

Thermal and Visual Comfort Maximization of an Unconditioned Space

Philadelphia, PA

Fall 2016 | ARCH 753 Building Performance Simulation

Di Fan

Penn Design | University of Pennsylvania

Climate Zone

Weather Data: Philadelphia International Ap, PA, USA, TMY3

Latitude: 39.87

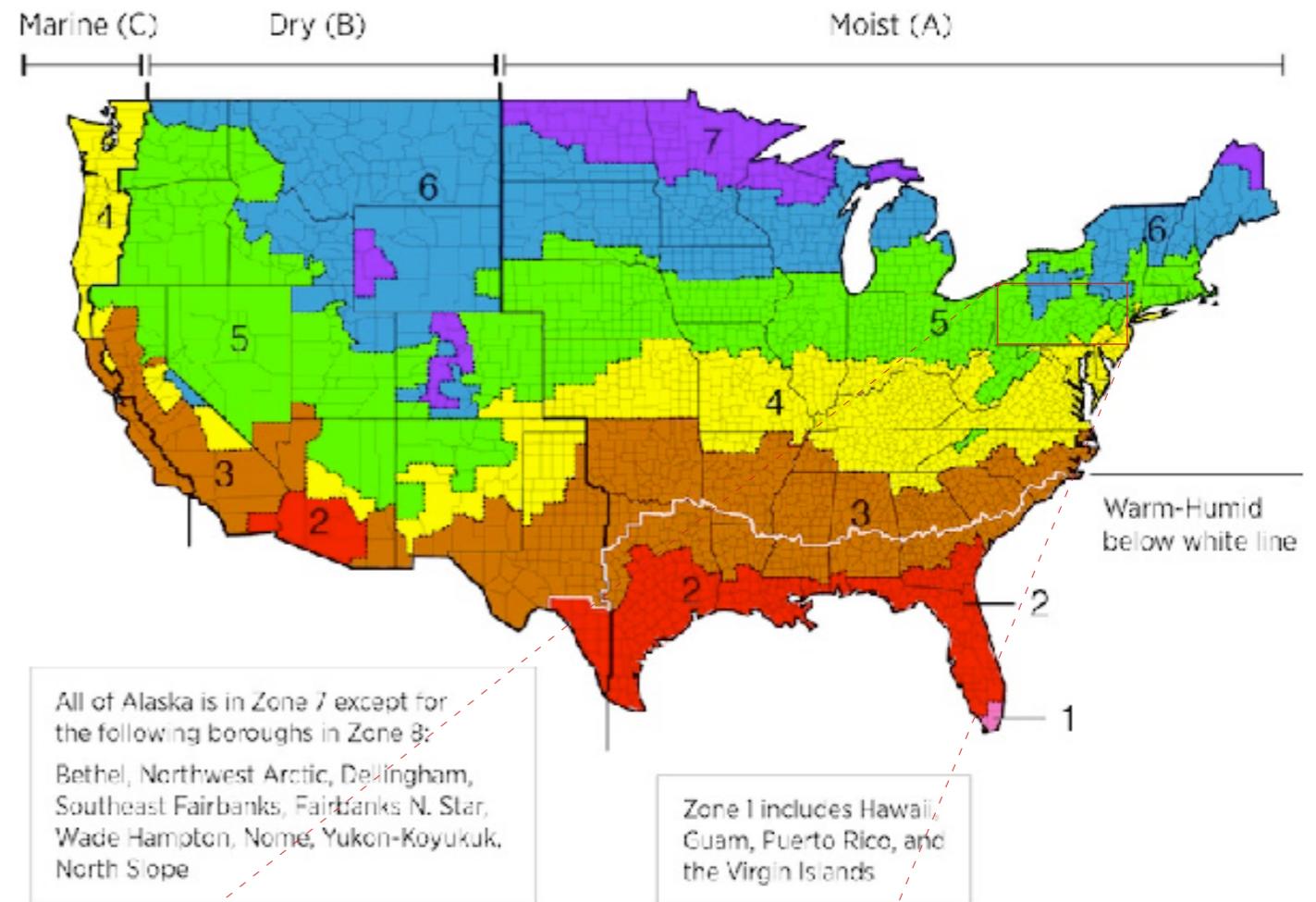
Longitude: -75.23

CDD: 1235

HDD: 4759

Climate Zone: 4A

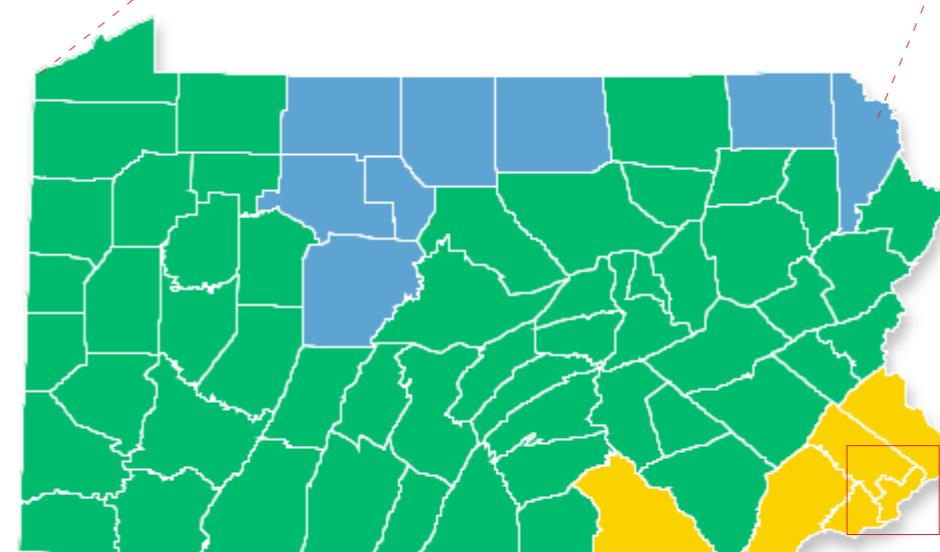
Characteristic: Mixed-Humid



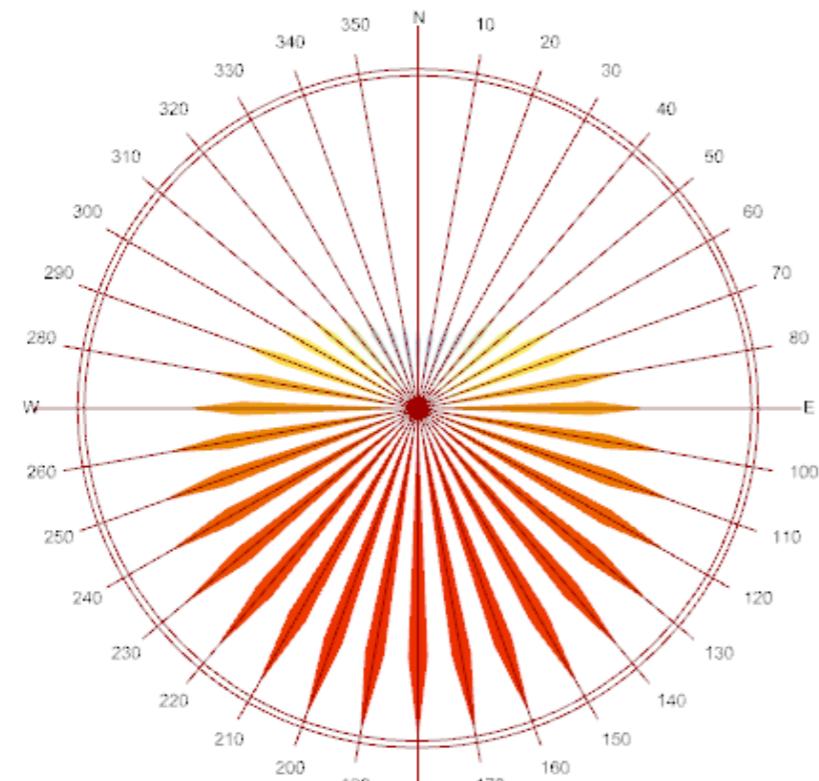
From the Climate Classification, the heating degree days of philly is very high, almost 4 times than cooling degree days. Thus, the design strategy would focus on the heating efficiency and thermal insulation.

