PAE

architectural applications a2

Energy and Comfort Modeling for the Net Zero Rocky Mountain Institute Headquarters

August 19, 2015

BUILDING ENERGY SIMULATION FORUM

Marc Brune, Ben Burnett, John Breshears

inspire interpret integrate

Project Visionary

Amory B. Lovins:

Oxford Don

MacArthur Fellow

Early green building theorist (Lovins Green Home, 1983)

Energy policy strategist ("The Soft Path" and others)

Founder, Rocky Mountain Institute (1982)

"At Rocky Mountain Institute we are practitioners, not theorists. We do solutions, not problems. We do transformation, not incrementalism."

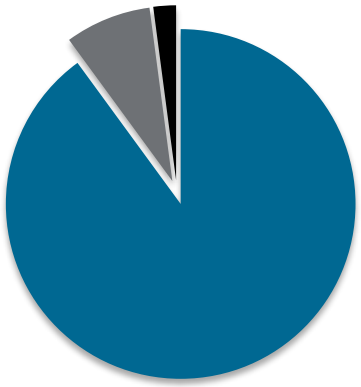
- Amory Lovins, RMI

Project Goals

1. LEED Platinum
2. Living Building Challenge Petal Certification
    1. Net Zero Energy
    2. Site
    3. Health
    4. Equity
    5. Beauty
3. Passive House Air Tightness Standards
4. No Mechanical Systems
5. Architecture 2030 Challenge goals (exceeded)
6. Energy Star target score of 100

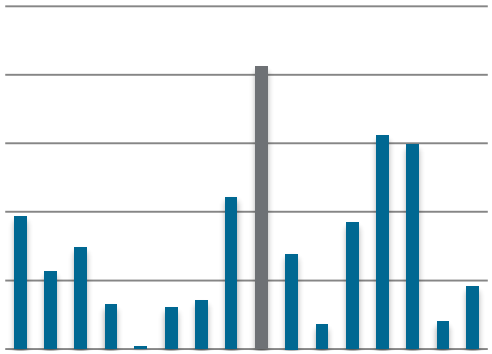
Project Replicability

architectural applications a2



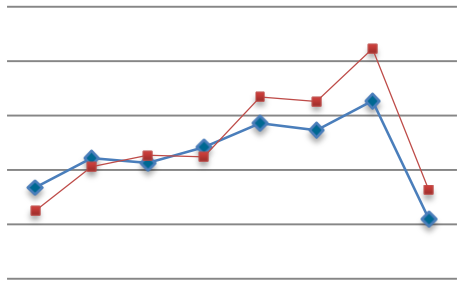
90%

of commercial buildings are under 25,000 SF



Offices

are the biggest use of commercial buildings under 25,000 SF



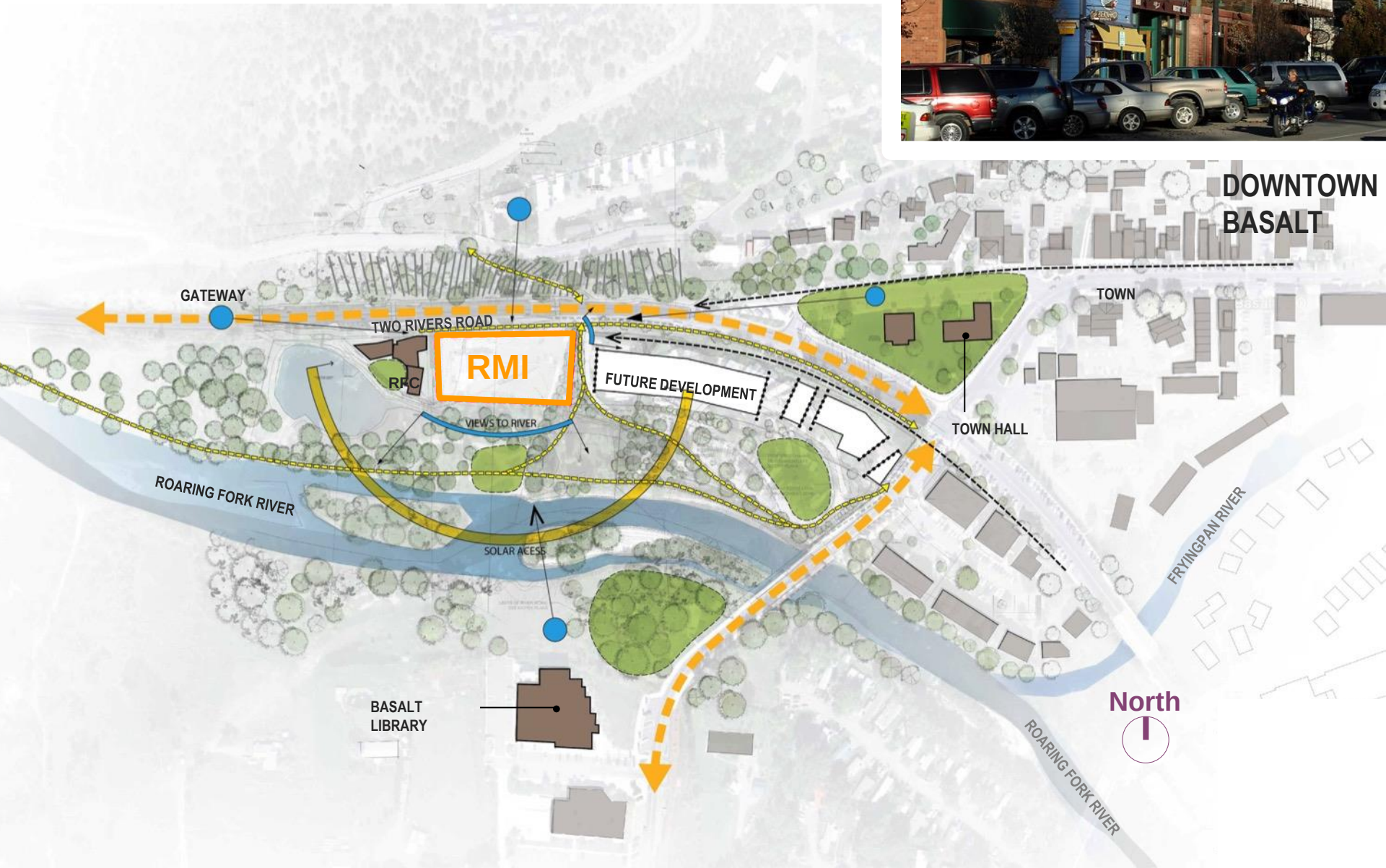
Half

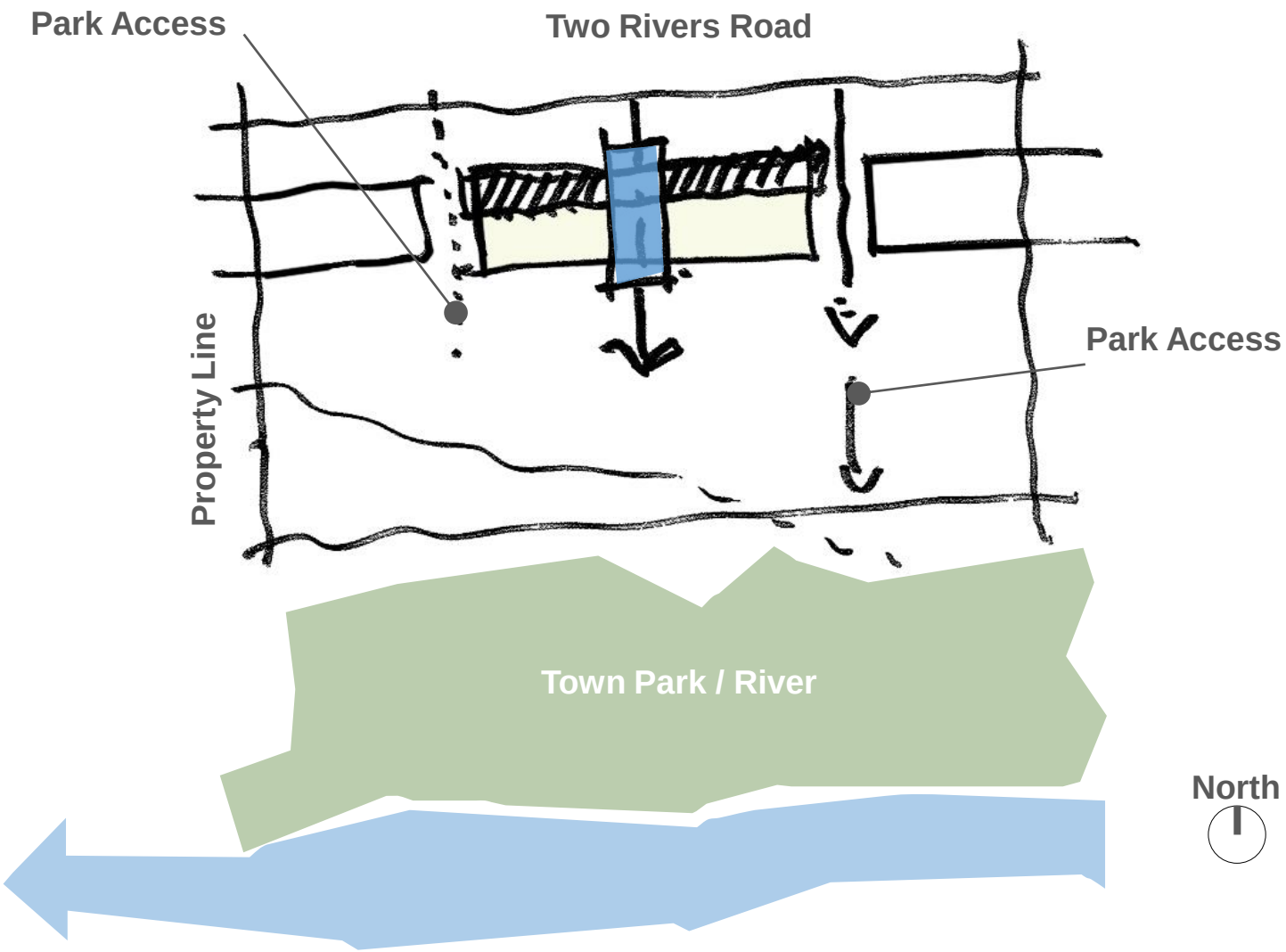
of commercial buildings under 25,000 SF are owner occupied

By 2035, about three-fourths of U.S. floor space will be new or renovated.

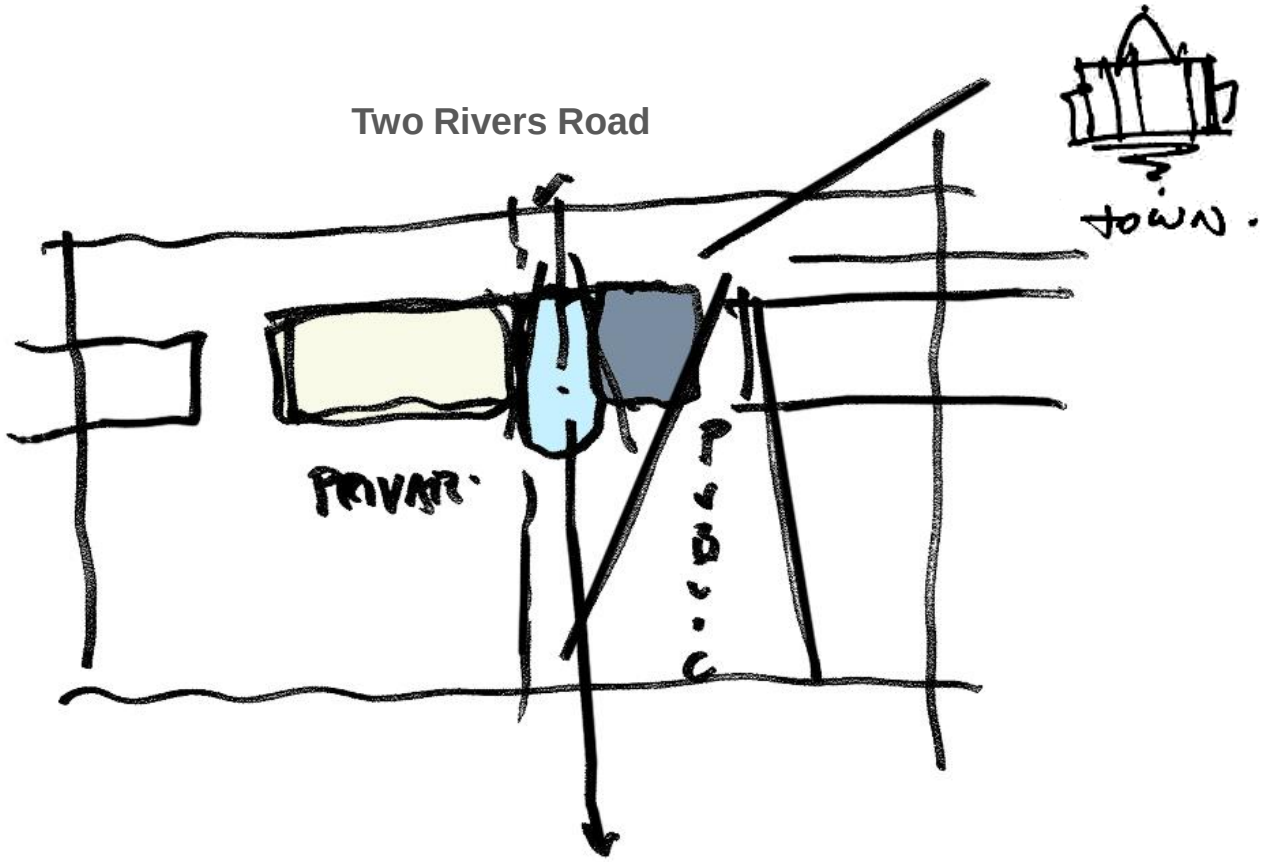

Ogden
Layton
Bountiful
Salt Lake City
Tooele
Sandy
Provo
Ashley National Forest
Price
Utah
Fishlake National Forest
Laramie
Cheyenne
Sidney
North Platte
Routt National Forest
Sterling
Greeley
Longmont
Boulder
Denver
Centennial
Castle Rock
McCook
Glenwood Springs
Grand Junction
Grand Mesa National Forest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


ROARING FORK VALLEY
I-70
I-70 TO EAGLE / VAIL
I-70 TO GRAND JUNTION
GLENWOOD SPRINGS
82
CARBONDALE
ROARING FORK RIVER
BASALT
FRYING PAN ROAD
FRYING PAN RIVER
RUEDI RESERVOIR
82
133
CRYSTAL RIVER
MT. SOPRIS
OLD SNOWMASS
WOODY CREEK
SNOWMASS VILLAGE
CLICK TO ZOOM +
ASPEN
CLICK TO ZOOM +
BUTTERMILK/ ASPEN HIGHLANDS
CLICK TO ZOOM +
REDSTONE
CAPITOL PEAK
133
HWY 133 TO MCCLURE PASS
PYRAMID PEAK
82
TO INDEPENDENCE PASS
N
W
E
S


DOWNTOWN
BASALT
GATEWAY
TWO RIVERS ROAD
RMI
RFC
FUTURE DEVELOPMENT
VIEWS TO RIVER
TOWN
TOWN HALL
ROARING FORK RIVER
SOLAR ACESS
FRYINGPAN RIVER
BASALT
LIBRARY
North
ROARING FORK RIVER


Park Access
Two Rivers Road
Property Line
Park Access
Town Park / River
North

Town Access



View

North

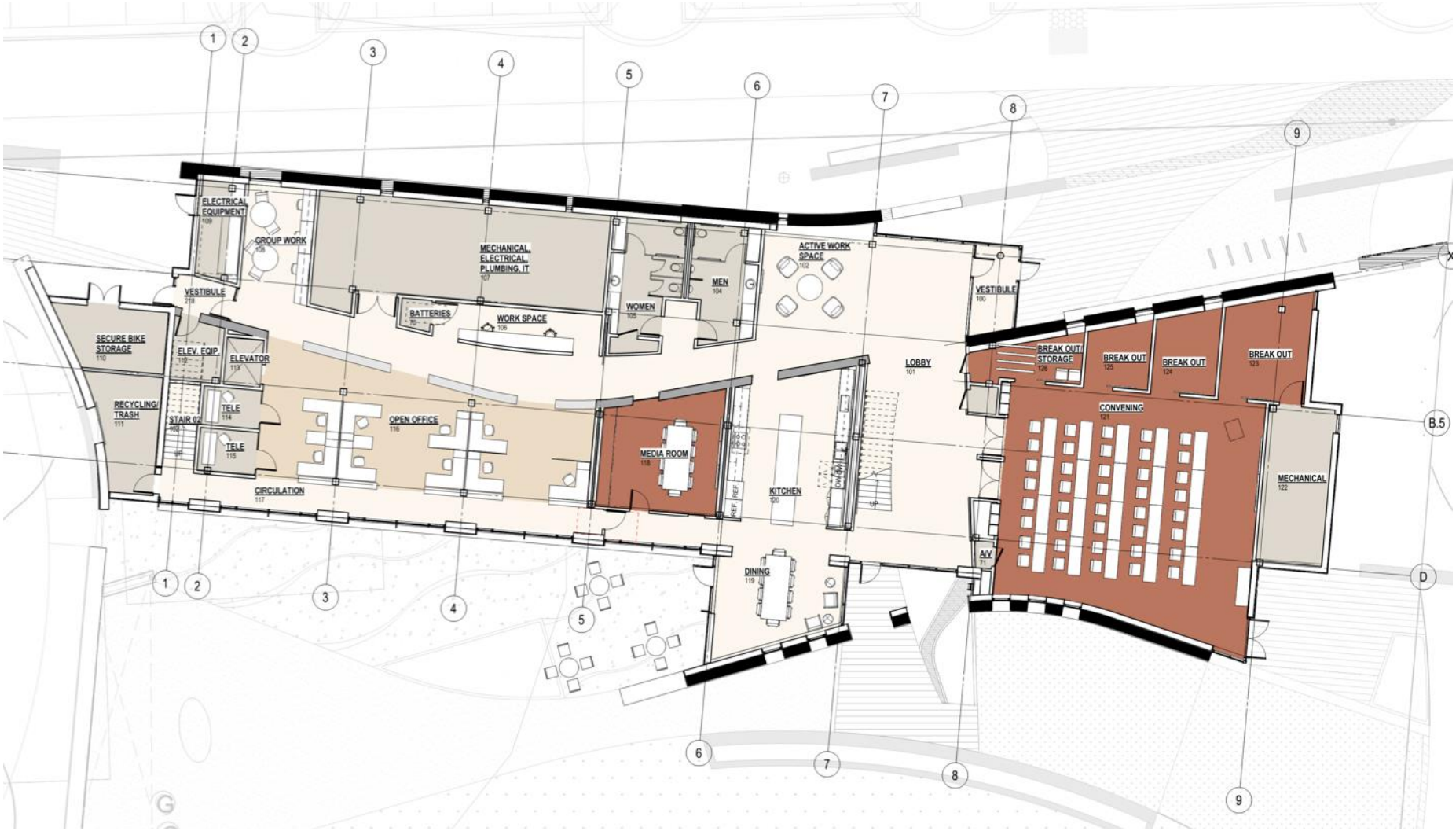
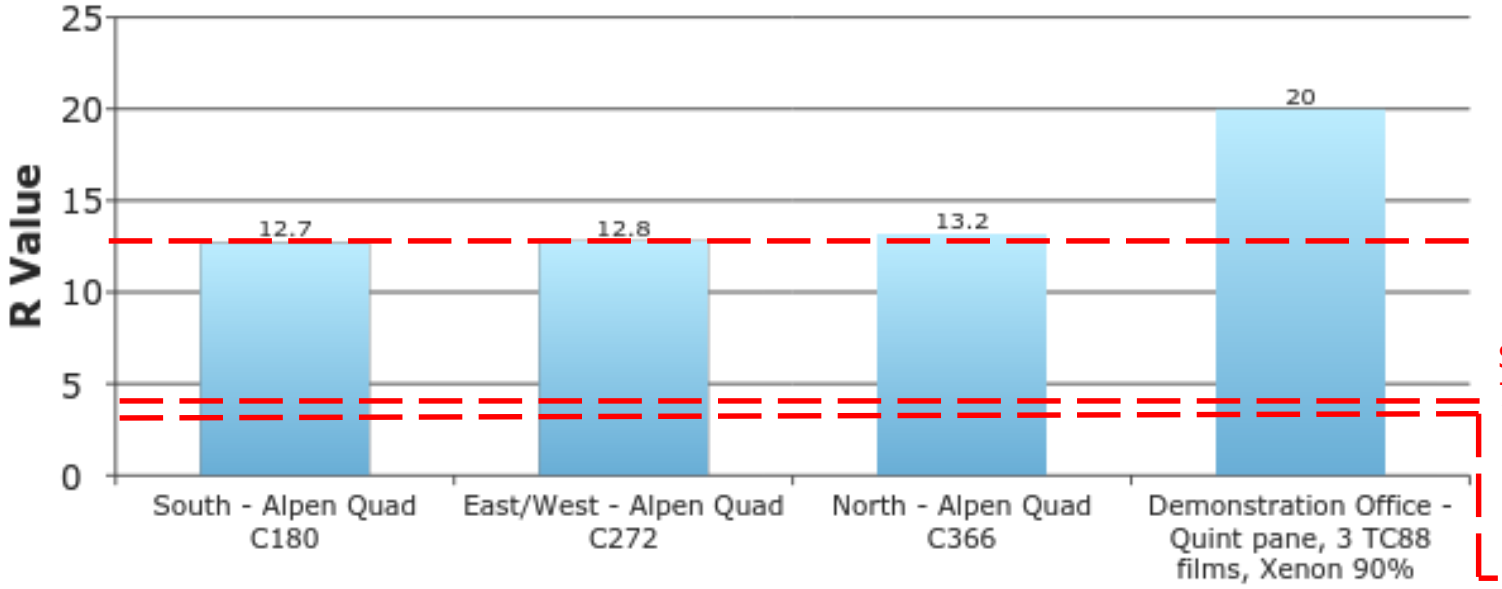
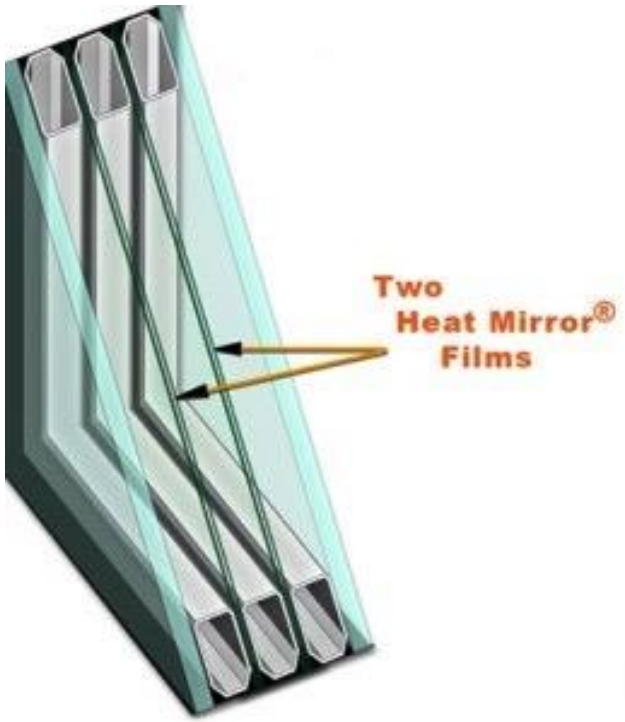
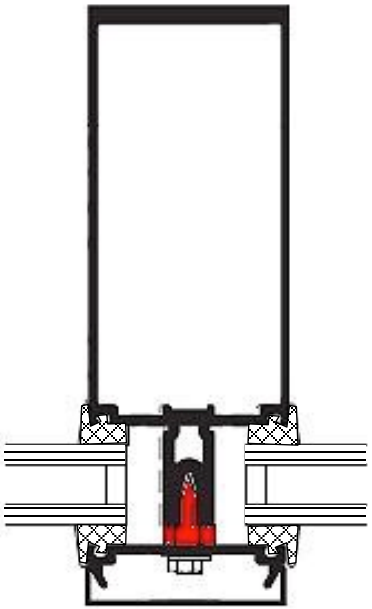

ELECTRICAL EQUIPMENT 109
GROUP WORK 108
MECHANICAL, ELECTRICAL, PLUMBING, IT 107
BATTERIES 70
WORK SPACE 106
WOMEN 105
MEN 104
ACTIVE WORK SPACE 102
VESTIBULE 100
VESTIBULE 118
SECURE BIKE STORAGE 110
ELEV. EQIP. 112
ELEVATOR 113
LOBBY 101
BREAK OUT STORAGE 126
BREAK OUT 125
BREAK OUT 124
BREAK OUT 123
RECYCLING/ TRASH 111
STAIR 02
TELE 114
TELE 115
OPEN OFFICE 116
CONVENING 121
MEDIA ROOM 118
KITCHEN 120
MECHANICAL 122
CIRCULATION 117
A/V 71
DINING 119
1
2
3
4
5
6
7
8
9
B.5
D
G

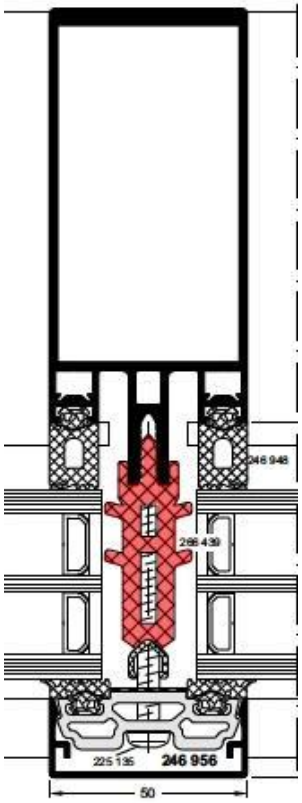
Image courtesy of ZGF Architects LLP

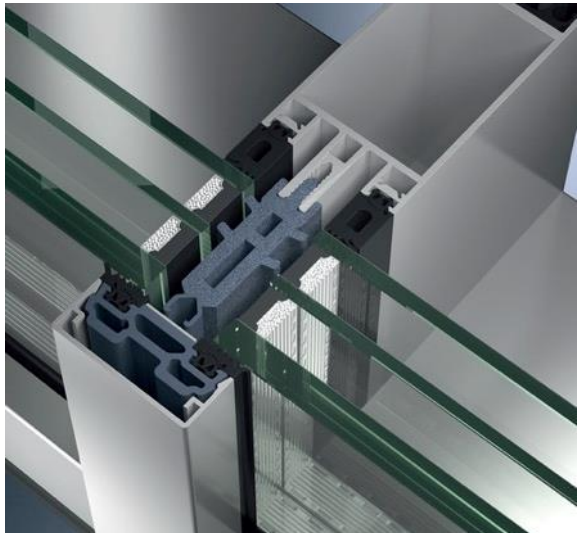
Image courtesy of ZGF Architects LLP

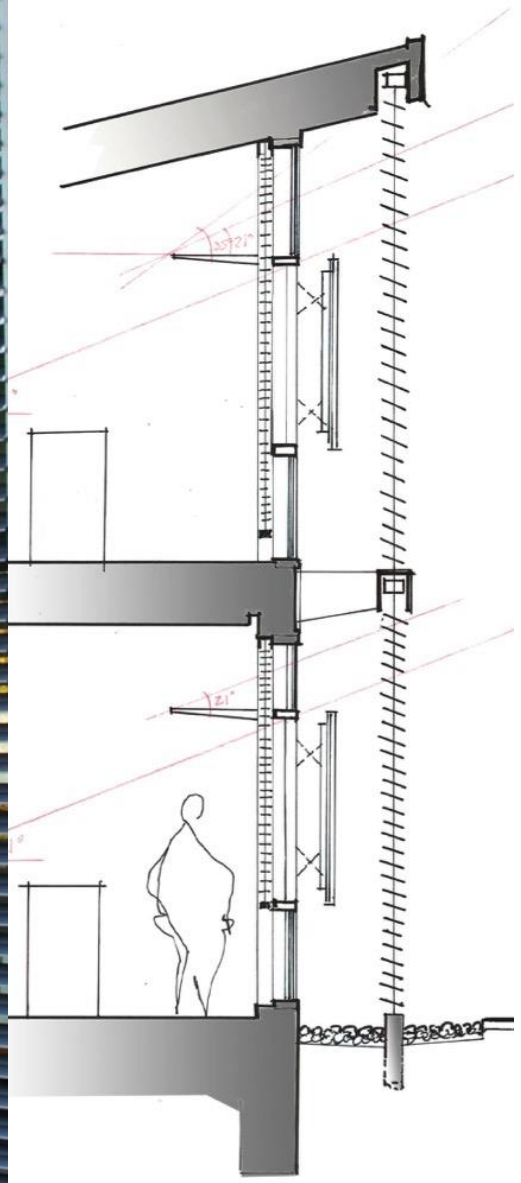

R Value
25
20
15
10
5
0
12.7
12.8
13.2
20
South - Alpen Quad C180
East/West - Alpen Quad C272
North - Alpen Quad C366
Demonstration Office - Quint pane, 3 TC88 films, Xenon 90%
R-13 2x4 wall with batt insulation
Solarban 70XL
R-2.6 Window code minimum.


