forest
San Juan National Forest

Rocky Mountain Institute Innovation Center

Basalt, CO

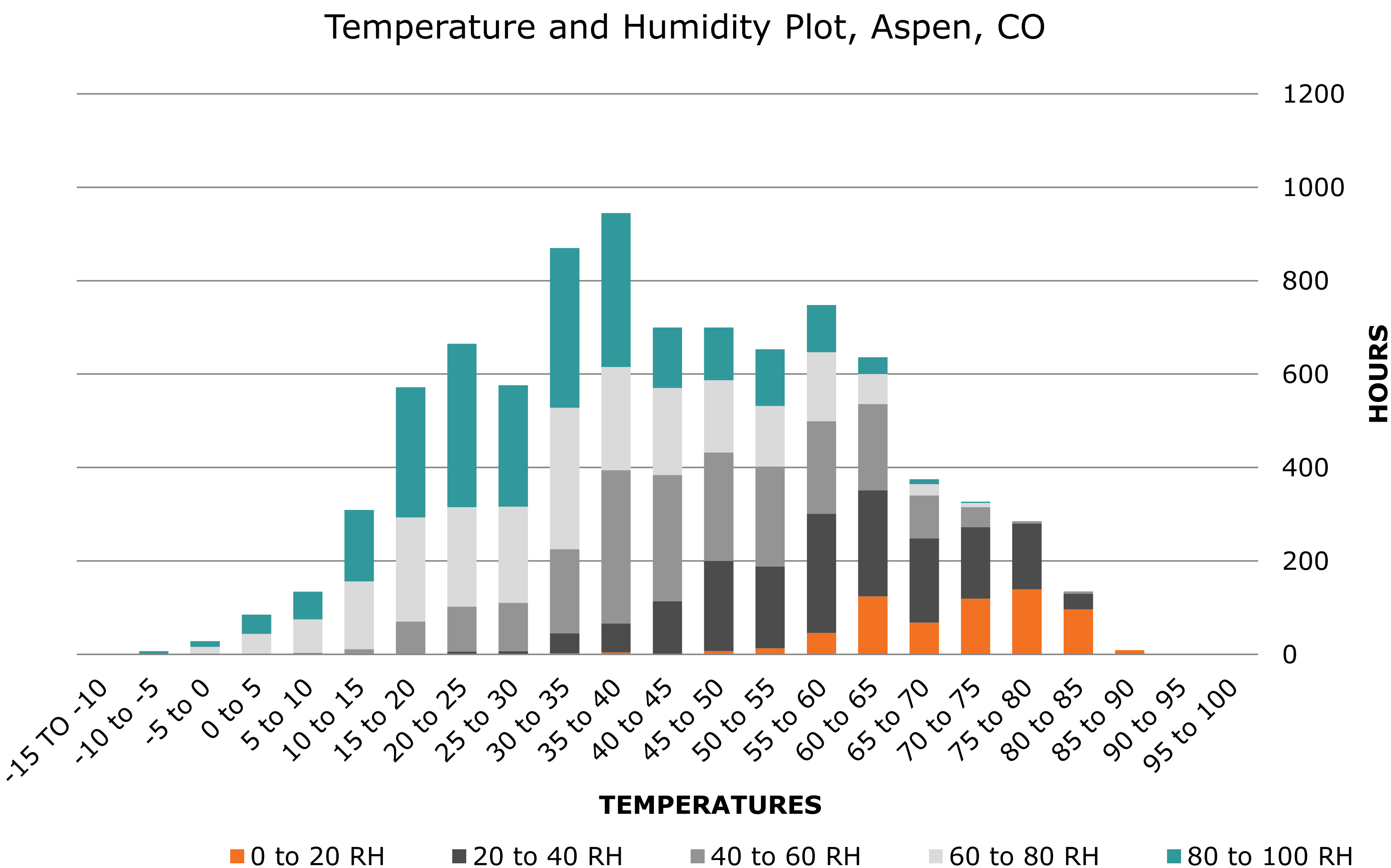
Architect: ZGF Architects


AOC
GREEN TO GOLD
The Innovator's Dilemma
PRIZE


White Steyer Impact Studio
Amory B. Lovins Atrium
Amory B. Lovins


Caulkins Room

Climate


Temperature and Humidity Plot, Aspen, CO
1200
1000
800
600
400
200
0
HOURS
-15 TO -10
-10 to -5
-5 to 0
0 to 5
5 to 10
10 to 15
15 to 20
20 to 25
25 to 30
30 to 35
35 to 40
40 to 45
45 to 50
50 to 55
55 to 60
60 to 65
65 to 70
70 to 75
75 to 80
80 to 85
85 to 90
90 to 95
95 to 100
TEMPERATURES
0 to 20 RH
20 to 40 RH
40 to 60 RH
60 to 80 RH
80 to 100 RH

Thermal Comfort

Thermal Comfort in the News

The New York Times

Chilly at Work? Office Formula Was Devised for Men

By PAM BELLUCK AUG. 3, 2015

Molly Mahannah wears a sweatshirt and blanket at work in Omaha, wrapping herself up "like a burrito."

Chris Machian for The New York Times

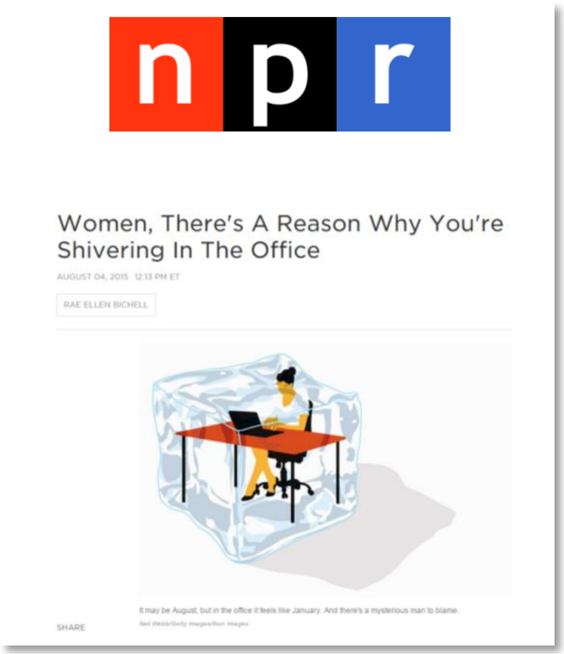
ScienceNews

MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC

Building standards aren't to blame for chilly offices

BY BETHANY BROOKSHIRE 4:28PM, AUGUST 11, 2015

A recent study calculated women's resting metabolic rate and preferred office temperatures. But to figure out why women tend to be cold in the office, look not to science but to the person who controls the thermostat.



npr

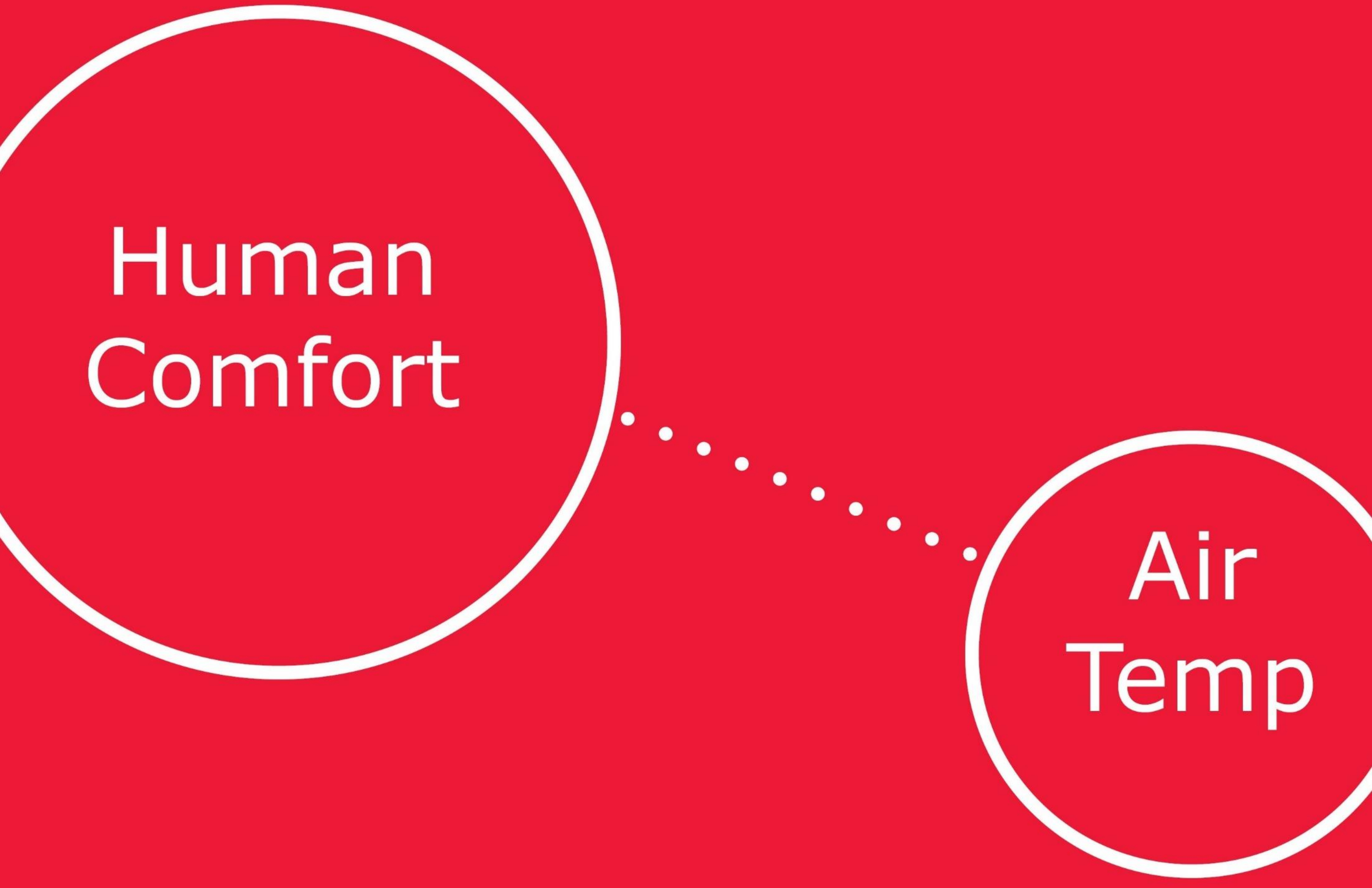
Women, There's A Reason Why You're Shivering In The Office

AUGUST 04, 2015 12:13 PM ET

RAE ELLEN BICHELL

It may be August, but in the office it feels like January. And there's a mysterious man to blame.

SHARE

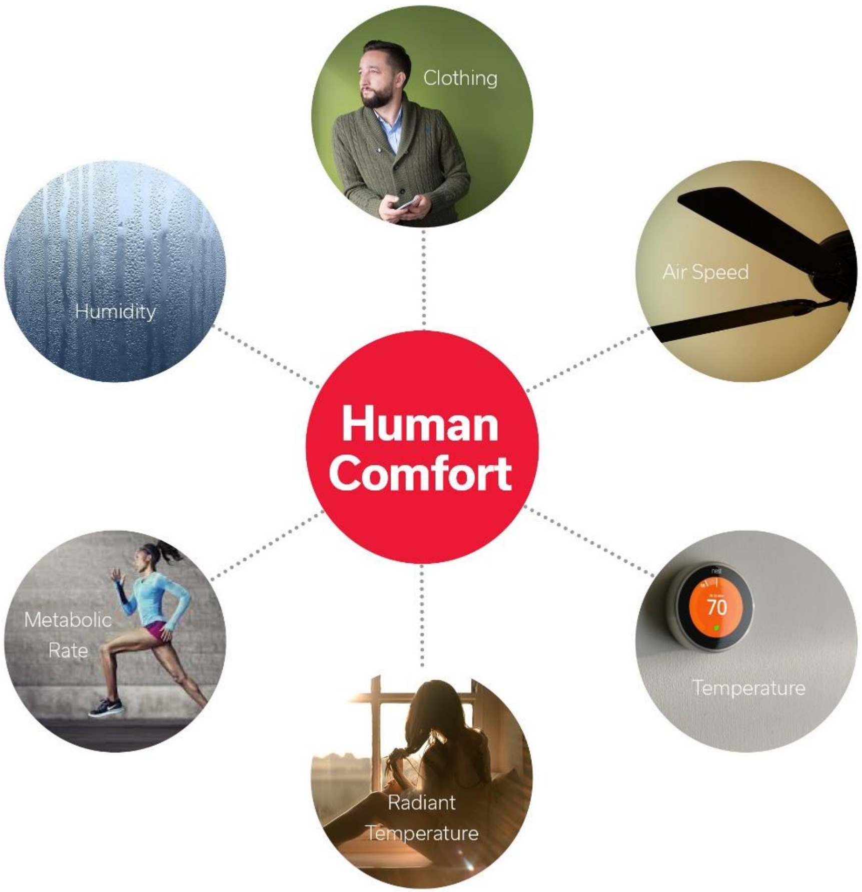

Human Comfort
Air Temp

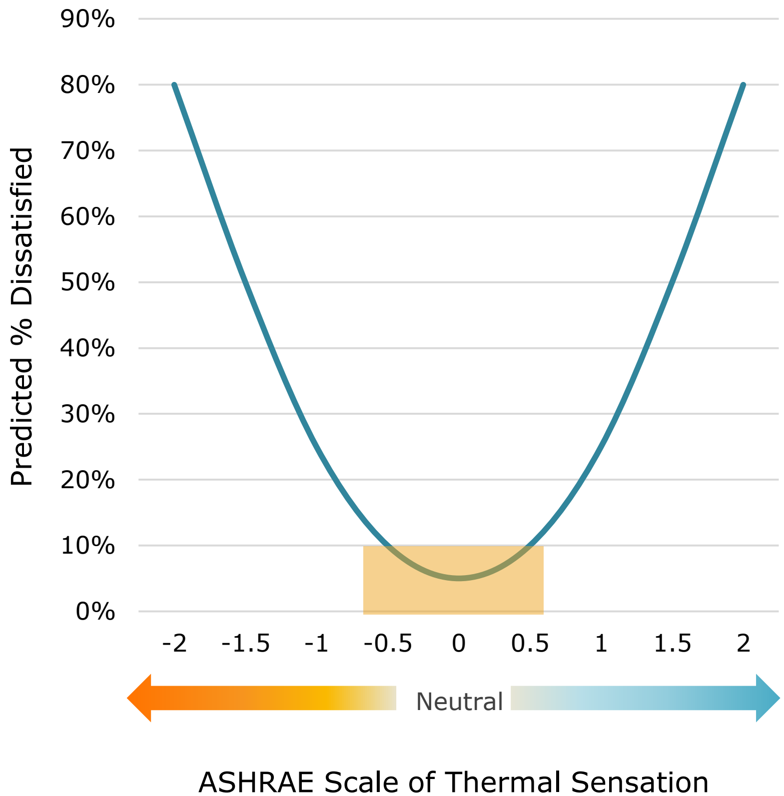
$$PMV = [0.303e^{-0.036M} + 0.028]\{(M - W) - 3.96E^{-8} f_{cl}[(t_{cl} + 273)^4 - (t_r + 273)^4] - f_{cl} h_c (t_{cl} - t_a) - 3.05[5.73 - 0.007(M - W) - p_a] - 0.42[(M - W) - 58.15] - 0.0173M(5.87 - p_a) - 0.0014M(34 - t_a)\}$$

ASHRAE Scale of Thermal Sensation

3	HOT
2	WARM
1	SLIGHTLY WARM
0	NEUTRAL
-1	SLIGHTLY COOL
-2	COOL
-3	COLD

Thermal Comfort Theory

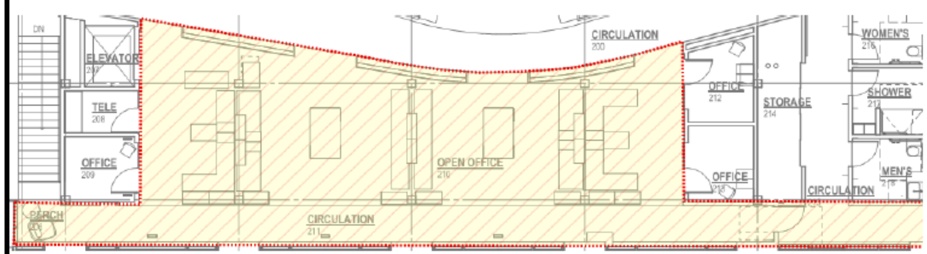




Room Data Sheet

2nd Floor Open Office (as designed)

Room Floor Plan



Internal Load Assumptions:

People	10
Equipment (Installed)	0.88 W/SF
Equipment (Operational)	0.37 W/SF
Lighting (Installed)	0.55 W/SF
Lighting (Operational)	0.40 W/SF
Daylighting	Auto Dimmers
Installed Heating	3.3 kW
Heating Setpoint	64 °F
Weather File	Aspen, CO Custom TMY10, 2004-2013