Residential Prescriptive Requirements For Zone 4 (2009 IECC)

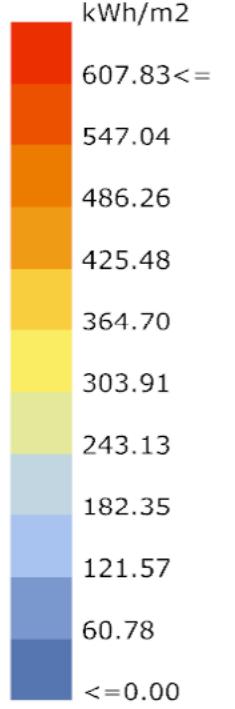
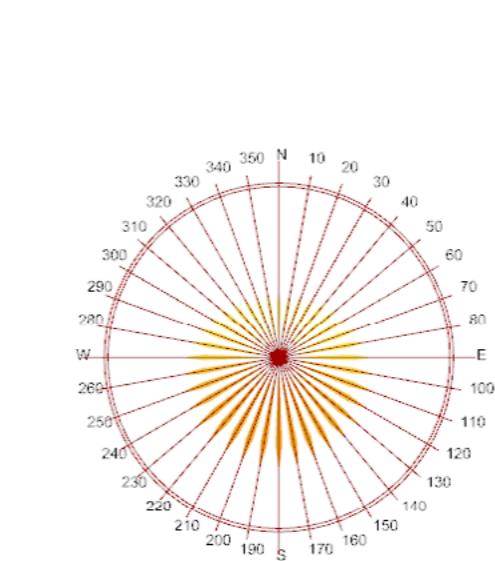
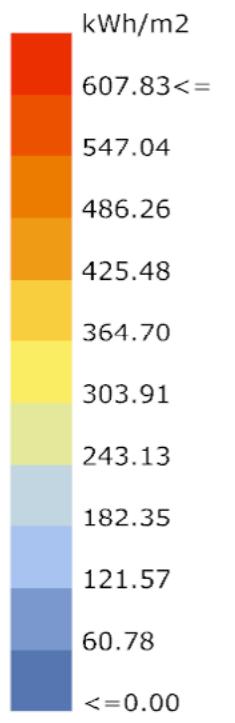
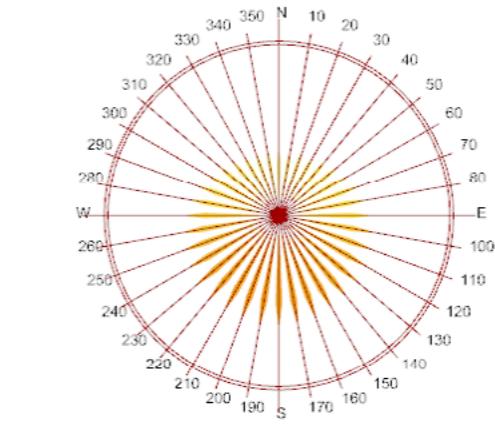
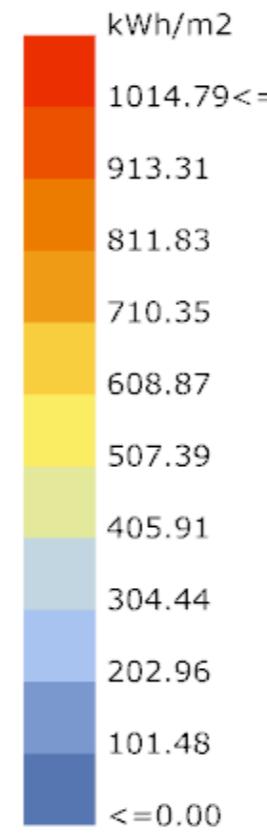
Climate Zone 4 (Except Marine)	
Ceiling R-value	38
Wood Frame Wall R-value	13
Mass Wall R-value ⁱ	5/10
Floor R-value	19
Basement Wall R-value ^c	10/13
Slab R-value ^d , Depth	10, 2 ft
Crawlspac Wall R-value ^c	10/13
Fenestration U-Factor ^b	0.35
Skylight U-Factor ^b	0.60
Glazed fenestration SHGC ^{b, e}	NR



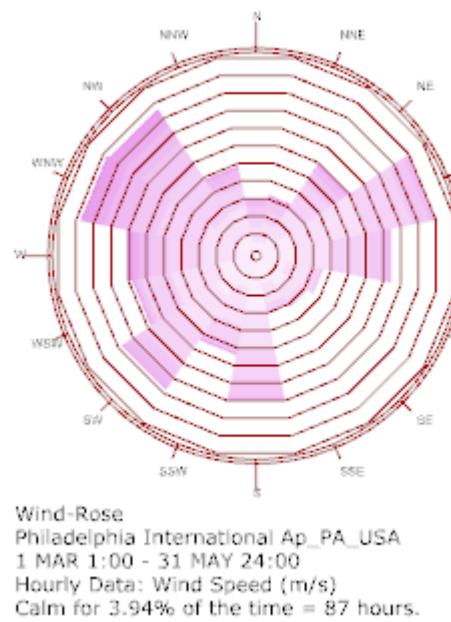
Solar Radiation



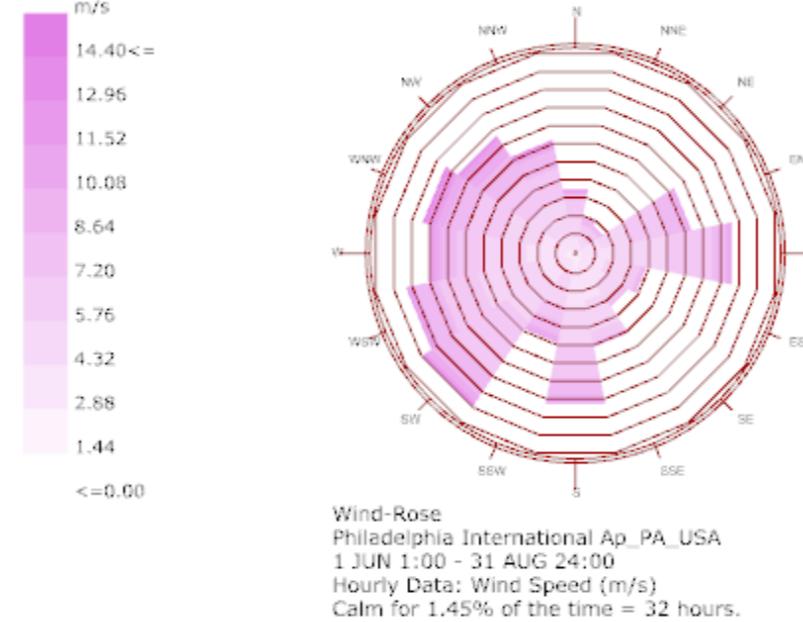
Most Solar Radiation come from the southern direction. There is little solar radiation gain from the northern part.



