Thermal & Visual Comfort Maximization of an Unconditioned Space

Building Performance Simulation

Master of Environmental Building Design

School of Design
University of Pennsylvania

Fall 2016

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Submitted by :
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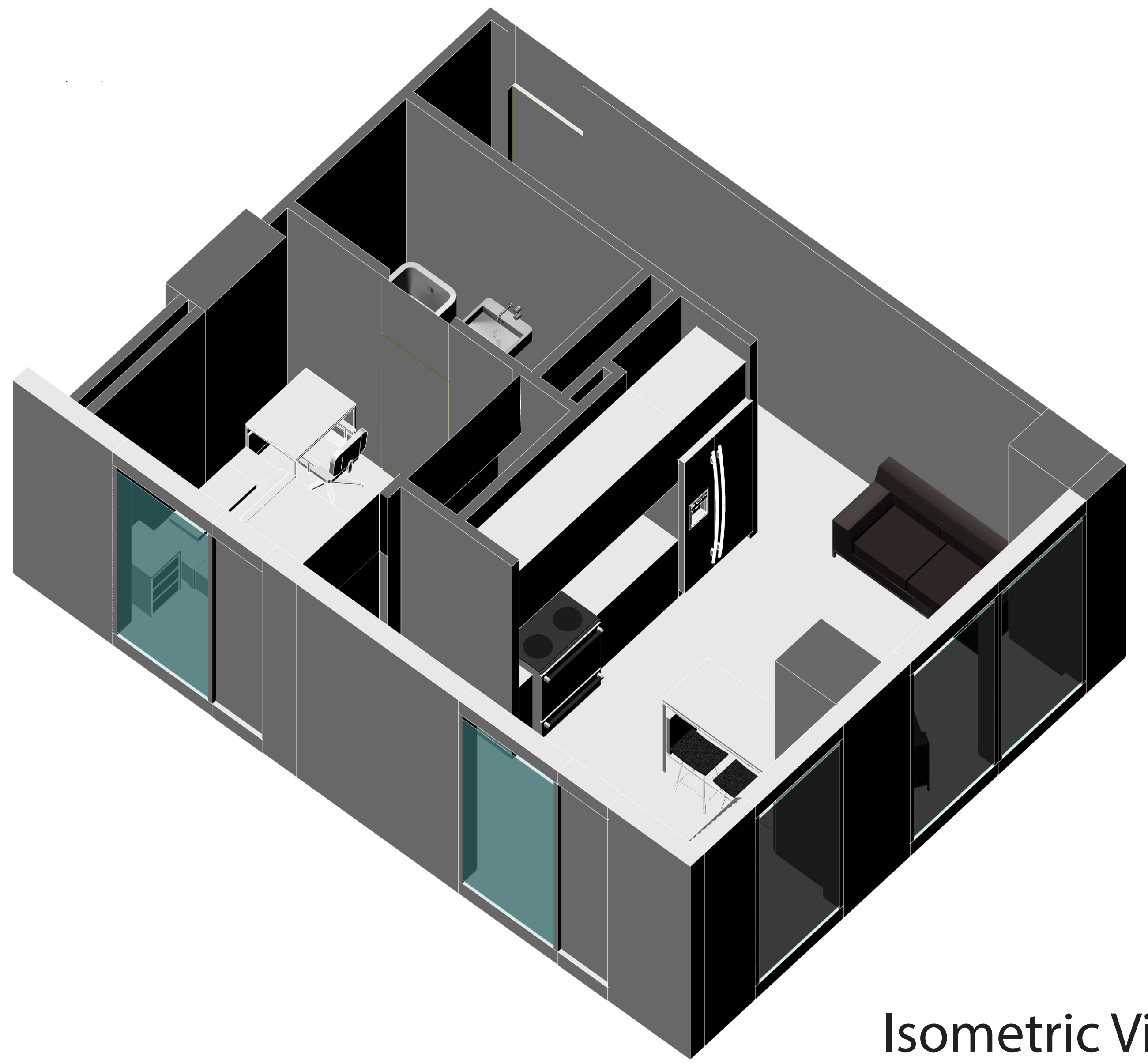
Project Description

Aim :

To re-design an unconditioned apartment in Philadelphia and achieve maximum thermal and visual comfort using passive design strategies.

Plan



Isometric View

Problems identified by occupants before climate analysis.

Problem 1 :
Direct sunlight on the bed in the morning creates disturbance, whereas the study table does not get enough natural light. The Hall gets glare in the morning and afternoon.

Possible solutions :
Blinds, Horizontal Louvres to shade the window in summers,
Changing the dimension of window to maybe create a clerestory

Problem 2 :
The apartment becomes extremely hot in summers and extremely cold in winters.

Possible solutions :
Same as problem 1
Adding insulation to walls and windows
Reducing the size of window

Problem 3 :
There is constant noise from the trains running on the railway tracks below the building towards the adjacent Train Station

Possible solutions :
Sound proofing the apartment.

Workflow and Climate Analysis

Method :

1. **Climate Analysis** of Philadelphia

a. Universal Thermal Climate Index
b. Windrose Diagram
c. Radiation Rose Diagram

2. Daylight Analysis and Energy Simulation of **Exisiting Apartment** (Base Case)

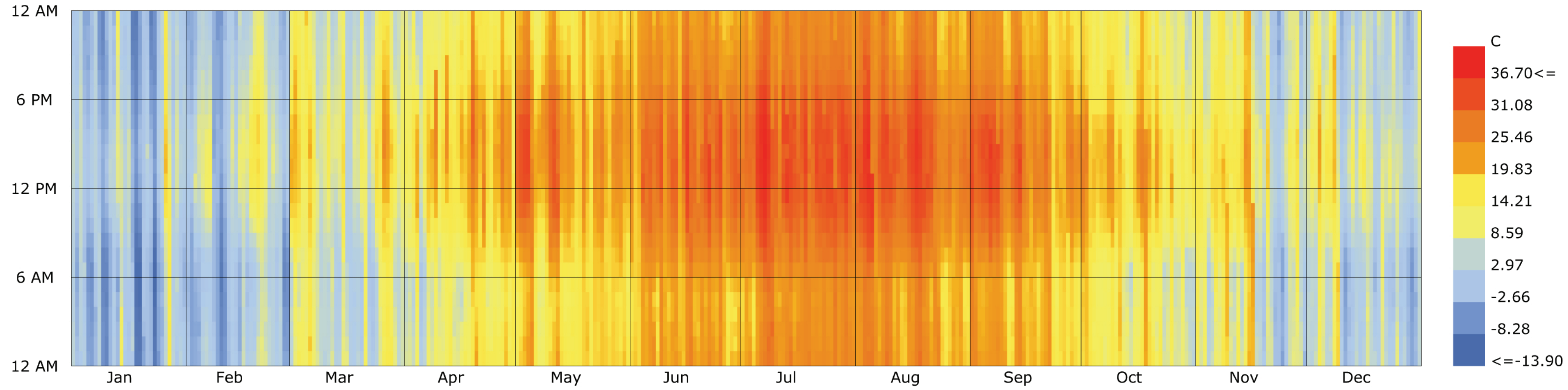
Daylight Analysis
a. Point-In-Time Grid Based Illuminance
b. Annual Useful Daylight Illuminance
c. Glare Analysis

Energy Use Simulation
a. Energy Balance Diagram
b. Psychrometric Chart
c. Surface Temperature Analysis

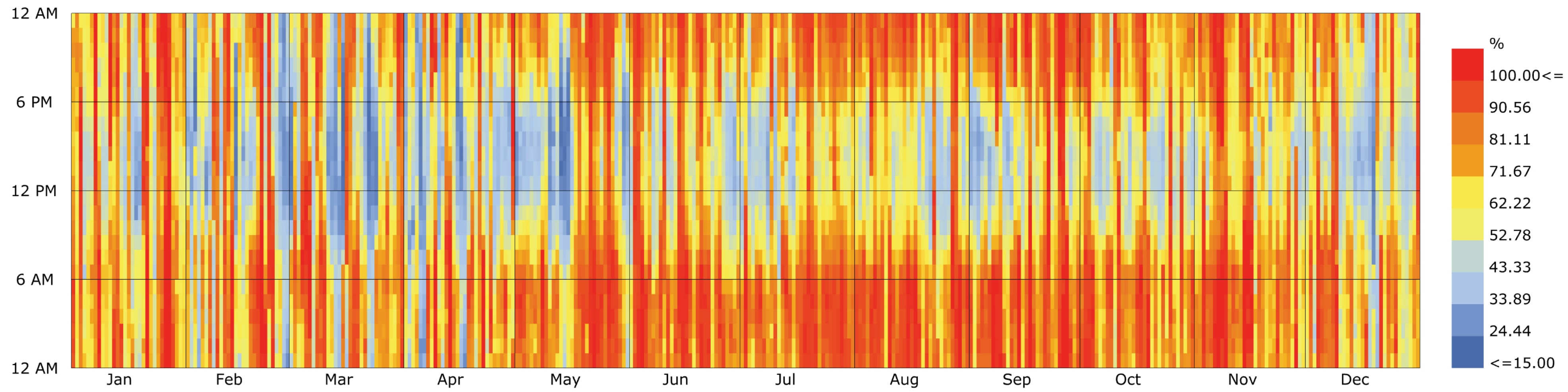
3. Achieve **Visual Comfort** by changing window to wall ratio and addition of shading devices.

4. Achieve **Thermal Comfort** by changing construction material, orientation and adding ventilation to the apartment.

5. Daylight Analysis and Energy Simulation of the re-designed apartment and comparison with base case.

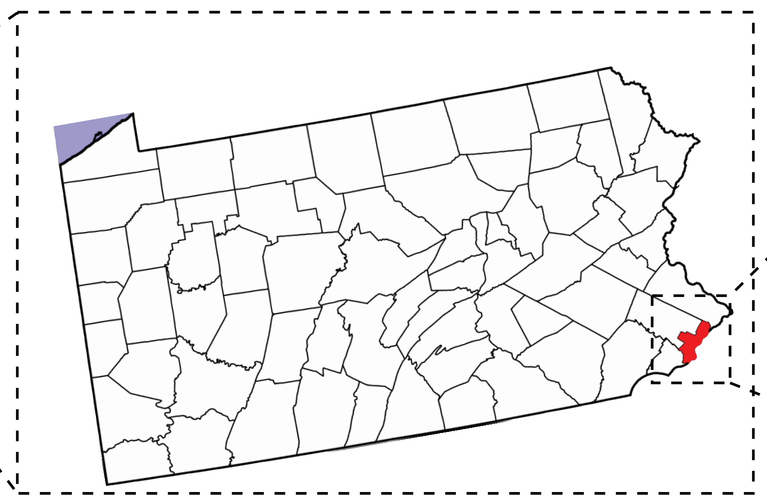


Dry Bulb Temperature (C) - Hourly
Philadelphia International Ap_PA_USA
1 JAN 1:00 - 31 DEC 24:00



Relative Humidity (%) - Hourly
Philadelphia International Ap_PA_USA
1 JAN 1:00 - 31 DEC 24:00

United States of America



Pennsylvania

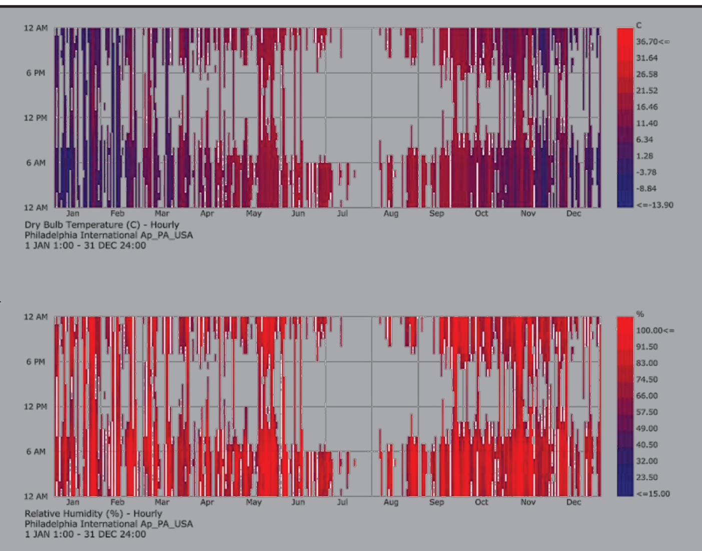
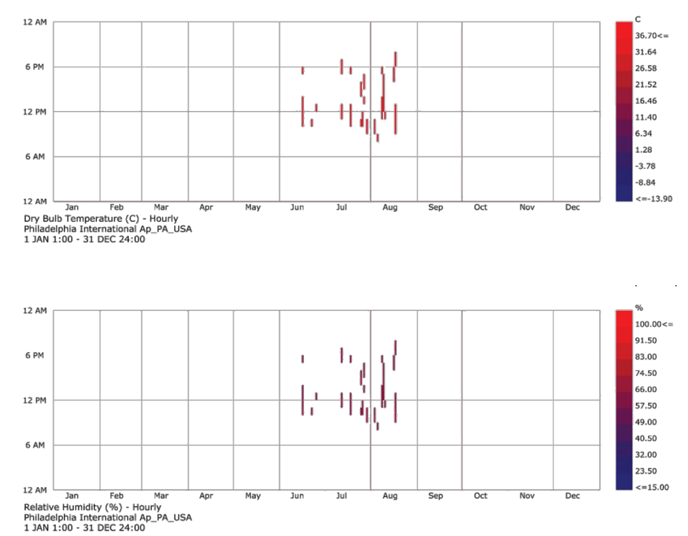
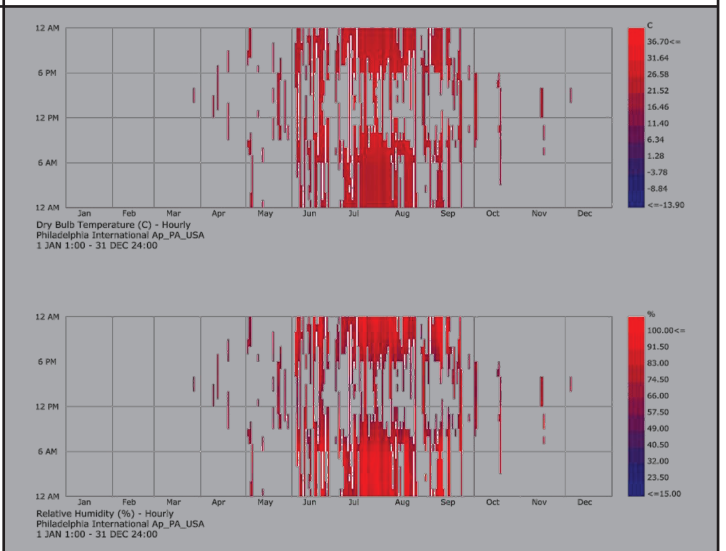
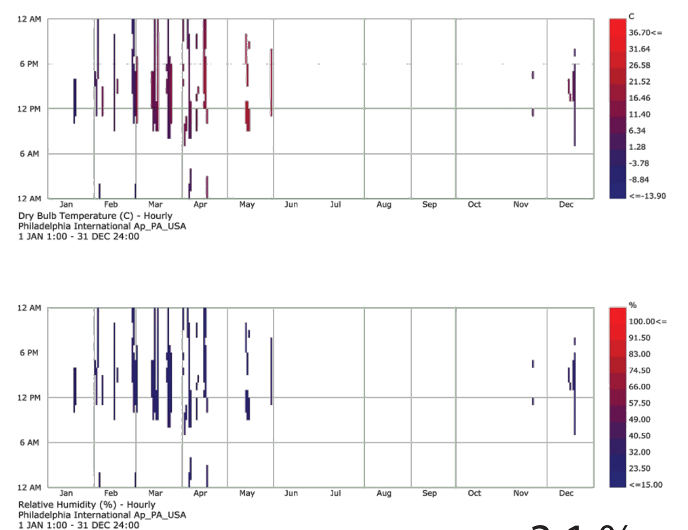
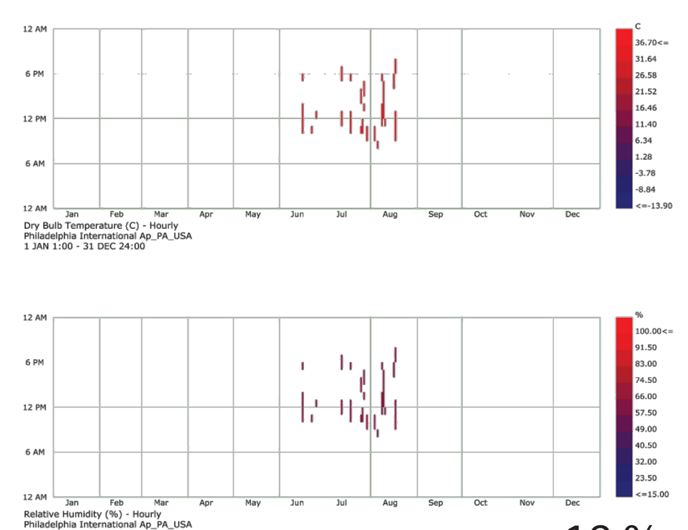
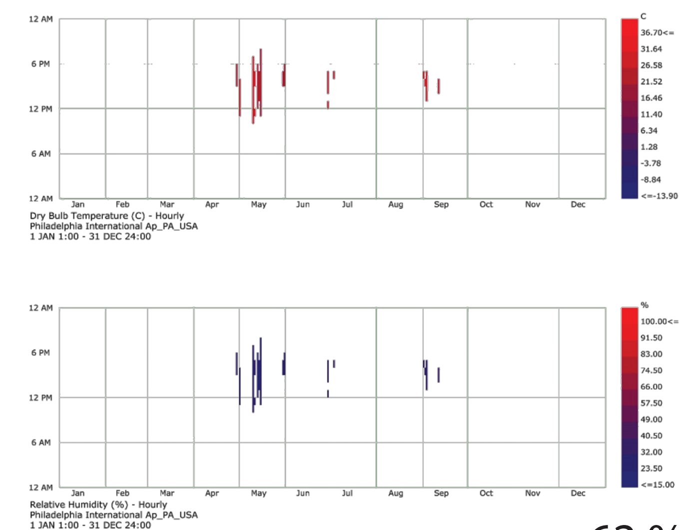
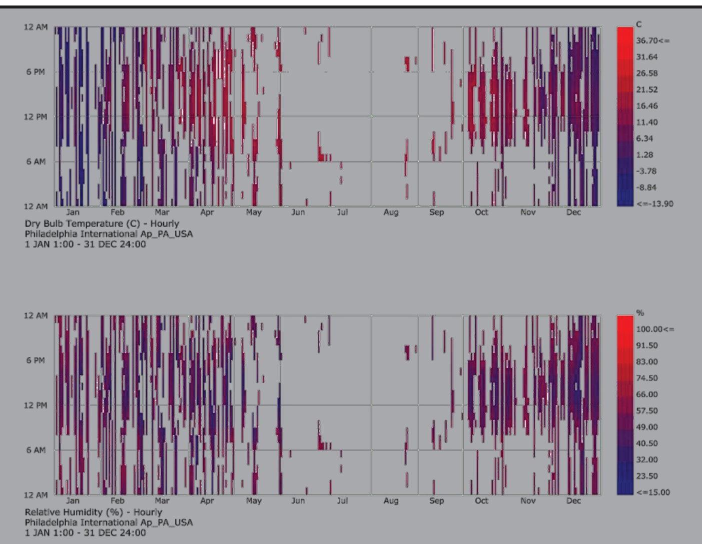
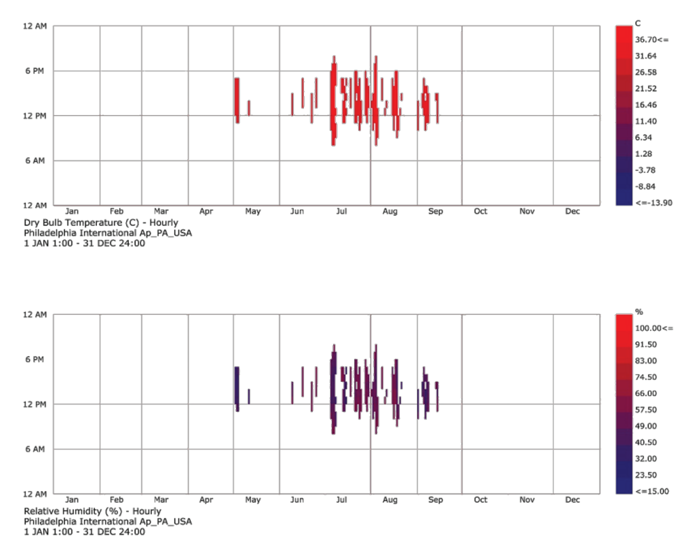
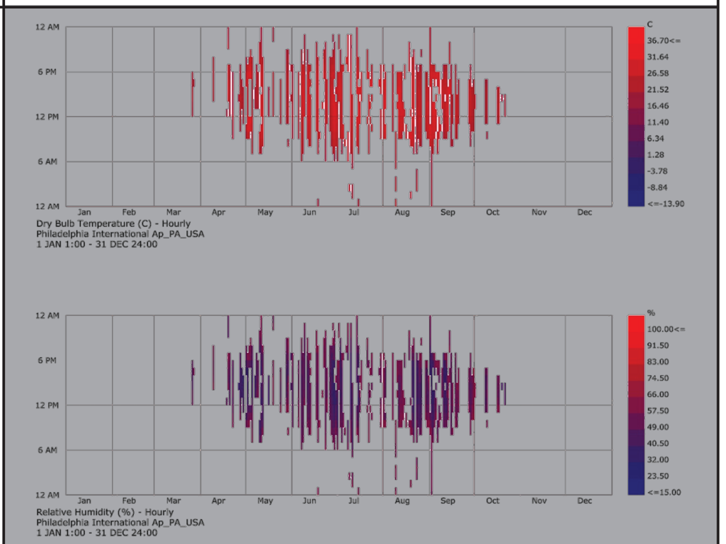
Philadelphia

Coordinates:
39°57 N 75°10 W

Weather Station :
Philadelphia International Airport
Data Source :
TMY3

Classified as ASHRAE 169-2006
Climate Zone Number 4
Climate Zone Subtype A

Climate Analysis

Relative Humidity \ Dry Bulb Temp.	Cold	Hot	Comfortable Temperature
Humid	 **Case I 43.5%**	 .31 %	 **Case II 16.3 %**
Dry	 3.1 %	 .18 %	 .62 %
Comfortable Relative Humidity	 **Case III 24.8 %**	 2.47 %	 **Case IV 10.1 %**

Considering comfortable dry bulb temperature in the range 20 - 30 degree celsius and comfortable relative humidity in the range 30 - 60 percent, the most prevalent climatic conditions are derived.

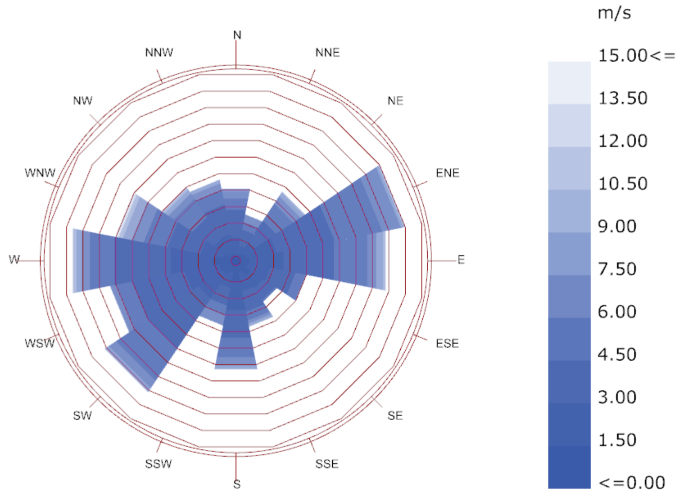
According to the prevailing dry bulb temperature and relative humidity in Philadelphia it is comfortable only **10%** of the year.

The table suggests the dominant climatic condition in Philadelphia is **Cold and Humid** (43.5%) , therefore the design strategies would be governed by them.

Climate Analysis

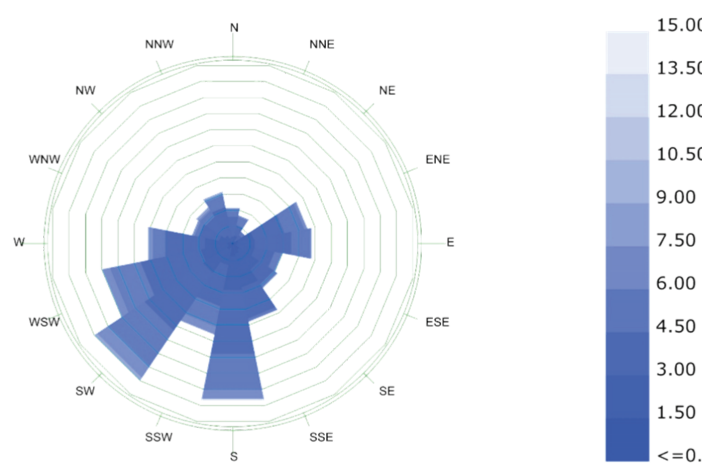
Wind Rose Diagrams

Case I 43.5 %



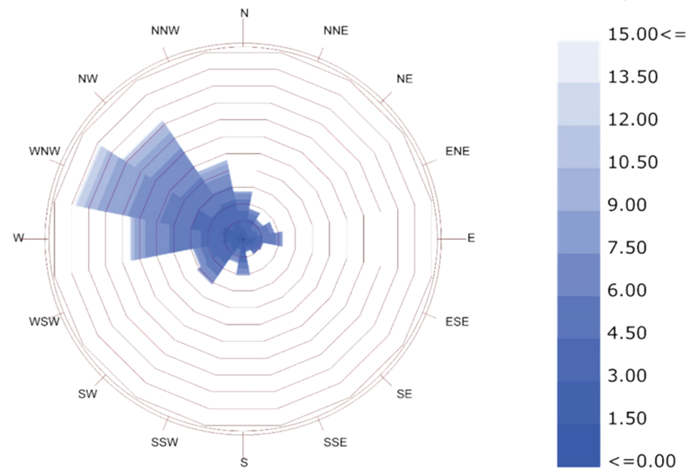
Wind-Rose
Philadelphia International Ap_PA_USA
1 JAN 1:00 - 31 DEC 24:00
Hourly Data: Wind Speed (m/s)
Calm for 2.01% of the time = 176 hours.
Each closed polyline shows frequency of 0.4%. = 38 hours.
... ...
Conditional Selection Applied:
Dry Bulb Temperature <= 20
and Relative Humidity >= 60
3809.0 hours of total 8760.0 hours (43.48%).

Case II 16.3 %



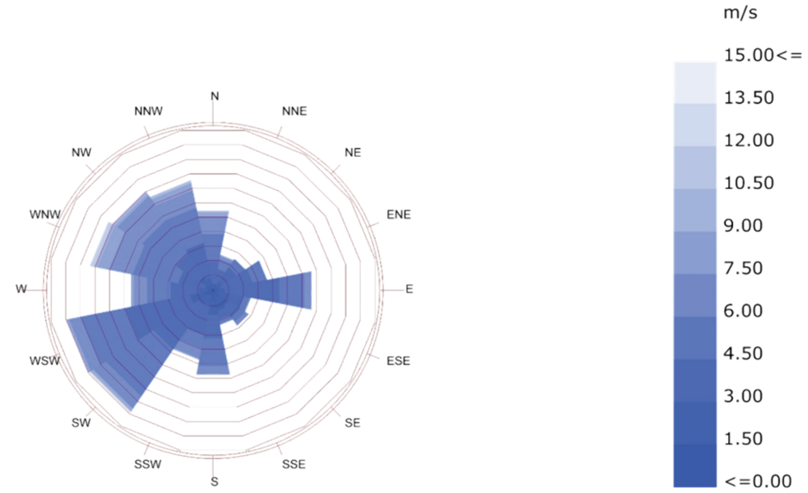
Wind-Rose
Philadelphia International Ap_PA_USA
1 JAN 1:00 - 31 DEC 24:00
Hourly Data: Wind Speed (m/s)
Calm for 0.24% of the time = 21 hours.
Each closed polyline shows frequency of 0.2%. = 19 hours.
... ...
Conditional Selection Applied:
20 <= Dry Bulb Temperature <= 30
and Relative Humidity >= 60
1428.0 hours of total 8760.0 hours (16.30%).

Case III 24.8 %



Wind-Rose
Philadelphia International Ap_PA_USA
1 JAN 1:00 - 31 DEC 24:00
Hourly Data: Wind Speed (m/s)
Calm for 0.50% of the time = 44 hours.
Each closed polyline shows frequency of 0.5%. = 40 hours.
... ...
Conditional Selection Applied:
20 >= Dry Bulb Temperature
and 30 <= Relative Humidity <= 60
2170.0 hours of total 8760.0 hours (24.77%).

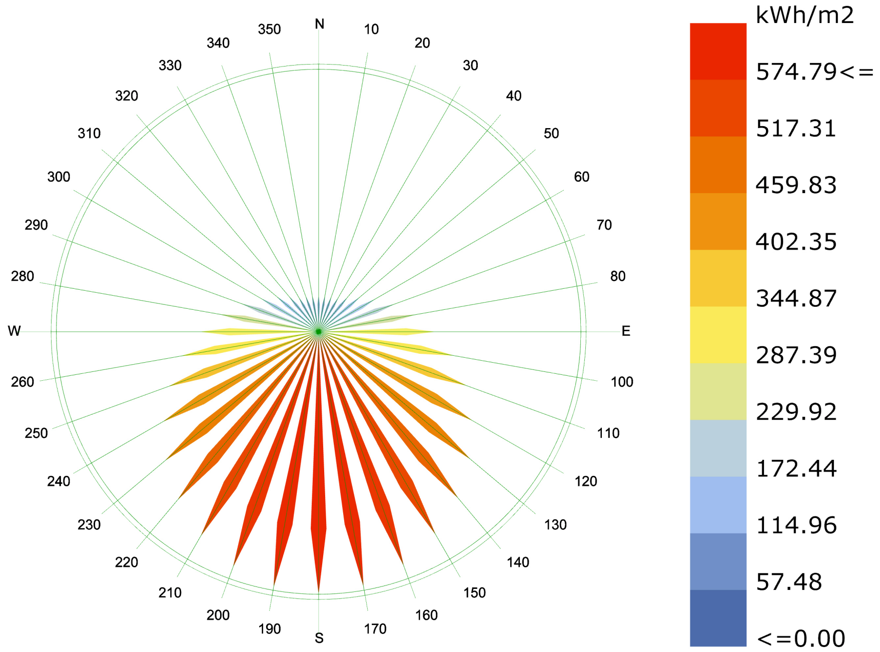
Case IV 10.1 %



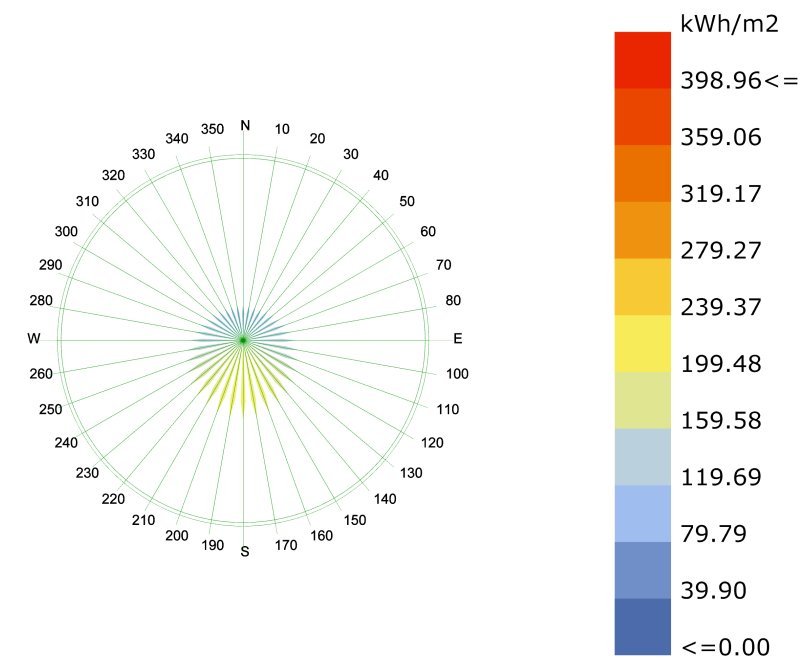
Wind-Rose
Philadelphia International Ap_PA_USA
1 JAN 1:00 - 31 DEC 24:00
Hourly Data: Wind Speed (m/s)
Calm for 0.11% of the time = 10 hours.
Each closed polyline shows frequency of 0.1%. = 9 hours.
... ...
Conditional Selection Applied:
20 <= Dry Bulb Temperature <= 30
and 30 <= Relative Humidity <= 60
885.0 hours of total 8760.0 hours (10.10%).

