High Performance Buildings and Occupant Comfort

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Learning Objectives for this Session

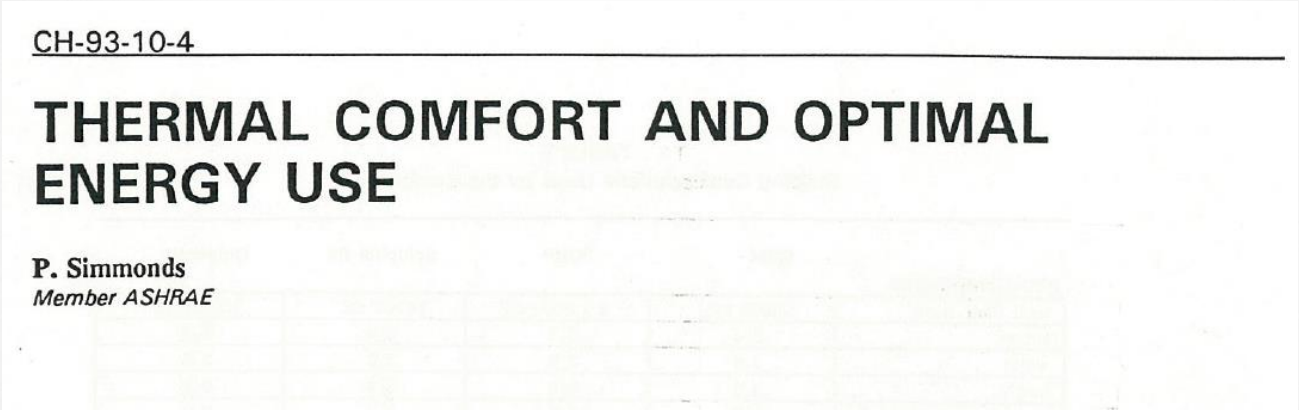
- **PPD/PMV analysis can be used for space comfort diagnostics.**
- **Using comfort analysis provides more information for the design team.**
- **Not all analysis tools are capable of simulating occupant comfort.**
- **Multiple use spaces still require to provide occupant comfort.**
- **To understand the application of radiant systems**
- **To understand the limitations of maintaining comfort**

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THERMAL COMFORT AND OPTIMAL ENERGY USE

P. Simmonds
Member ASHRAE

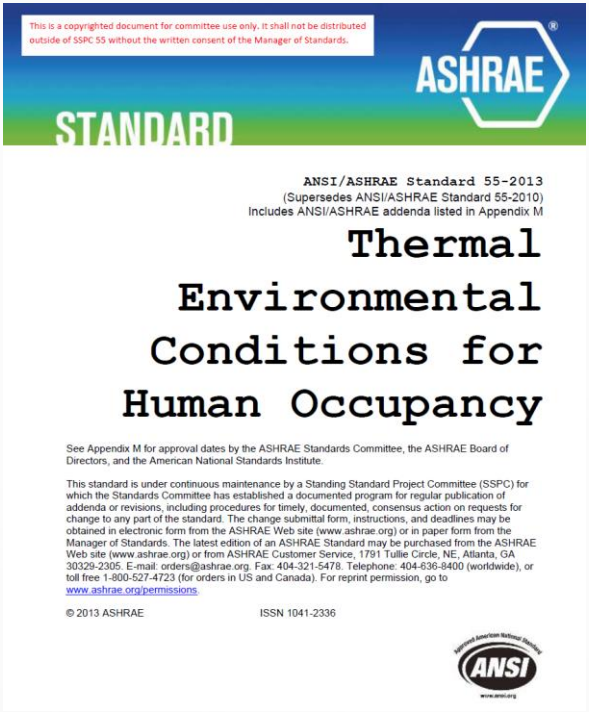
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Thermal Comfort Standard



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ASHRAE

STANDARD

ANSI/ASHRAE Standard 55-2013
(Supersedes ANSI/ASHRAE Standard 55-2010)
Includes ANSI/ASHRAE addenda listed in Appendix M

Thermal Environmental Conditions for Human Occupancy

See Appendix M for approval dates by the ASHRAE Standards Committee, the ASHRAE Board of Directors, and the American National Standards Institute.

This standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE Web site (www.ashrae.org) or in paper form from the Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from the ASHRAE Web site (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 404-321-5478. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

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ANSI



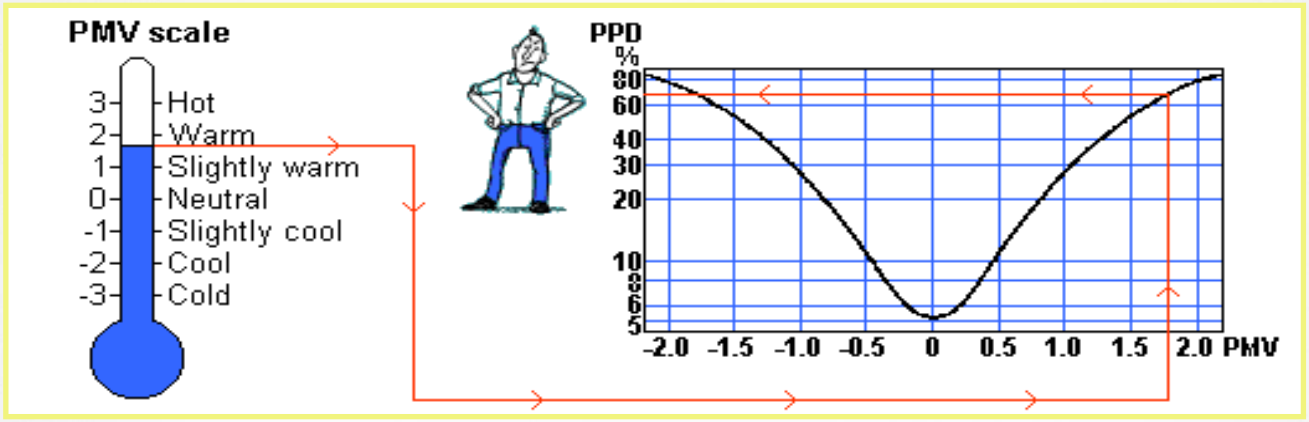
Definitions

- ***predicted mean vote (PMV):*** an index that predicts the mean value of the votes of a large group of persons on the seven-point thermal sensation scale.

- ***predicted percentage of dissatisfied (PPD):*** an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people determined from PMV.

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THERMAL COMFORT



- 1) Metabolic rate.
- 2) Clothing insulation.
- 3) Air temperature.
- 4) Radiant temperature
- 5) Air speed.
- 6) Humidity

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Thermal Comfort Calculations

The PMV is given by the following equations:

$$PMV = \left(0{,}303e^{-0{,}036M} + 0{,}028\right)$$

$$\begin{bmatrix} (M-W) - 3{,}05\cdot 10^{-3}\{5733 - 6{,}99(M-W) - p_a\} - 0{,}42\{(M-W) - 58{,}15\} \\ -1{,}7\cdot 10^{-5} M(5867 - p_a) - 0{,}0014M(34 - t_a) \\ -3{,}96\cdot 10^{-8} f_{cl}\left\{(t_{cl}+273)^4 - (\bar{t}_r+273)^4\right\} - f_{cl}h_c(t_{cl} - t_a) \end{bmatrix}$$

where

$$t_{cl} = 35{,}7 - 0{,}028(M-W) - I_{cl}\left[3{,}96\cdot 10^{-8} f_{cl}\left\{(t_{cl}+273)^4 - (\bar{t}_r+273)^4 + f_{cl}h_{cl}(t_{cl}-t_a)\right\}\right]$$

$$h_c = 2{,}38(t_{cl}-t_a)^{0{,}25} \text{ for } 2{,}38(t_{cl}-t_a)^{0{,}25} > 12{,}1\sqrt{v_{ar}}$$

$$= 12{,}1\sqrt{v_{ar}} \quad \text{for } 2{,}38(t_{cl}-t_a)^{0{,}25} < 12{,}1\sqrt{v_{ar}}$$

$$f_{cl} = 1{,}00 + 1{,}290I_{cl} \ldots \text{for } I_{cl} < 0{,}078 m^2\cdot KW^{-1}$$

$$= 1{,}05 + 0{,}545I_{cl} \quad \text{for } I_{cl} > 0{,}078 m^2\cdot KW^{-1}$$

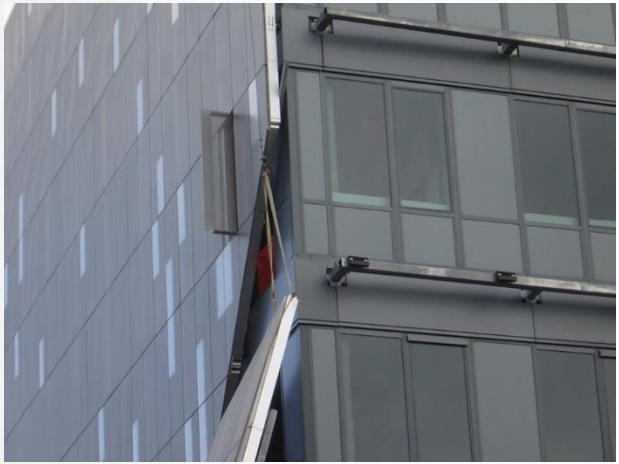
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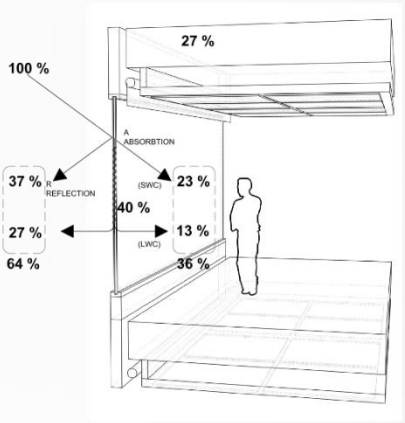
Cooper Union



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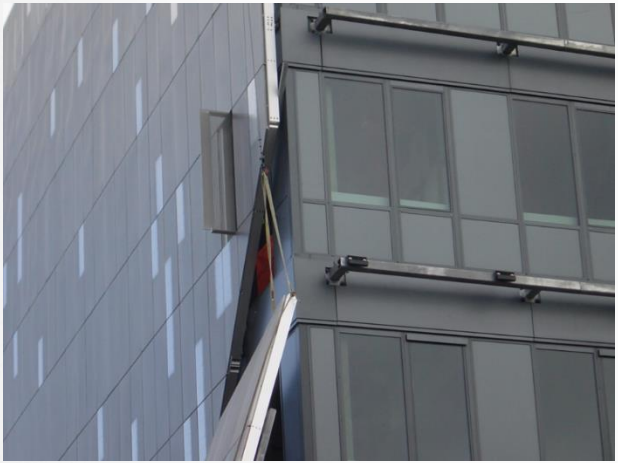
“Single” Facade

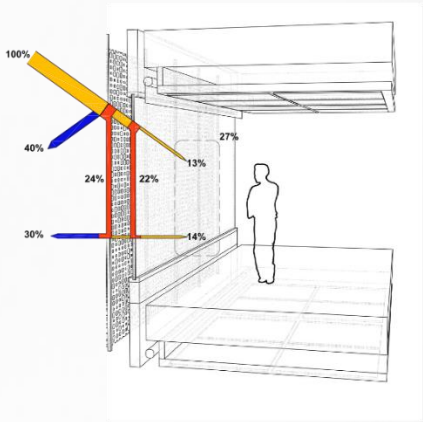




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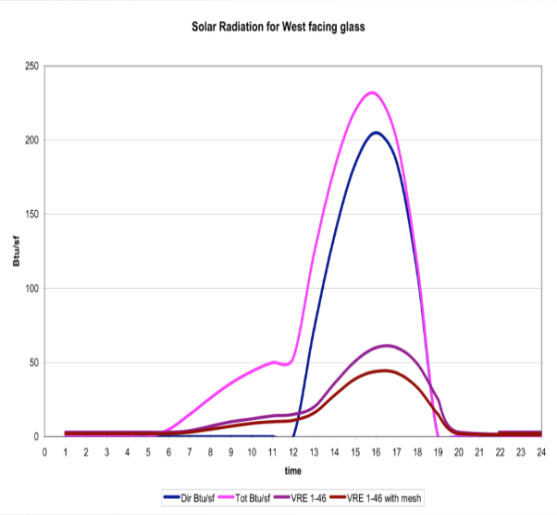
“Double” facade

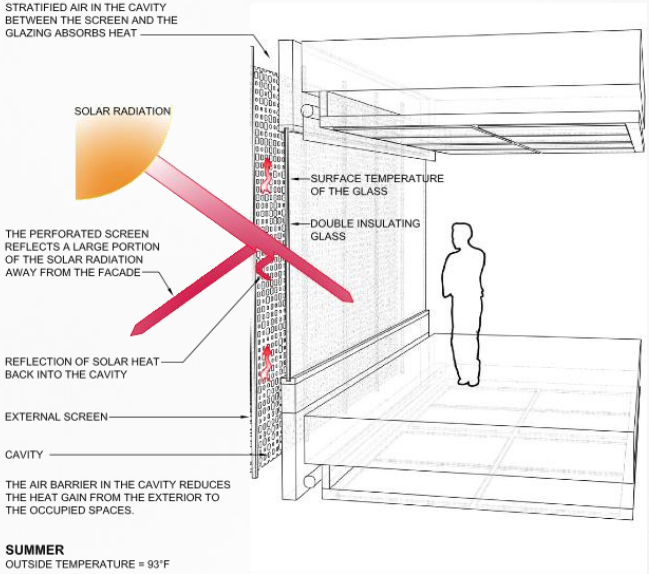




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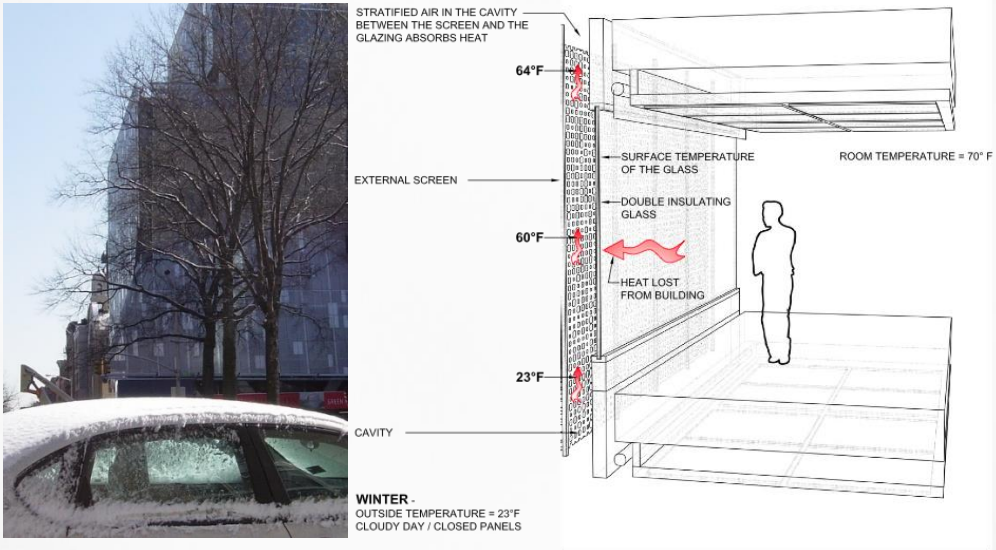
The efficiency of the façade-summer





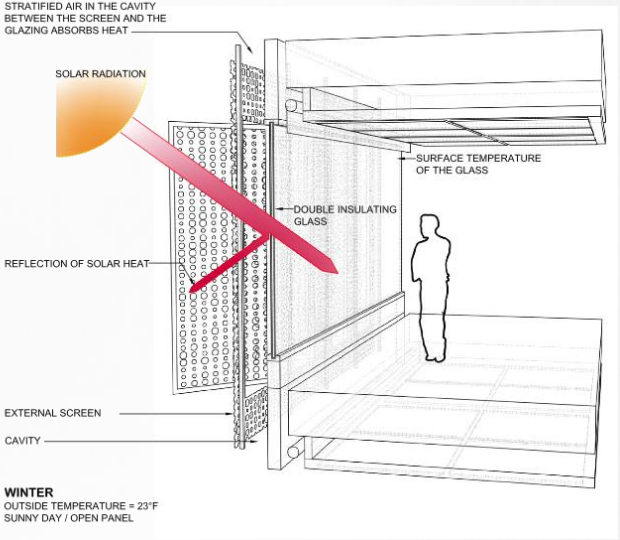
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The efficiency of the façade-winter



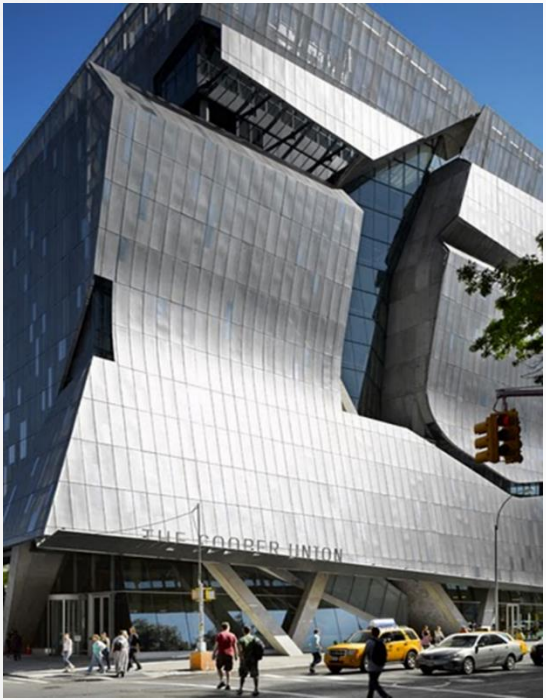
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The efficiency of the façade-midseason



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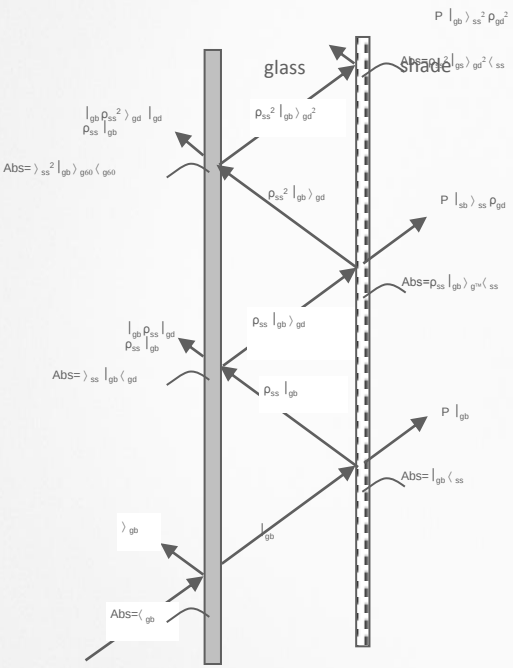
The Living Skin





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The mathematical calculations



"Abs" denotes the fraction of absorbed short wave energy for the glass or shade on each successive reflection. The portion of the incident beam short wave energy that is ultimately absorbed by the shade, Abs_{bss}, is:

$$Abs_{bss} = \tau_{gb}\alpha_{ss}\sum_{n=0}^{\infty}[\rho_{ss}\rho_{gd}]^n = \frac{\tau_{gb}\alpha_{ss}}{1-\rho_{ss}\rho_{gd}}$$

where

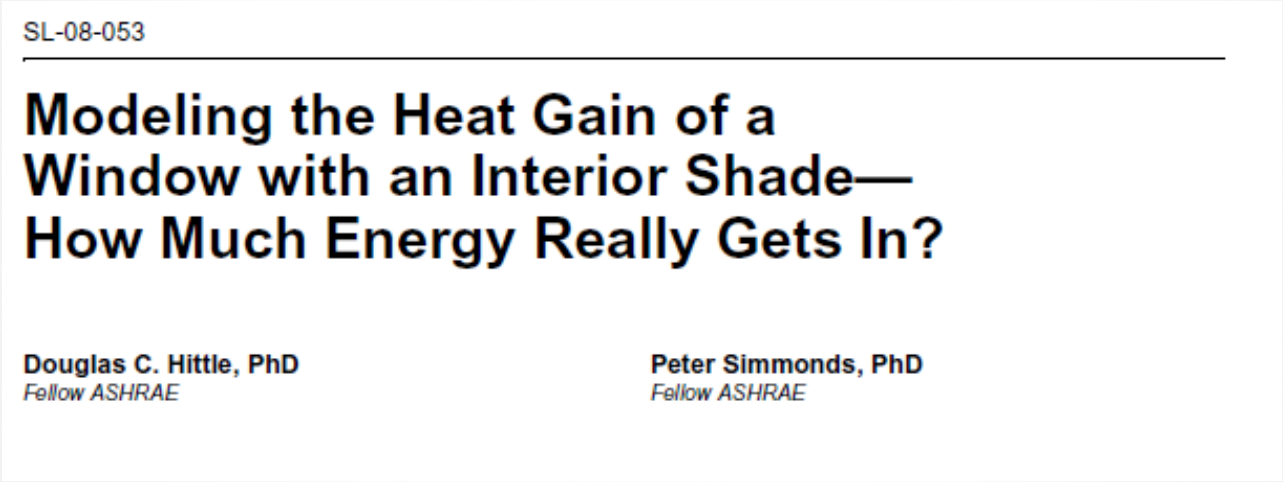
t_{gb}=short wave transmittance of the glass (a function of incidence angle, θ)

α_{ss}=short wave absorptance of the shade

ρ_{gd}=diffuse reflectance of the glass

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Cooper Union



SL-08-053

Modeling the Heat Gain of a Window with an Interior Shade— How Much Energy Really Gets In?