Two Heat Mirror® Films

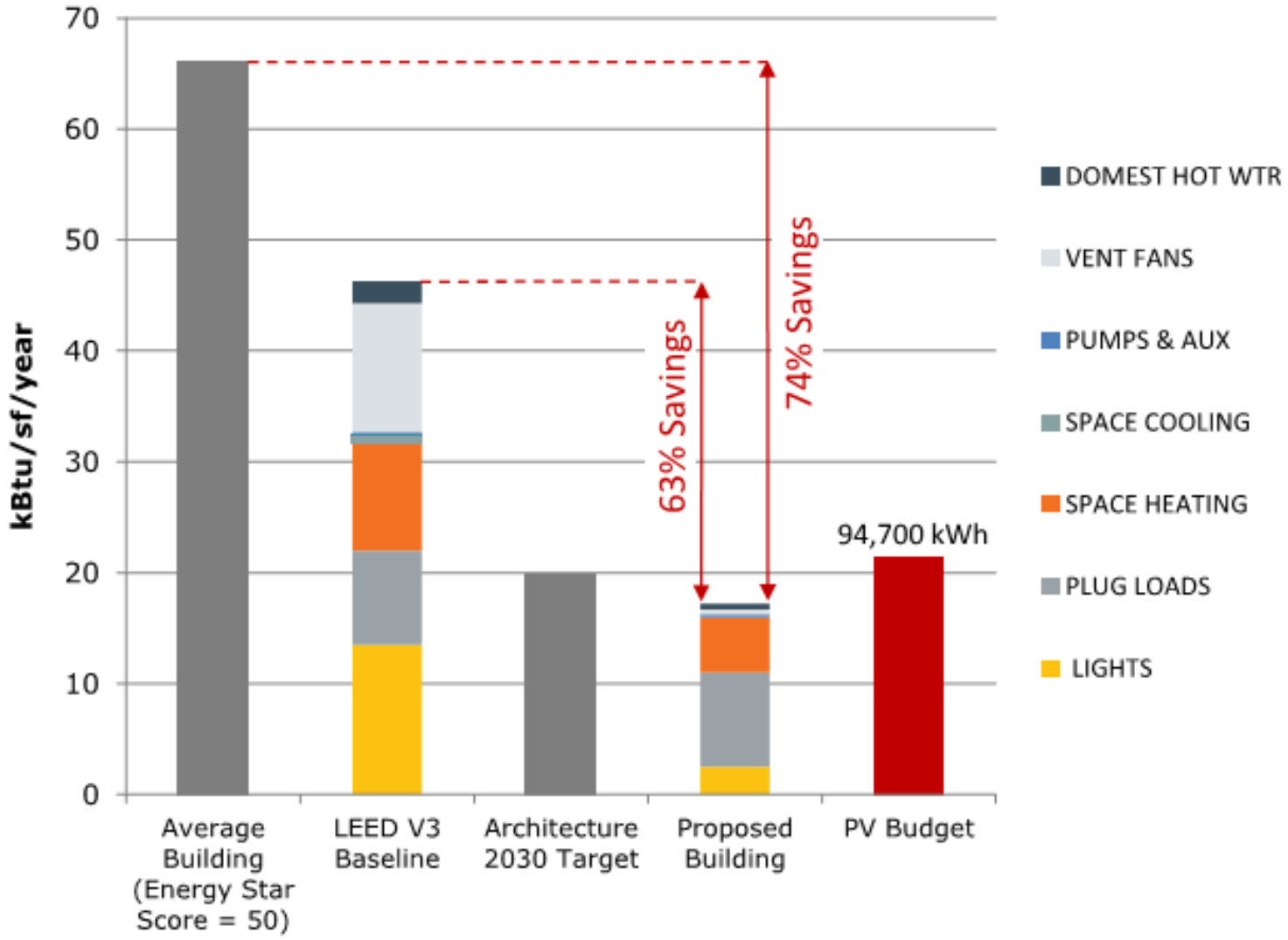



246 948
295 439
225 135
246 956
50

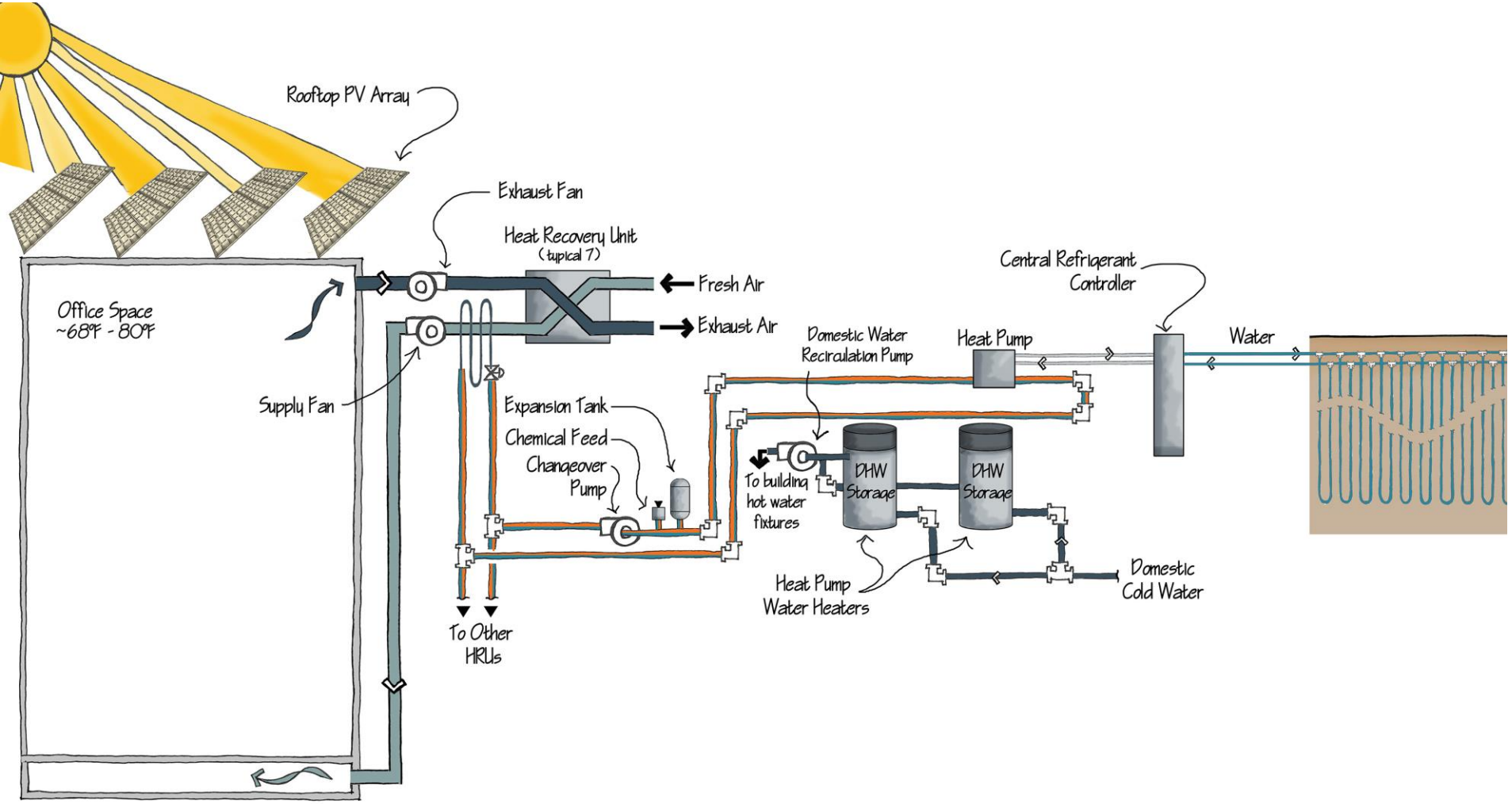




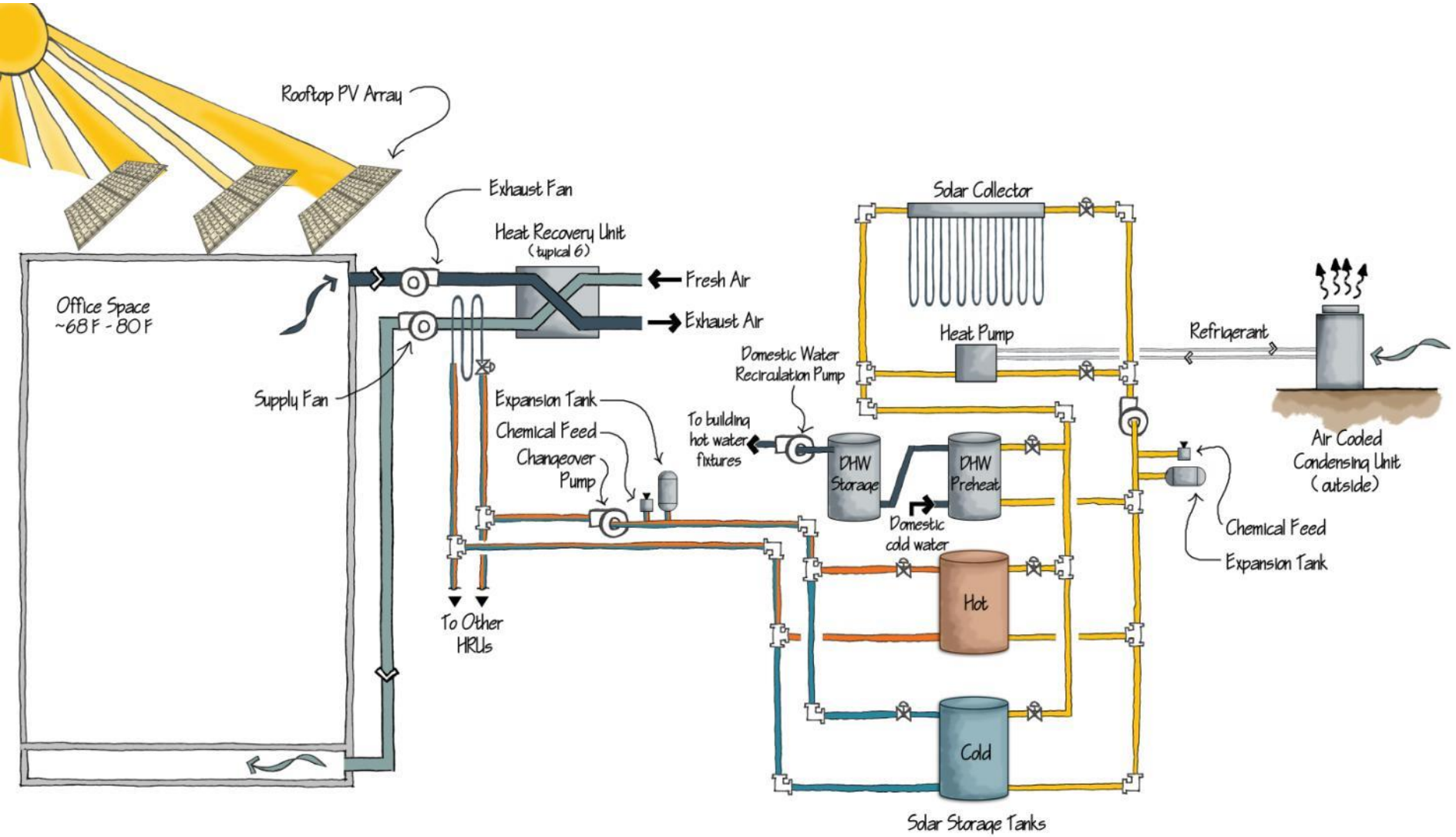
Energy Goals



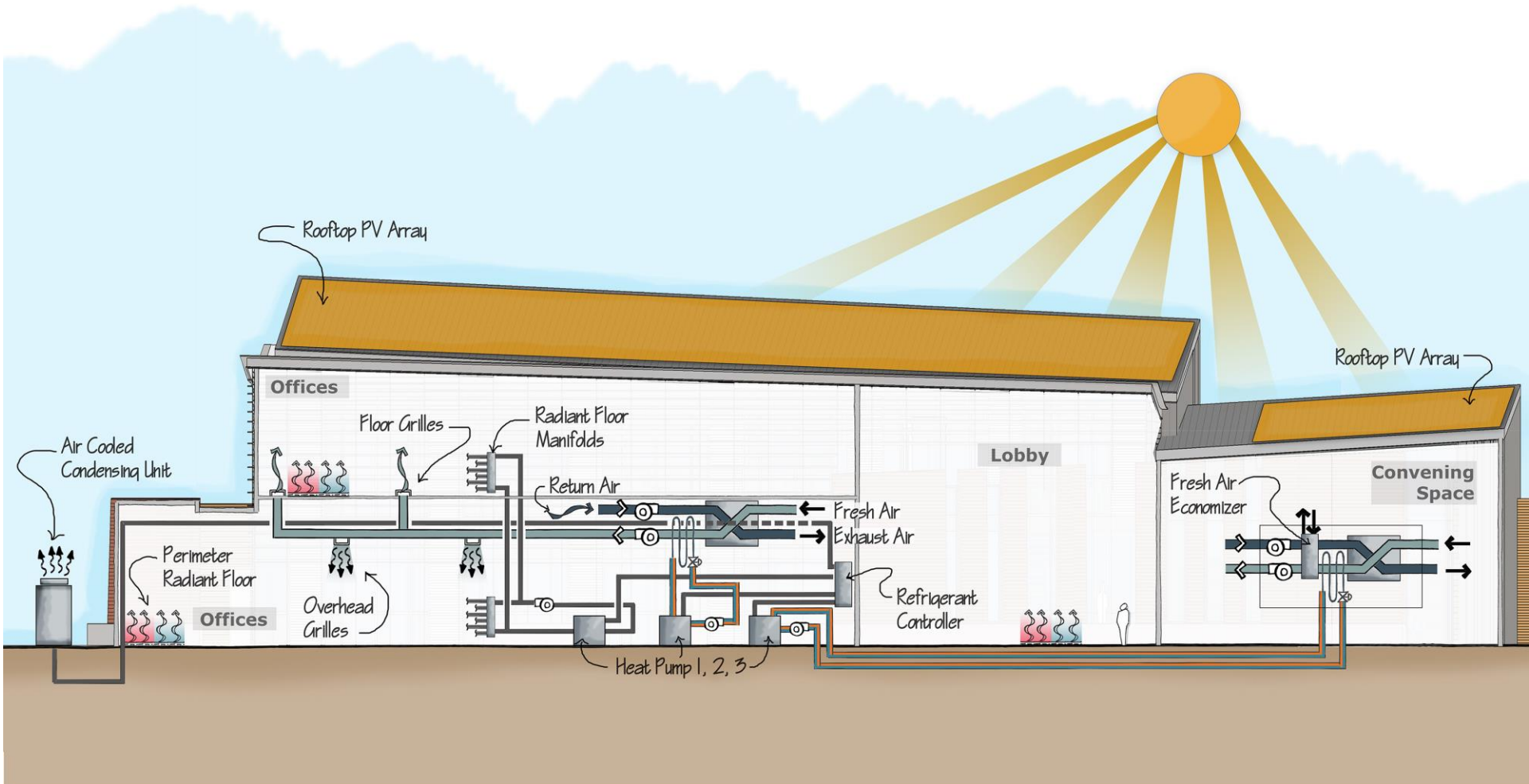
HVAC Systems: Geothermal



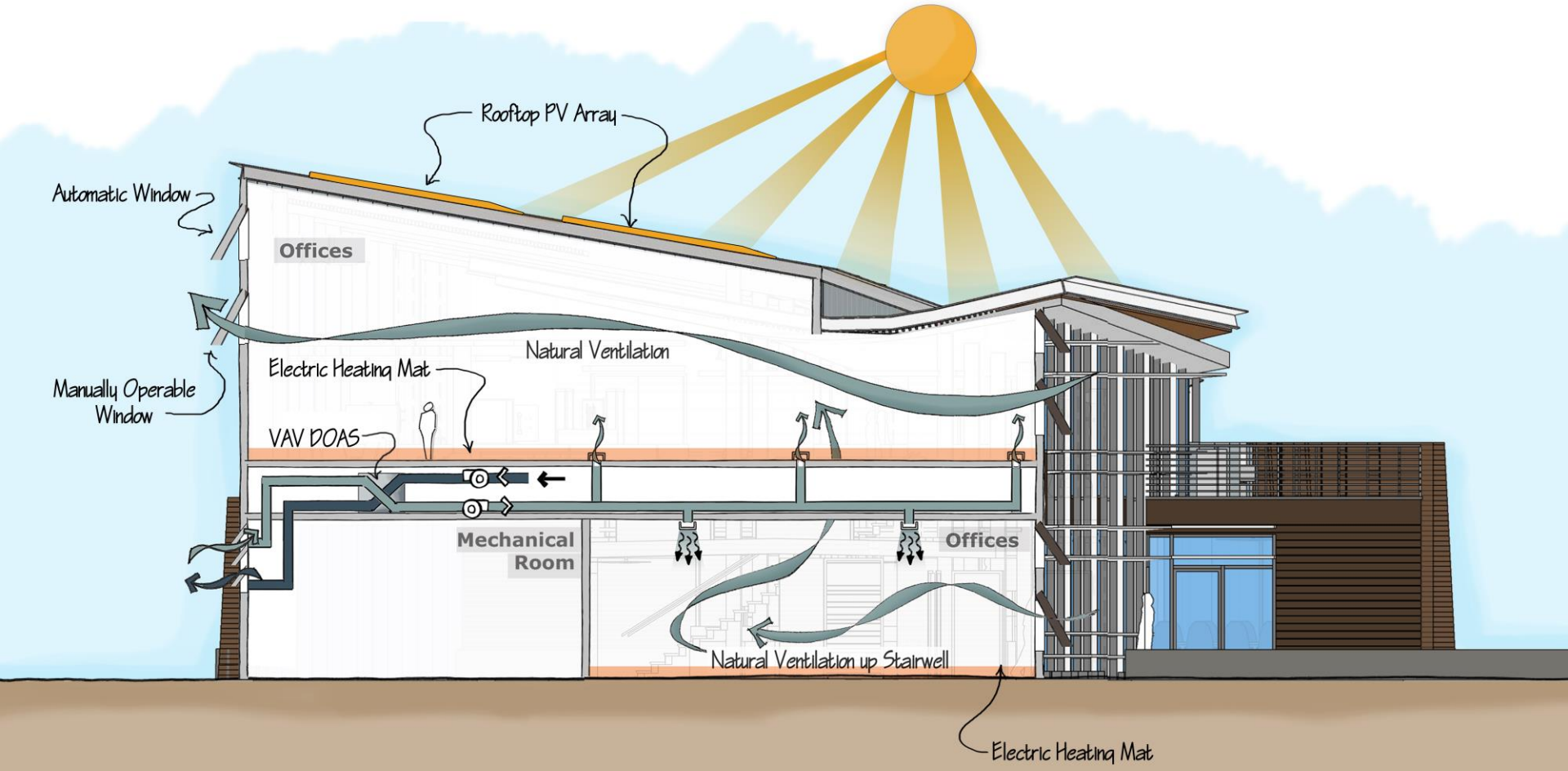
HVAC Systems: Solar + Air Source



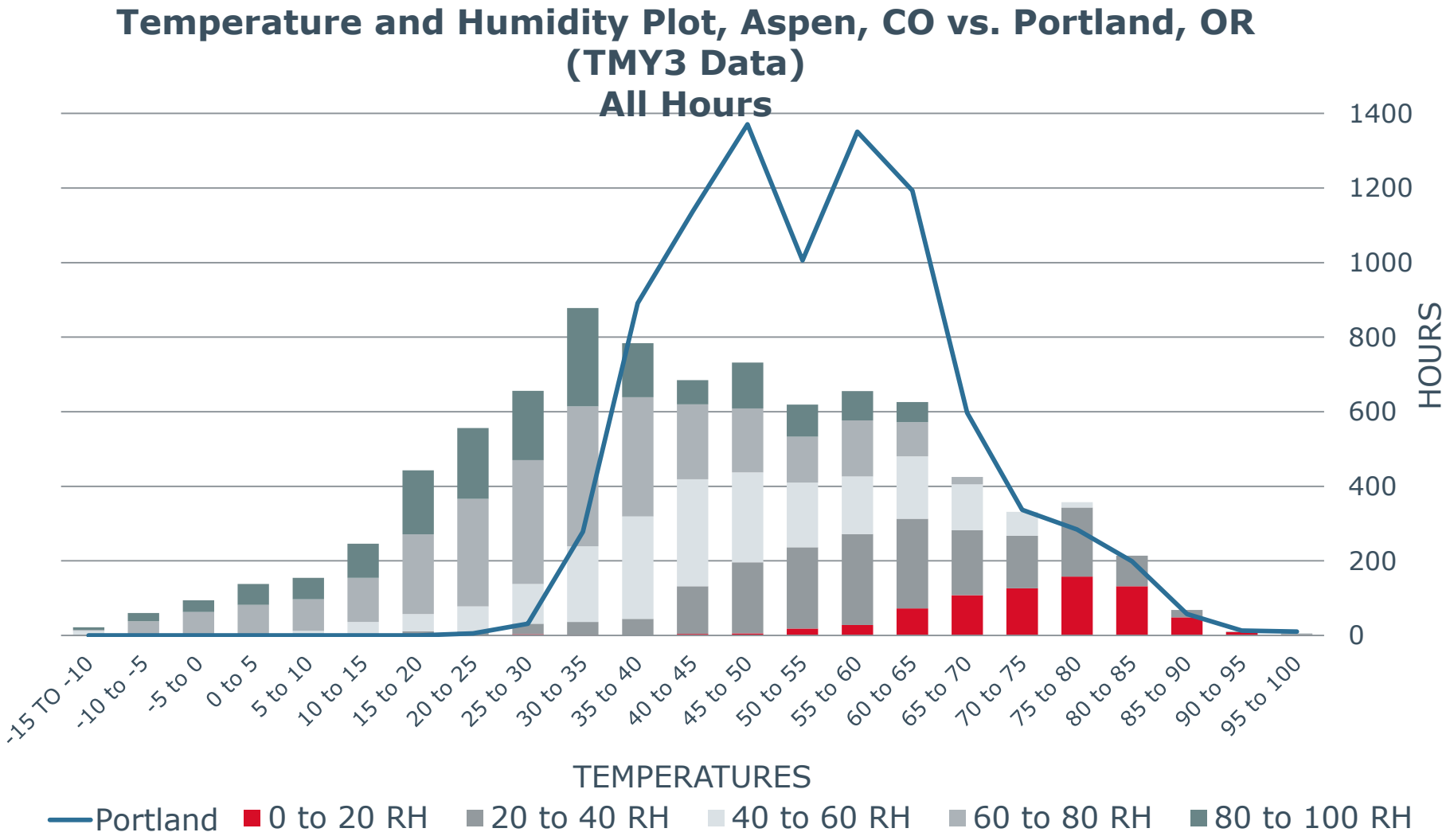
HVAC Systems: Just Air Cooled



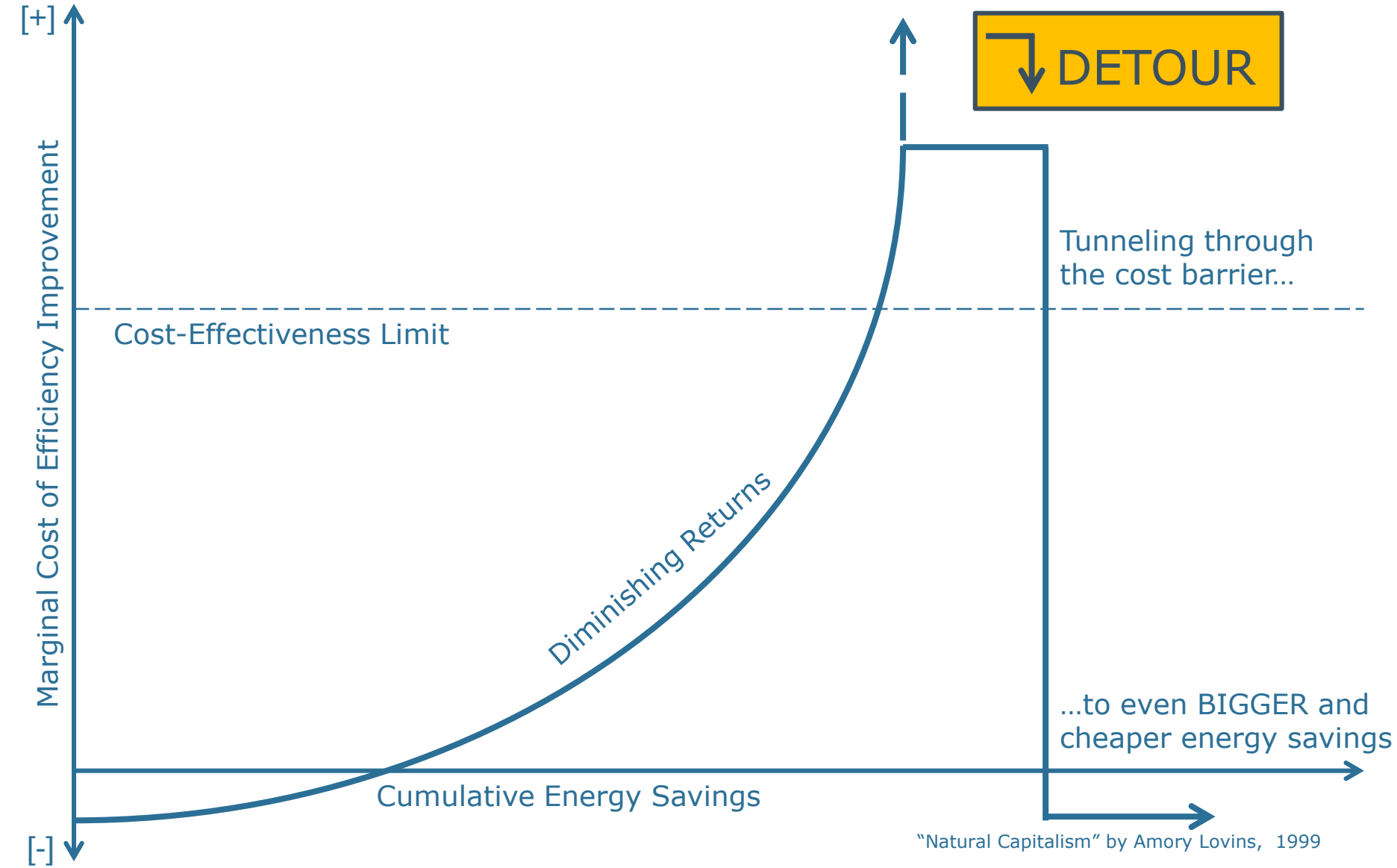
HVAC Systems: No Cooling, Electric Heating



Climate


Temperature and Humidity Plot, Aspen, CO vs. Portland, OR
(TMY3 Data)
All Hours
1400
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
Portland
0 to 20 RH
20 to 40 RH
40 to 60 RH
60 to 80 RH
80 to 100 RH

Tunneling Through the Cost Barrier



Tunneling Through the Cost Barrier

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.