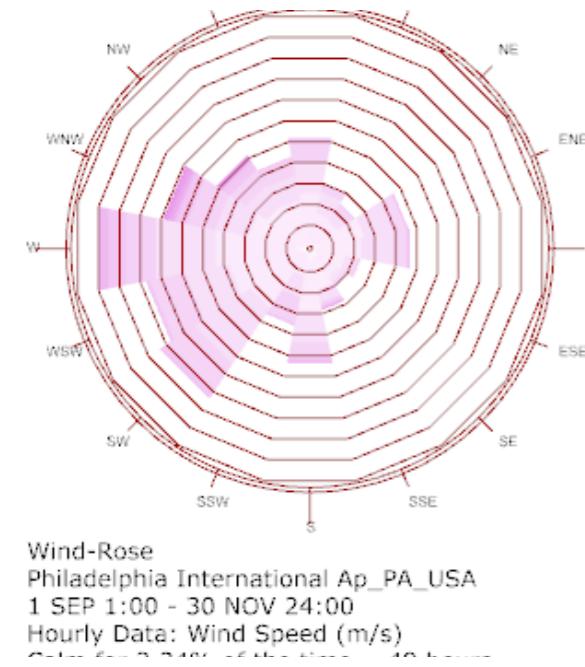
Wind Frequency



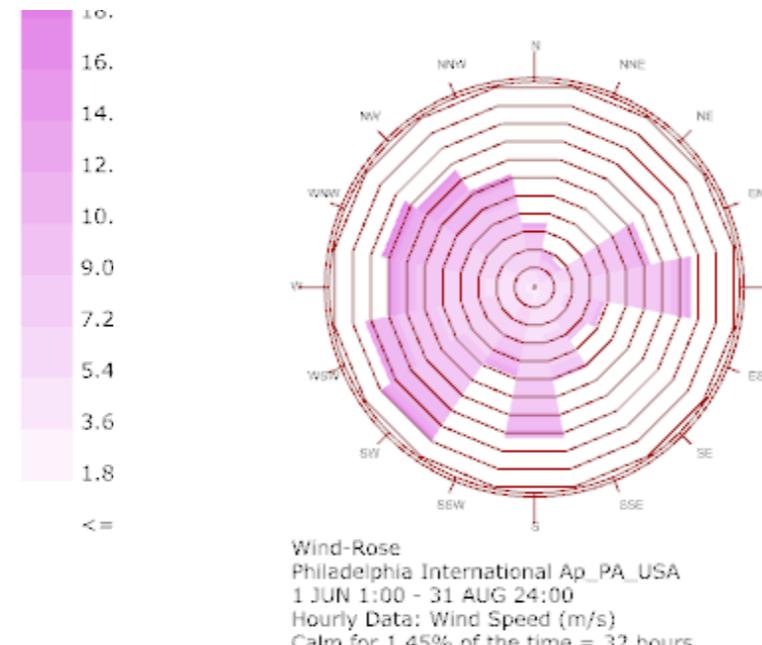
Spring Wind Frequency



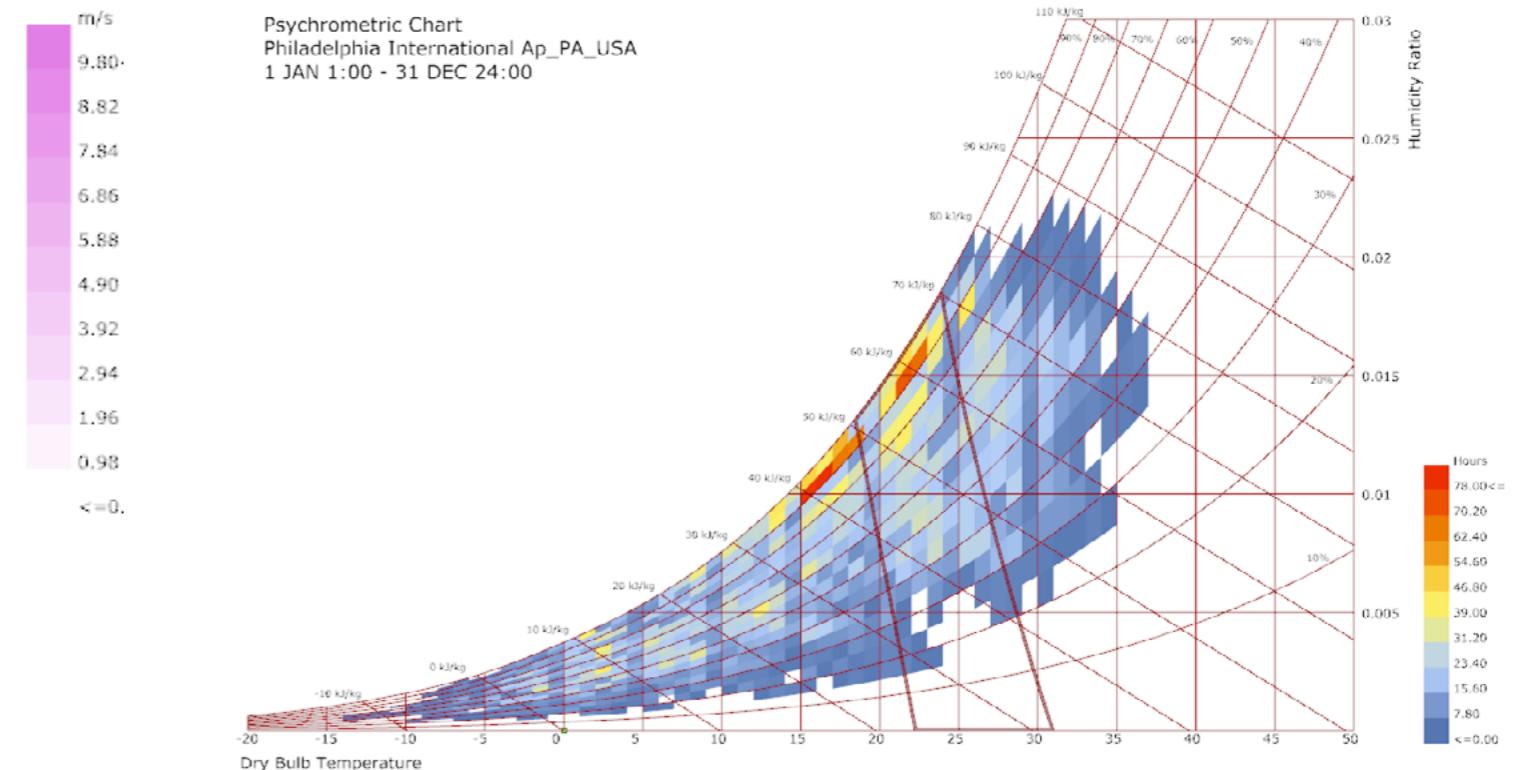
Summer Wind Frequency



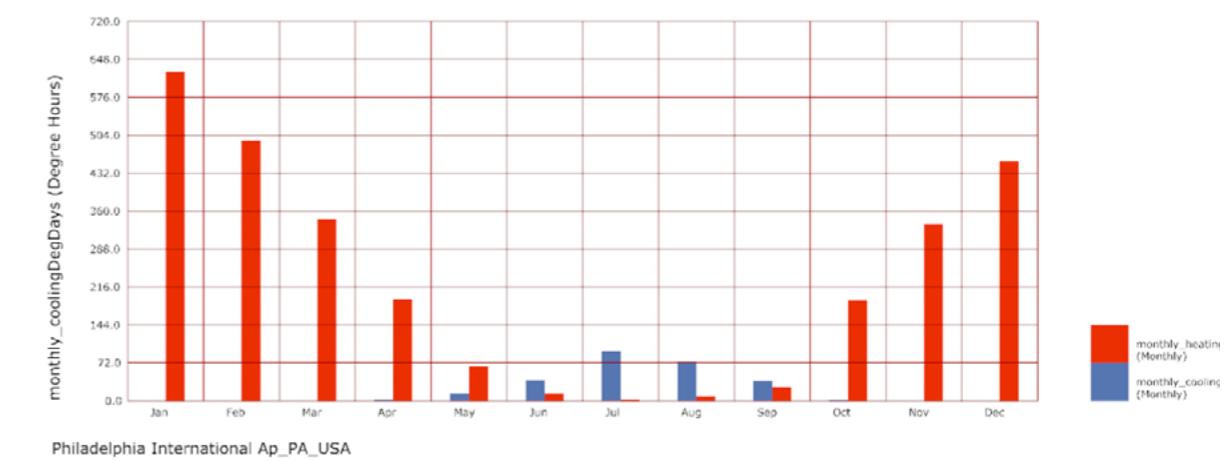
Autumn Wind Frequency



Winter Wind Frequency



Psychrometric Chart



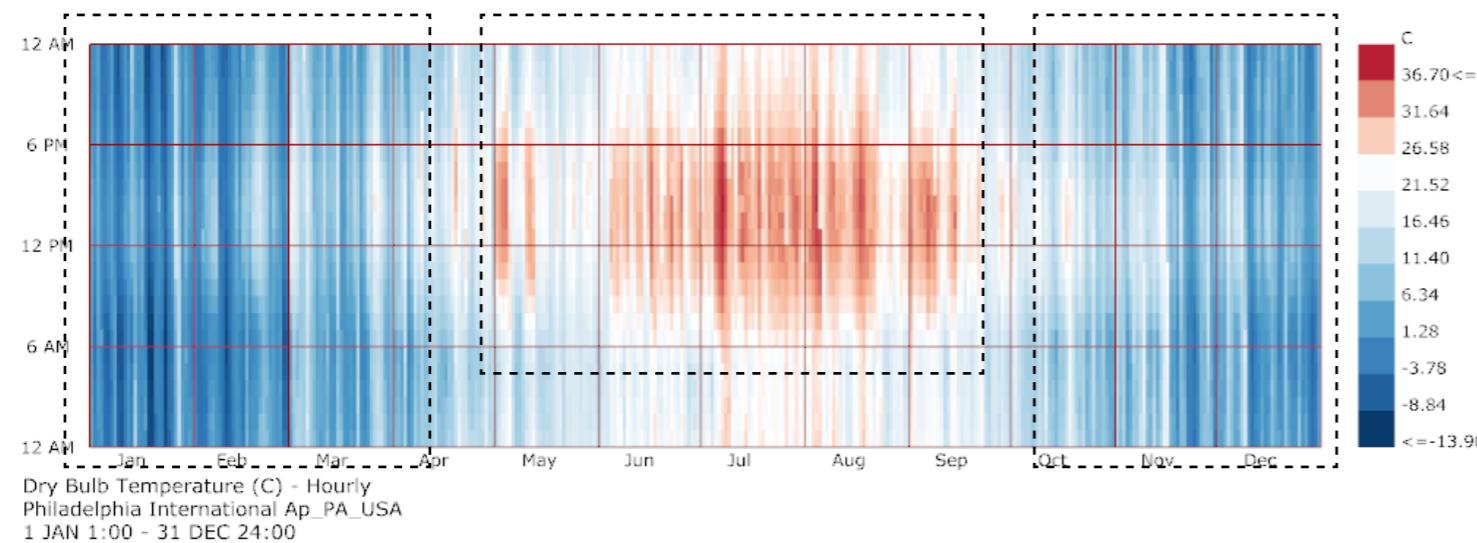
Monthly Heating and Cooling Degree Days

From two charts above, we can see that Philadelphia has a lot of cold days from November to April. And also during summer, there are hot days especially from July to August. The Heating degree days is higher than Cooling degree days. Thus, how to get the maximum solar energy gain is one of the main concern of increasing annual comfort days of the dream room.

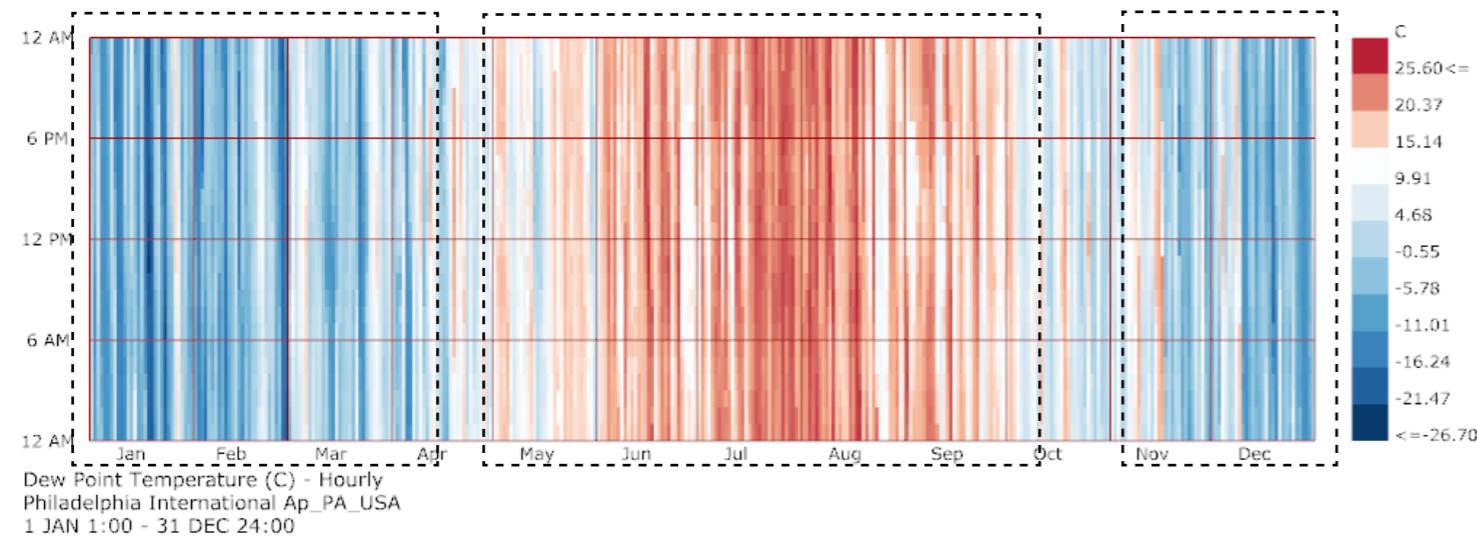
From the wind frequency chart, we could see that there is a high rate of south west to east wind through the whole year, thus introducing openings at this direction during summer time may help increase ventilation and evaporation to decrease the high temperature in the room.