Radiation Rose Diagrams

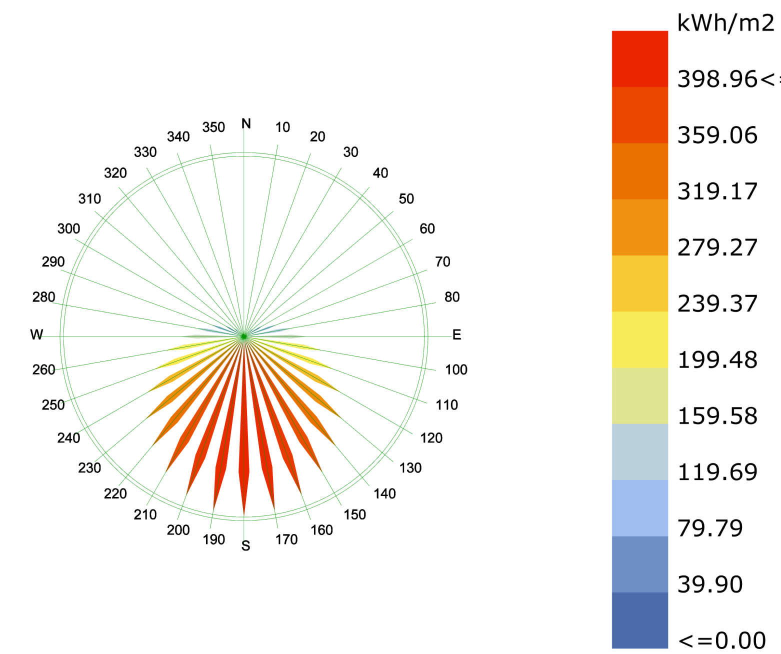
Case I 43.5 % & Case III 24.8 %



Total Radiation(kWh/m2)
Philadelphia_International_Ap_PA_USA
21 SEP 1:00 - 21 MAR 24:00

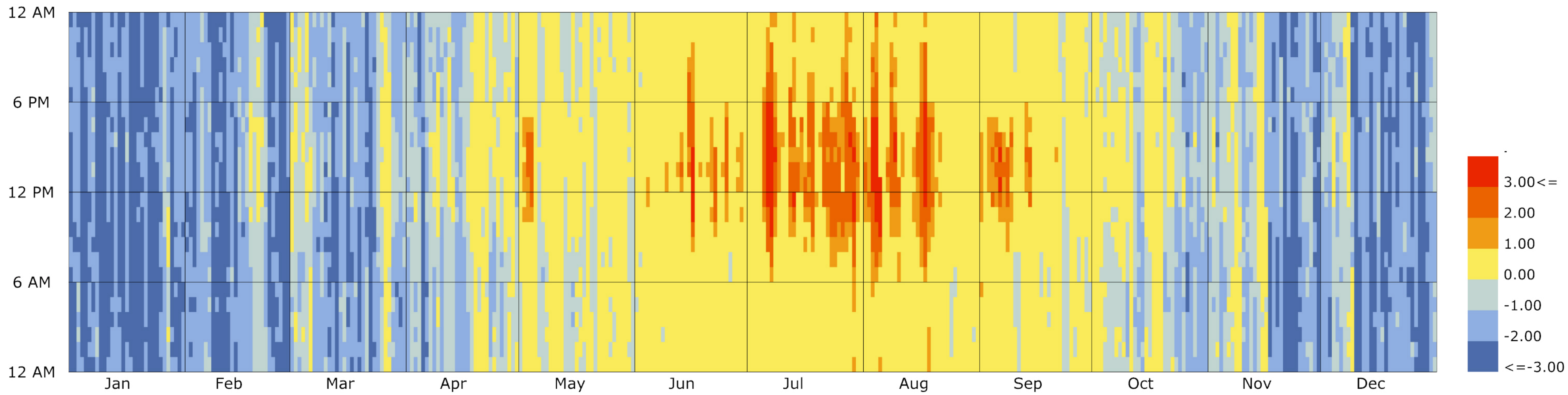


Diffuse Radiation(kWh/m2)
Philadelphia_International_Ap_PA_USA
21 SEP 1:00 - 21 MAR 24:00

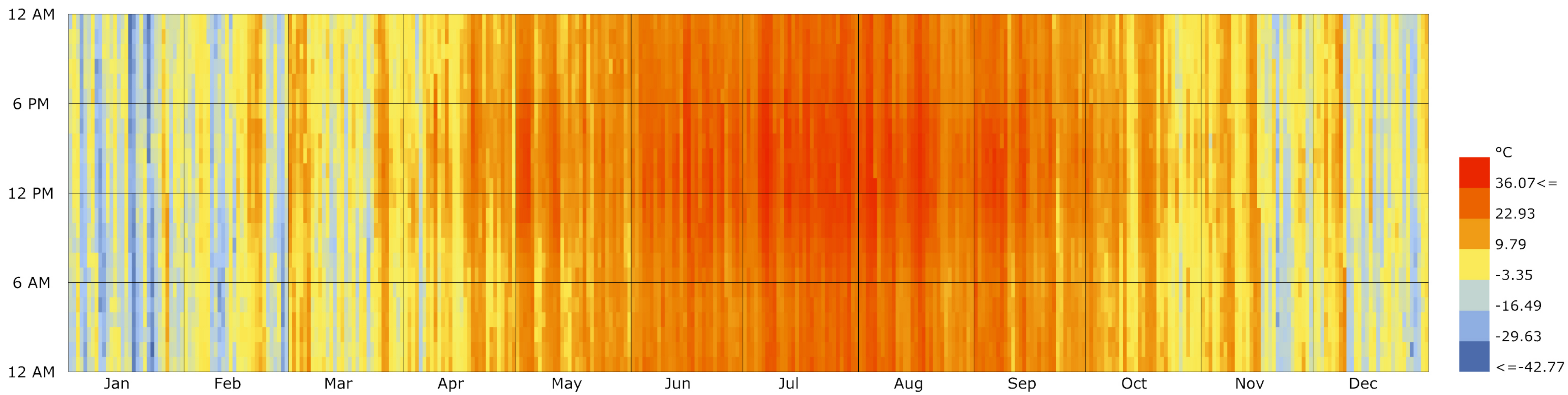


Direct Radiation(kWh/m2)
Philadelphia_International_Ap_PA_USA
21 SEP 1:00 - 21 MAR 24:00

Climate Analysis



Outdoor Comfort (-3 = Extreme Cold | -2 = Cold | -1 = Cool | 0 = Comfort | 1 = Warm | 2 = Hot | 3 = Extreme Heat) - Hourly
Philadelphia International Ap_PA_USA
1 JAN 1:00 - 31 DEC 24:00



Universal Thermal Climate Index (°C) - Hourly
Philadelphia International Ap_PA_USA
1 JAN 1:00 - 31 DEC 24:00

Preliminary Design Strategies

Strategy I

As seen in the table Philadelphia is below comfortable temperature for 67% of the year therefore the air temperature needs to be increased, a common strategy to do this passively is to incorporate solar heat gains with high thermal mass materials.

Orientation : South Facing Building

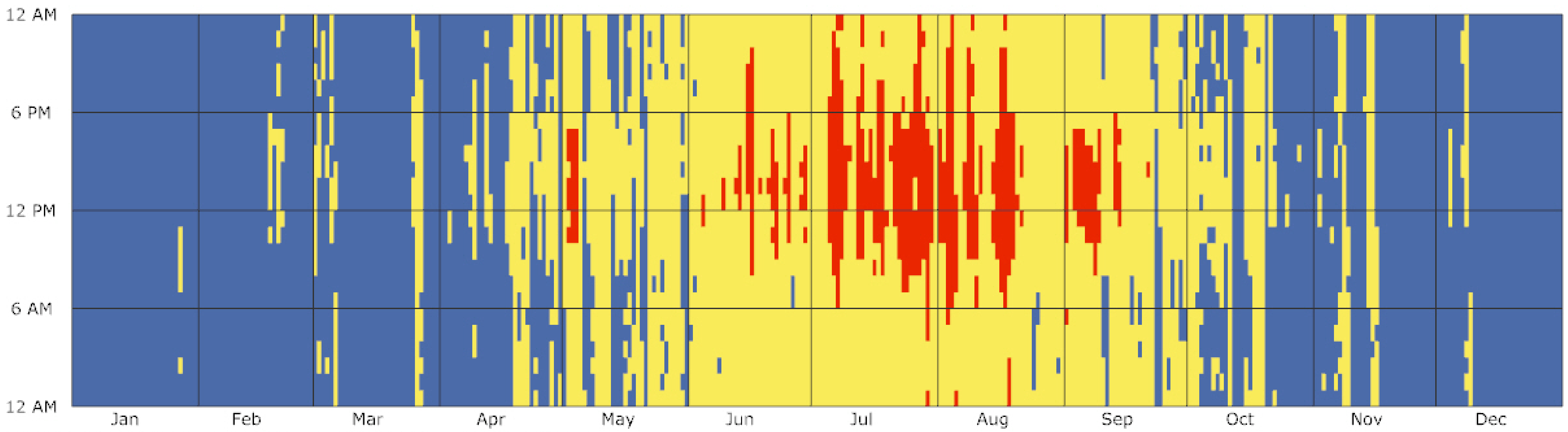
Strategy II

As seen in Case I and Case III the temperature is low, therefore wind to be blocked from Northwest Direction.

For Case II the temperature is comfortable but humidity is high, therefore natural ventilation to be enhanced from Southwest Direction.

When Humidity is too high it can be decreased with the use of desiccants.

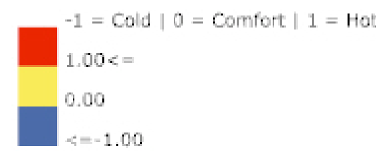
Climate Analysis

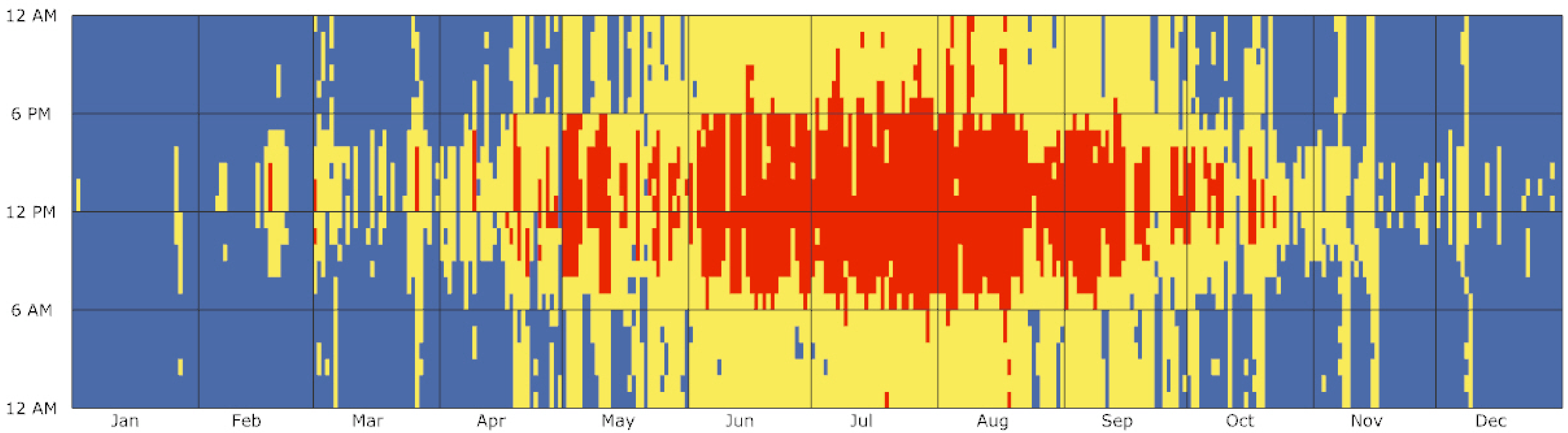


Thermal Stress (-1 = Cold | 0 = Comfort | 1 = Hot) - Hourly
Philadelphia International Ap_PA_USA
1 JAN 1:00 - 31 DEC 24:00

Thermal Stress

Comfortable	41.28%
Heat Stress	3.14%
Cold Stress	34.34%

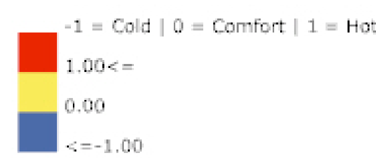




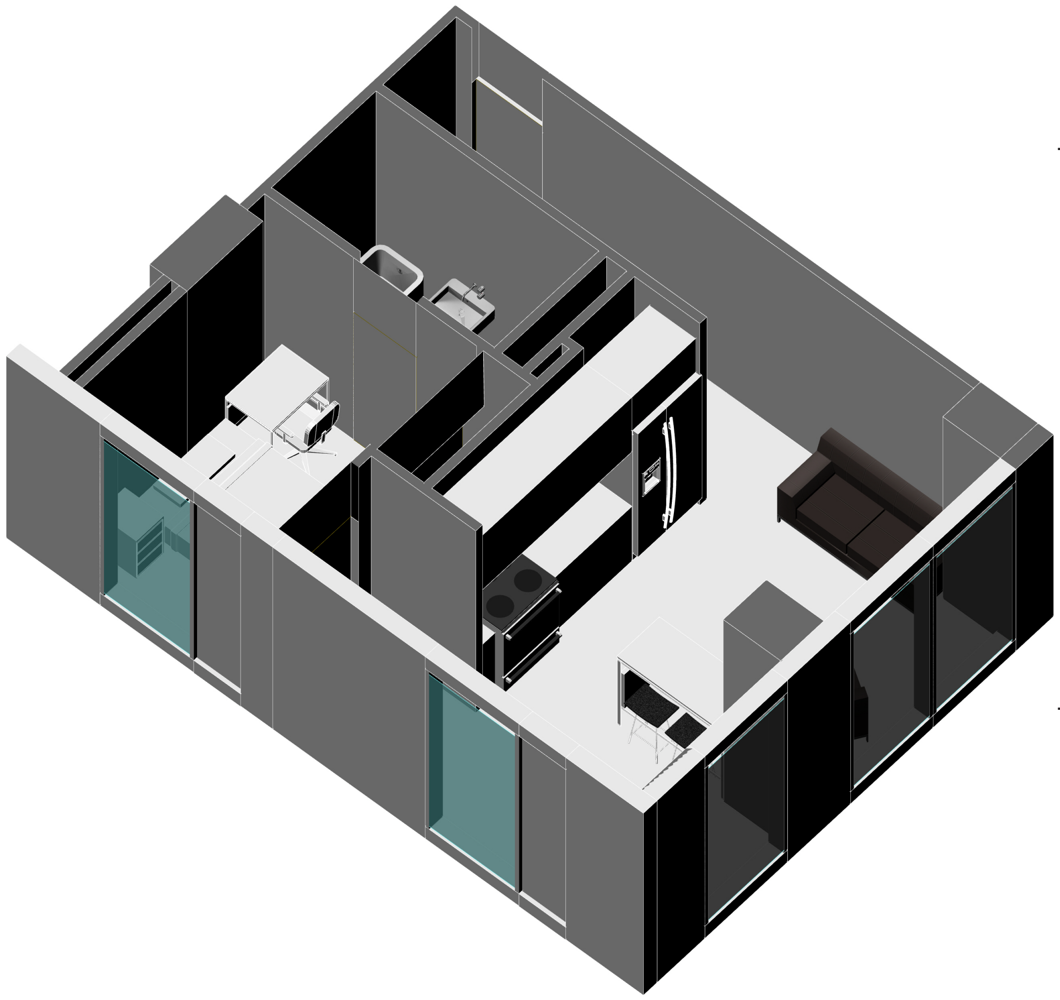
Thermal Stress (-1 = Cold | 0 = Comfort | 1 = Hot) - Hourly
Philadelphia International Ap_PA_USA
1 JAN 1:00 - 31 DEC 24:00

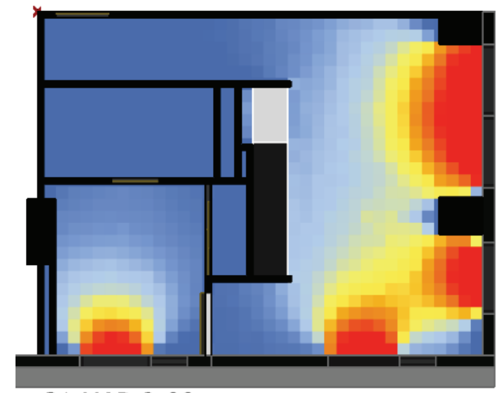
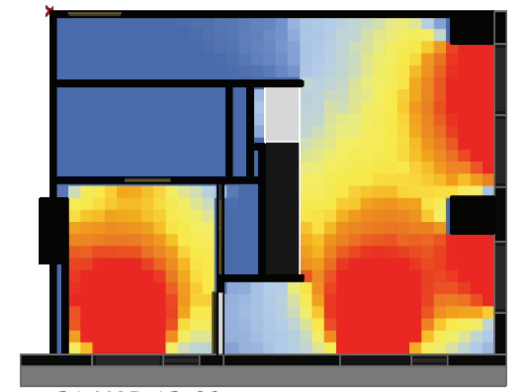
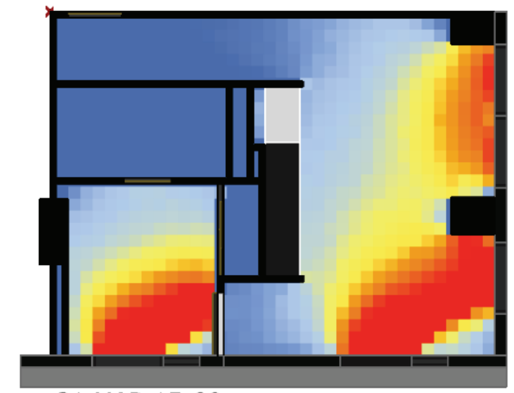
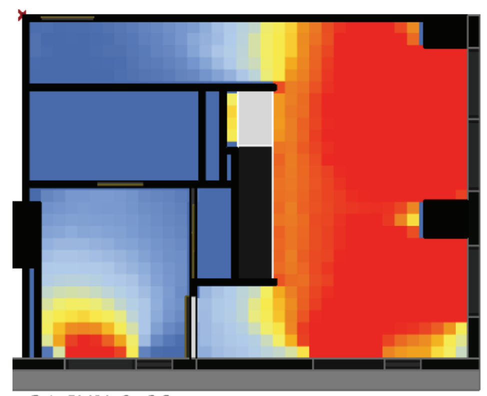
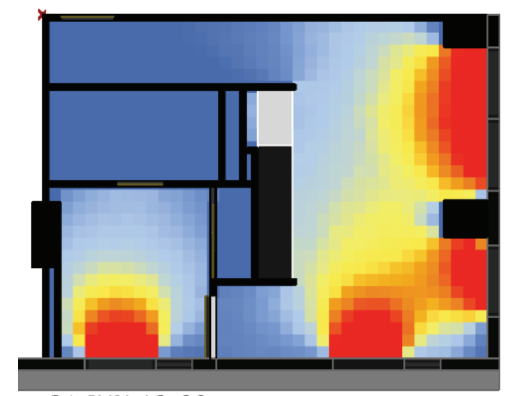
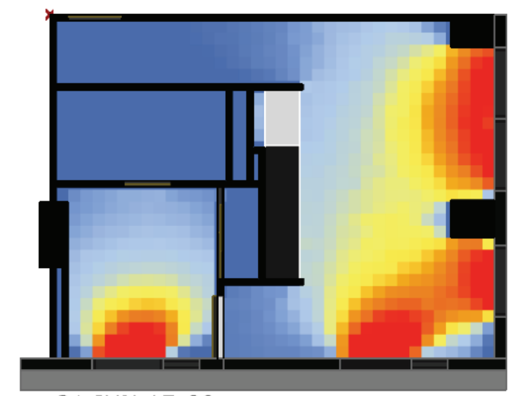
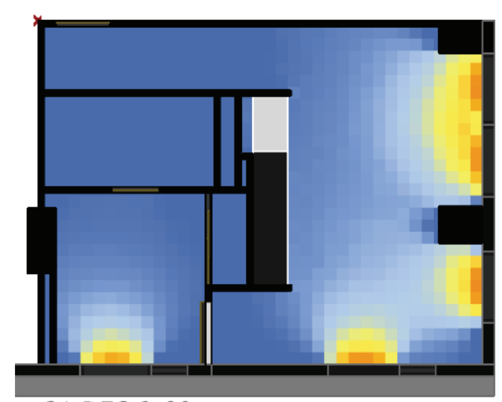
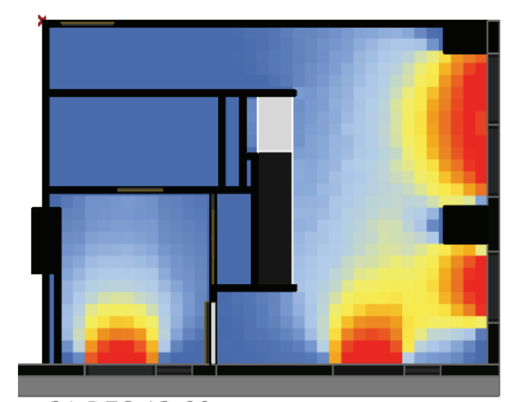
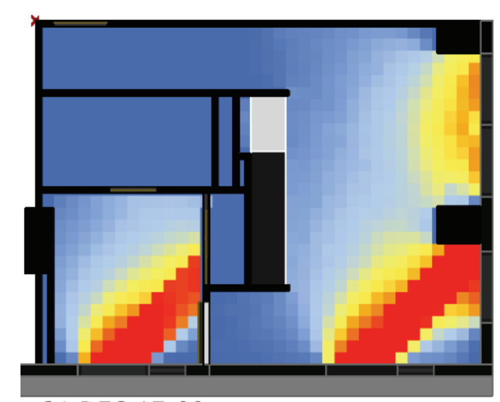
Thermal Stress with effect of radiation

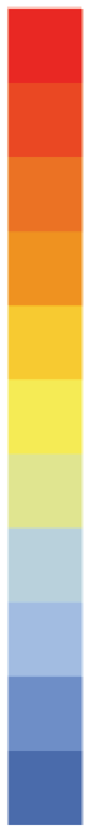
Comfortable	37.34%
Heat Stress	12.51%
Cold Stress	31.64%



Point-In-Time Grid Based Illuminance **Baseline Case**



Date \ Time	9 :00	12 :00	15 :00
21st March	 21 MAR 9:00	 21 MAR 12:00	 21 MAR 15:00
21st June	 21 JUN 9:00	 21 JUN 12:00	 21 JUN 15:00
21st December	 21 DEC 9:00	 21 DEC 12:00	 21 DEC 15:00



The space is well daylit in December with some patches of excess light.

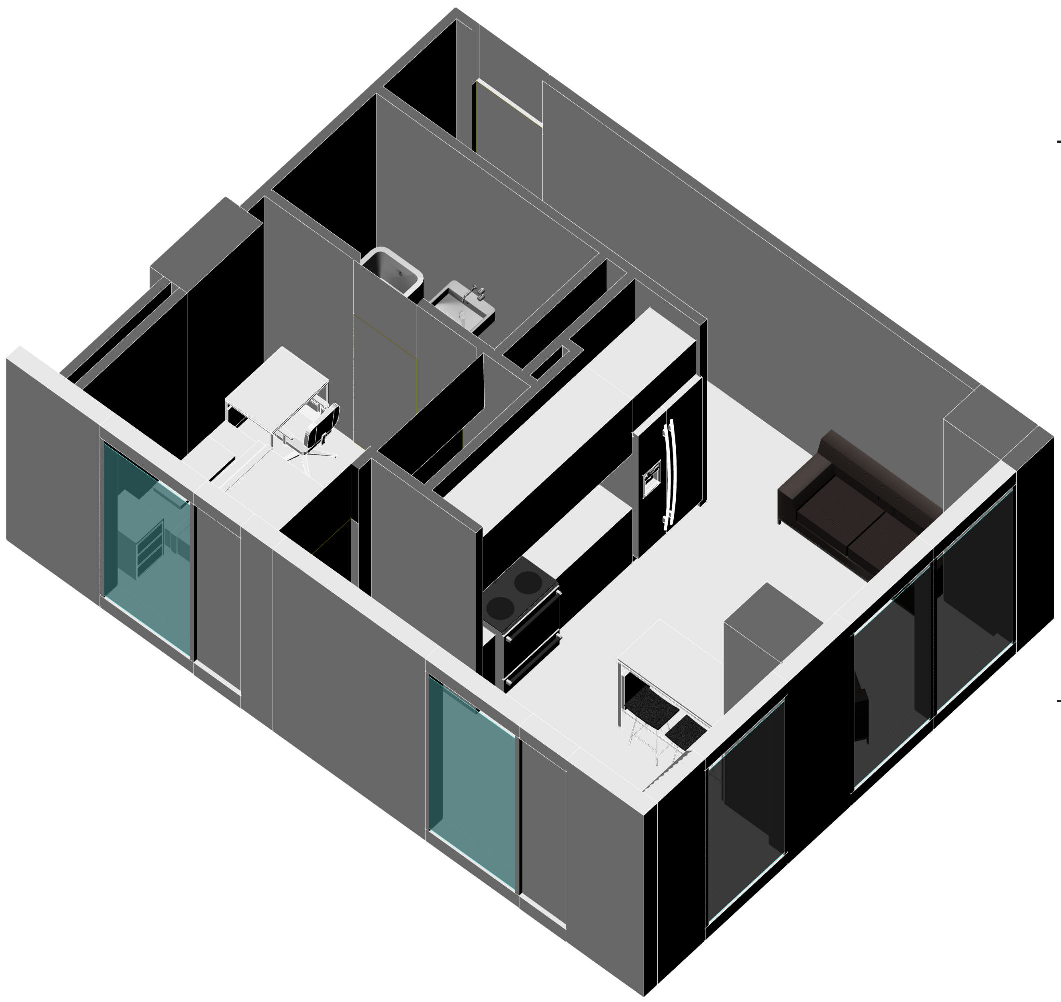
March and June face excessive daylight which needs to be reduced using different design techniques.

Window Wall Ratio	
North	0
West	0
South	.25
East	.48

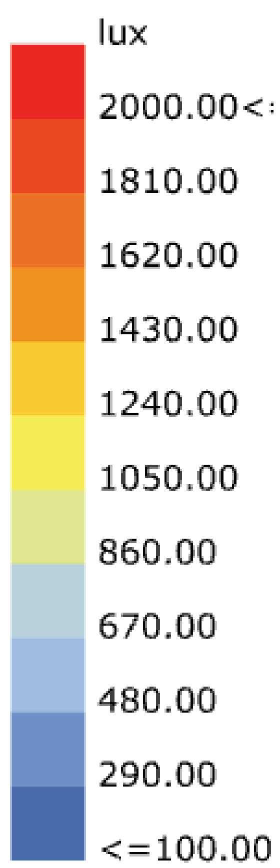
Rotation Angle 0°

Blinds	No	
	East	South
Depth of Shading	0	0
Number of Blinds	0	0

Point-In-Time Grid Based Illuminance : **Baseline Case with Context**



Addition of context (high rise on the south side) reduces daylight in March and June at noon.



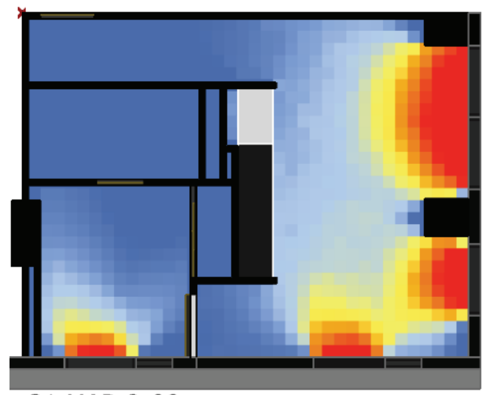
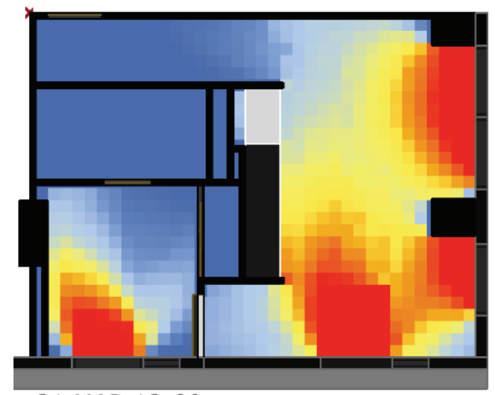
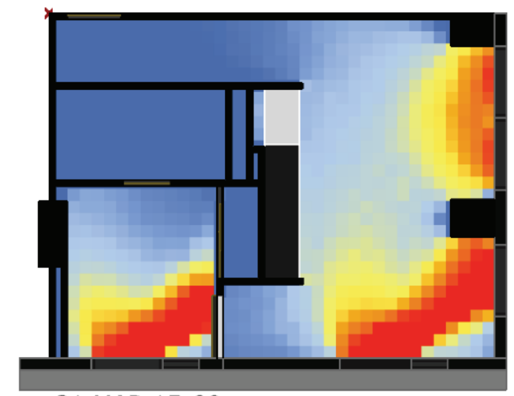
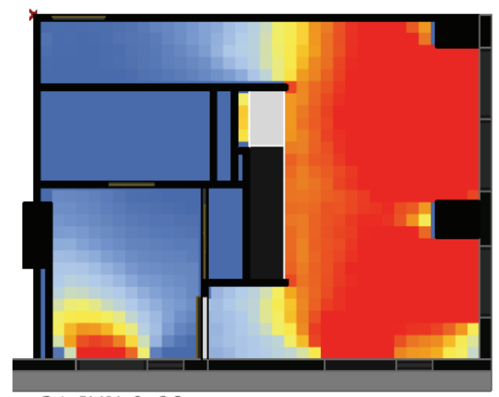
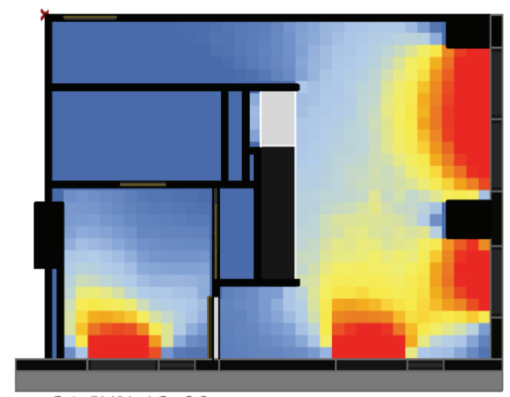
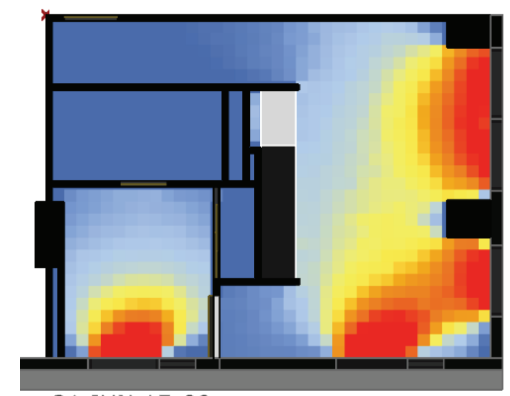
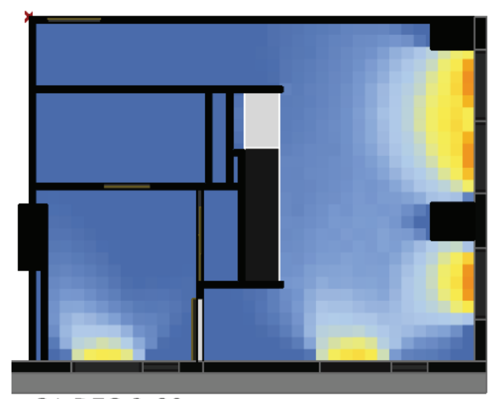
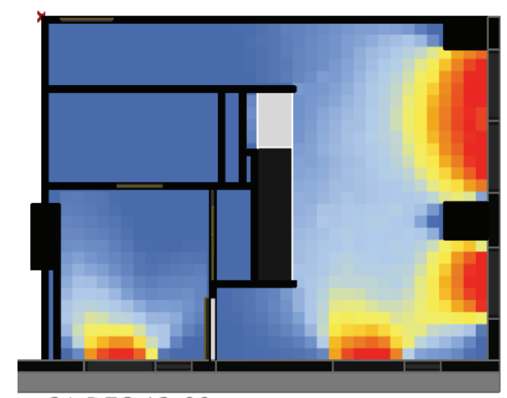
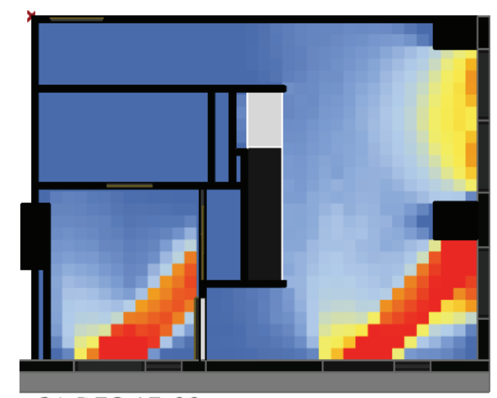
Window Wall Ratio

North	0
West	0
South	.25
East	.48

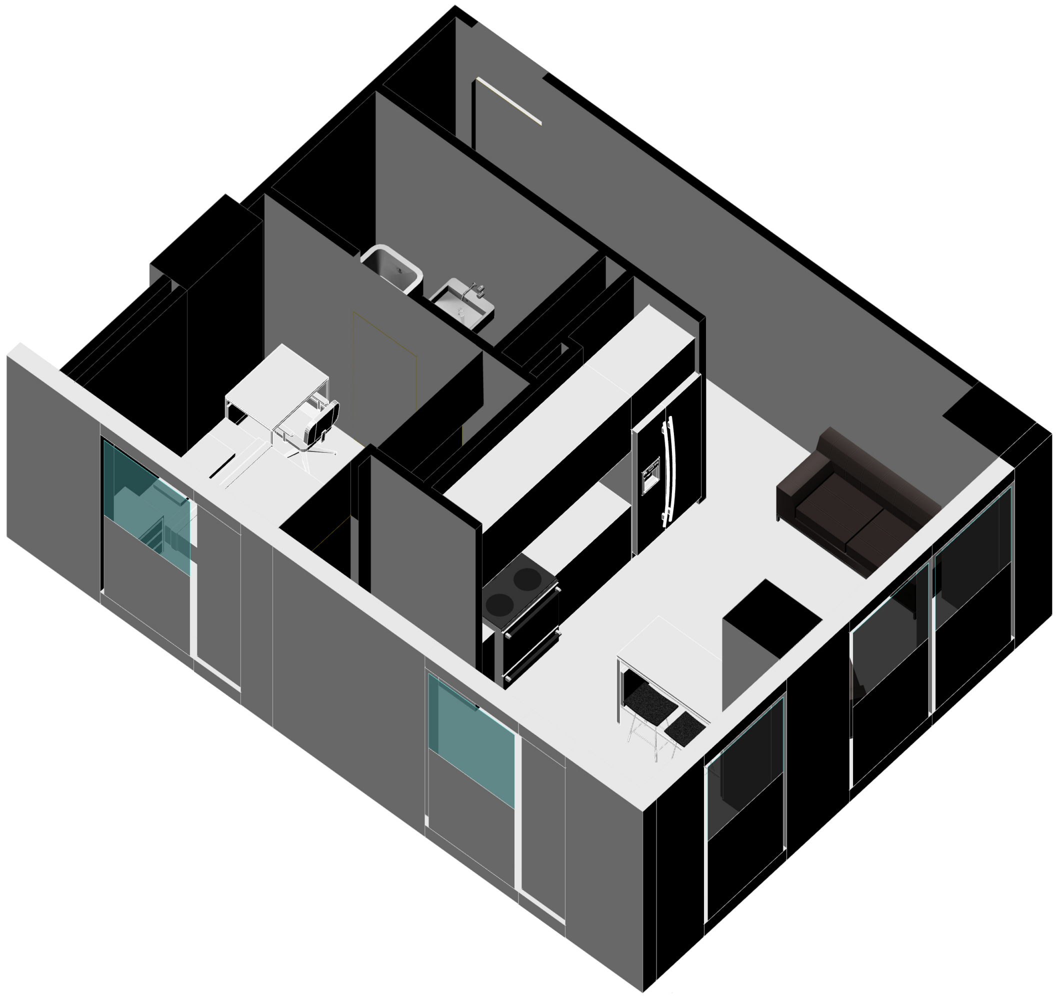
Rotation Angle 0°

Blinds No

	East	South
Depth of Shading	0	0
Number of Blinds	0	0

Time / Date	9 :00	12 :00	15 :00
21st March	 21 MAR 9:00	 21 MAR 12:00	 21 MAR 15:00
21st June	 21 JUN 9:00	 21 JUN 12:00	 21 JUN 15:00
21st December	 21 DEC 9:00	 21 DEC 12:00	 21 DEC 15:00

Point-In-Time Grid Based Illuminance **Case1**



To cut off daylight the window size is reduced and they are kept at the top of wall.