Tunneling Through the Cost Barrier

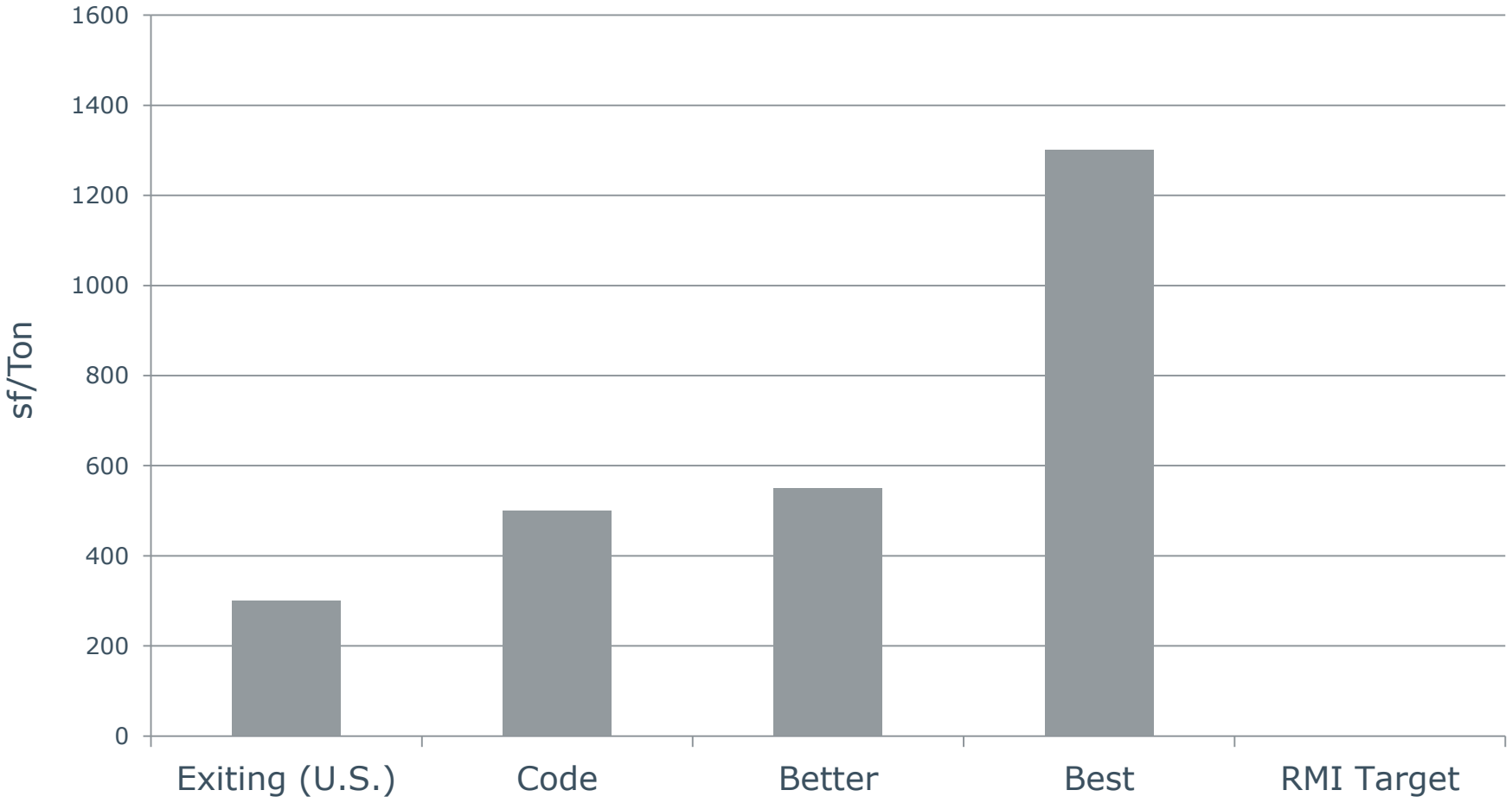
DESIGN TARGET	UNITS	EXISTING (U.S.)	BETTER	BEST PRACTICE	RMI DESIGN
Delivered energy intensity	kBTU/sf-y	90	40-60	<30	17.2
Lighting power density: connected load	W/sf	1.5	0.8	0.4-0.6	0.49
Lighting power density: as-used net of controls	W/sf	1.5	0.6	0.1-0.3	0.27
Installed computers/appliances/tasklighting	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.

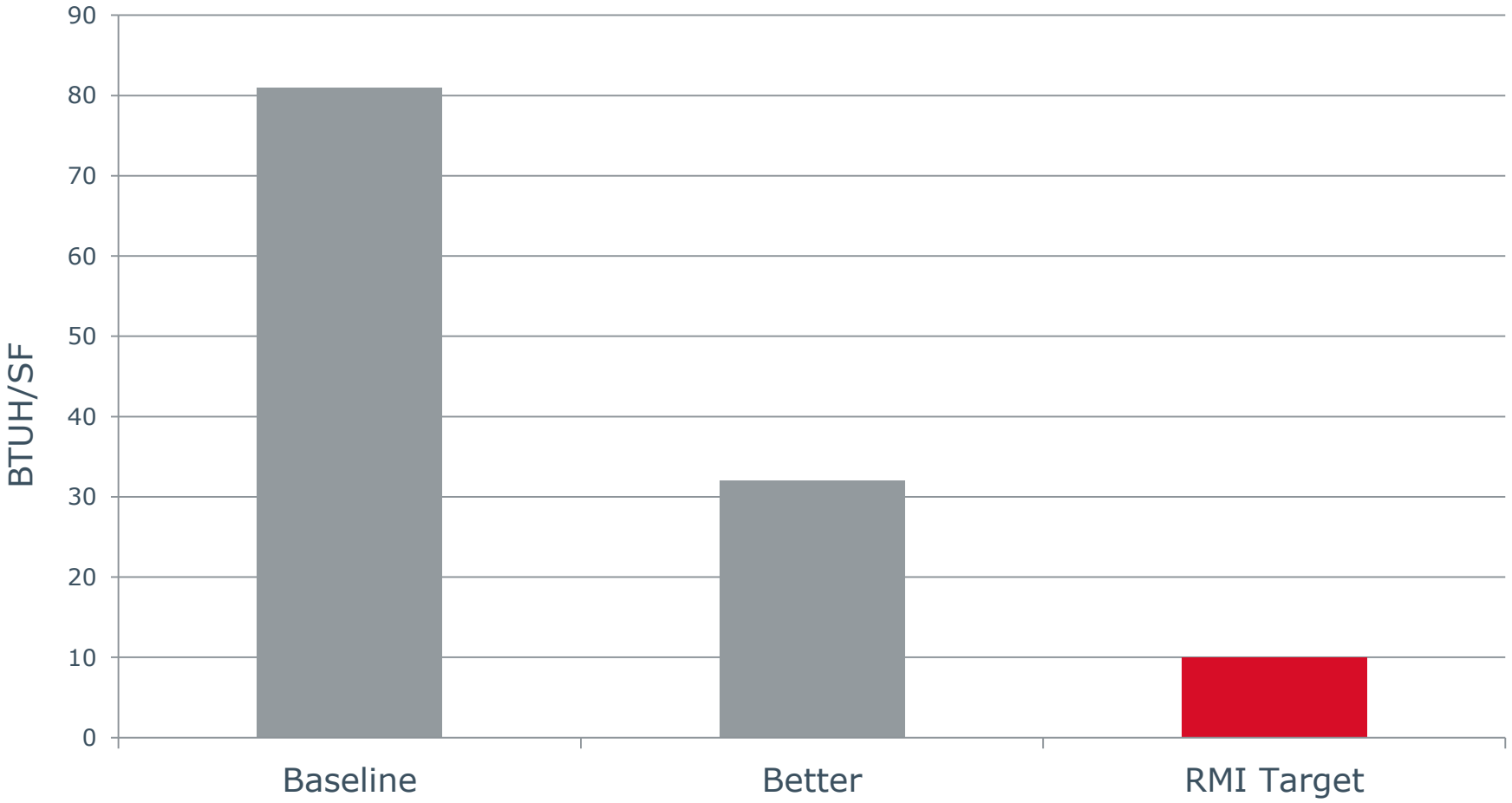
Cooling Loads - Installed

Mechanical Cooling in Buildings

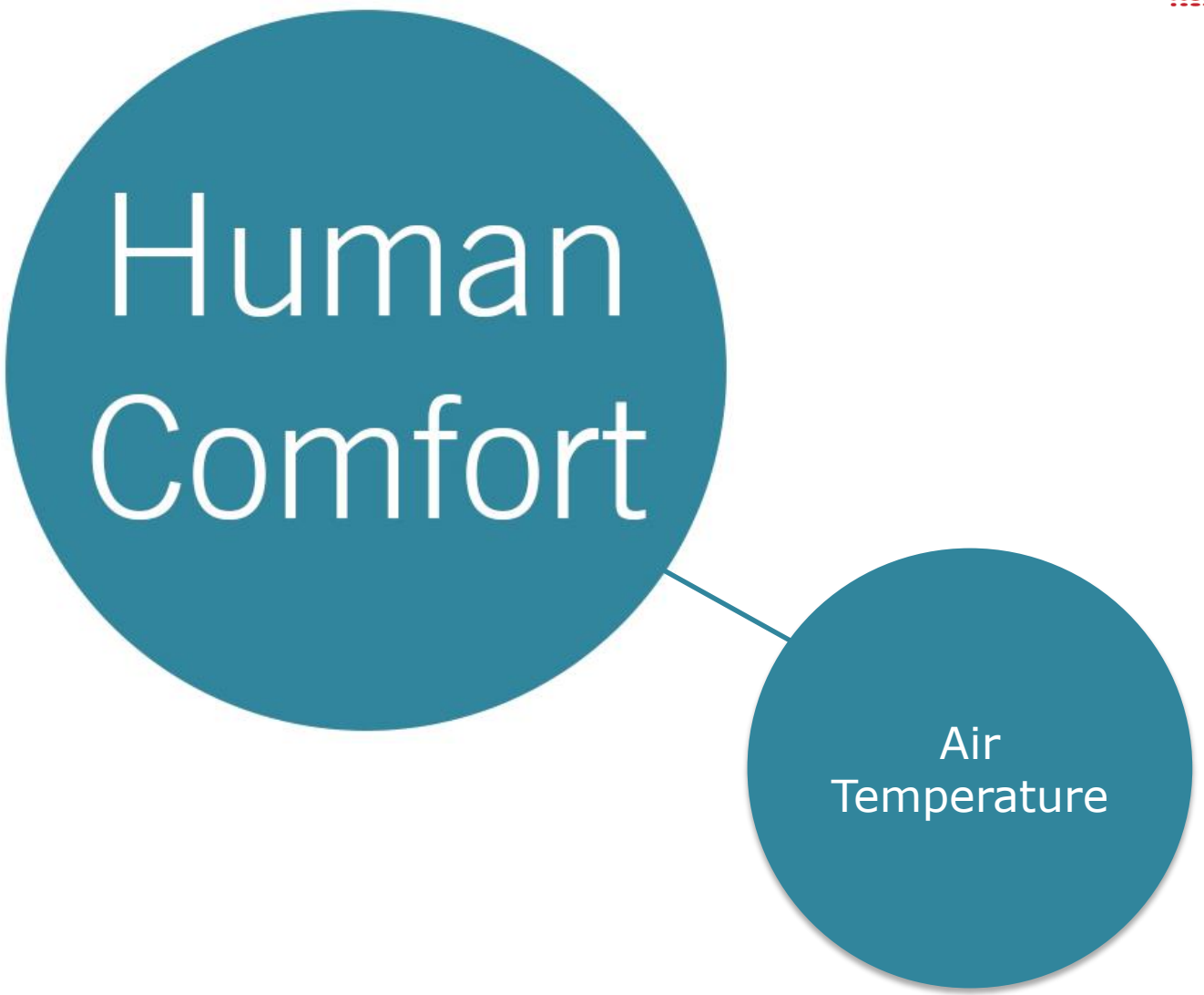


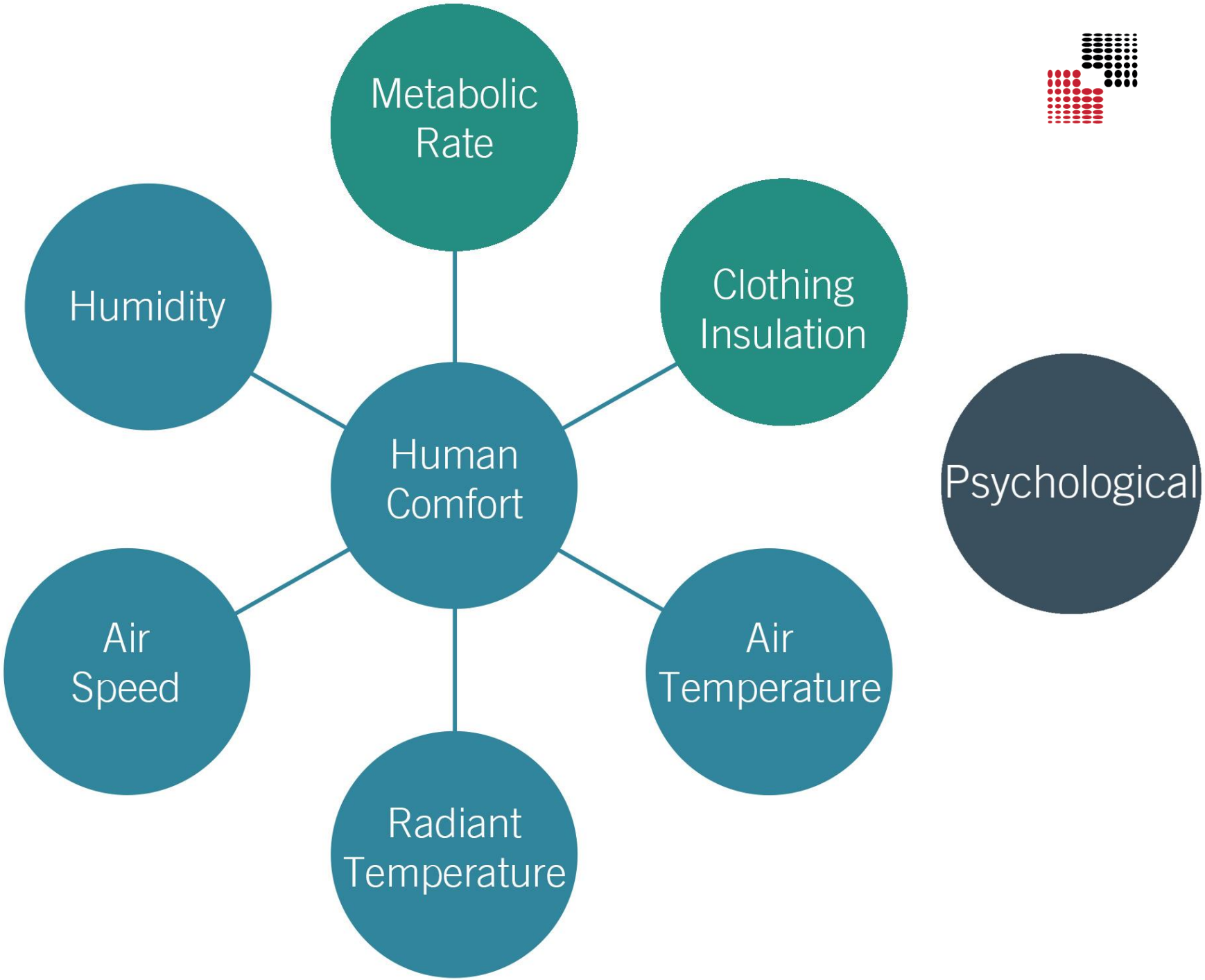
Heating Loads – Installed

Mechanical Heating in Buildings



RMI Electric Heating System


Human
Comfort
Air
Temperature


Metabolic Rate
Humidity
Clothing Insulation
Human Comfort
Psychological
Air Speed
Air Temperature
Radiant Temperature

Berkeley CBE Comfort Tool

CBE Thermal Comfort Tool

ASHRAE-55 | Compare | Ranges

Select method: PMV method

Air temperature
77.0 °F — Use operative temperature

Mean radiant temperature
77.0 °F

Air speed
20 fpm — Local air speed control

Humidity
50 % — Relative humidity

Metabolic rate
1.2 met — Standing, relaxed: 1.2

Clothing level
0.5 clo — Typical summer indoor

Create custom ensemble

Dynamic predictive clothing

LEED documentation

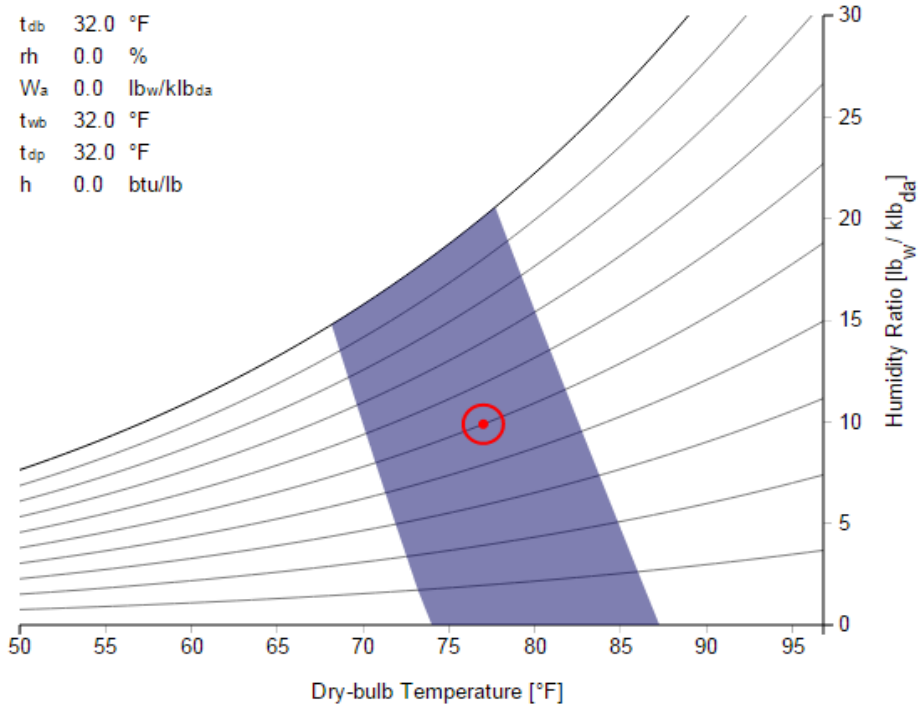
Globe temp | SolarCal | Specify pressure | SI IP | Local discomfort | ? Help

✓ Complies with ASHRAE Standard 55-2010

PMV	0.08
PPD	5%
Sensation	Neutral
SET	77.4°F

Psychrometric chart (air temperature)

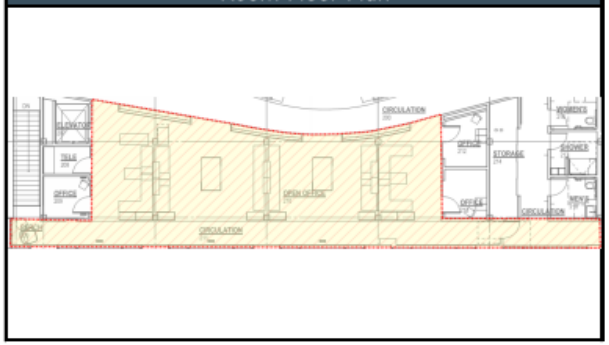
t_{db} 32.0 °F
rh 0.0 %
W_a 0.0 lb_w/klb_{da}
t_{wb} 32.0 °F
t_{dp} 32.0 °F
h 0.0 btu/lb



Room Data Sheet

2nd Floor
Open Office

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

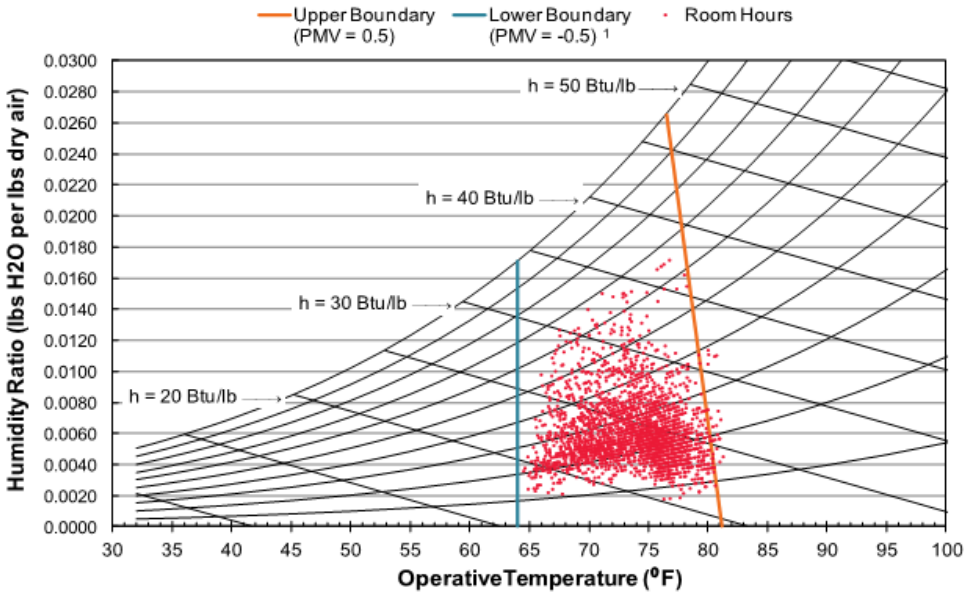
Schedule Description

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.