Exterior Factors

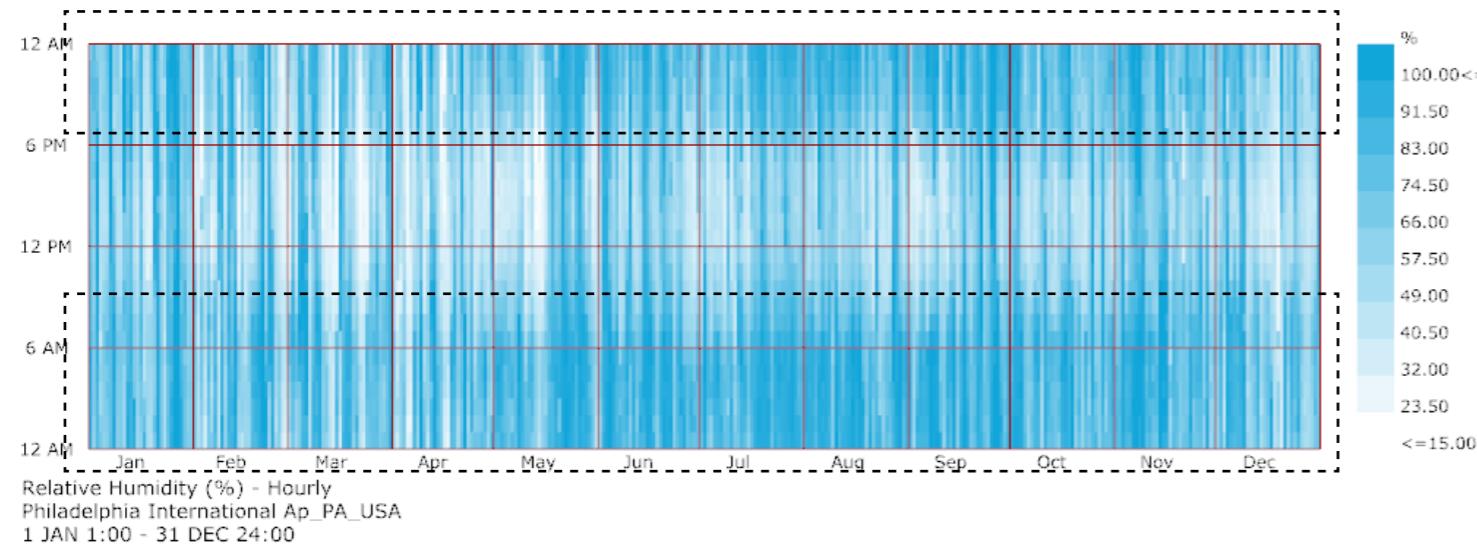
Dry Bulb Temperature



Dew Bulb Temperature



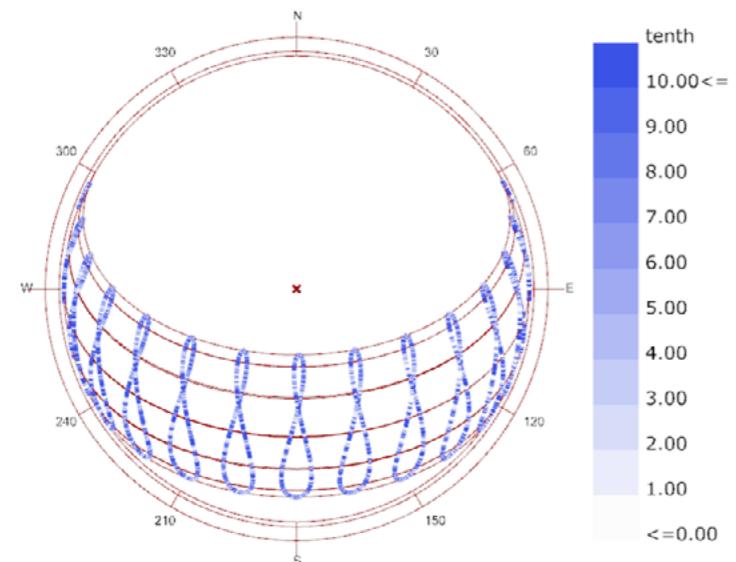
Relative Humidity



From the TMY3 data, we could know that the temperature in Philadelphia has a extreme difference between winter and summer time. From June to September, the temperature is mainly between 26 - 36 celsius degree. However, during winter time, the temperature is mainly bewteen - 13 to 6 celsius degree. According to the chart of relative humidity, the humidity is relatively high during nighttime than in daytime through the whole year. The high ratio of relative humidity increase the heat stress during summer time, especially at nighttime, and decrease part of the cold stress in winter time. Besides, the buidling type of this project is residential apartment, and the main occupied hour is from 6pm to 8am, in which the outside temperature is not as high as daytime. Thus, introduce evaporative strategy by increasing the ventilation of the room during summer time, especially during night can help get more comfort hours in the dream room.

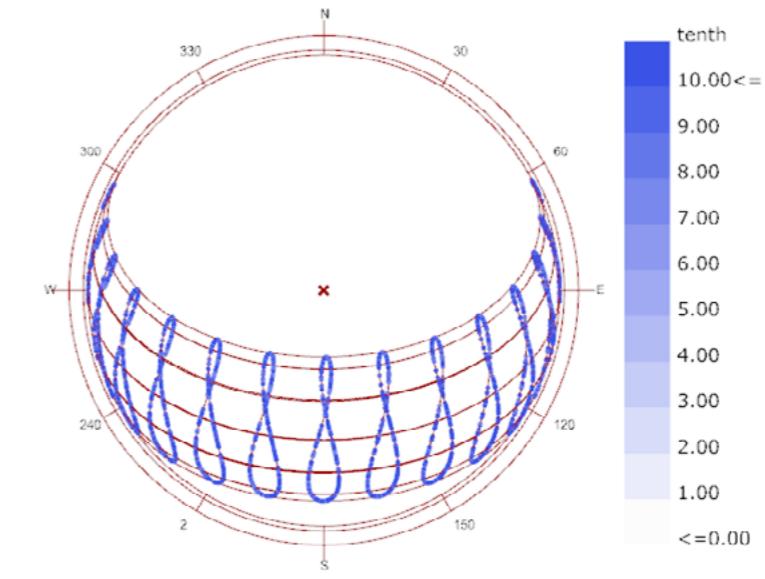
Sun Path

Annual Sun Positions



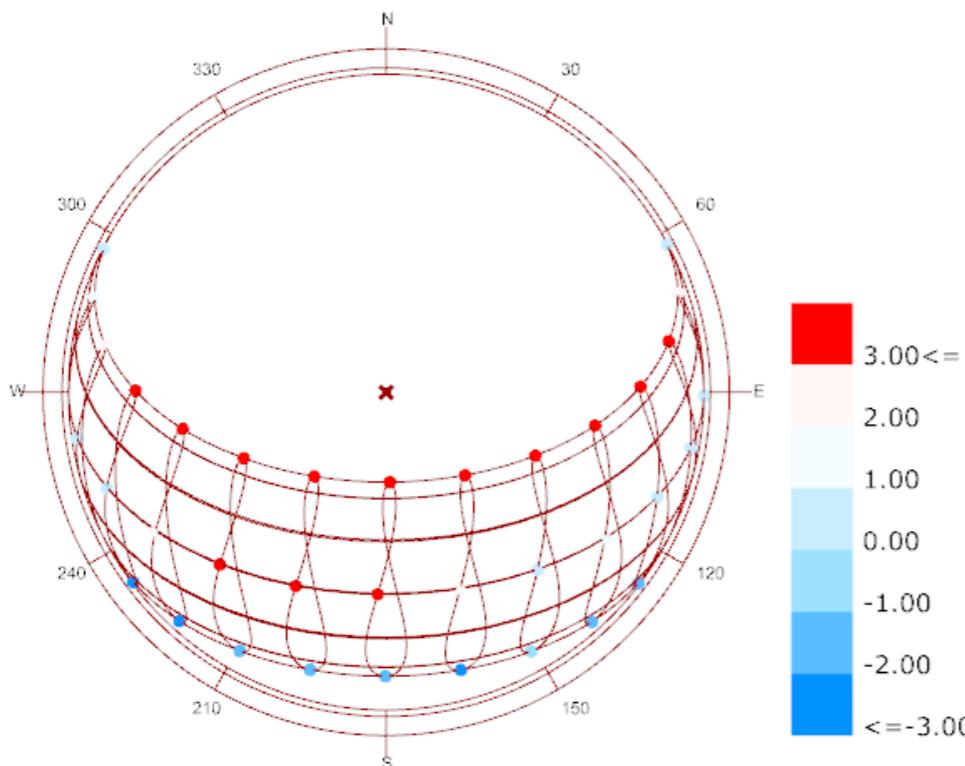
Sun-Path Diagram - Latitude: 39.87
Hourly Data: Total Cloud Cover (tenth)
Philadelphia International Ap_PA_USA