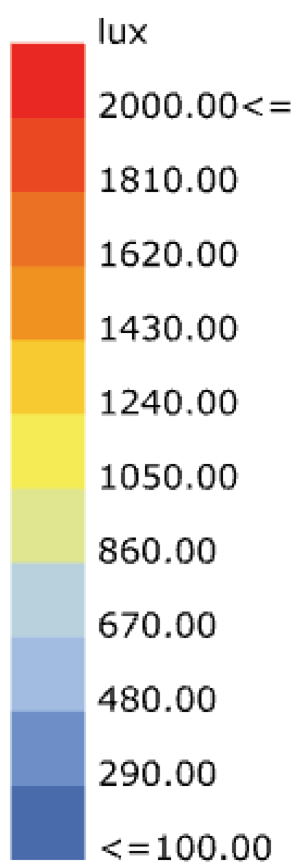
Window Wall Ratio

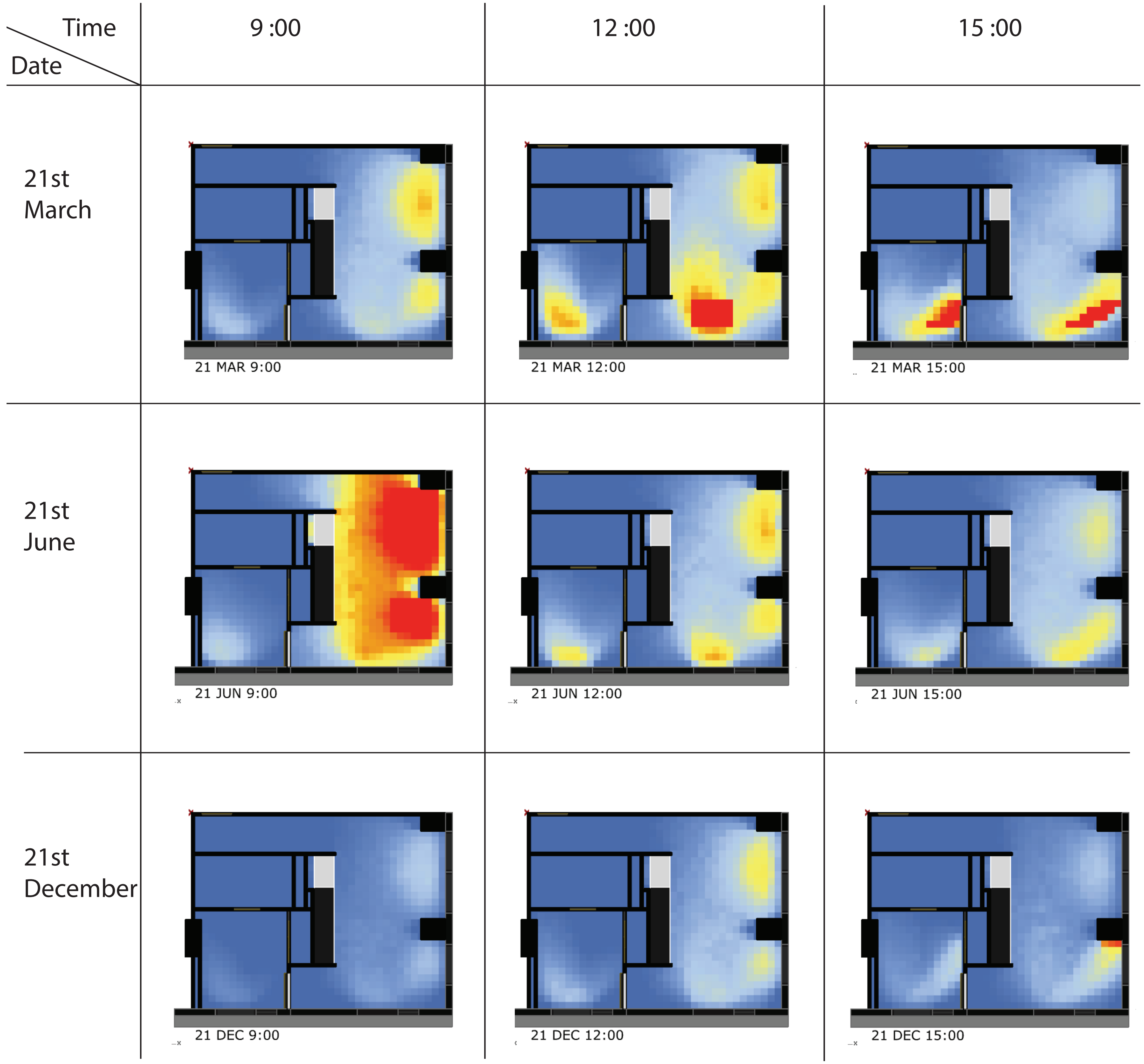
North	0
West	0
South	.125
East	.24

Rotation Angle 0°

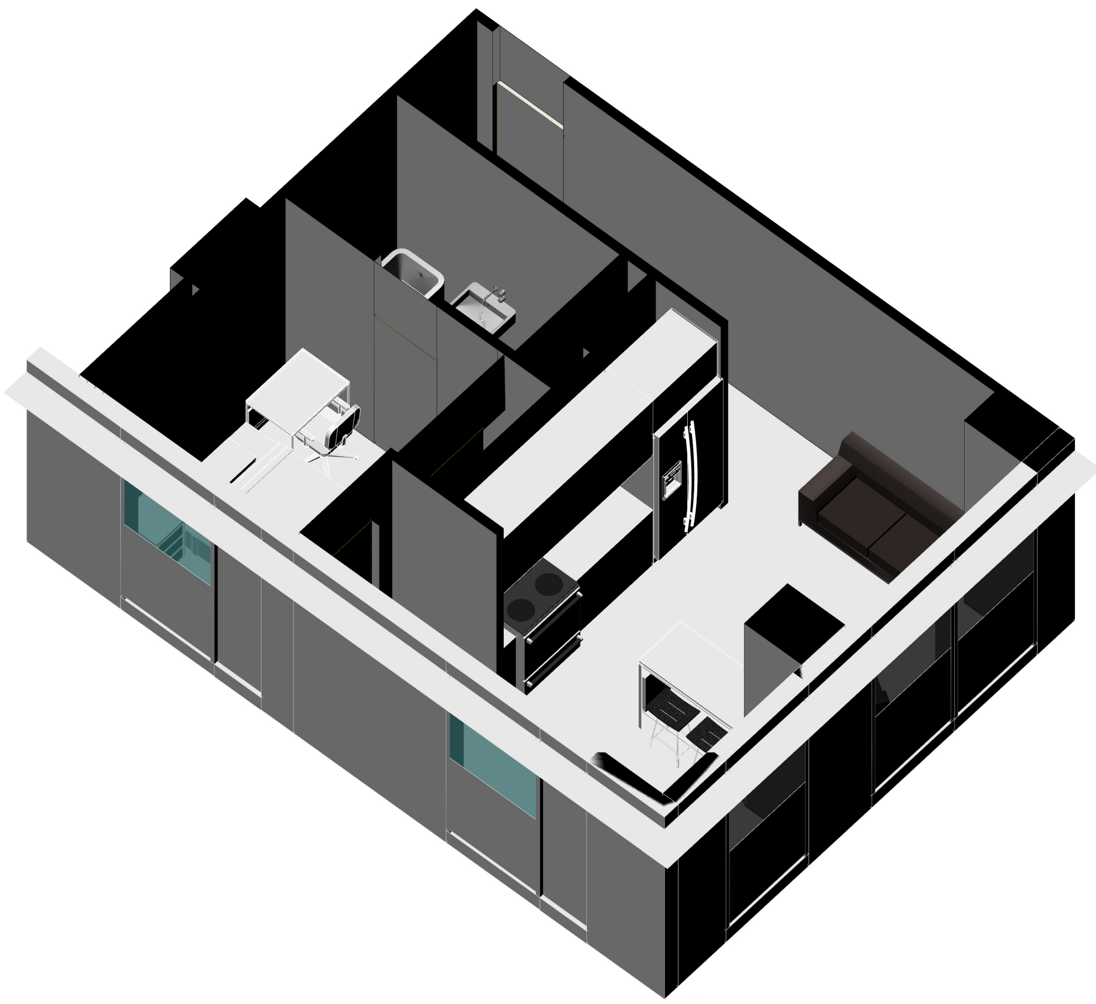
Blinds No

	East	South
Depth of Shading	0	0
Number of Blinds	0	0

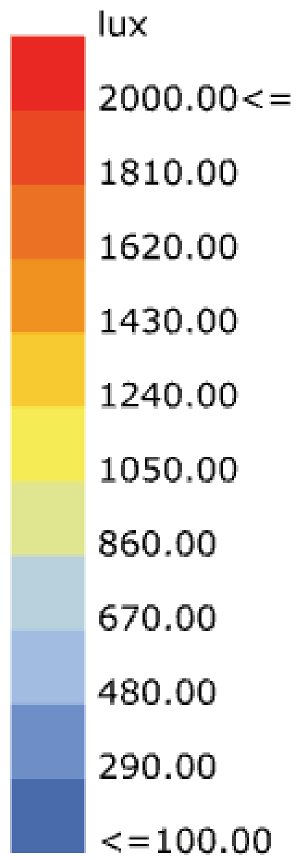


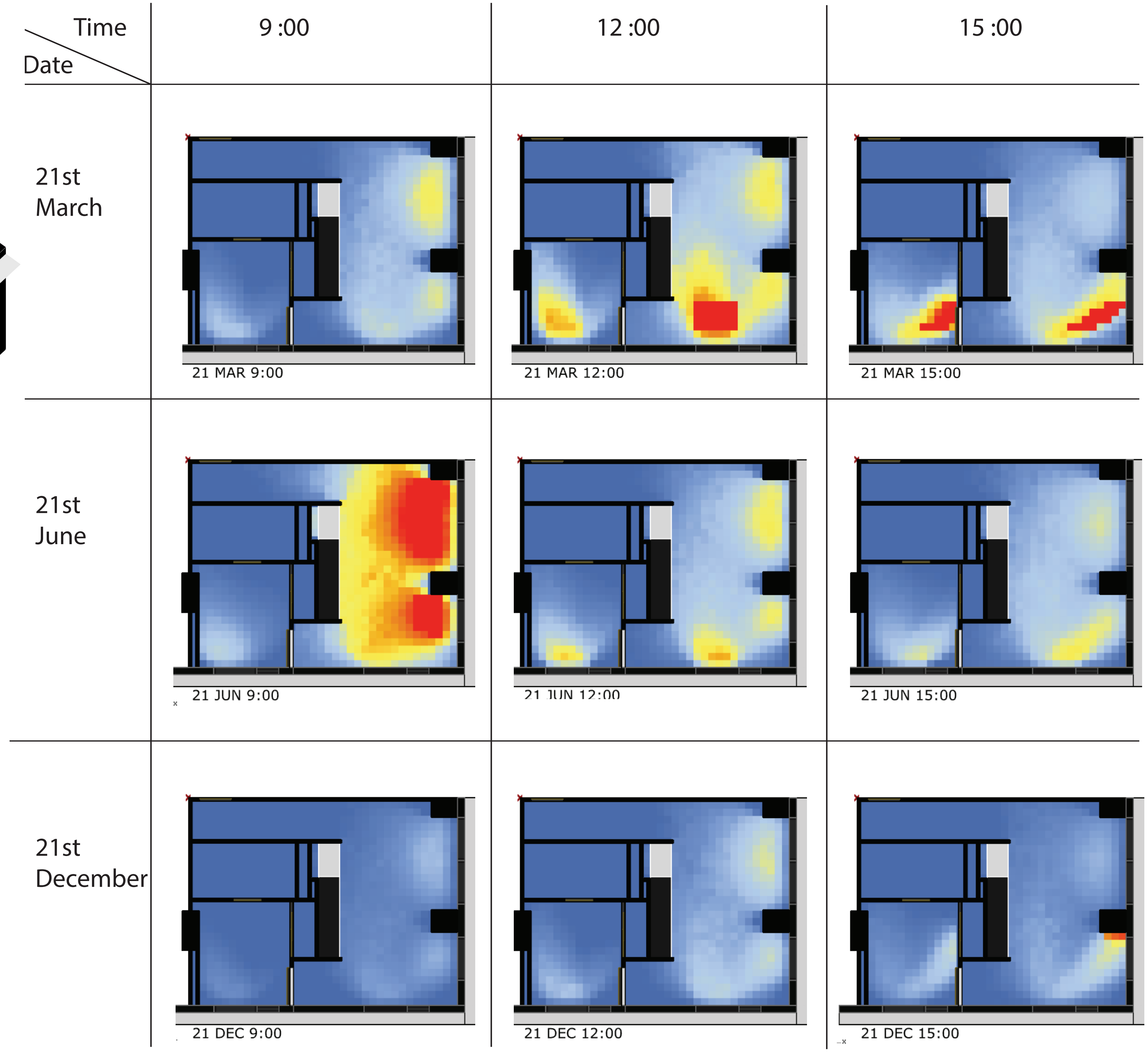


Point-In-Time Grid Based Illuminance **Case2**



Addition of horizontal overhang on south and east facade helps in shading the interiors.



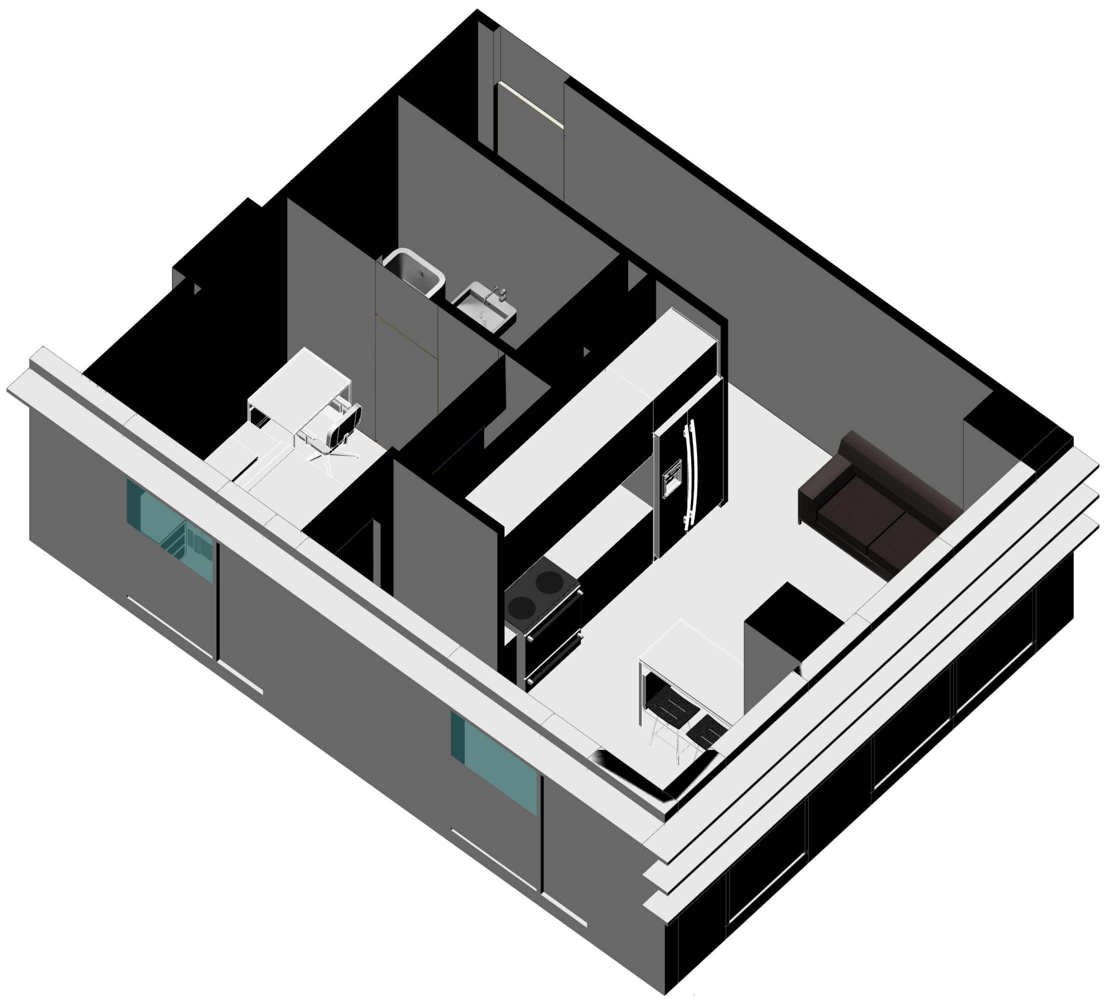


Window Wall Ratio

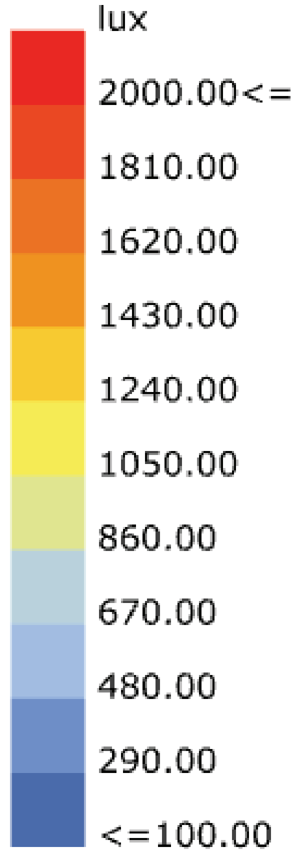
North	0
West	0
South	.125
East	.24

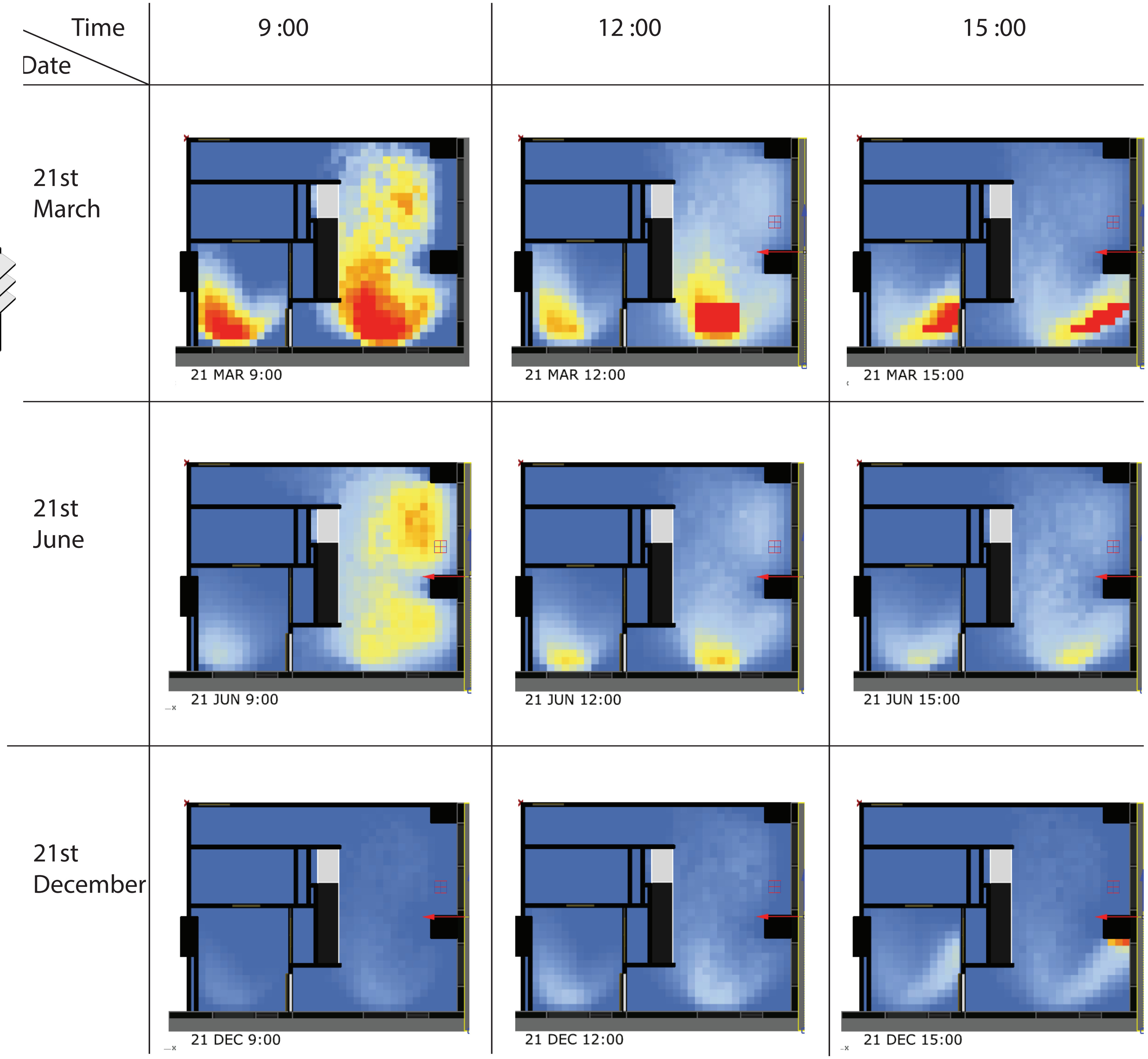
Rotation Angle	0°	
Blinds	Yes	
	East	South
Depth of Shading	0.3	0.3
Number of Blinds	1	1

Point-In-Time Grid Based Illuminance **Case3**



Addition of horizontal overhangs on south facade helps in shading the interiors primarily in the month of June when the Sun is at higher angle.



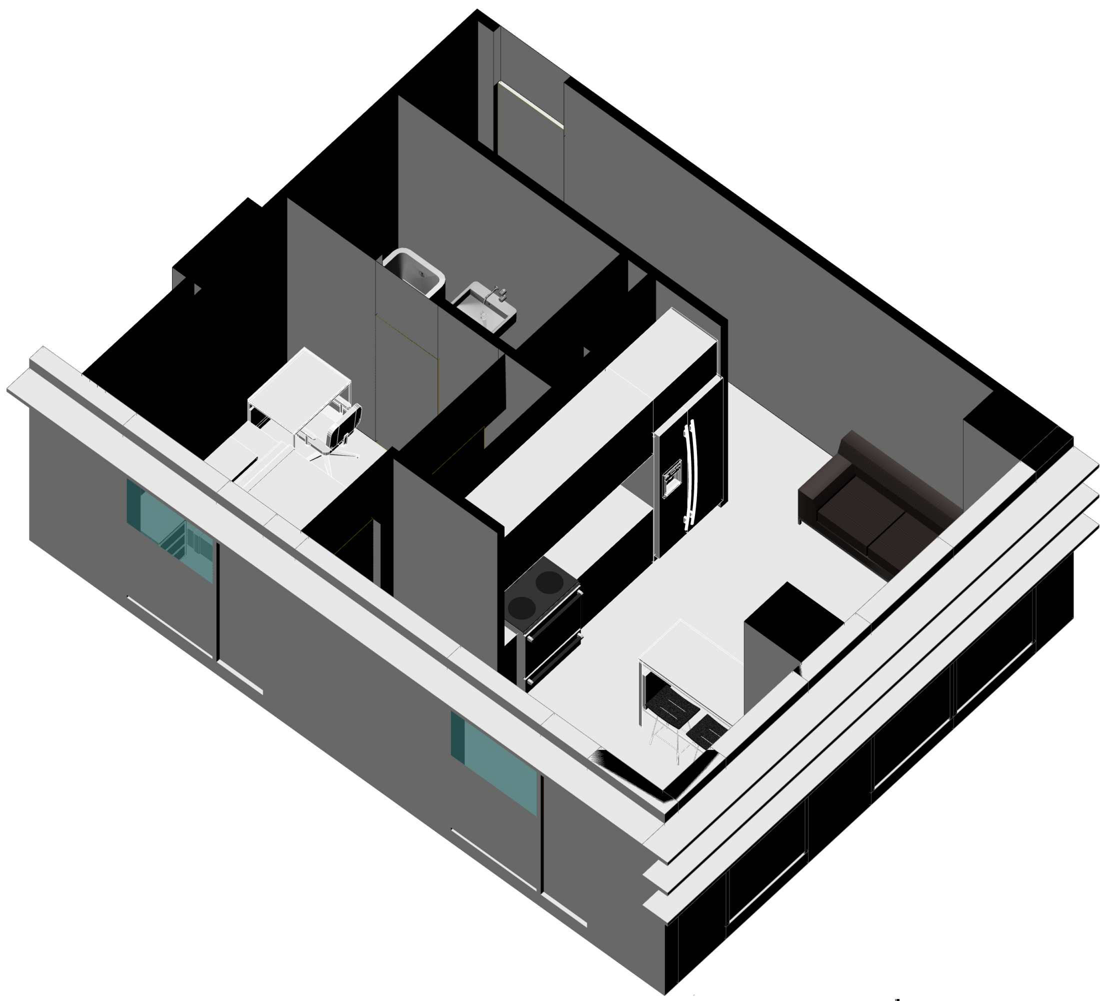


Window Wall Ratio

North	0
West	0
South	.125
East	.24

Rotation Angle	0°	
Blinds	Yes	
	East	South
Depth of Shading	0.3	0.3
Number of Blinds	3	1

Point-In-Time Grid Based Illuminance **Case3**



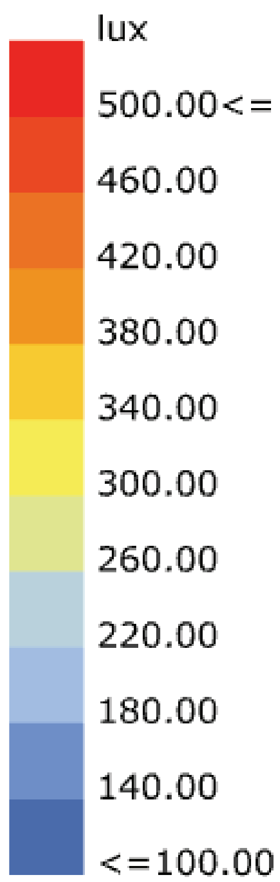
Addition of horizontal overhang on east face helps in shading the interiors.

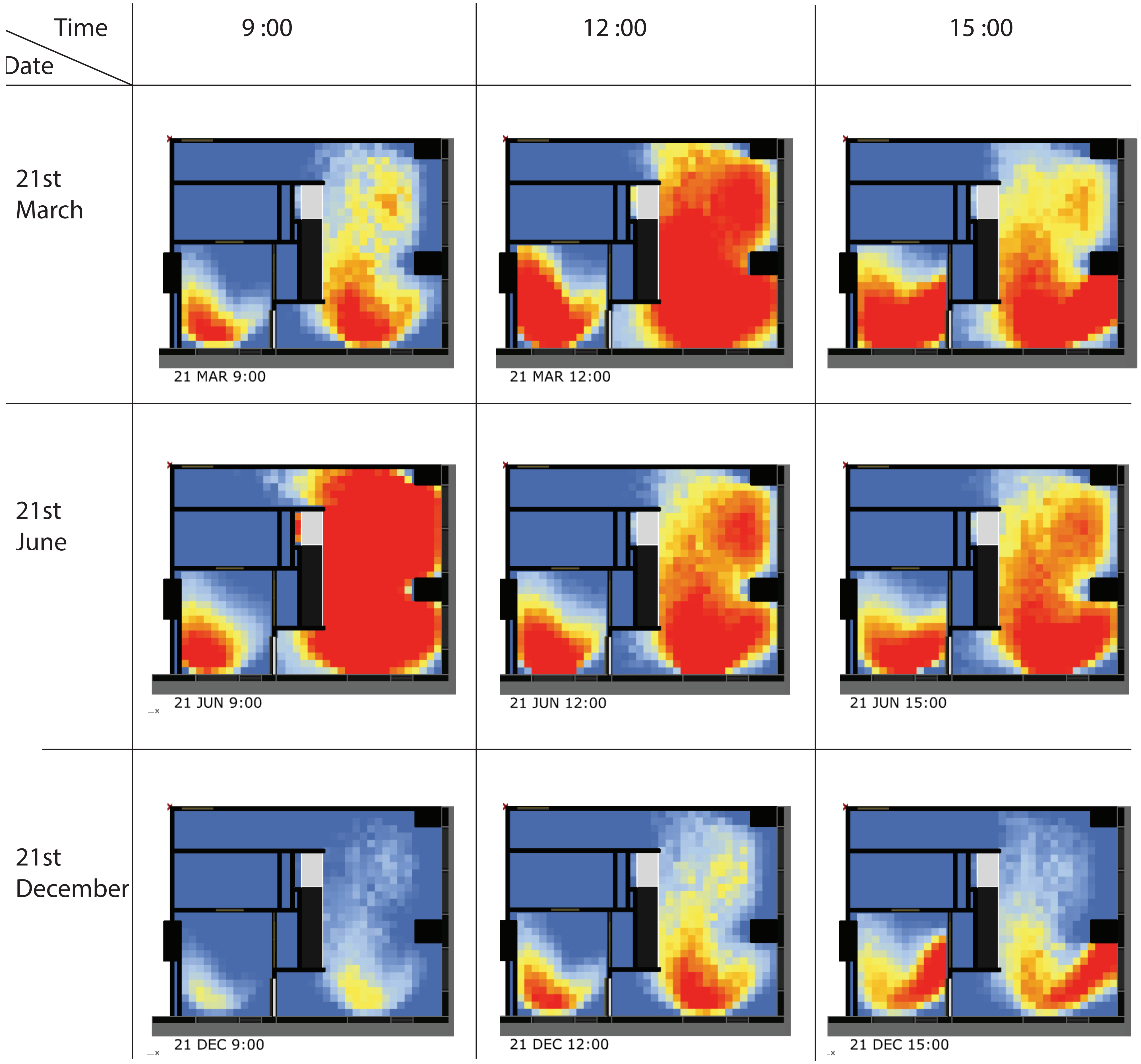
The analysis for improved case is done with a legend between 100 - 500 lux to ennsure that the apartment is well daylit at all test hours in a year.

Window Wall Ratio

North	0
West	0
South	.125
East	.24

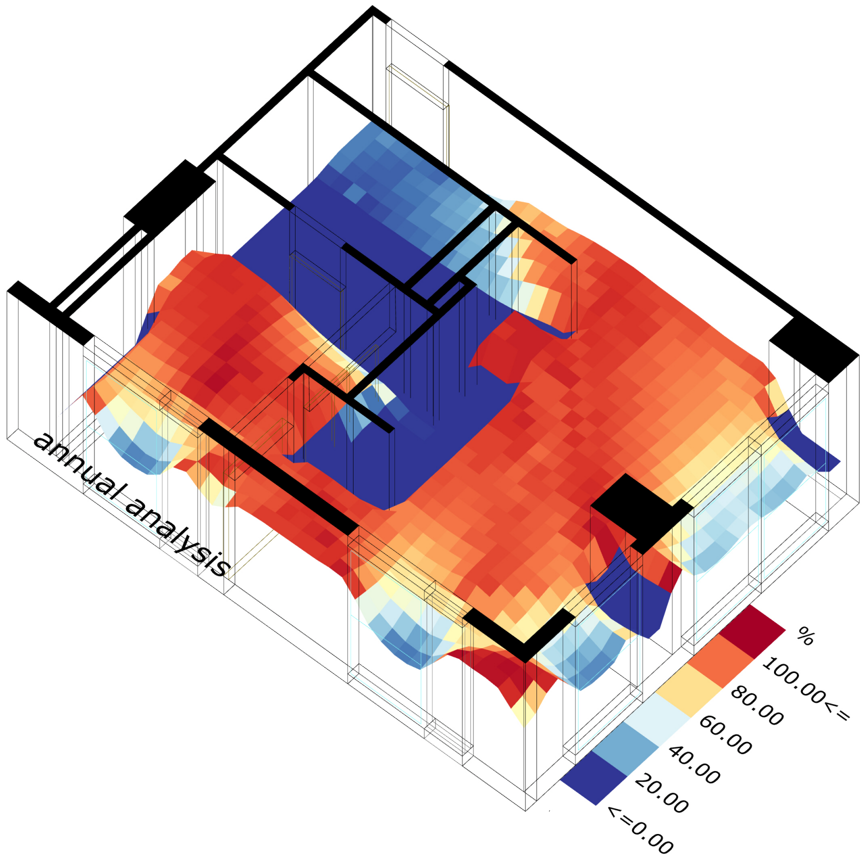
Rotation Angle	0°	
Blinds	Yes	
	East	South
Depth of Shading	0.3	0.3
Number of Blinds	3	1





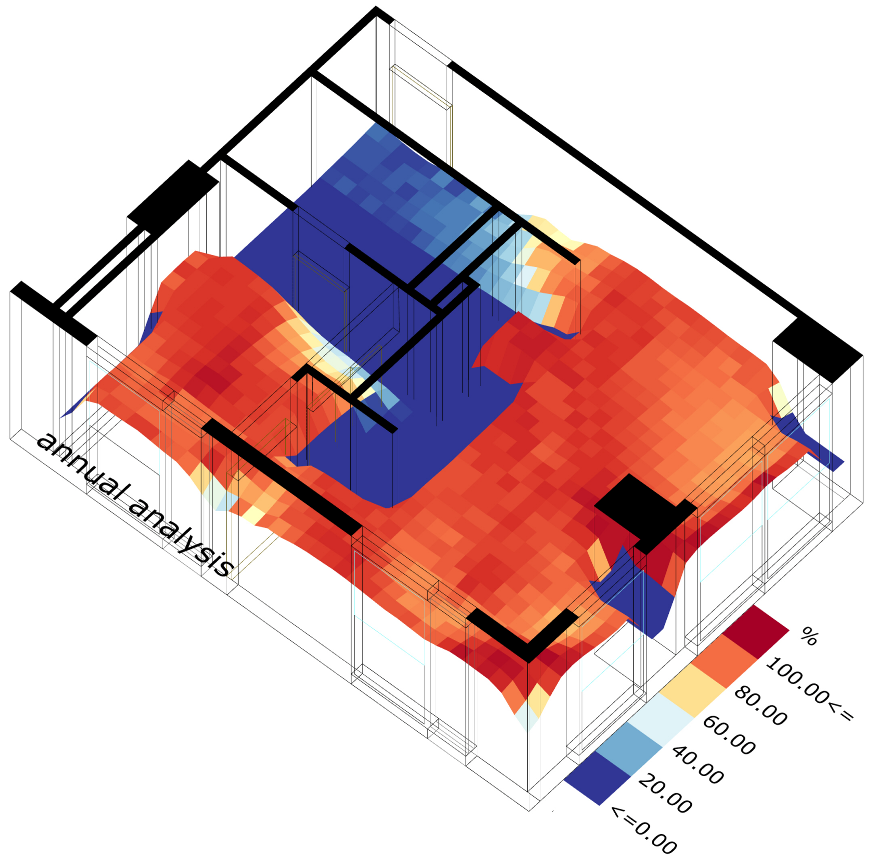
Annual Daylight Analysis **Useful Daylight Illuminance**

Baseline Case
100 < UDLI < 2000



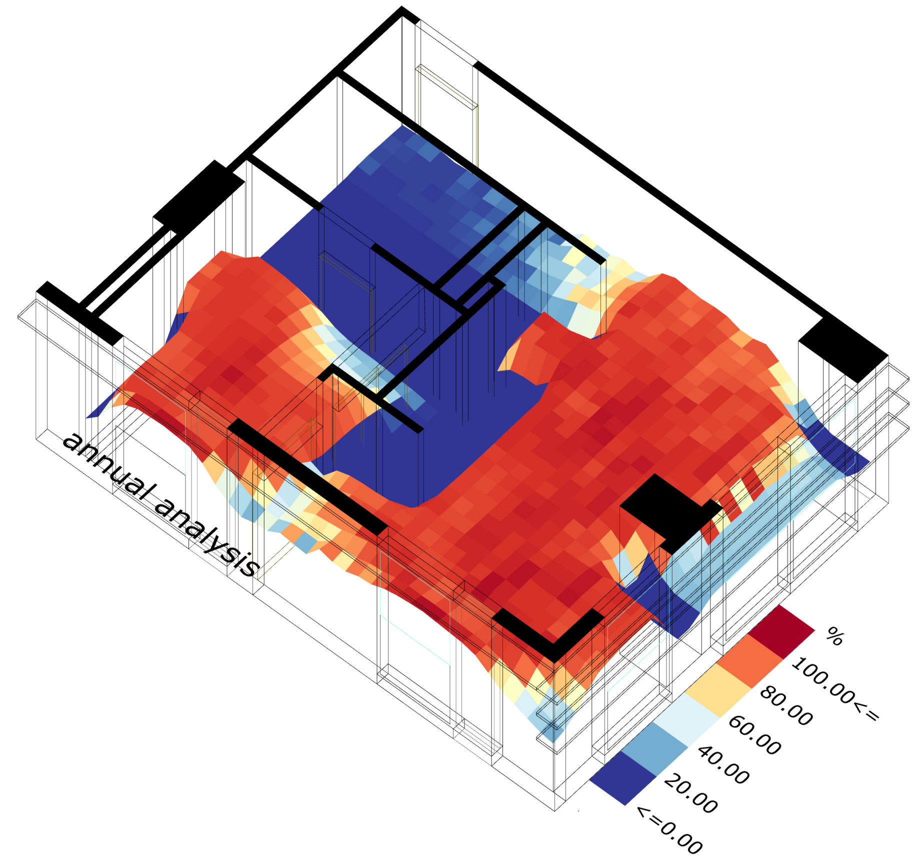
Useful Daylight Illuminance for Base case depicts areas close to the windows to be not well daylit. They can be either poorly daylit or overlit.