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):	19 FPM

Room Thermal Comfort Performance

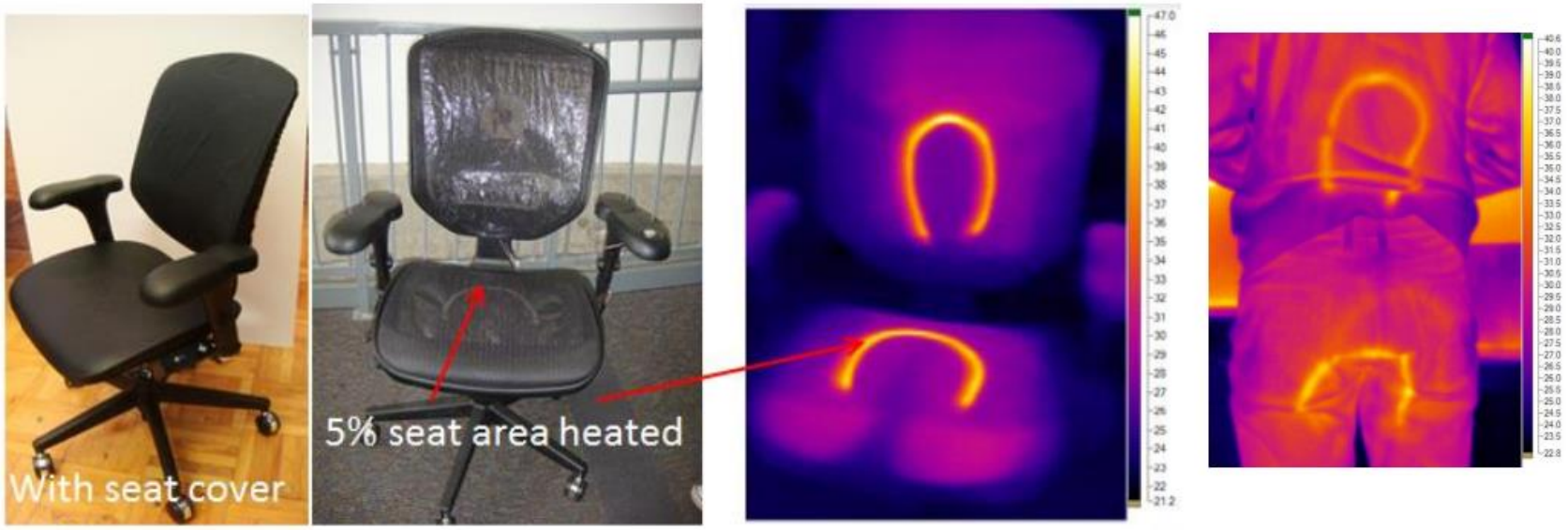


1. Lower boundary is based on implementation of the CBE Personal Comfort System

Thermal Comfort

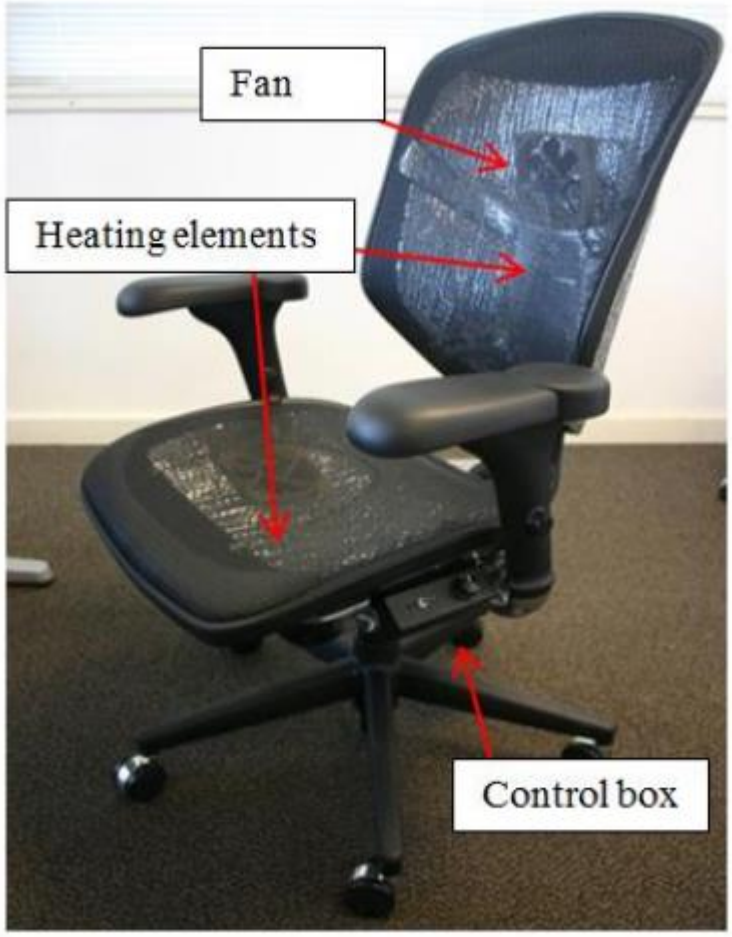
Personal Comfort System

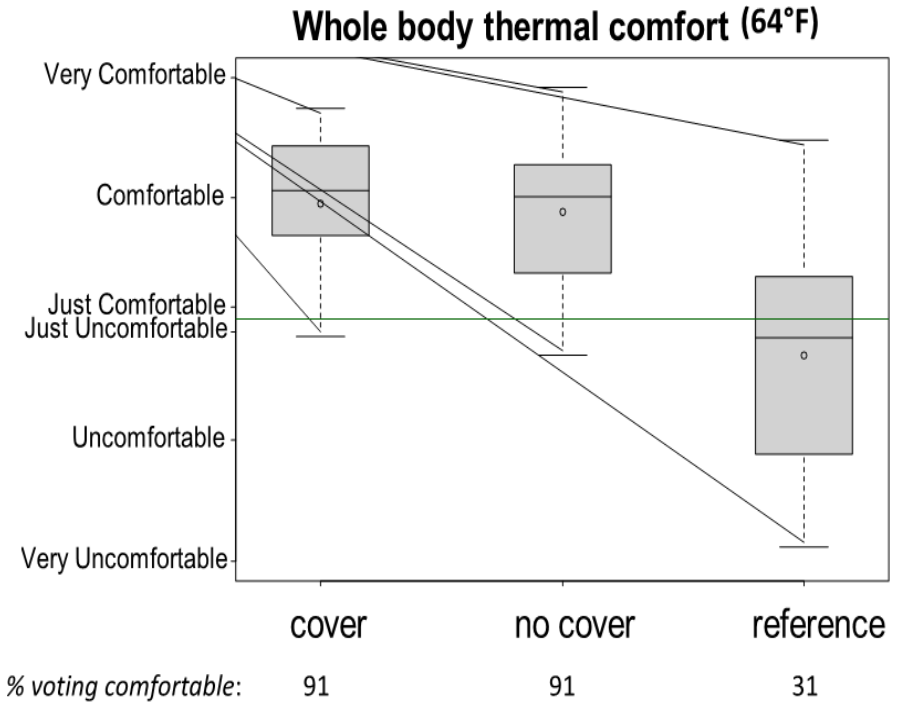
Heat the people, not the space!



Thermal Comfort

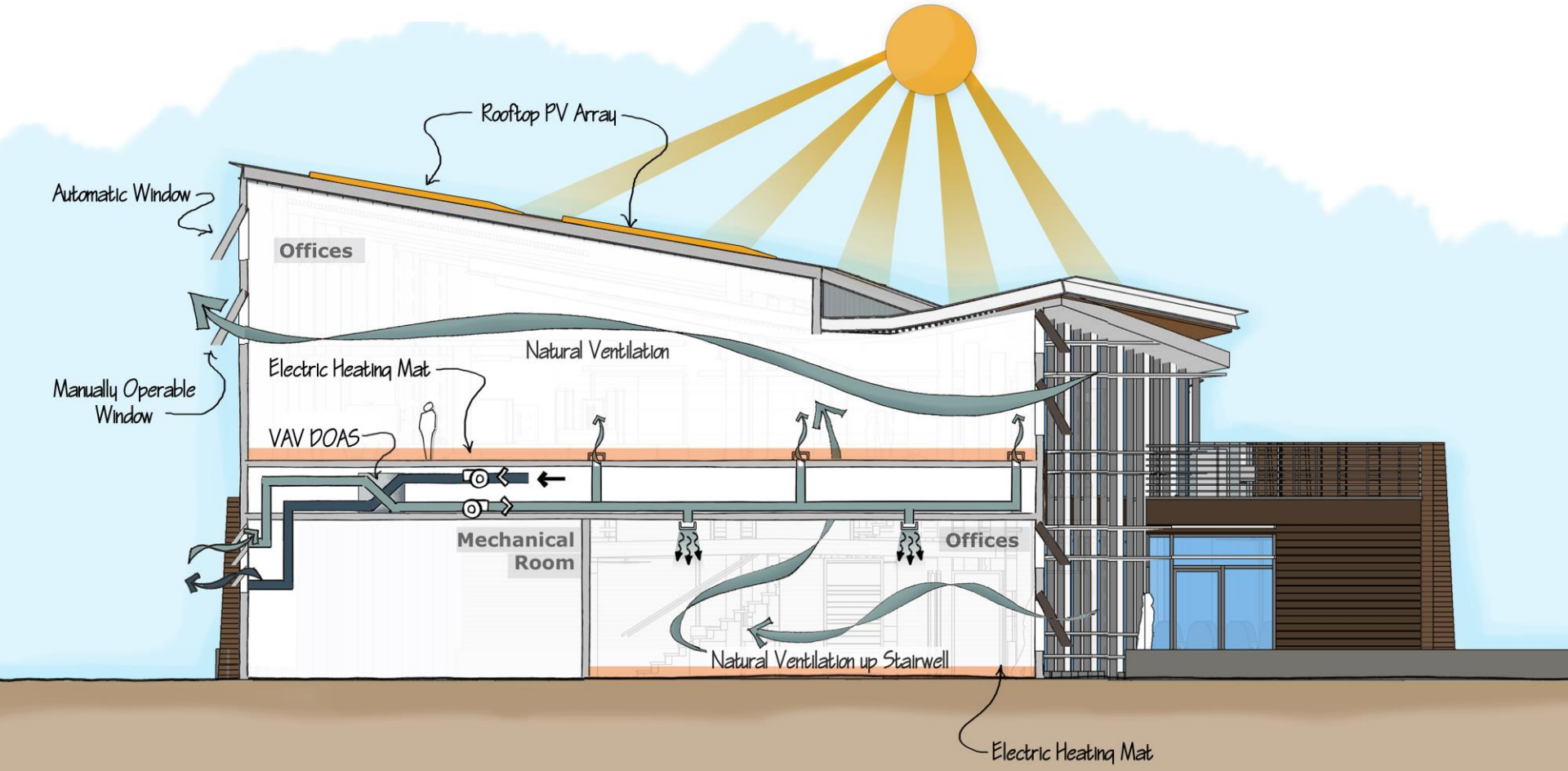
Personal Comfort System





HVAC Systems:

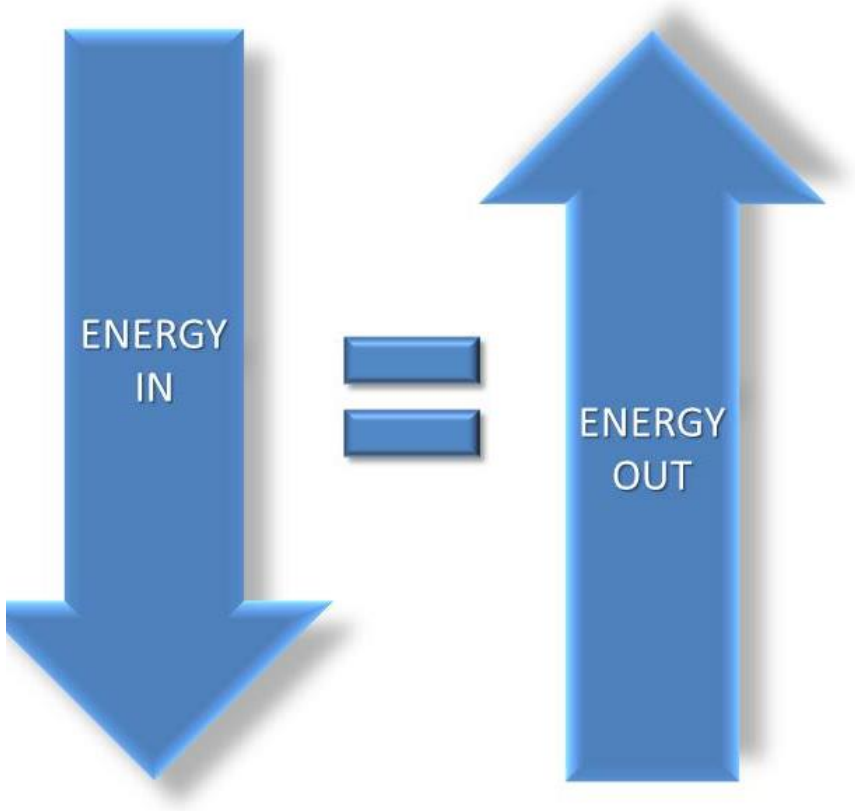
Designing the un-system



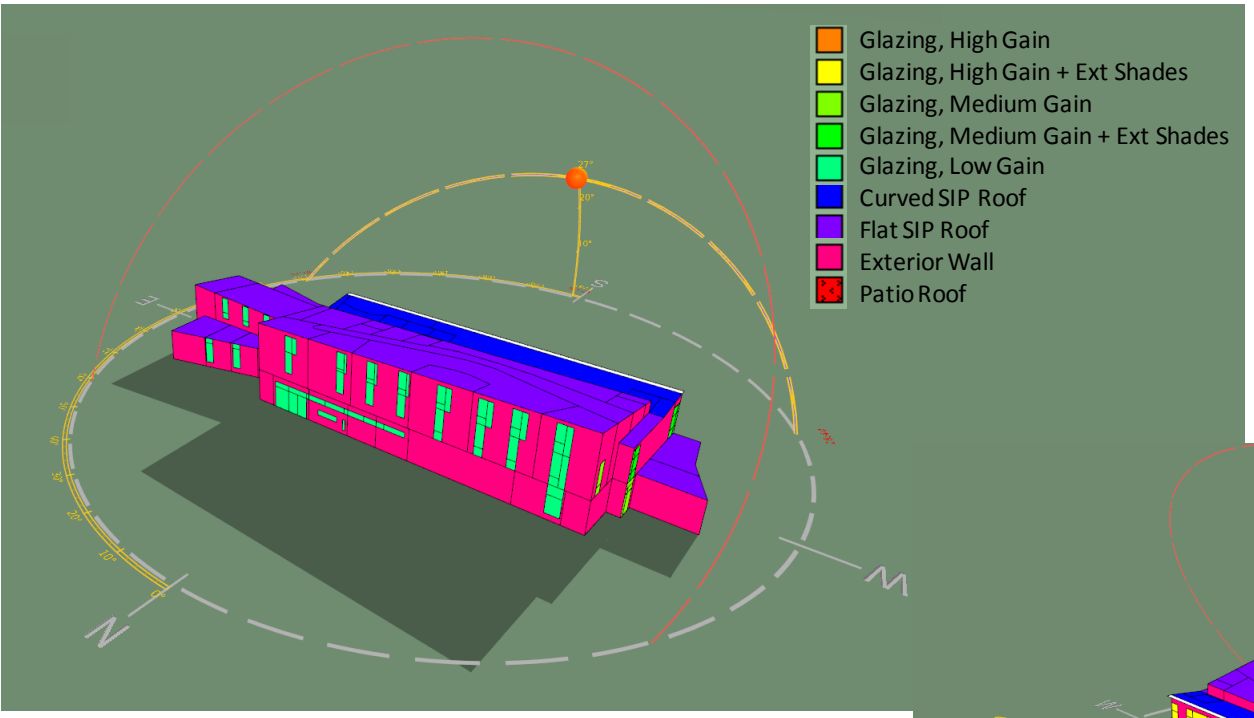
Energy Modeling

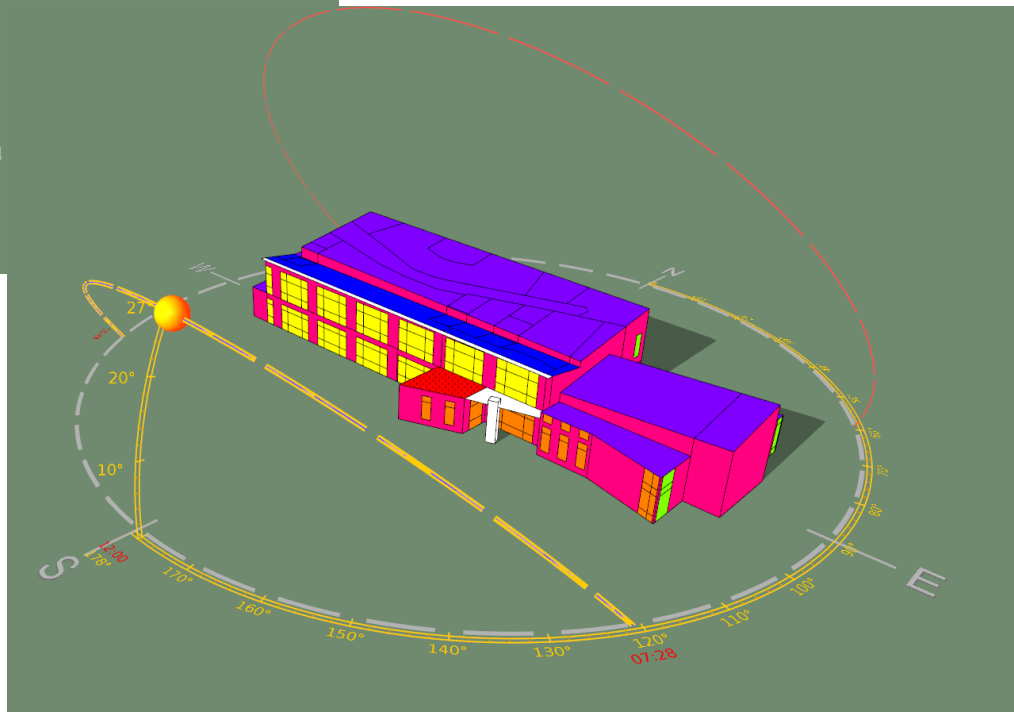
IES Software

- IES calculates a complete energy balance for the building.
- This means: loads in IES are based on the actual resultant temperatures.
- Useful for Passive Analysis.



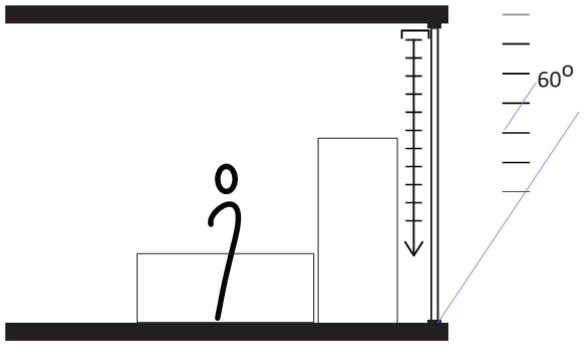
IES-VE

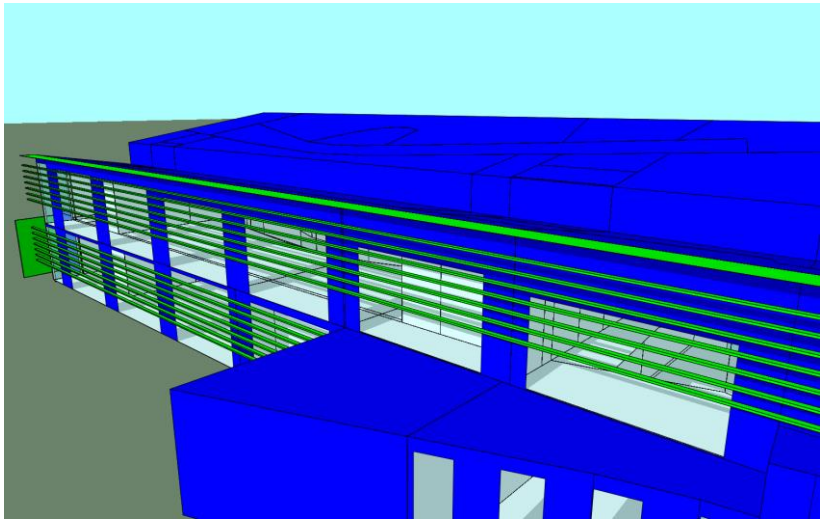

Glazing, High Gain
Glazing, High Gain + Ext Shades
Glazing, Medium Gain
Glazing, Medium Gain + Ext Shades
Glazing, Low Gain
Curved SIP Roof
Flat SIP Roof
Exterior Wall
Patio Roof