Sun Positions (Sky Cover >6)



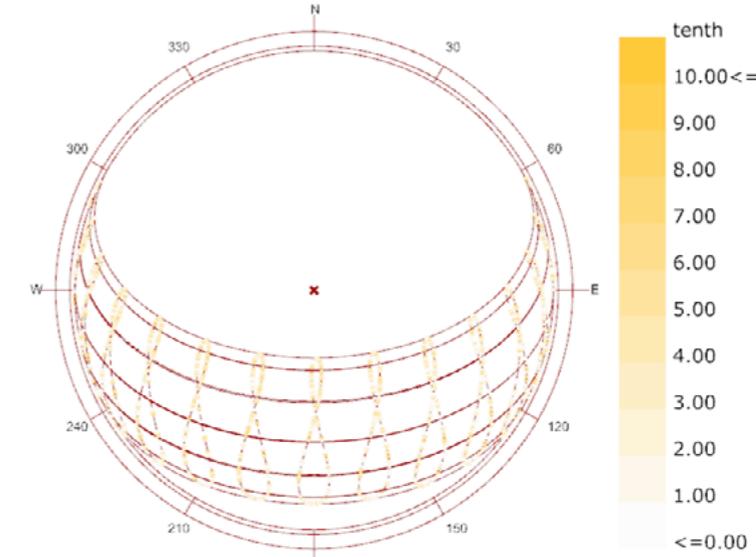
Sun-Path Diagram - Latitude: 39.87
Hourly Data: Total Cloud Cover (tenth)
Philadelphia International Ap_PA_USA
...
Conditional Selection Applied:
Total Cloud Cover>6
2324.0 hours of total 4398.0 sun up hours(52.84%).

Annual Comfort on Sun Path



Sun-Path Diagram- Latitude : 39.87
Hourly Data: Ourdoor Comfort (-3 = Extreme Cold | -2 = Cold | -1 = Cool | 0 = Comfort |
1 = Warm | 2 = Hot | 3 = Extreme Hot)
Philadelphia International Ap_PA_USA

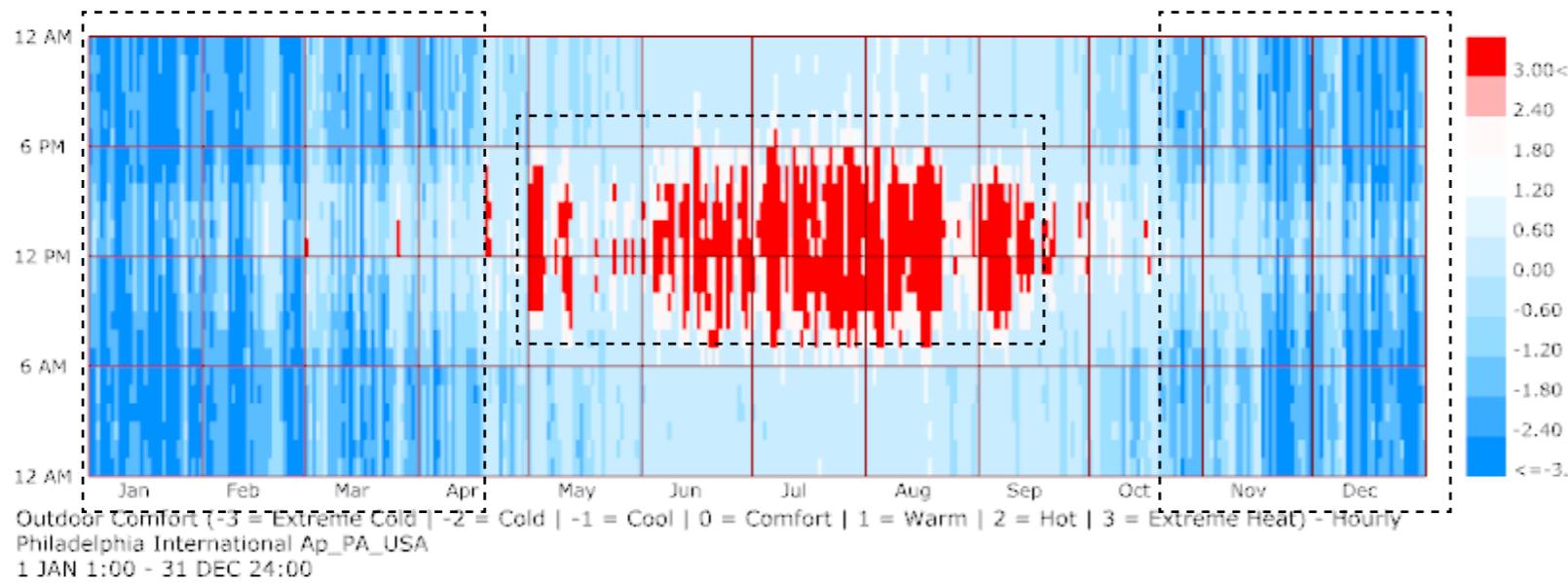
Sun Positions (Sky Cover <6)



Sun-Path Diagram - Latitude: 39.87
Hourly Data: Total Cloud Cover (tenth)
Philadelphia International Ap_PA_USA
...
Conditional Selection Applied:
Total Cloud Cover<6
1858.0 hours of total 4398.0 sun up hours(42.25%).

UTCI

UTCI Range (Temperature, RH%, Wind Speed, MRT)

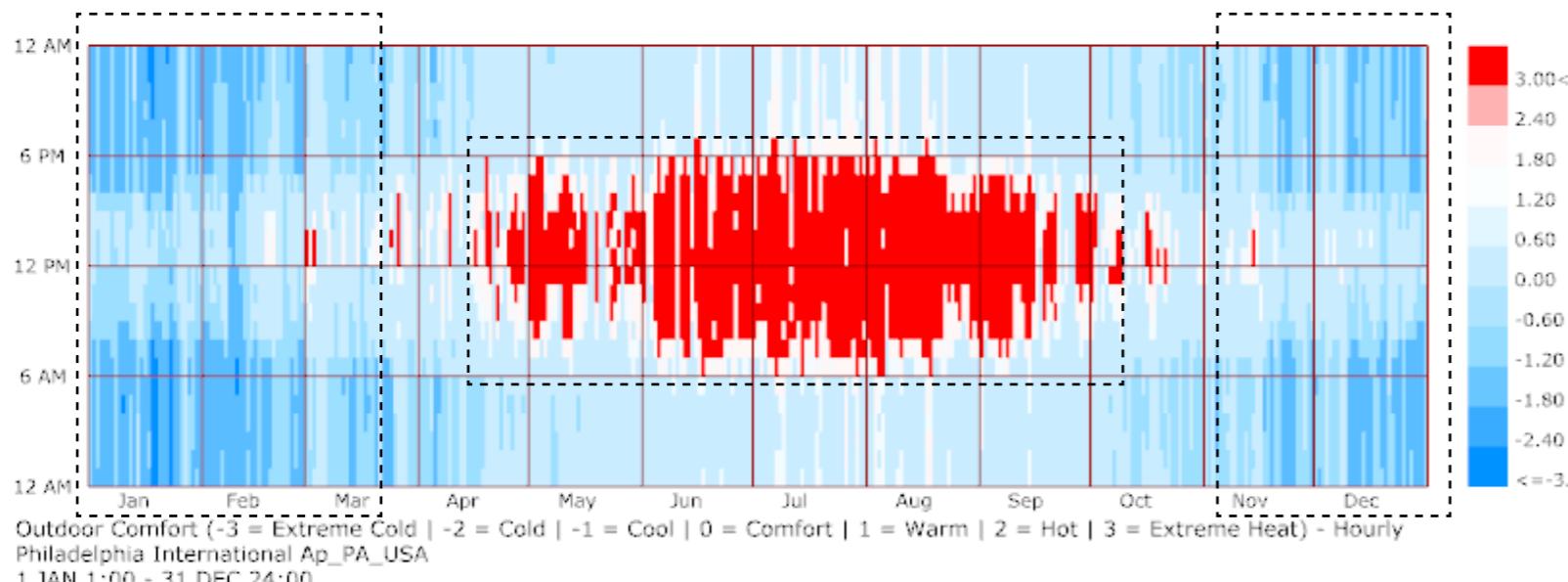


Percent of Time Comfortable: **37.34**

Percent of Heat Stress: 12.51

Percent of Cold Stress: 31.64

UTCI Range (Temperature, RH%, MRT)