Case 1
100 < UDLI < 2000



Useful Daylight Illuminance increases to 80% when window size is reduced this depicts that the area along the windows were overly daylit. Reducing the window wall ratio blocks the excessive daylight in the perimeter areas.

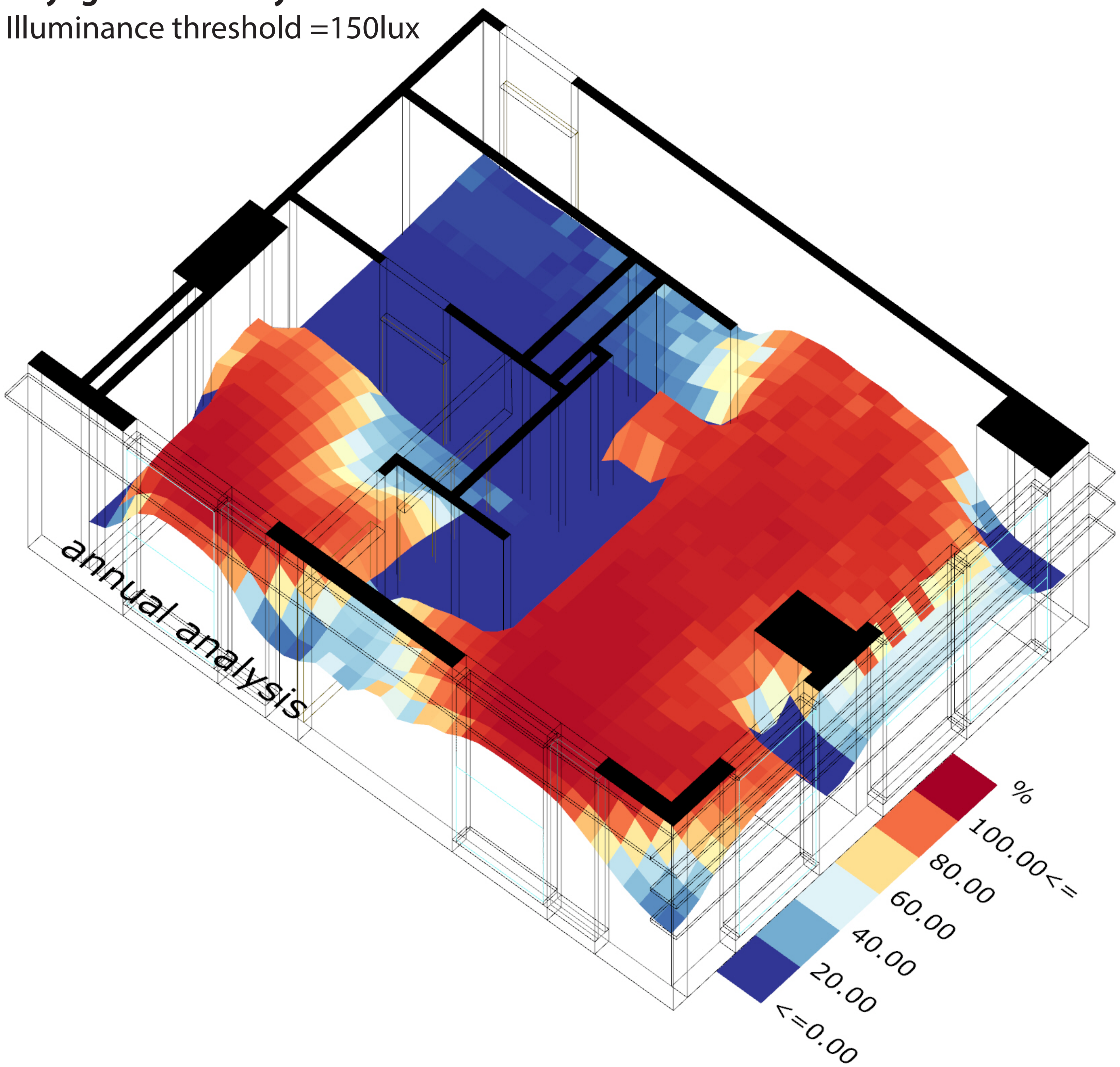
Case 3
100 < UDLI < 2000

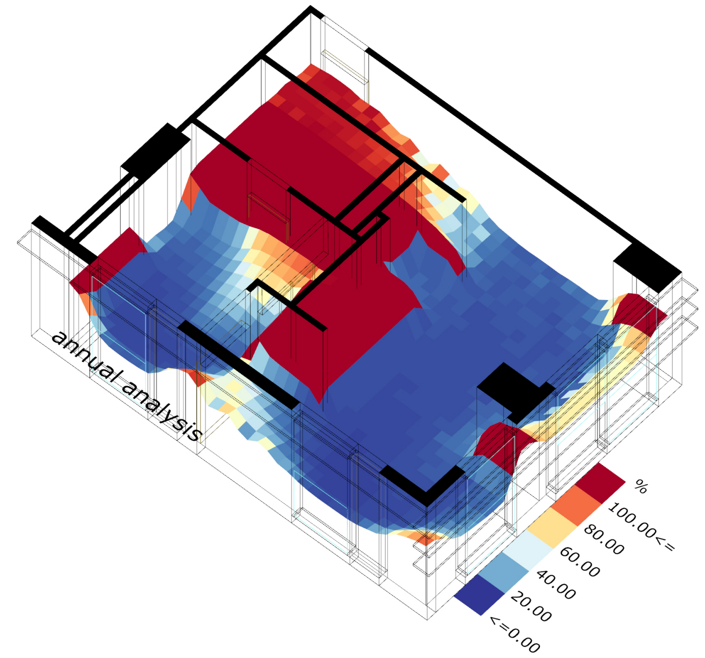


Useful Daylight Illuminance for when window size is reduced and horizontal overhangs are added according to point in time analysis, creates poorly daylit areas along the window.

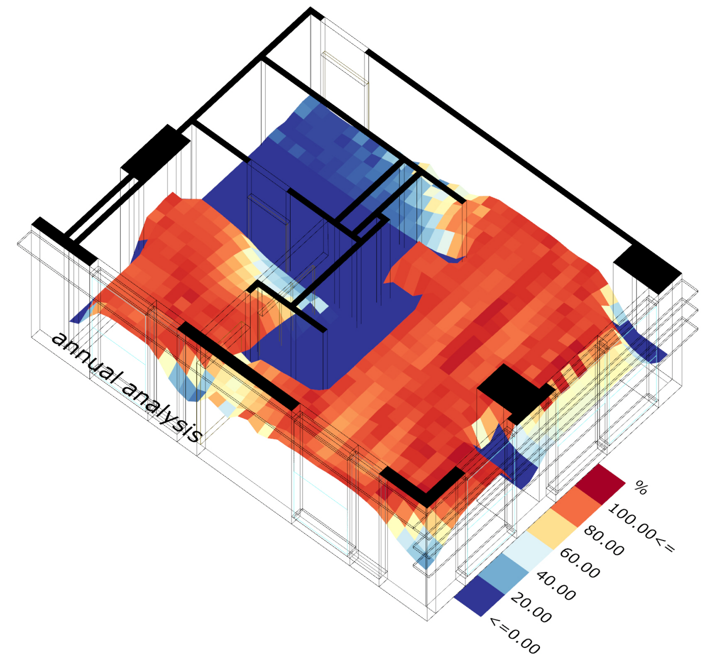
Annual Daylight Analysis

Daylight Autonomy
Illuminance threshold =150lux

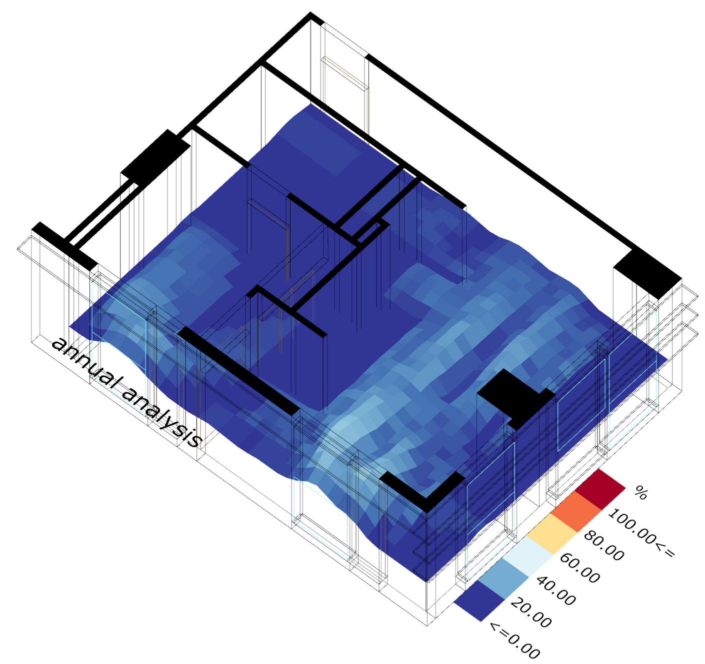




UDLI < 100



100 < UDLI < 2000



UDLI > 2000

Daylight Autonomy is the percentage of the occupancy time that an area is lit above the threshold Illuminanve level. Illuminance threshold is considered to be 150 lux which is given standard for homes. The above diagram shows that the apartment is above 150 lux level for almost 90% time of the year or more.

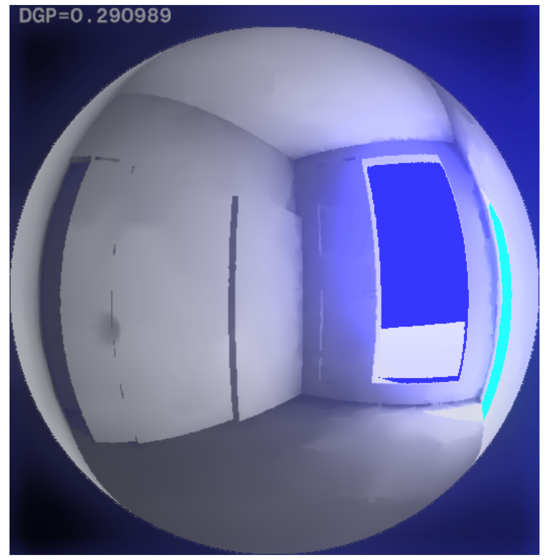
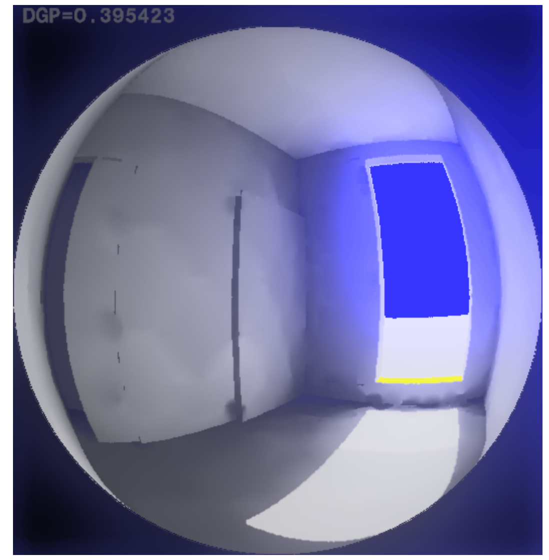
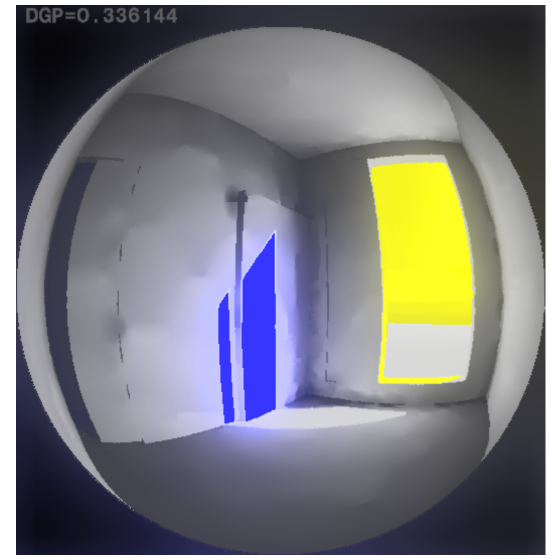
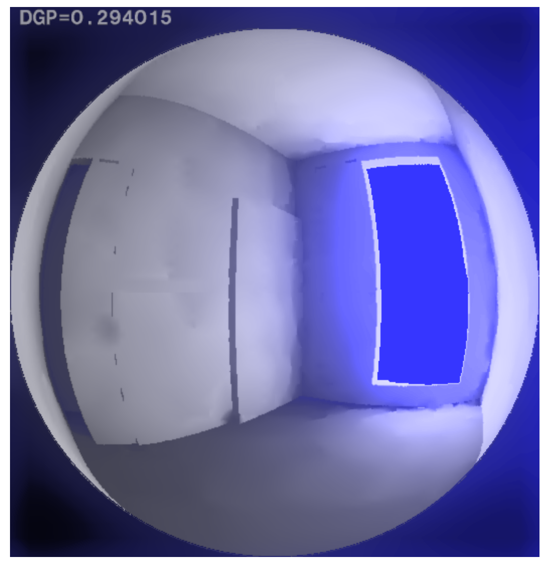
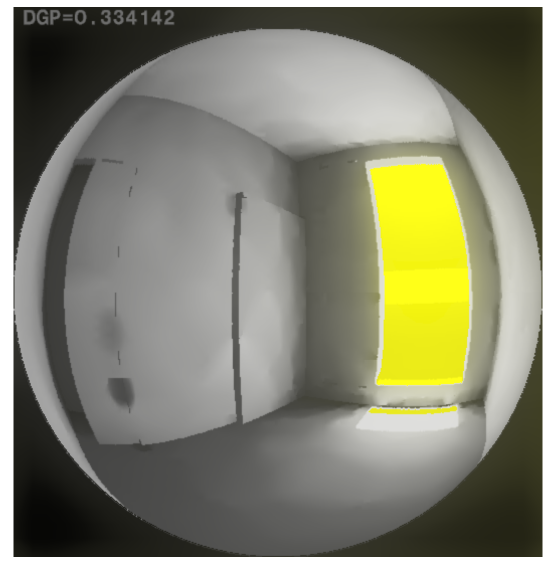
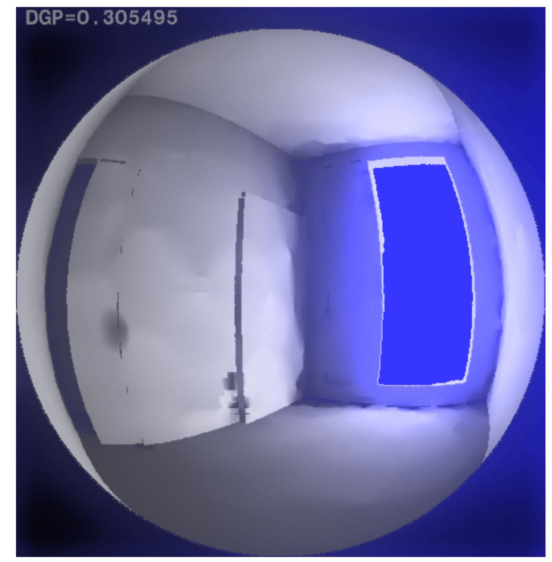
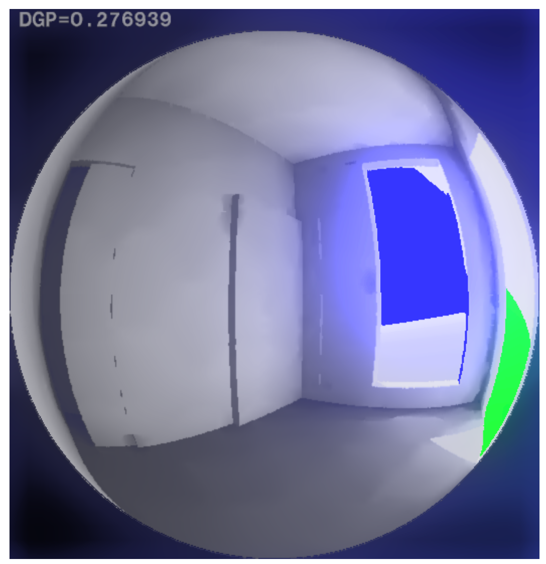
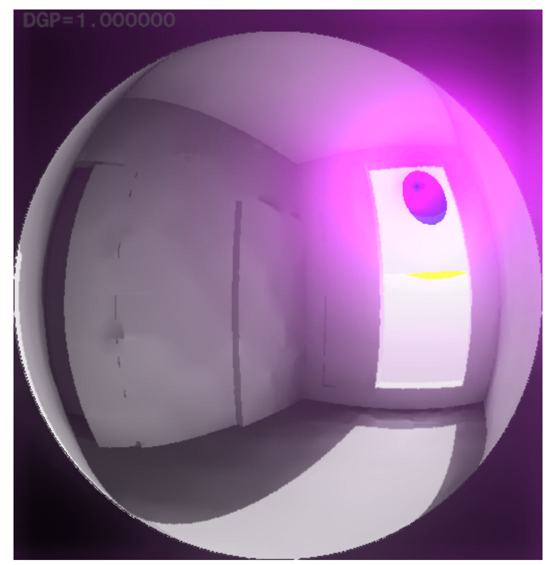
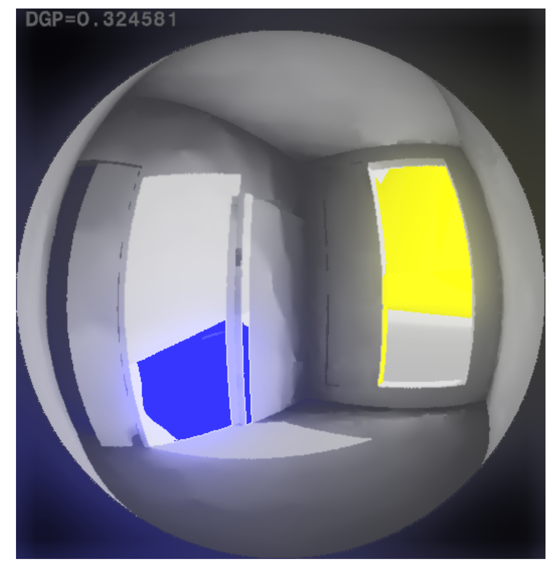
Also, it can be inferred from Useful Daylight Illuminance that the Apartment daylight level lies within the range of 100-2000 lux throughout the occupancy time.

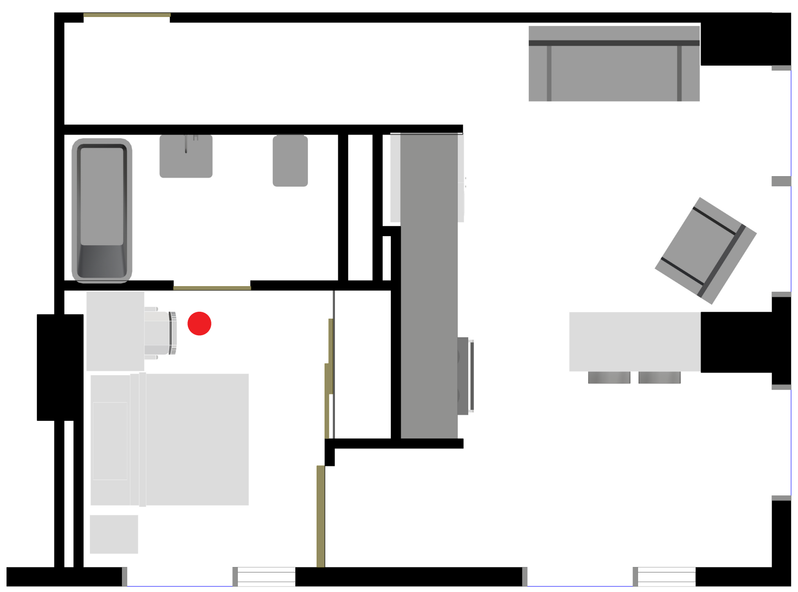
Glare Analysis **Bedroom Base Case**

DGP : Daylight Glare Probability

Imperceptible Glare [0.35>DGP]
Perceptible Glare [0.4 > DGP >= 0.35]
Disturbing Glare [0.45 > DGP > =0.4]
Intolerable Glare [DGP>=0.45}

The bedroom is visually comfortable in accordance with glare analysis. Only in December at noon there is intolerable glare that should be considered in design.

Time / Date	9 :00	12 :00	15 :00
21st March			
21st June			
21st December			



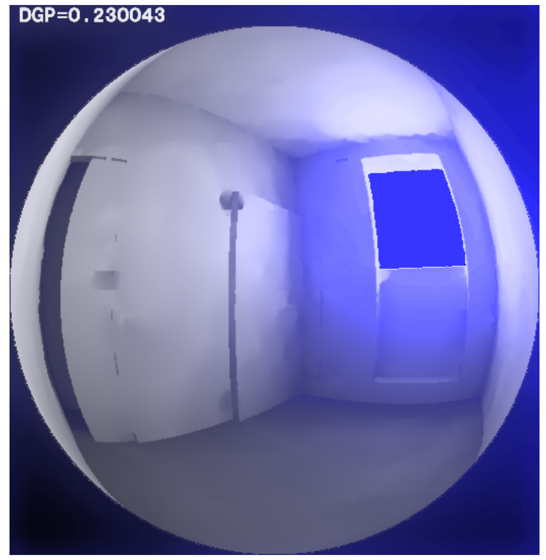
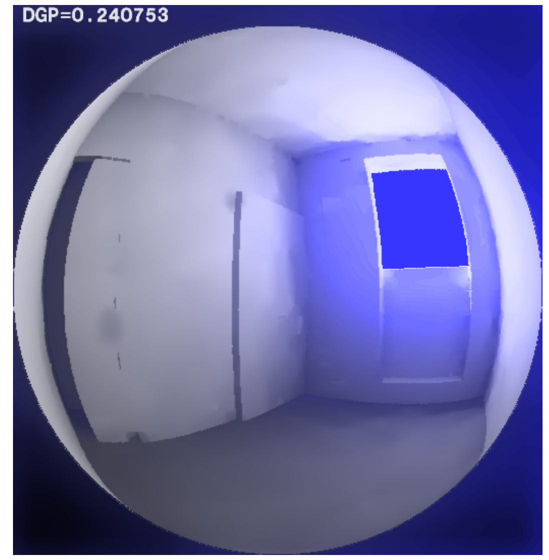
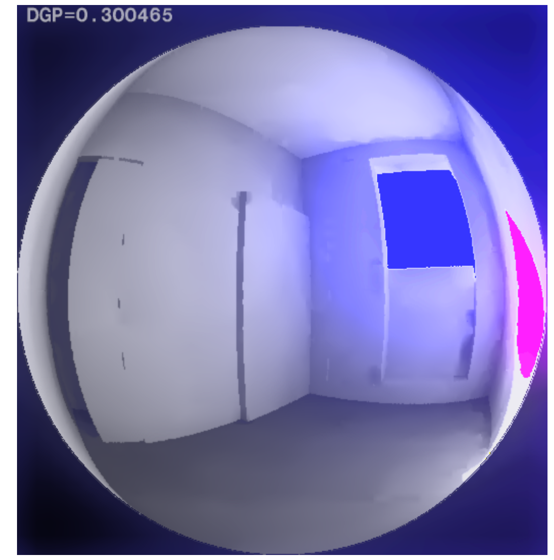
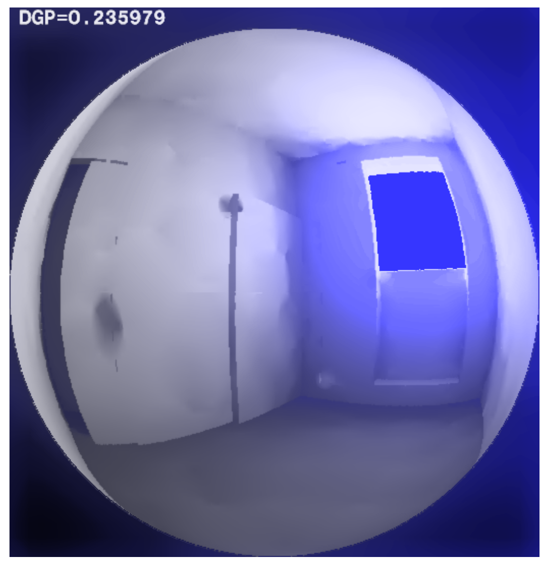
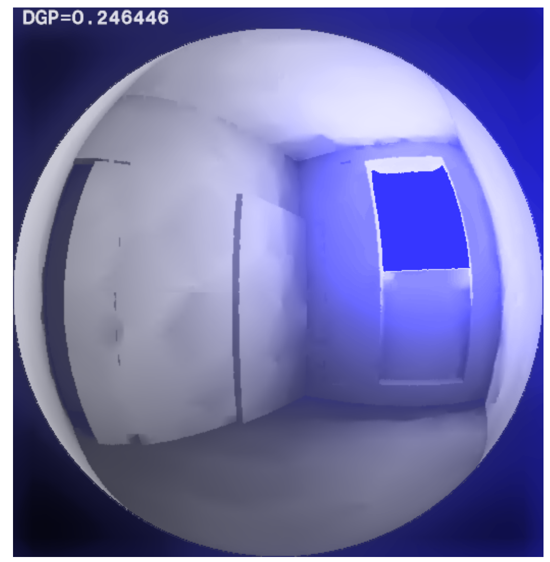
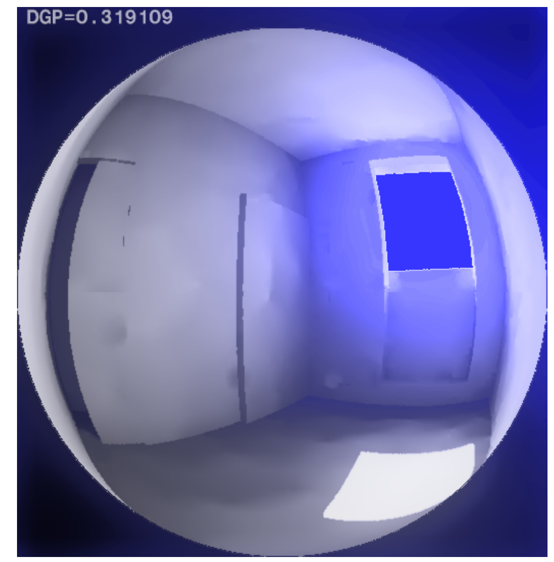
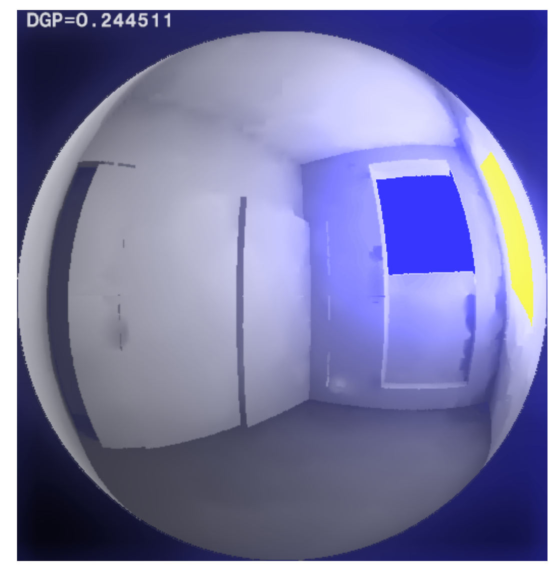
Location of test point

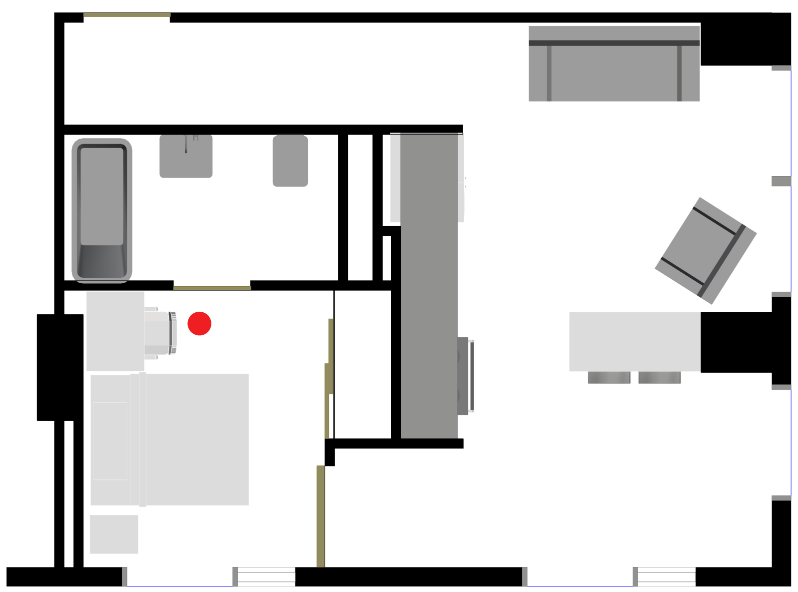
Glare Analysis **Bedroom Improved Case**

DGP : Daylight Glare Probability

Imperceptible Glare [0.35>DGP]
Perceptible Glare [0.4 > DGP >= 0.35]
Disturbing Glare [0.45 > DGP > =0.4]
Intolerable Glare [DGP>=0.45}

All the readings show that there is imperceptible glare in the room after the addition of shading devices.