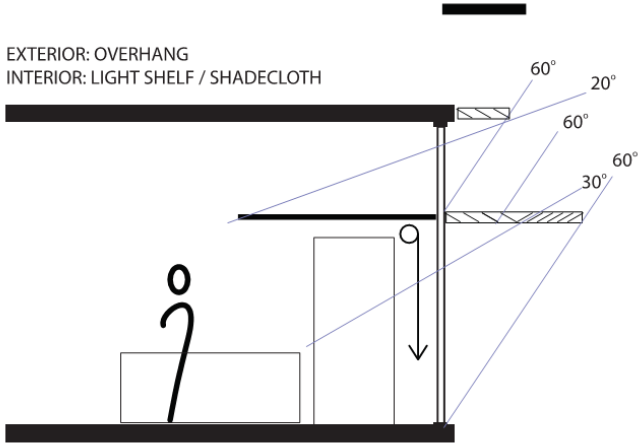

21°
20°
10°
S
E
178°
170°
160°
150°
140°
130°
120°
110°
07:28

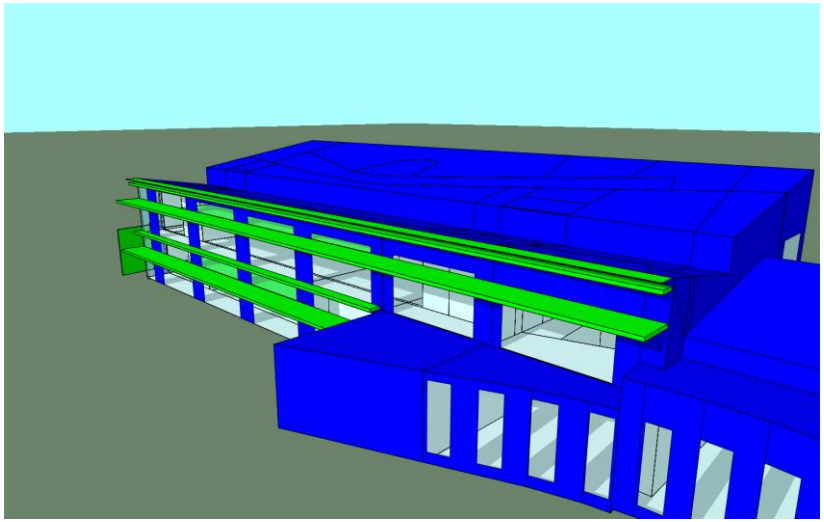
IES-VE

Shading Studies



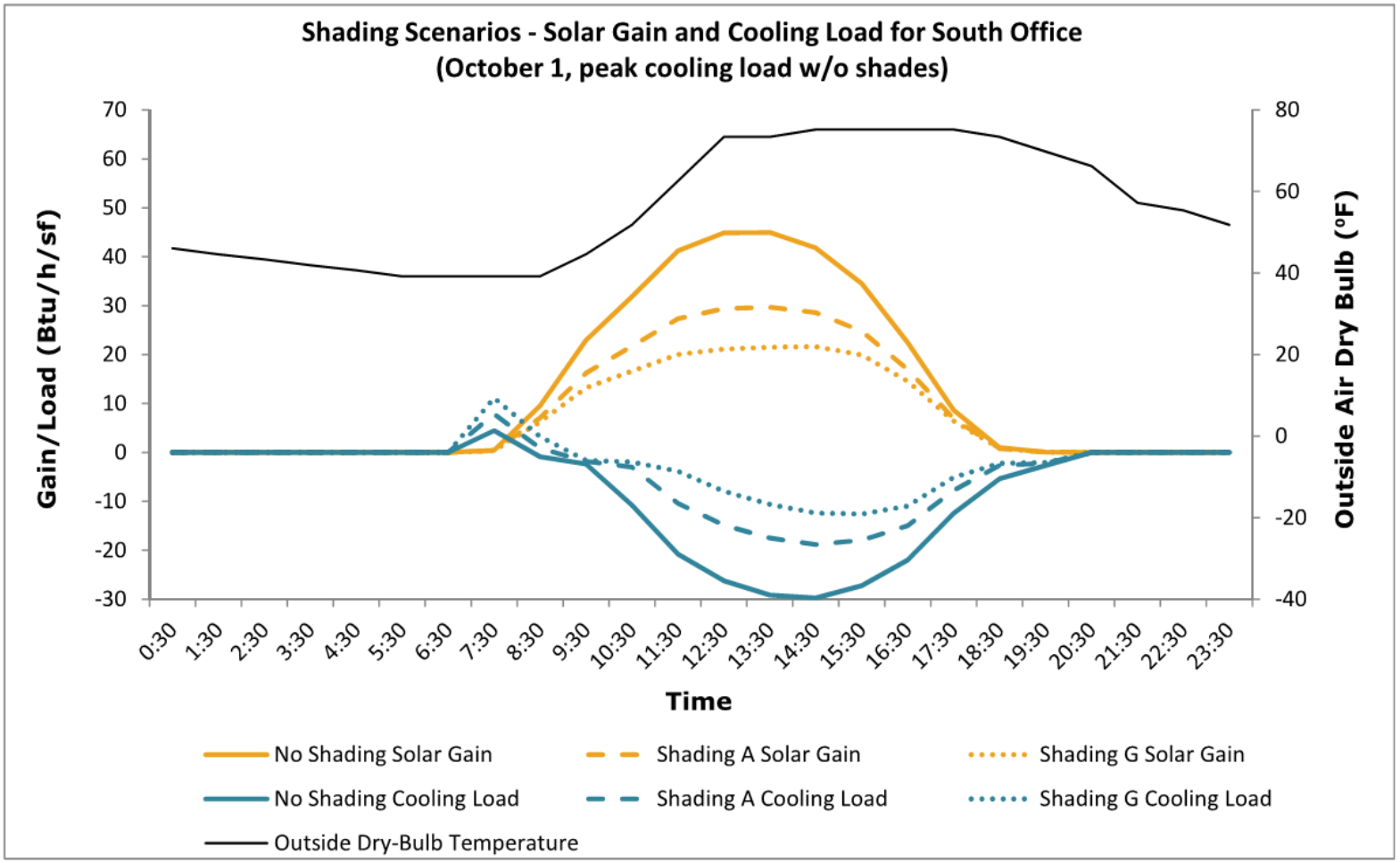






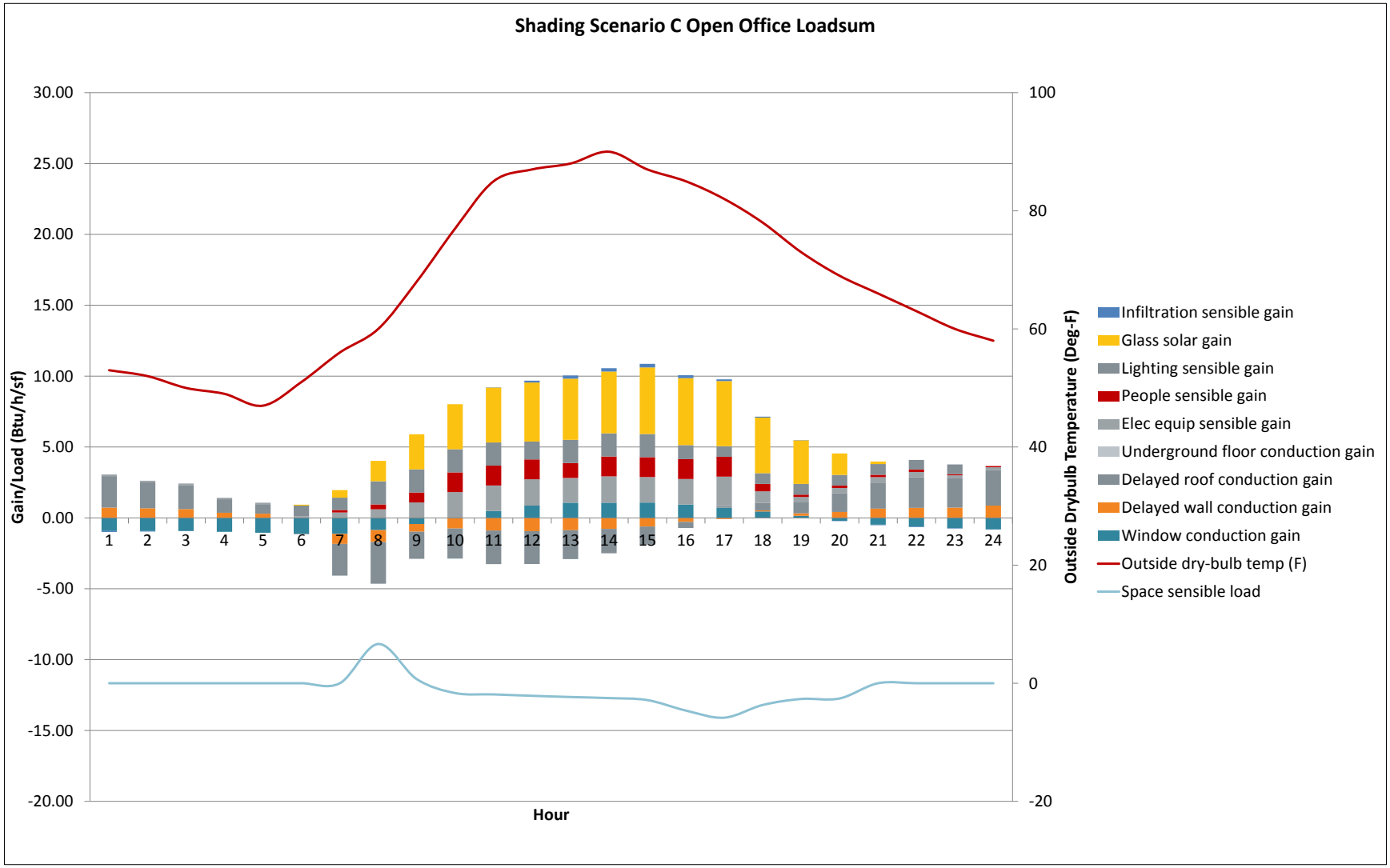
IES-VE

Shading Studies



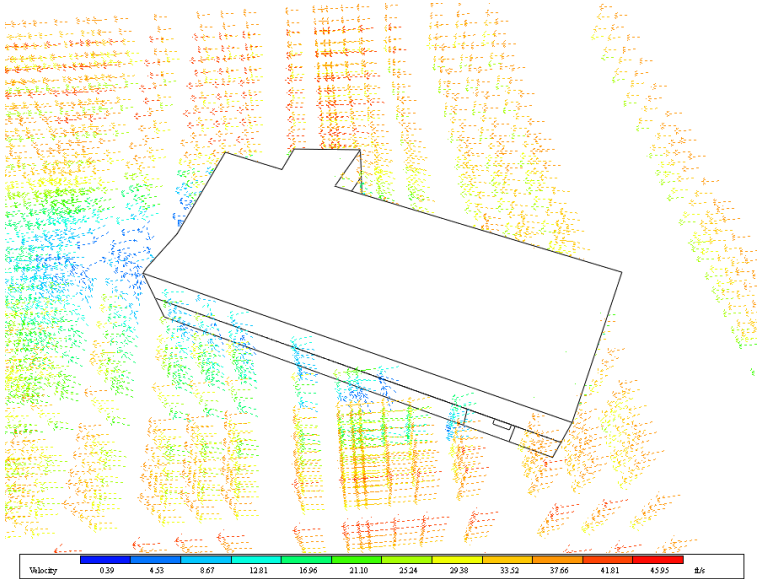
IES-VE

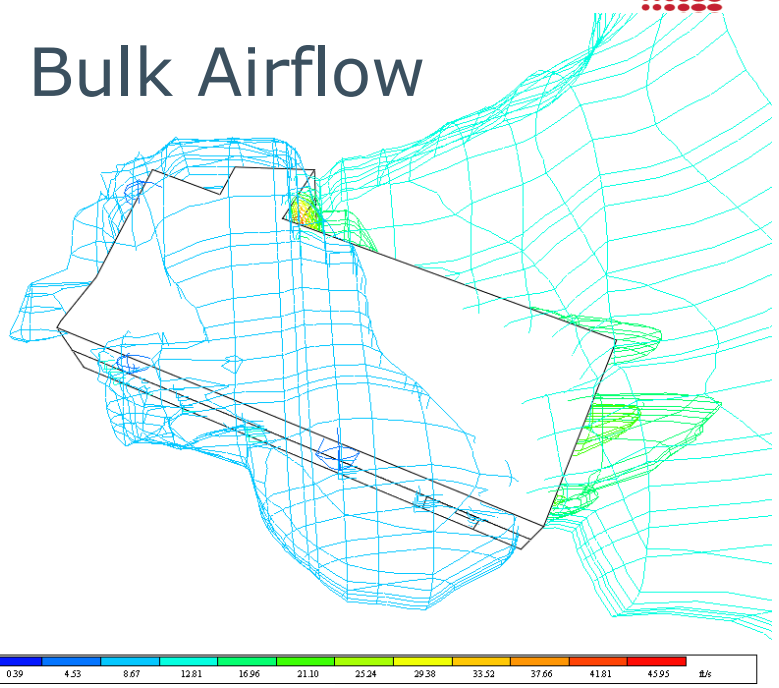
Shading Studies

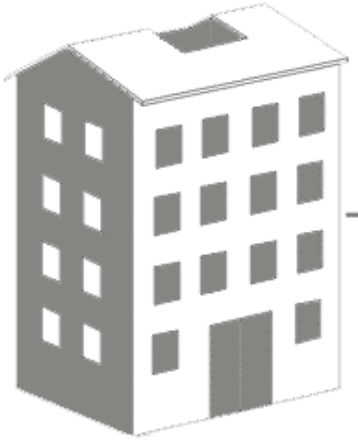


IES-VE

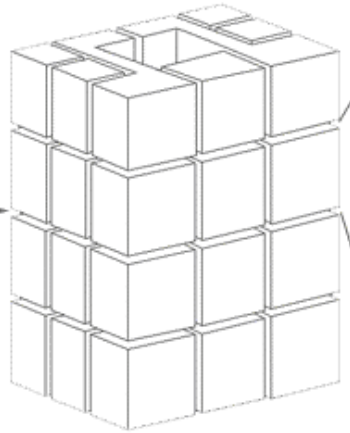
Natural Ventilation – CFD vs. Bulk Airflow



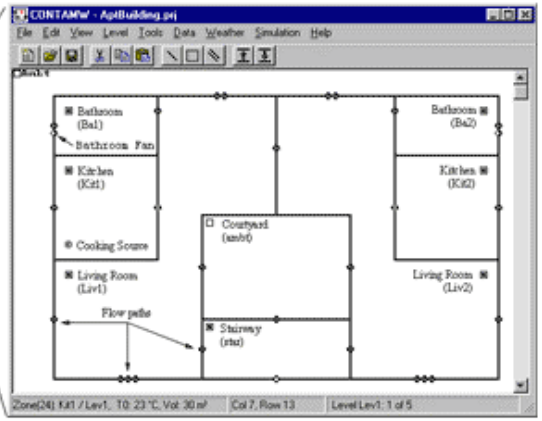




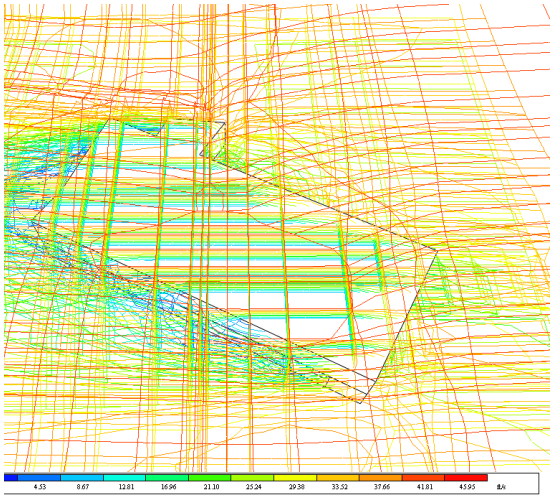
Real Building

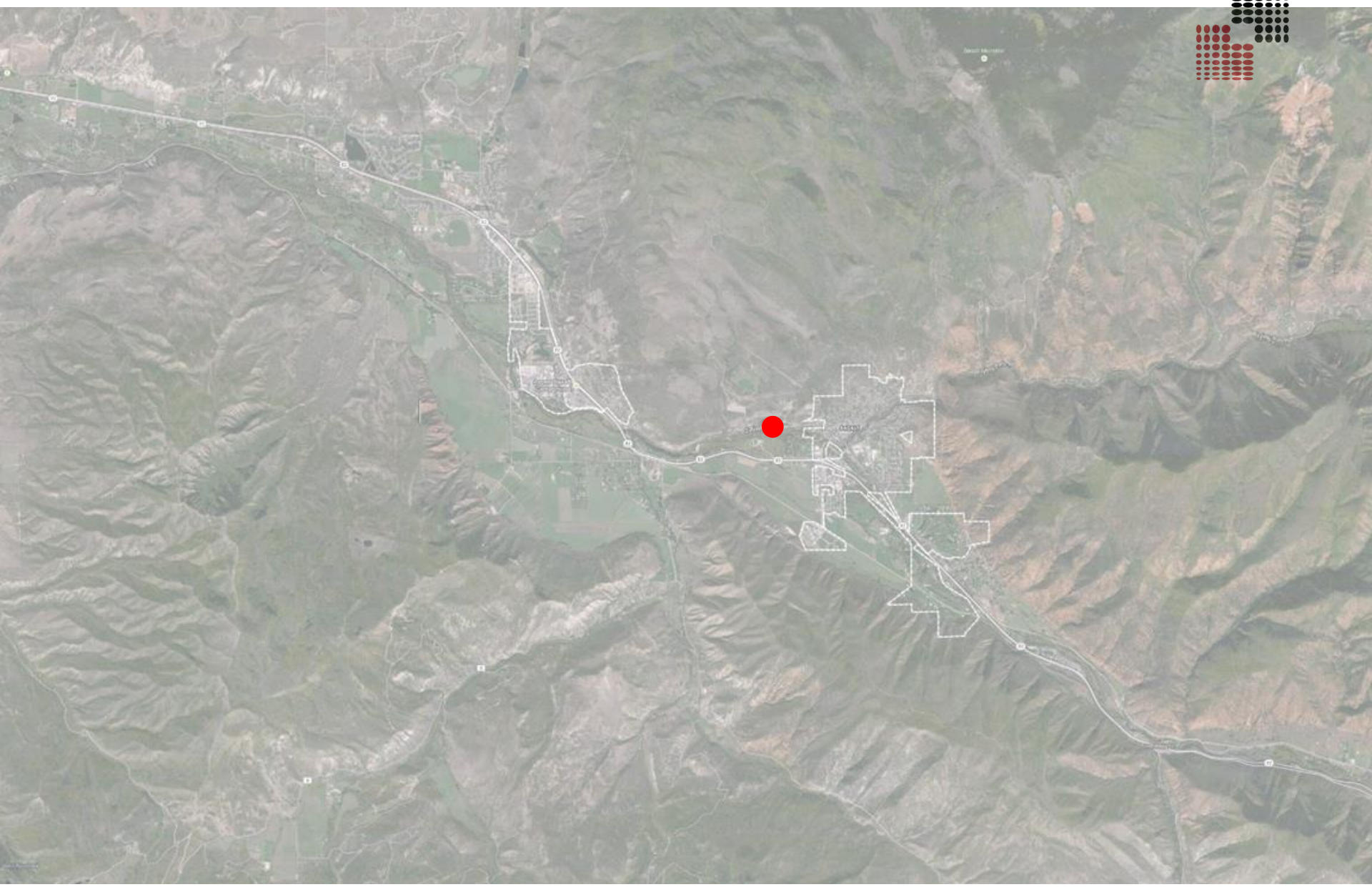


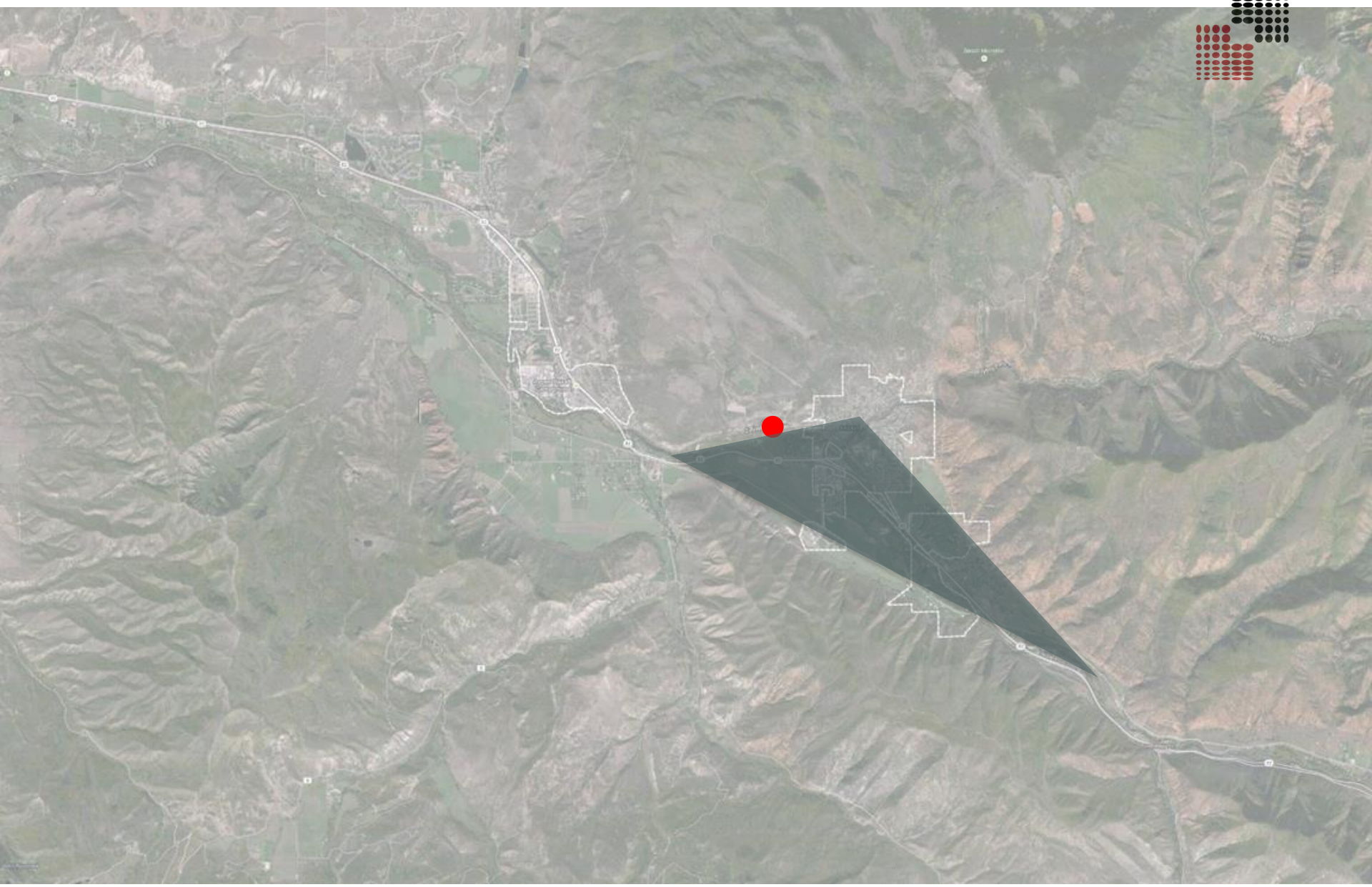
Idealized Building



CONTAM Building Model

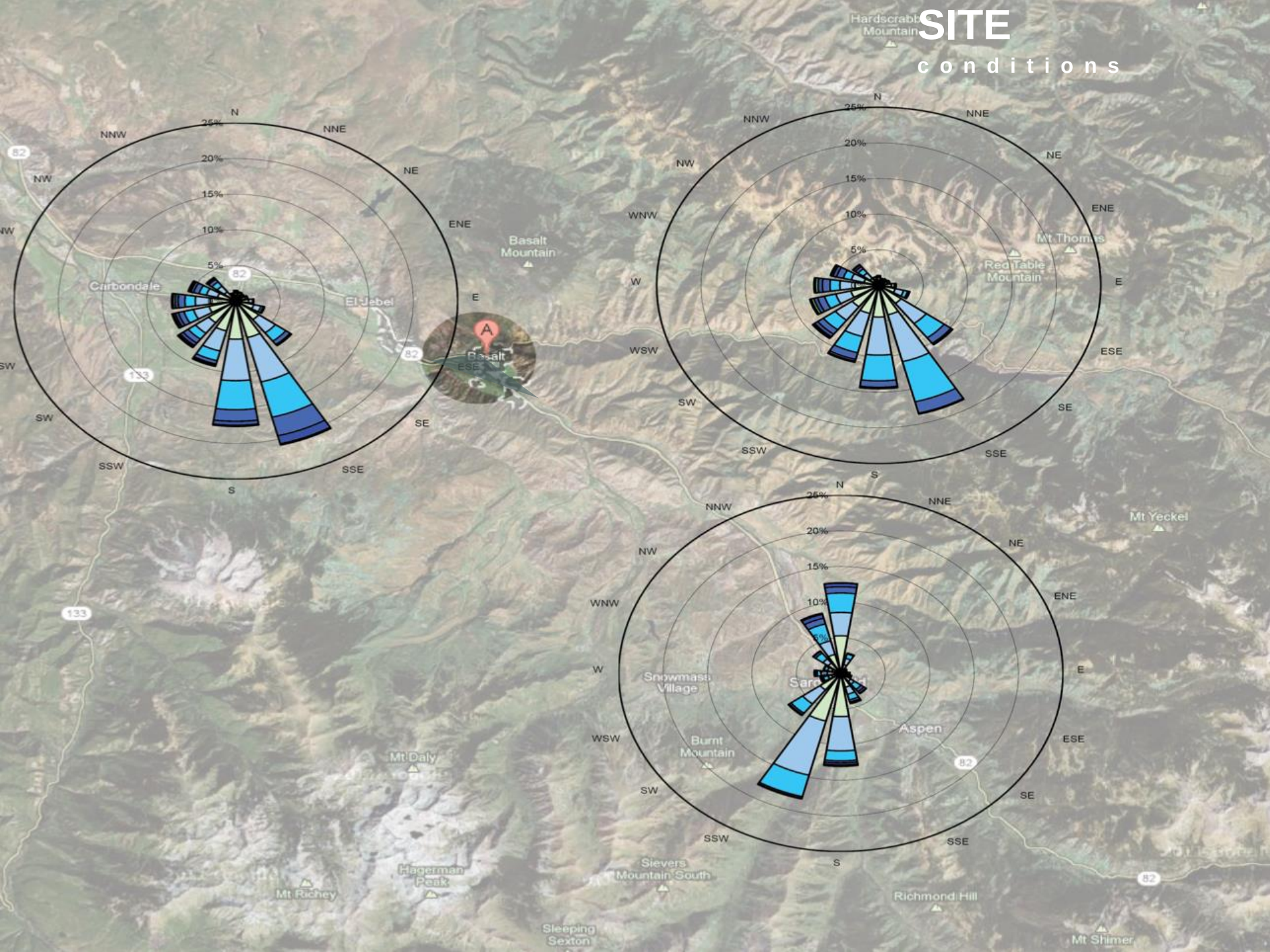






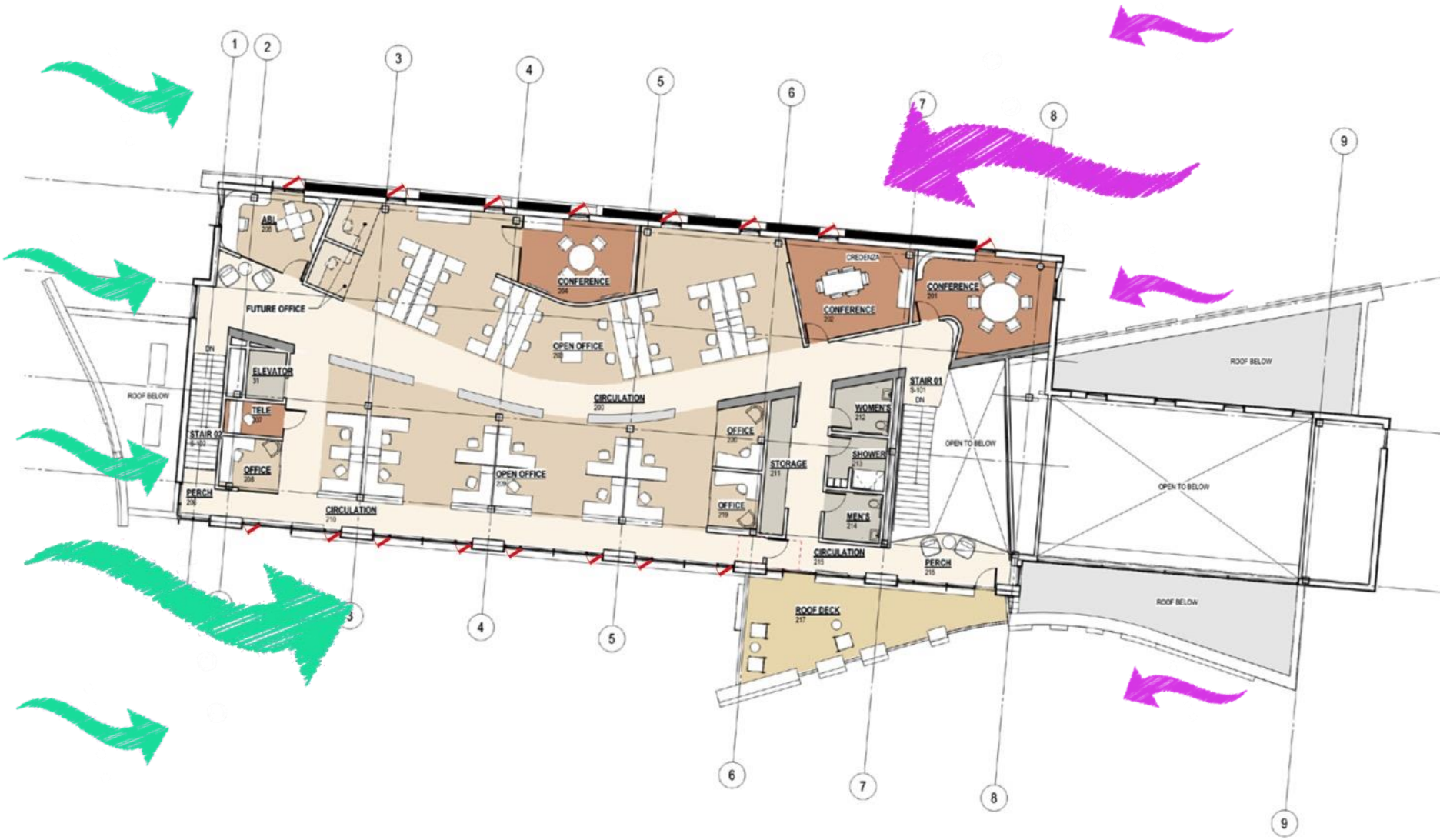
SITE

conditions



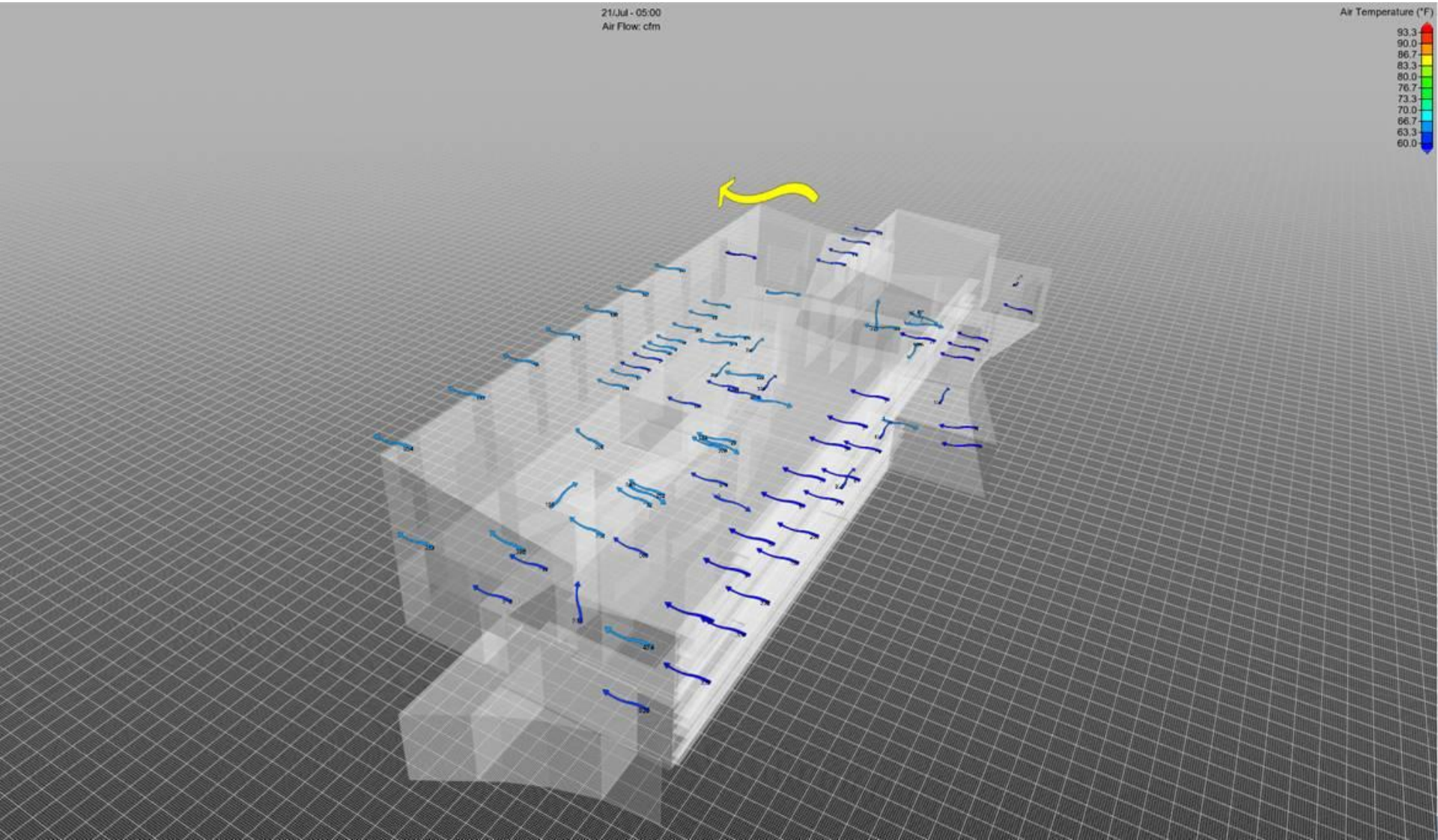
Dominant Wind Direction,
Summer Daytime - (upriver)