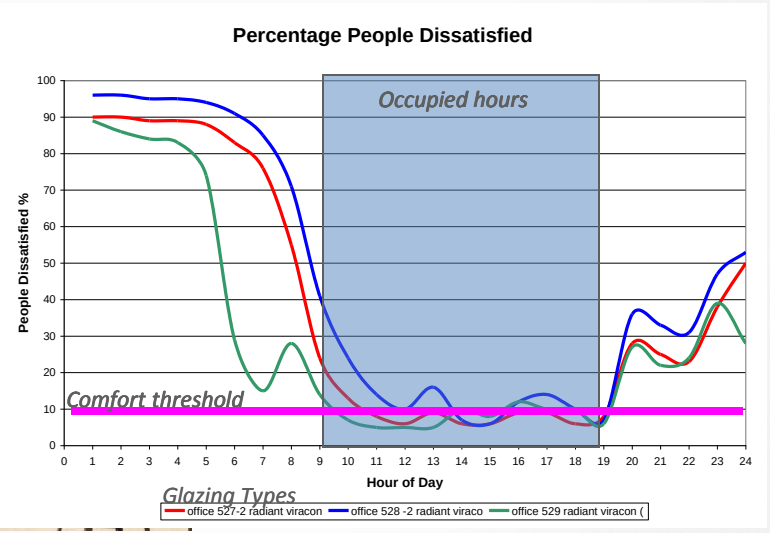
Douglas C. Hittle, PhD
Fellow ASHRAE

Peter Simmonds, PhD
Fellow ASHRAE

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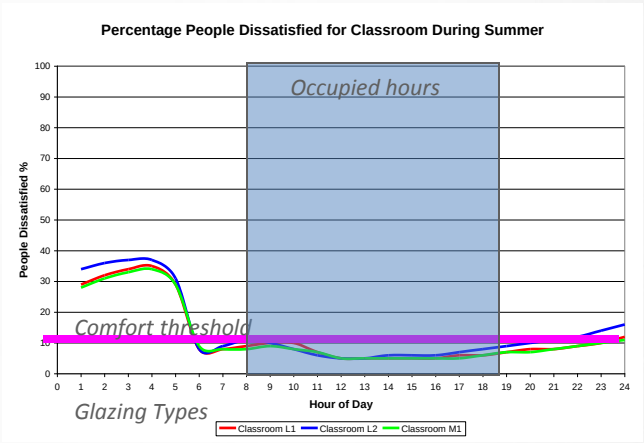




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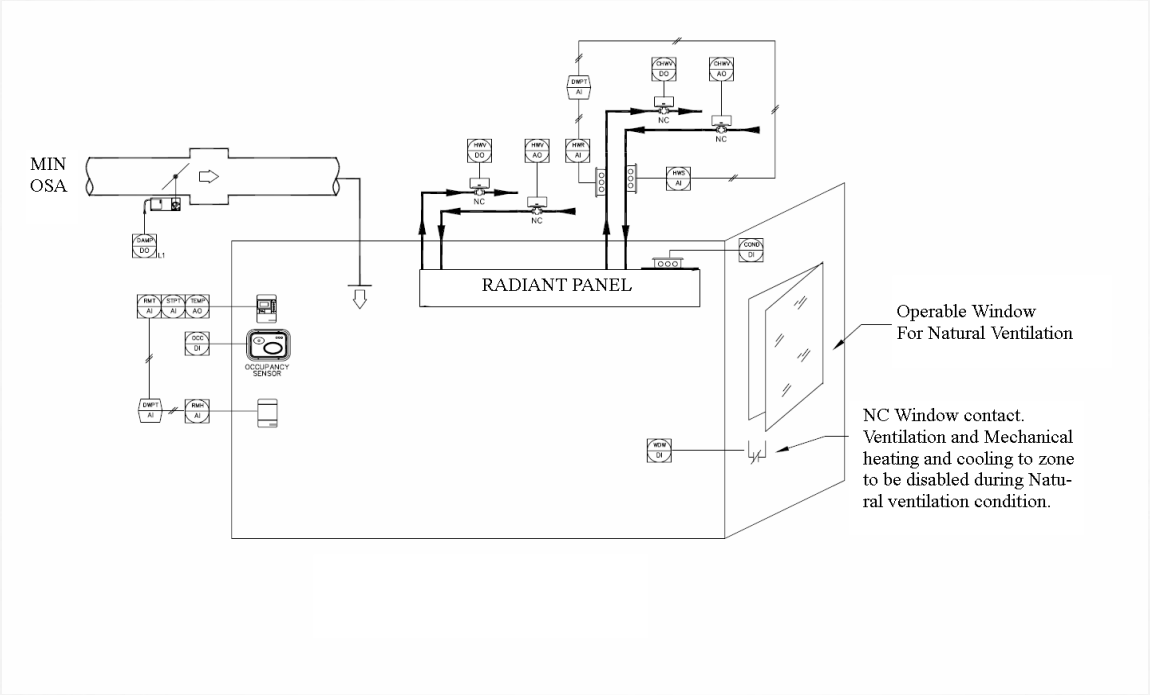
Cooper Union- Results

LEED 2.2, using the ASHRAE 90.1, 2004 standard, the resulting utility cost savings are $400,770 compared to $602,672 for the budget case.. The total energy cost savings is 34% and is therefore eligible for 7 LEED points.

- NYSERDA Energy Compliance, the proposed case is predicted at consuming 1,170,365 kWh of electricity per year and the budget case is predicted at consuming 2,184,932 kWh of electricity per year. This is a 46% reduction below the budget case.

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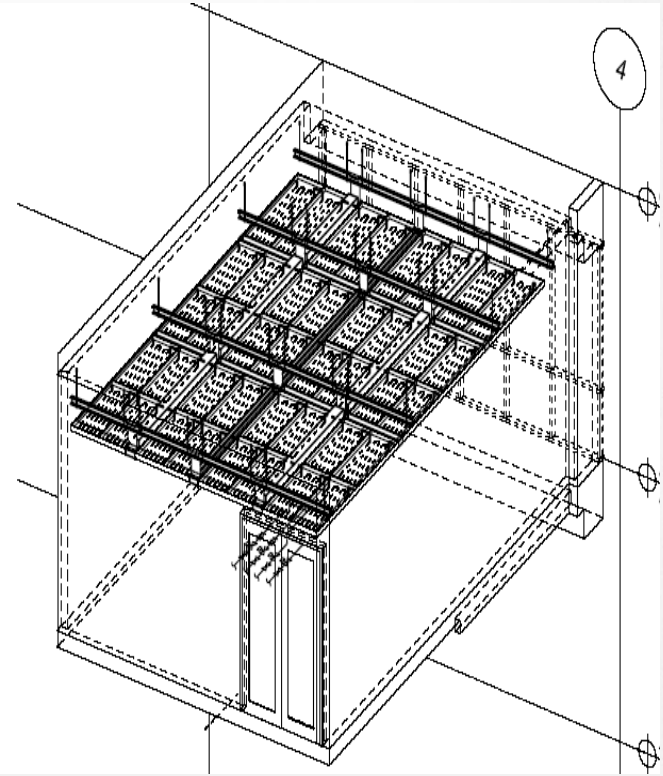
Space Control System



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Radiant Ceiling





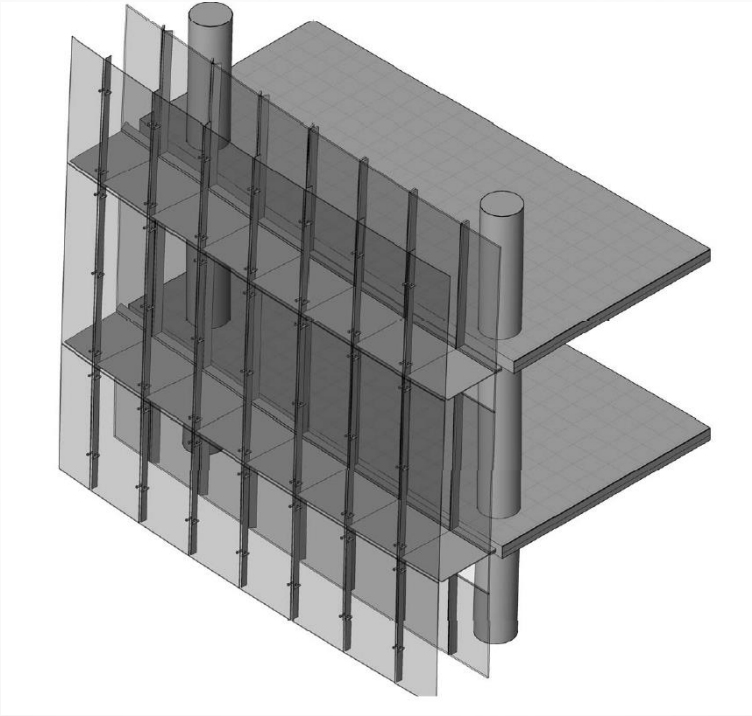
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Harbin Bank, Beijing

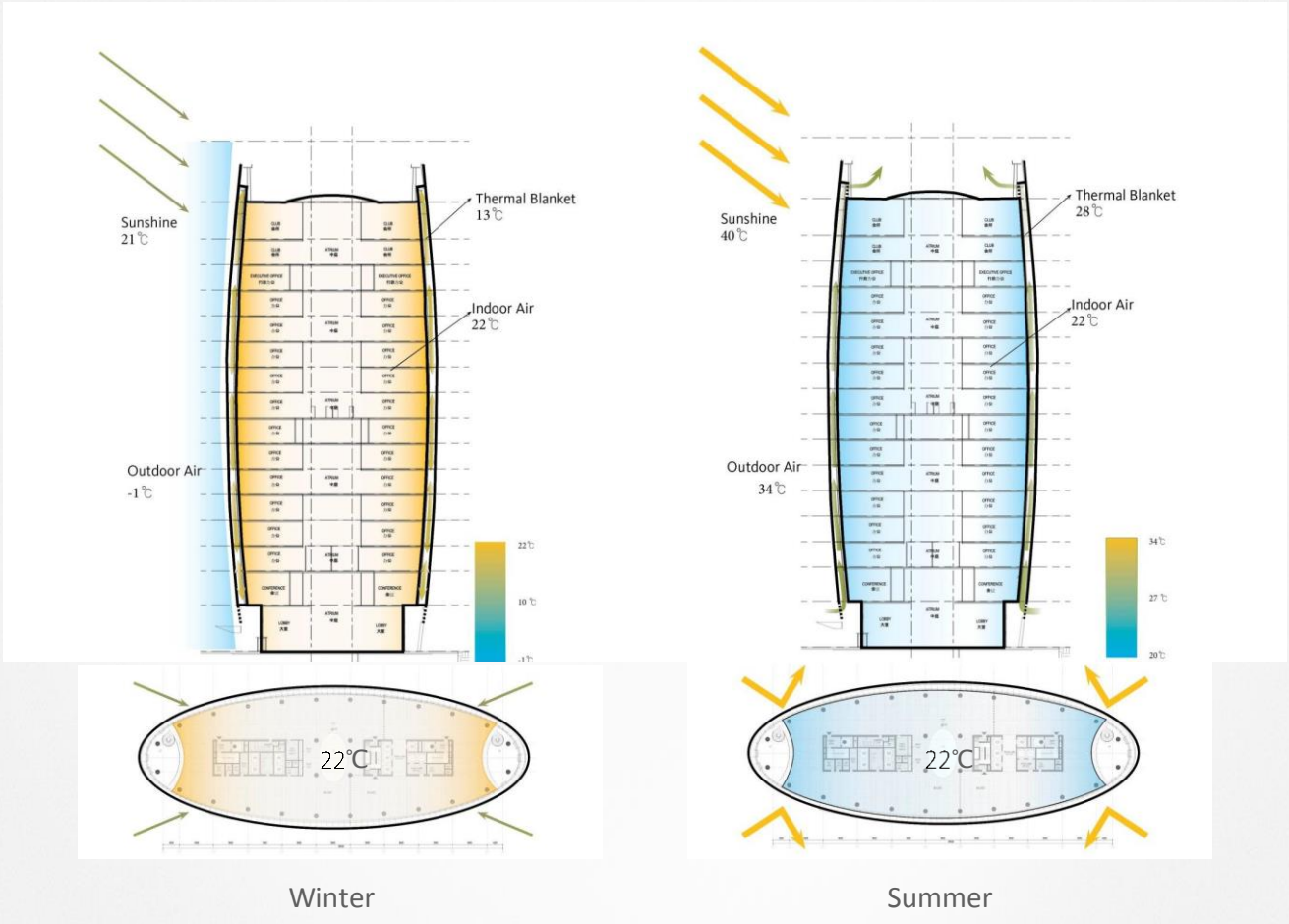


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The Climate Facade



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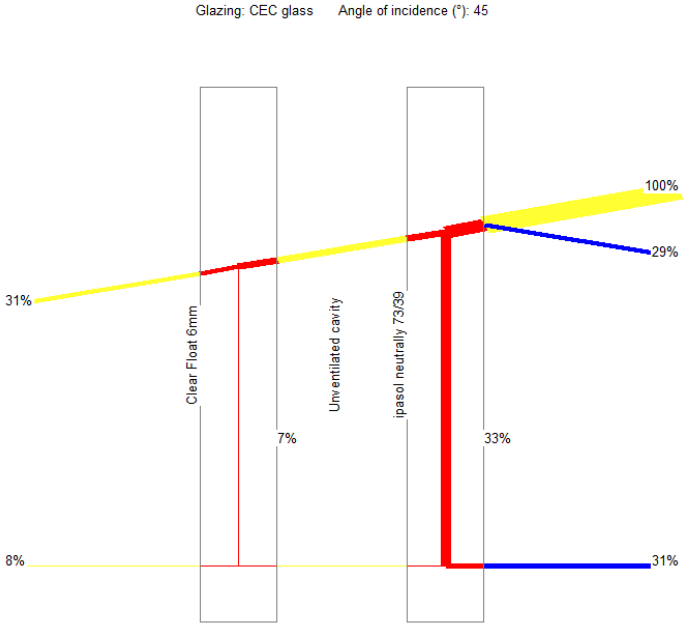


Winter

Summer

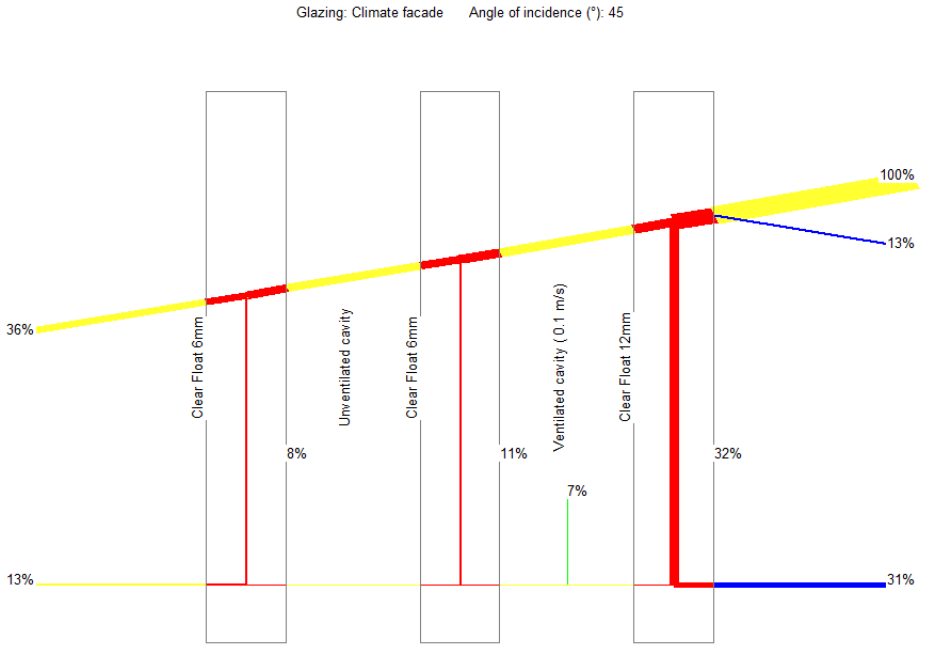
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China Energy Code Glass



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Climate Façade Winter



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Climate Façade- Summer



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Façade Performance

FAÇADE				
SUMMER	China Energy code	Climate Façade	Difference	% Difference
Transmission	259,200	182,736	76,464	29.50%
solar Radiation	1,922,400	538,272	1,384,128	72.00%
total	2,181,600	721,008	1,460,592	66.95%
WINTER	China Energy code	Climate Façade	Difference	% Difference
Transmission	-864,000	-609,120	-254,880	29.50%
solar Radiation	2,122,000	2,588,840	466,840	18.03%
total	1,258,000	1,979,720		

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Typical floor

TYPICAL FLOOR				
SUMMER	China Energy code	Climate Façade	Difference	% Difference
Transmission	30,964	16,514	14,450	46.67%
solar Radiation	90,441	34,359	56,081	62.01%
total	121,404	50,873	70,531	58.10%
WINTER	China Energy code	Climate Façade	Difference	% Difference
Transmission	-103,212	-55,046	-48,166	46.67%
solar Radiation	105,195	177,324	72,129	40.68%
total	1,983	122,278		

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Required Supply Air Volumes

- Summer

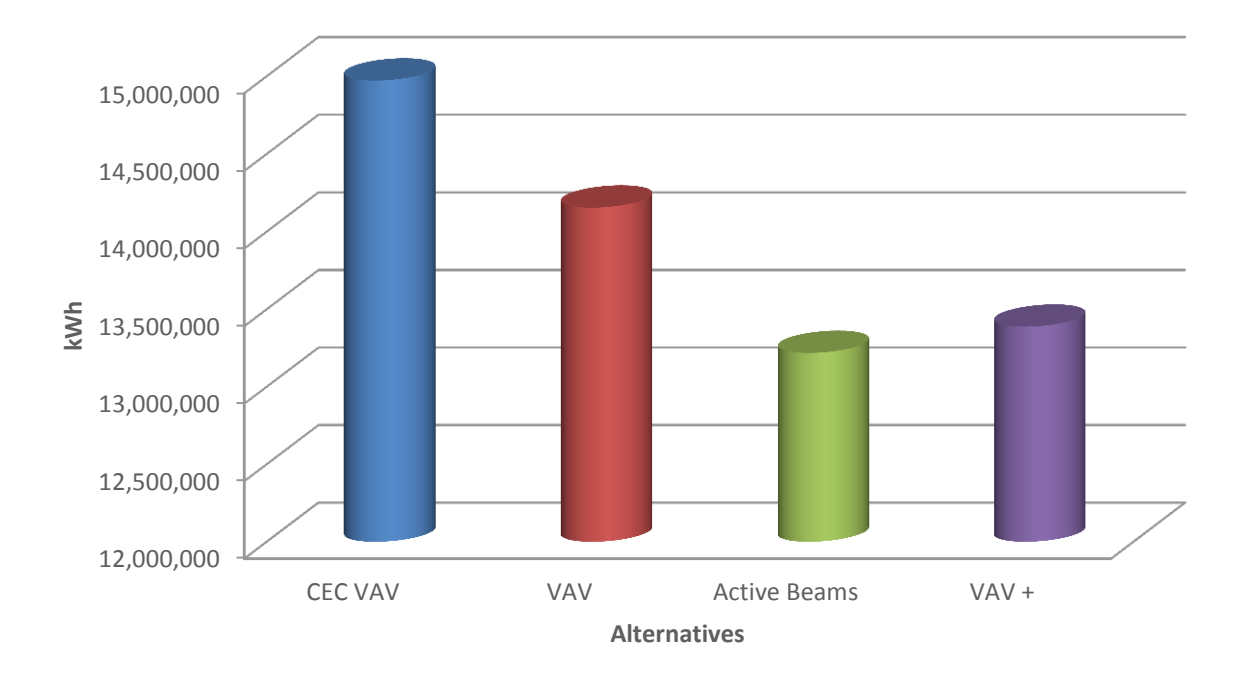
  CEC VAV = (61,000m^3/h)
  VAV = (42,000 m^3/h)
  AB = (8,300 m^3/h)

- Winter

  CEC = 5.4 m^3/s (19,440 m^3/h)
  Proposed =5.4 m^3/s (19,440 m^3/h)

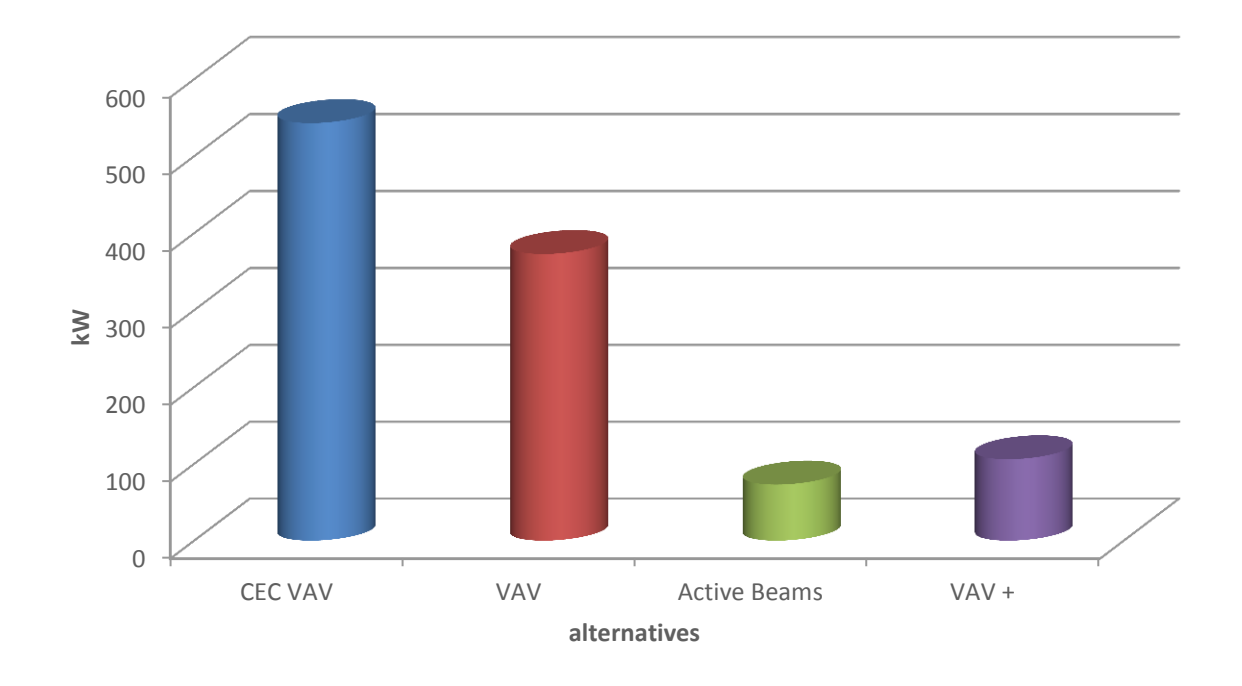
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Annual Electric Consumption