Comfort Design Parameters

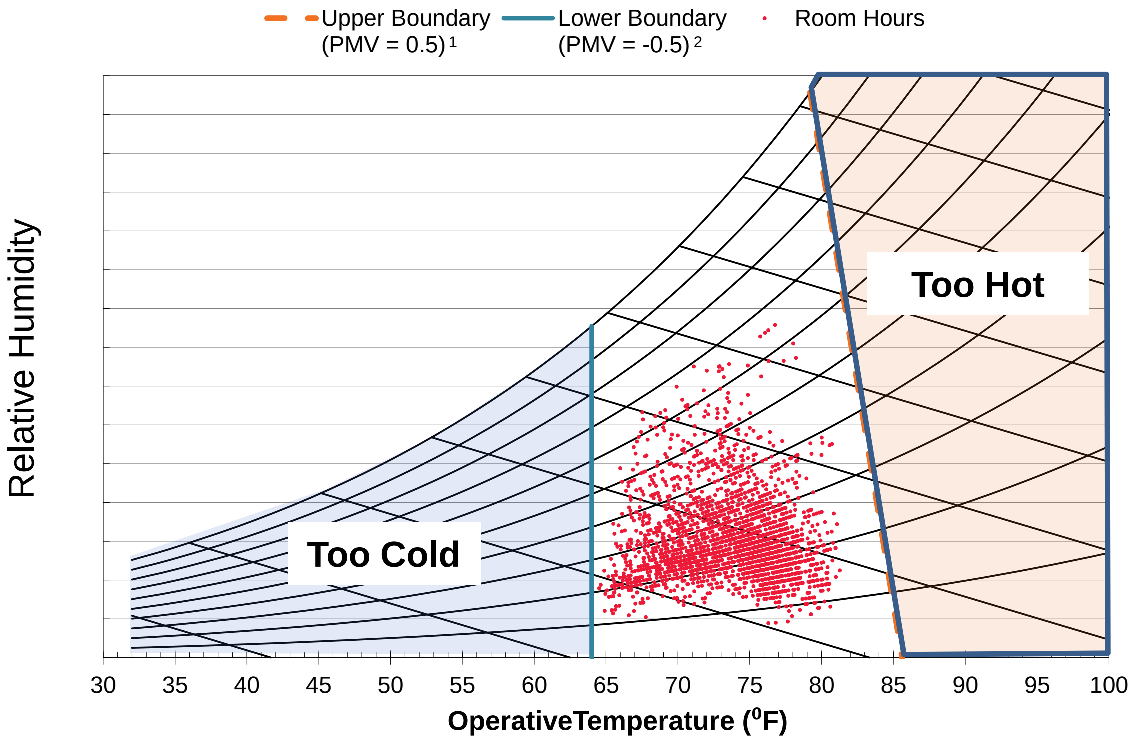
Heating		Cooling	
Clo (max):	1.01	Clo (min):	0.57
(Trousers, sweater, T-shirt)		(Trousers, short sleeves)	
Met (min):	1.0	Met (max):	1.2
(Sitting, relaxed)		(Standing, relaxed)	
Air Speed:	19 FPM	Air Speed (max):	50 FPM

Schedule Description

Occupied weekdays 8:00am to 5:00pm. Equipment tracks occupancy, turning down to 7% load when unoccupied. Lighting is on with automatic daylight dimming when occupied, off when unoccupied.

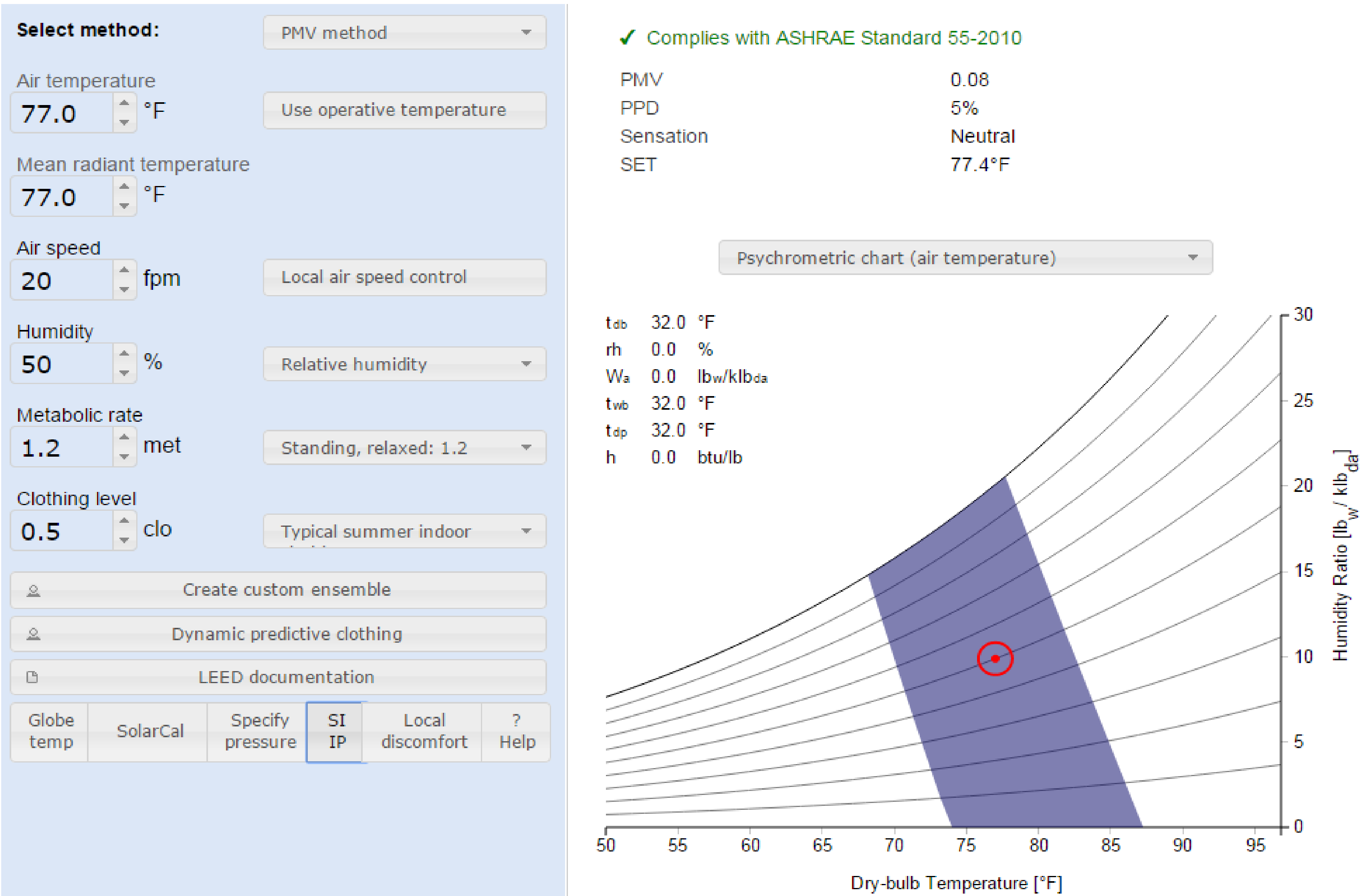
As Designed

Room Thermal Comfort Performance



1. Upper boundary is based on the Elevated Air Speed Model, ASHRAE Standard 55-2013 Appendix G
2. Lower boundary is based on implementation of the CBE Personal Comfort System

CBE Thermal Comfort Tool

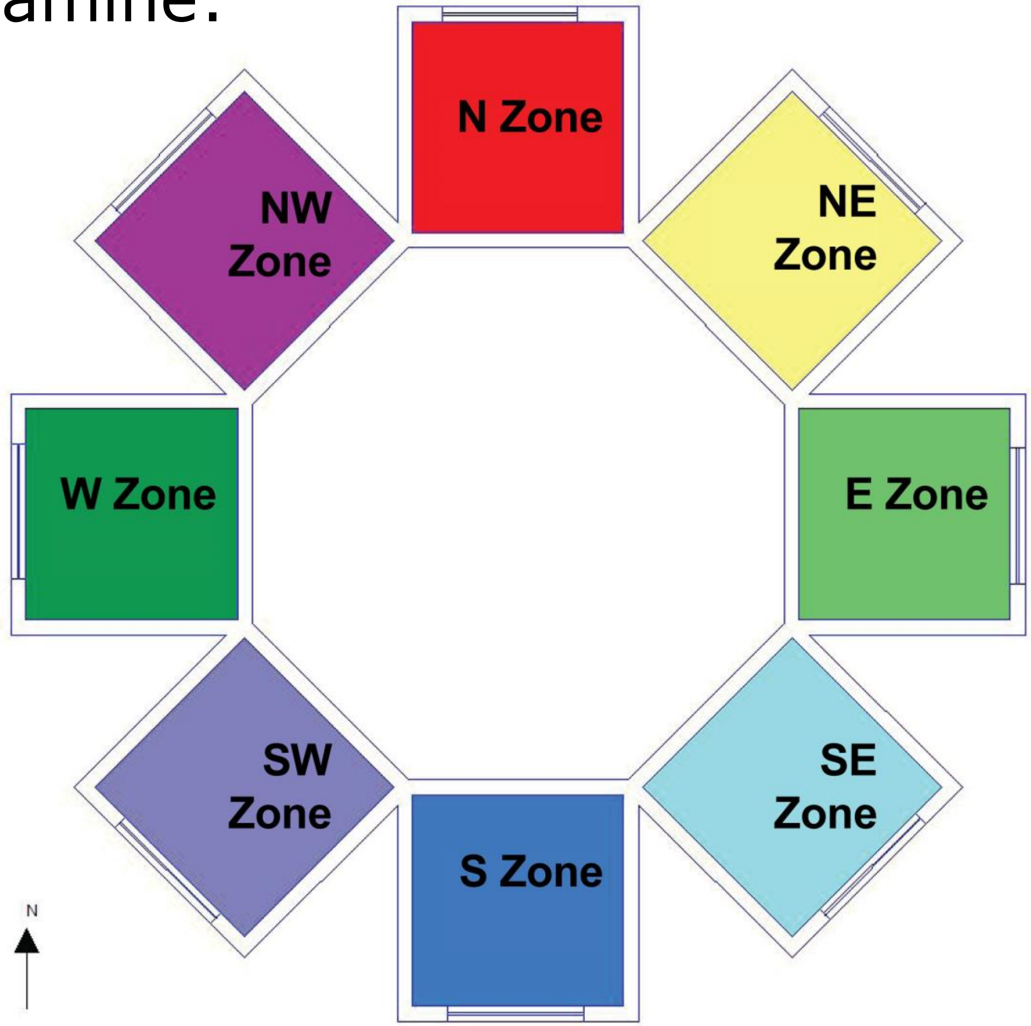


Controlling Peak Loads

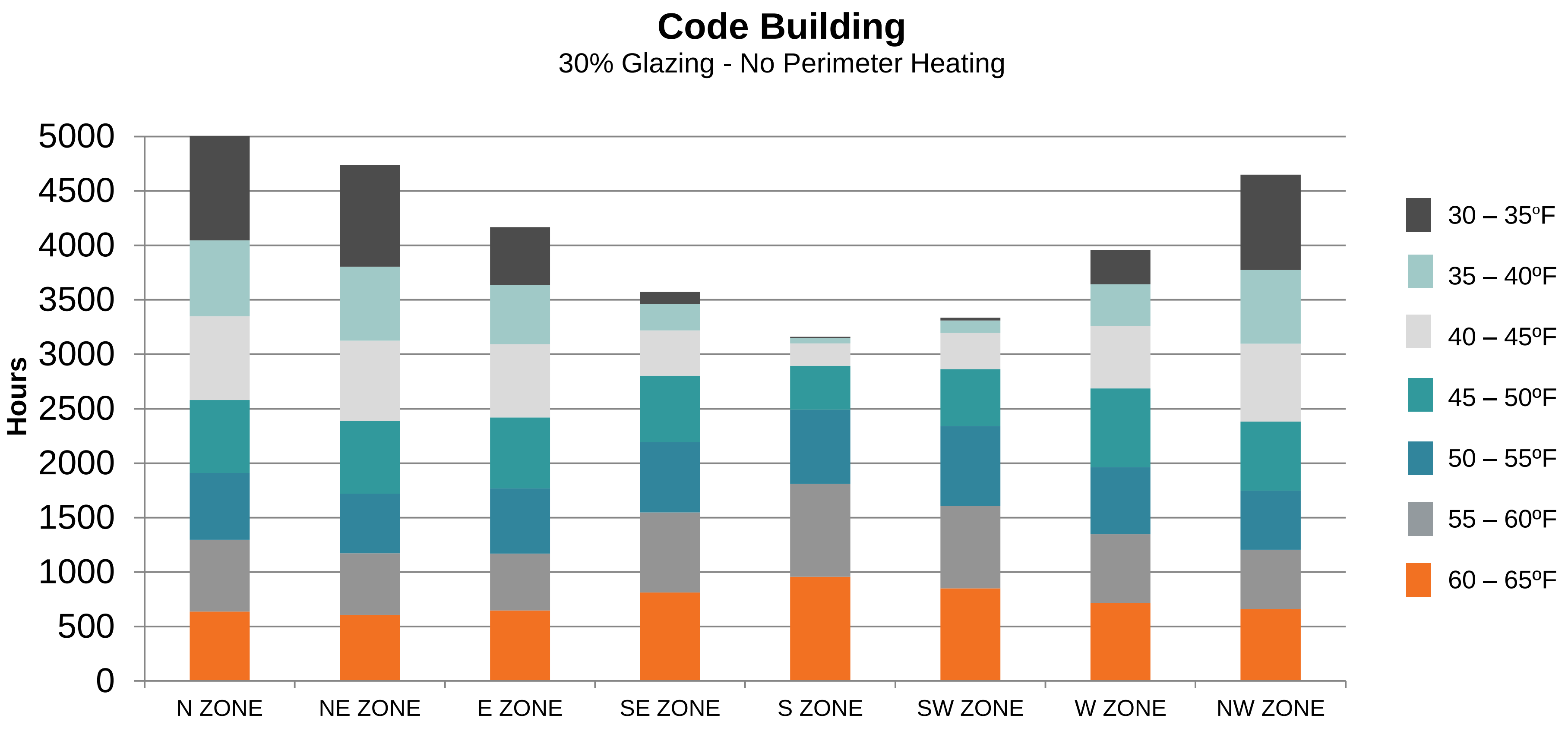
Earliest Modeling

Simplified model to examine:

- Energy Use
- Peak Loads
- Comfort

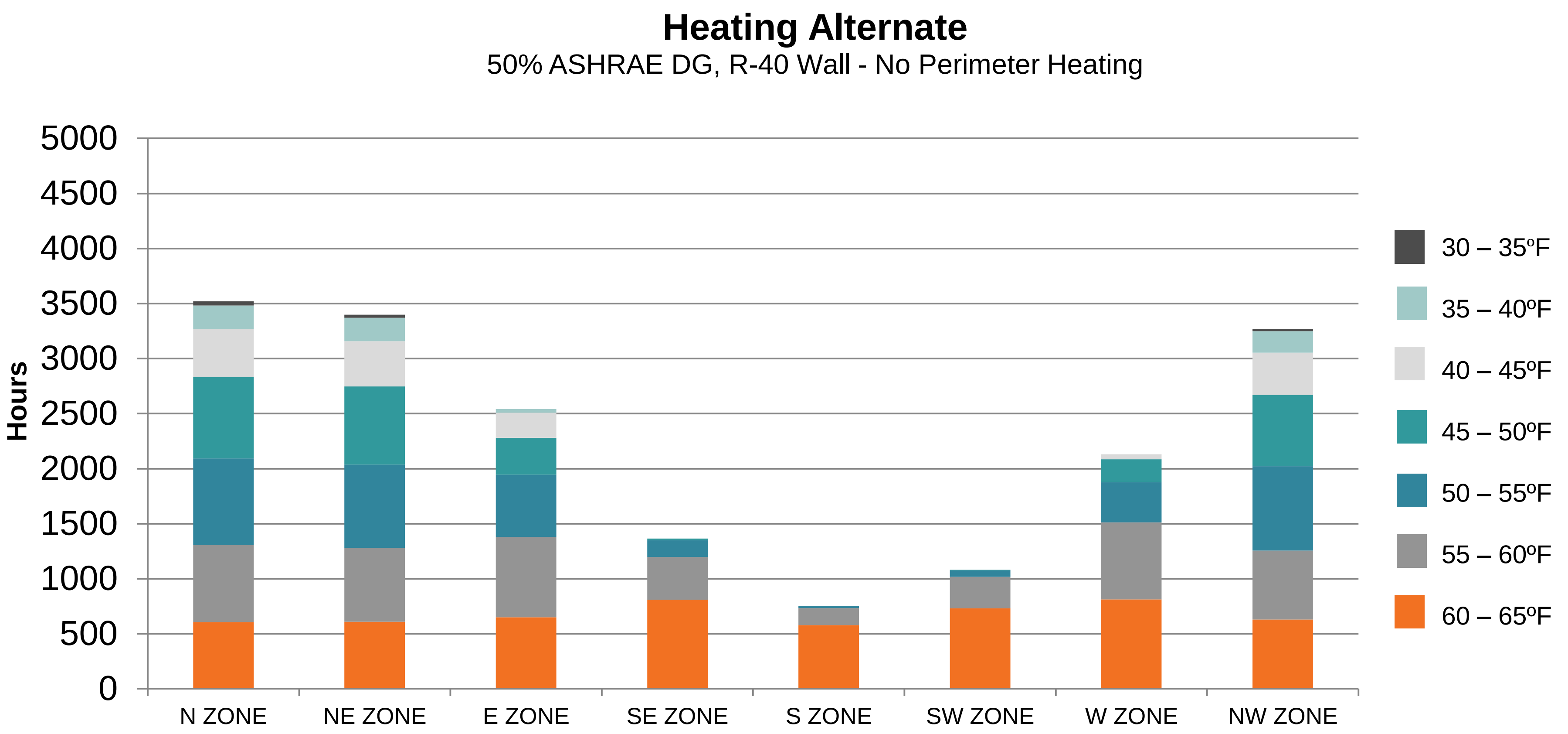


Heating



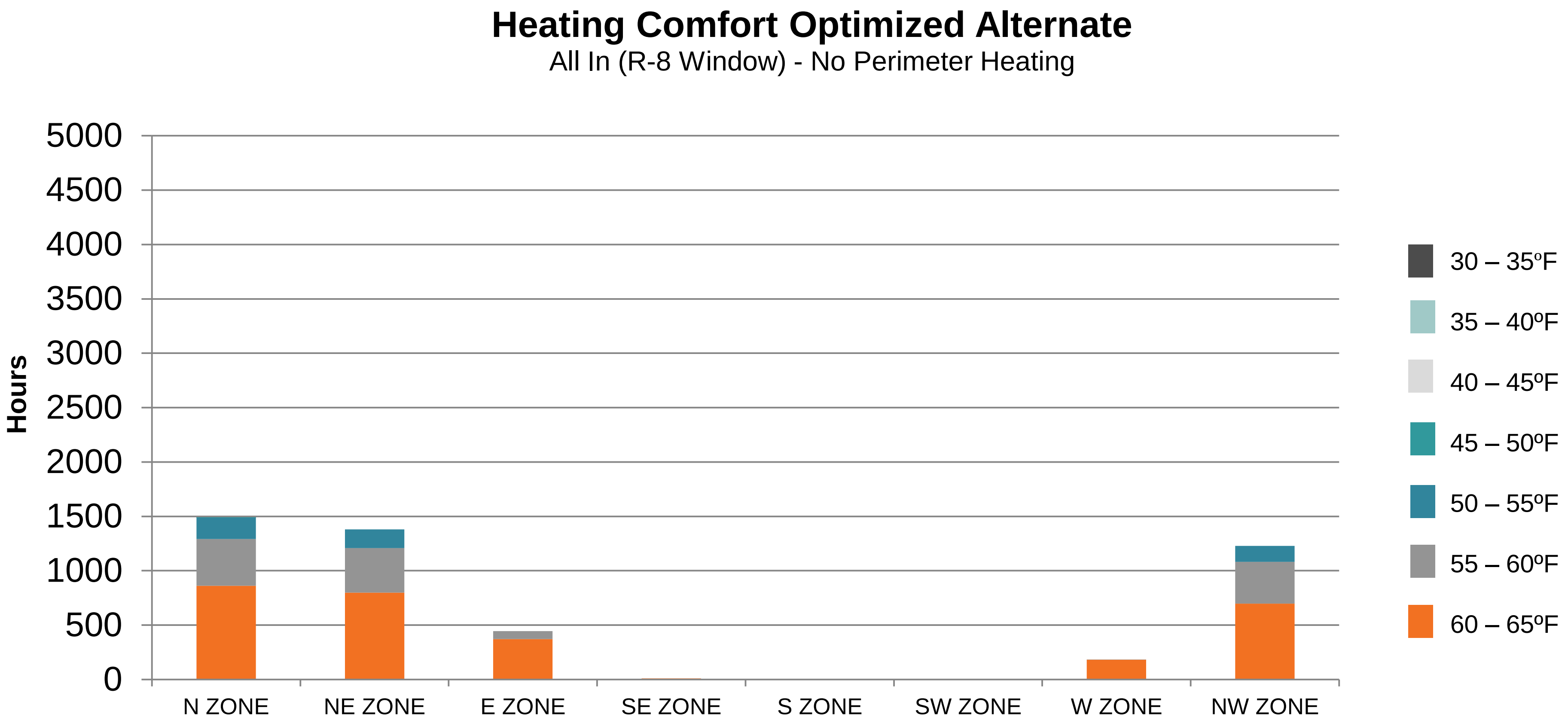
Code Building
30% Glazing - No Perimeter Heating
Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
N ZONE
NE ZONE
E ZONE
SE ZONE
S ZONE
SW ZONE
W ZONE
NW ZONE
30 – 35ºF
35 – 40ºF
40 – 45ºF
45 – 50ºF
50 – 55ºF
55 – 60ºF
60 – 65ºF

Heating



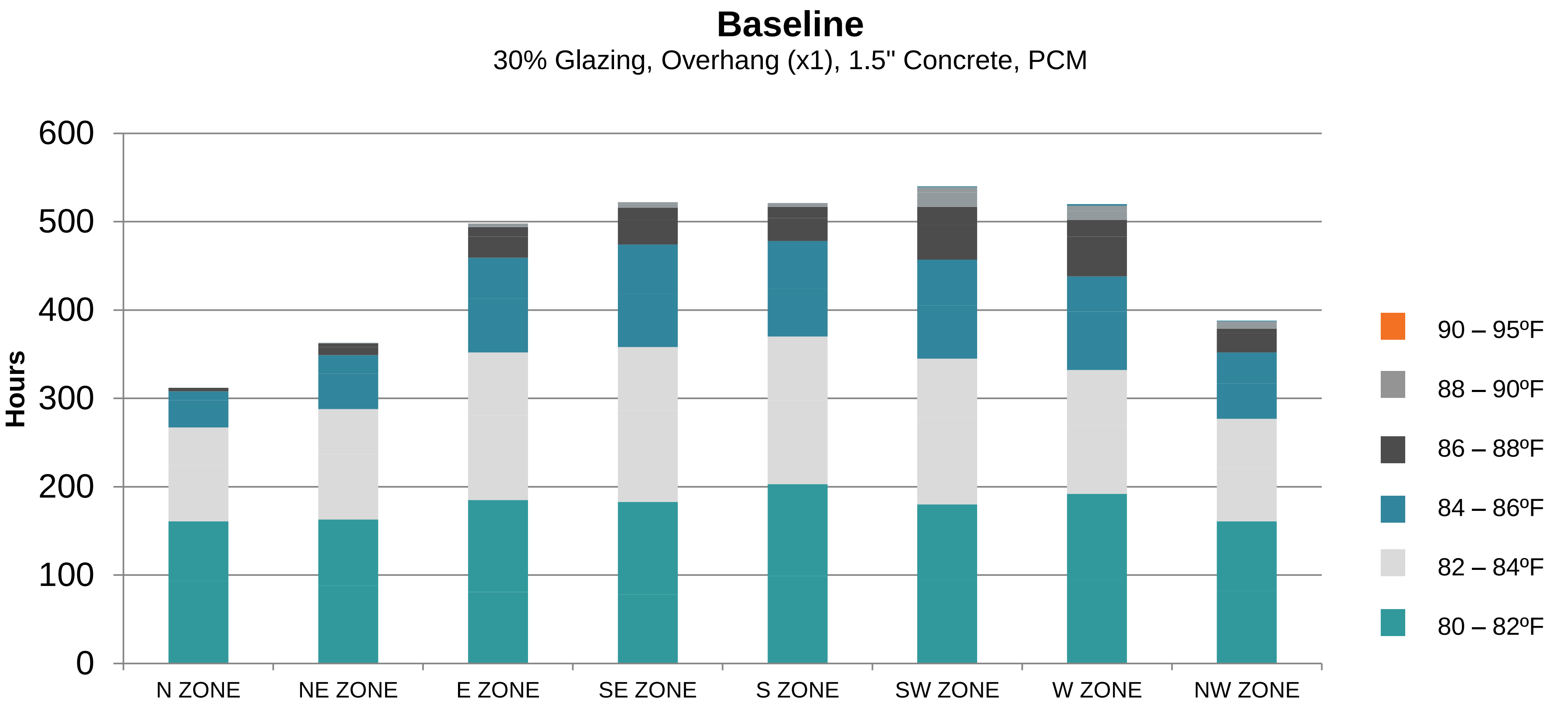
Heating Alternate
50% ASHRAE DG, R-40 Wall - No Perimeter Heating
Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
N ZONE
NE ZONE
E ZONE
SE ZONE
S ZONE
SW ZONE
W ZONE
NW ZONE
30 – 35ºF
35 – 40ºF
40 – 45ºF
45 – 50ºF
50 – 55ºF
55 – 60ºF
60 – 65ºF

Heating

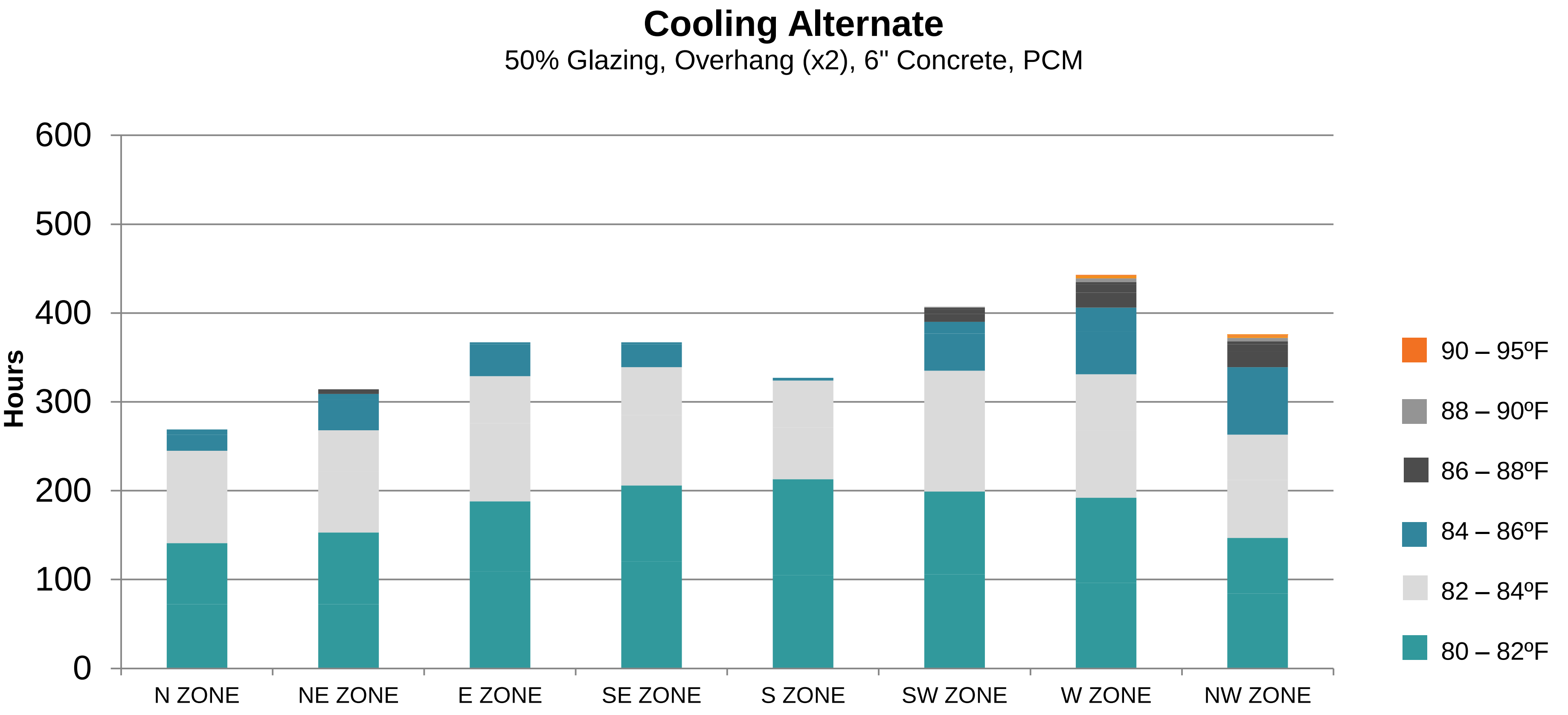


Heating Comfort Optimized Alternate
All In (R-8 Window) - No Perimeter Heating
Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
N ZONE
NE ZONE
E ZONE
SE ZONE
S ZONE
SW ZONE
W ZONE
NW ZONE
30 – 35ºF
35 – 40ºF
40 – 45ºF
45 – 50ºF
50 – 55ºF
55 – 60ºF
60 – 65ºF

Cooling

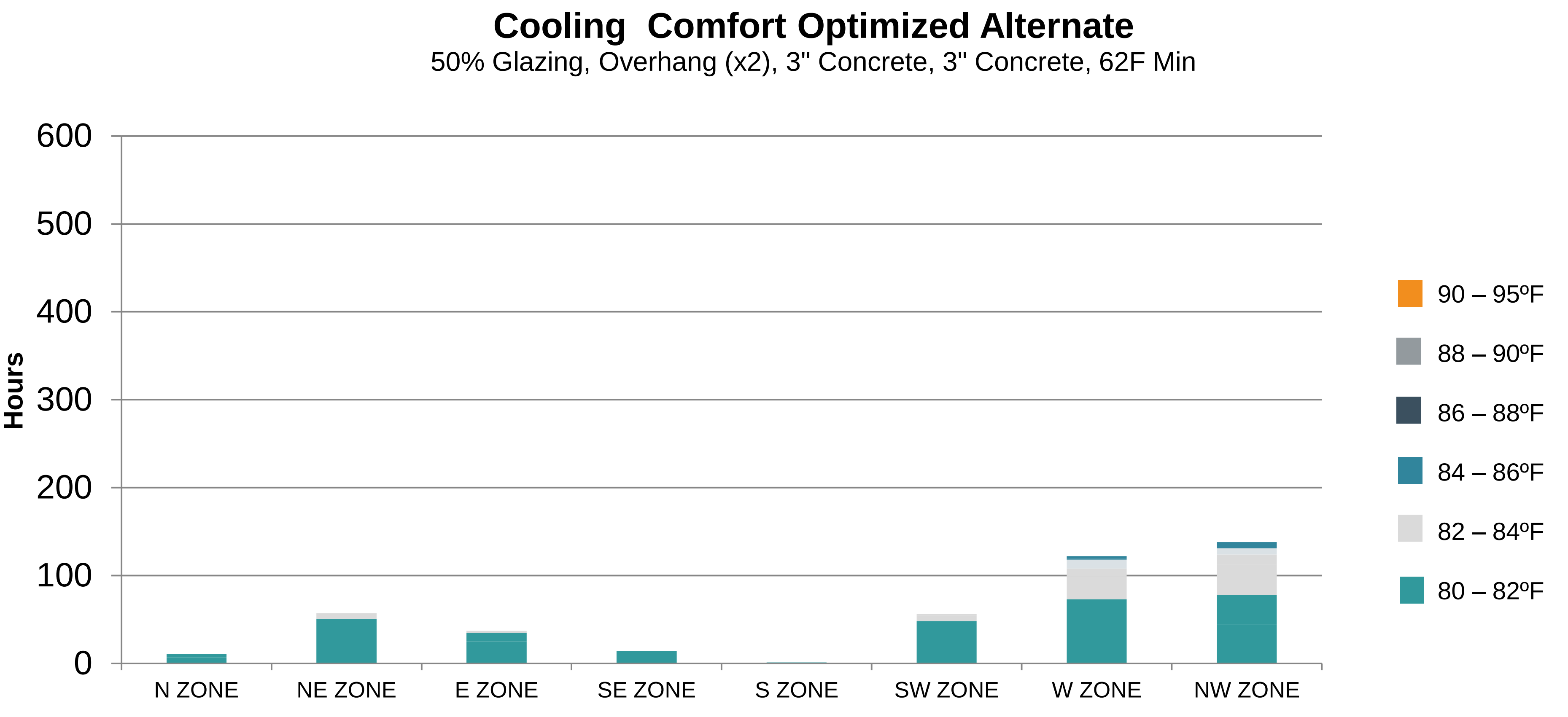

Baseline
30% Glazing, Overhang (x1), 1.5" Concrete, PCM
Hours
600
500
400
300
200
100
0
N ZONE
NE ZONE
E ZONE
SE ZONE
S ZONE
SW ZONE
W ZONE
NW ZONE
90 – 95ºF
88 – 90ºF
86 – 88ºF
84 – 86ºF
82 – 84ºF
80 – 82ºF