Dominant Wind Direction,
Summer Night - (downriver)



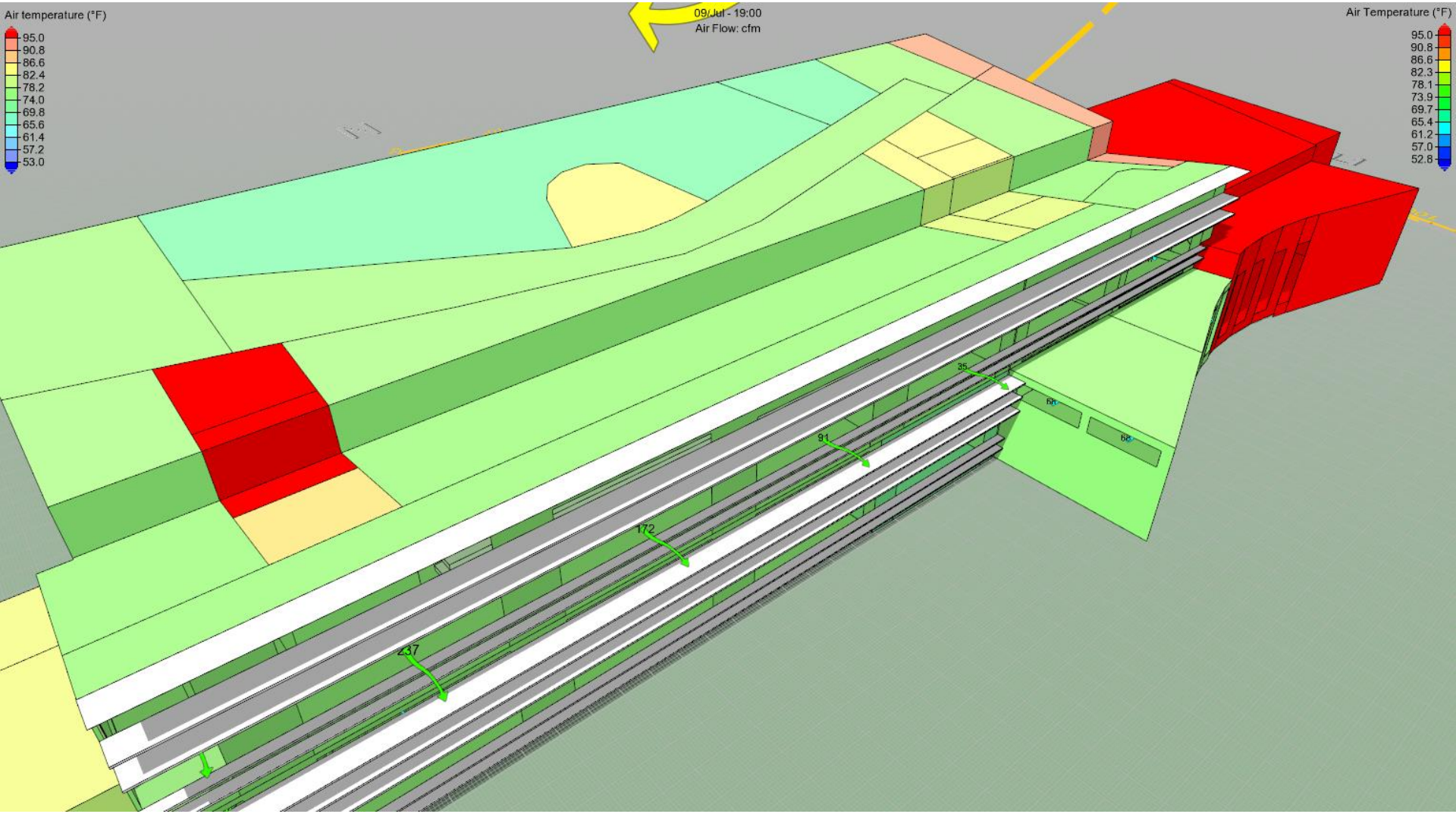
IES-VE

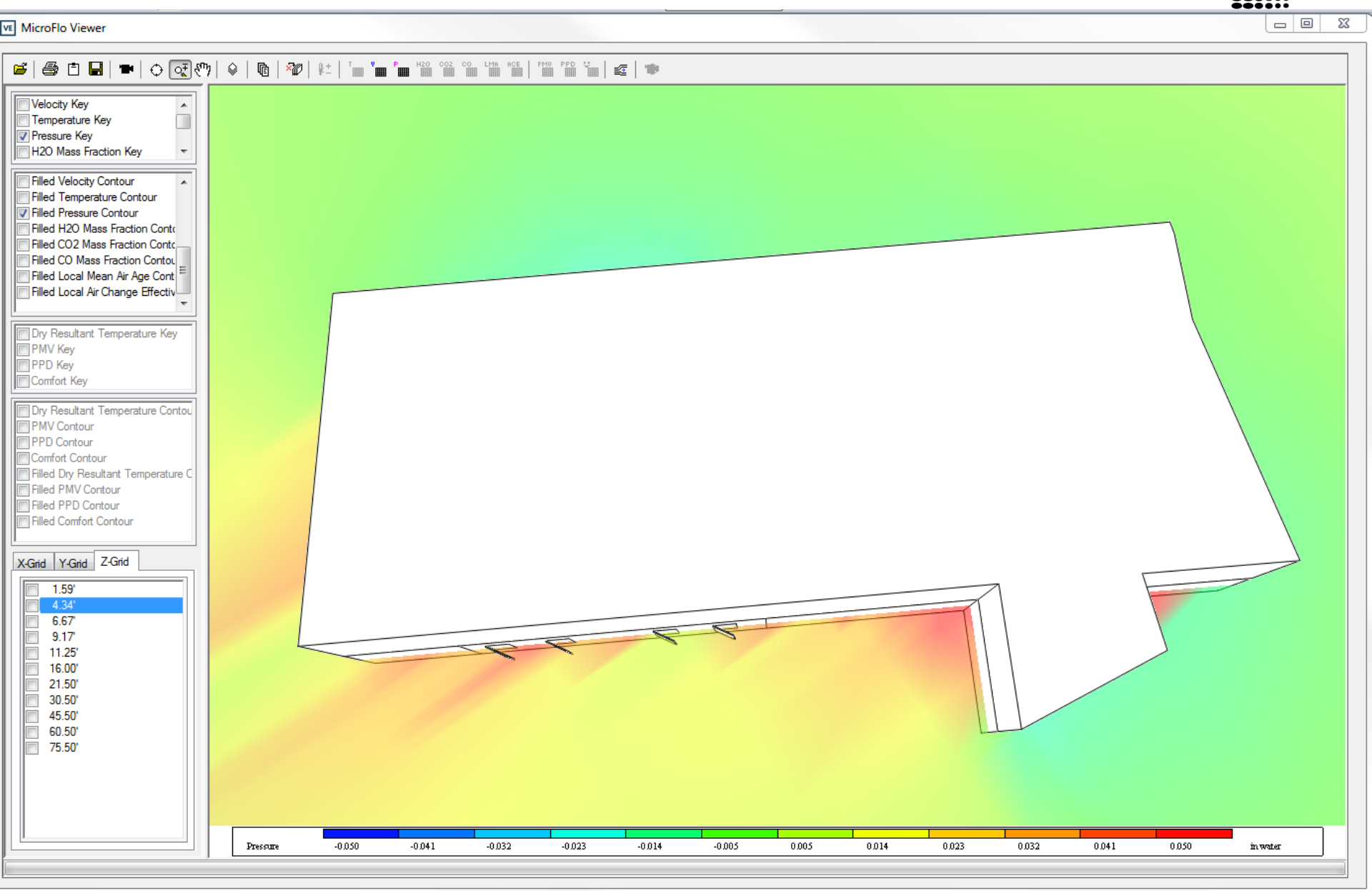
Natural Ventilation – MacroFlo



IES-VE

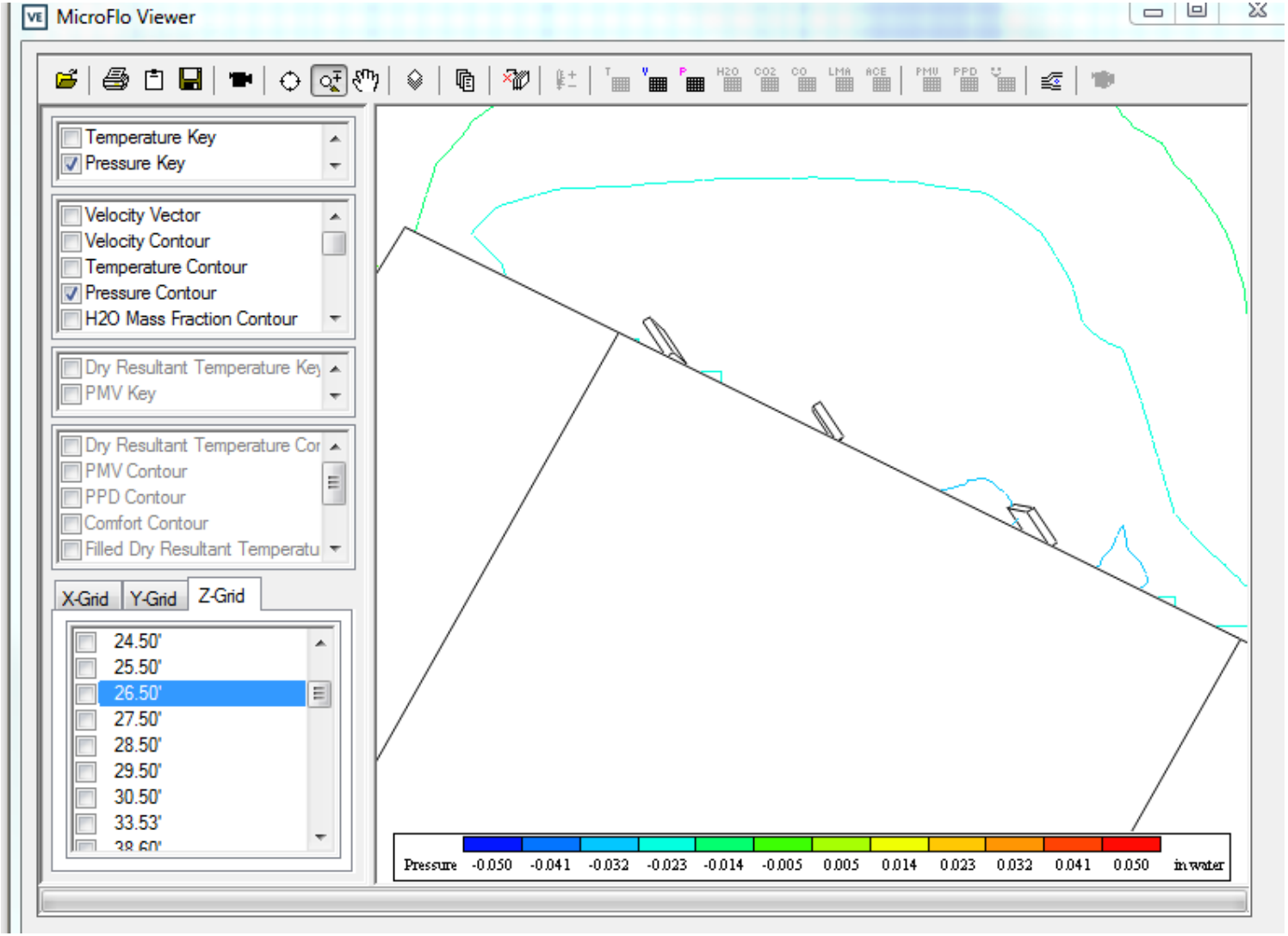
Natural Ventilation – MacroFlo




MicroFlo Viewer
Velocity Key
Temperature Key
Pressure Key
H2O Mass Fraction Key
Filled Velocity Contour
Filled Temperature Contour
Filled Pressure Contour
Filled H2O Mass Fraction Contc
Filled CO2 Mass Fraction Contc
Filled CO Mass Fraction Contou
Filled Local Mean Air Age Cont
Filled Local Air Change Effectiv
Dry Resultant Temperature Key
PMV Key
PPD Key
Comfort Key
Dry Resultant Temperature Contou
PMV Contour
PPD Contour
Comfort Contour
Filled Dry Resultant Temperature C
Filled PMV Contour
Filled PPD Contour
Filled Comfort Contour
X-Grid
Y-Grid
Z-Grid
1.59'
4.34'
6.67'
9.17'
11.25'
16.00'
21.50'
30.50'
45.50'
60.50'
75.50'
Pressure
-0.050
-0.041
-0.032
-0.023
-0.014
-0.005
0.005
0.014
0.023
0.032
0.041
0.050
in water