Time / Date	9 :00	12 :00	15 :00
21st March			
21st June			
21st December			



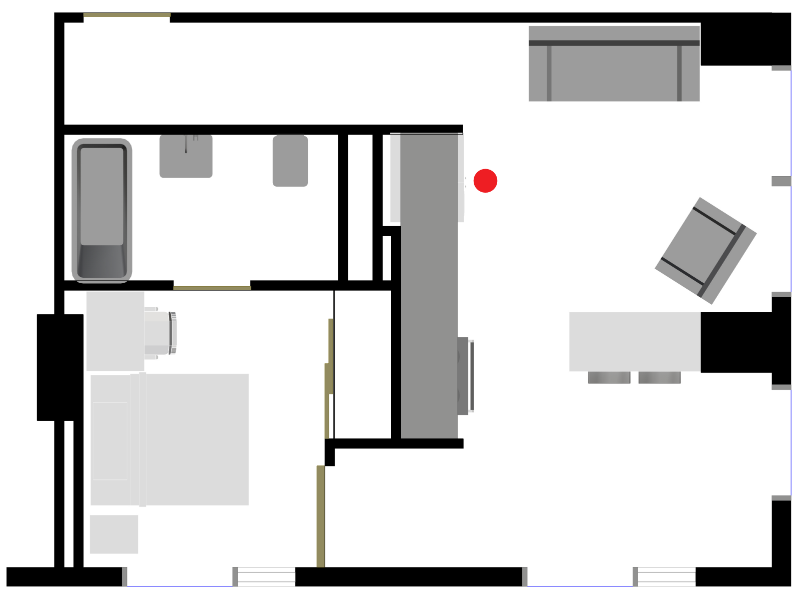
Location of test point

Glare Analysis **Hall Base Case**

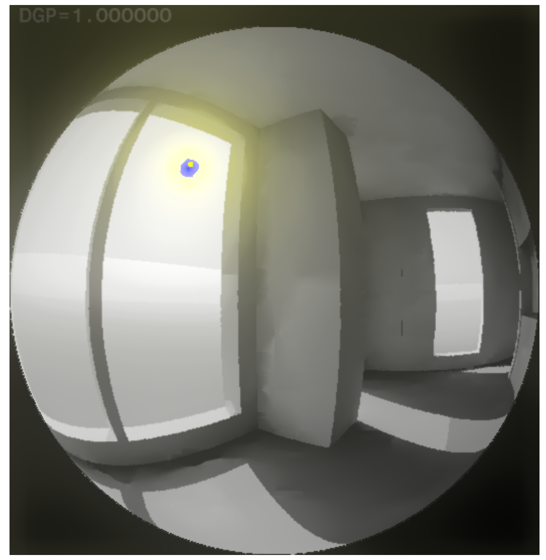
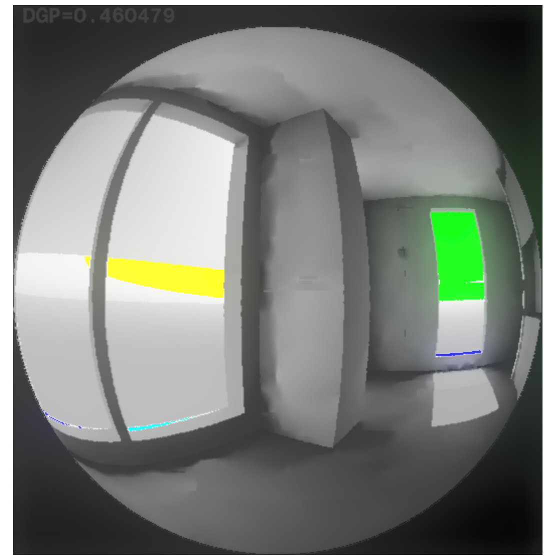
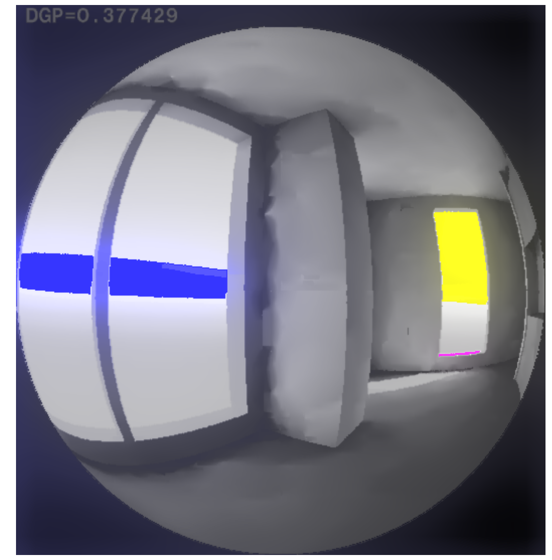
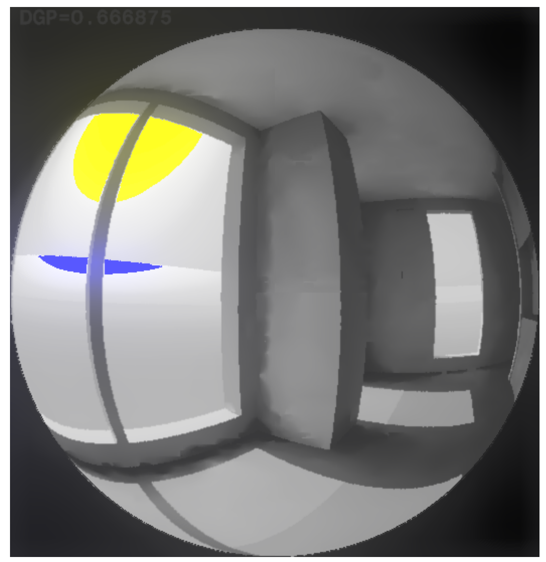
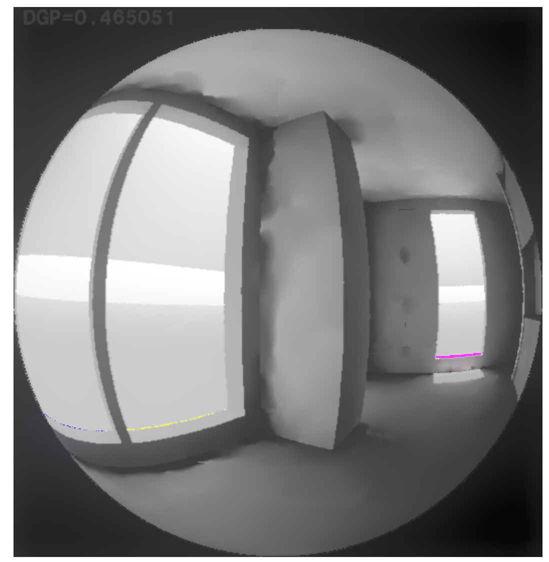
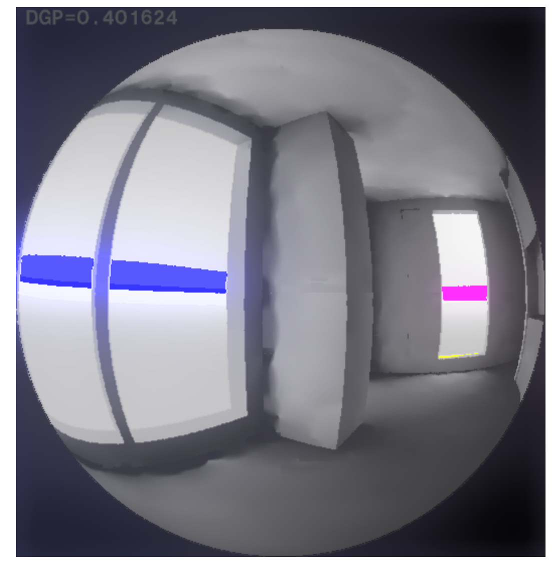
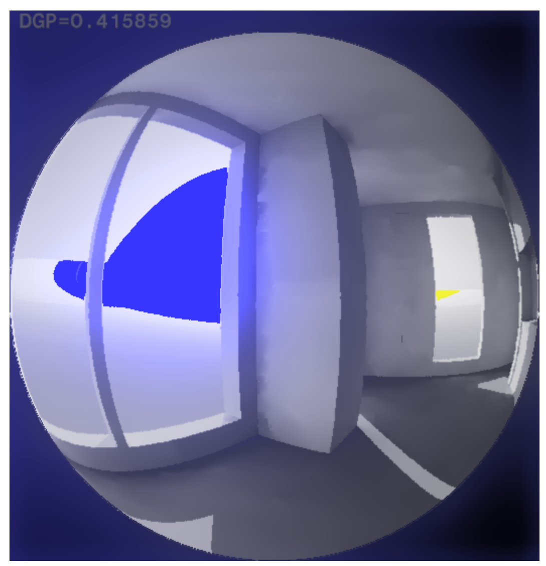
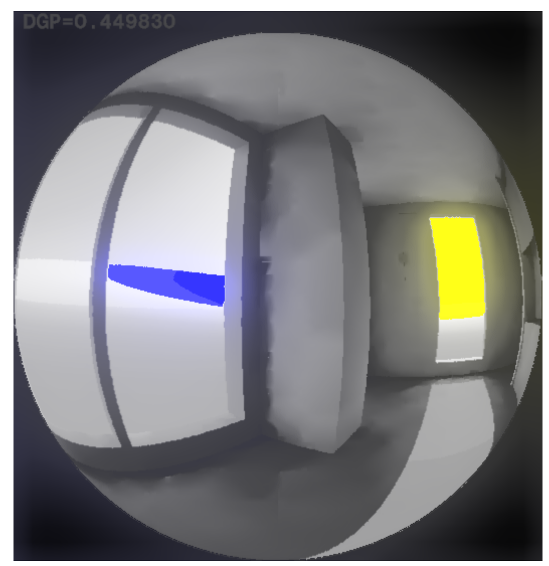
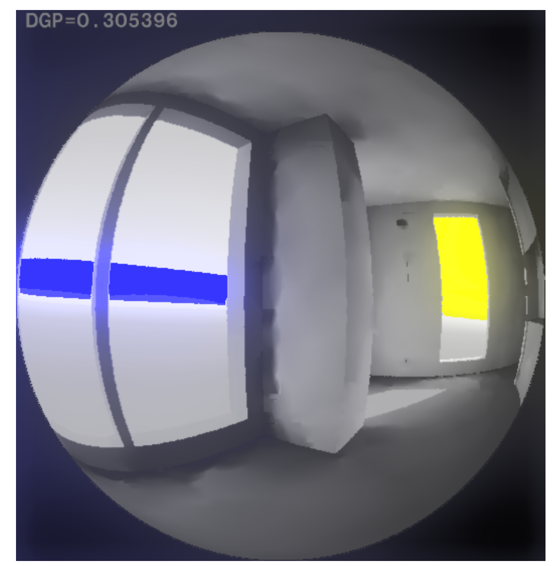
DGP : Daylight Glare Probability

Imperceptible Glare [0.35>DGP]
Perceptible Glare [0.4 > DGP >= 0.35]
Disturbing Glare [0.45 > DGP > =0.4]
Intolerable Glare [DGP>=0.45}

The Hall has disturbing intolerable glare throughout the year which should be kept in consideration while designing.



Location of test point

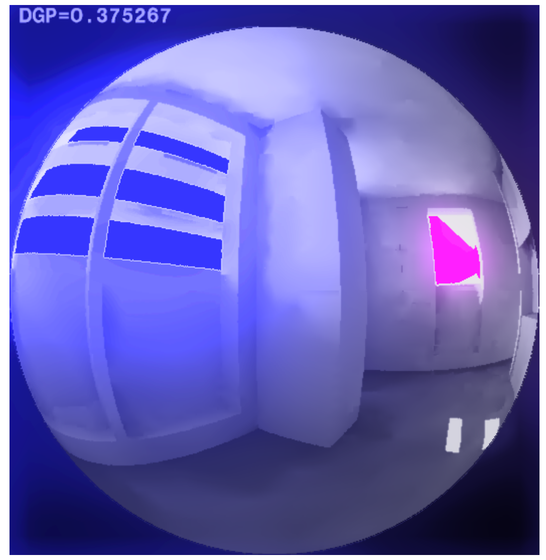
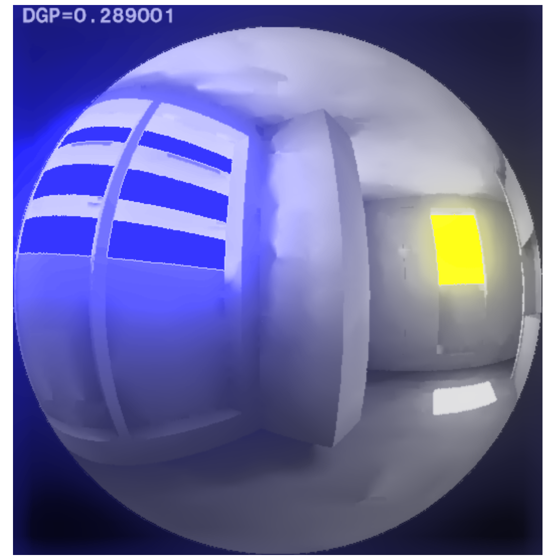
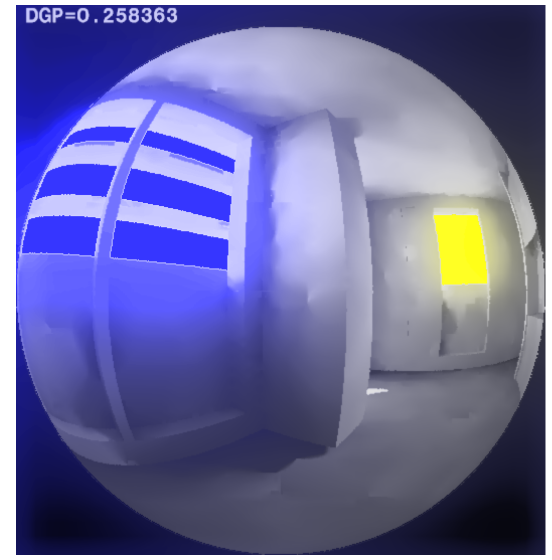
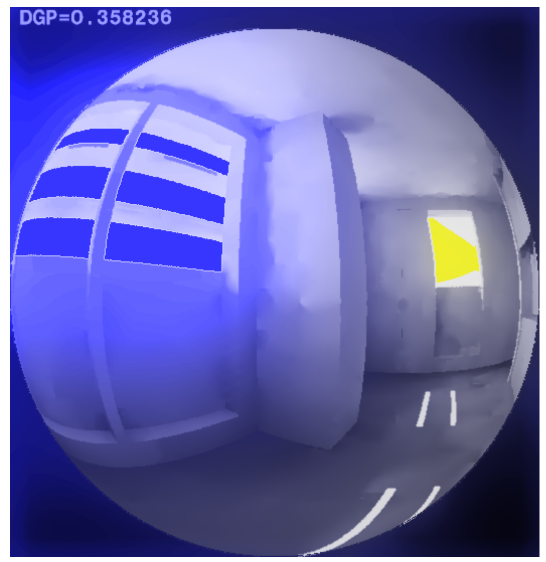
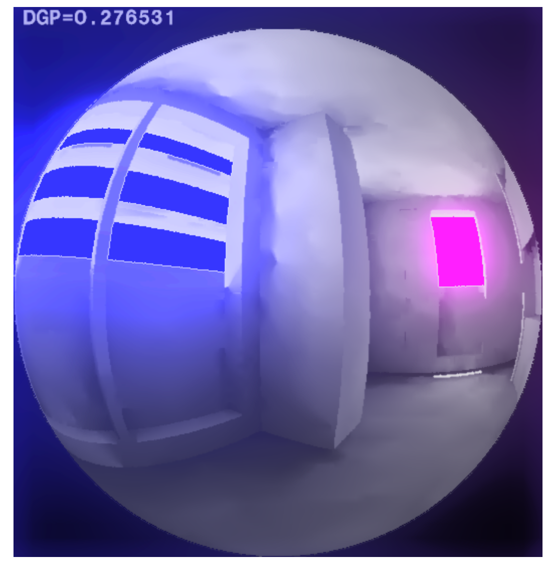
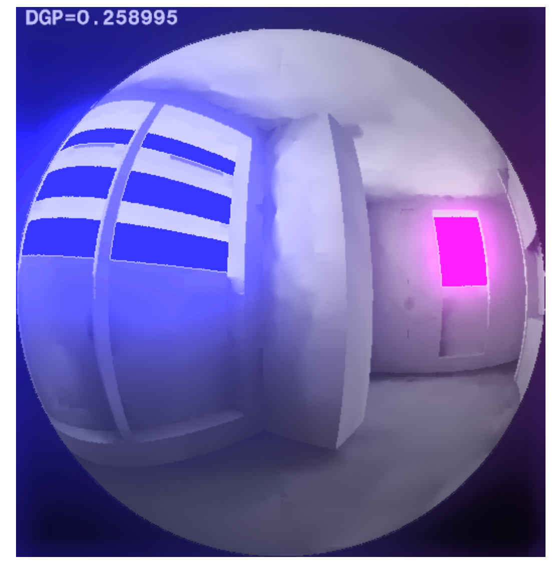
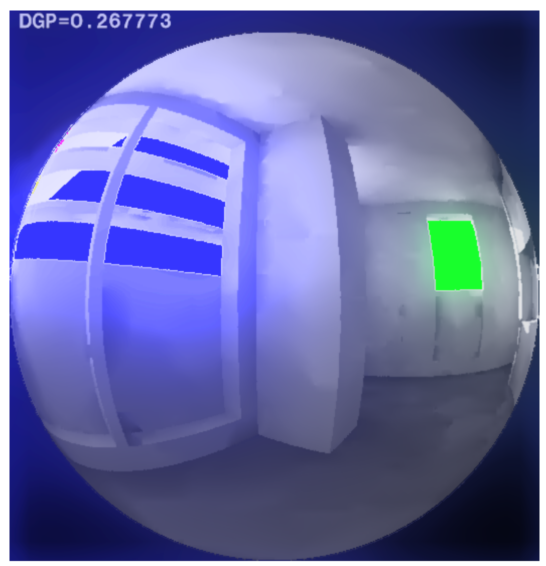
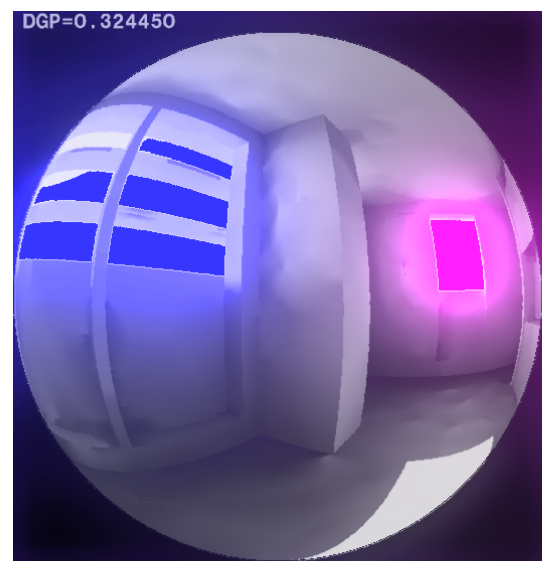
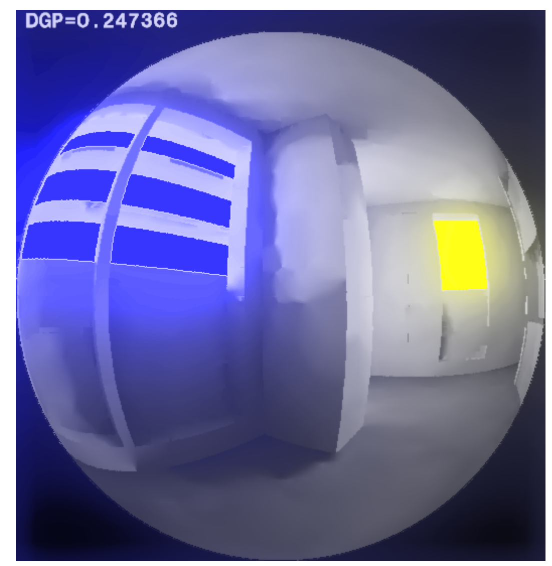
Time / Date	9 :00	12 :00	15 :00
21st March			
21st June			
21st December			

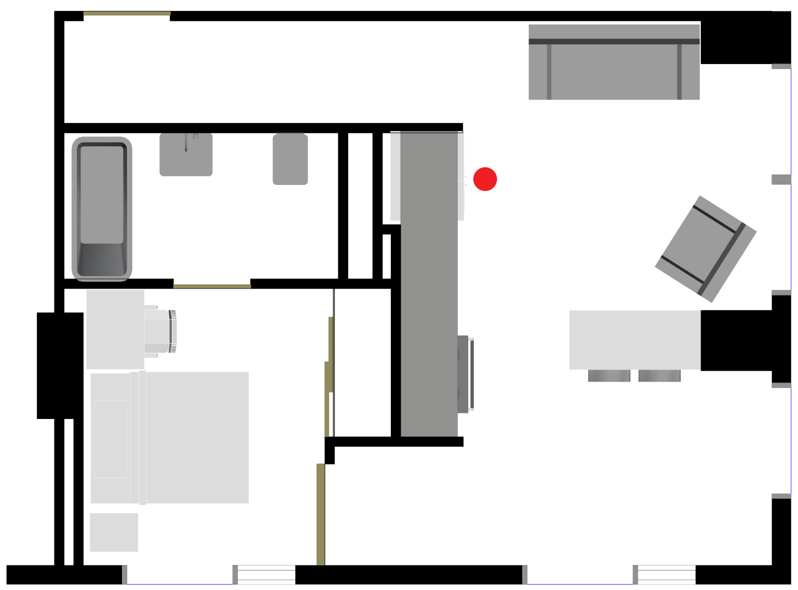
Glare Analysis **Hall Improved Case**

DGP : Daylight Glare Probability

Imperceptible Glare [0.35>DGP]
Perceptible Glare [0.4 > DGP >= 0.35]
Disturbing Glare [0.45 > DGP > =0.4]
Intolerable Glare [DGP>=0.45}

Reduction in window size and addition of horizontal overhangs solve the problem of glare in the hall by bringing it down to imperceptible glare.

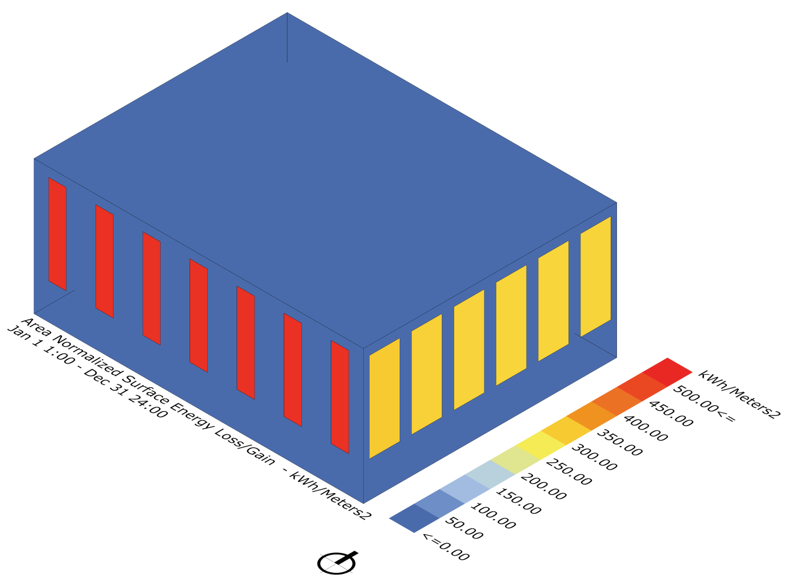
Time / Date	9 :00	12 :00	15 :00
21st March			
21st June			
21st December			



Location of test point

Energy Simulation **Orientation Study**

Baseline Case Geometry and Construction



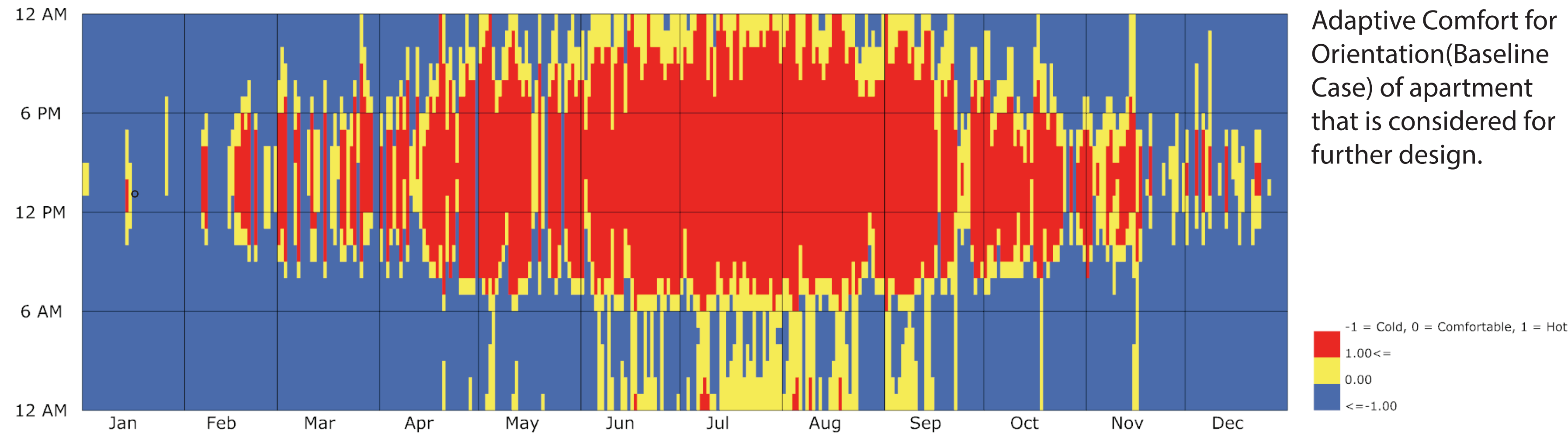
Blinds	No
Construction	
Exterior Wall	R5.5
Exterior Window	R0.1
	SHGC 0.7
Exterior Roof	R9.2
Floor Slab	Existing Slab
Natural Ventilation	No
Min Indoor Temp.	-°C
Max Indoor Temp.	-°C
Min Outdoor Temp	-°C
Max Outdoor Temp.	-°C
Air change hour	2

Angle	WWR 0.25	WWR 0.48	Comfort	Hot	Cold
(Baseline Case) 0°	South	East	16.31%	29.33%	54.36%
45°	South-East	North-East	16.14%	27.02%	56.84%
90°	East	North	16.21%	24.95%	58.84%
135°	North-East	North-West	16.02%	24.41%	59.58%
180°	North	West	16.23%	25.30%	58.47%
225°	North-West	South-West	16.08%	27.65%	56.27%
270°	West	South	16.46%	29.52%	54.02%
315°	South-West	South-East	16.34%	30.48%	53.18%

Considered

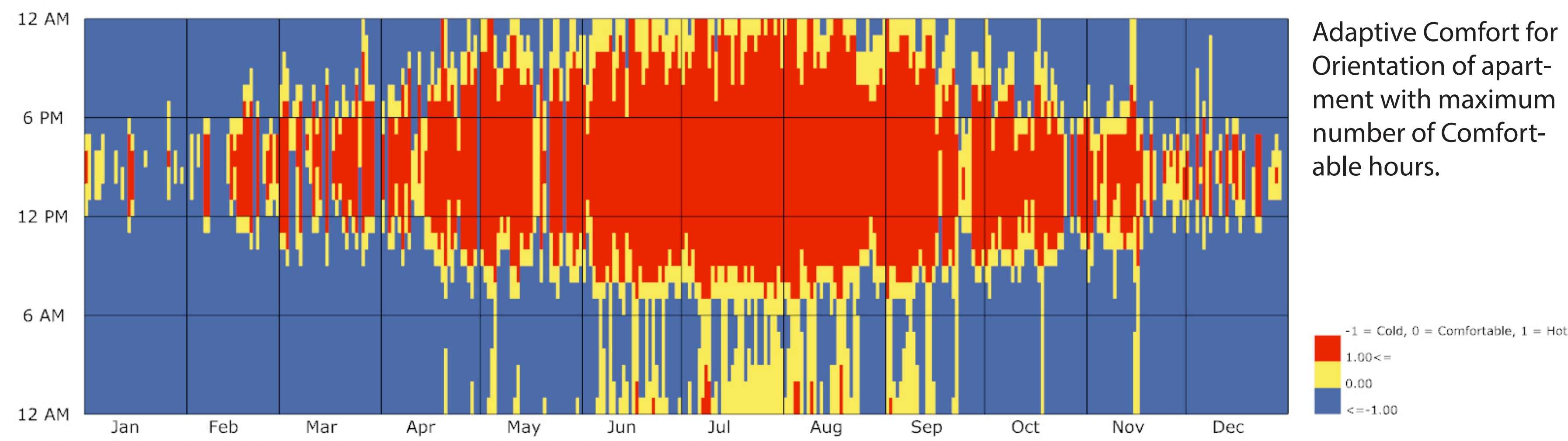
Desirable

Undesirable



Adaptive Comfort for ZONE_0_T (-1 = Cold, 0 = Comfortable, 1 = Hot) - Hourly
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00

Adaptive Comfort for Orientation(Baseline Case) of apartment that is considered for further design.



Adaptive Comfort for ZONE_0_T (-1 = Cold, 0 = Comfortable, 1 = Hot) - Hourly
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00

Adaptive Comfort for Orientation of apartment with maximum number of Comfortable hours.

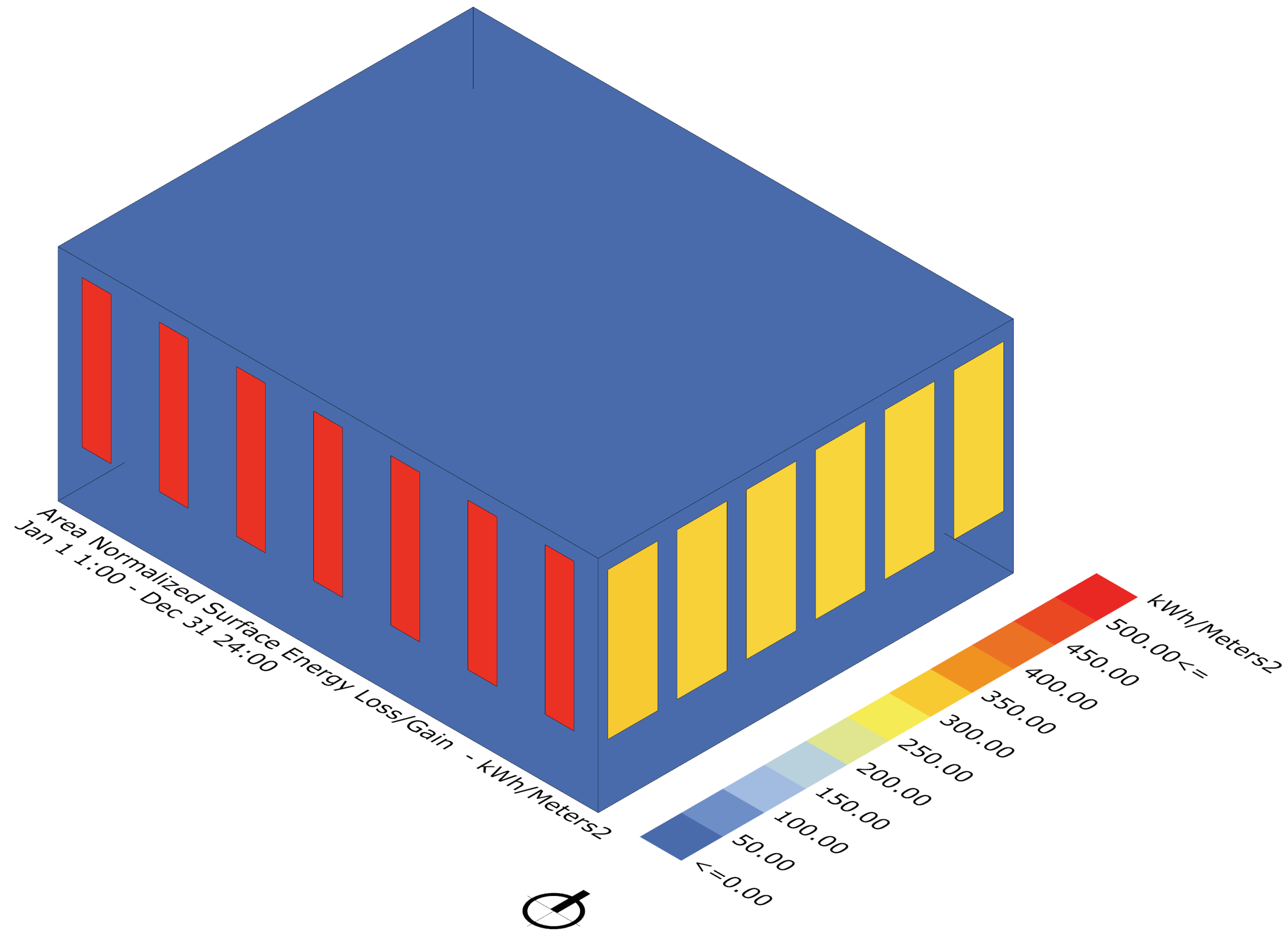
The comparison between orientation suggests that rotation of 270° makes the apartment most comfortable that is 16.46%

The second best case is a rotation of 315° with 16.34% of comfotable hours, but this is the worst scenario for summers amounting to 30.48 % of hot hours.

The third best orientation that is 0° (Baseline Case) with 16.31% will be considered for further design iterations, because this case has 54.36% cold hours as compared to the worst case which is 59.58%.

It is also observed that having the maximum WWR on the South facade gives the maximum thermally comfortable hours.

Energy Simulation **Baseline Case**



Window Wall Ratio

North	0
West	0
South	.25
East	.48

Rotation Angle 0°

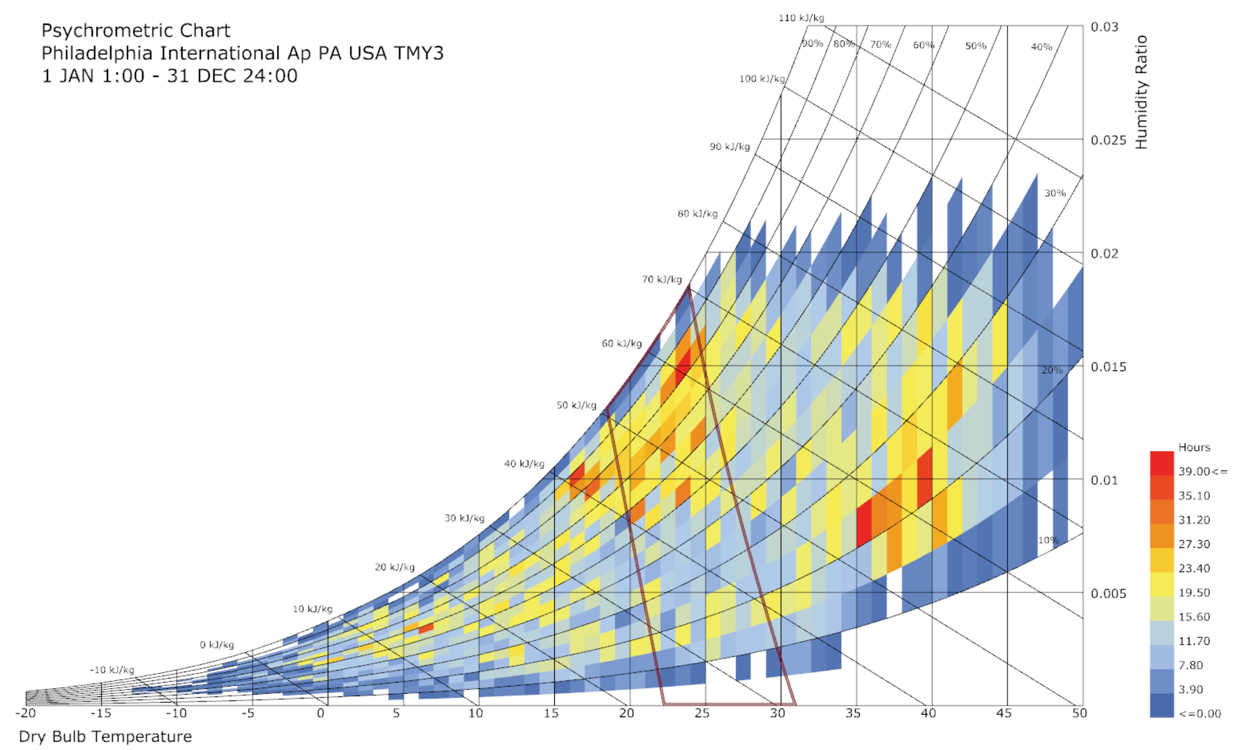
Blinds	No	
	East	South
Depth of Shading	0	0
Number of Blinds	0	0

Construction

Exterior Wall	R5.5
Exterior Window	R0.1
	SHGC 0.7
Exterior Roof	R9.2
Floor Slab	Existing Slab
Natural Ventilation	No
Min Indoor Temp.	-°C
Max Indoor Temp.	-°C
Min Outdoor Temp	-°C
Max Outdoor Temp.	-°C
Air change hour	2

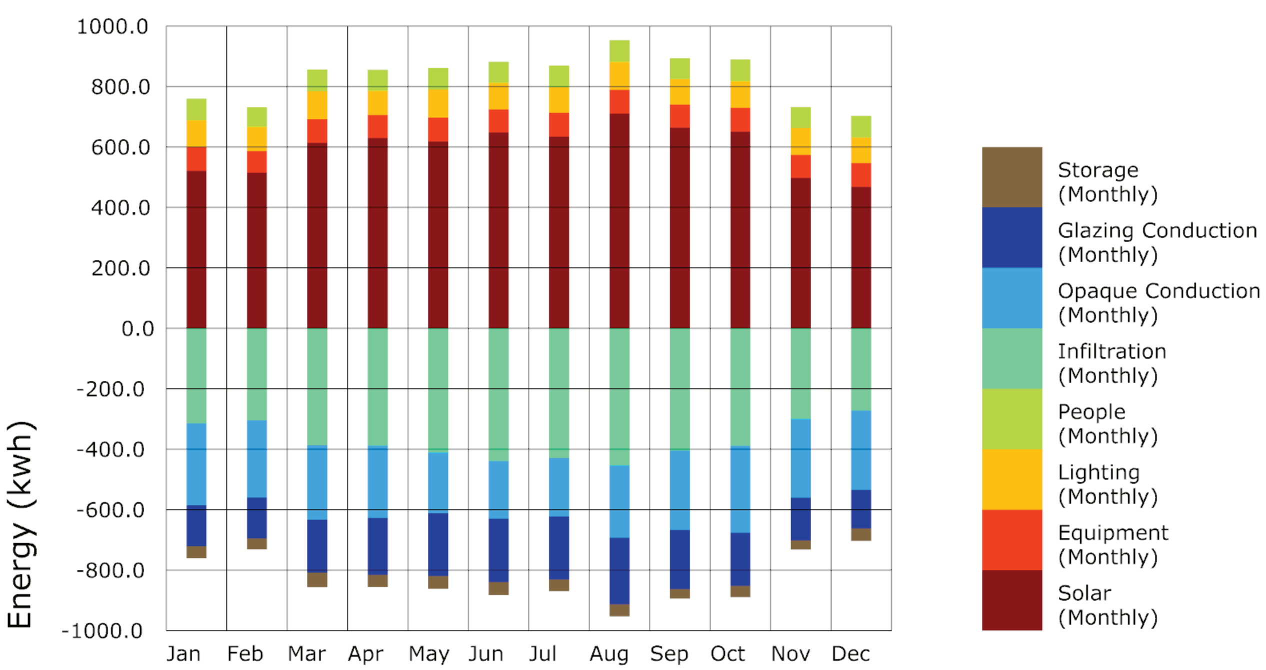
For the base case it is observed more than 50% of the year the apartment is cold and almost 30% of the year it is Hot.