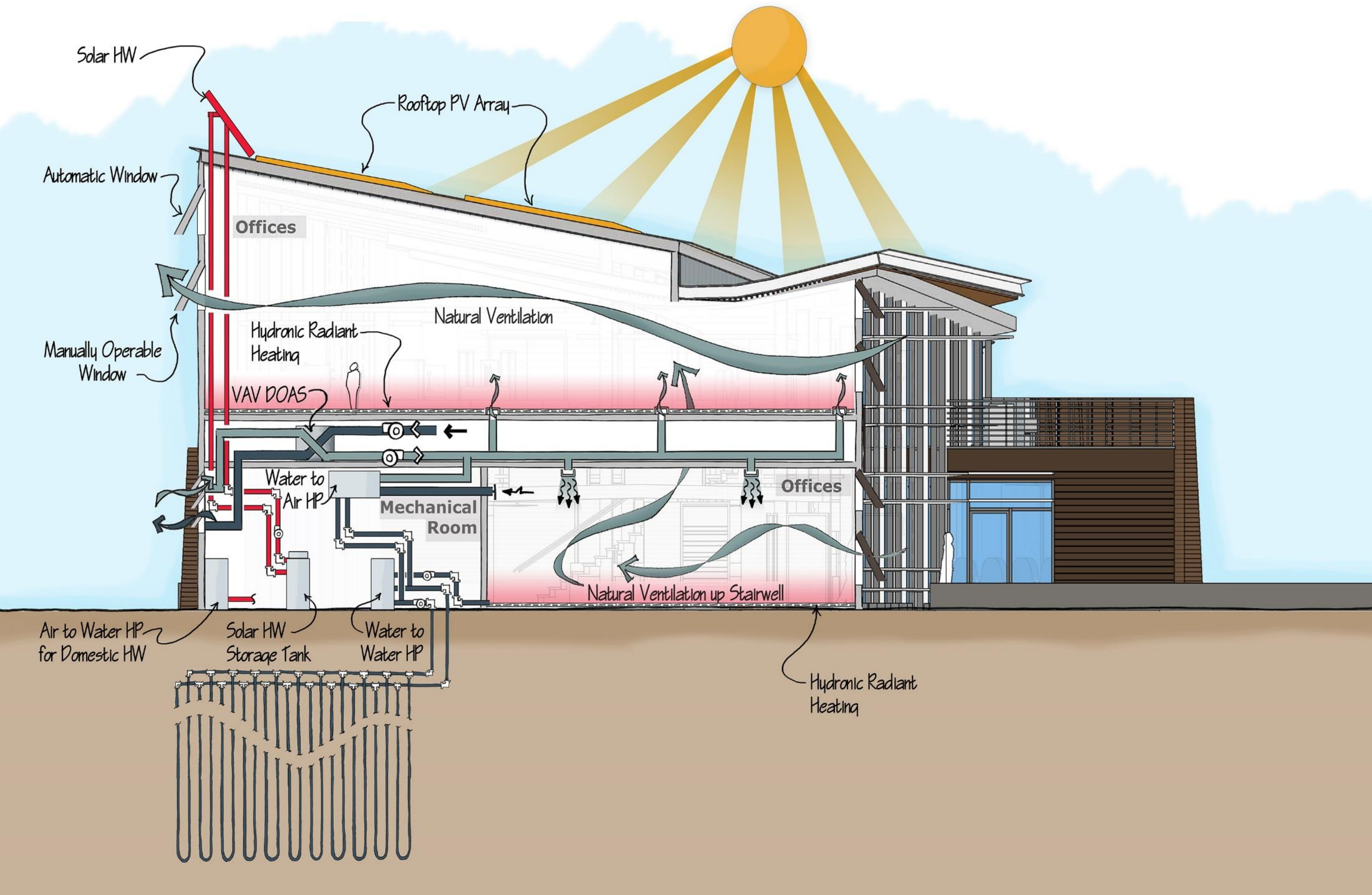
Cooling

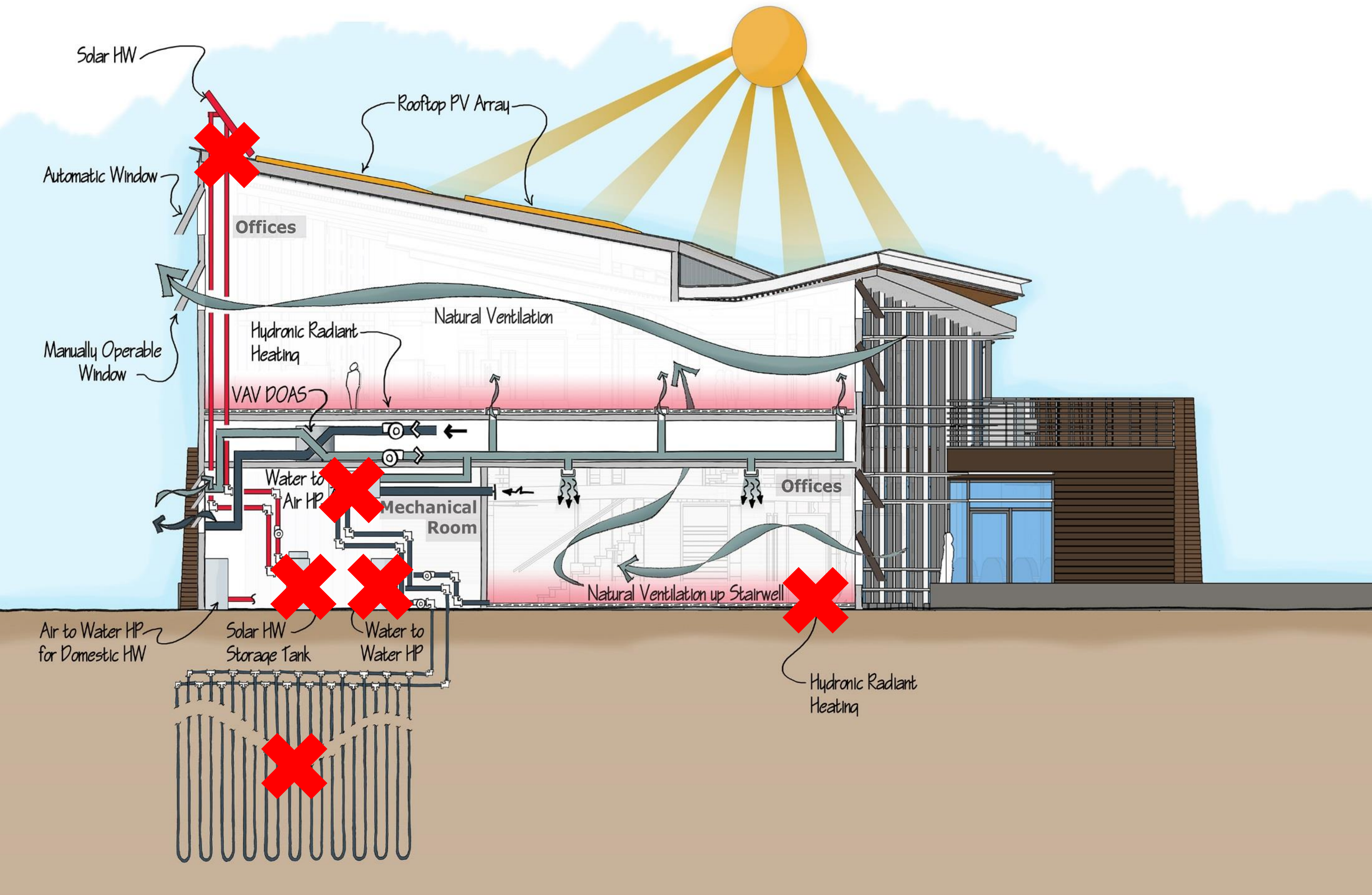


Cooling Alternate
50% Glazing, Overhang (x2), 6" Concrete, PCM
Hours
600
500
400
300
200
100
0
N ZONE
NE ZONE
E ZONE
SE ZONE
S ZONE
SW ZONE
W ZONE
NW ZONE
90 – 95ºF
88 – 90ºF
86 – 88ºF
84 – 86ºF
82 – 84ºF
80 – 82ºF

Cooling


Cooling Comfort Optimized Alternate
50% Glazing, Overhang (x2), 3" Concrete, 3" Concrete, 62F Min
Hours
600
500
400
300
200
100
0
N ZONE
NE ZONE
E ZONE
SE ZONE
S ZONE
SW ZONE
W ZONE
NW ZONE
90 – 95ºF
88 – 90ºF
86 – 88ºF
84 – 86ºF
82 – 84ºF
80 – 82ºF


Solar HW
Rooftop PV Array
Automatic Window
Offices
Natural Ventilation
Hydronic Radiant Heating
Manually Operable Window
VAV DOAS
Water to Air HP
Mechanical Room
Offices
Natural Ventilation up Stairwell
Air to Water HP for Domestic HW
Solar HW Storage Tank
Water to Water HP
Hydronic Radiant Heating



Solar HW
Rooftop PV Array
Automatic Window
Offices
Natural Ventilation
Hydronic Radiant Heating
Manually Operable Window
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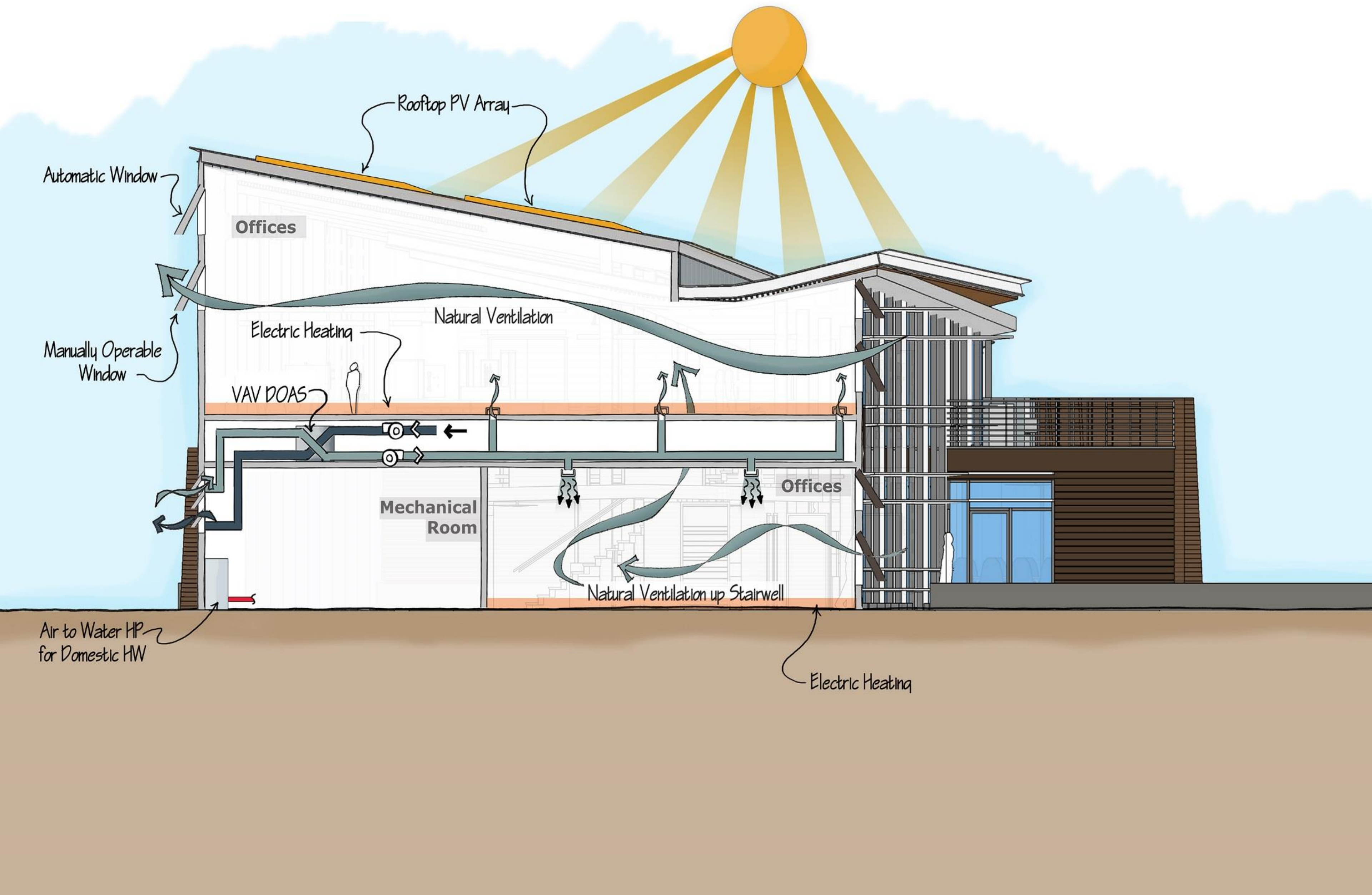
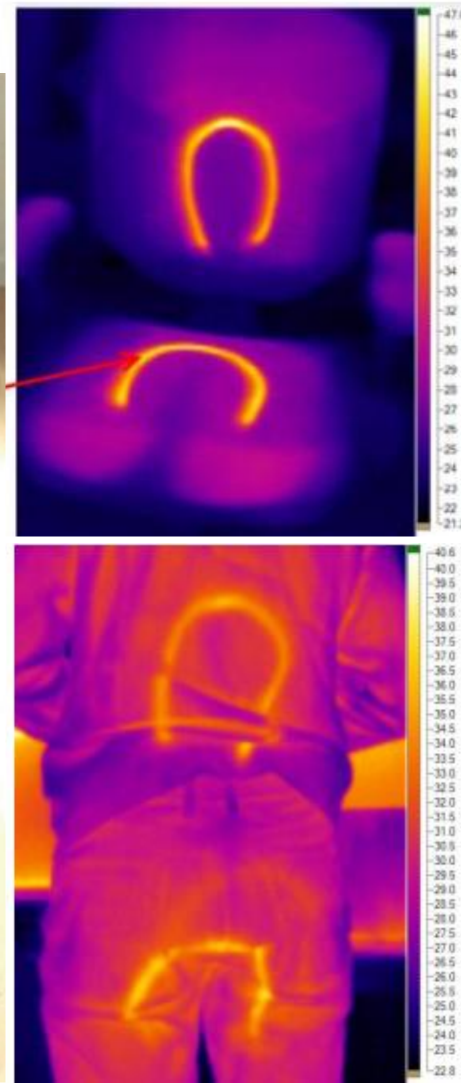
Water to Air HP
Mechanical Room
Offices
Natural Ventilation up Stairwell
Air to Water HP for Domestic HW
Solar HW Storage Tank
Water to Water HP
Hydronic Radiant Heating

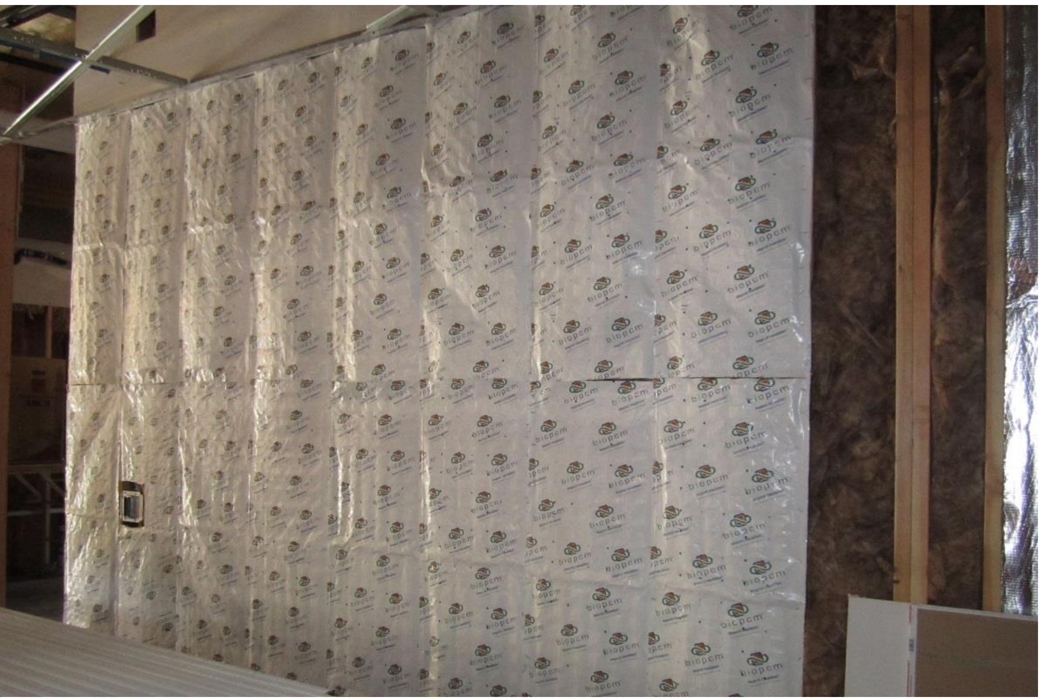

Rooftop PV Array
Automatic Window
Offices
Natural Ventilation
Electric Heating
Manually Operable Window
VAV DOAS
Offices
Mechanical Room
Natural Ventilation up Stairwell
Air to Water HP for Domestic HW
Electric Heating