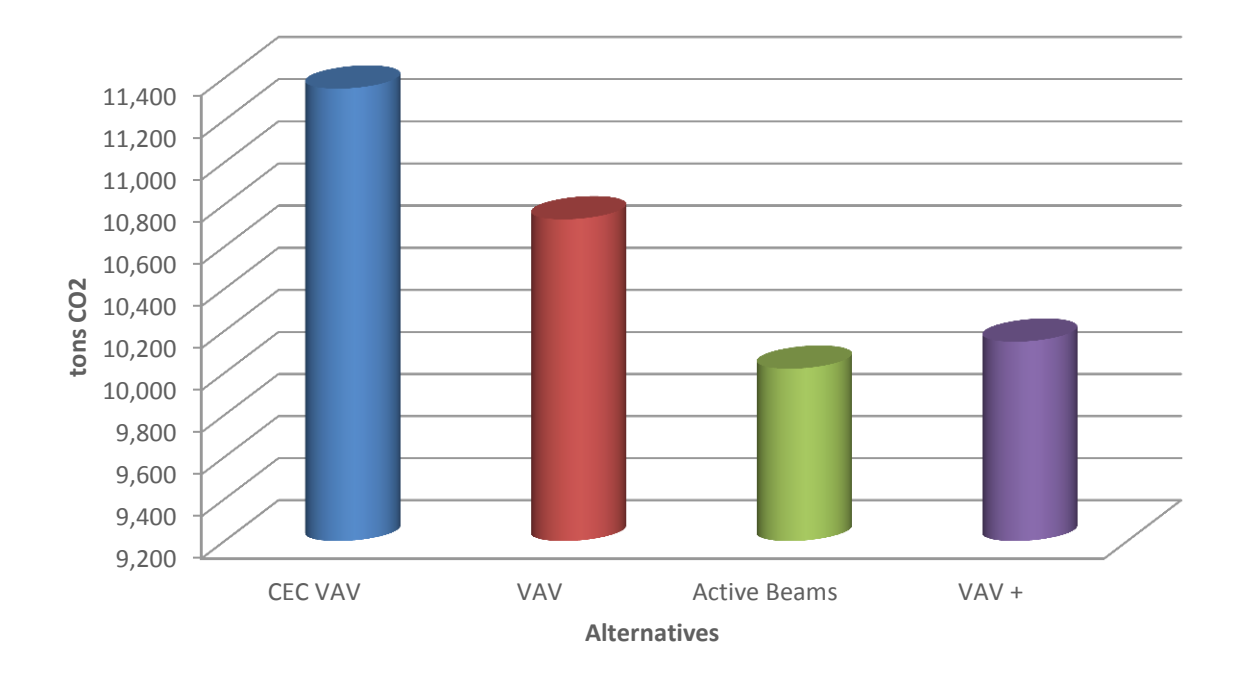
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Fan Power



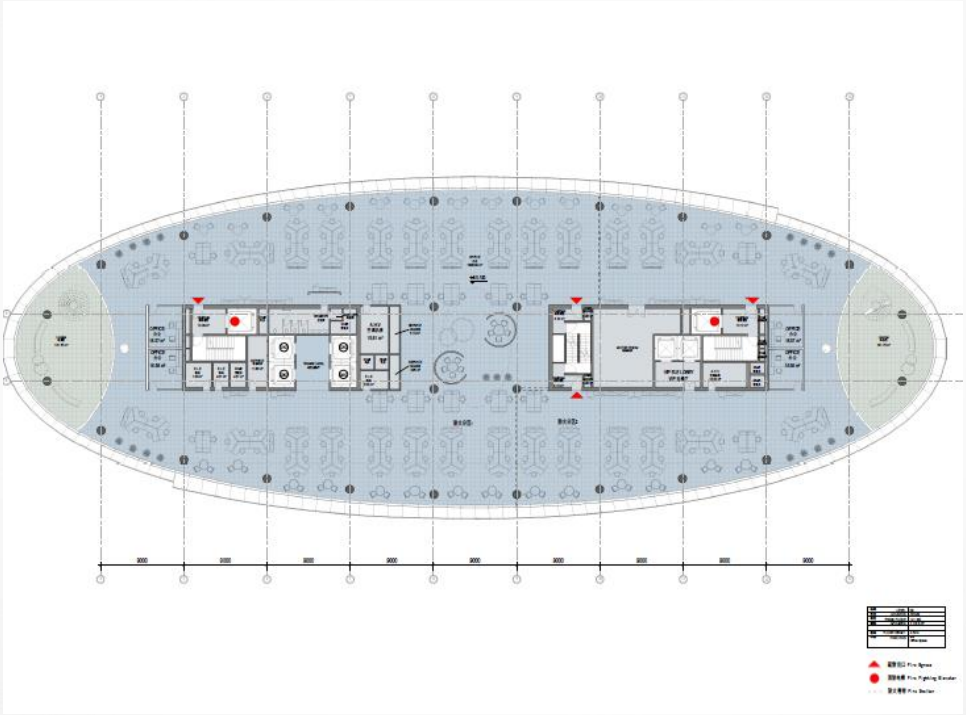
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CO2 Emissions



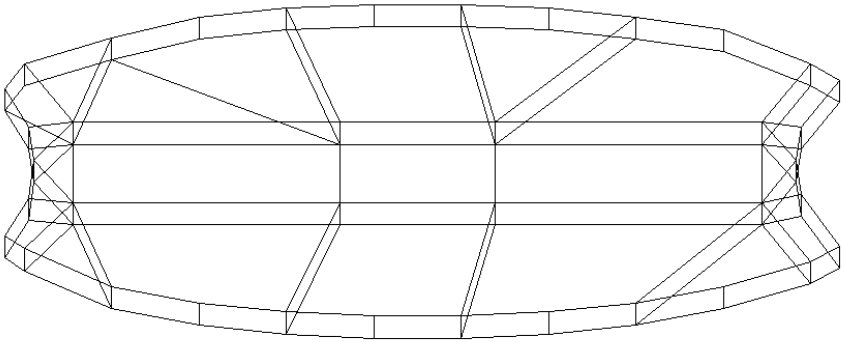
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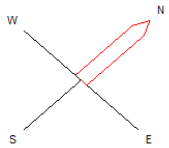
Typical Floor

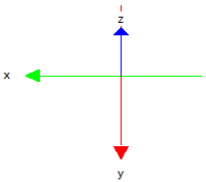


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Simulation Model

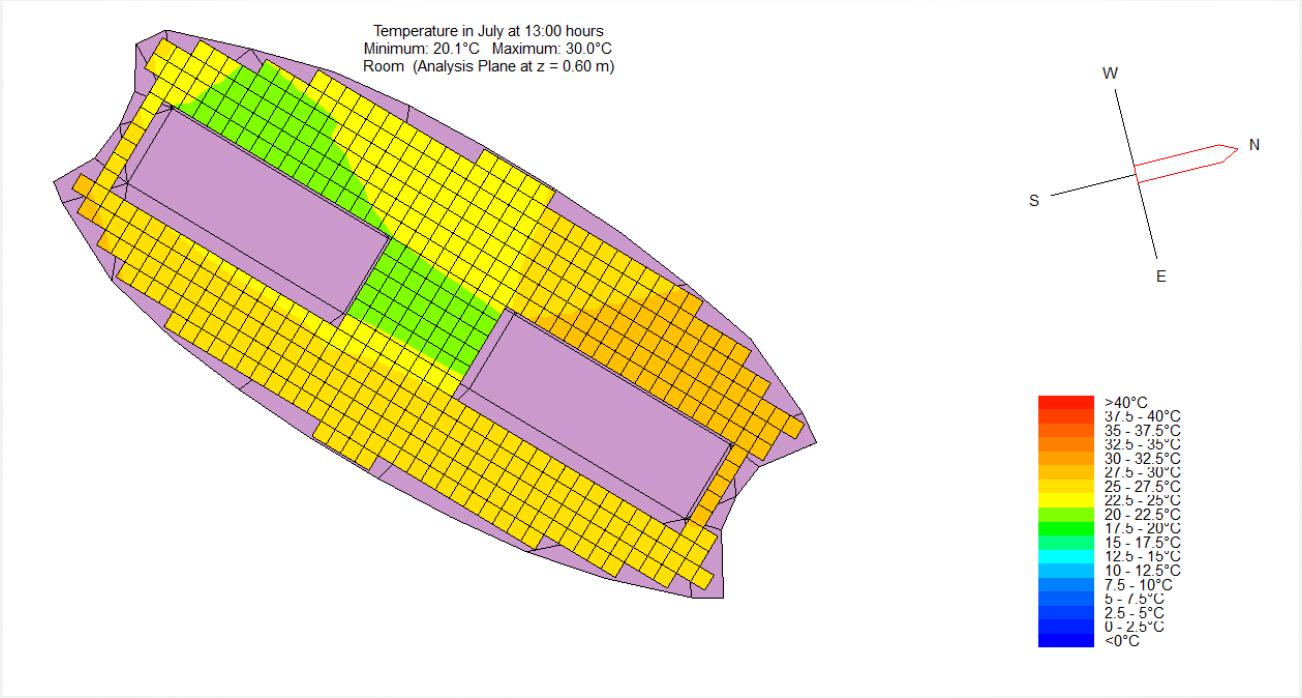






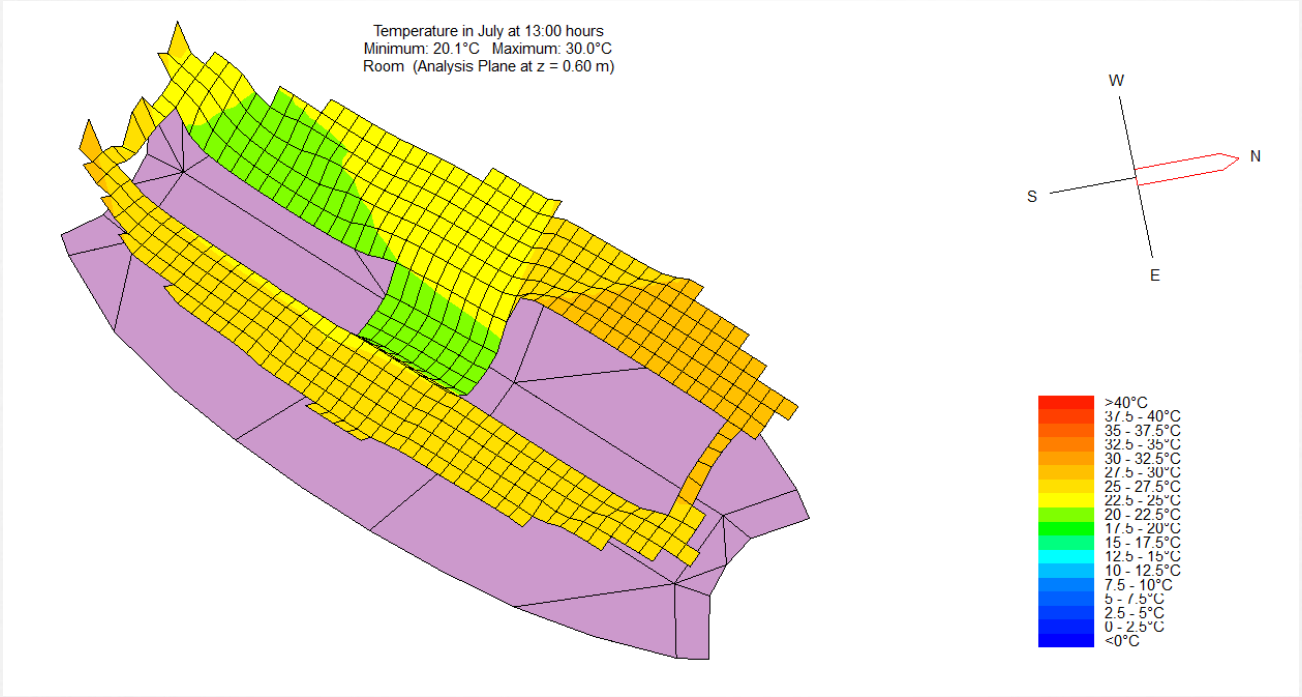
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Analysis Plane



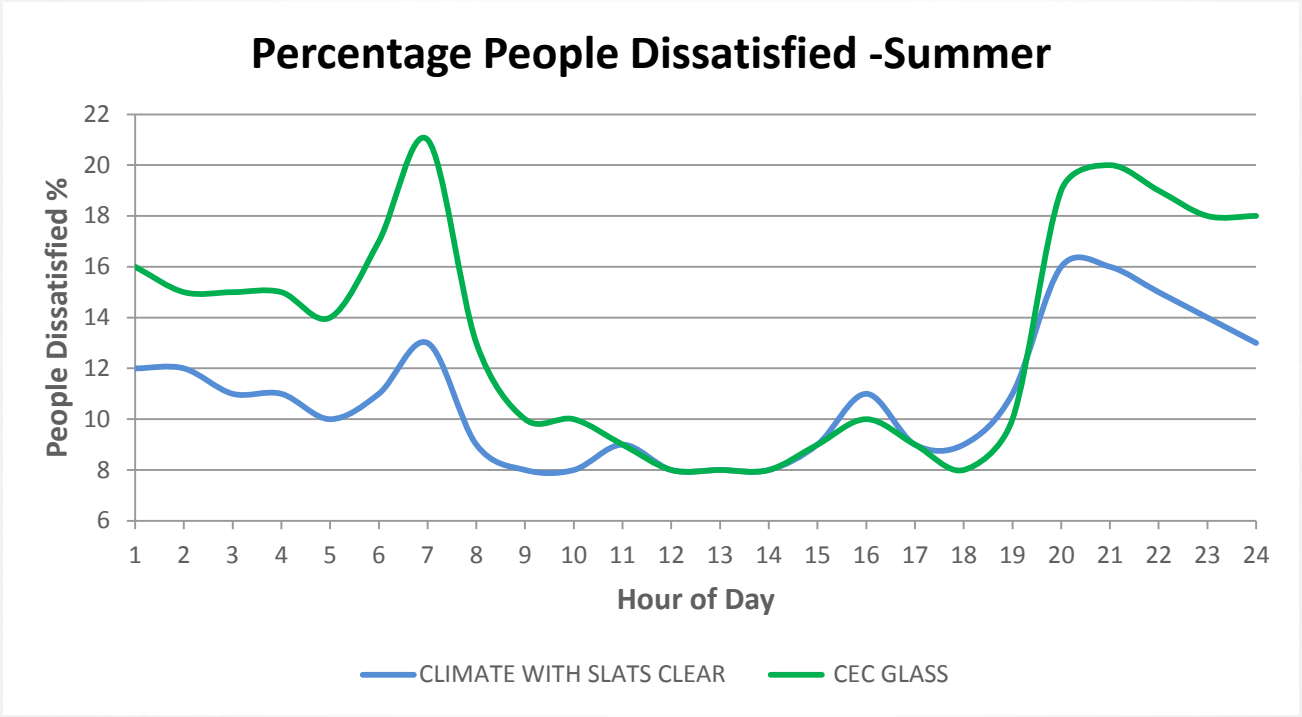
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Analysis Plane



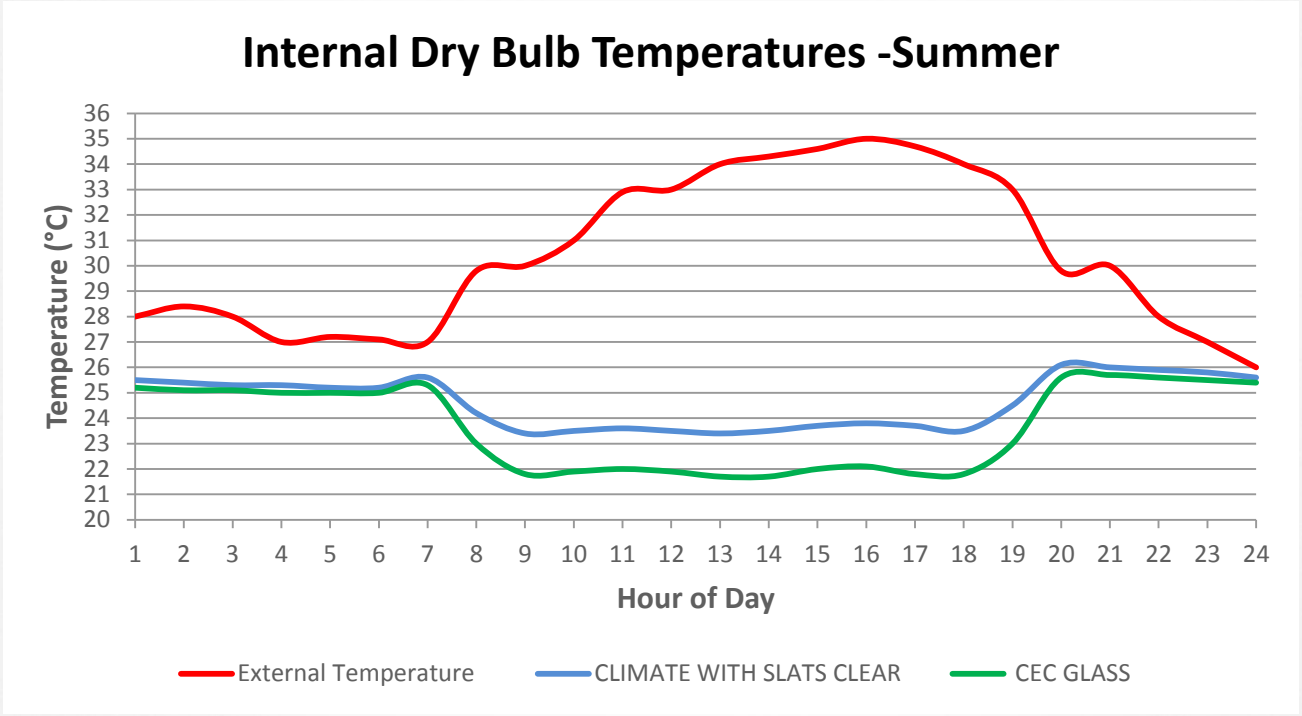
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Summer Comparison



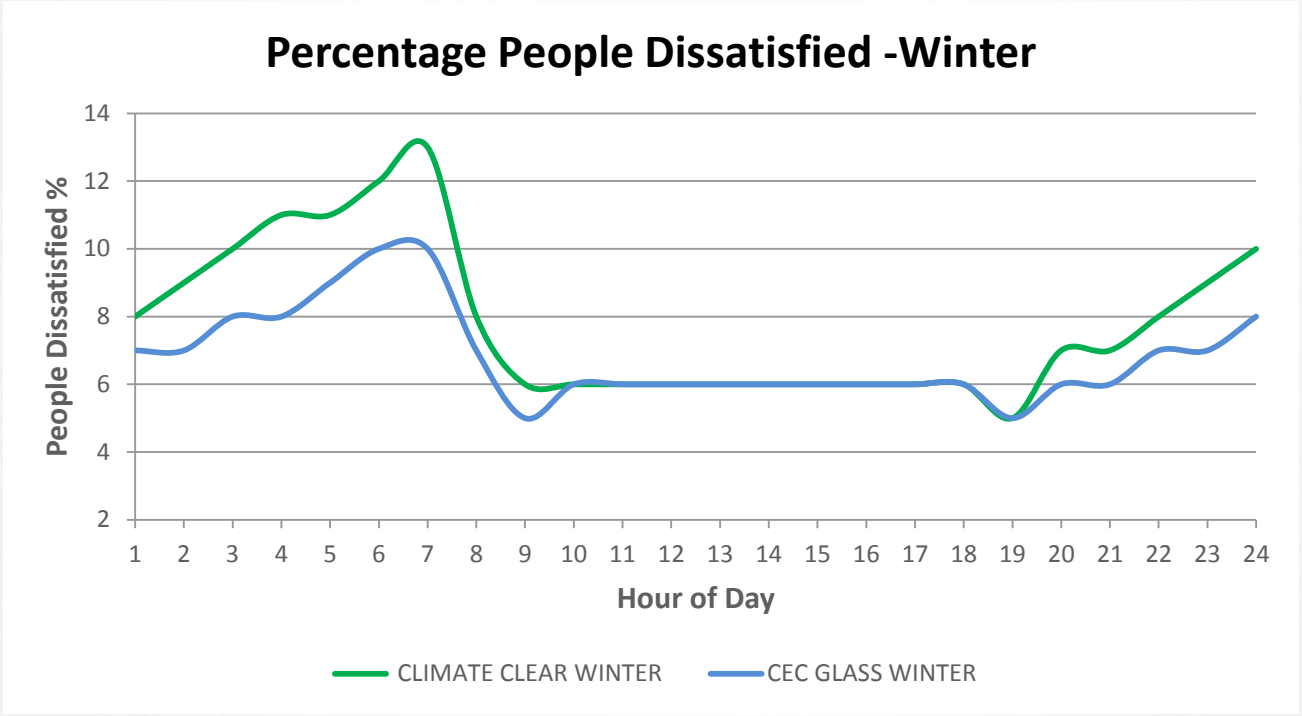
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Summer Comparison



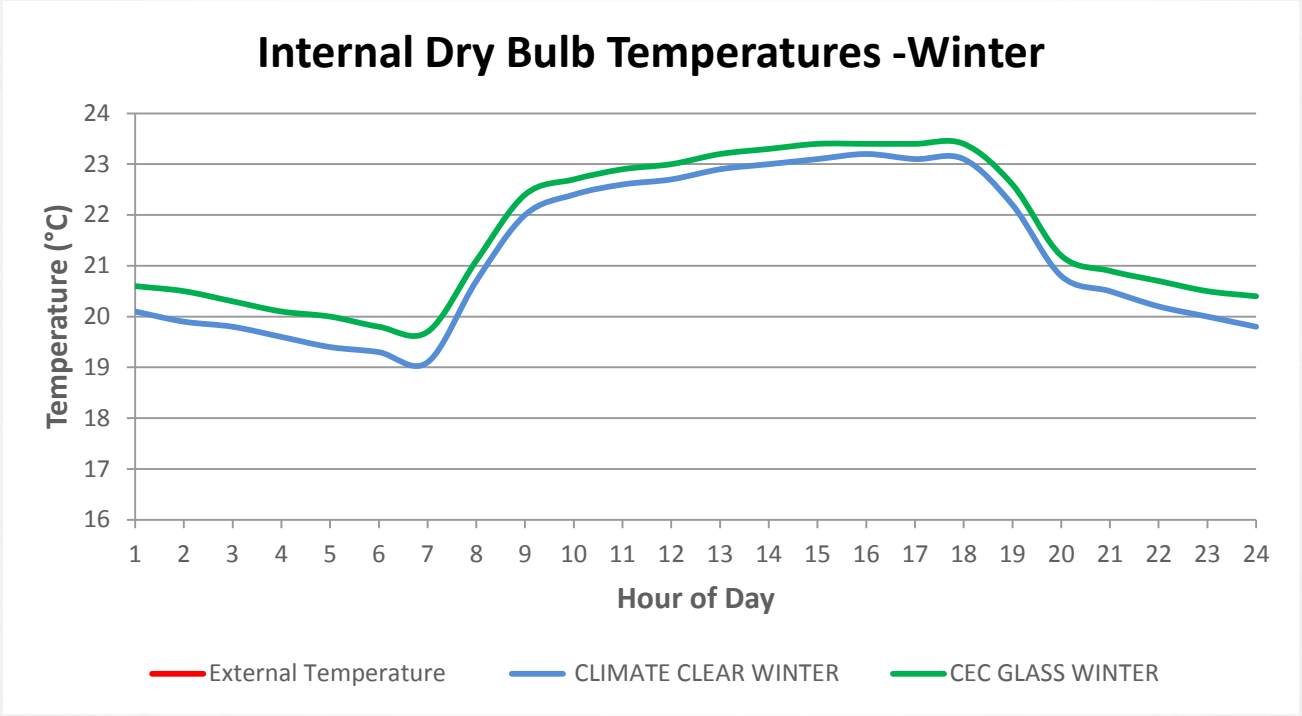
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Winter Comparison



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Winter Comparison



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Pearl River, China

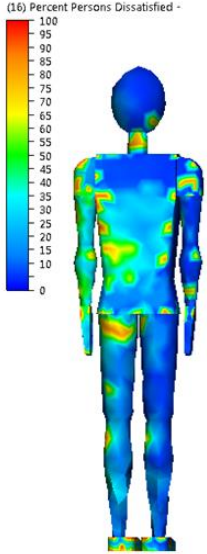


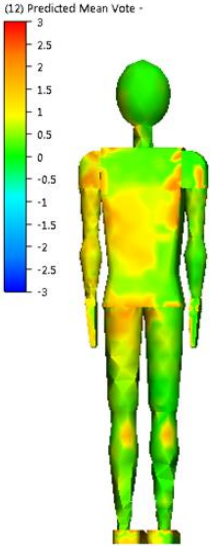
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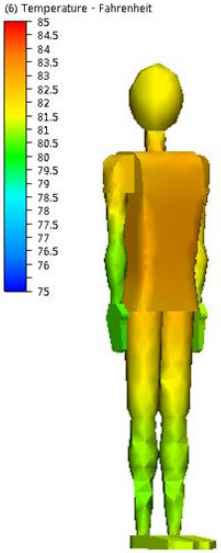
Thermal Comfort

Human Models from Autodesk Simulation CFD

Can be used to map PPD, PMV, and temperature.