Percent of Time Comfortable: **45.38**

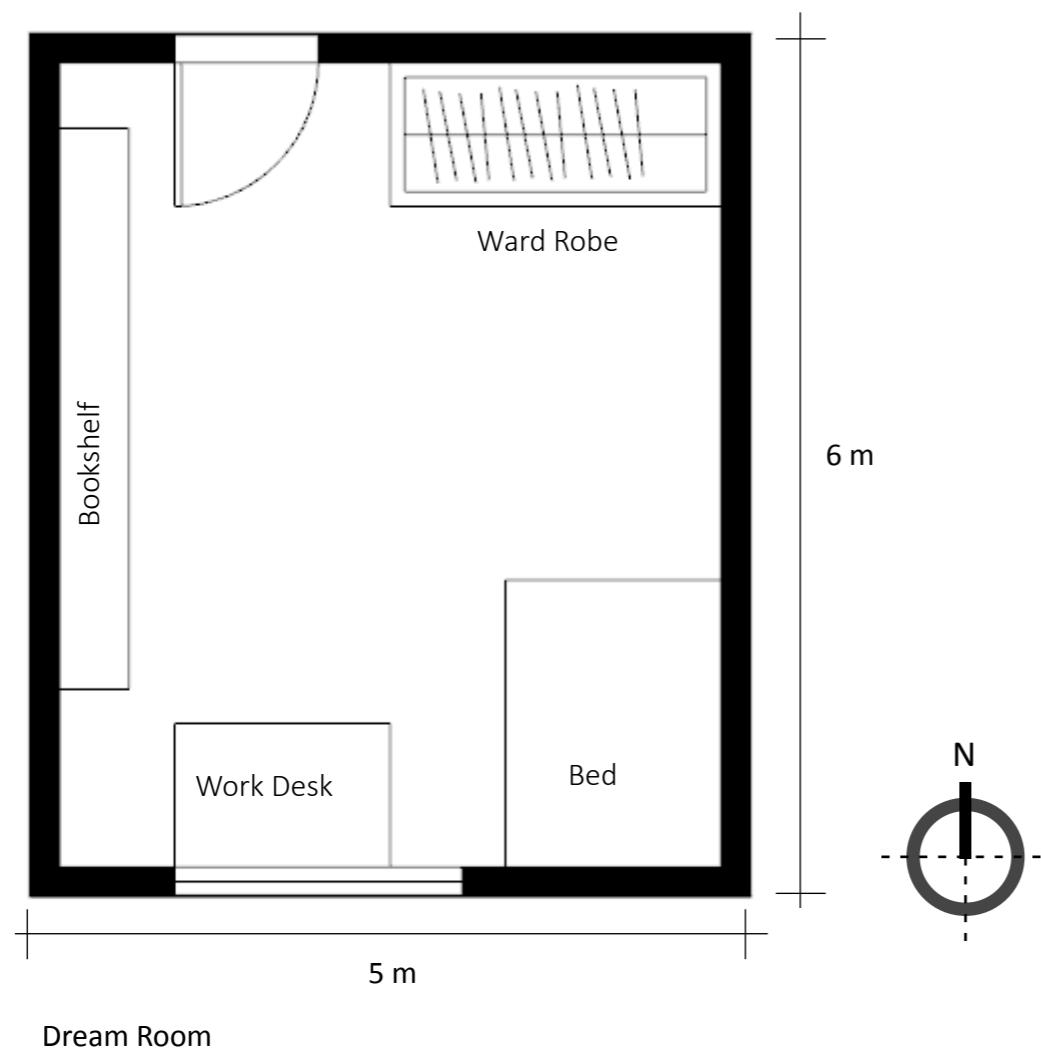
Percent of Heat Stress: 20.19

Percent of Cold Stress: 11.42

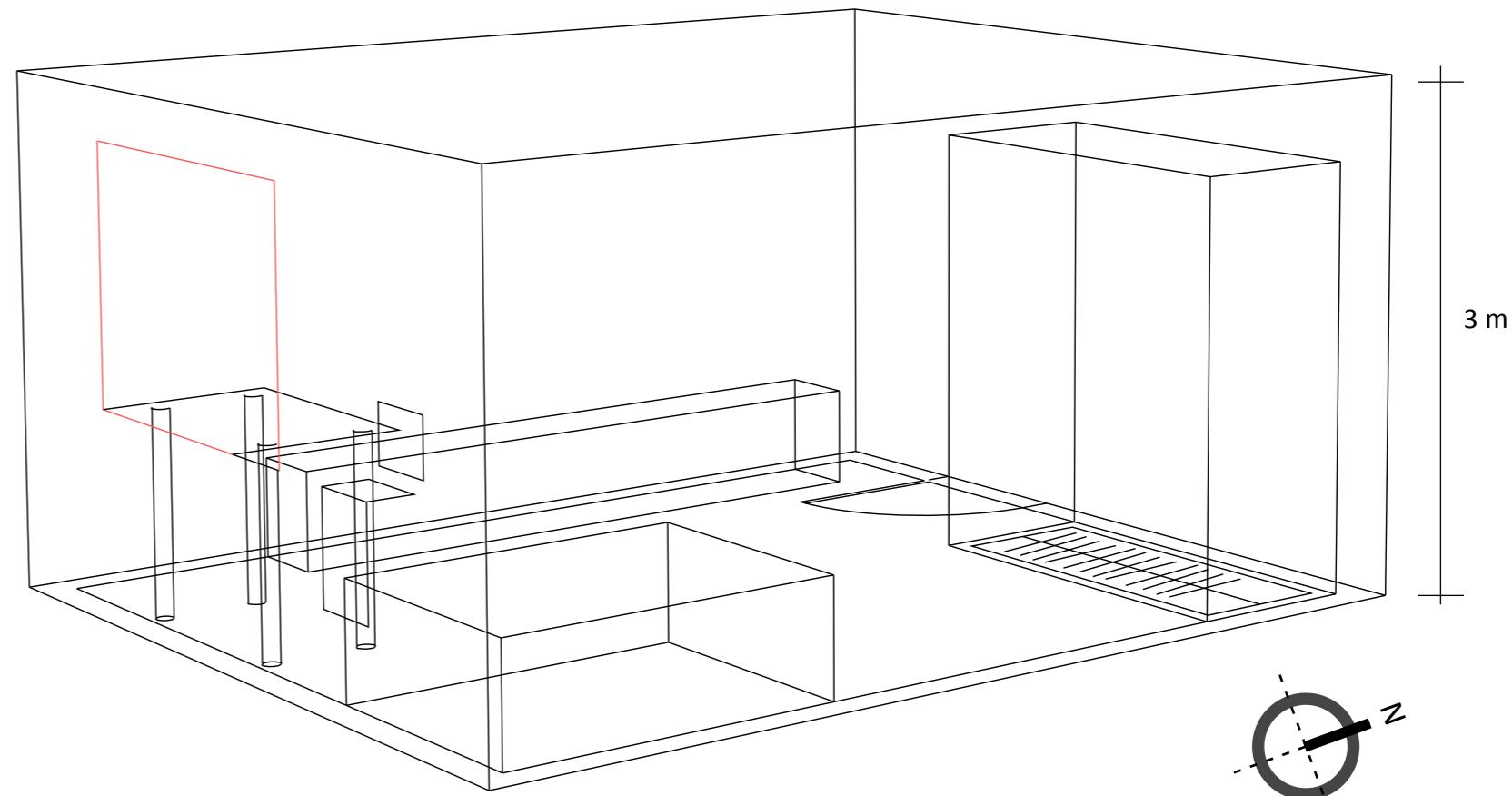
UTCI, is Universal Thermal Climate Index, meaning the temperature of what the weather “feels like” and it takes into account radiant temperature(usually including solar radiation),relative humidity, wind speed and uses them in a human energy balance model to give a temperature value that is indicative of the heat stress or cold stress felt by the human body.”

From the UTCI mapping on the left, the main issue is there is strong cold stress during winter time and also a high portion of heat stress during the daytime in summer. The annual comfortable time increases from 37.34 to 45.38 when not considering local wind condition. Therefore, prevent passive ventilation during winter and introduce it during summer time may help increase more interior comfort time.

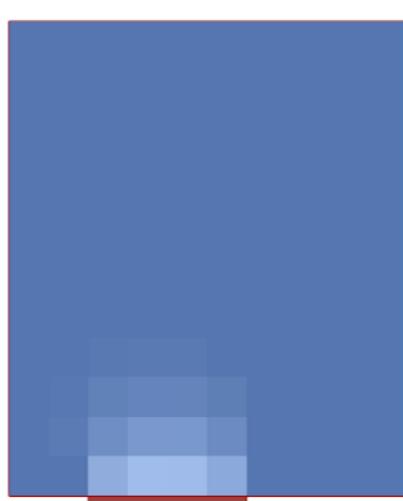
Dream Room Model



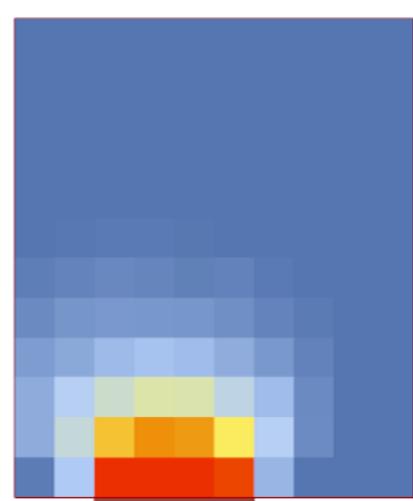
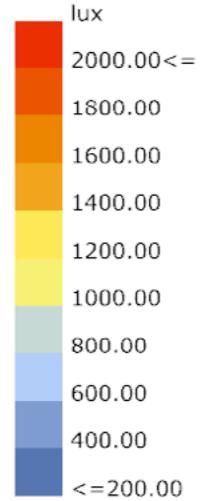
Area: 30 m²
Glazing Area: 3m²
Orientation: South 0 Degree
Program: Midrise Apartment
Occupied Hour: 6PM- 8AM



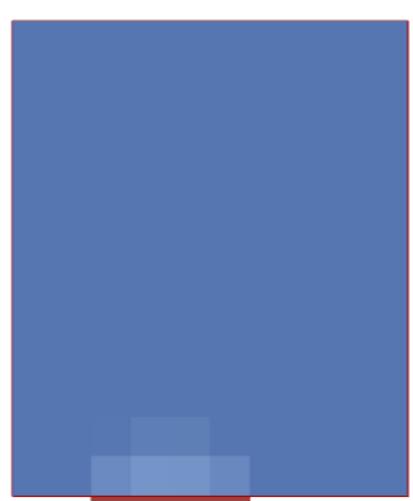
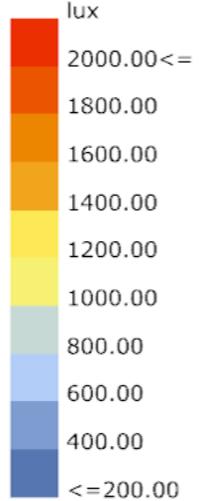
Daylight Simulation