Personal Comfort - Hyperchair

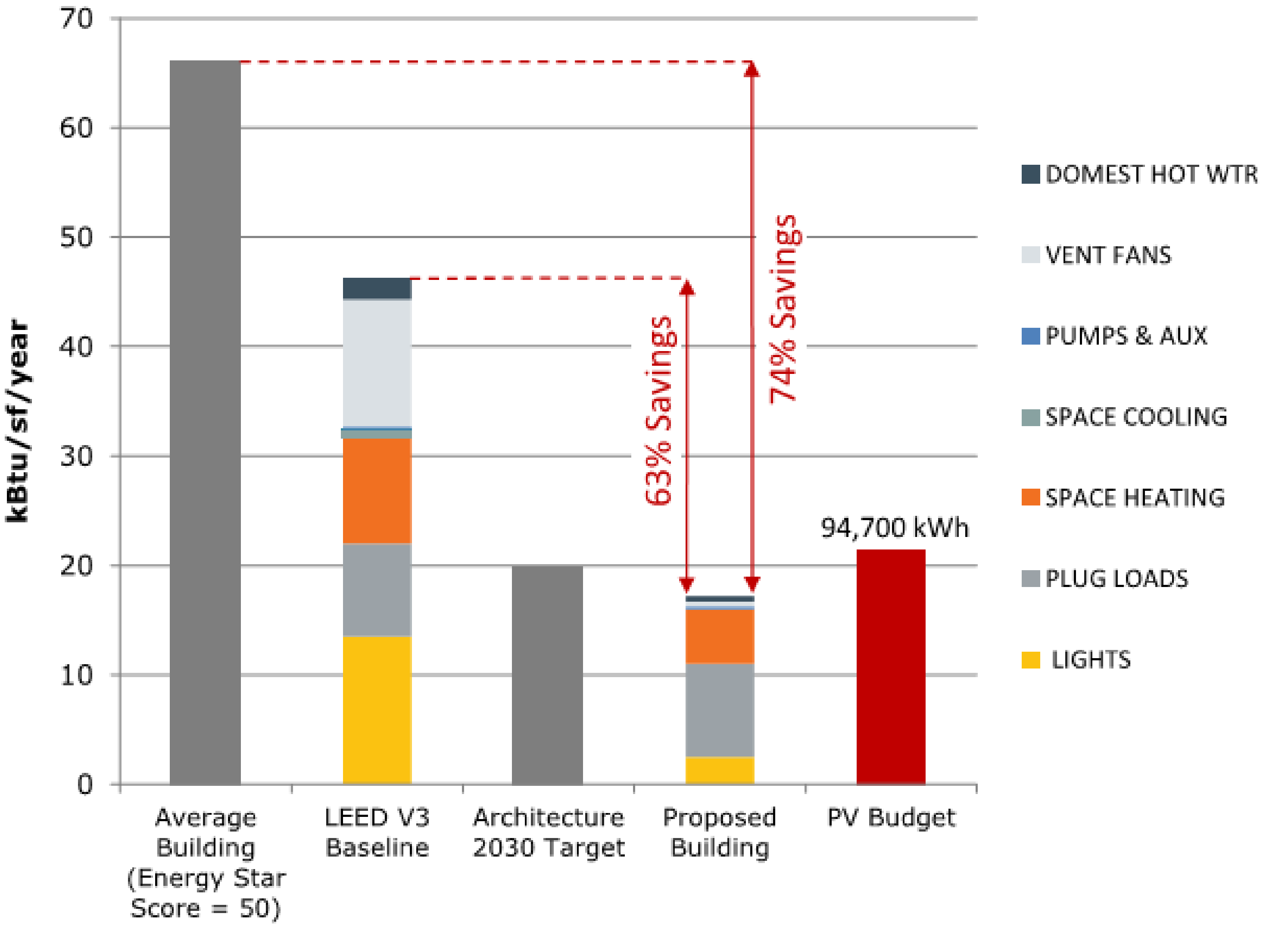


Personal Comfort

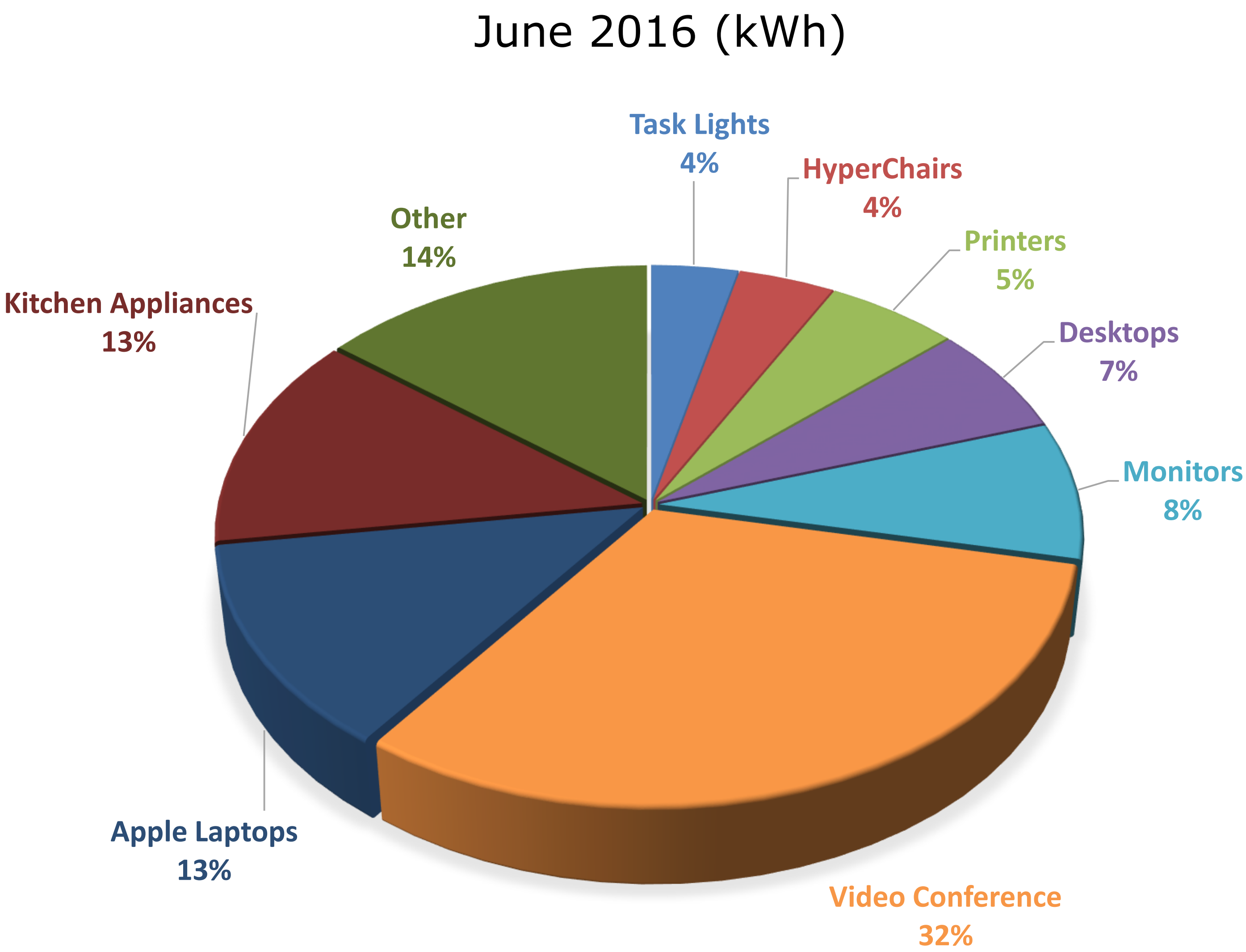
Capture the Heat



Expected Energy Use

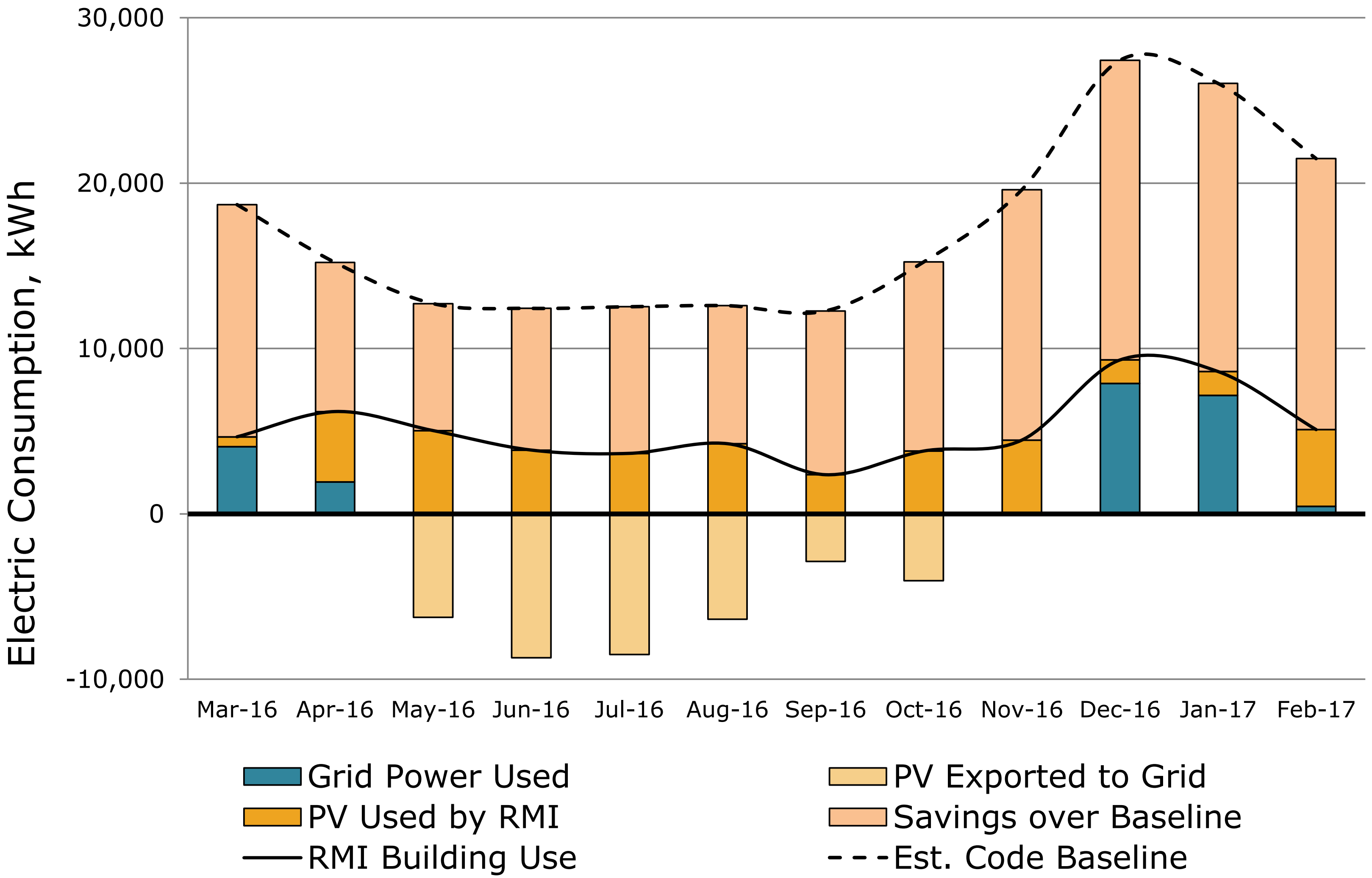


Breakdown of Plug Loads

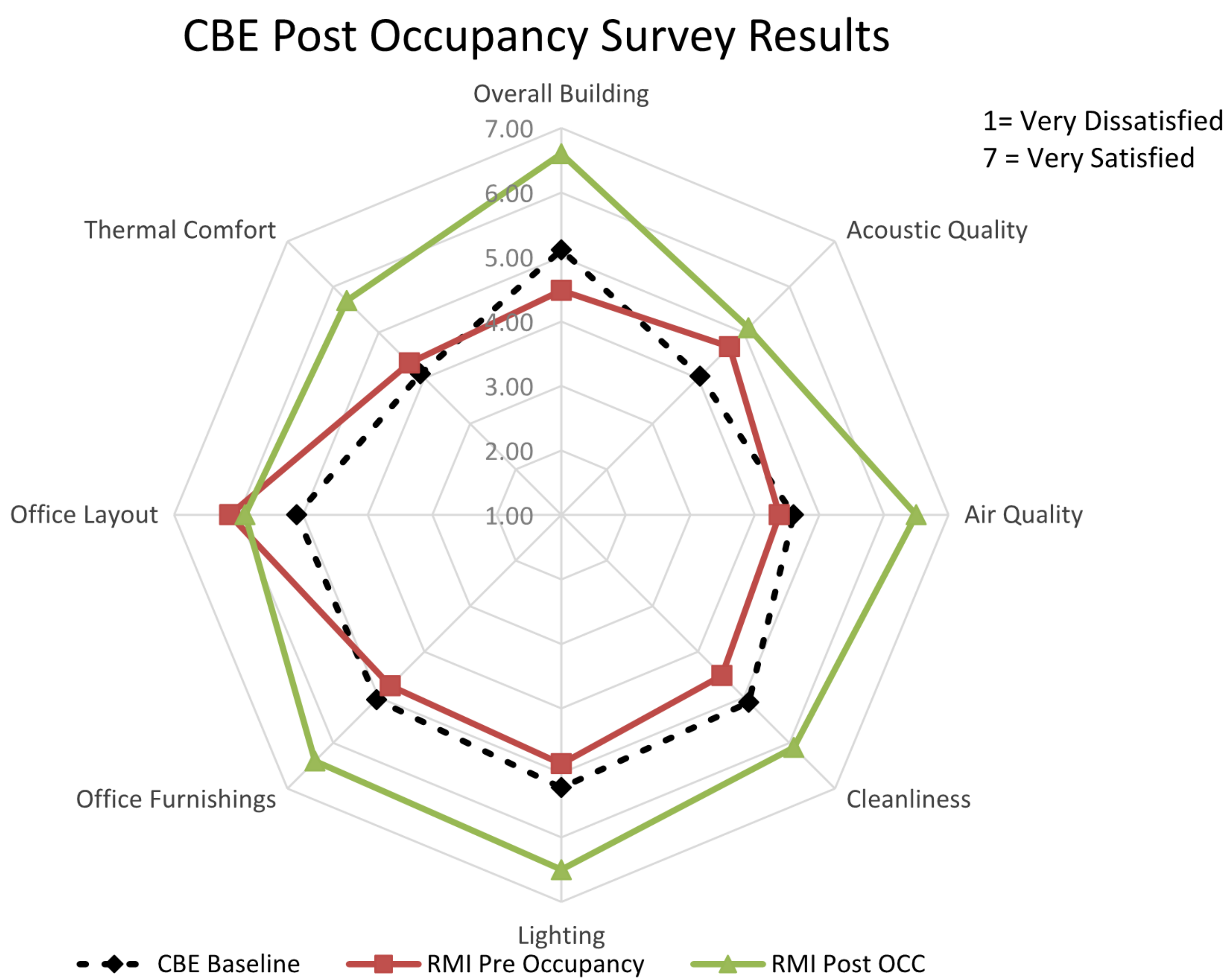


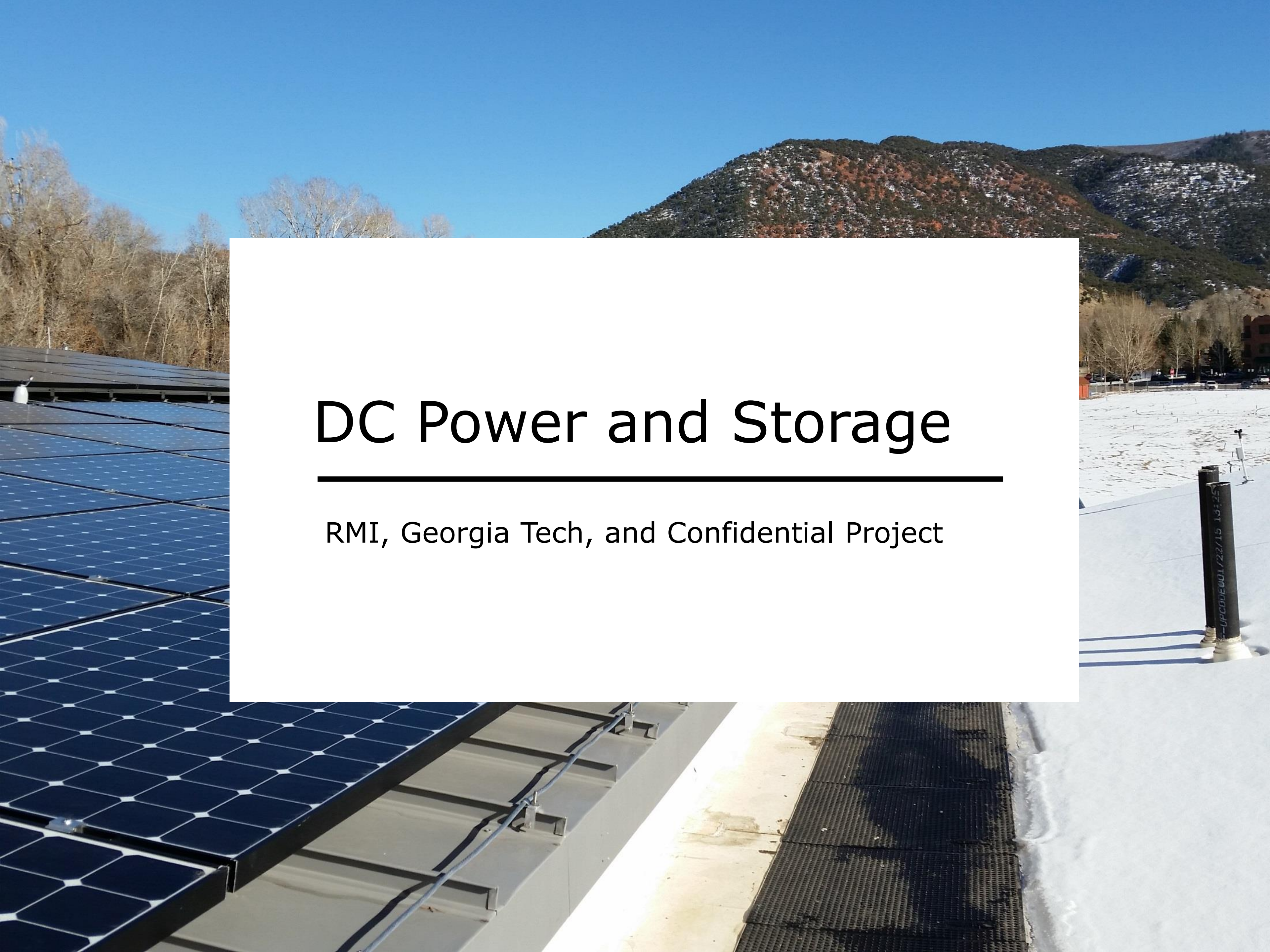
Results: Actual Performance

Actual EUI is 15.9 kbtu/ft²/yr, <u>lower</u> than modelled EUI of 17.2 kbtu/ft²/yr