The geometry of the window is different from the model but the WWR is same as Energy Simulation does not take into consideration the location of glazing.

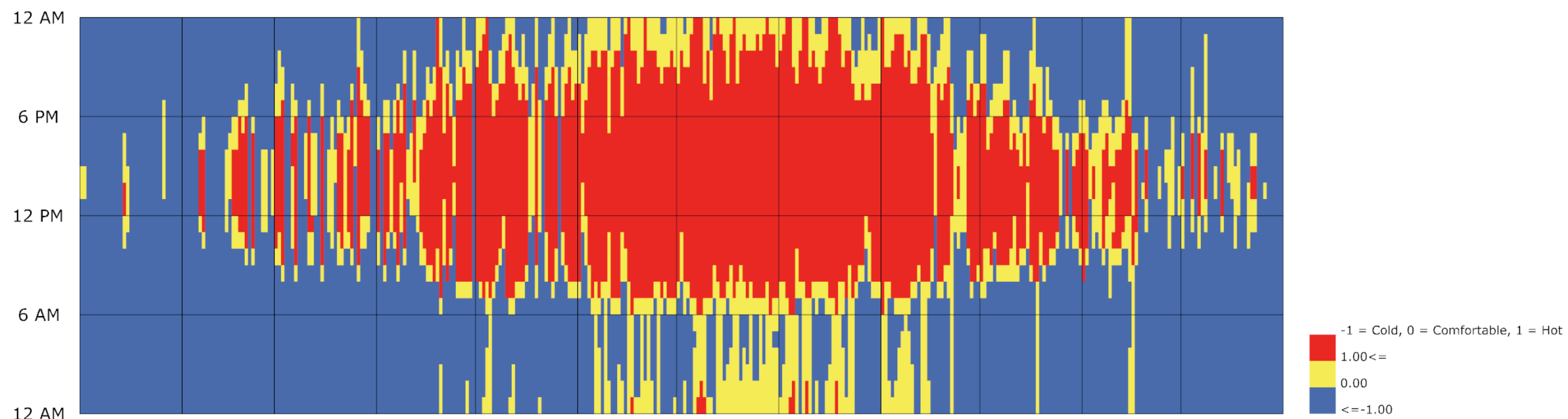


Adaptive
Comfortable (%): 16.31
Hot (%): 29.33
Cold (%): 54.36

Psychrometric Chart
Comfortable (%):19.43
Predicted Mean Vote
Comfortable (%):10.73

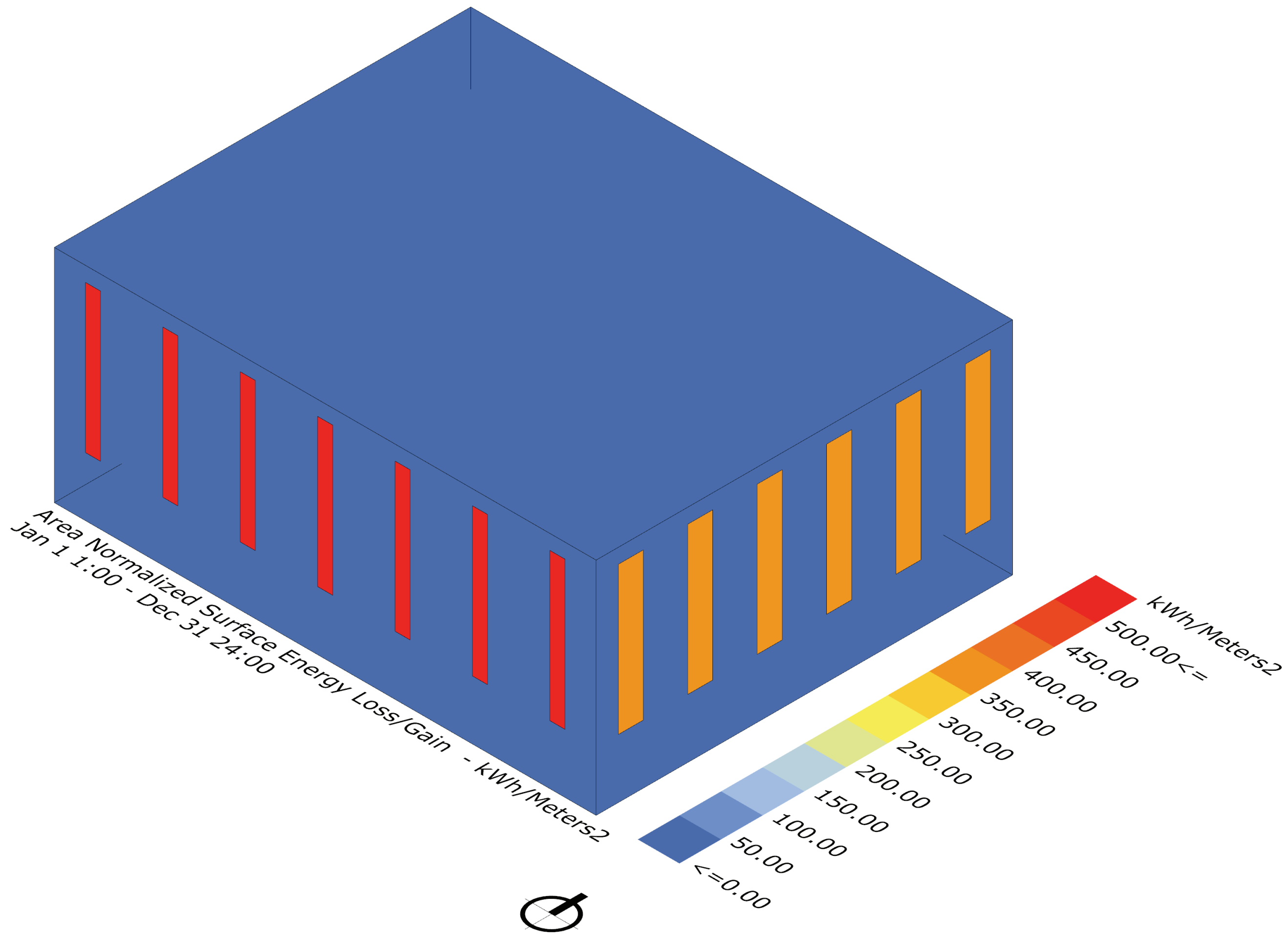


Apartment Energy Balance Diagram



Adaptive Comfort for ZONE_0_T (-1 = Cold, 0 = Comfortable, 1 = Hot) - Hourly
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00

Energy Simulation **Case 1**



Window Wall Ratio
North 0
West 0
South **.125**
East **.24**

Rotation Angle 0°

Blinds No

	East	South
Depth of Shading	0	0
Number of Blinds	0	0

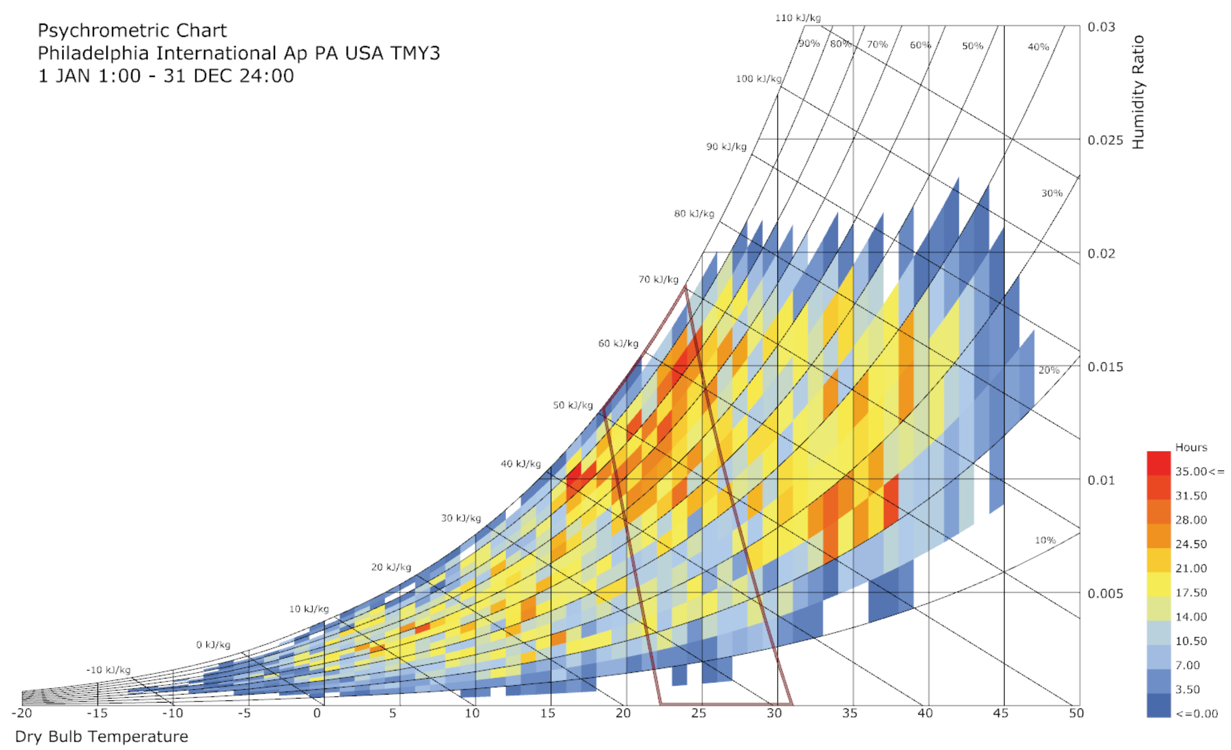
Construction
Exterior Wall R5.5
Exterior Window R0.1
SHGC 0.7
Exterior Roof R9.2

Floor Slab Existing Slab

Natural Ventilation No
Min Indoor Temp. -°C
Max Indoor Temp. -°C
Min Outdoor Temp -°C
Max Outdoor Temp. -°C

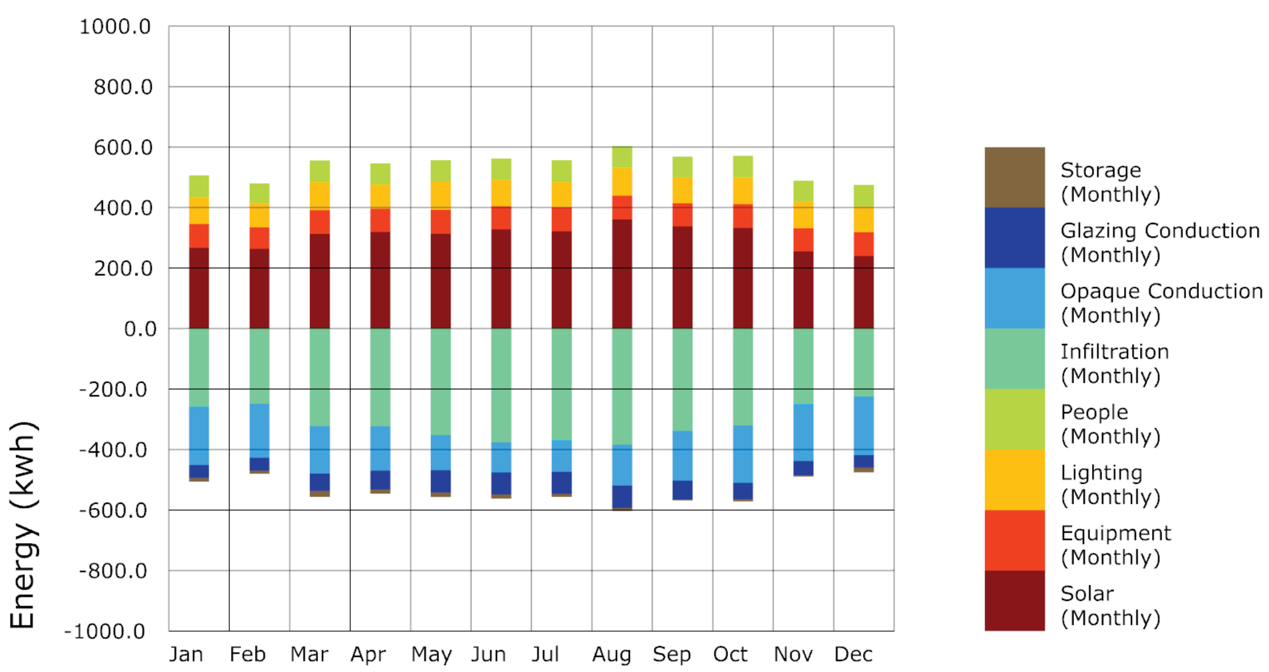
Air change hour 2

Applying design changes that solve the problem of excessive daylight and glare. Reducing the WWR reduces heat stress by 5% but, comfort percentage does not increase as there is an increase in cold percentage.

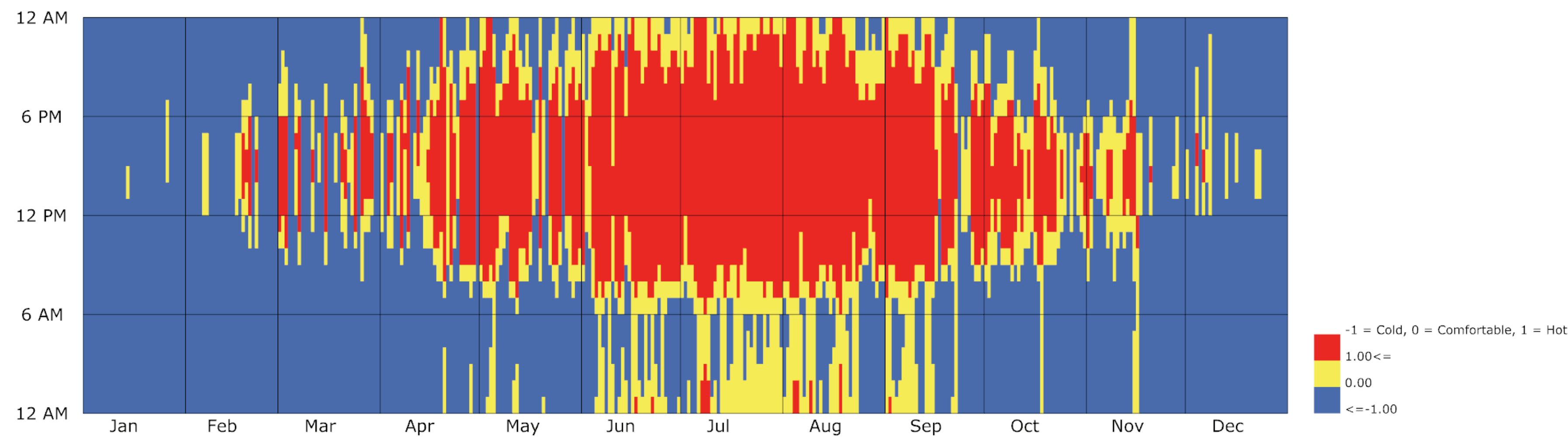


Adaptive
Comfortable (%): 17.08
Hot (%): 25.57
Cold (%): 57.35

Psychrometric Chart
Comfortable (%):19.74
Predicted Mean Vote
Comfortable (%):10.84

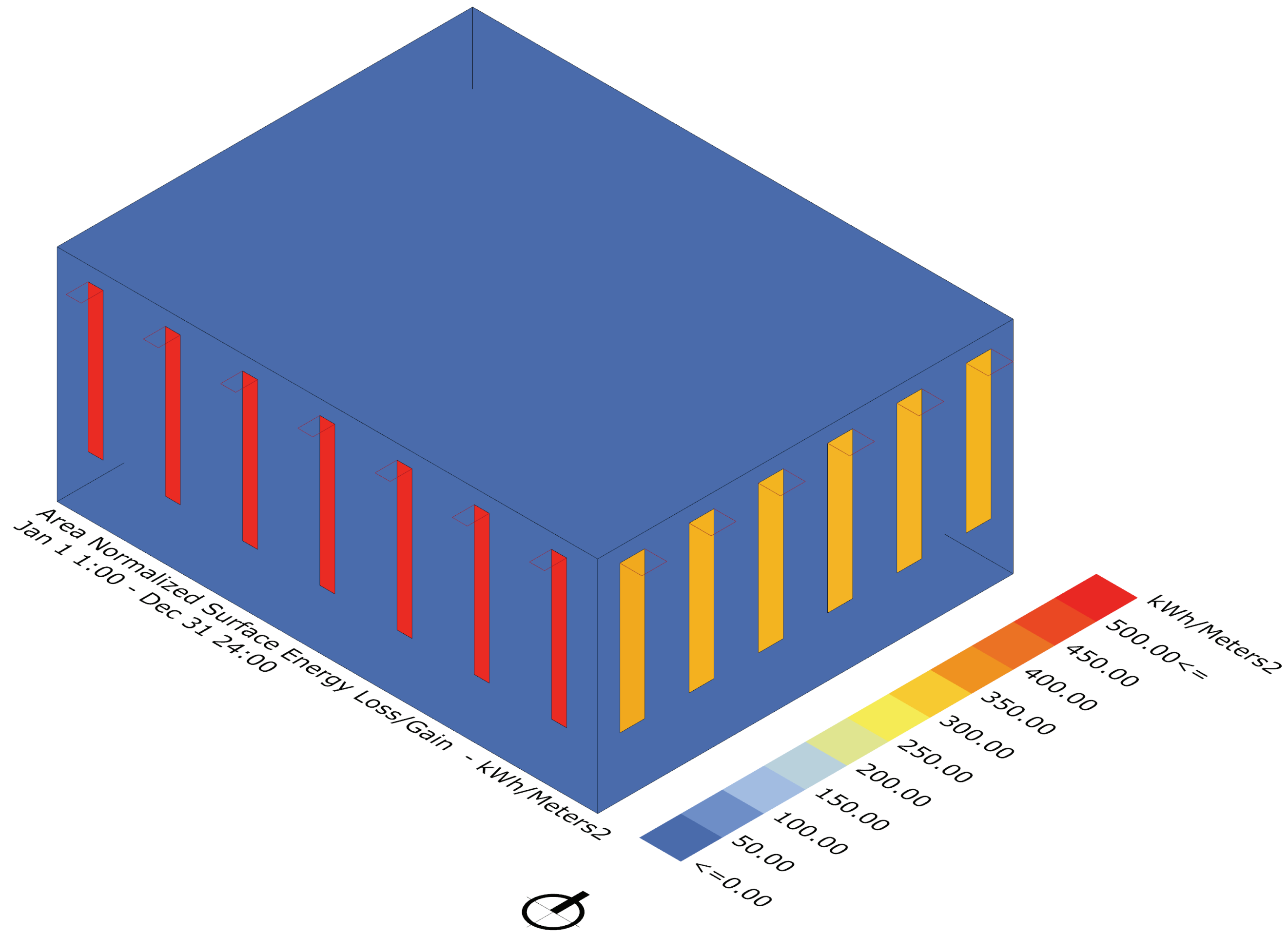


Apartment Energy Balance Diagram



Adaptive Comfort for ZONE_0_T (-1 = Cold, 0 = Comfortable, 1 = Hot) - Hourly
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00

Energy Simulation **Case 2**



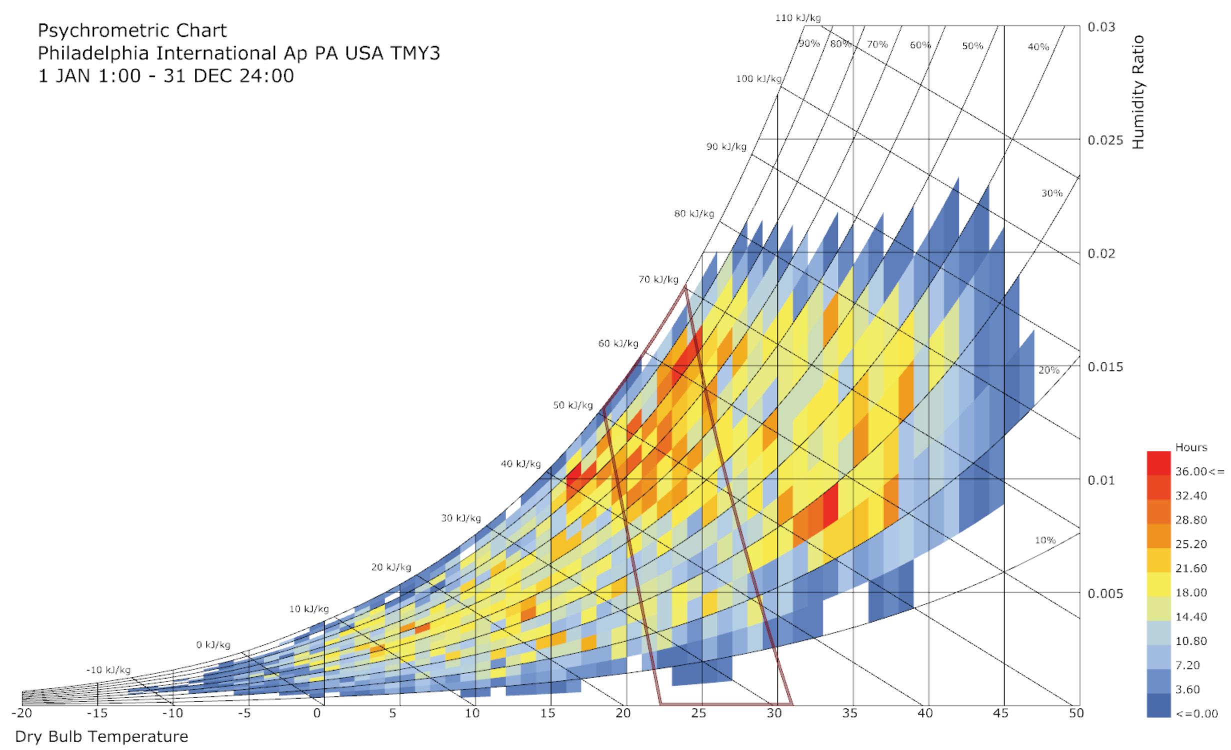
Window Wall Ratio	
North	0
West	0
South	.125
East	.24

Rotation Angle 0°

Blinds	**Yes**	
	East.	South
Depth of Shading	**0.3**	**0.3**
Number of Blinds	**1**	**1**

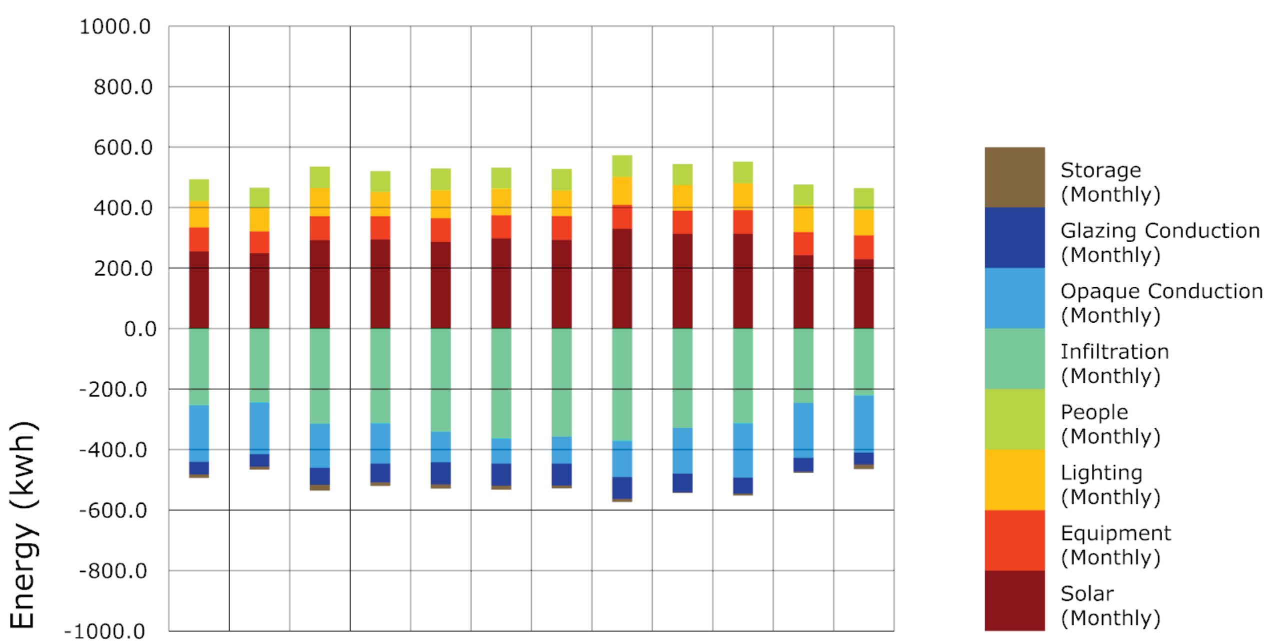
Construction	
Exterior Wall	R5.5
Exterior Window	R0.1
	SHGC 0.7
Exterior Roof	R9.2
Floor Slab	Existing Slab
Natural Ventilation	No
Min Indoor Temp.	-°C
Max Indoor Temp.	-°C
Min Outdoor Temp	-°C
Max Outdoor Temp.	-°C
Air change hour	2

Addition of horizontal overhangs over the south and east windows do not have much contribuition to thermal comfort of the apartment.

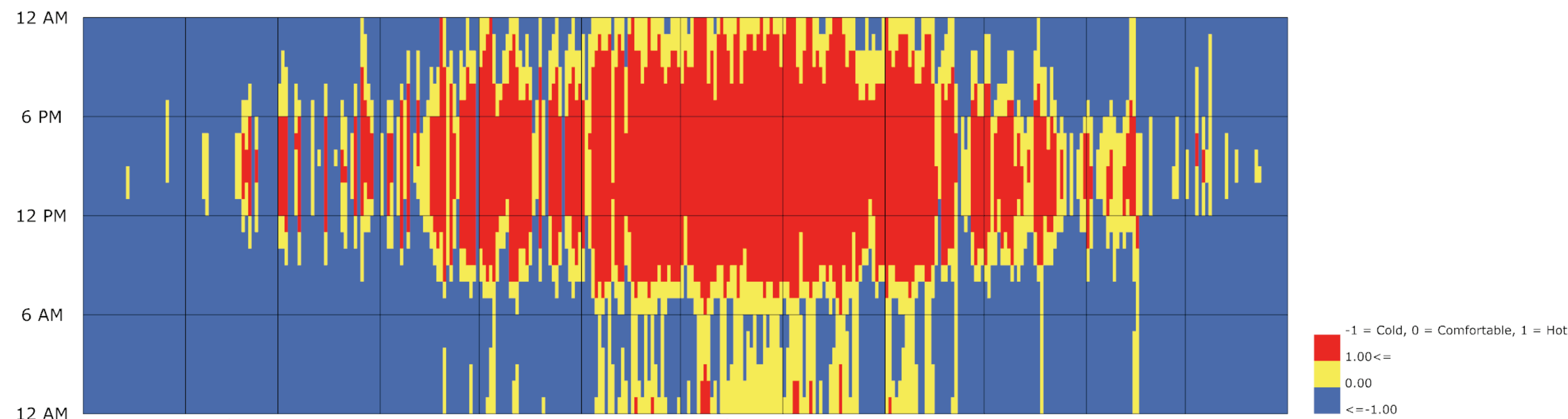


Adaptive
Comfortable (%): 17.41
Hot (%): 24.85
Cold (%): 57.74

Psychrometric Chart
Comfortable (%):19.77
Predicted Mean Vote
Comfortable (%):10.74

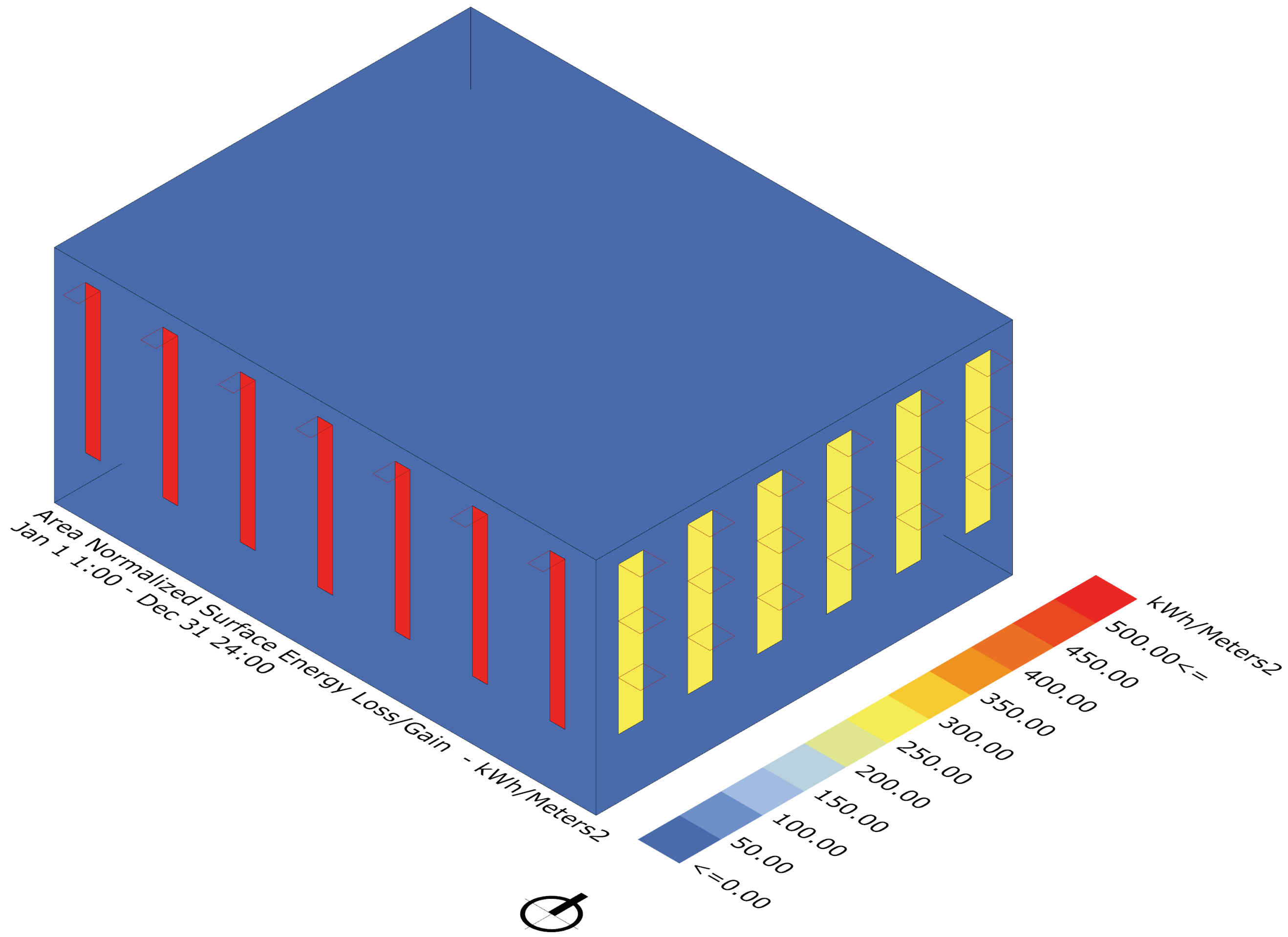


Apartment Energy Balance Diagram



Adaptive Comfort for ZONE_0_T (-1 = Cold, 0 = Comfortable, 1 = Hot) - Hourly
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00

Energy Simulation **Case 3**



Window Wall Ratio

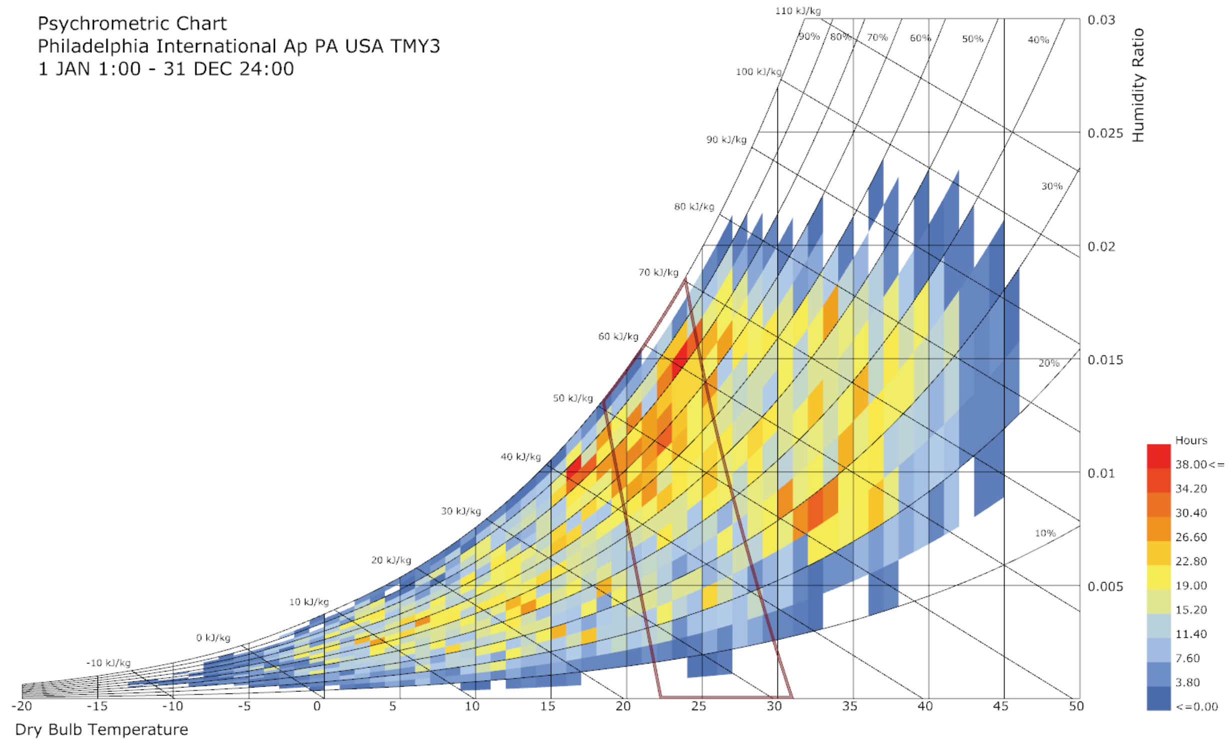
North	0
West	0
South	.125
East	.24

Rotation Angle 0°

Blinds	Yes	
	East.	South
Depth of Shading	0.3	0.3
Number of Blinds	**3**	1

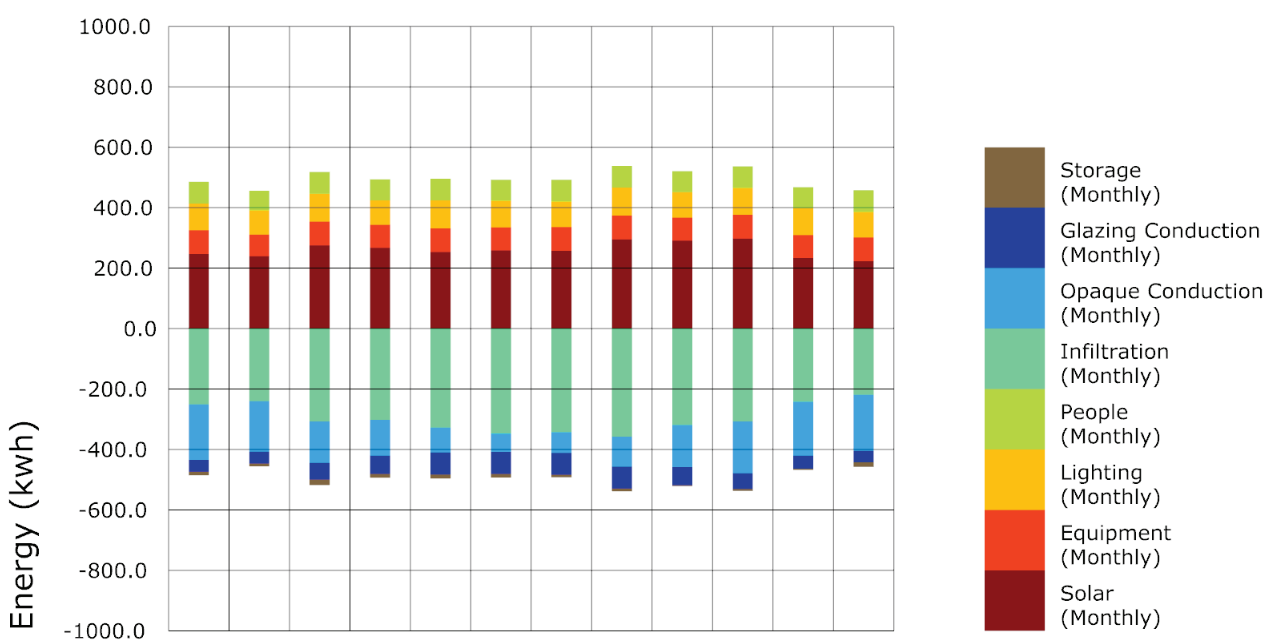
Construction	
Exterior Wall	R5.5
Exterior Window	R0.1
	SHGC 0.7
Exterior Roof	R9.2
Floor Slab	Existing Slab
Natural Ventilation	No
Min Indoor Temp.	-°C
Max Indoor Temp.	-°C
Min Outdoor Temp	-°C
Max Outdoor Temp.	-°C
Air change hour	2

Addition of horizontal overhangs over the east windows do not have much contribuition to thermal comfort of the apartment.