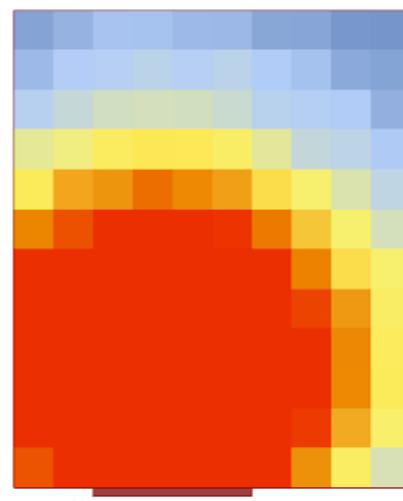
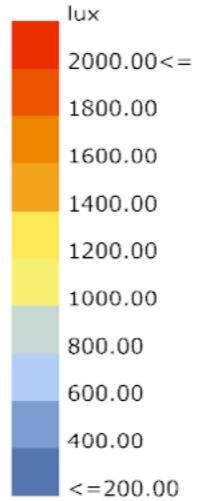
21 March 9:00 am



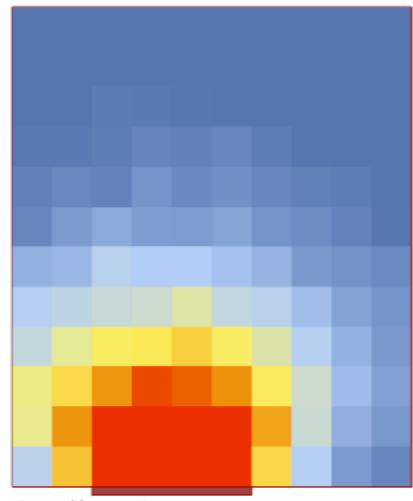
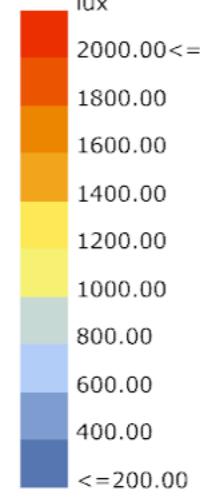
21 June 9:00 am



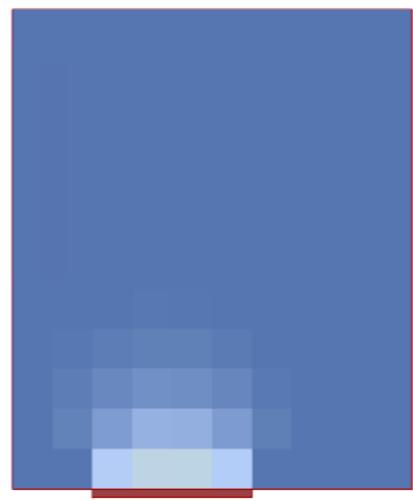
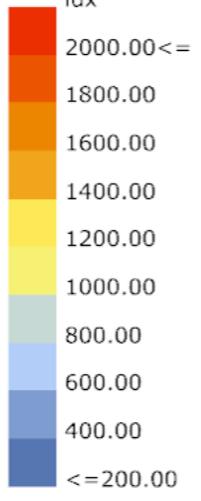
21 Dec 9:00 am



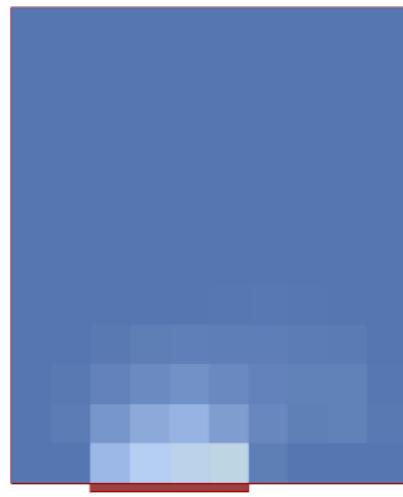
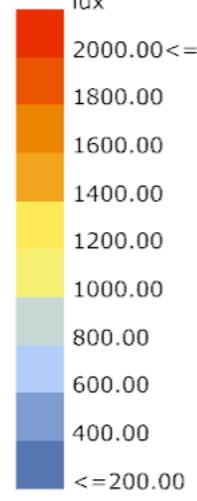
21 March 12:00 am



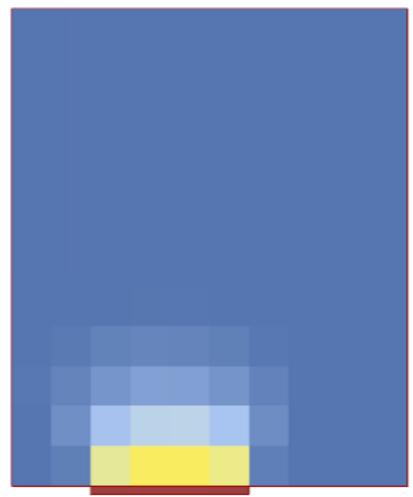
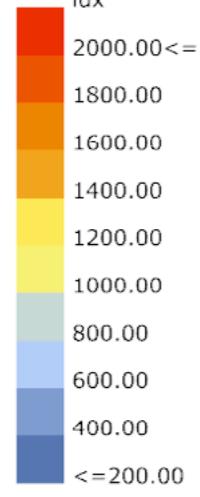
21 June 12:00 am



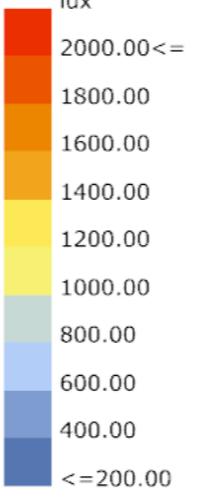
21 Dec 12:00 am



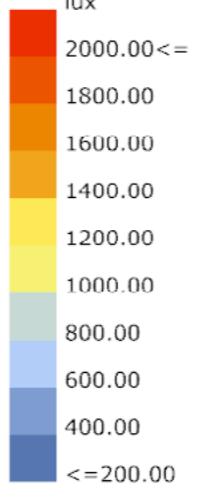
21 March 17:00 am



21 June 17:00 am



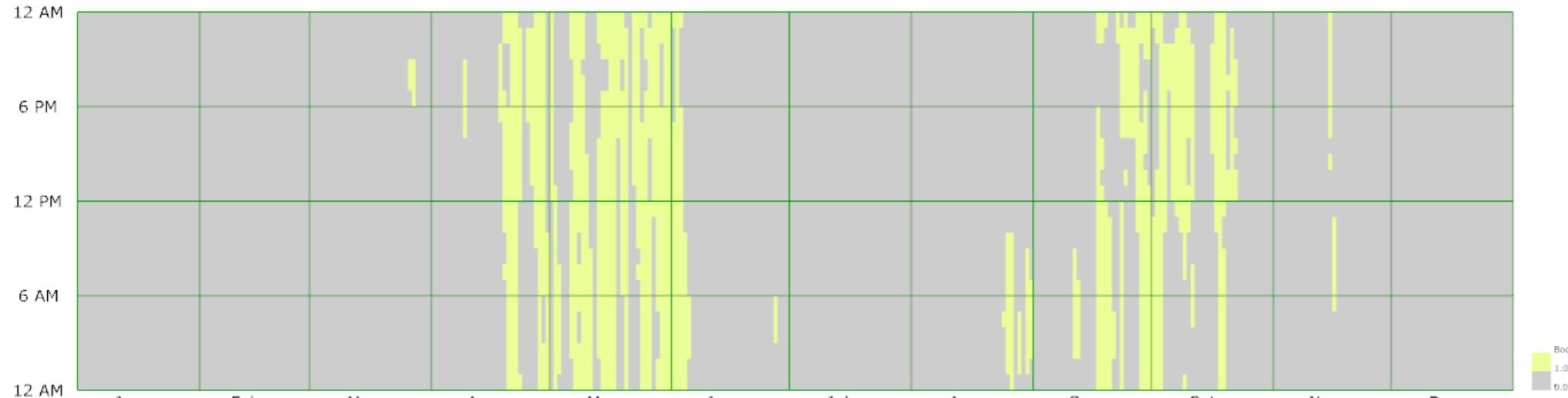
21 Dec 17:00 am



From annual daylight simulation, we could find that the northern part of the room can not get enough daylight through the whole year. And at the window front, which is the southern part of the room may have some glare issues around noon from spring to summer. As the main occupied hour of the apartment is from 8PM to 8AM, daylight problem is not the main issue of the room. However, introducing proper openings at the northern wall to get more daylight under the condition of increasing natural ventilation and solar gain in cold seasons would be a direction for the following steps of modification.