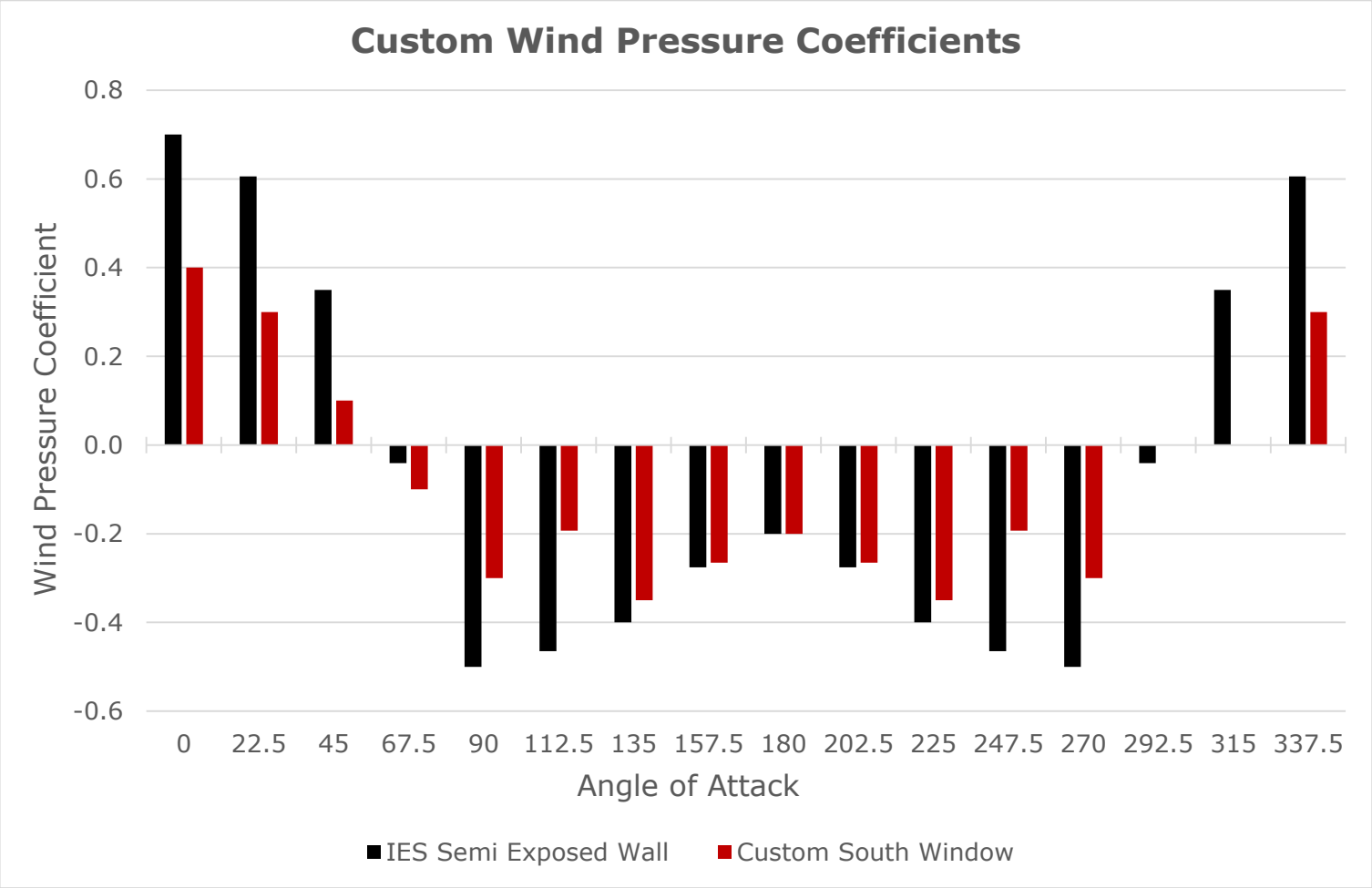
IES-VE

Natural Ventilation - MicroFlo



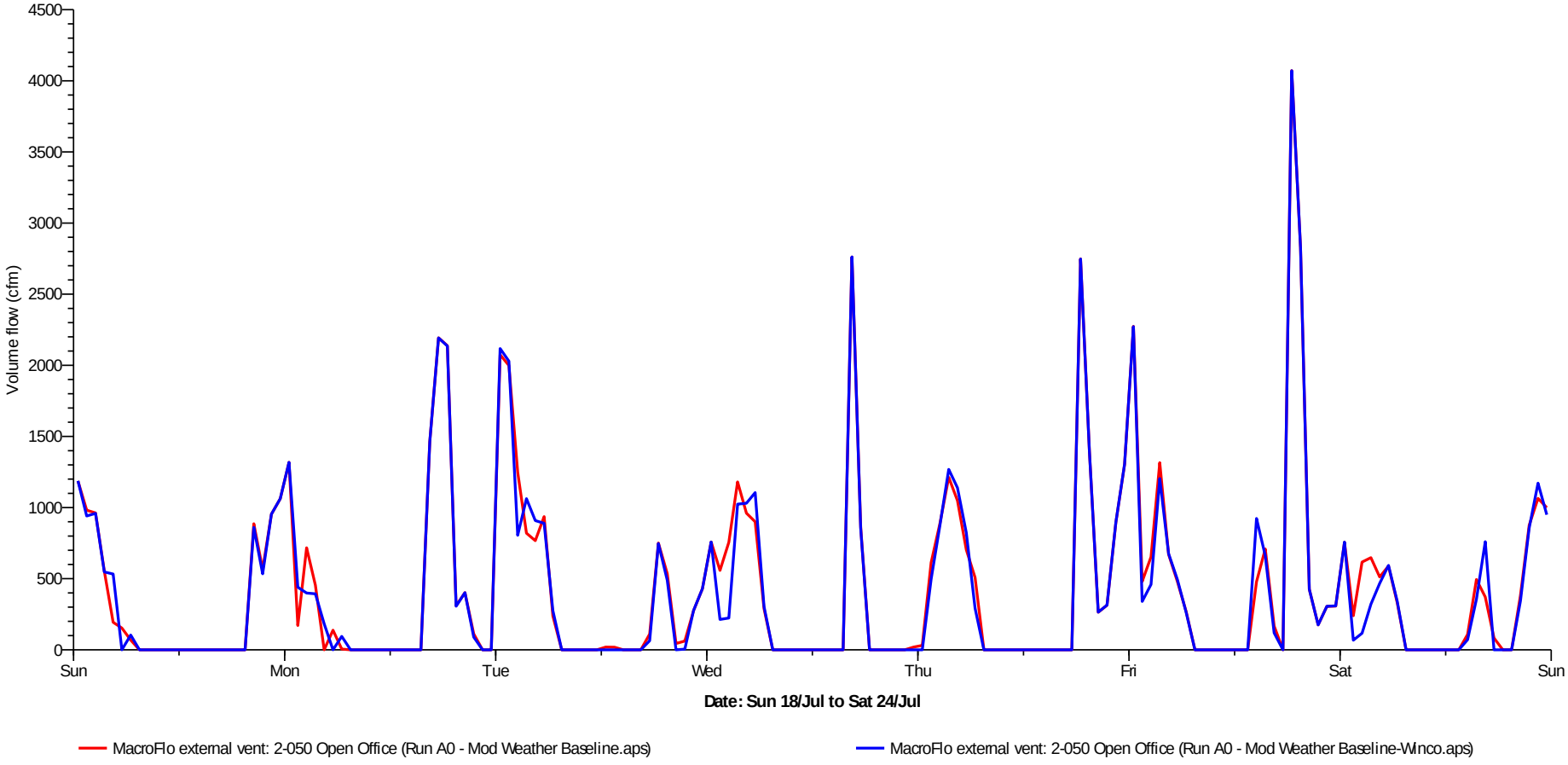
IES-VE

Natural Ventilation - MicroFlo



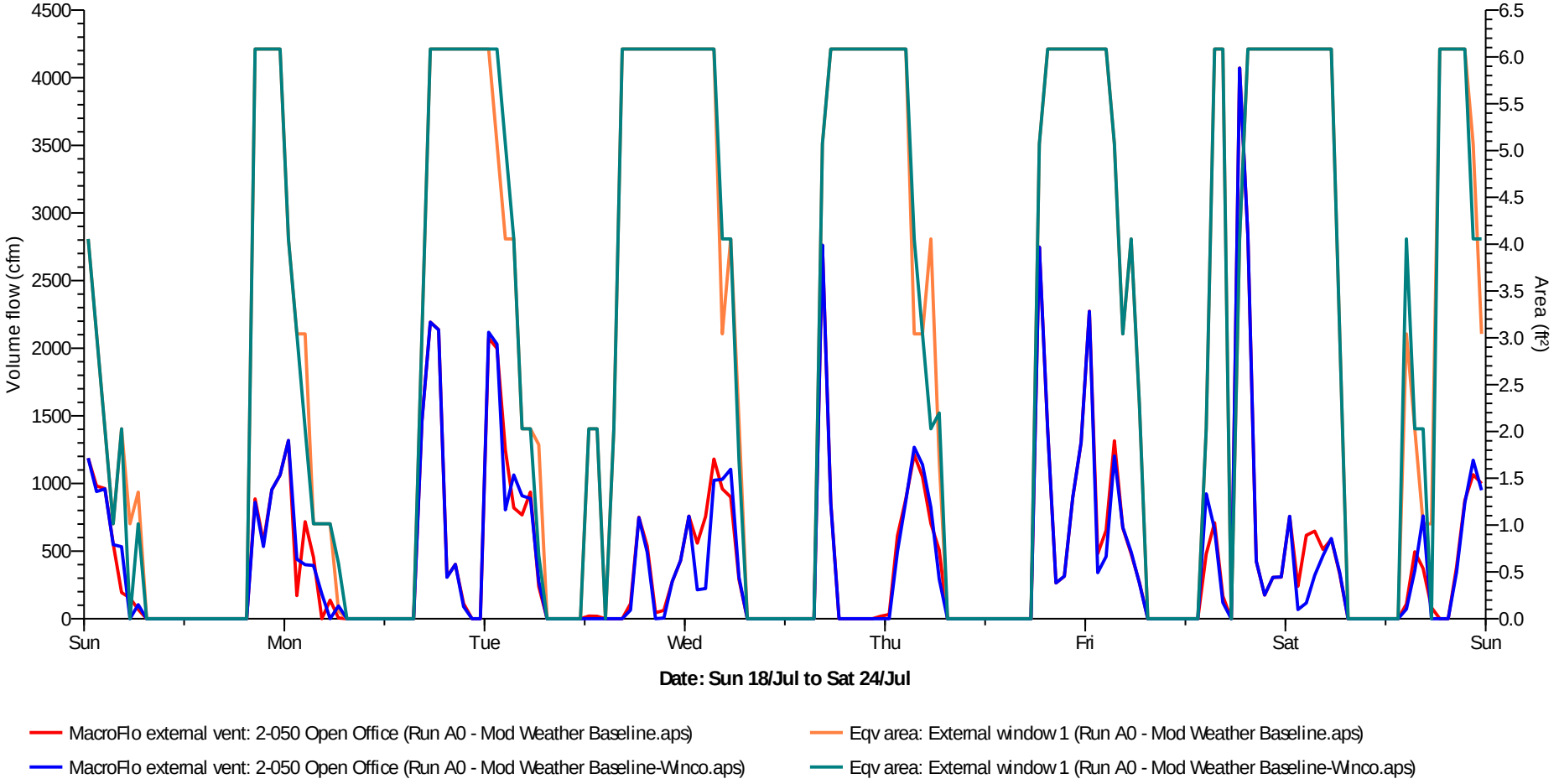
IES-VE

Natural Ventilation – MicroFlo->MacroFlo



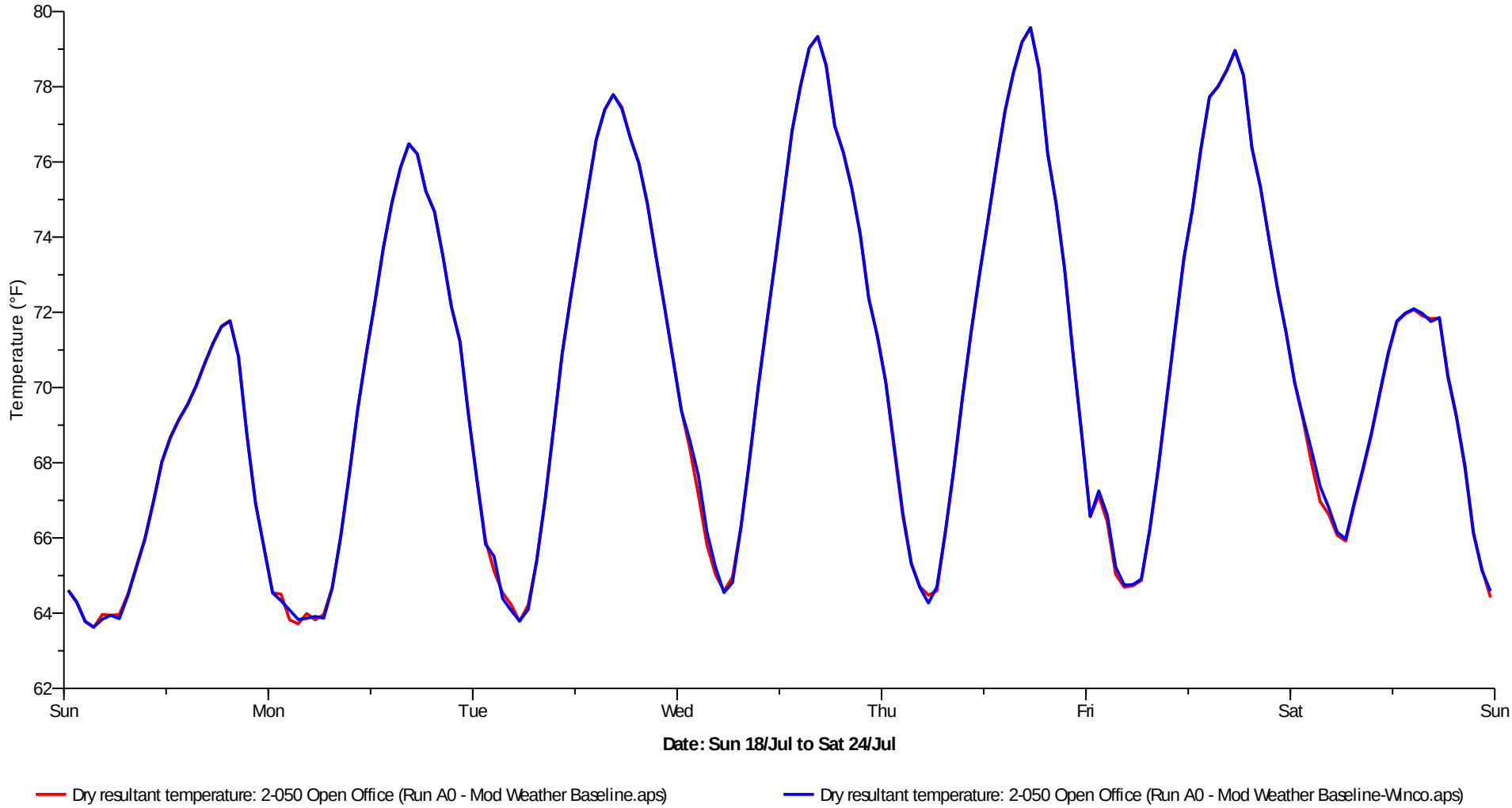
IES-VE

Natural Ventilation – MicroFlo->MacroFlo



IES-VE

Natural Ventilation – MicroFlo->MacroFlo



IES-VE

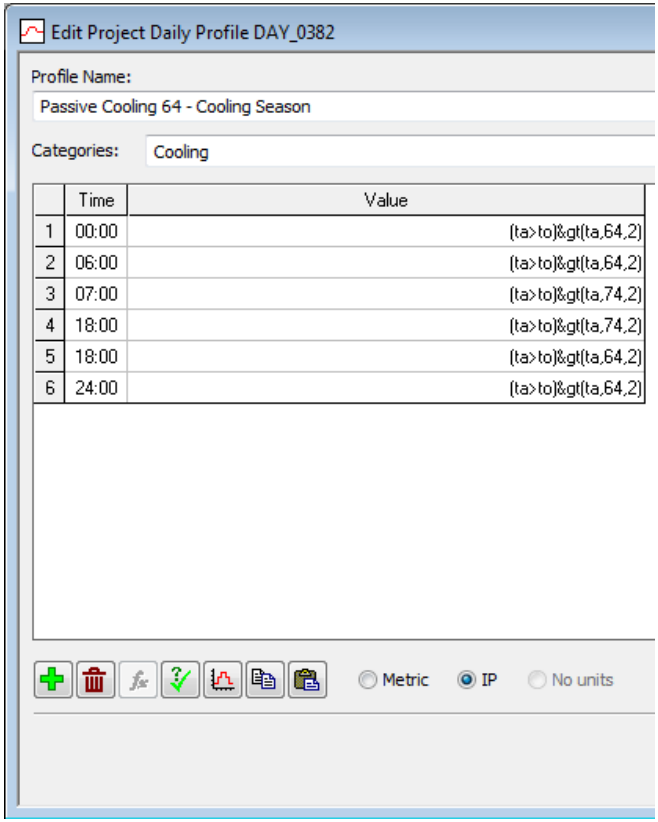
Natural Ventilation – Window Controls

12.7.1. Weather variables

Variable	Description	Metric unit	IP unit
ws	wind speed	m/s	ft/s
wd	wind direction	degrees clockwise from north	degrees clockwise from north
to	outside air temperature	°C	°F
go	outside air moisture	kg/kg	lb/lb
igh	global radiation on the horizontal plane	W/m^2	$Btu/(h \cdot ft^2)$
ifh	diffuse radiation on the horizontal plane	W/m^2	$Btu/(h \cdot ft^2)$
idn	direct normal radiation	W/m^2	$Btu/(h \cdot ft^2)$

12.7.2. Room variables

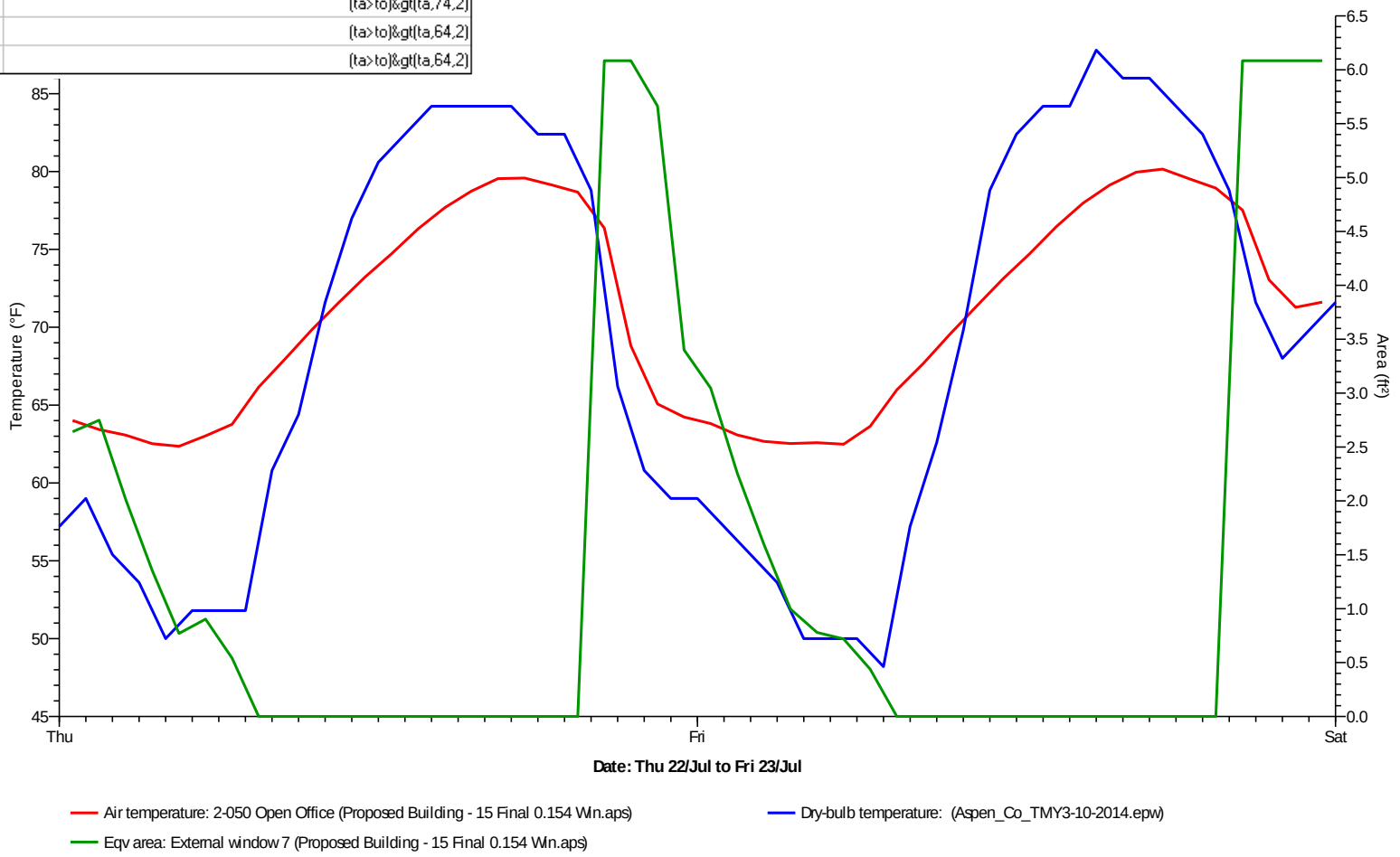
Variable	Description	Metric unit	IP unit
ta	room air temperature	°C	°F
tr	room mean radiant temperature	°C	°F
tdr	room dry resultant temperature	°C	°F
ta_	adjacent room air temperature	°C	°F
g	room moisture content	kg/kg	lb/lb
g_	adjacent room moisture content	kg/kg	lb/lb
rh	room relative humidity	%	%
rh_	adjacent room relative humidity	%	%
sol	short-wave solar gain to room	W	Btu/h
co2	room carbon dioxide concentration	ppm	ppm
e1	room illuminance (sensor 1)	lux	fc
e2	room illuminance (sensor 2)	lux	fc



IES-VE

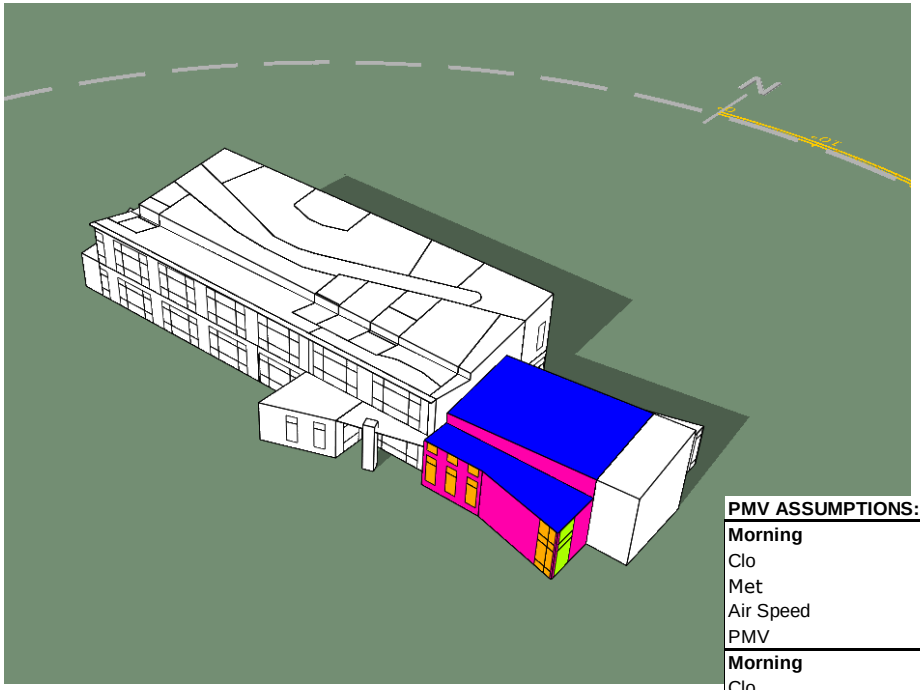
Natural Ventilation – Window Controls

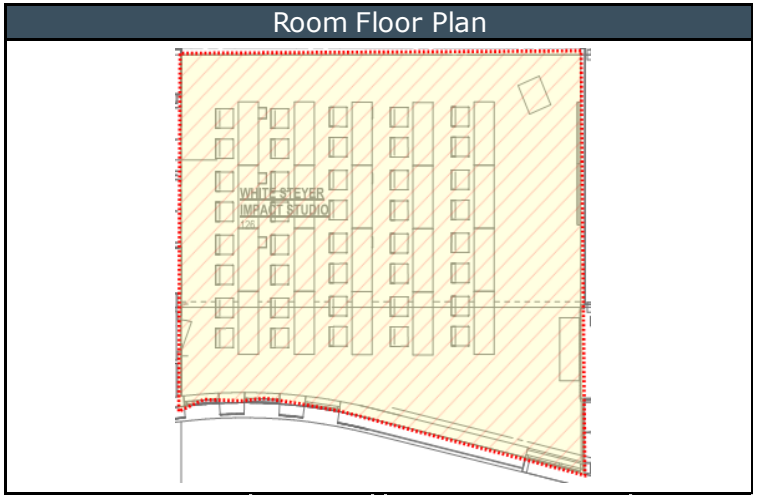
	Time	Value
1	00:00	(ta>to)&gt(ta,64.2)
2	06:00	(ta>to)&gt(ta,64.2)
3	07:00	(ta>to)&gt(ta,74.2)
4	18:00	(ta>to)&gt(ta,74.2)
5	18:00	(ta>to)&gt(ta,64.2)
6	24:00	(ta>to)&gt(ta,64.2)



Model Results

Thermal Comfort



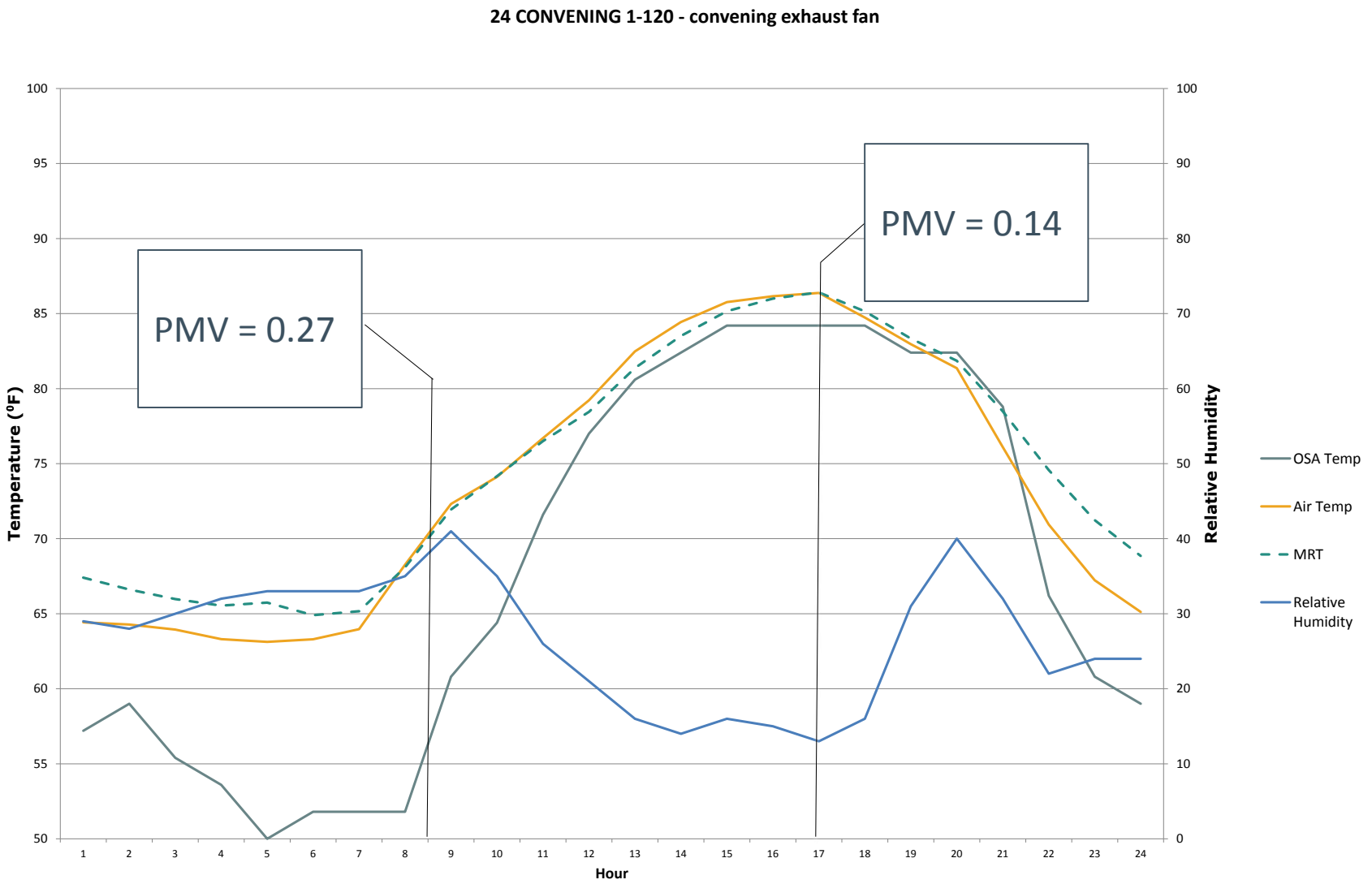


PMV ASSUMPTIONS:

Morning		**Afternoon**	
Clo	1.0	Clo	0.57
Met	1.0	Met	1.0
Air Speed	19 FPM	Air Speed	200 FPM
PMV	-0.34	PMV	-0.85
Morning		**Afternoon**	
Clo	1.0	Clo	0.57
Met	1.7	Met	1.7
Air Speed	19 FPM	Air Speed	200 FPM
PMV	0.72	PMV	0.04
Morning		**Afternoon**	
Clo	0.57	Clo	1.0
Met	1.0	Met	1.0
Air Speed	19 FPM	Air Speed	200 FPM
PMV	-1.27	PMV	0.15
Morning		**Afternoon**	
Clo	0.57	Clo	1.00
Met	1.7	Met	1.7
Air Speed	19 FPM	Air Speed	200 FPM
PMV	0.26	PMV	0.77