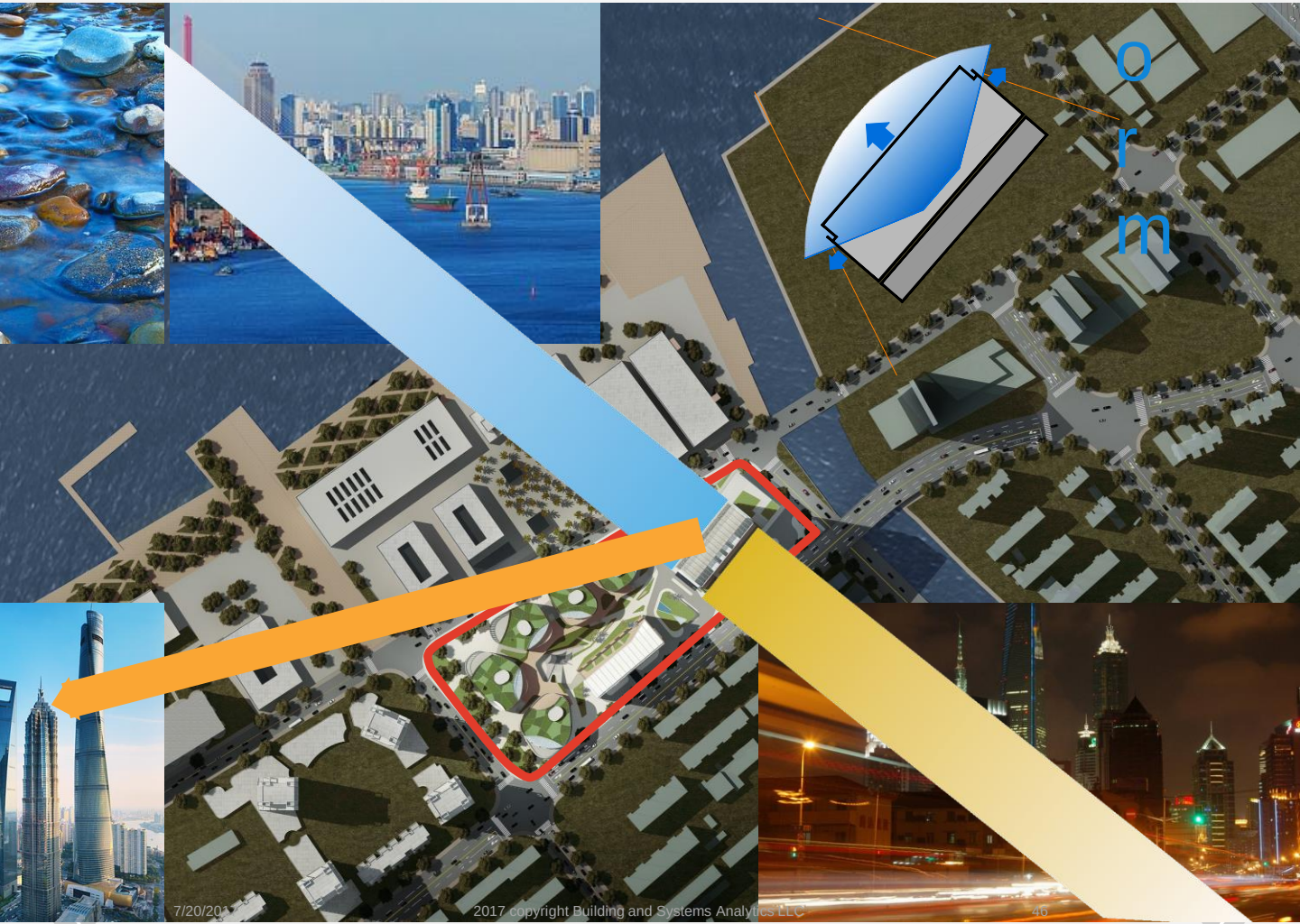


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Vaanke Binjiang

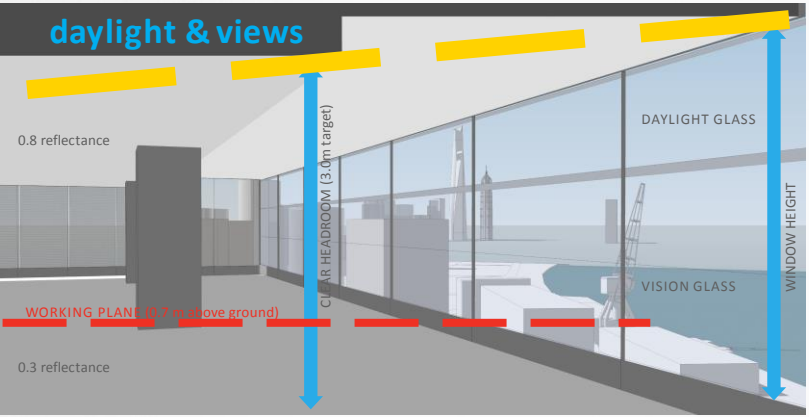


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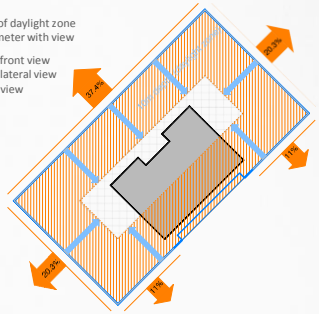
Building Physics

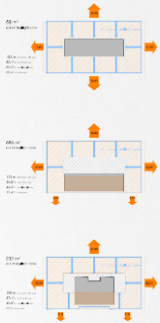


BALANCE OF DAYLIGHT & VIEW PREFERENCE

232 m² out of daylight zone
155 m perimeter with view

37.4% river front view
40.6% river lateral view
22.0% back view



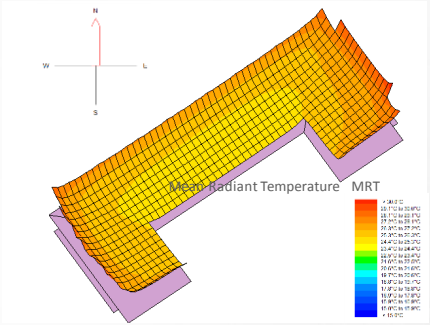


thermal comfort



DISTRIBUTED LIGHT LEVELS IN DEEP PLAN OFFICE

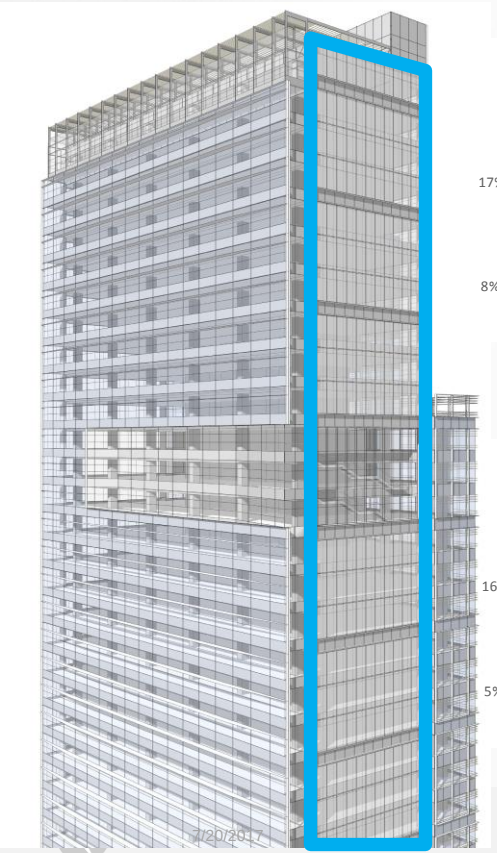
LUX LEVELS ON WORK PLANE FOR 10 000 LUX SKY ILLUMINANCE (CIE OVERCAST SKY)



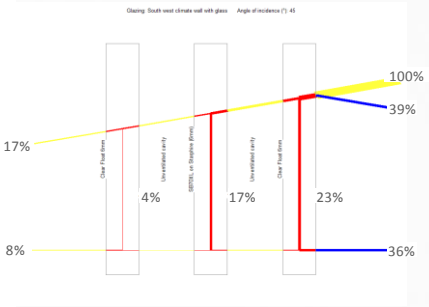


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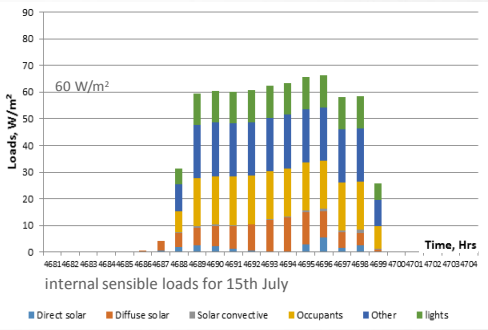
Façade Analysis



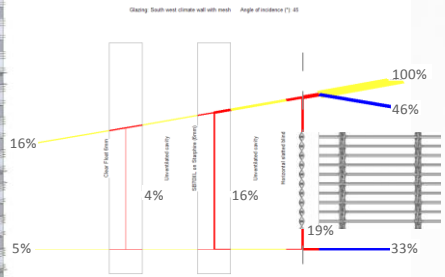
CLIMATE FACADE WITH GLASS OUTER LAYER



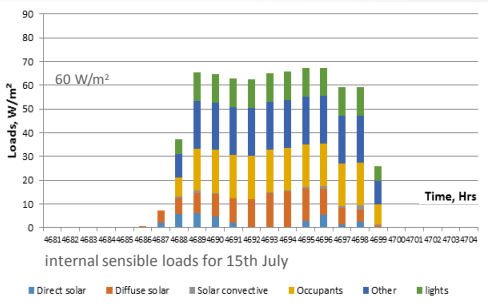
IMPACT ON COOLING LOADS



CLIMATE FACADE WITH EXTERIOR MESH LAYER



IMPACT ON COOLING LOADS

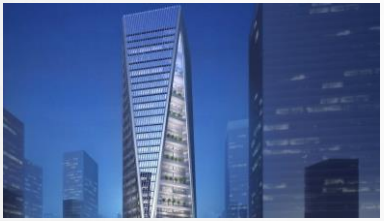


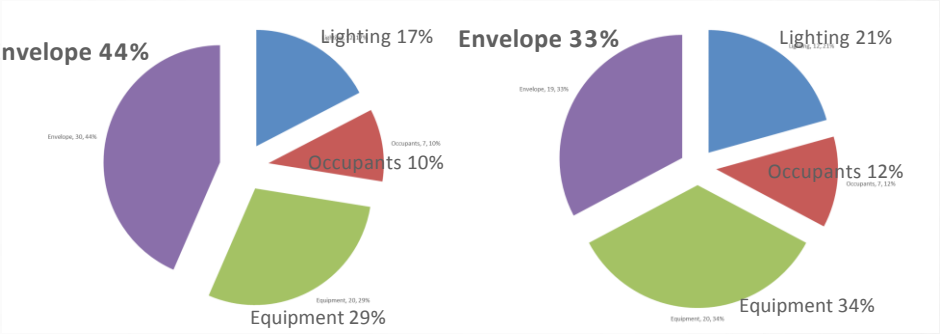
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Breakdown of Energy components







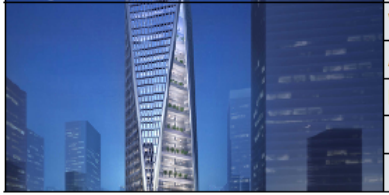


China Energy Code Baseline

proposed Facade Design

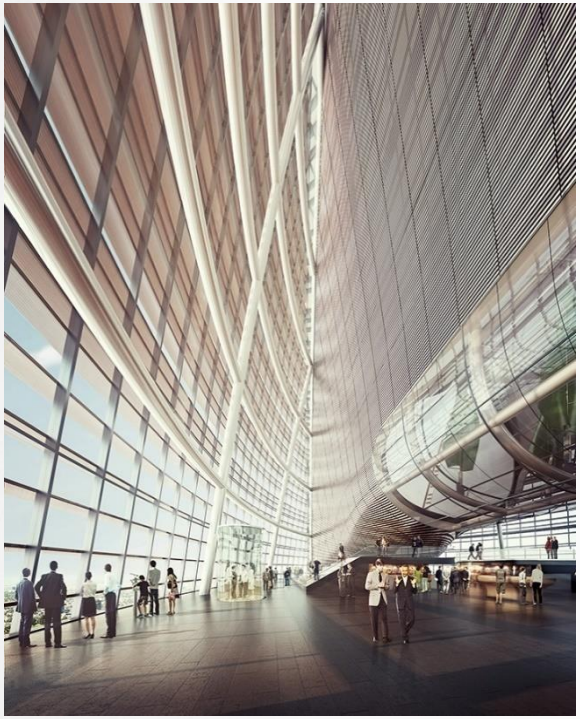
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EUI Energy Use Intensity

	Scenarios	Cooling Load thermal kW	Cooling Energy thermal kWh/a	Emission metric tonnes CO_2/a	EUI kWh/m²/a
Harbin Bank 44 800 m² 	CEC Base Case	5,264	8,127,616	11,325	333
	Option 1	4,234	6,536,678	10,754	317
	Option 2	4,234	6,536,678	10,754	317
	Option 3	4,368	6,744,192	10,829	319
	Option 4	5,085	7,850,931	11,225	331
	7/31 proposed glass	4,413	6,813,363	10,853	320
Binjiang Riverside 58 800 m² 	VAV LDI proposal	6,519	10,064,737	14,197	318
	VAV Base Case	5,949	9,185,667	13,789	309
	VAV & HP Glass	5,380	8,306,598	13,381	300
	Active Beams	5,564	8,591,140	12,048	270
	VAV+	5,564	8,591,140	12,131	272
	VRV	5,863	9,052,240	12,322	276
Qianhai Tower 44 400 m² 	VAV Base Case	5,780	8,923,927	11,950	355
	VAV & HP Glass	5,182	8,001,349	11,522	342
	Active Beams	4,603	7,106,760	10,226	304
	Radiant Ceiling	4,603	7,106,760	10,324	306

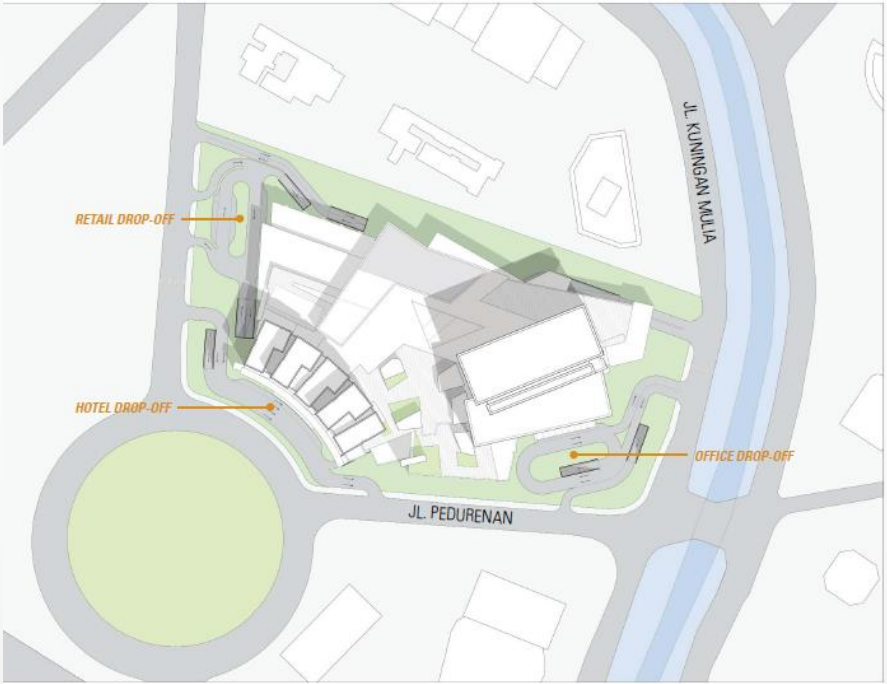
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Pertamina Energy Tower