Key Findings – Occupant Surveys





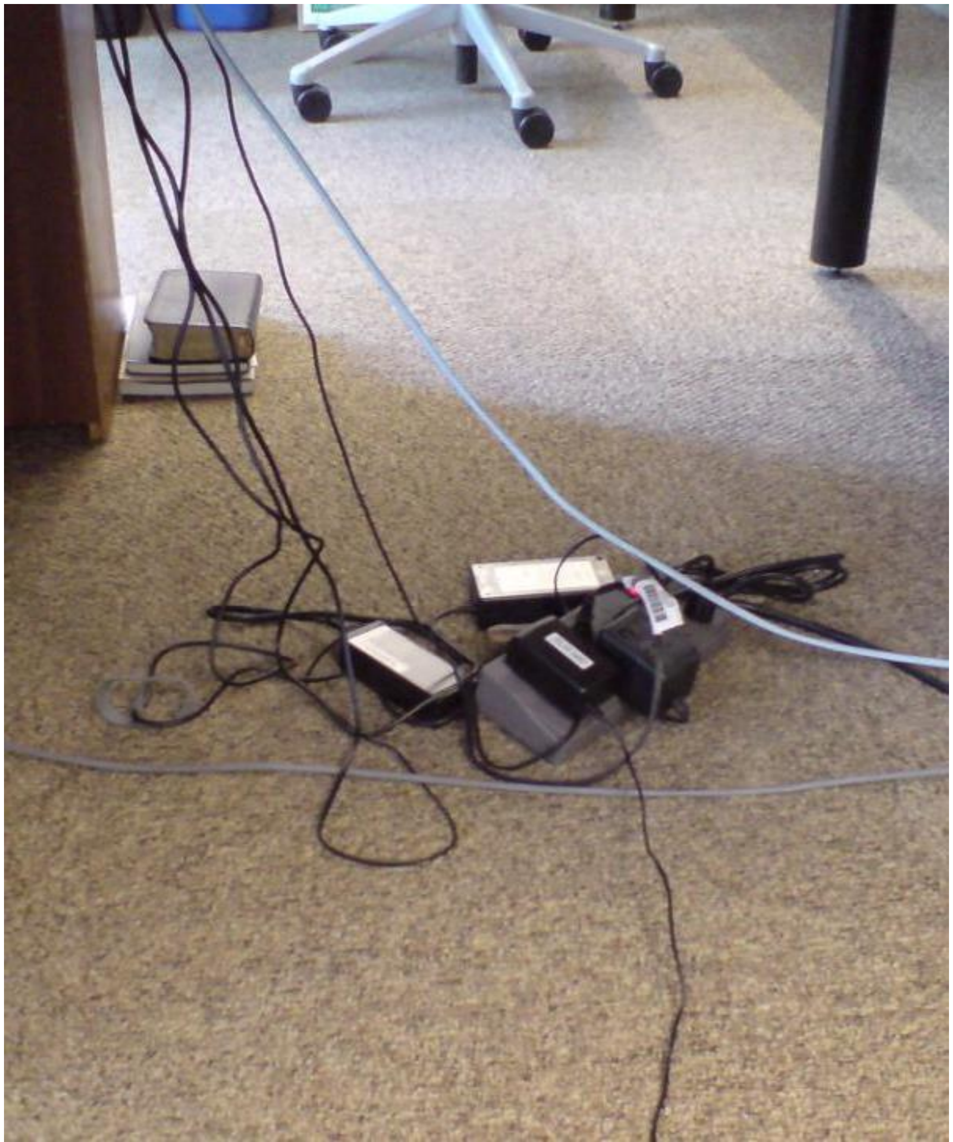
DC Power and Storage

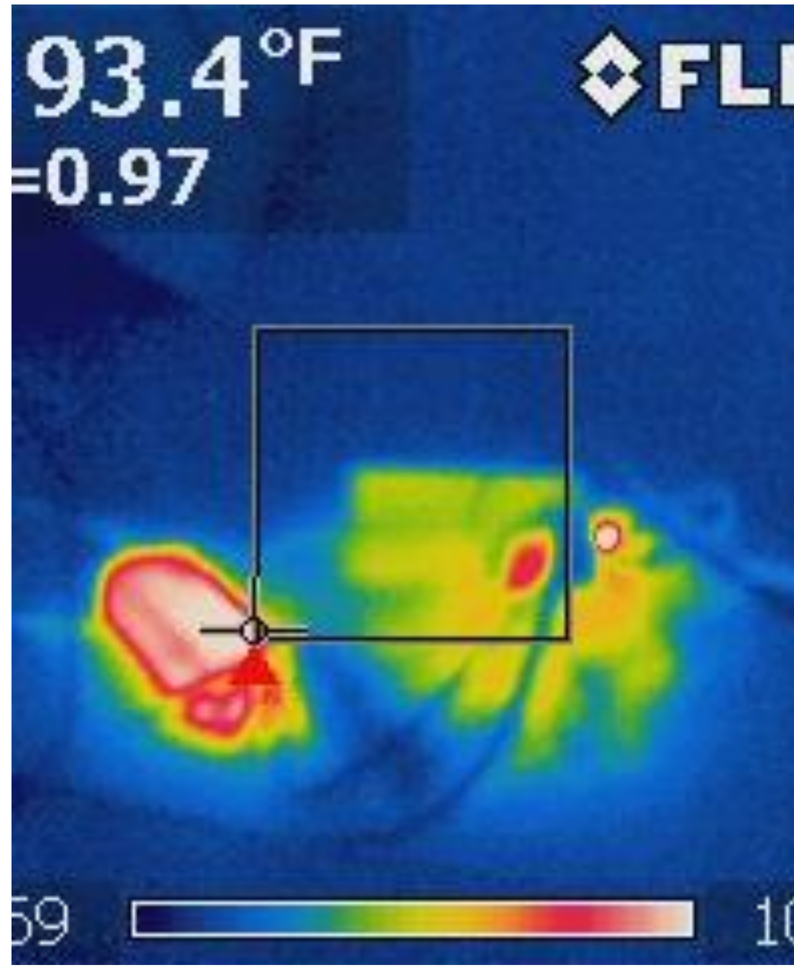
RMI, Georgia Tech, and Confidential Project

What Happened?

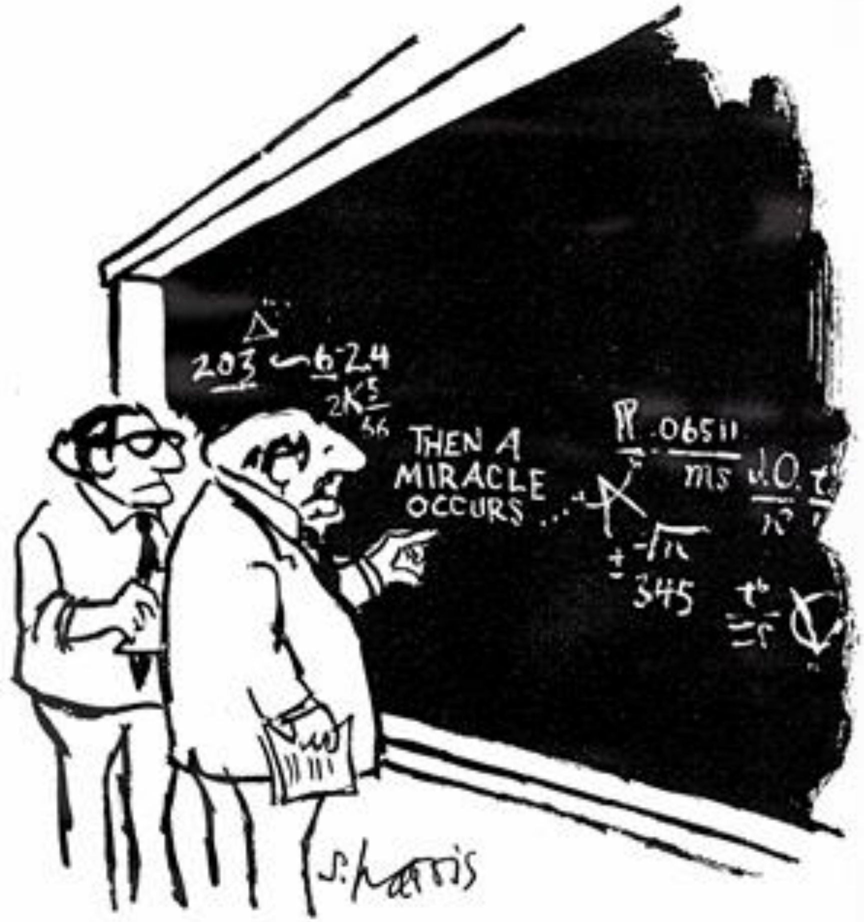
Direct Current

Plug Load Losses



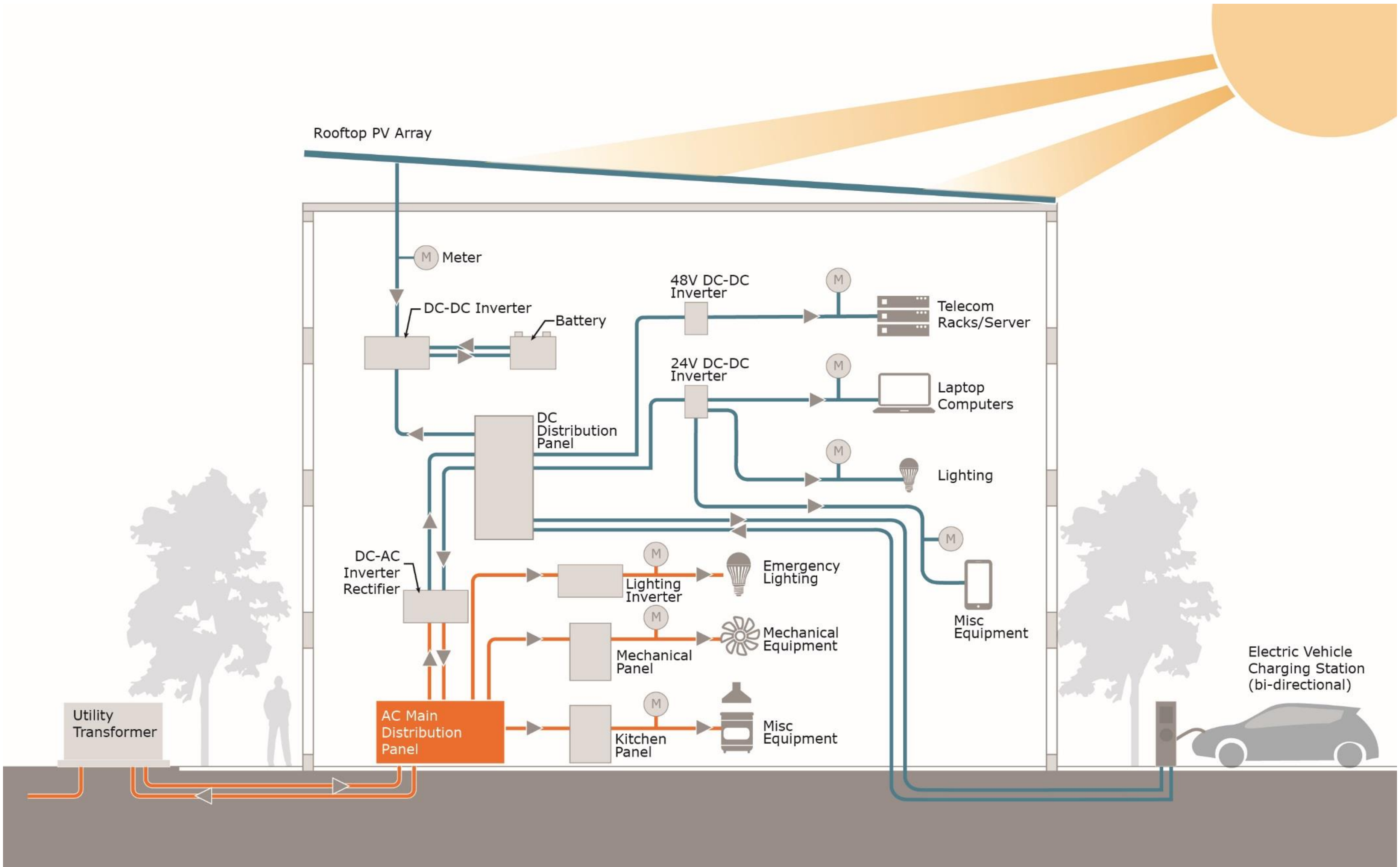


Ahead of Our Time?



"I THINK YOU SHOULD BE MORE EXPLICIT HERE IN STEP TWO."