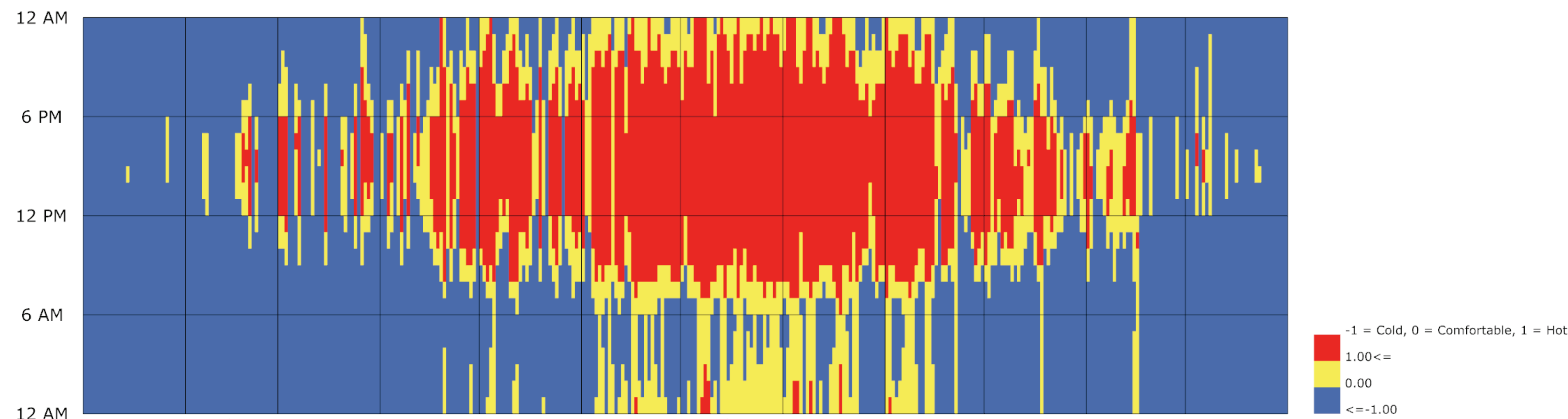


Adaptive
Comfortable (%): 17.66
Hot (%): 24.17
Cold (%): 58.17

Psychrometric Chart
Comfortable (%):19.82
Predicted Mean Vote
Comfortable (%):10.84



Apartment Energy Balance Diagram



Adaptive Comfort for ZONE_0_T (-1 = Cold, 0 = Comfortable, 1 = Hot) - Hourly
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00

Energy Simulation **Case 4**

Window Wall Ratio

North	0
West	0
South	.125
East	.24

Rotation Angle 0°

Blinds Yes

	East.	South
Depth of Shading	0.3	0.3
Number of Blinds	3	1

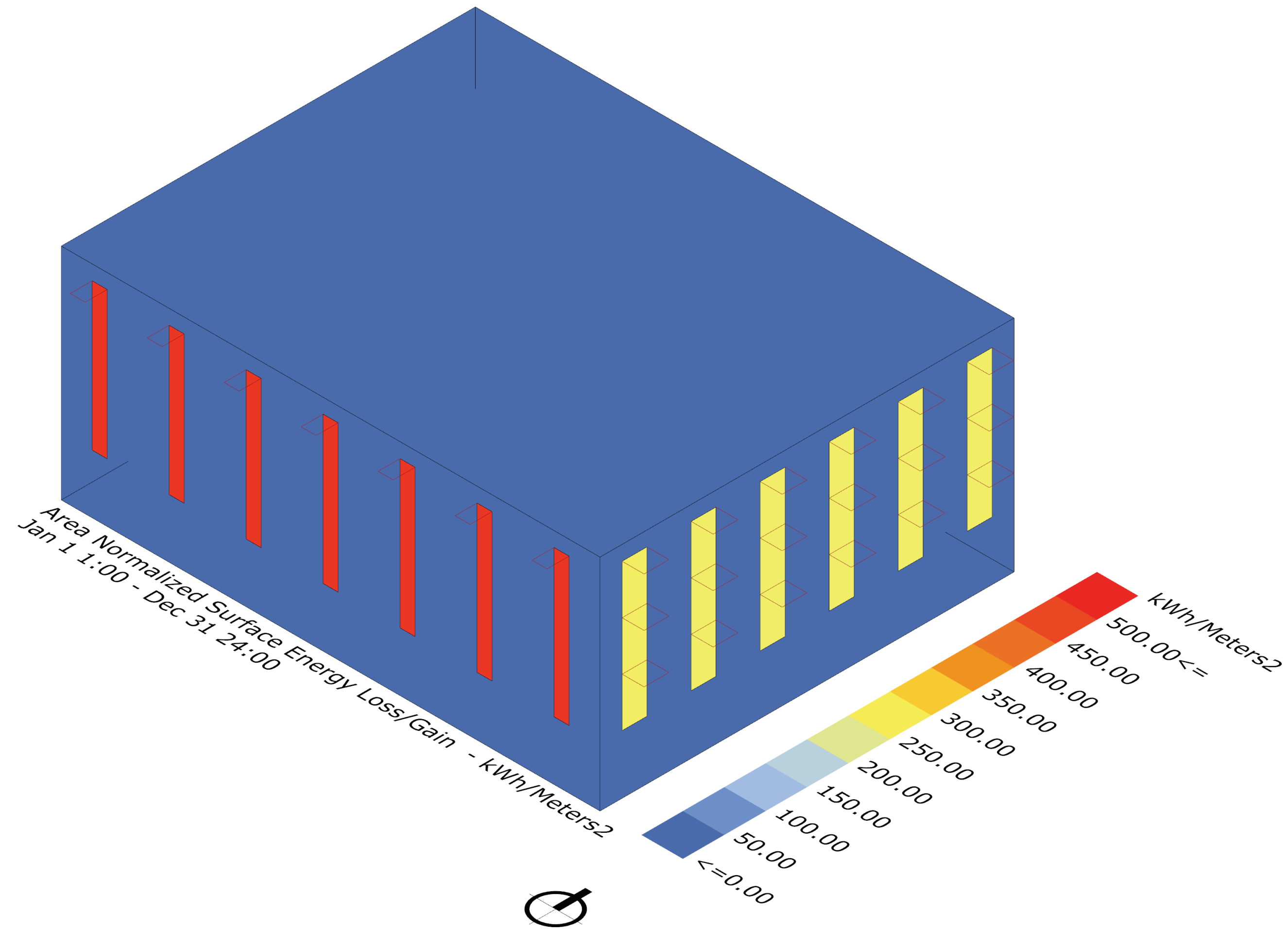
Construction

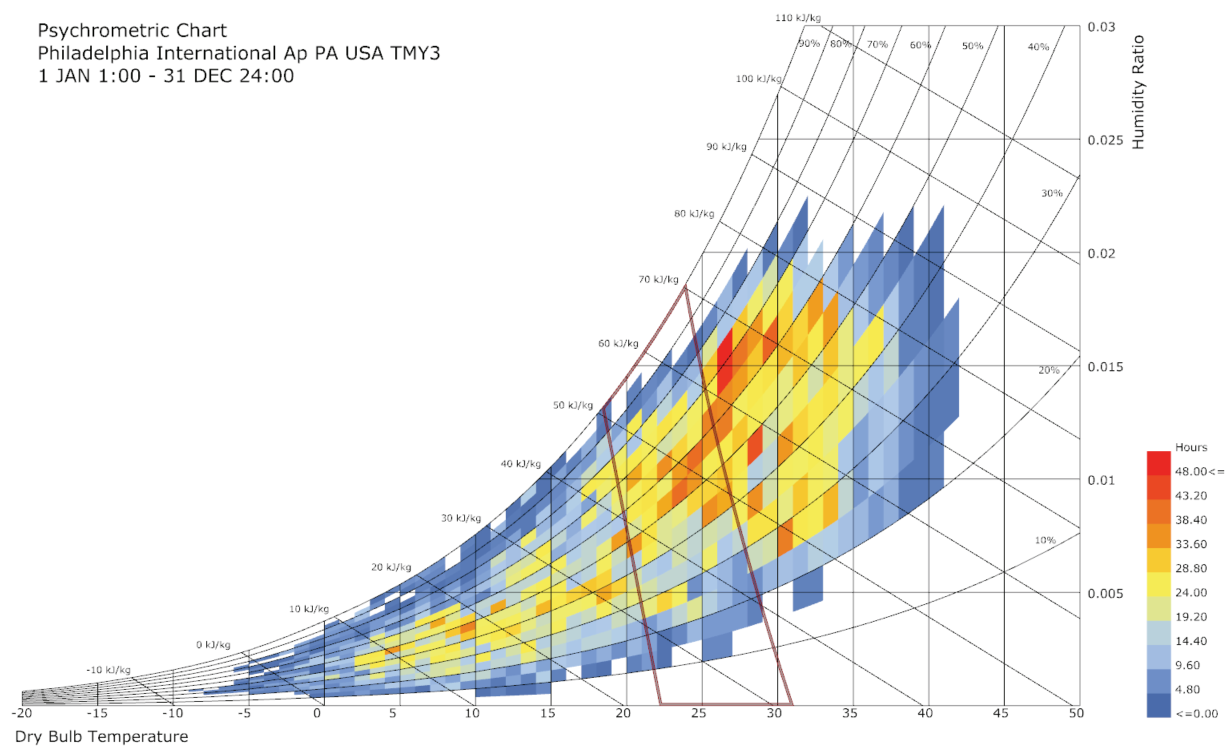
Exterior Wall	**R34.4**
Exterior Window	R0.1
	SHGC 0.7
Exterior Roof	**R34.4**
Floor Slab	Existing Slab

Natural Ventilation No

Min Indoor Temp.	-°C
Max Indoor Temp.	-°C
Min Outdoor Temp	-°C
Max Outdoor Temp.	-°C
Air change hour	2

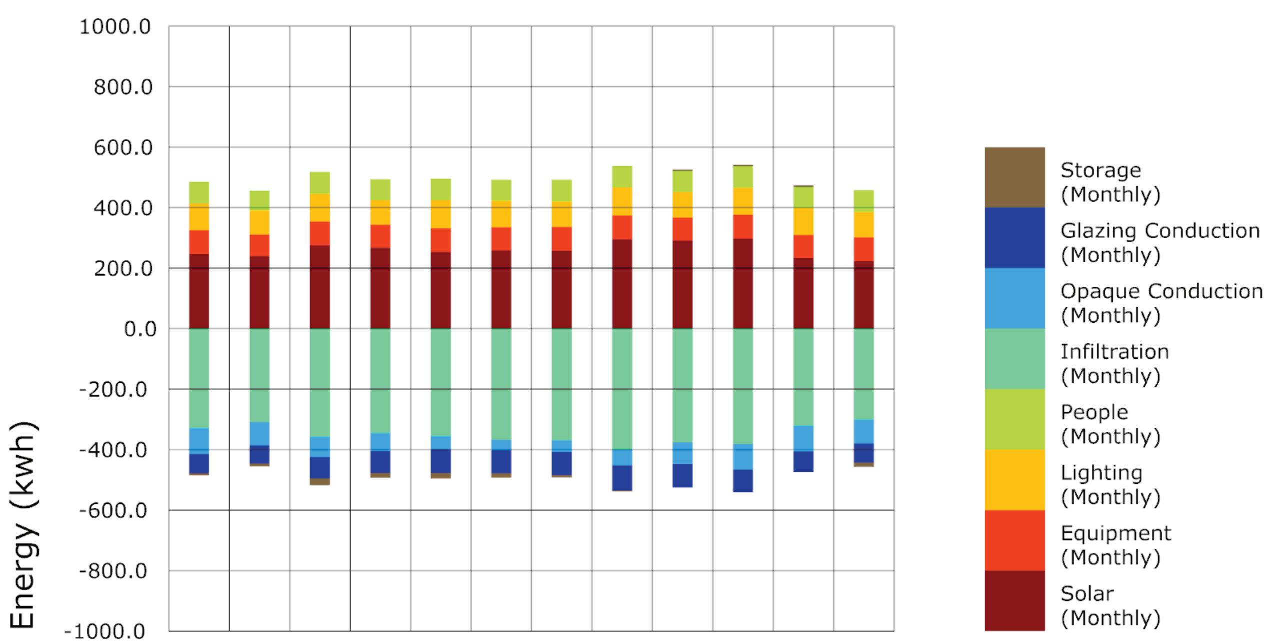
Increasing the R-value (insulation properties) of exterior walls and roof create a reduction in cold hours by 6% but increase hot hours by 2%, therefore a cumulative increase of 4% in comfortable hours is recorded.



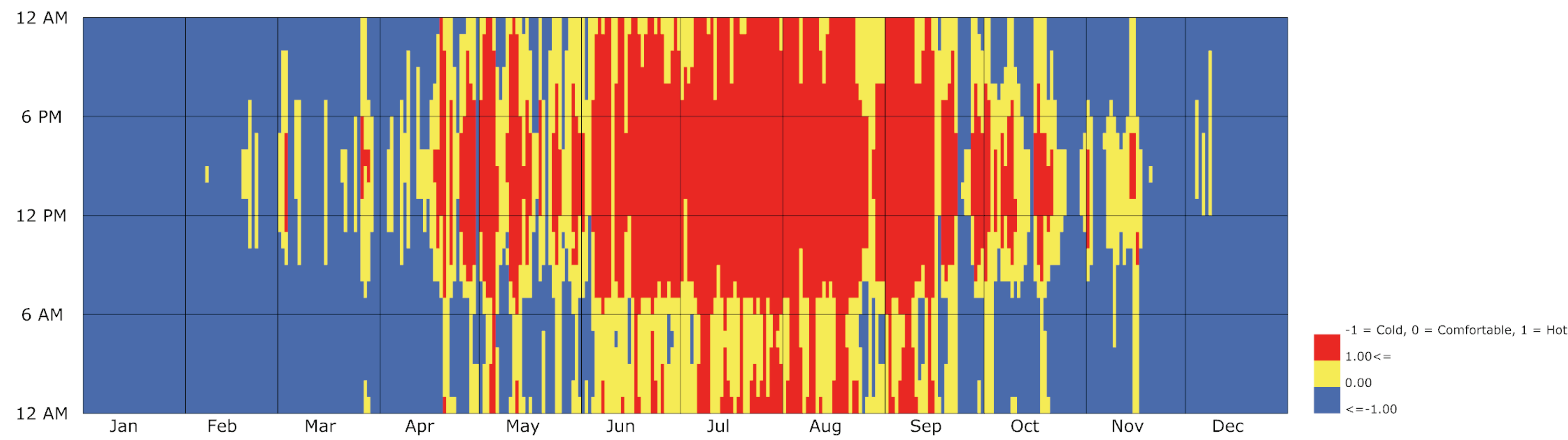


Adaptive
Comfortable (%): 21.19
Hot (%): 26.31
Cold (%): 52.5

Psychrometric Chart
Comfortable (%):19.66
Predicted Mean Vote
Comfortable (%):10.58



Apartment Energy Balance Diagram



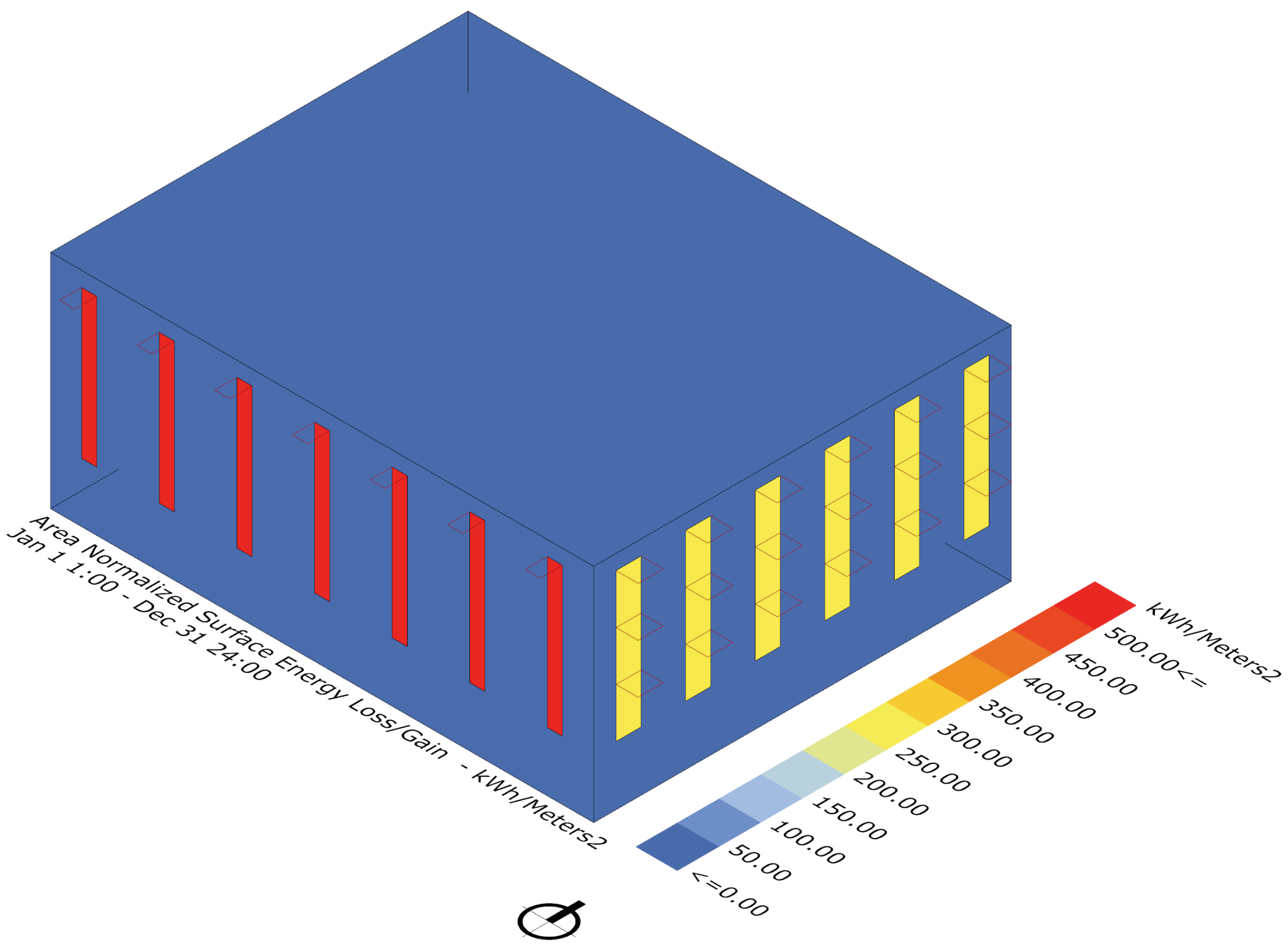
Adaptive Comfort for ZONE_0_T (-1 = Cold, 0 = Comfortable, 1 = Hot) - Hourly
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00

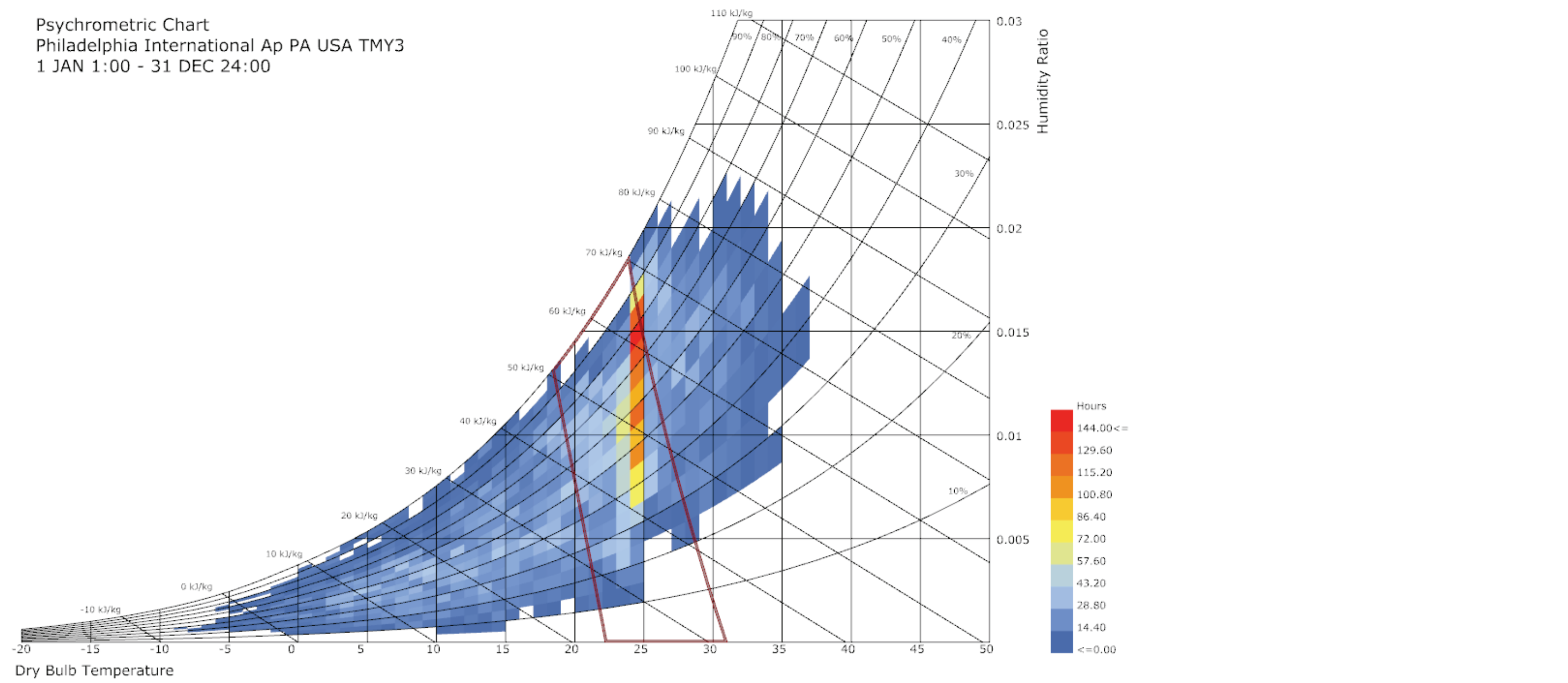
Energy Simulation **Case 5**

Window Wall Ratio		
North	0	
West	0	
South	.125	
East	.24	
Rotation Angle	0°	
Blinds	Yes	
	East.	South
Depth of Shading	0.3	0.3
Number of Blinds	3	1

Construction	
Exterior Wall	R34.4
Exterior Window	R0.1
	SHGC 0.7
Exterior Roof	R34.4
Floor Slab	Existing Slab
Natural Ventilation	**Yes**
Min Indoor Temp.	**25°C**
Max Indoor Temp.	-°C
Min Outdoor Temp	-°C
Max Outdoor Temp.	-°C
Air change hour	2

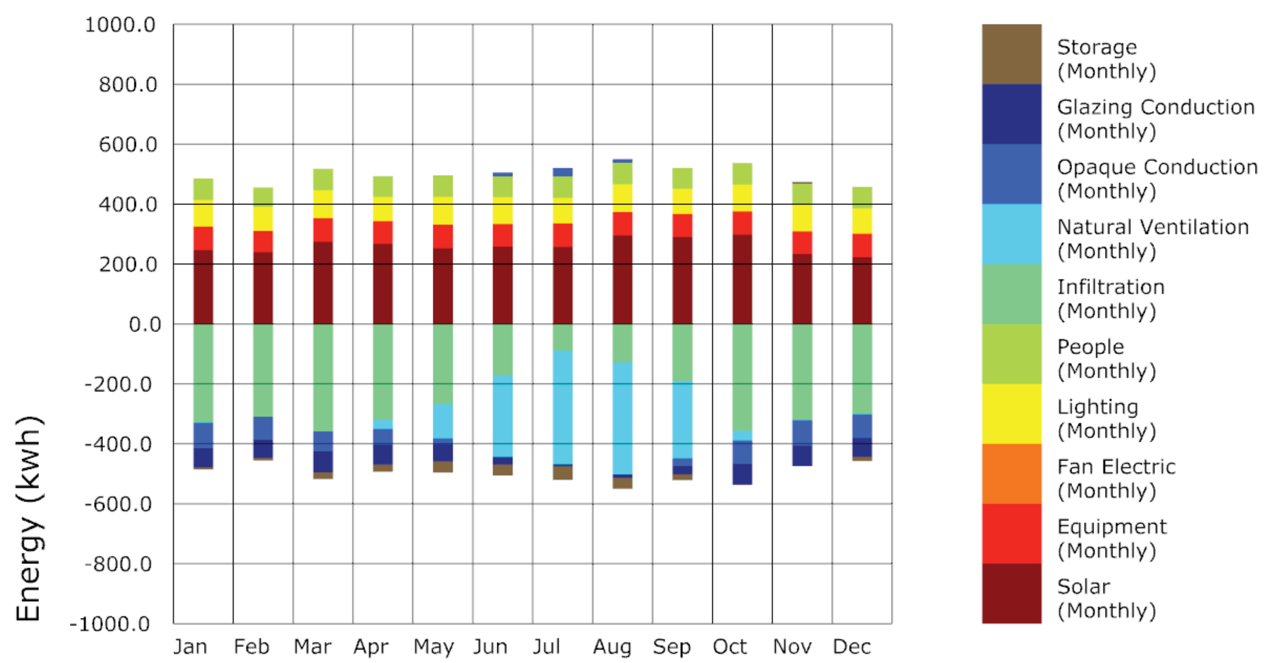
Openable windows almost solve the issue of hot hours by reducing them to 11.42% from 26.31%. One condition is applied to opening of windows that the minumim indoor temperature should be 25°C.



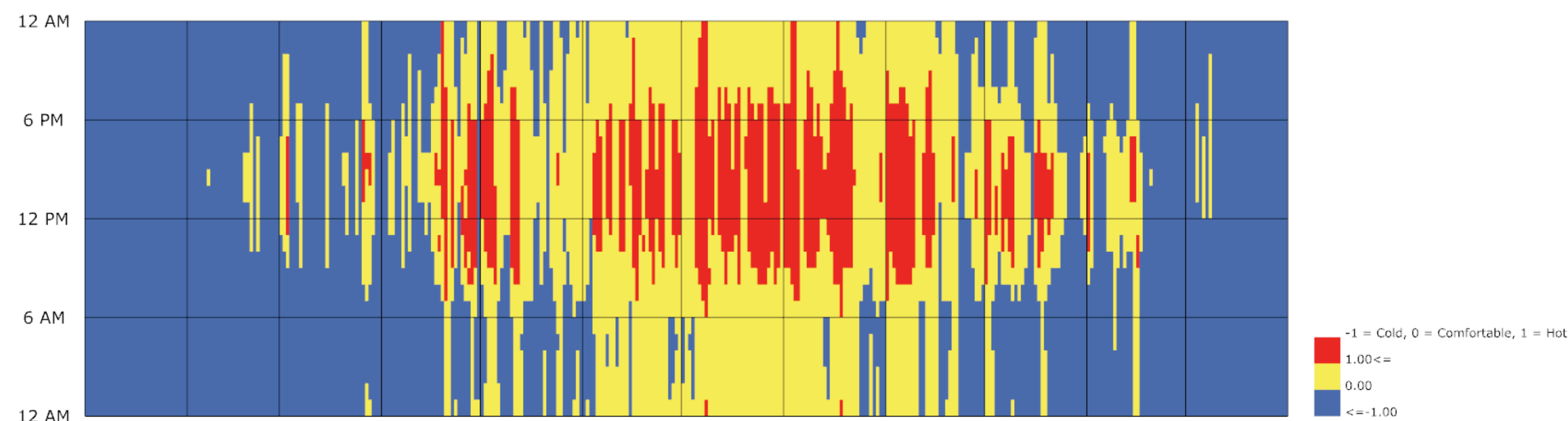


Adaptive
Comfortable (%): 34.62
Hot (%): 11.42
Cold (%): 53.96

Psychrometric Chart
Comfortable (%):32.6
Predicted Mean Vote
Comfortable (%):15.18



Apartment Energy Balance Diagram



Adaptive Comfort for ZONE_0_T (-1 = Cold, 0 = Comfortable, 1 = Hot) - Hourly
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00

Energy Simulation **Case 6**

Window Wall Ratio

North	0
West	0
South	.125
East	.24

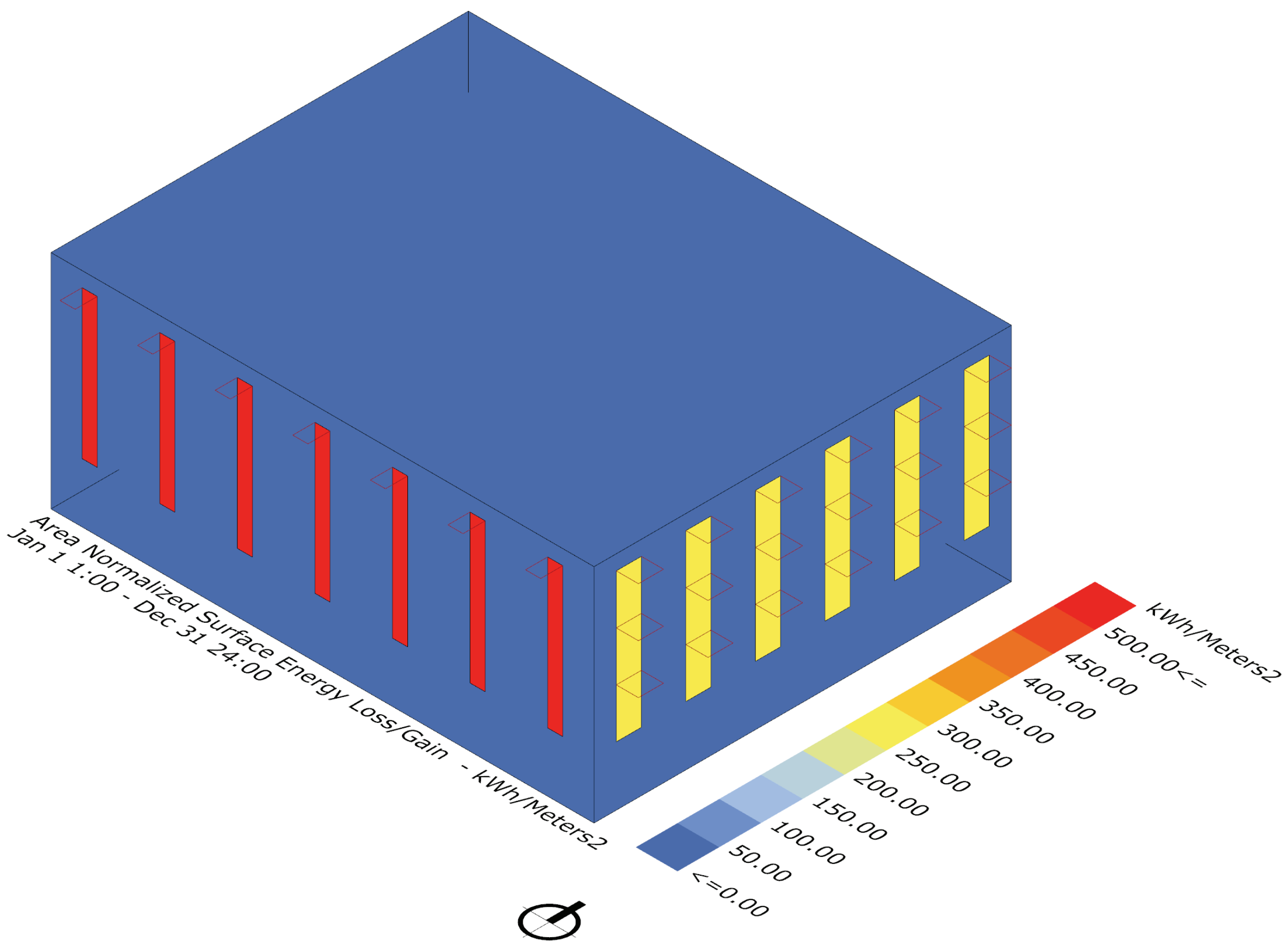
Rotation Angle 0°

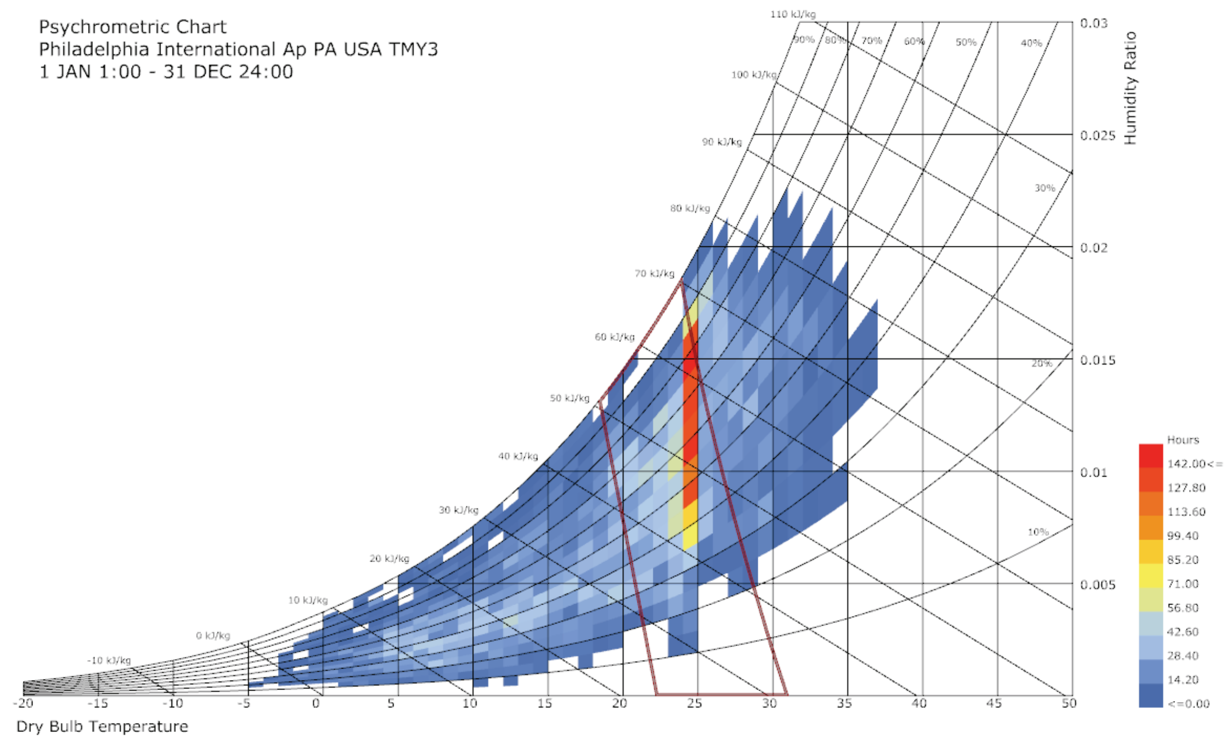
Blinds	Yes	
	East.	South
Depth of Shading	0.3	0.3
Number of Blinds	3	1