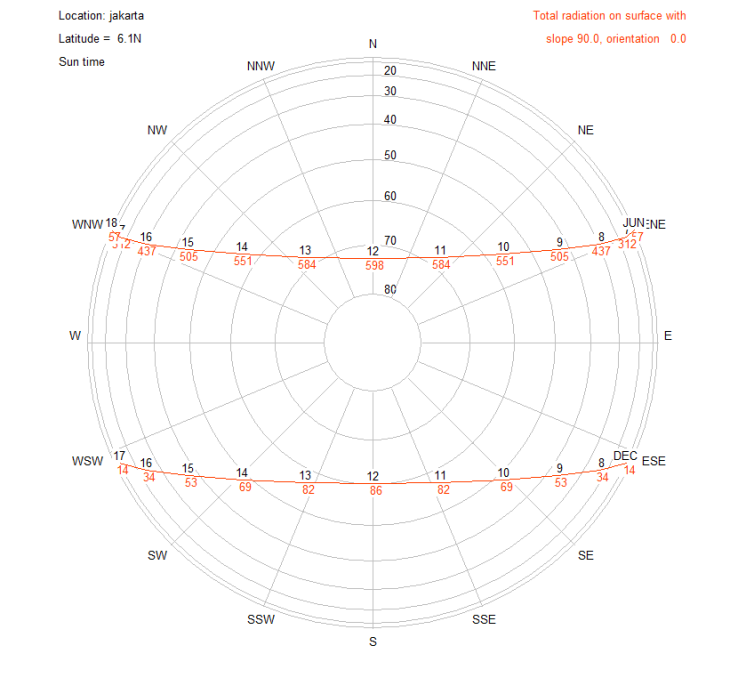




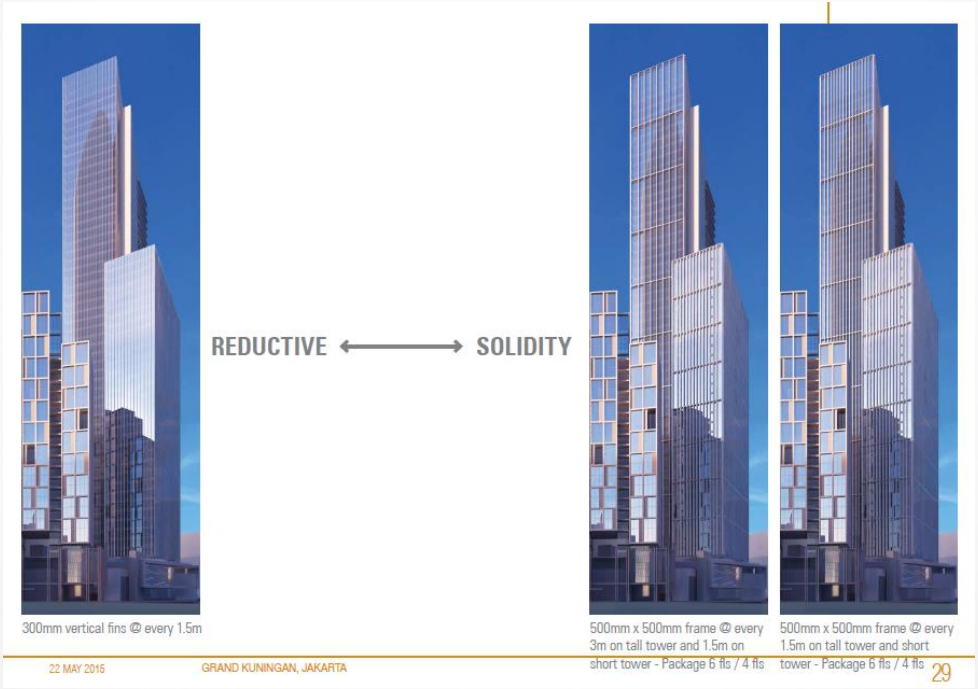
Pertamina Energy Tower



Sunpath Diagram - Jakarta



GRAND KUNINGAN - JAKARTA



GRAND KUNINGAN - JAKARTA



3m modules
Package of 6 fls / 4 fls

6m modules
Package of 6 fls / 4 fls

9m modules
Package of 6 fls / 4 fls

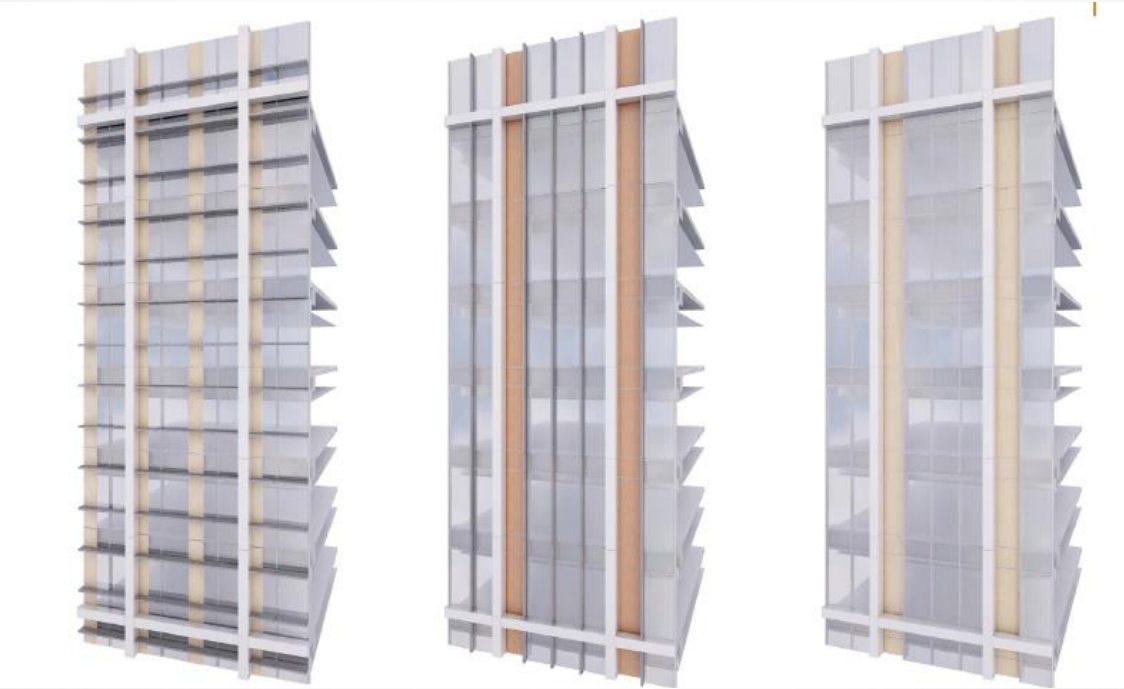
6m modules with 2 horizontal fins per floor
Package of 6 fls / 4 fls

6m modules with 3 horizontal fins per floor
Package of 6 fls / 4 fls

GRAND KUNINGAN - JAKARTA



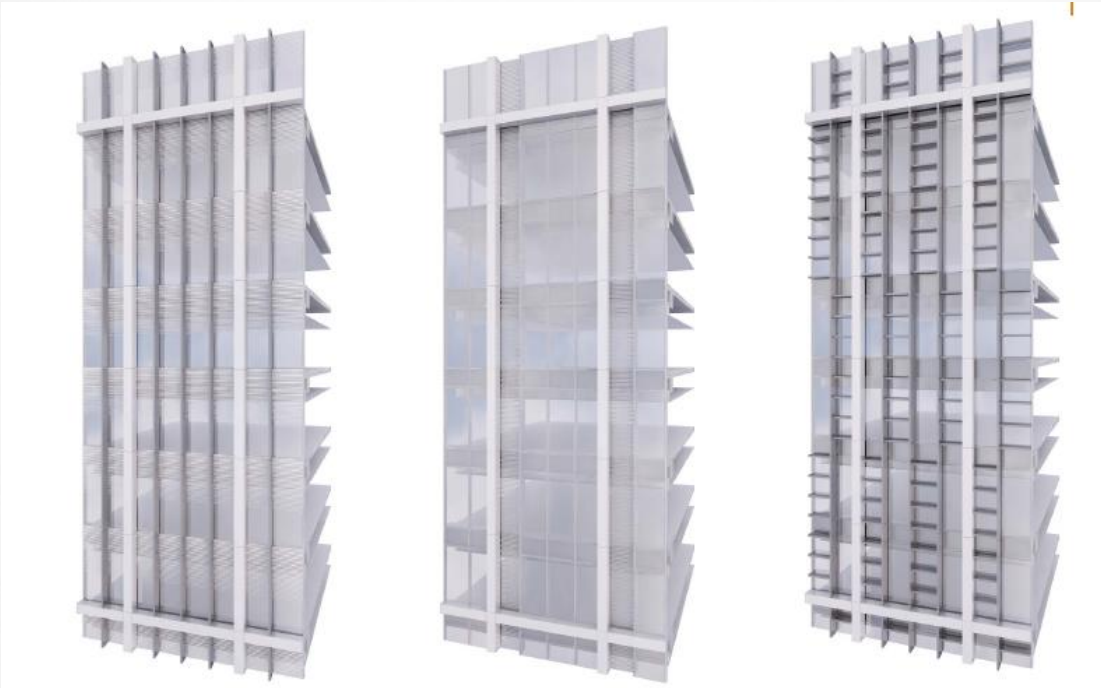
GRAND KUNINGAN - JAKARTA



GRAND KUNINGAN - JAKARTA



GRAND KUNINGAN - JAKARTA



Solar shading

Window Gains:													
Sun	Solar rad	Incident rad				Wind	Shadow area		Room Loads (light or heavy room)				
Time	Dir	Tot	Ang	Dir	Tot	area	Gross	Net	E Lw	E Hw	Air	Tot Lw	Tot Hw
	W/m²	W/m²	°	W	W	m²	m²	m²	W	W	W	W	W
100	0	0	90	0	0	619.2	0	0	5161	12903	0	5161	12903
200	0	0	90	0	0	619.2	0	0	5161	12903	0	5161	12903
300	0	0	90	0	0	619.2	0	0	5161	12903	0	5161	12903
400	0	0	90	0	0	619.2	0	0	5161	12903	0	5161	12903
500	0	0	90	0	0	619.2	0	0	5161	12903	0	5161	12903
600	0	5	90	0	3338	619.2	0	0	5161	12903	0	5161	12903
700	0	52	90	0	32005	619.2	0	0	7679	14837	0	7679	14837
800	0	107	90	0	66472	619.2	0	0	14775	17285	0	14775	17285
900	0	160	90	0	99288	619.2	0	0	22785	22401	0	22785	22401
1000	0	207	90	0	128121	619.2	0	0	30266	27910	0	30266	27910
1100	0	243	90	0	150364	619.2	0	0	36652	32841	0	36652	32841
1200	0	258	90	0	159917	619.2	0	0	41119	36570	0	41119	36570
1300	278	521	76	129604	279969	619.2	153.6	153.6	50318	46530	0	50318	46530
1400	522	729	63	280066	408187	619.2	83.1	83.1	72646	56489	0	72646	56489
1500	700	861	50	390211	489499	619.2	62	62	105467	69108	0	105467	69108
1600	768	876	37	434397	500869	619.2	53.9	53.9	125008	86572	0	125008	86572
1700	629	680	28	356860	388866	619.2	51.7	51.7	122183	91759	0	122183	91759
1800	121	127	23	68559	71897	619.2	53.4	53.4	83559	76025	0	83559	76025
1900	0	0	90	0	0	619.2	0	0	18972	59309	0	18972	59309
2000	0	0	90	0	0	619.2	0	0	5161	21535	0	5161	21535
2100	0	0	90	0	0	619.2	0	0	5161	12903	0	5161	12903
2200	0	0	90	0	0	619.2	0	0	5161	12903	0	5161	12903
2300	0	0	90	0	0	619.2	0	0	5161	12903	0	5161	12903
2400	0	0	90	0	0	619.2	0	0	5161	12903	0	5161	12903

Summary of results

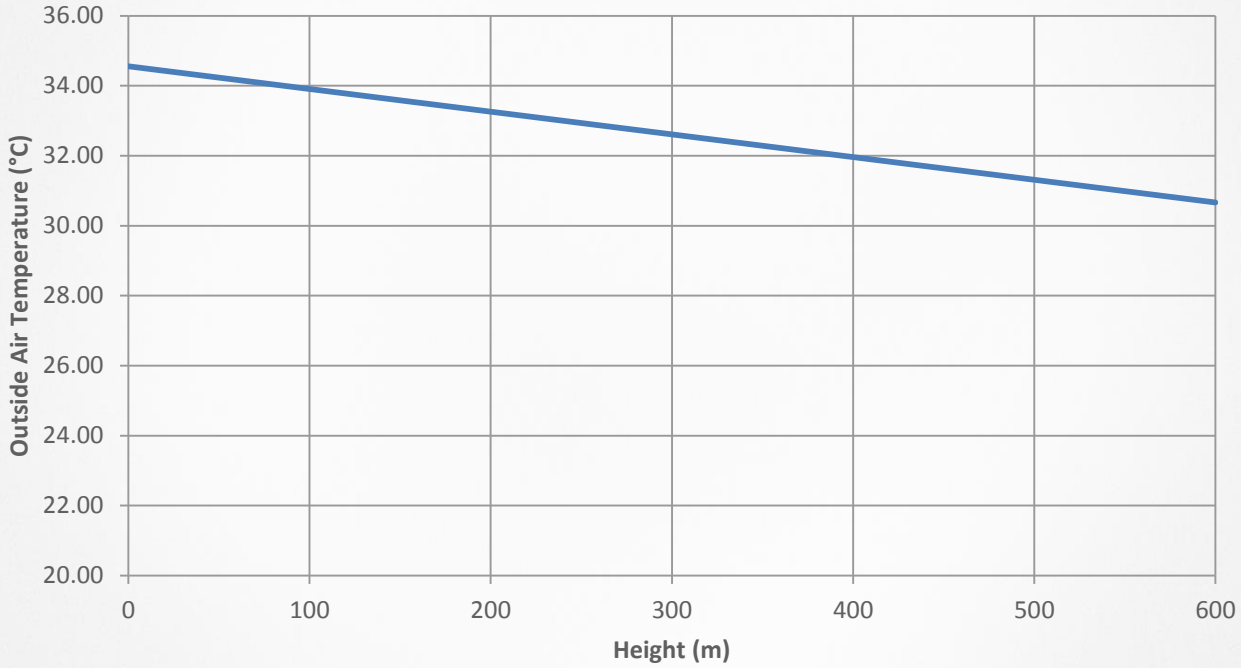
Option	13:00	14:00	15:00	16:00	17:00	18:00
1	25%	25%	25%	25%	25%	25%
2	45%	34%	31%	29%	29%	29%
3	74%	58%	55%	47%	47%	47%
5	28%	22%	19%	16%	17%	17%
7	53%	25%	14%	8%	4%	0%
8	84%	54%	36%	16%	17%	17%
9	97%	83%	83%	83%	83%	83%
11	45%	34%	25%	23%	23%	23%
12	57%	40%	31%	29%	29%	29%

Chapter 4 – Climate Data

The ambient climatic conditions vary with altitude, and these changes in ambient conditions can seriously affect load calculations and performance of super- and megatall buildings.

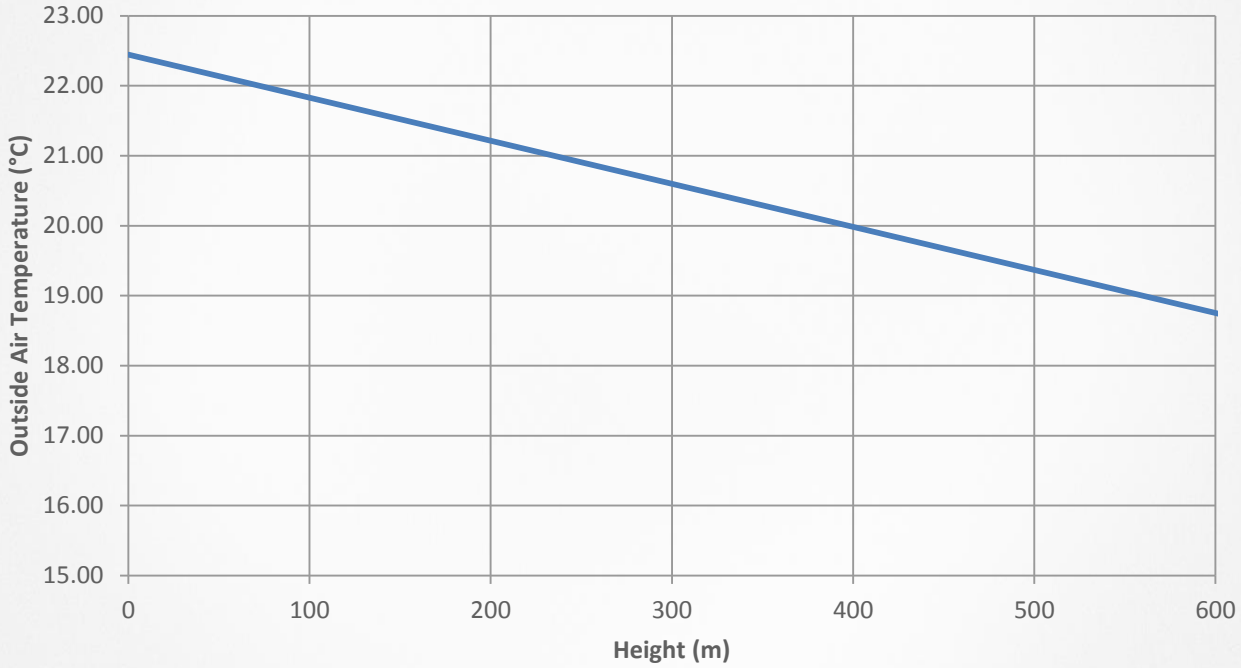
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Ambient Temperature Kuala Lumpur Summer



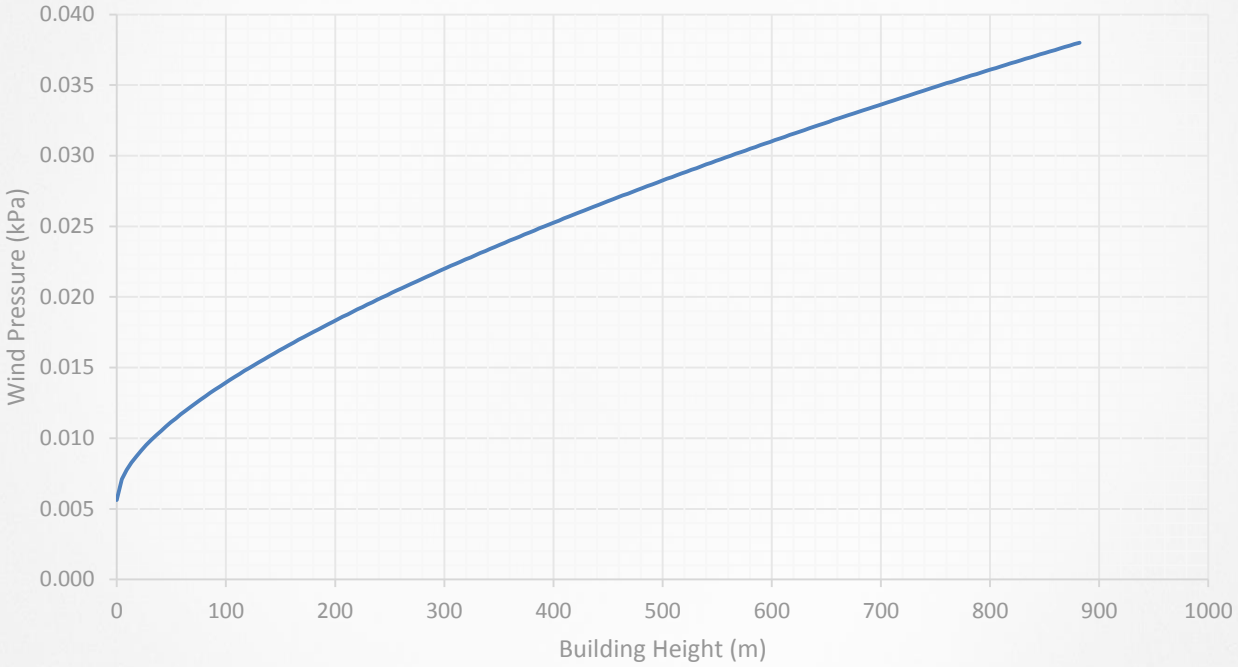
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Ambient Temperature Kuala Lumpur Winter



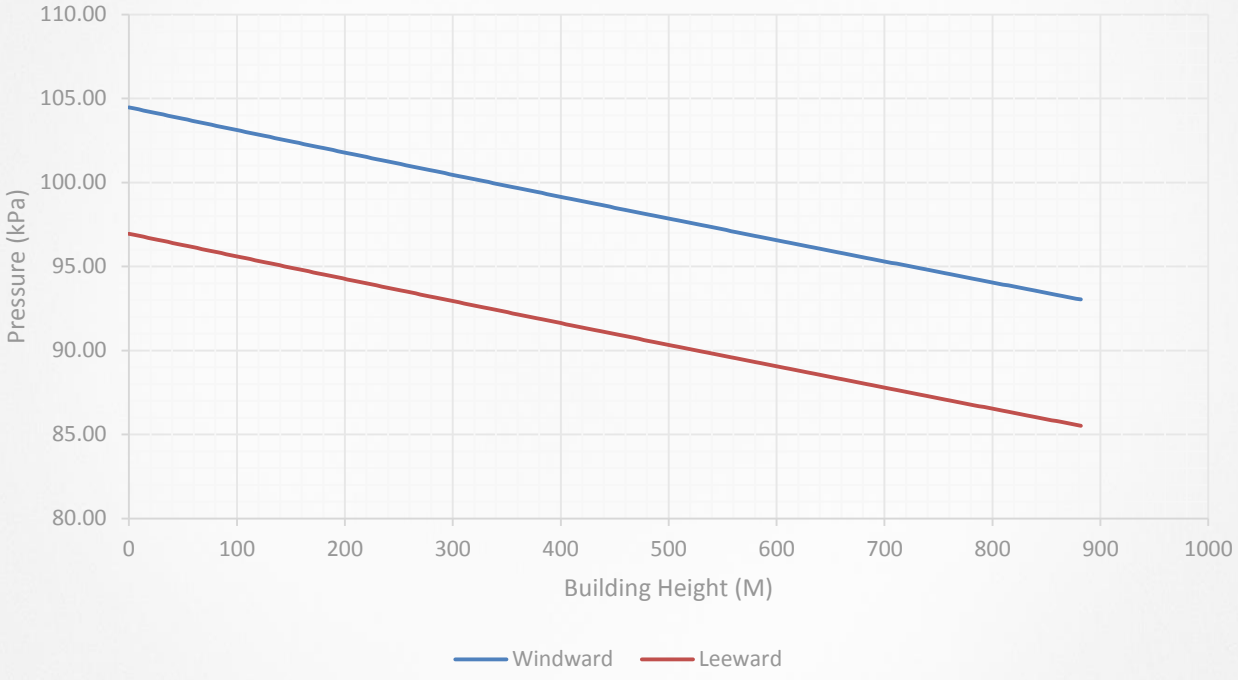
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Wind Pressure Kuala Lumpur



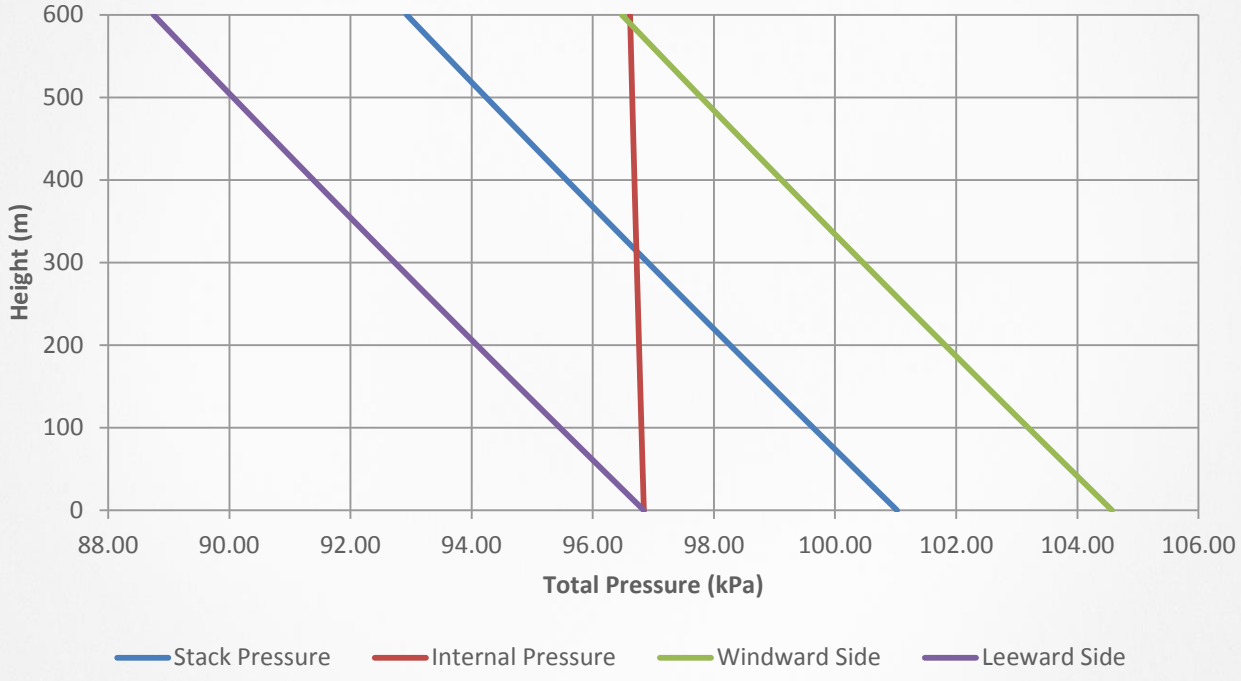
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Wind Pressure Kuala Lumpur