DC Distribution



USB - C

RMI Battery System

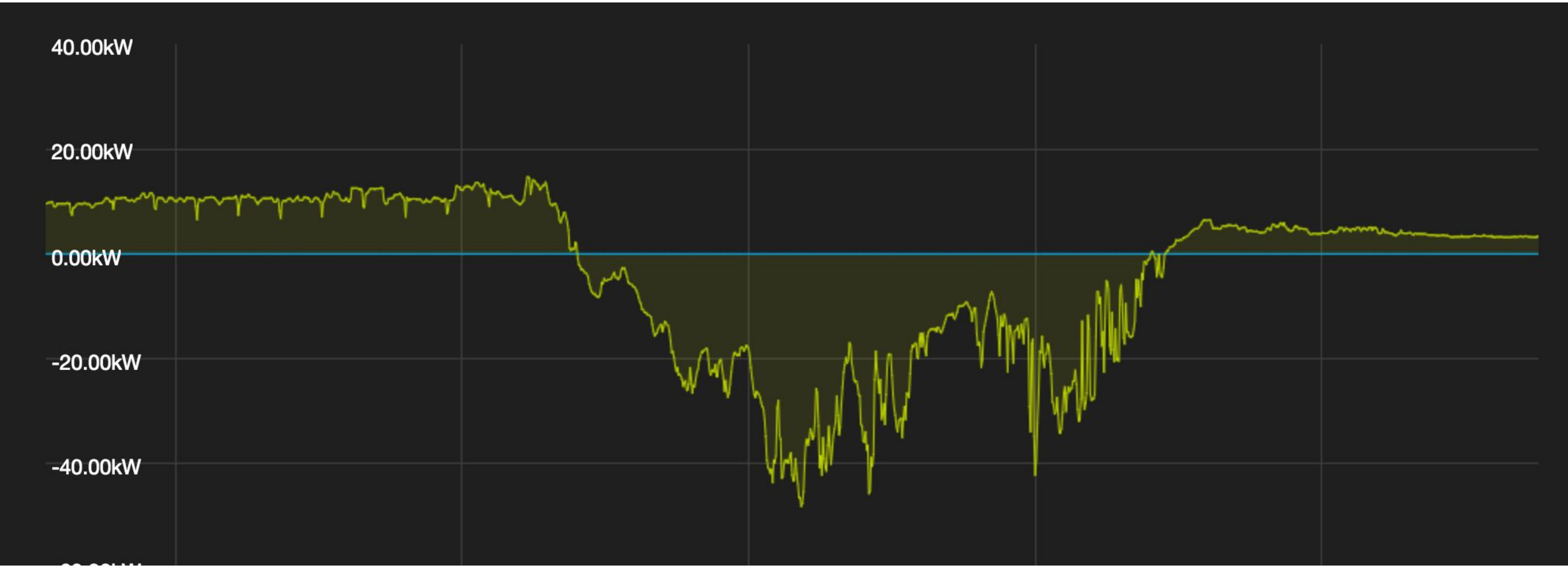
Current Requirements:
- Peak shaving
- Test demand response scenarios, including rate structures

Future Requirements:
- Islanding
- Integration with bi-directional electric vehicles
- DC distribution

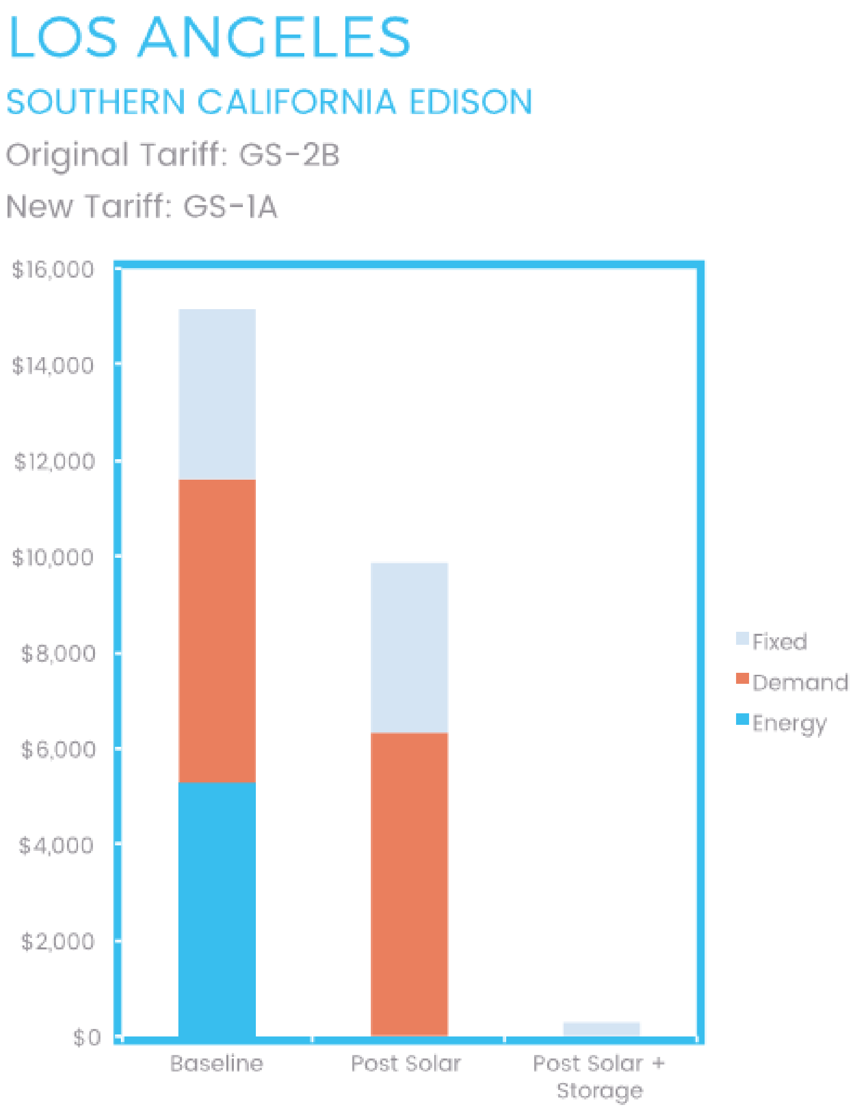
Installed!

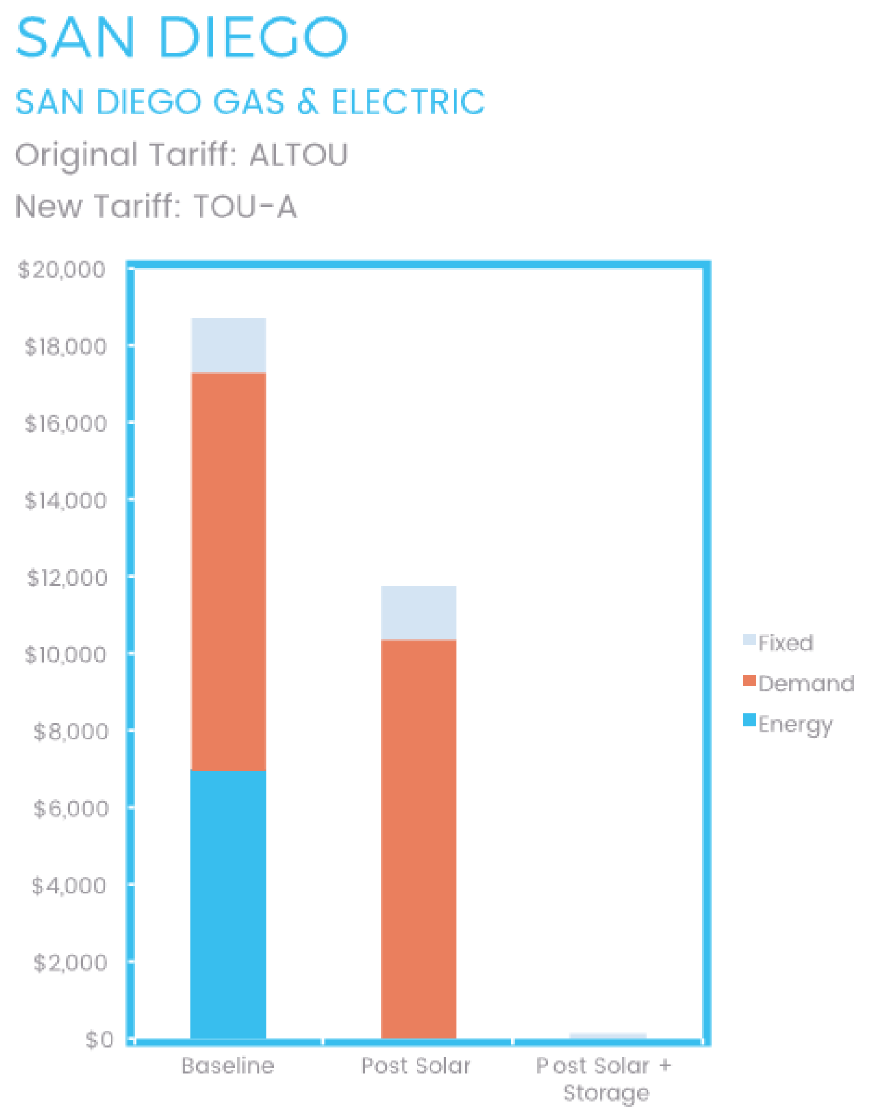
Battery Performance

- Goal was to keep peak demand below 50kW to avoid peak demand charges
- Most of the time below 10 kW
- Performance tests held under 10kw "demand peak"