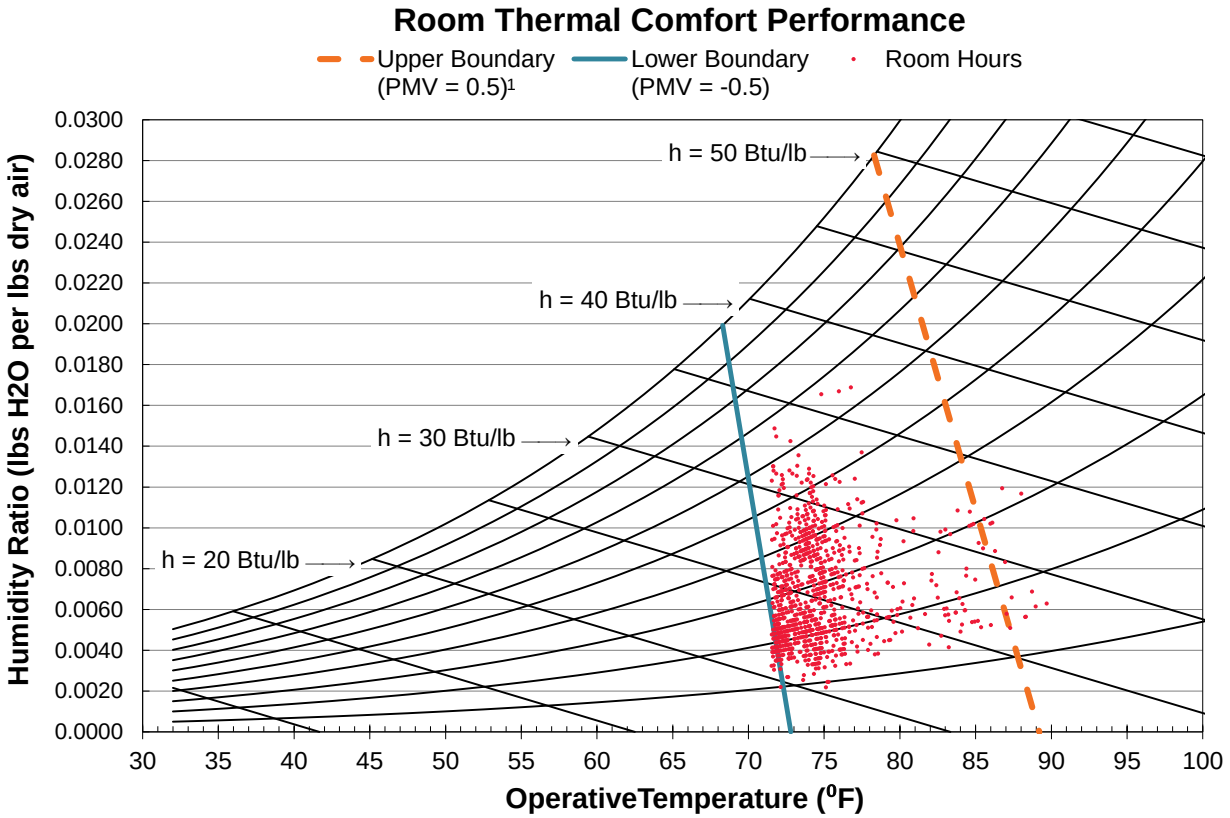
Model Results

Thermal Comfort



Model Results

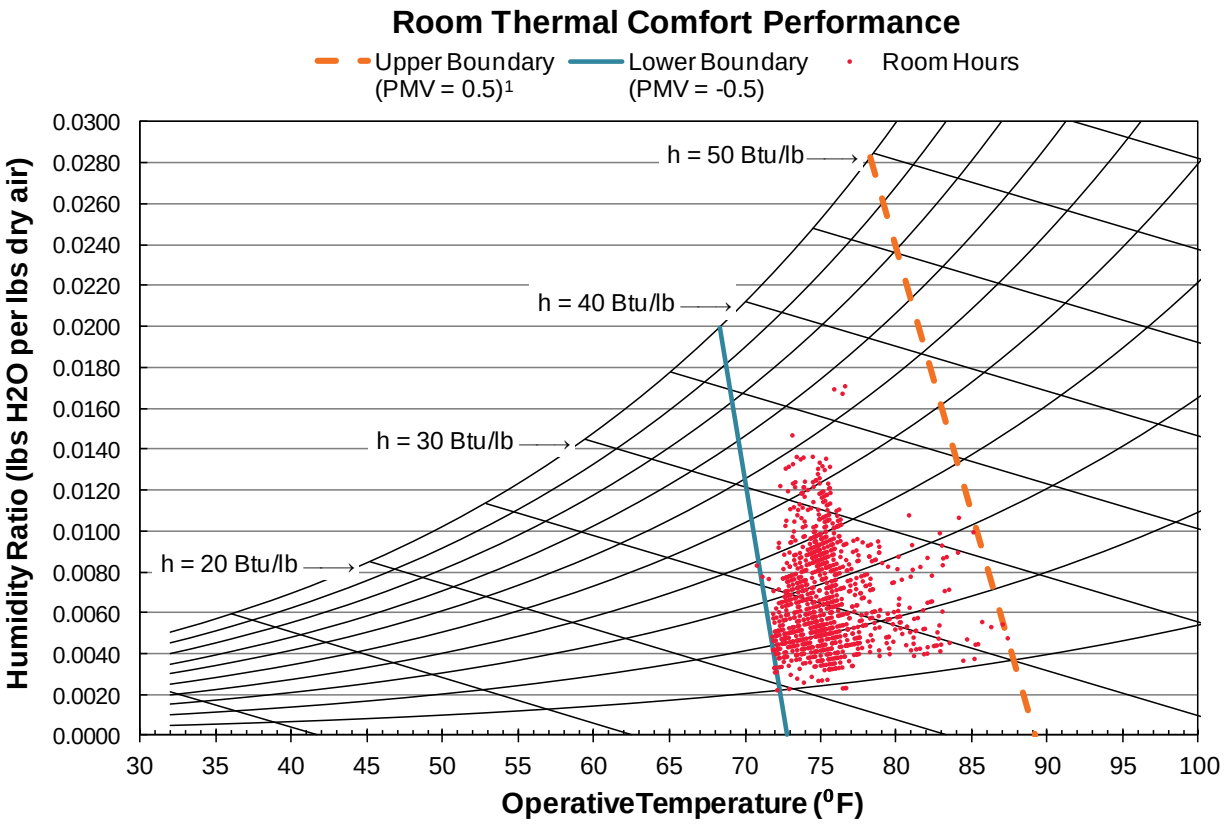
Thermal Comfort



1. Upper boundary is based on the Elevated Air Speed Model, ASHRAE Standard 55-2013 Appendix G

Model Results

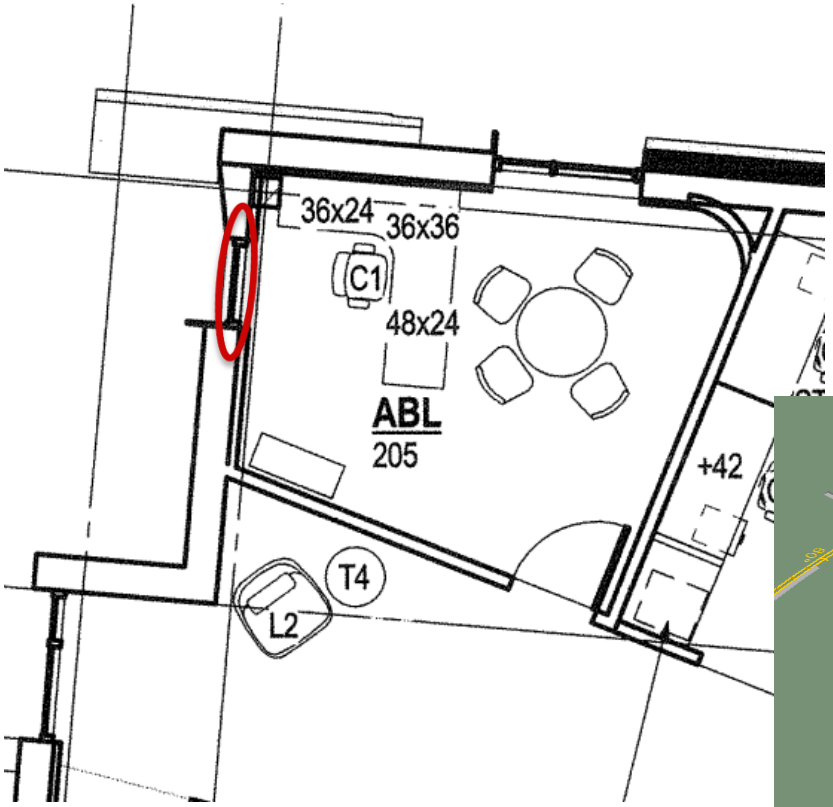
Thermal Comfort

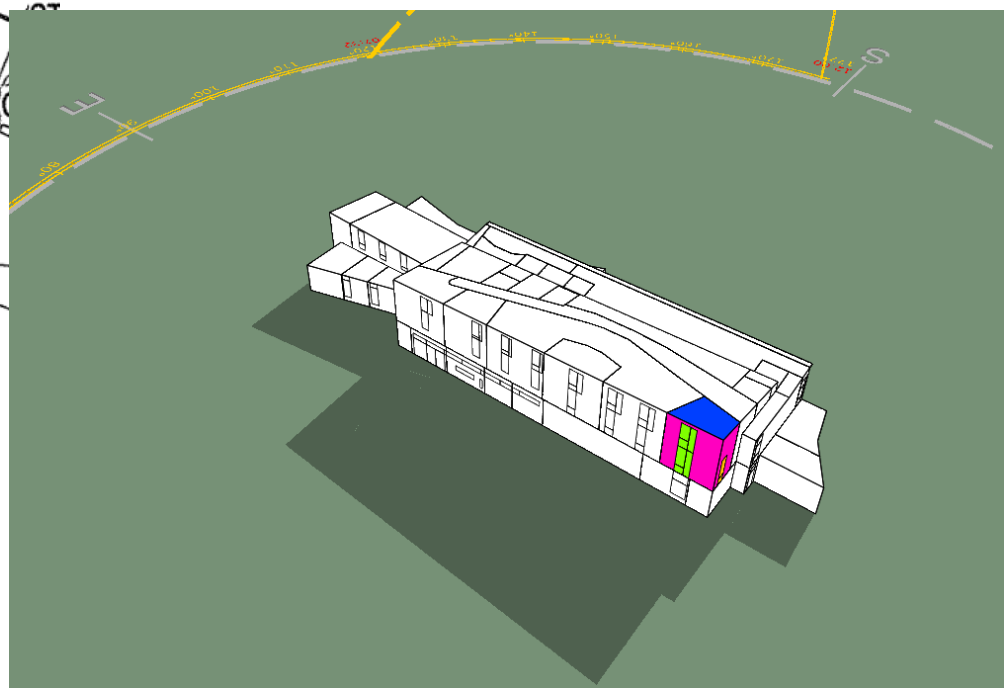


1. Upper boundary is based on the Elevated Air Speed Model, ASHRAE Standard 55-2013 Appendix G

Model Results

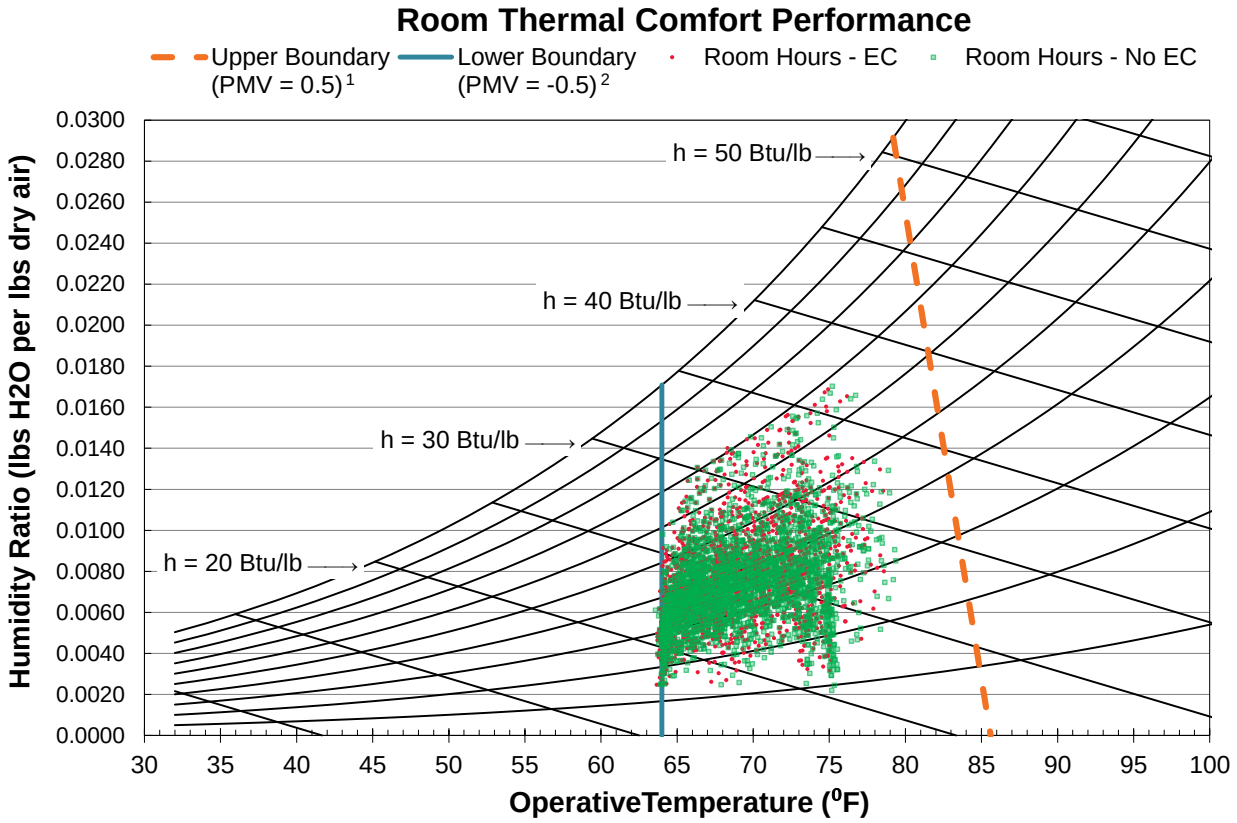
Thermal Comfort





Model Results

Thermal Comfort

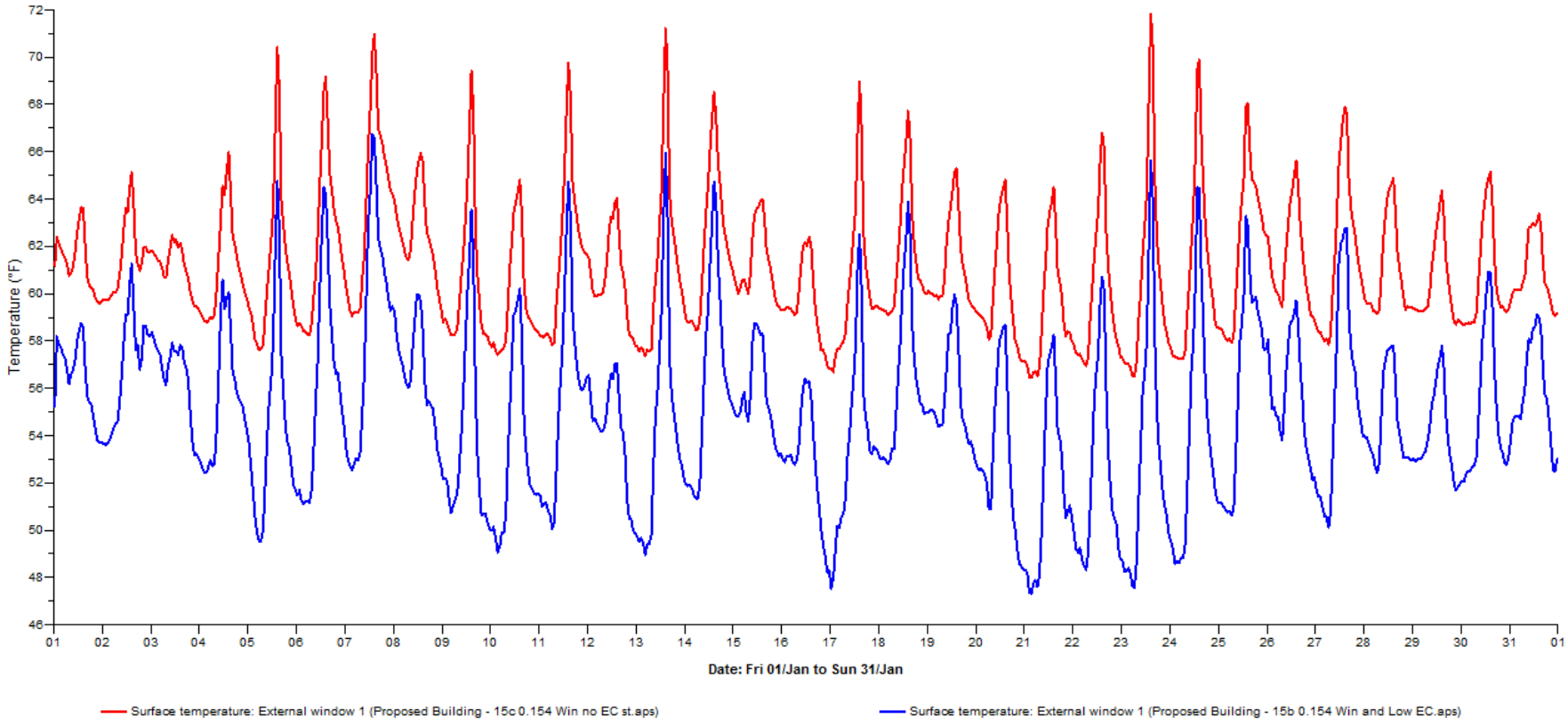


1. Upper boundary is based on the Elevated Air Speed Model, ASHRAE Standard 55-2013 Appendix G

2. Lower boundary is based on implementation of the CBE Personal Comfort System (Heated, Ventilated Chair)

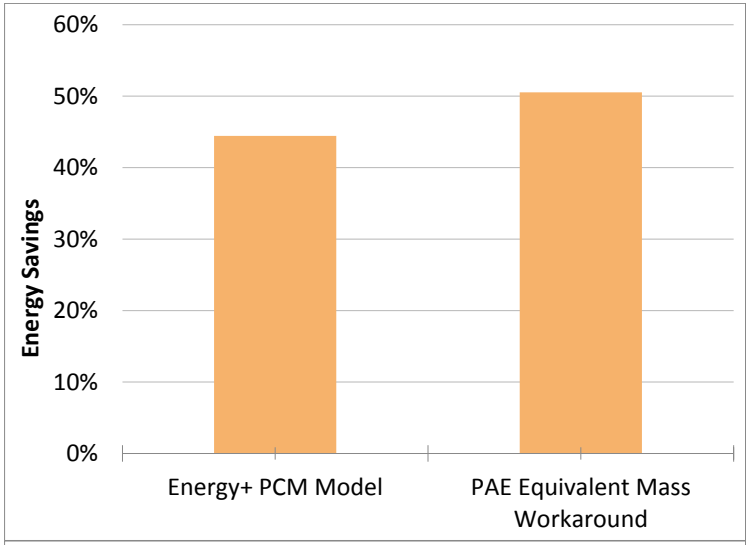
Model Results

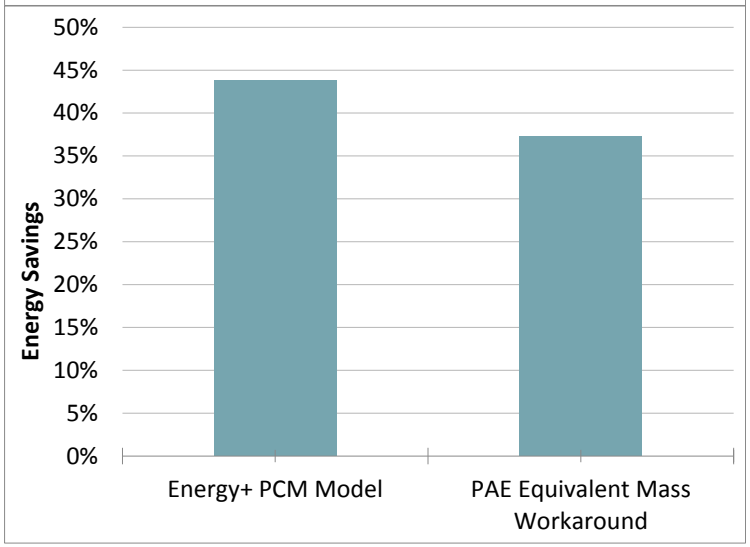
Thermal Comfort



Model Results

Shortcomings/Workarounds - PCM





Model Results

Shortcomings/Workarounds

- Shading/EC Control

What else is new in Feature Pack 1?

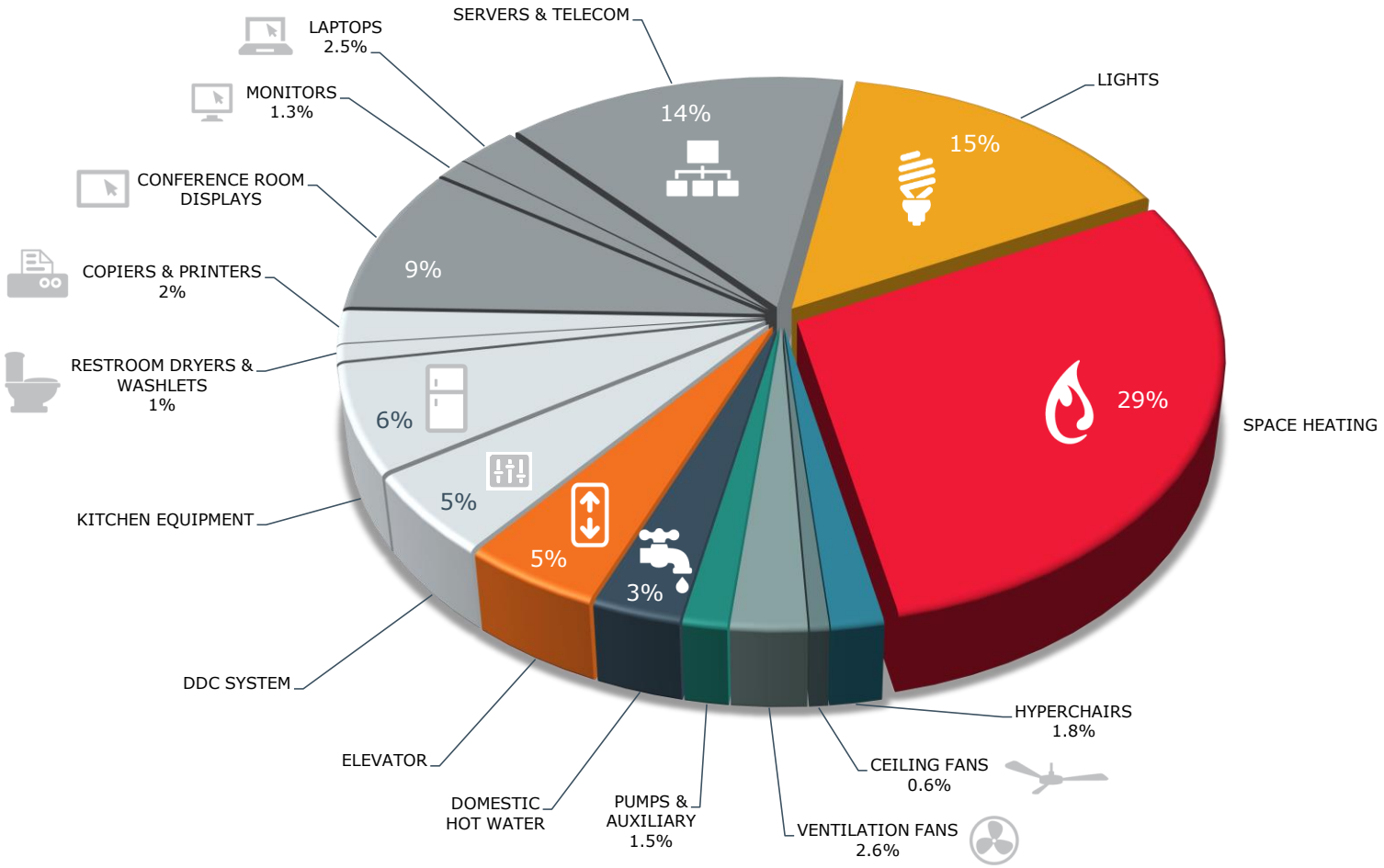
Electrochromic Glazing

- Glazed Constructions can be assigned electrochromic properties.
- Specify properties of the glazing when in clear mode and tinted mode and also operation schedule and formula for switching between modes based on variables e.g. incident irradiance on the window or room air temperature.

- Input Verification
- Parametric Runs

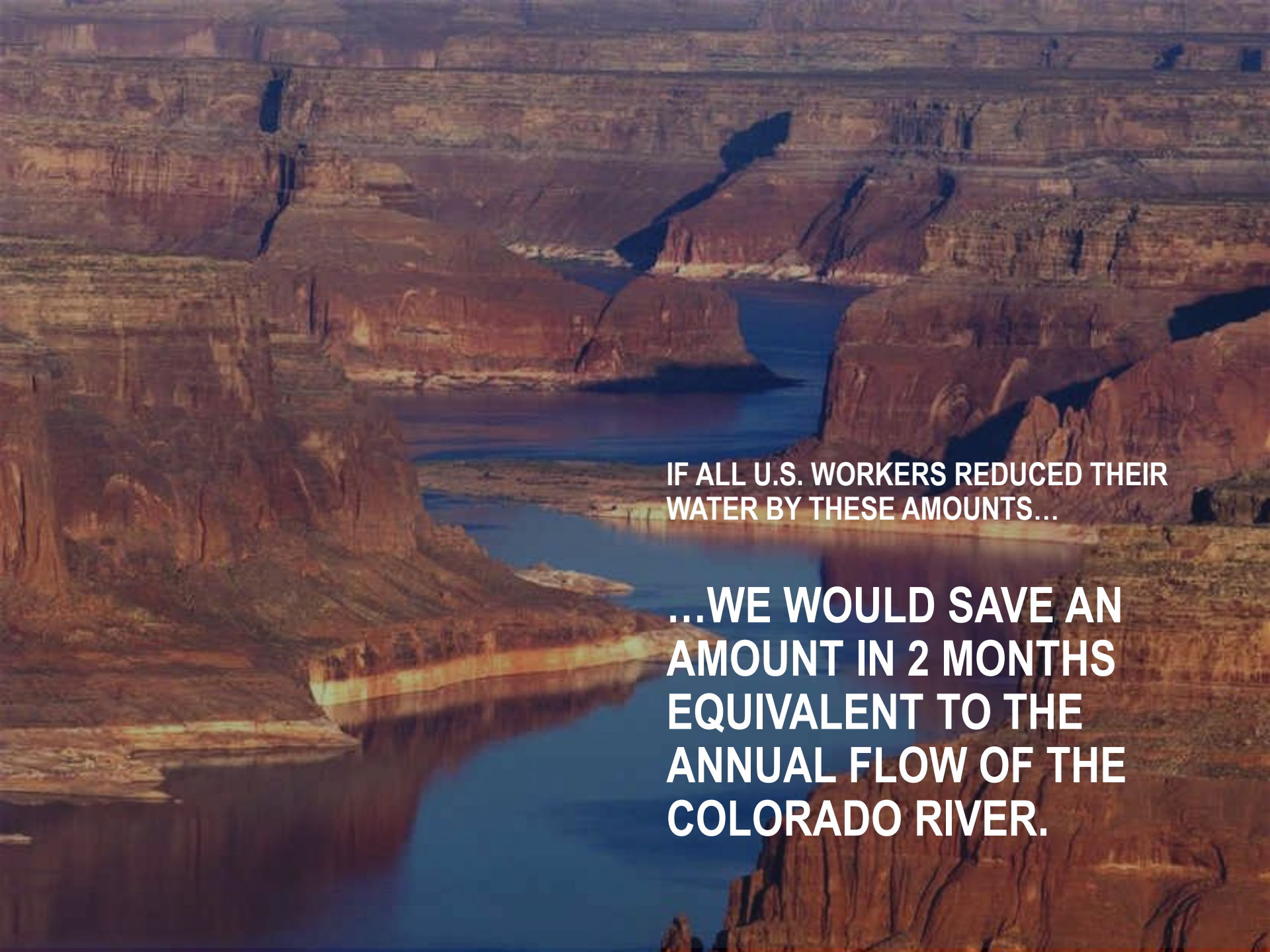
Model Results

Energy



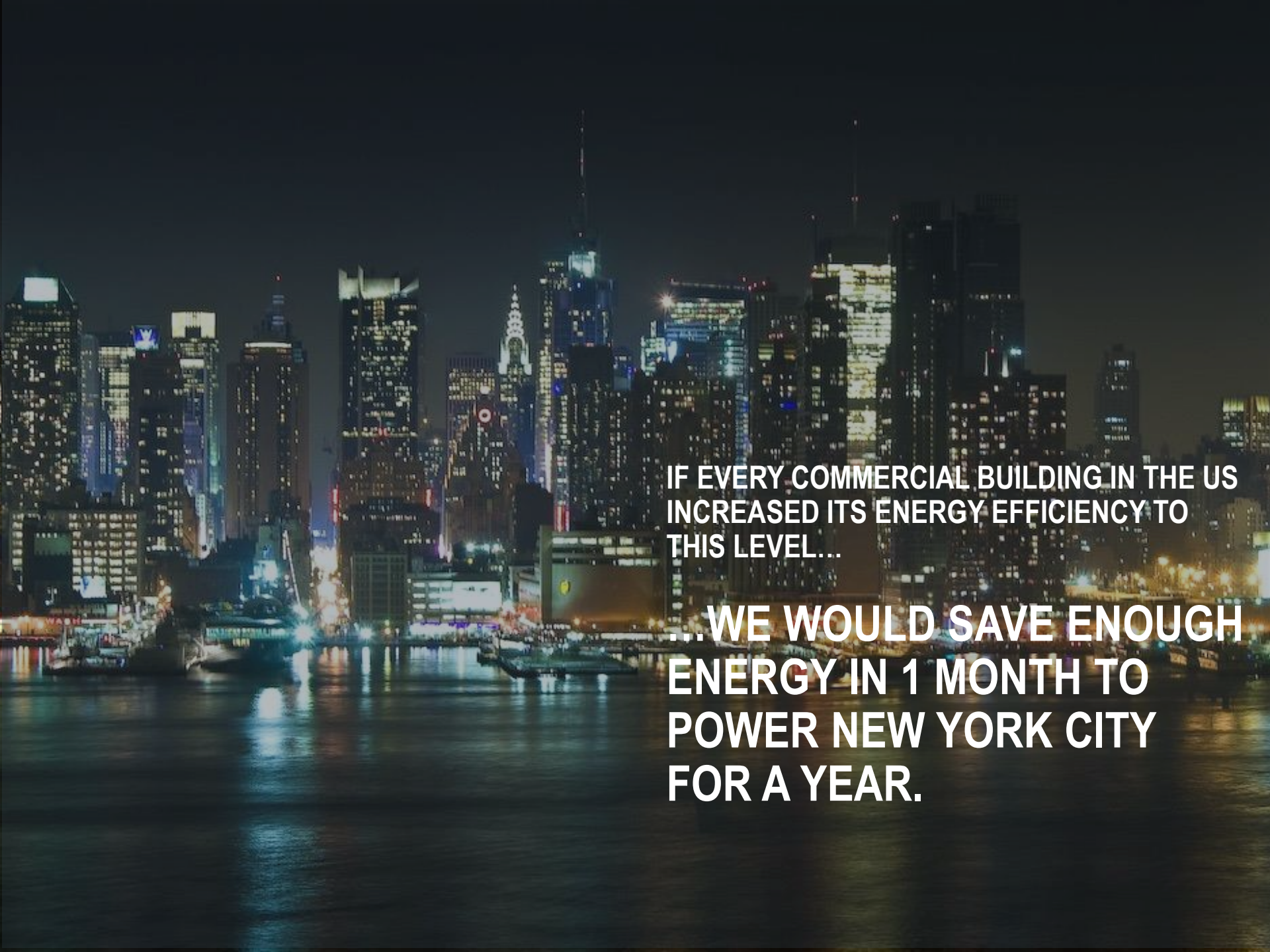
IF ALL LOW- AND MID RISE BUILDINGS IN THE US WERE CONSTRUCTED FROM RECLAIMED COLORADO BEETLE-KILL TIMBER…

…WE COULD MEET THE NEW BUILDING DEMAND FOR THE NEXT 17 YEARS.



IF ALL U.S. WORKERS REDUCED THEIR WATER BY THESE AMOUNTS…

…WE WOULD SAVE AN AMOUNT IN 2 MONTHS EQUIVALENT TO THE ANNUAL FLOW OF THE COLORADO RIVER.


IF EVERY COMMERCIAL BUILDING IN THE US INCREASED ITS ENERGY EFFICIENCY TO THIS LEVEL...
...WE WOULD SAVE ENOUGH ENERGY IN 1 MONTH TO POWER NEW YORK CITY FOR A YEAR.

Marc Brune, PE, LEED AP, Senior Associate, PAE
marc.brune@pae-engineers.com

Ben Burnett, PE, PAE
ben.burnett@pae-engineers.com

John Breshears, Founder and President, Architectural Applications
jbreshears@architecturalapplications.com

inspire interpret integrate