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Stack Effect- Kuala Lumpur Summer



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Base Case- Code Compliant

- Base case
- Glass 40%
- SHGC= 0.25
- Lighting =1.2W.m2
- Equipment = 2W/m2
- Occupants = 1/10m2

- Option 1
- Glass 60%
- SHGC= 0.25
- Lighting =1.2W.m2
- Equipment = 2W/m2
- Occupants = 1/10m2

- Option 2
- Glass 60%
- SHGC= 0.18
- Lighting =1.2W.m2
- Equipment = 2W/m2
- Occupants = 1/10m2

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Base Case- Net Zero

- Base case
- Glass 40%
- SHGC= 0.25
- Lighting =0.4W.m2
- Equipment = 0.6 W/m2
- Occupants = 1/10m2

- Option 1
- Glass 60%
- SHGC= 0.25
- Lighting =0.4W.m2
- Equipment = 0.6 W/m2
- Occupants = 1/10m2

- Option 2
- Glass 60%
- SHGC= 0.18
- Lighting =0.4W.m2
- Equipment = 0.6 W/m2
- Occupants = 1/10m2

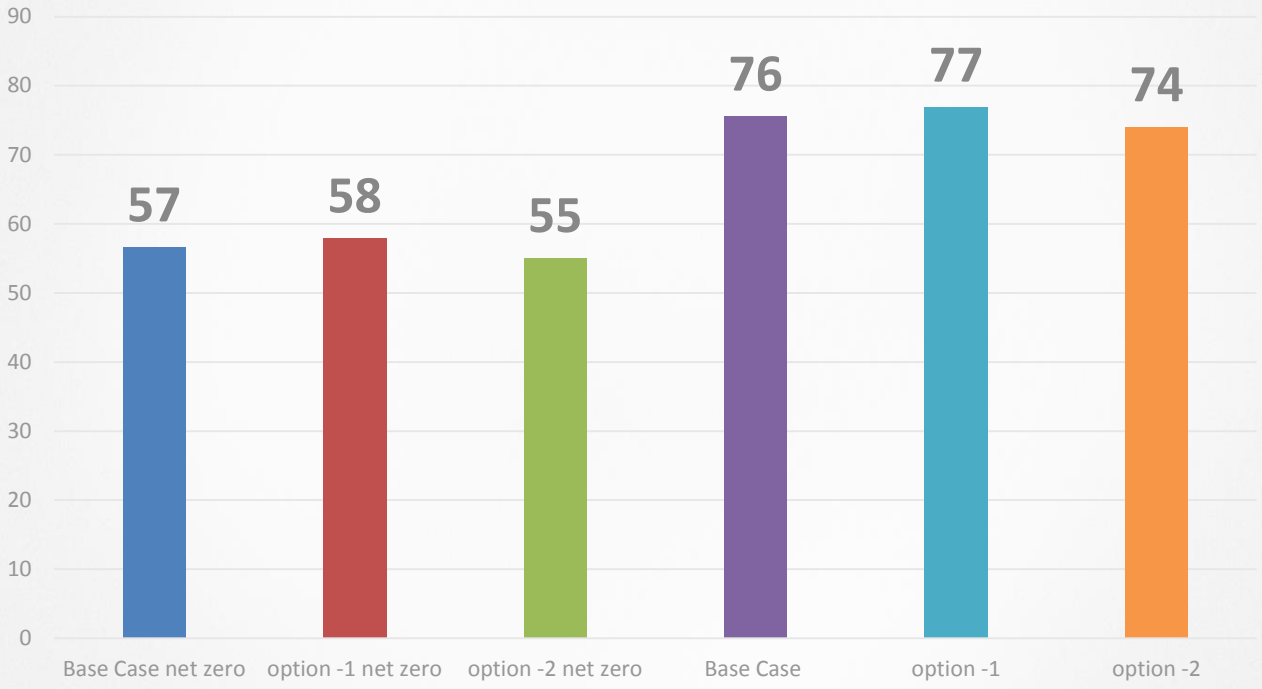
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Façade Loads

Height	Base Case	Option 1	Option 2
0m	18.43 W/m2	19.98 W/m2	16.9 W/m2
150m	18.34 W/m2	19.87 W/m2	16.78 W/m2
250m	17.82 W/m2	19.16 W/m2	16.08 W/m2
350m	17.27 W/m2	18.43 W/m2	15.35 W/m2
450m	16.73 W/m2	17.71 W/m2	14.62 W/m2
600m	15.92 W/m2	16.62 W/m2	13.53 W/m2

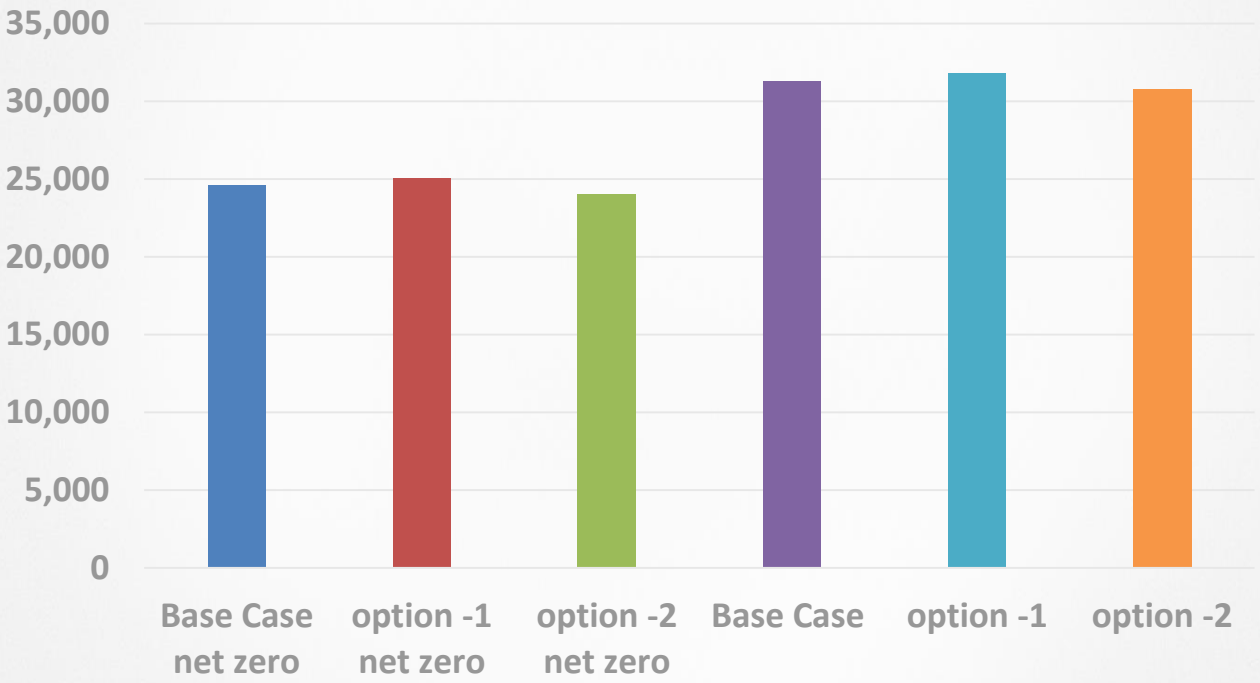
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Comparison of EUI (kWh/m2)



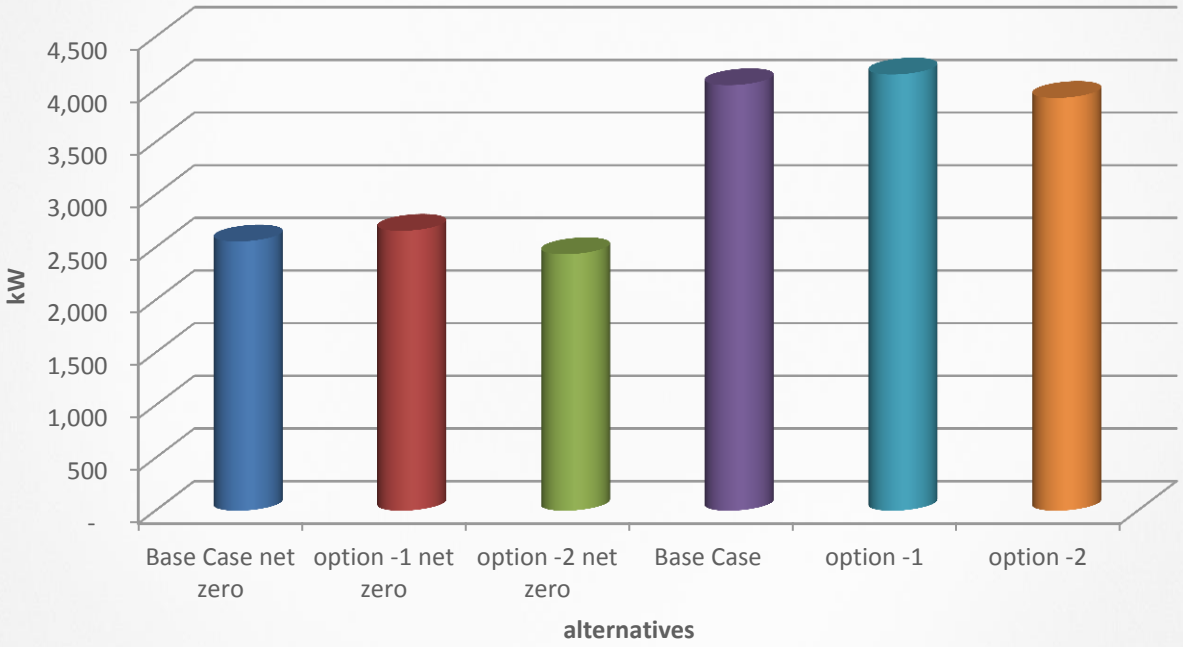
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Cooling Load (kW)



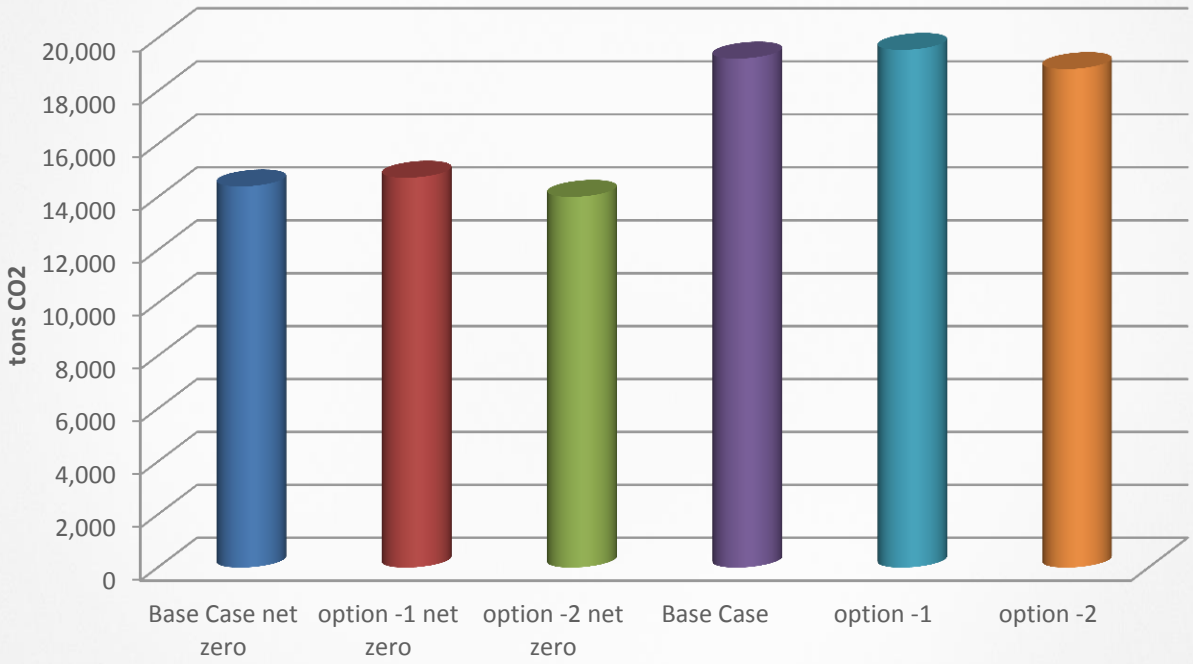
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Fan Power (kW)



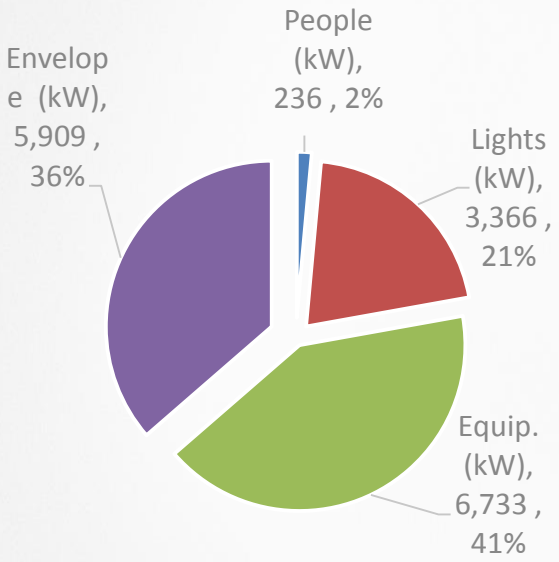
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CO_2 Emissions

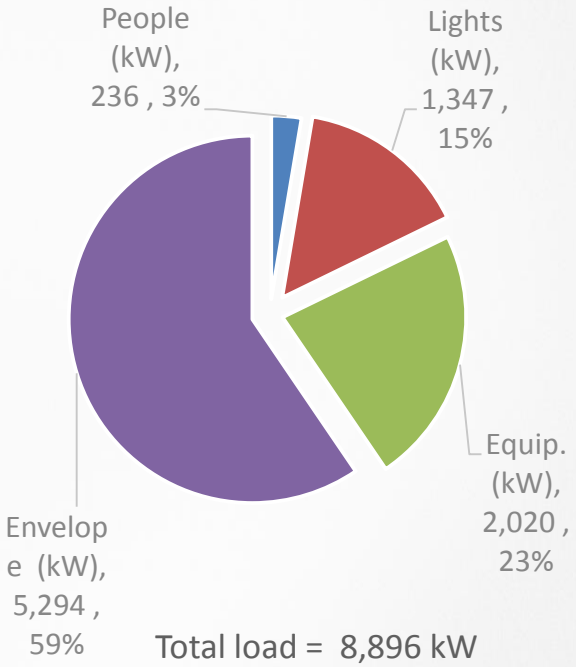


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Breakdown of Energy Components



Total load = 16,244 kW

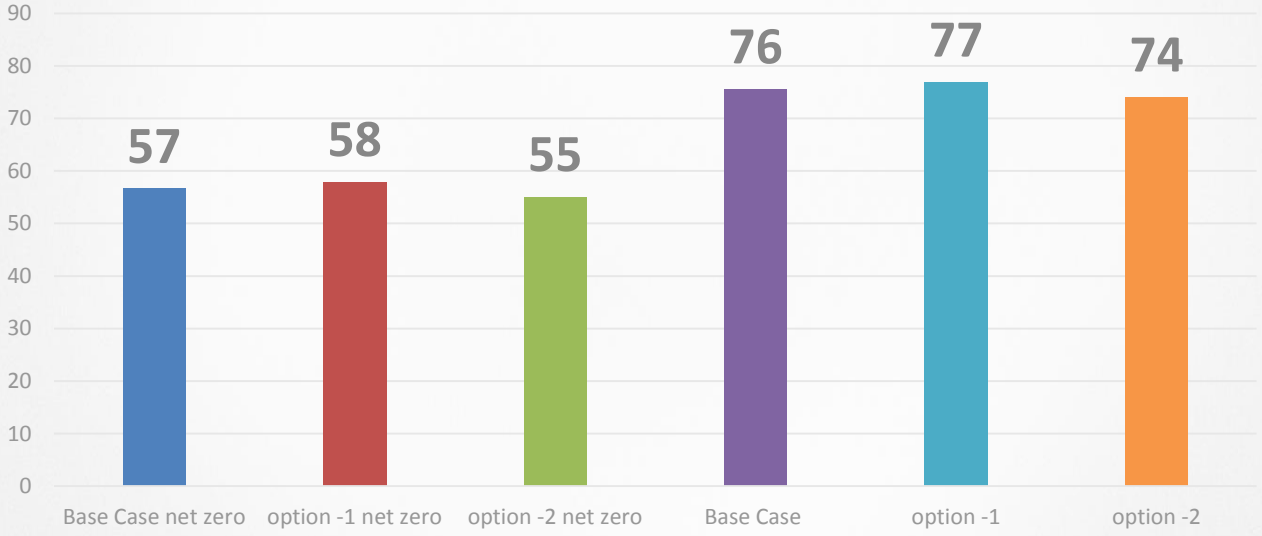


Total load = 8,896 kW

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Energy Use Intensity (EUI)

This new *Design Guide* presents EUI data when modeling buildings and data from existing buildings which are used to “guide” the energy modeling results and the performance of the building being designed.



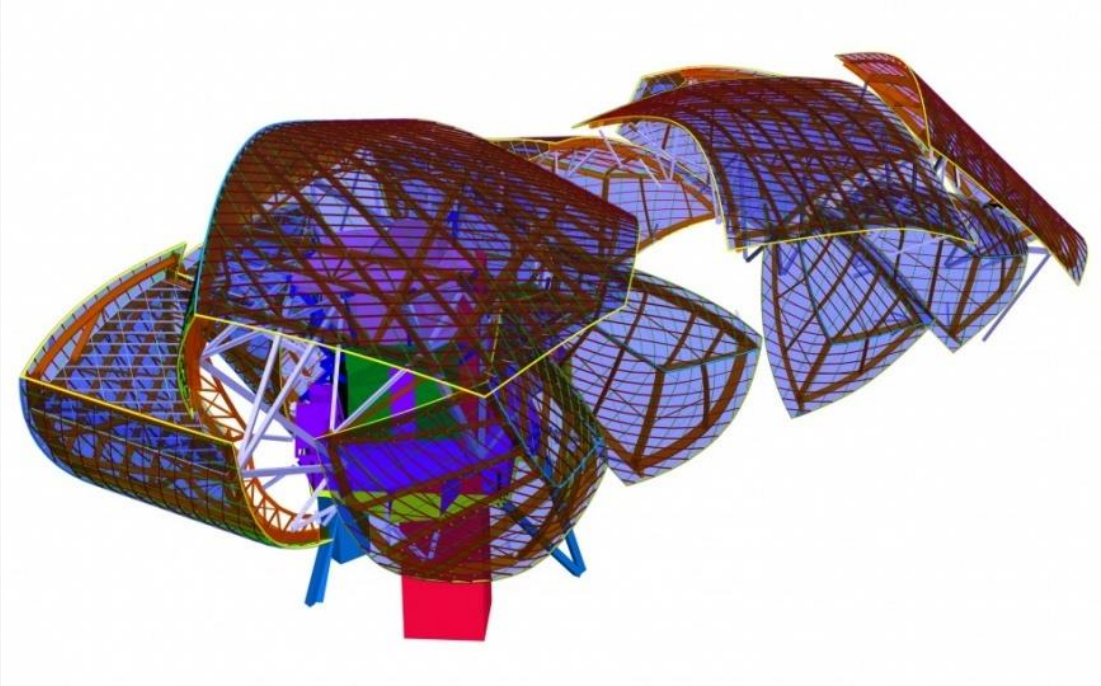
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LVMH- Paris



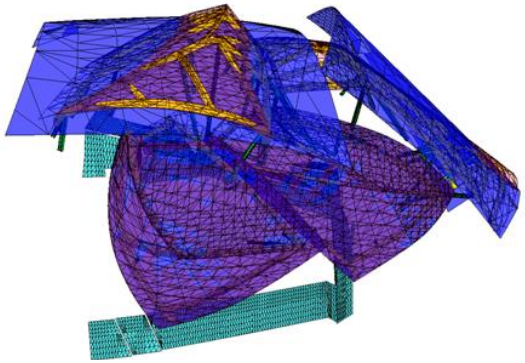
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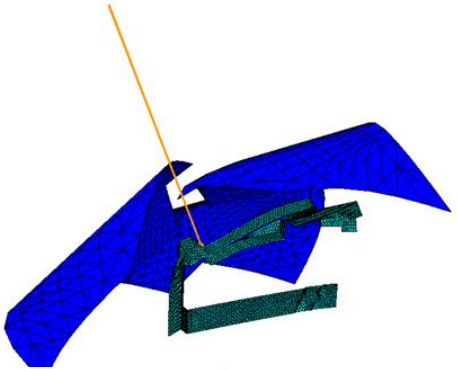
LVMH- Paris

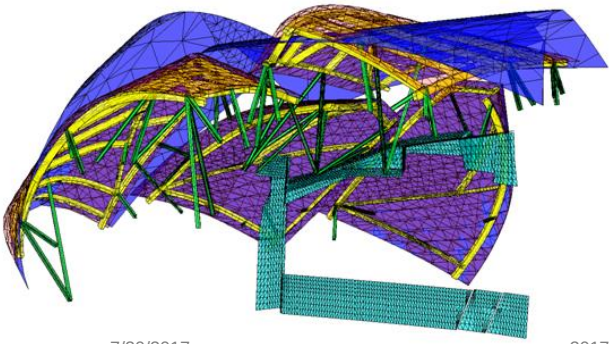


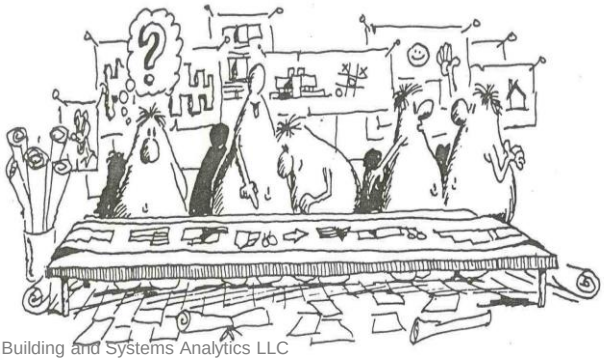
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What results are we trying to provide?