Demand Charge Avoidance – Geli Study moving RMI to California

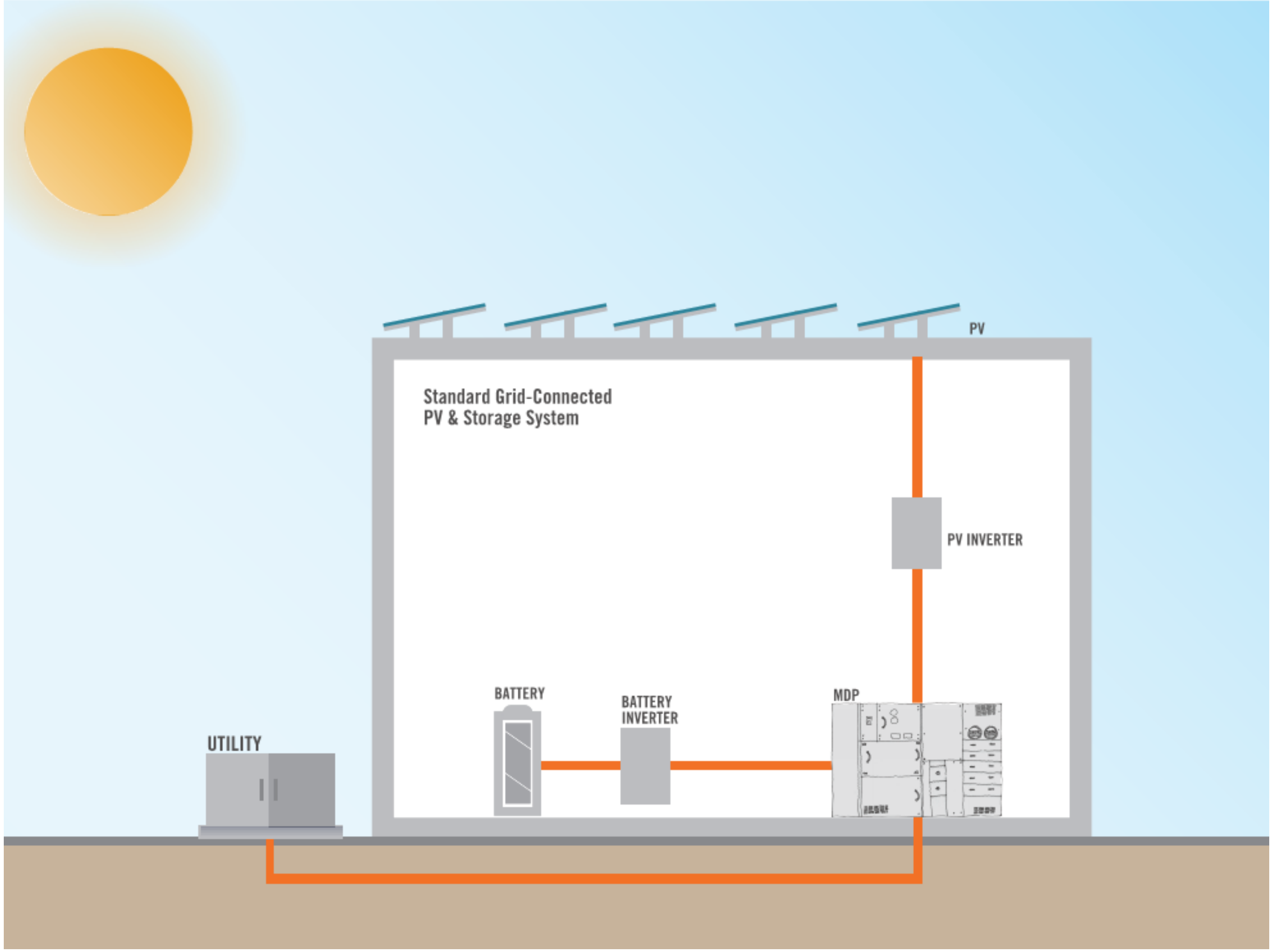




Geli Case Study

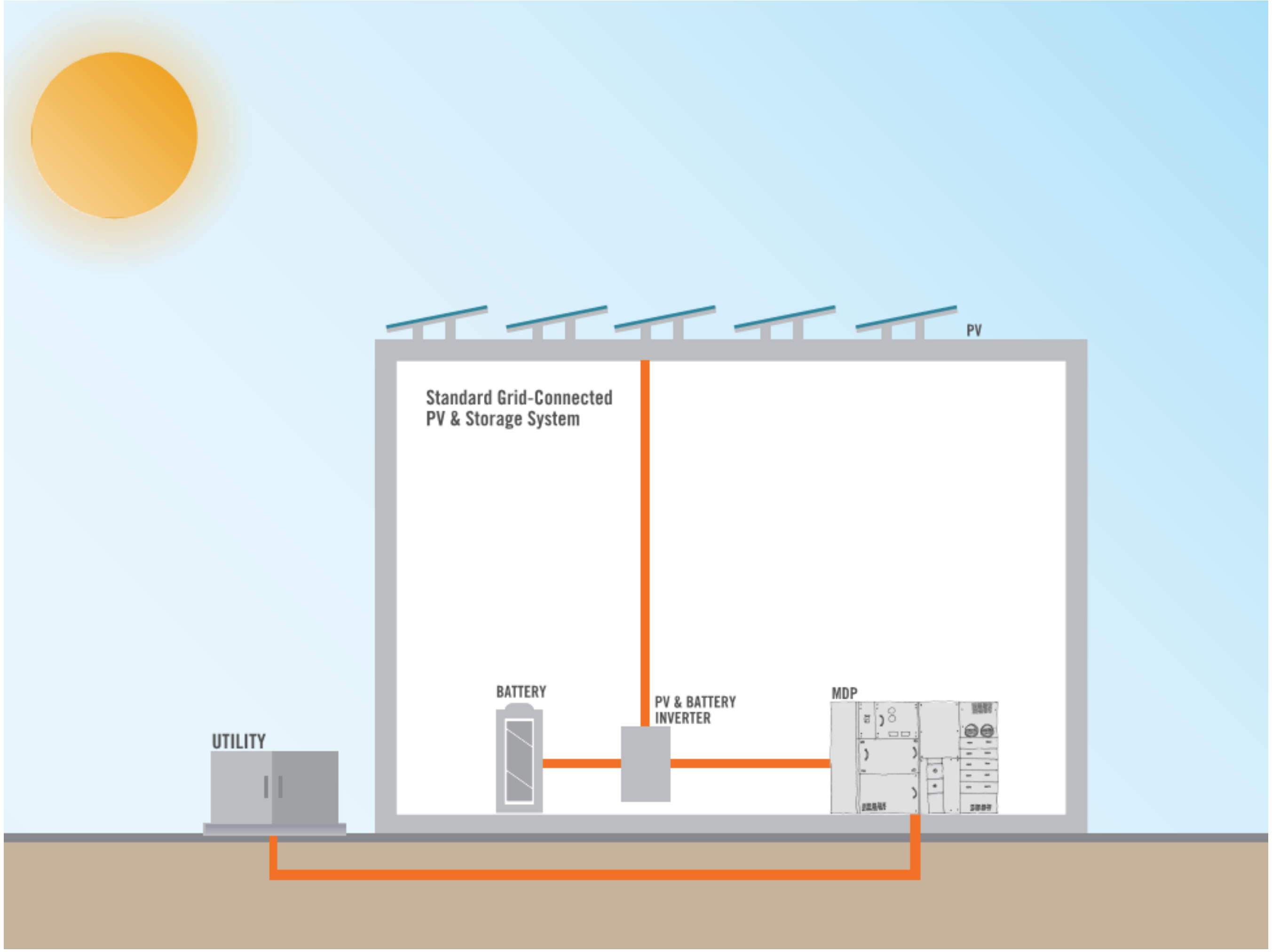
Traditional PV/Storage - RMI

Separate Inverters

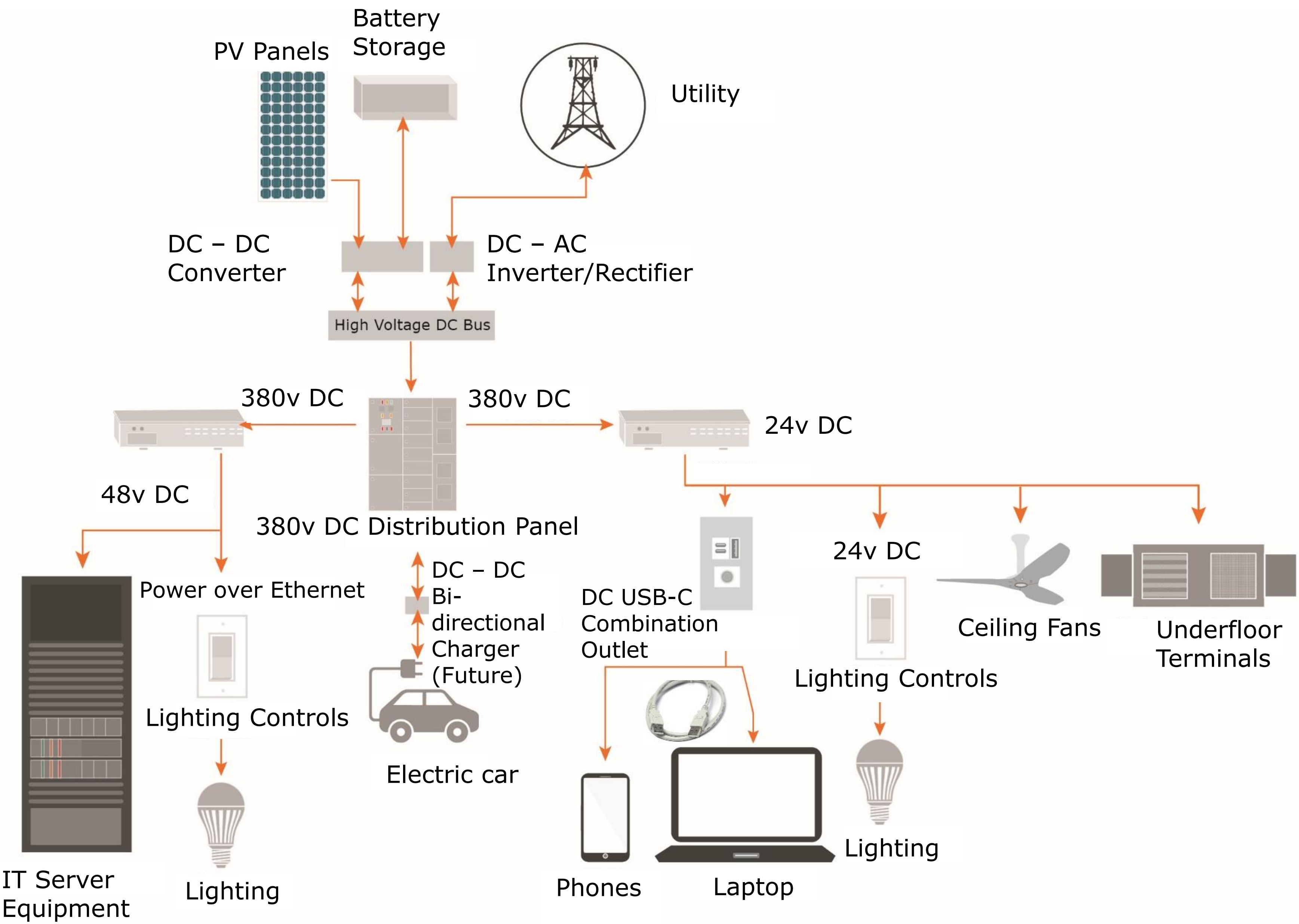


Shared DC Bus PV/Storage – Georgia Tech

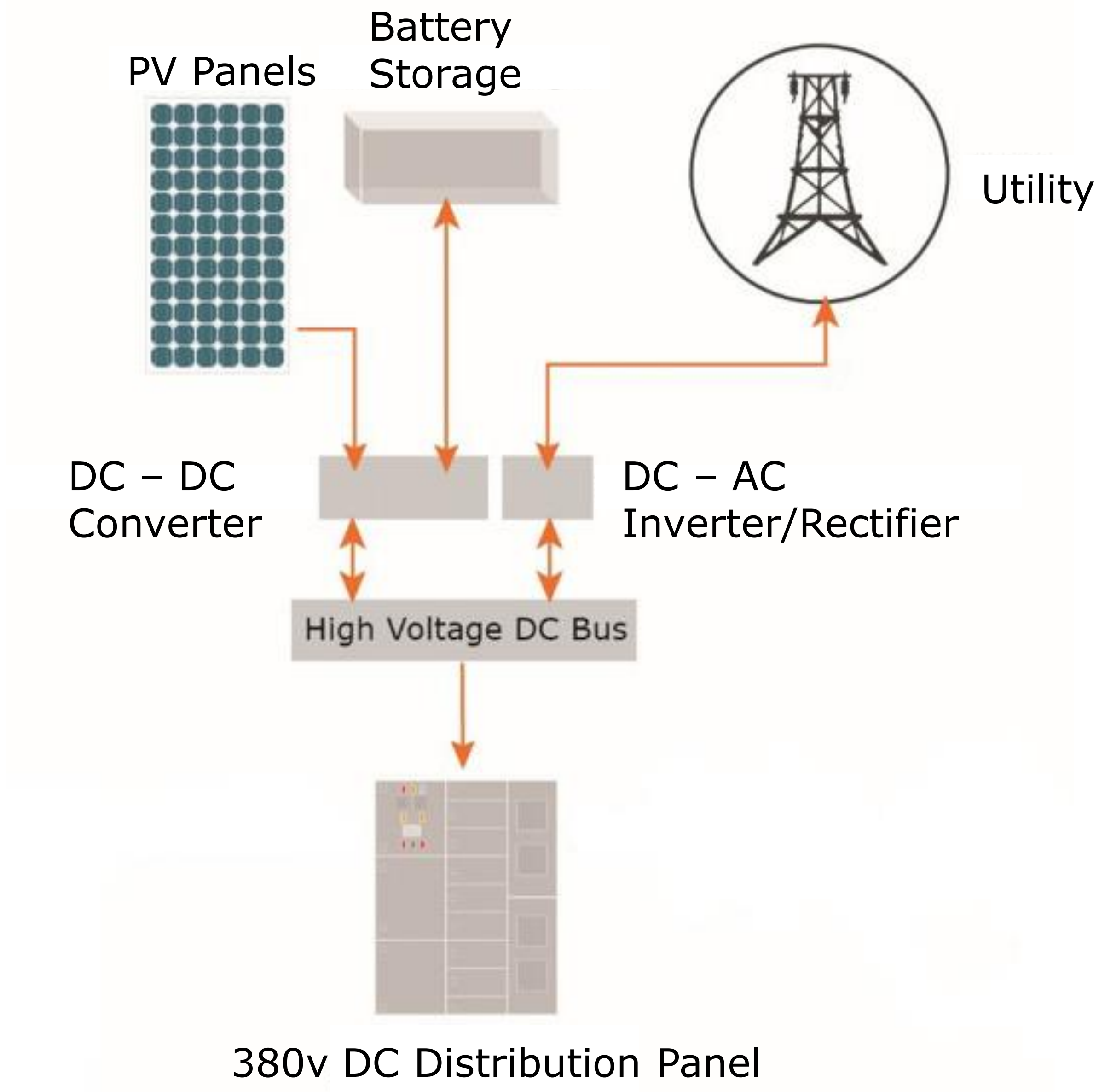
Shared Inverter



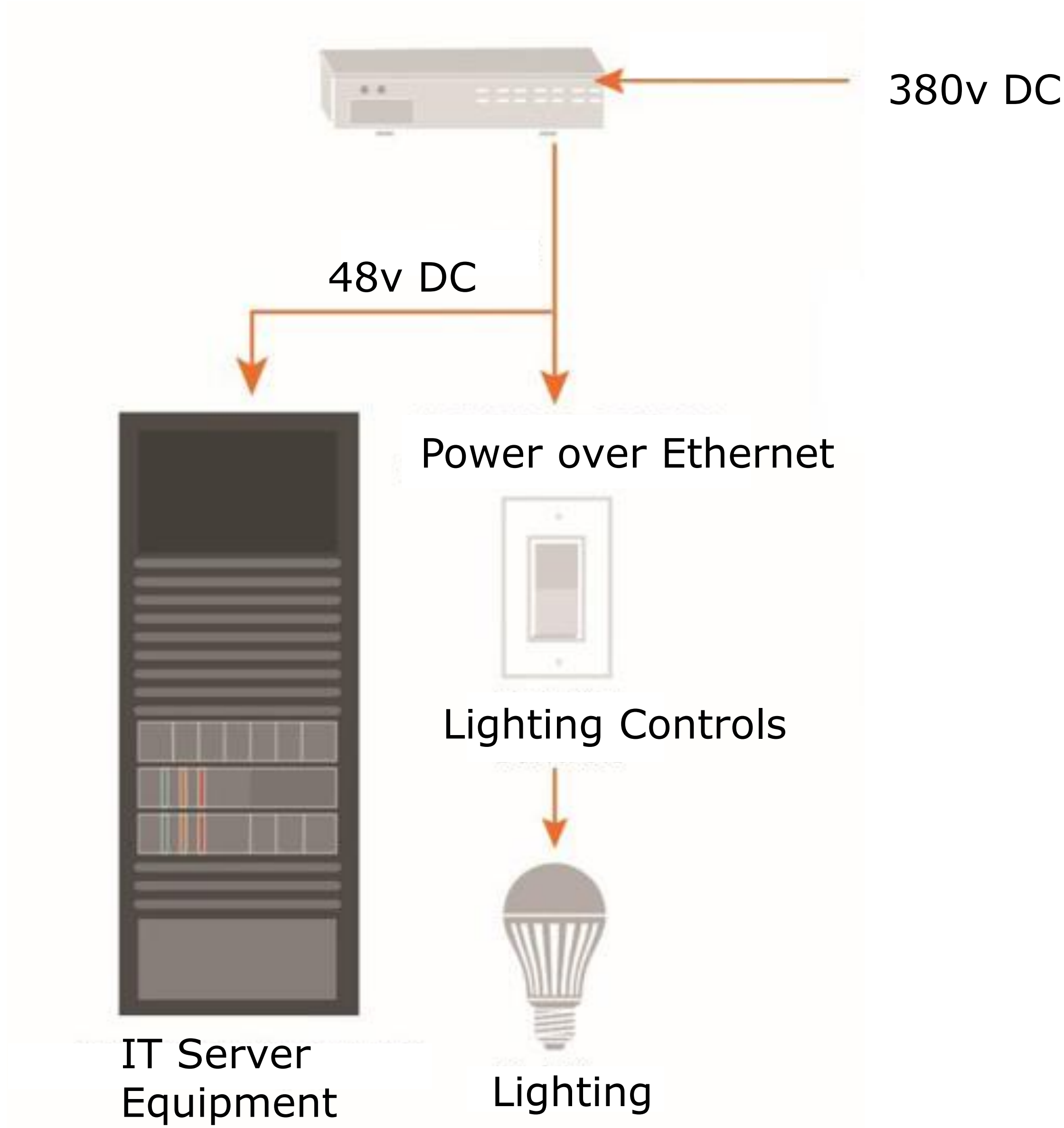
Shared DC Bus PV/Storage – Confidential Project



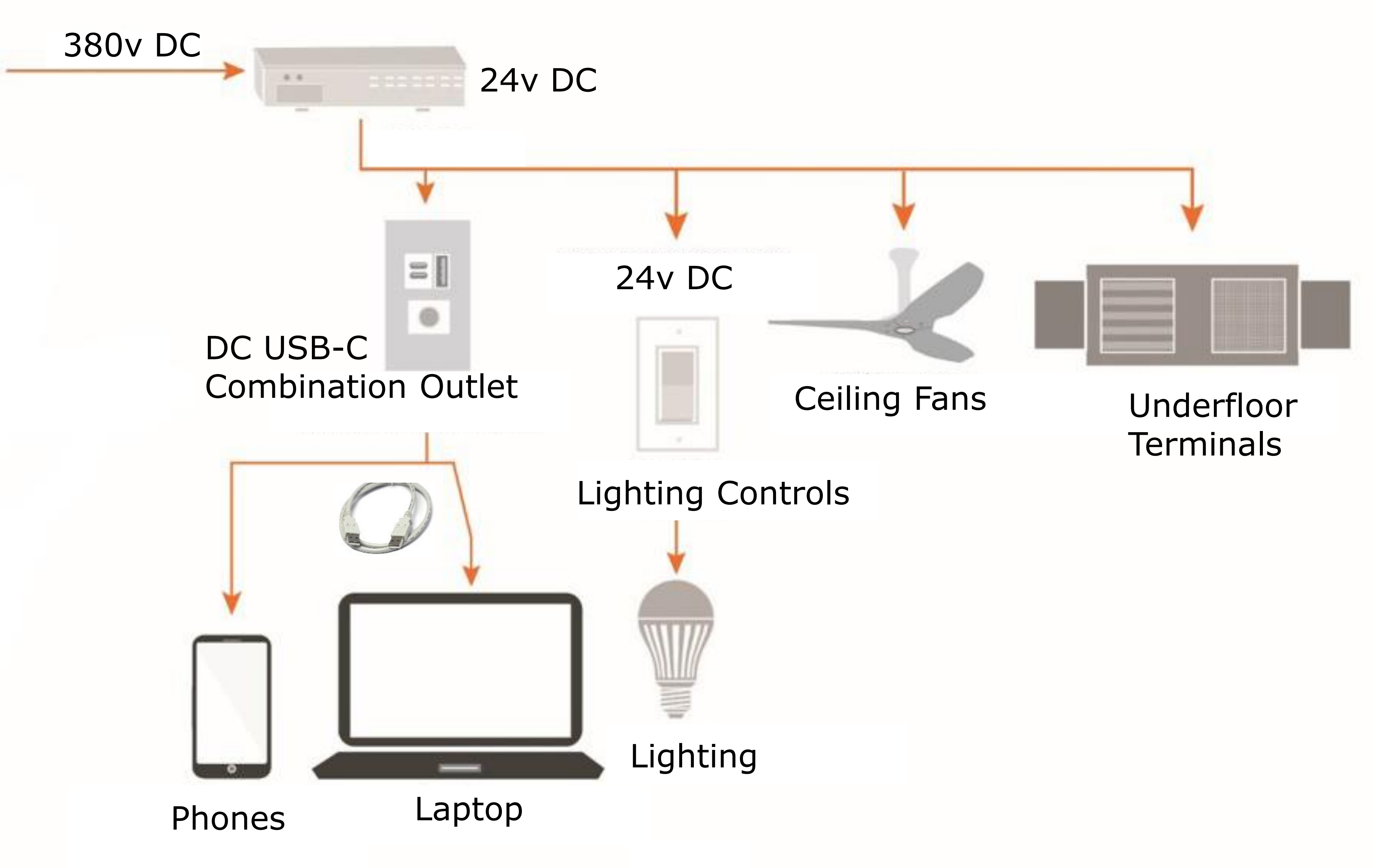
Shared DC Bus PV/Storage – Confidential Project



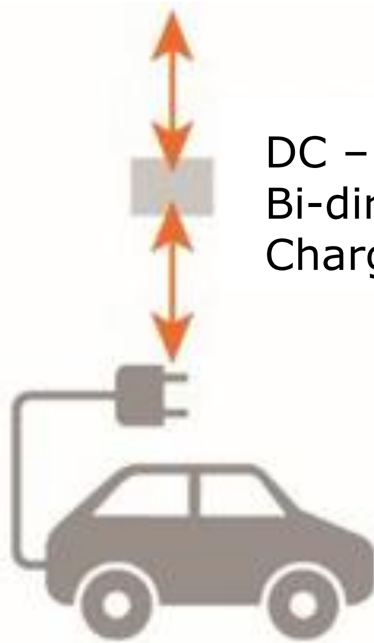
Shared DC Bus PV/Storage – Confidential Project



Shared DC Bus PV/Storage – Confidential Project



Shared DC Bus PV/Storage – Confidential Project



NETZERO ENERGY BUILDING CERTIFICATION℠

THE NET ZERO CHALLENGE

	SINGLE FAMILY NEW	RETRO-FIT	MULTI-FAMILY	LOW RISE OFFICE	MID & HIGH RISE OFFICE	EDUCA-TIONAL	INSTITU-TIONAL
HOT HUMID		Willowbrook		PNC BANK		HPA	AS-EPA
MIXED HUMID	Zero Energy House					Tyson	Brock Chrisney
HOT DRY				DPR Phoenix			
MIXED DRY				Integral Office			
MARINE	Eco-Sense Residence	Zero Cottage	zHome	Painter's Hall	Bullitt Center	Bertschi School	Packard Foundation HQ
COLD		Mission Zero		Omega Institute		Hood River Middle School	Phipps
VERY COLD				RMI			

Creating a better environment

PAE

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By the numbers

DESIGN TARGET	UNITS	EXISTING (U.S.)	BETTER	BEST PRACTICE	RMI DESIGN
Delivered energy intensity	kBTU/sf-y	90	40-60	<30	17.2
Lighting power density: connected load	W/sf	1.5	0.8	0.4-0.6	0.49
Lighting power density: as-used net of controls	W/sf	1.5	0.6	0.1-0.3	0.27
Installed computers/appliances/tasklighting	W/sf	4-6	1-2	<0.5	0.88
Glazing R-value (center of glass)	sf-F°-h/BTU	1-2	6-10	≥20	12
Window R-value (including frame)	sf-F°-h/BTU	1	3	7-8	6.5
Glazing spectral selectivity*	$k_e = T_{vis}/SC$	1.0	1.2	>2.0	1.5-2.3
Roof solar absorptance and infrared emittance	α, ε	0.8, 0.2	0.4, 0.4	0.08, 0.97	N/A, PV Covers Roof
Whole-building airtightness	cfm/sf @ 0.3" w.g.	1.0	0.4	<0.25	0.20
Installed mechanical cooling	sf/ton	250-350	500-600	1,200-1,400+	None
Cooling design-hour efficiency**	kW/ton	1.9	1.2-1.5	<0.6	0.00
Level of installed perimeter heating	-	extensive	minimal	none	minimal
*A measure of how well the glacing lets in light without heat **Whole system, including pumps, fans, and cooling towers as well as chillers					
ADDITIONAL DESIGN TARGET ITEMS					
Wall R-value	sf-F°-h/BTU				R-50
Roof R-value	sf-F°-h/BTU				R-67 [1]
Window to wall ratio	%				26%
Heat recovery effectiveness	%				90% (Winter)
Installed mechanical heating	BTU/h-sf				7.5 BTU/h-sf

1. Individual roof sections vary between R-40 and R-80 for different shapes and constructions. This value represents an area-weighted average.

This table (except for the "Additional Target Items") is from a Book entitled "Re-inventing Fire: Bold Business Solutions for the New Energy Era" by Amory Lovins (2011). It is Table 3- "Benchmarking a New U.S. Office Building" (p. 108). These targets were developed by the Rocky Mountain Institute and are typical of a new midsize -to-large Class A office in an average US climate like the Mid-Atlantic states.

PAE