Construction

Exterior Wall	R34.4
Exterior Window	R0.1
	SHGC 0.7
Exterior Roof	R34.4
Floor Slab	**Existing Slab + 8 inches**
Natural Ventilation	Yes
Min Indoor Temp.	25°C
Max Indoor Temp.	-°C
Min Outdoor Temp	-°C
Max Outdoor Temp.	-°C
Air change hour	2

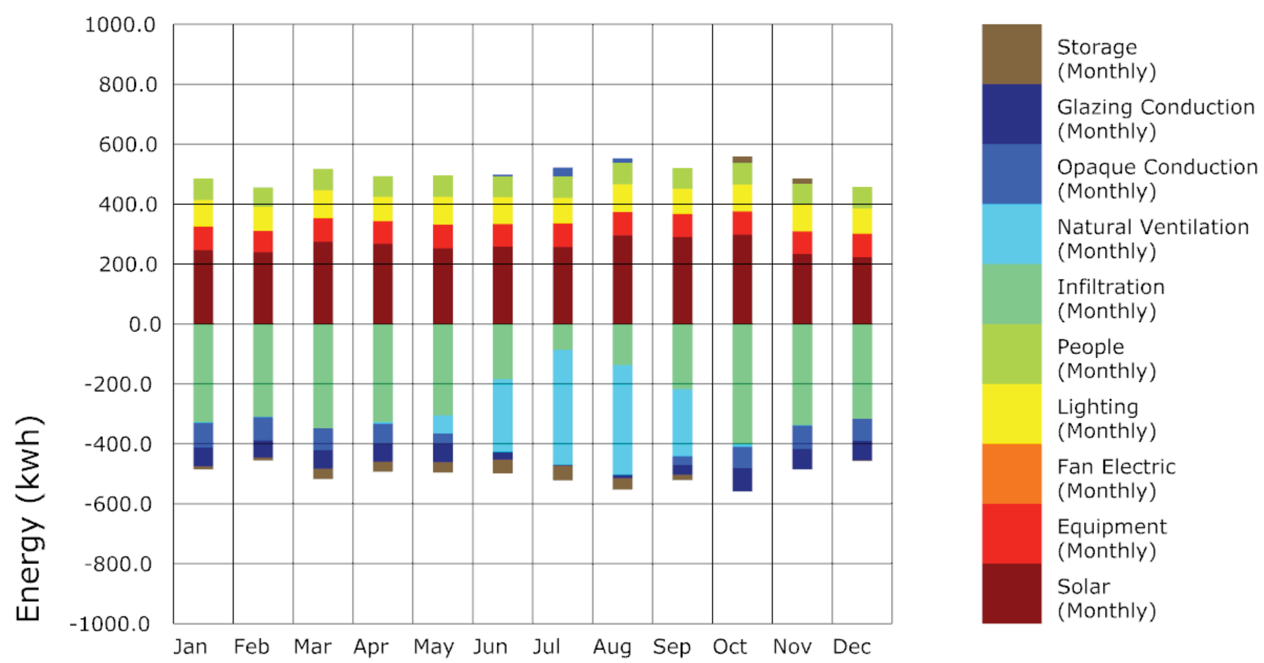
Addition of Thermal Mass increases the comfort percentage by 2% showing an decrease in both hot hours and cold hours.



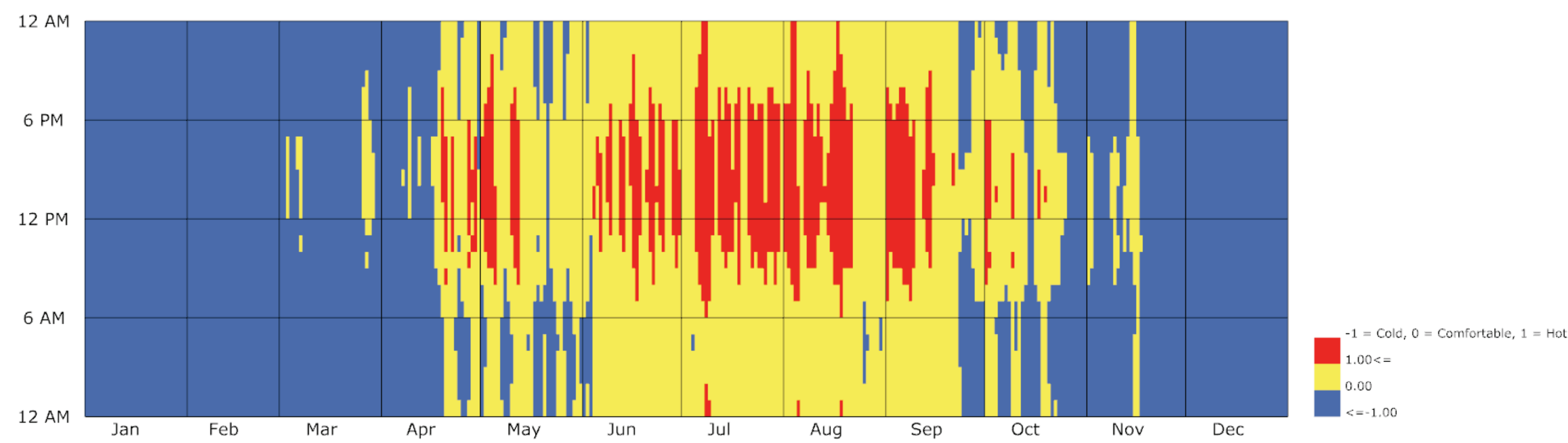


Adaptive
Comfortable (%): 37.97
Hot (%): 9.43
Cold (%): 52.6

Psychrometric Chart
Comfortable (%):33.46
Predicted Mean Vote
Comfortable (%):14.83

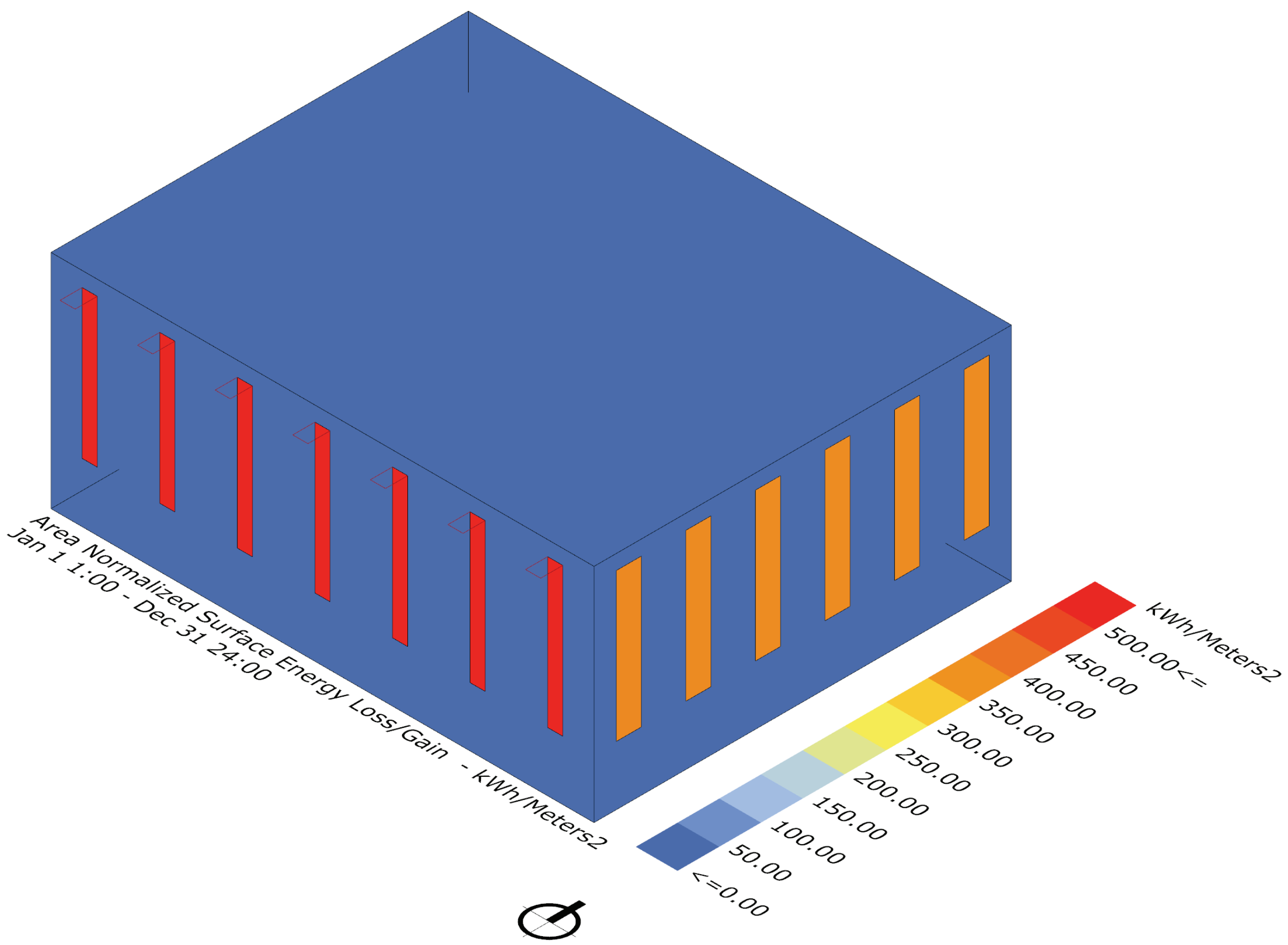


Apartment Energy Balance Diagram



Adaptive Comfort for ZONE_0_T (-1 = Cold, 0 = Comfortable, 1 = Hot) - Hourly
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00

Energy Simulation **Case 7**



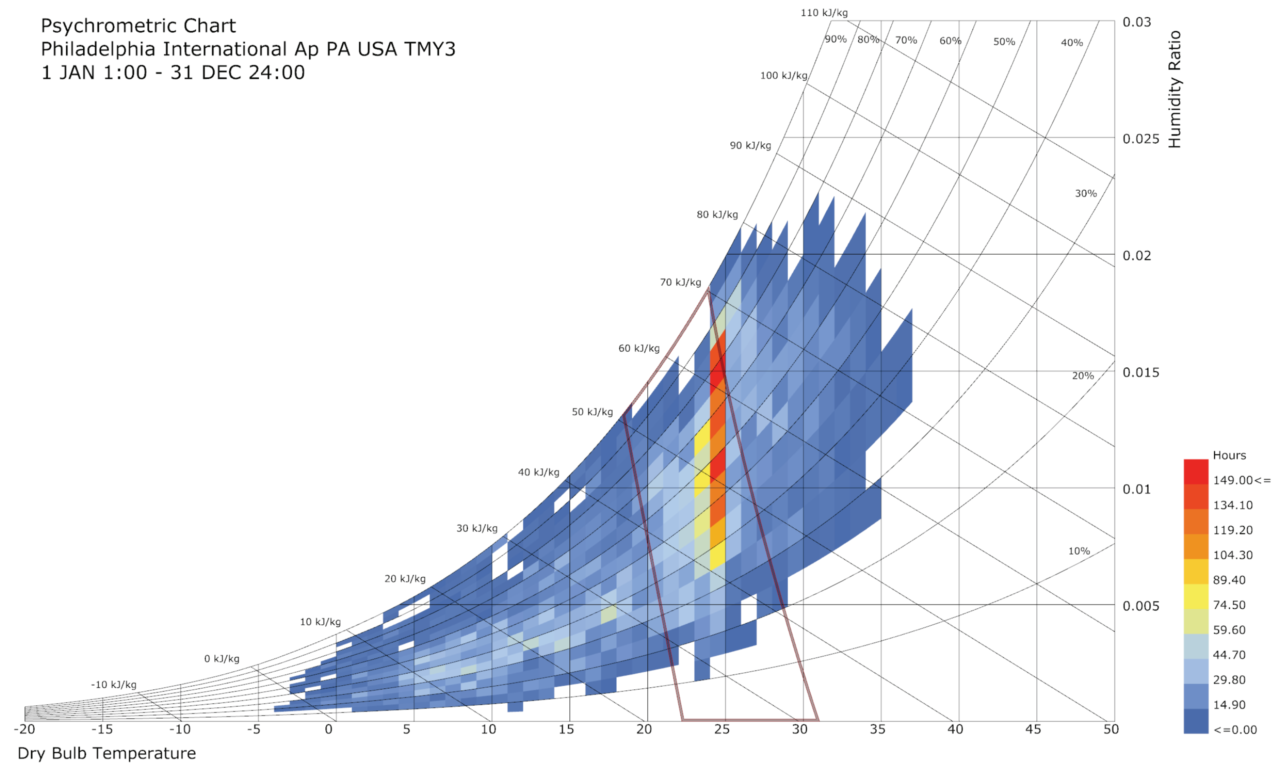
Window Wall Ratio
North 0
West 0
South .125
East .24

Rotation Angle 0°

Blinds	Yes	
	East.	South
Depth of Shading	**0**	0.3
Number of Blinds	**0**	1

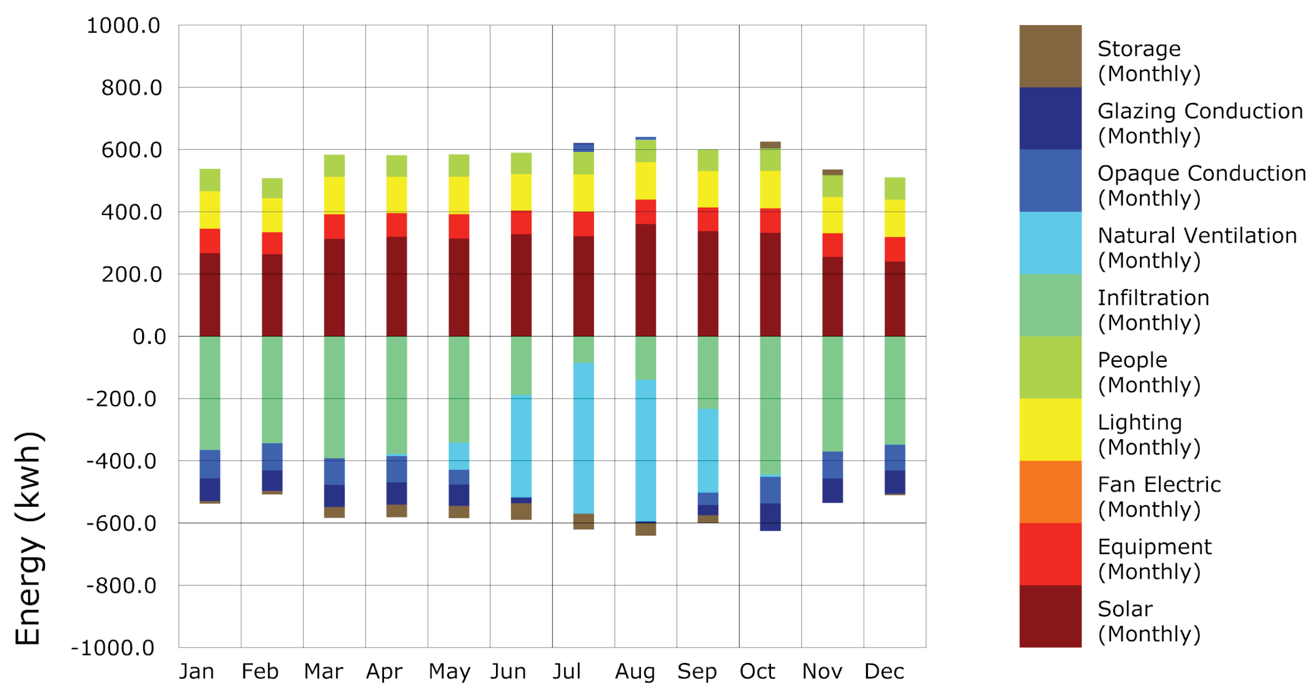
Construction	
Exterior Wall	R34.4
Exterior Window	R0.1
	SHGC 0.7
Exterior Roof	R34.4
Floor Slab	Existing Slab + 8 inches
Natural Ventilation	Yes
Min Indoor Temp.	25°C
Max Indoor Temp.	-°C
Min Outdoor Temp	-°C
Max Outdoor Temp.	-°C
Air change hour	2

It is observed that removing blinds from the East facade increases thermal comfort by 2%, therefore the blinds can be designed to be deployable that can be used during times of excessive glare.

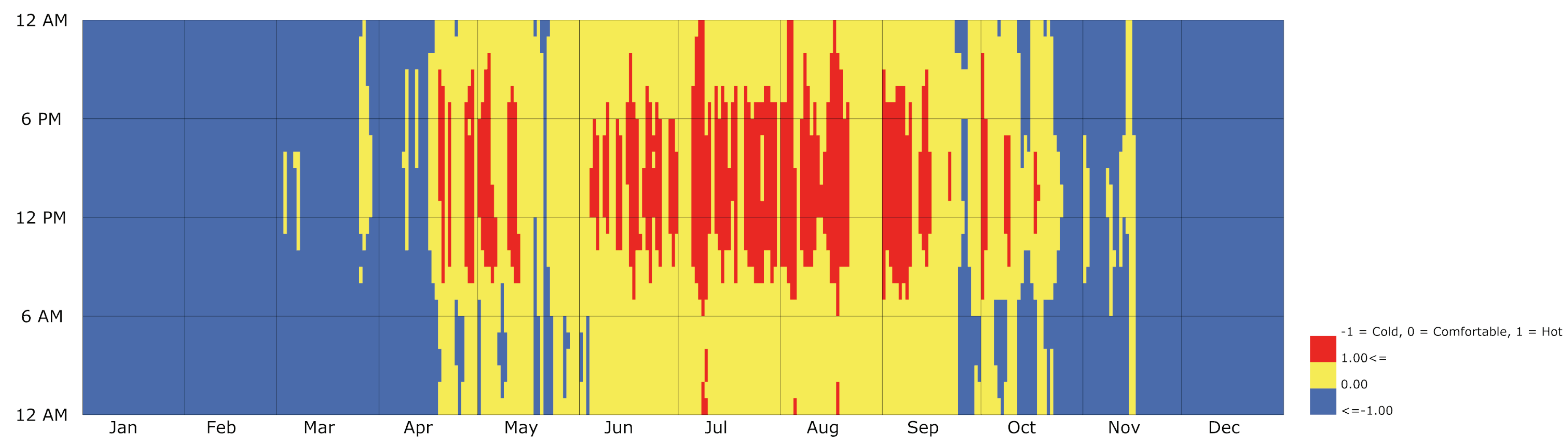


Adaptive
Comfortable (%): 39.73
Hot (%): 10.63
Cold (%): 49.65

Psychrometric Chart
Comfortable (%):35.51
Predicted Mean Vote
Comfortable (%):15.9



Apartment Energy Balance Diagram



Adaptive Comfort for ZONE_0_T (-1 = Cold, 0 = Comfortable, 1 = Hot) - Hourly
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00

Conclusions

Visual Comfort for Improved Case

Daylight

According to the point in time Daylight Analysis, the apartment gets lux levels between 100-500 on 21st March, 21st June and 21st December at 9am , 12 noon and 3pm.

The Daylight Autonomy is 90% for the whole apartment with a minimum threshold level of 150 lux.

Glare

The intolerable and disturbing glare conditions in the hall and bedroom have been solved by design of appropriate shading devices and the new glare analysis depicts impercebtible glare for 21st March, 21st June and 21st December at 9am , 12 noon and 3pm.

Thermal Comfort for Improved Case

The Base Case showed a adaptive comfort of 16.31% which has increased to 39.73% by implementing different passive design strategies like :

Reduction in Window Wall Ratio

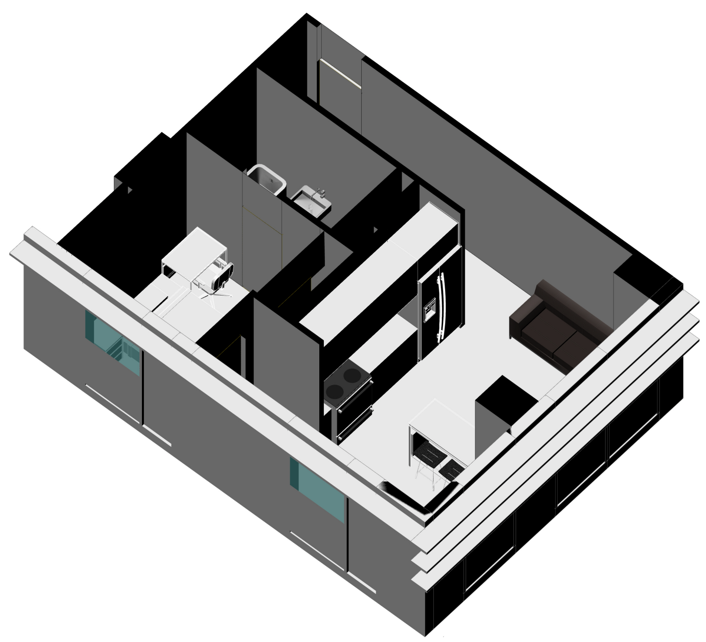
Increasing insulation value of materials used for construction of exterior walls and roof

Addition of shading devices on the exterior facades

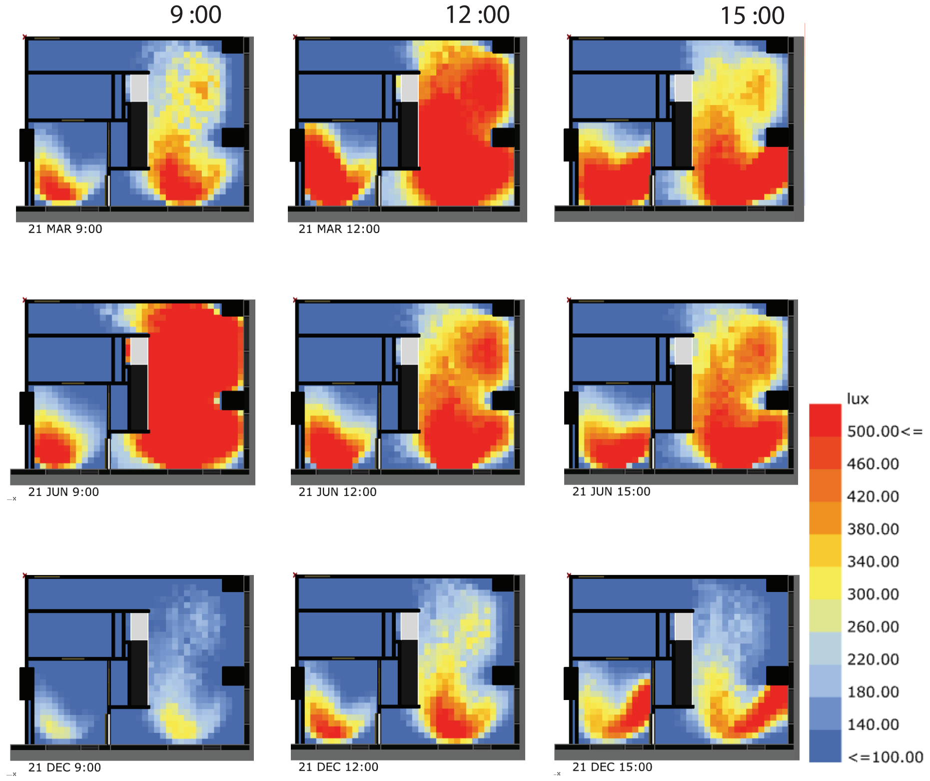
Addition to the thermal mass of the building by increasing thickness of floor slab

Making windows openable and therefore allowing ventilation

Improved Case



Point-in-time Grid Based Daylight Analysis

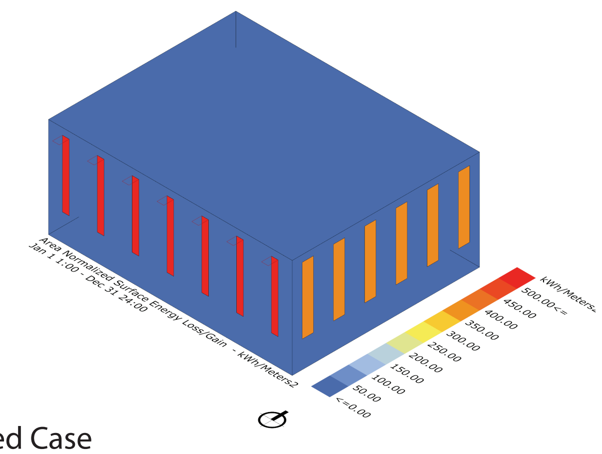


Thermal Comfort was limited to 40% as the uncomfortable hours are primarily cold hours which cannot be made comfortable using passive strategies due to lack of sun radiation in winter months. It is observed in the outdoor comfort chart that sun radiation had no or mild effect in comfort hours during winter months.

Adaptive Comfort
Comfortable **39.73%**
Hot **10.63%**
Cold **49.65%**

Psychrometric Chart
Comfortable **35.51%**

Predicted Mean Vote
Comfortable **15.9%**

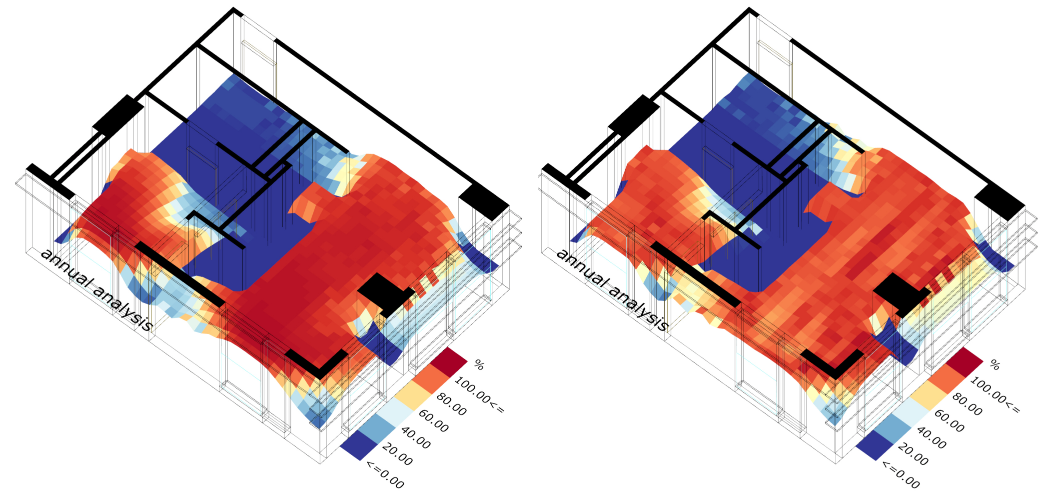


Design Specifications for Improved Case

Window Wall Ratio		
North	0	
West	0	
South	.125	
East	.24	
Rotation Angle	0°	
Blinds	Yes	
	East.	South
Depth of Shading	0.3	0.3
Number of Blinds	3	1

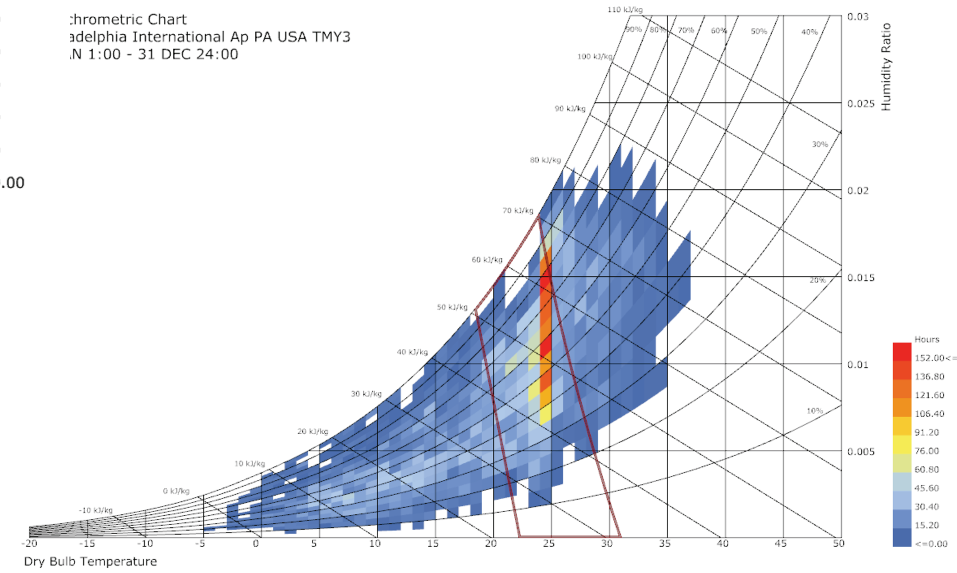
Construction	
Exterior Wall	R34.4
Exterior Window	R0.1
	SHGC 0.7
Exterior Roof	R34.4
Floor Slab	Existing Slab + 8 inches
Natural Ventilation	Yes
Min Indoor Temp.	25°C
Max Indoor Temp.	-°C
Min Outdoor Temp	-°C
Max Outdoor Temp.	-°C
Air change hour	2

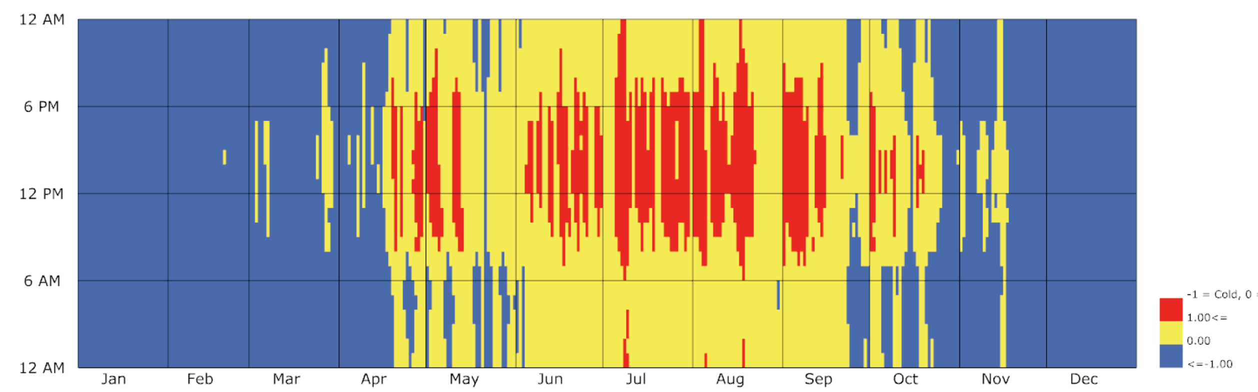
Annual Daylight Analysis



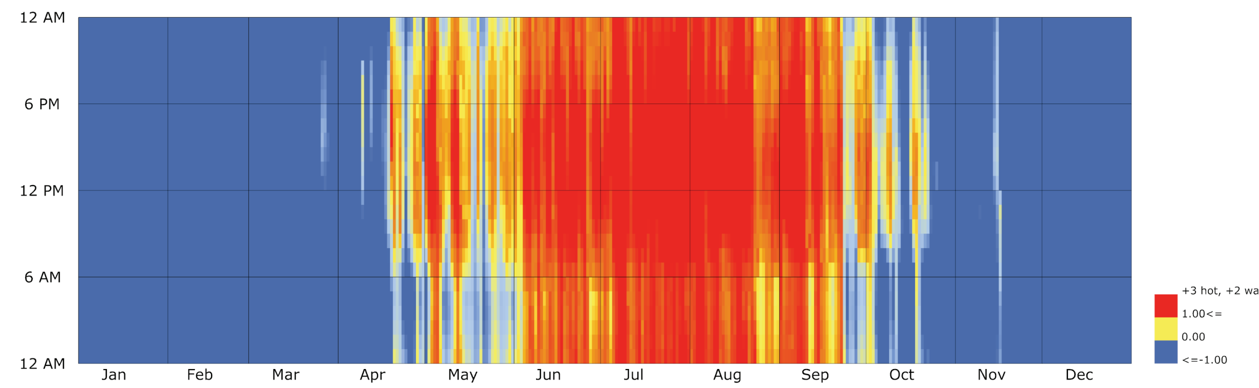
DLA (Illuminance threshold = 150lux)   100 < UDLI < 2000

ermal Comfort Charts





Adaptive Comfort for ZONE_0_T (-1 = Cold, 0 = Comfortable, 1 = Hot) - Hourly
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00



Predicted Mean Vote for ZONE_0_T (+3 hot, +2 warm, +1 slightly warm, 0 neutral, -1 slightly cool, -2 cool, -3 cold) - Hourly
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00