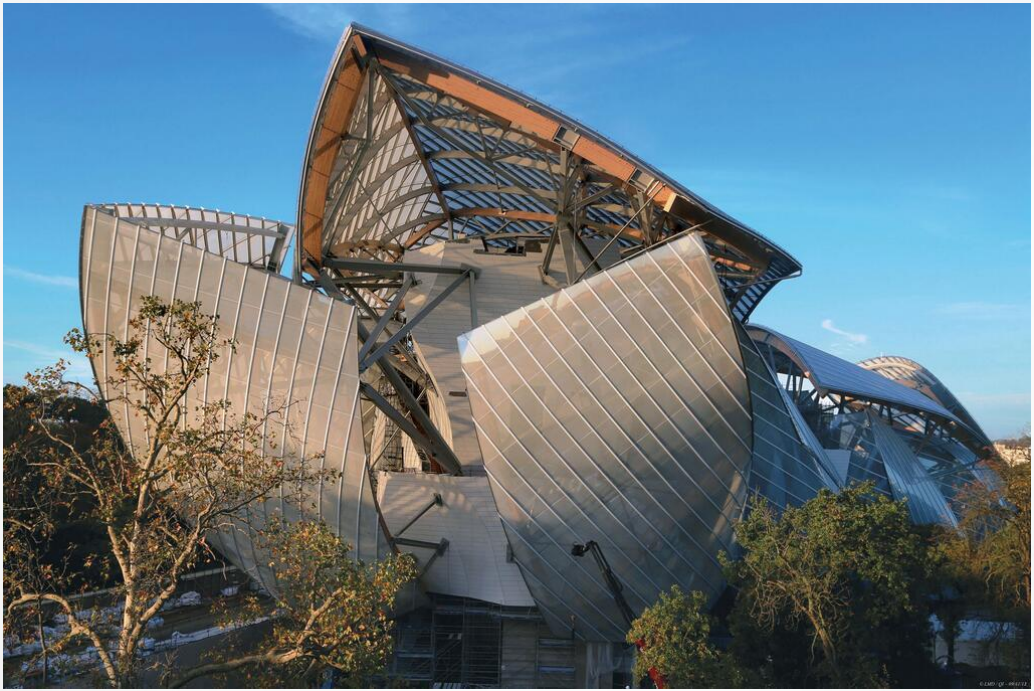
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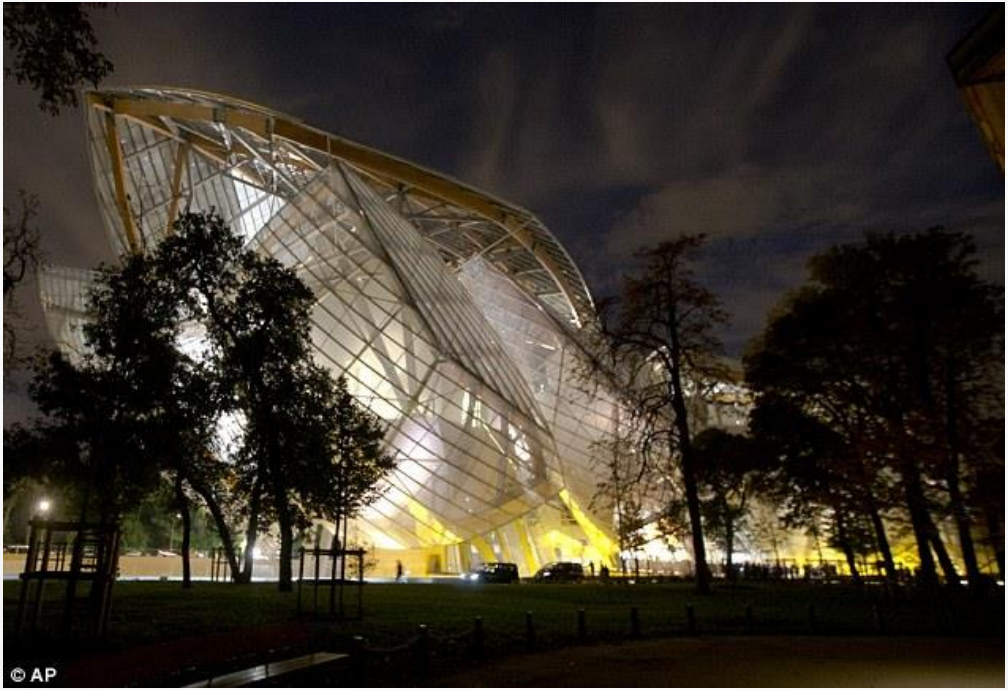
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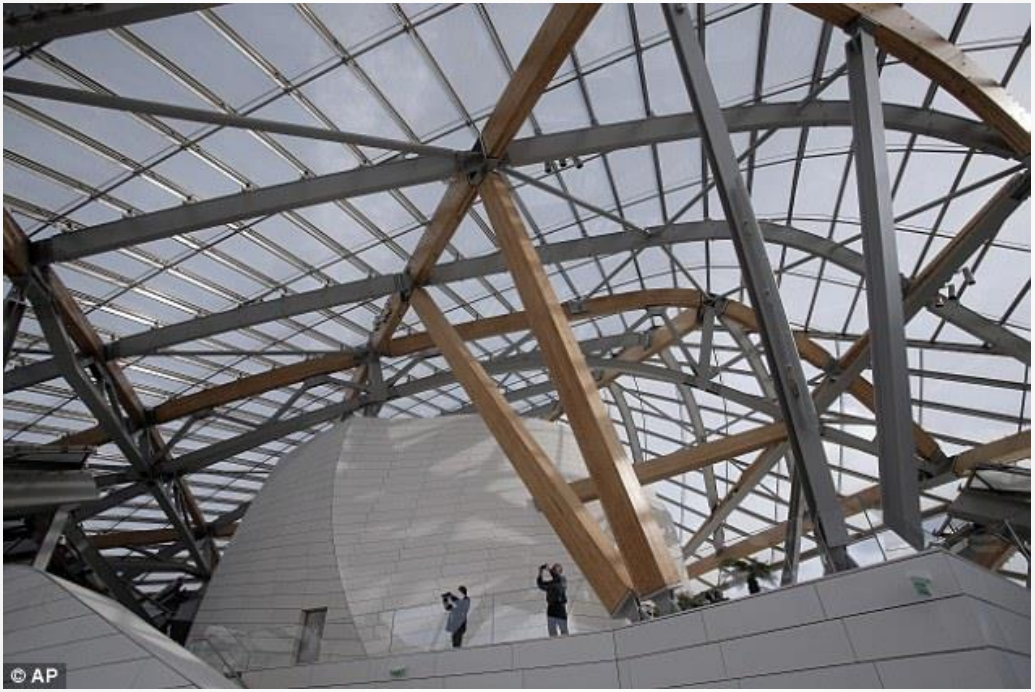
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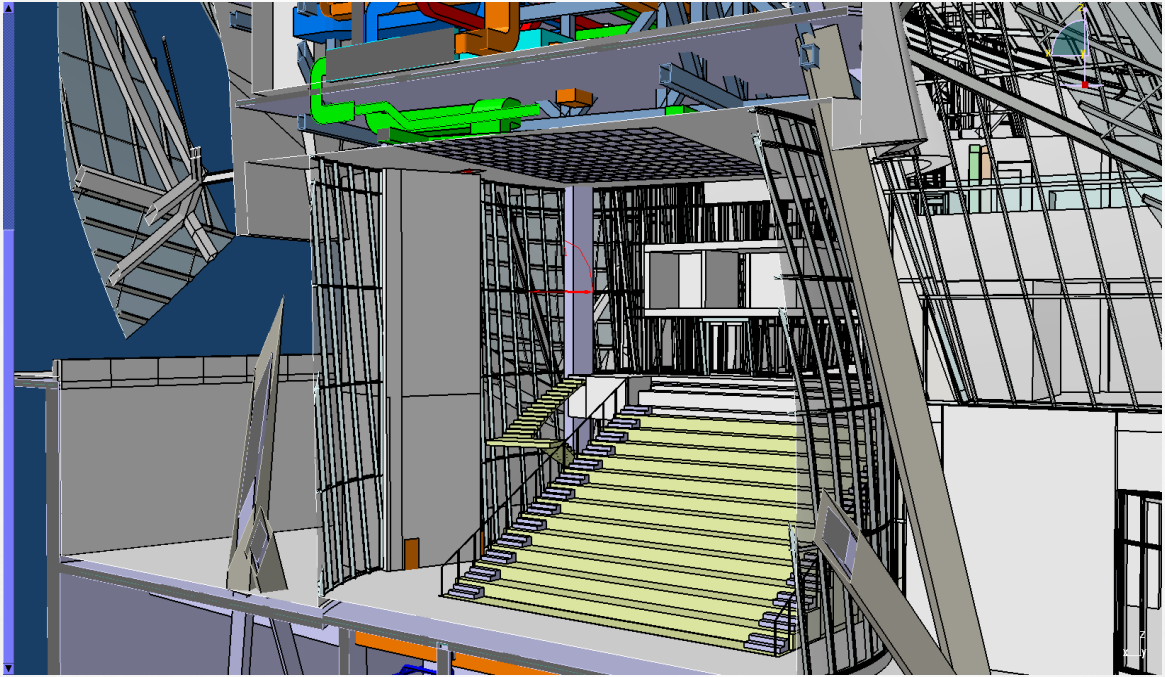
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The Forum

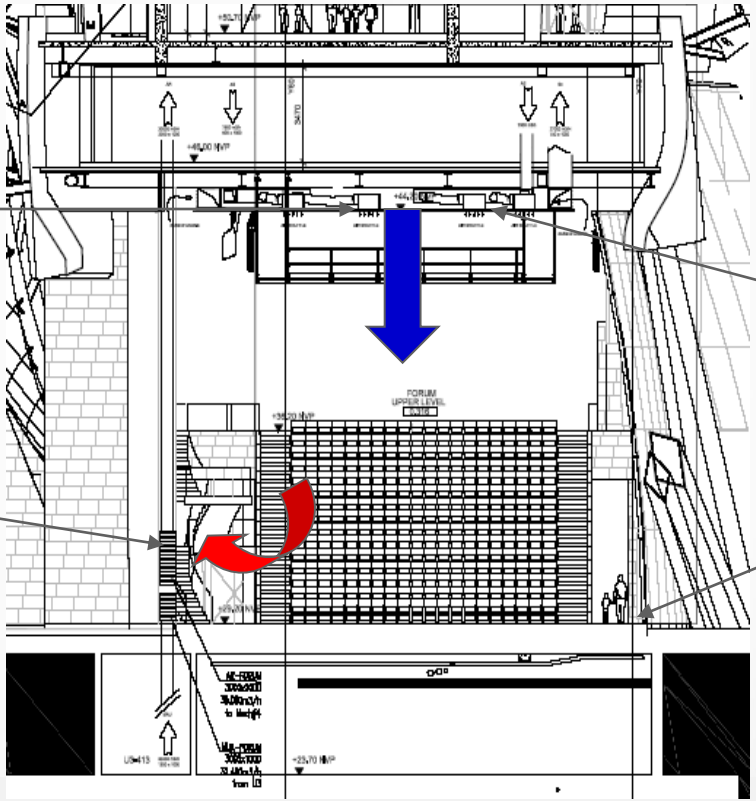


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Forum Conditioning system

Variable volume displacement ventilation system

Exhaust air

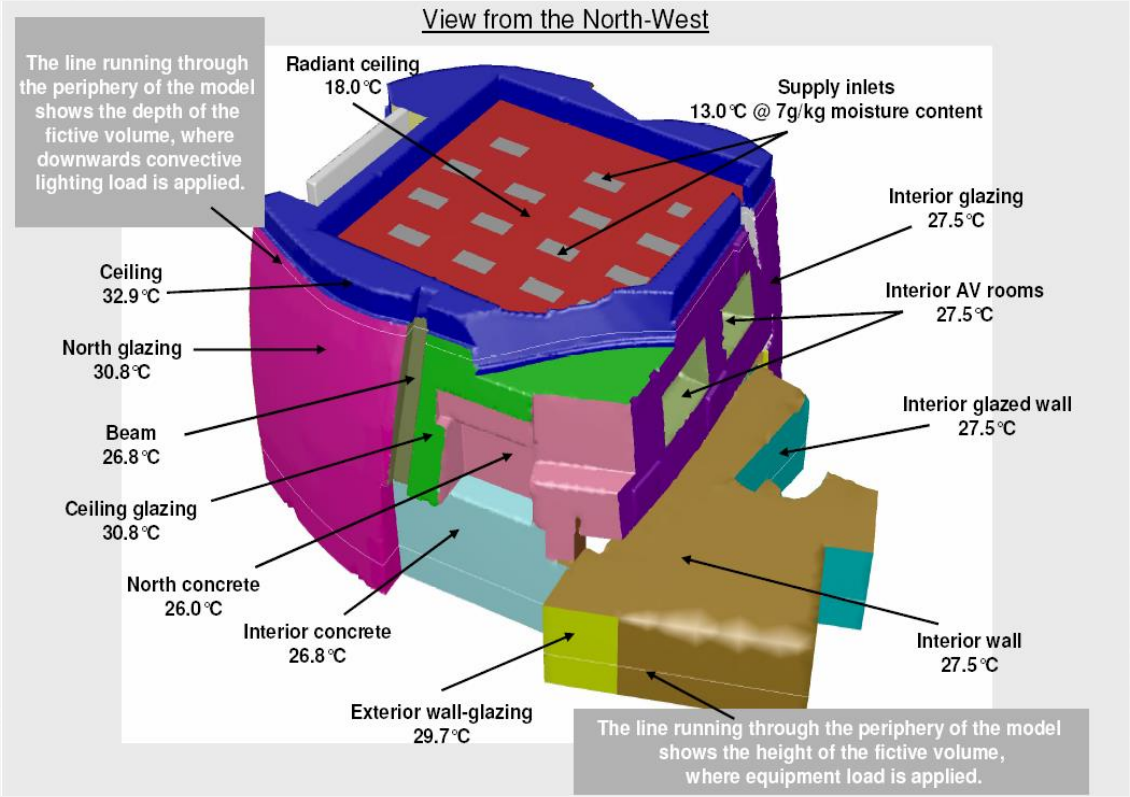


Radiant ceiling for heating and cooling

Radiant floor for heating and cooling

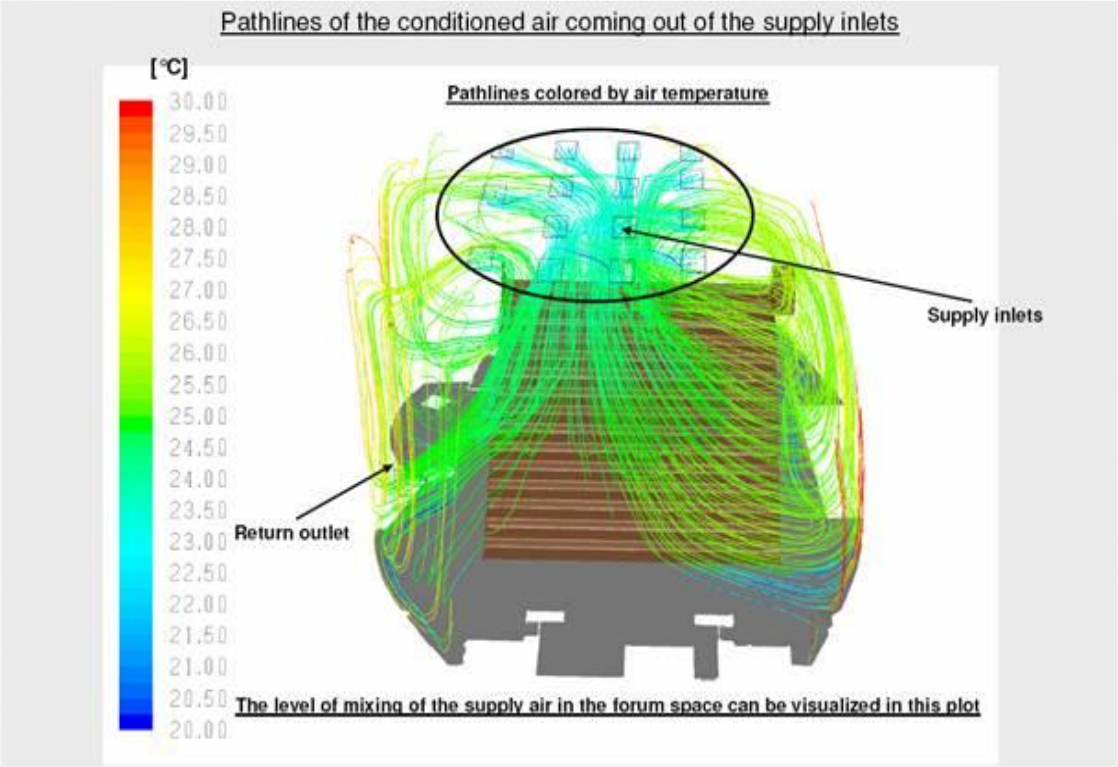
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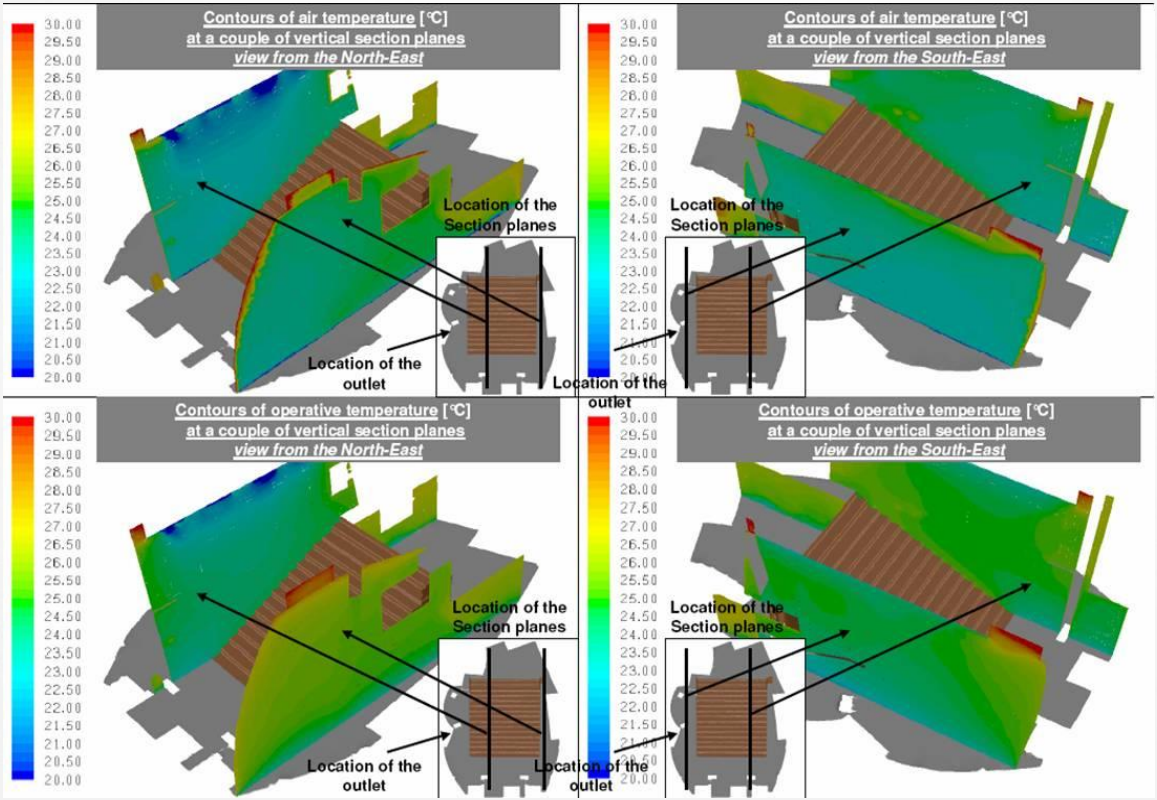
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CFD for Comfort analysis



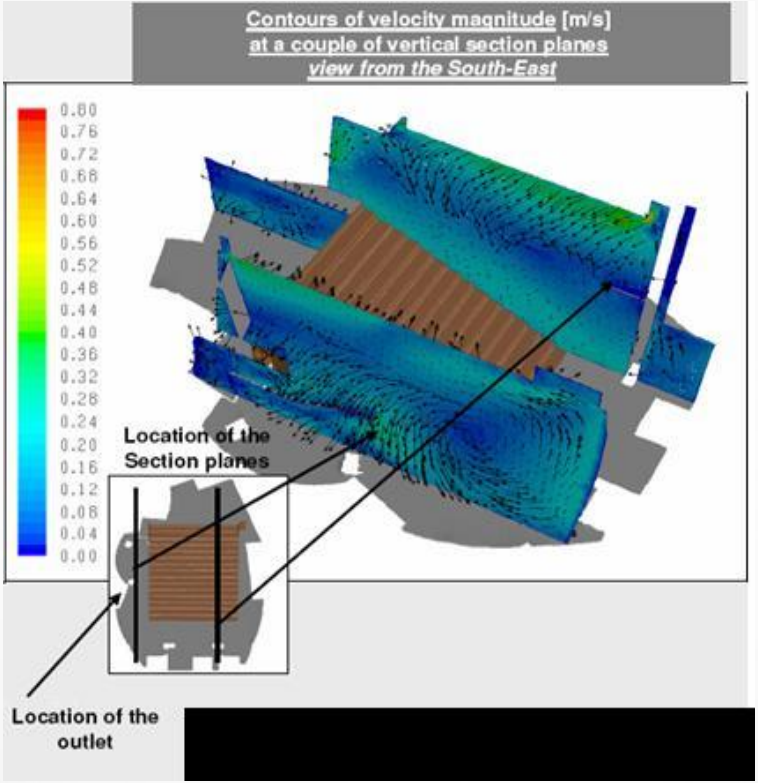
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CFD for Comfort analysis



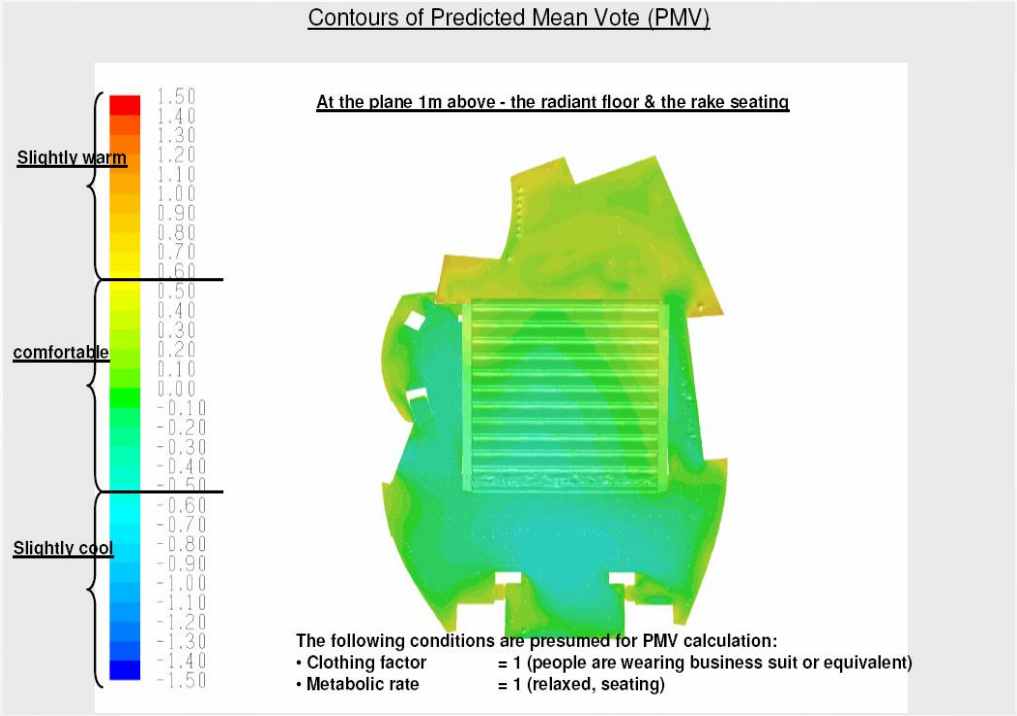
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CFD for Comfort analysis



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CFD for Comfort analysis



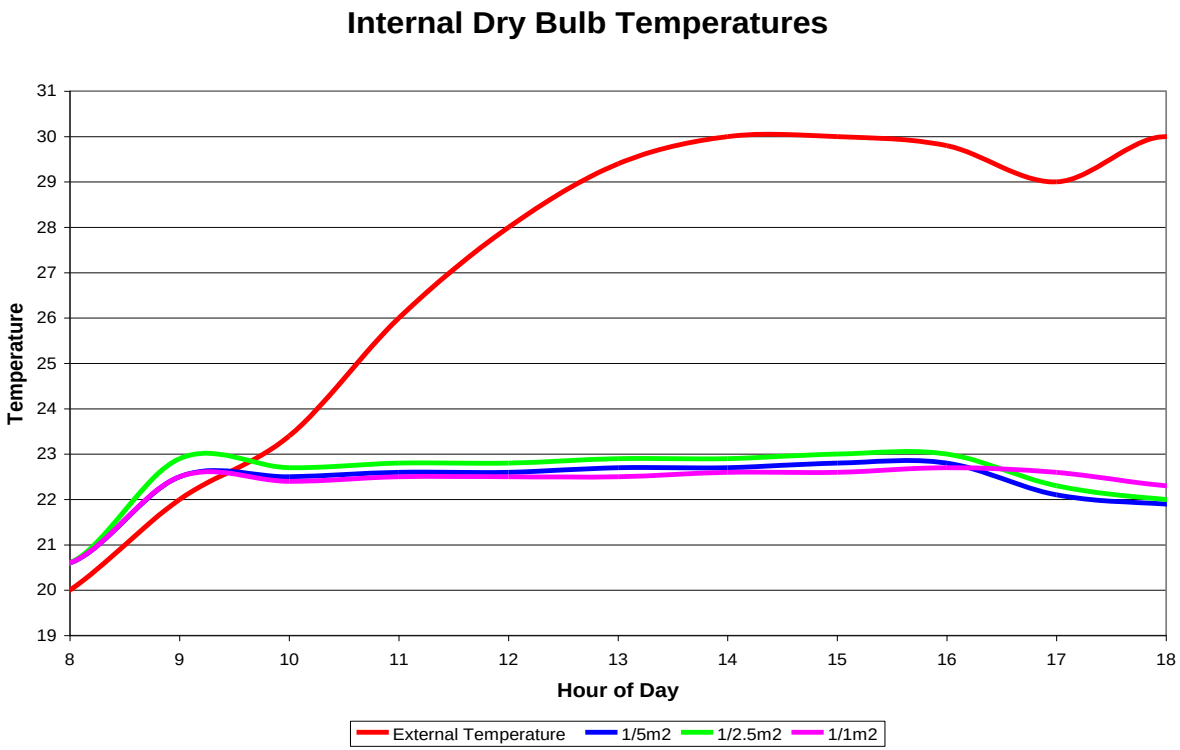
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LVMH- Paris



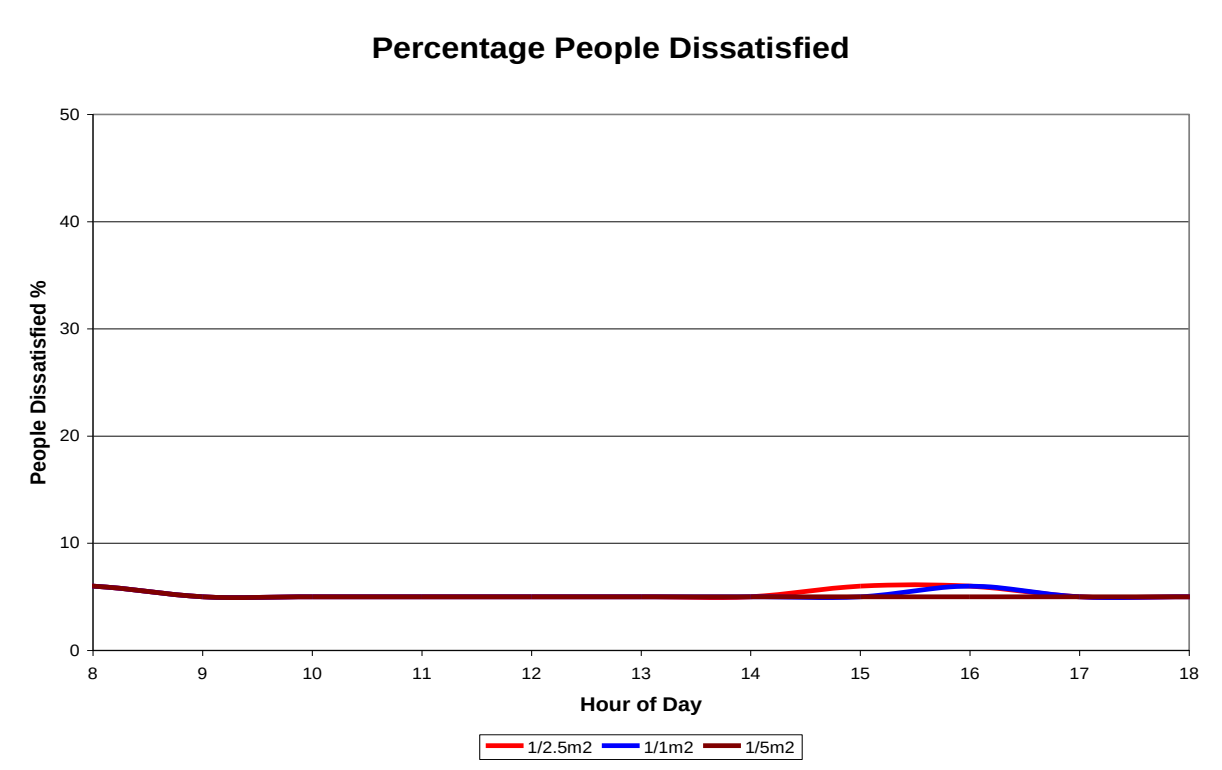
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Comfort Analysis



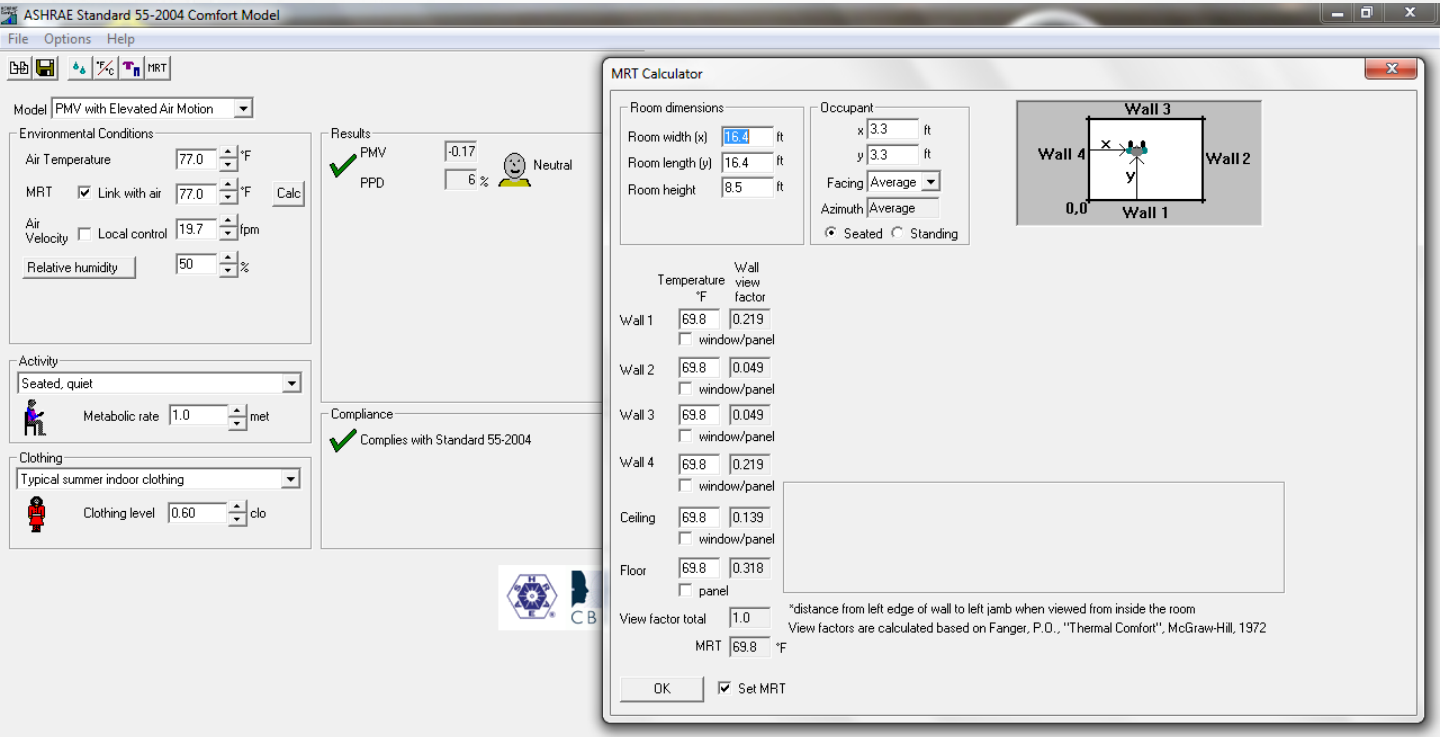
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PPD results



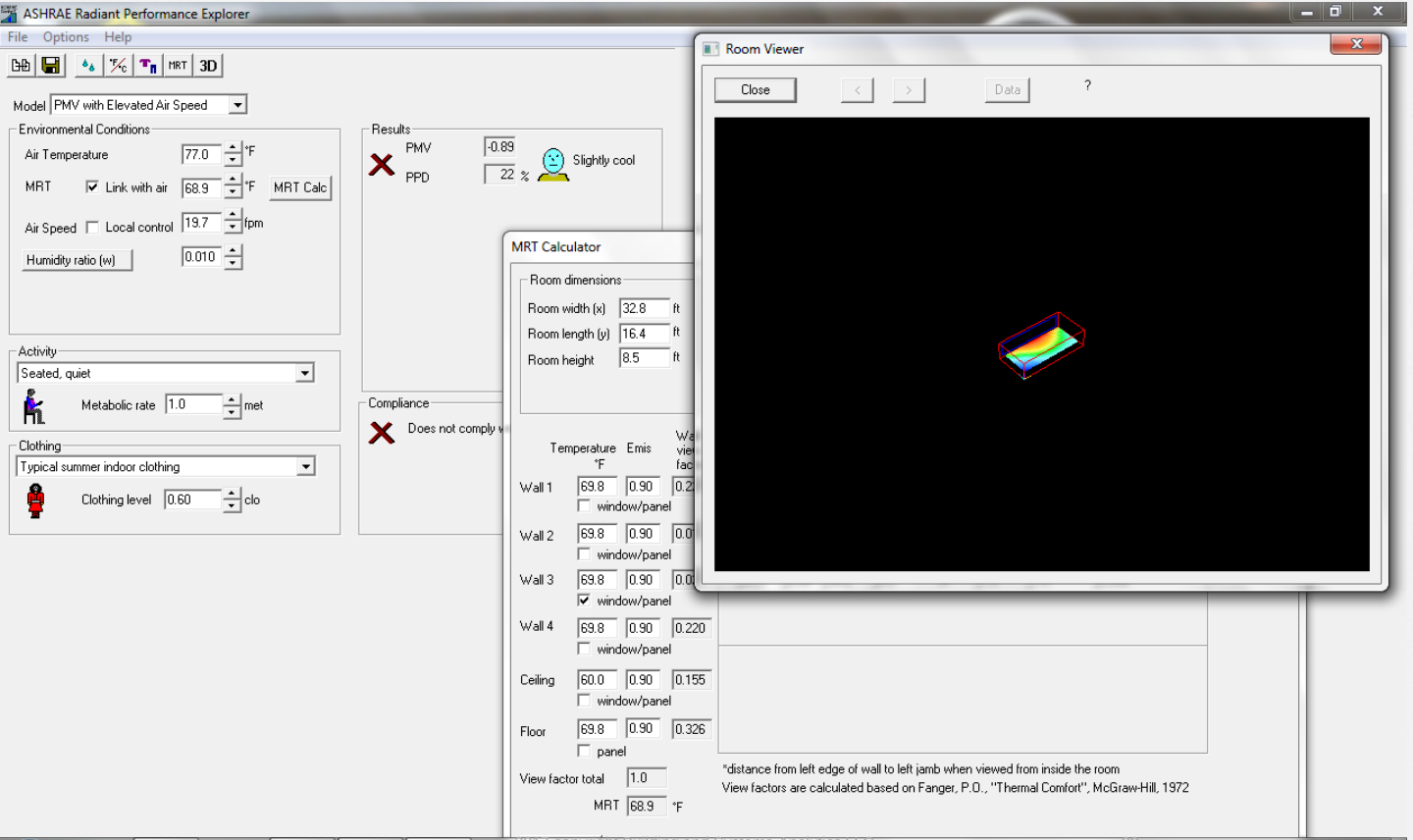
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ASHRAE Thermal Comfort Tool



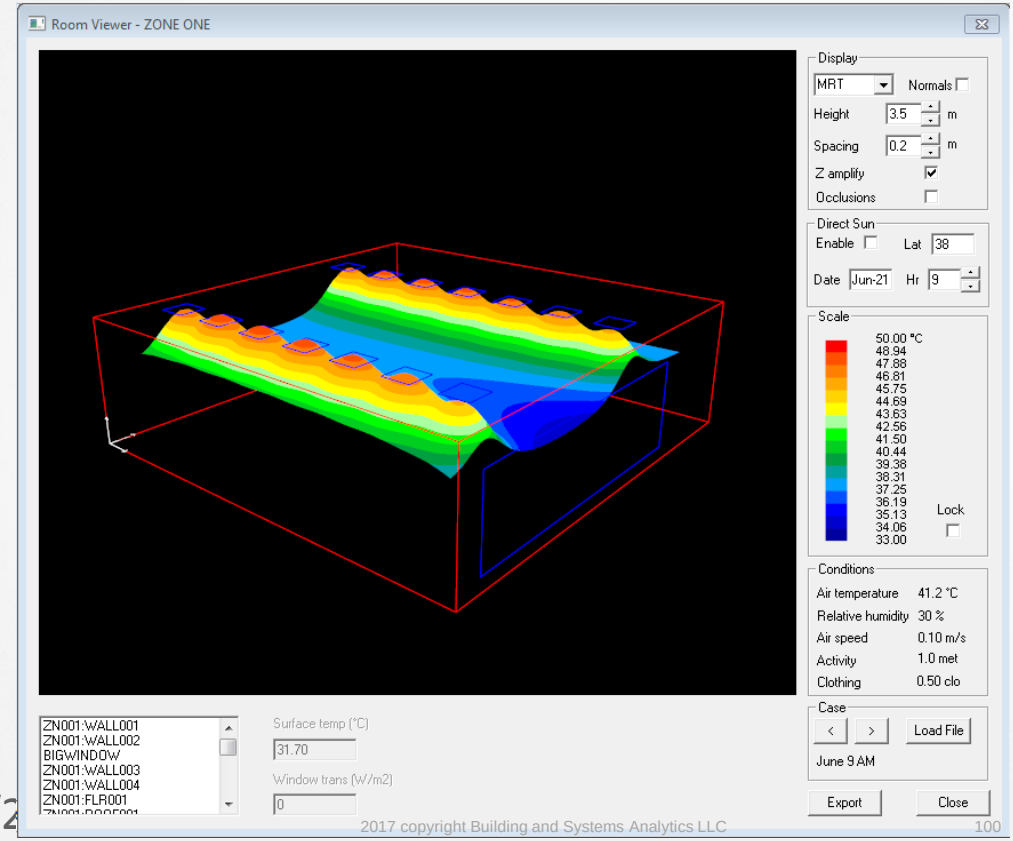
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RPE Design Tool



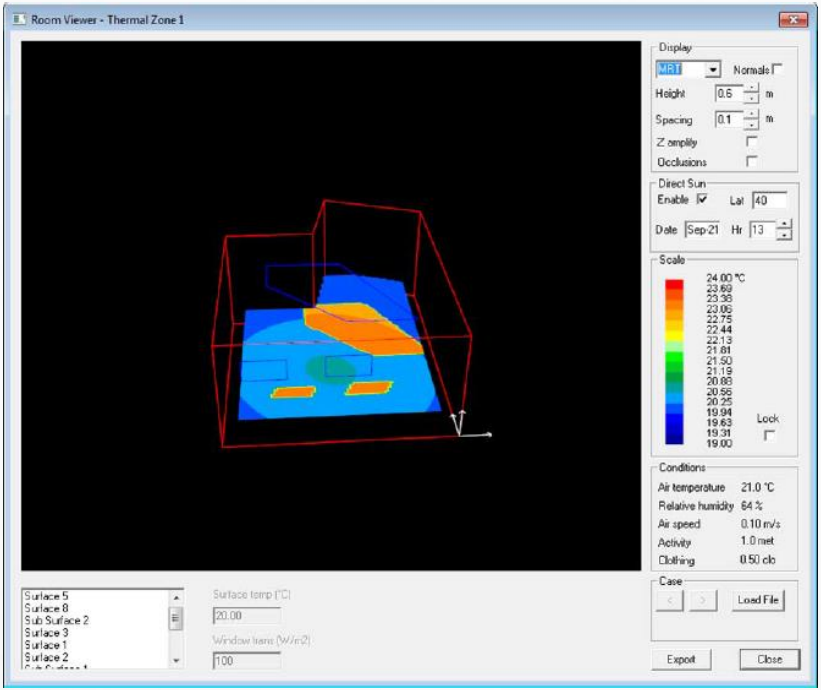
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RPE Design Tool



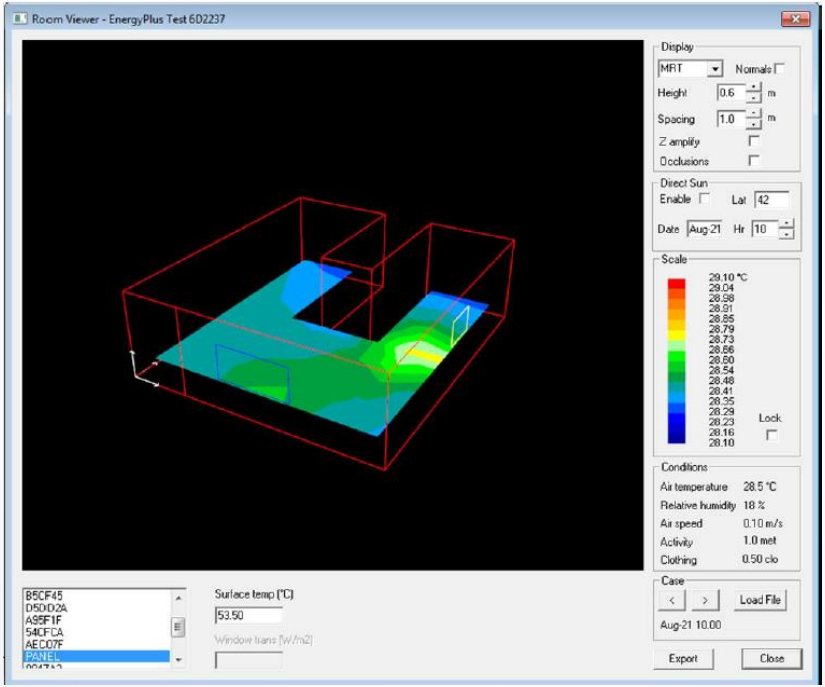
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RPE Design Tool



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RPE Design Tool



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The ultimate comfort clothing



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Questions

- Will Thermal Comfort ever be code enforced?
- What are the liabilities of designing for Thermal Comfort compliance?
- How do you commission Thermal Comfort operated spaces?
- Will people actually be comfortable in Thermal Comfort operated spaces?
- How do you calculate adaptive comfort for naturally ventilated spaces?

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THANK YOU SLIDE

For More Details

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