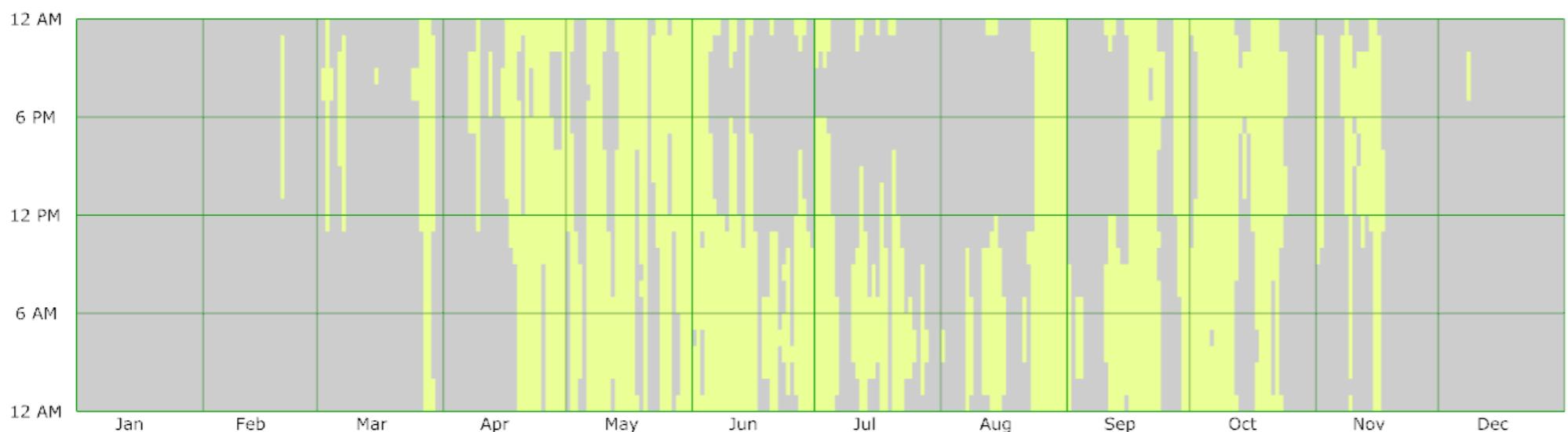
Indoor Comfort

PMV / Adaptive Comfort (without natural ventilation)



Comfortable Or Not for DREAM_ROOM_IN_PHILADELPHIA (Boolean) - Hourly
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00

Percentage of Time Comfortable(without natural ventilation) : 14

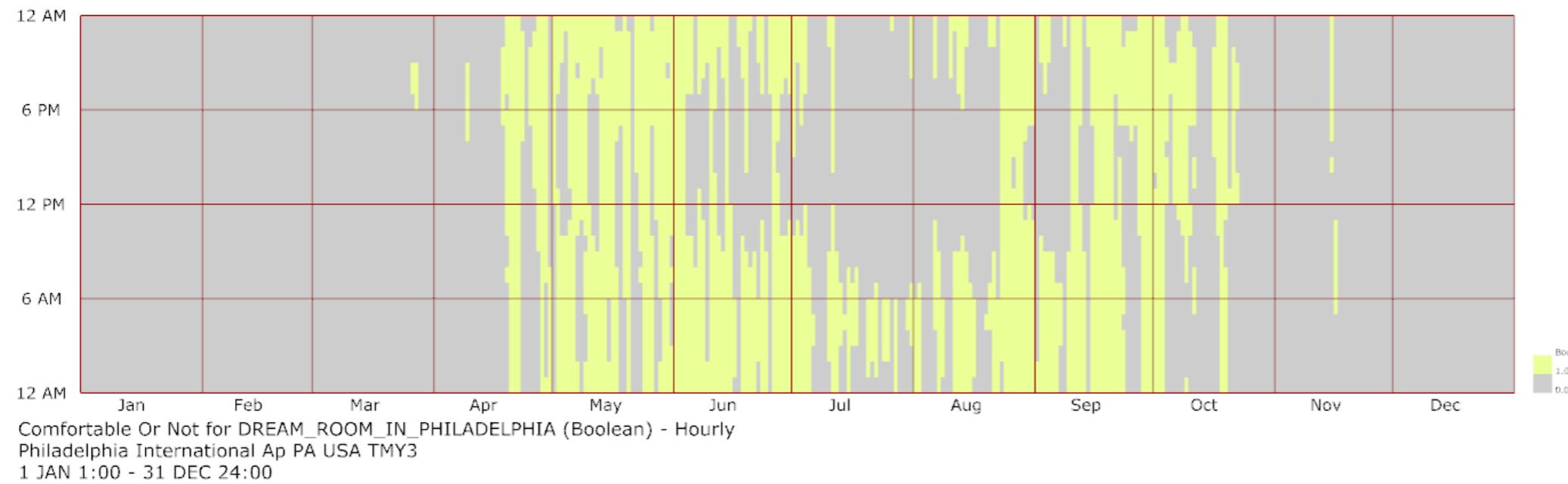


Comfortable Or Not for DREAM_ROOM_IN_PHILADELPHIA (Boolean) - Hourly
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00

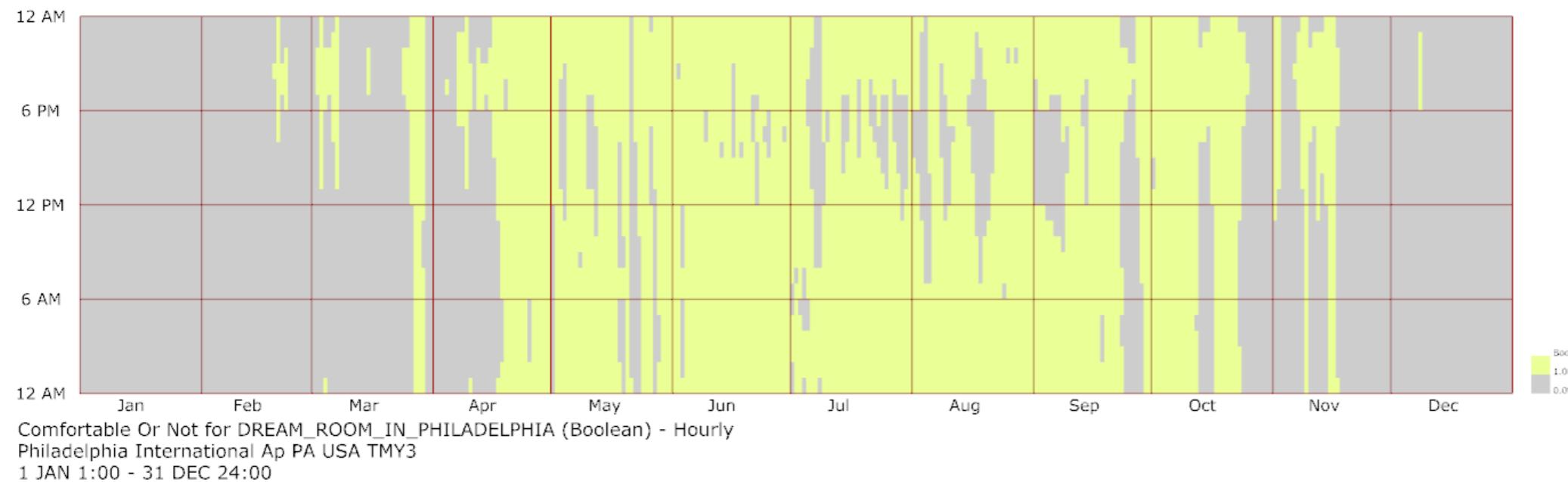
Percentage of Time Comfortable(without natural ventilation) : 32.54

Indoor Comfort

PMV / Adaptive Comfort (with natural ventilation)



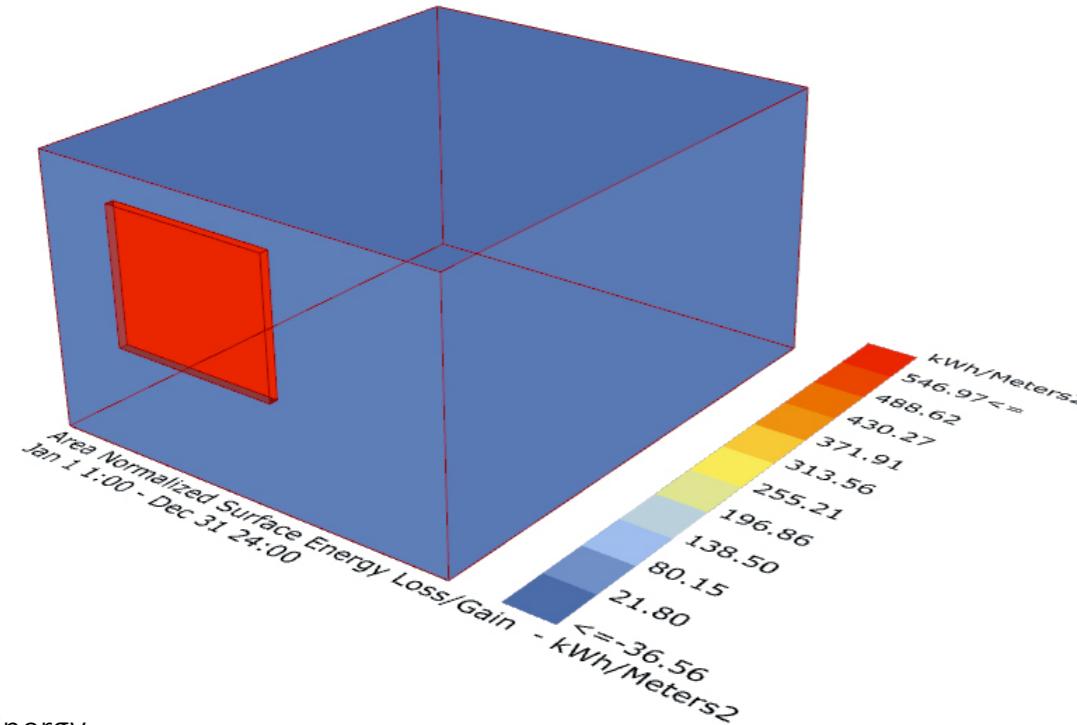
Percentage of Time Comfortable(with natural ventilation) : 26.90



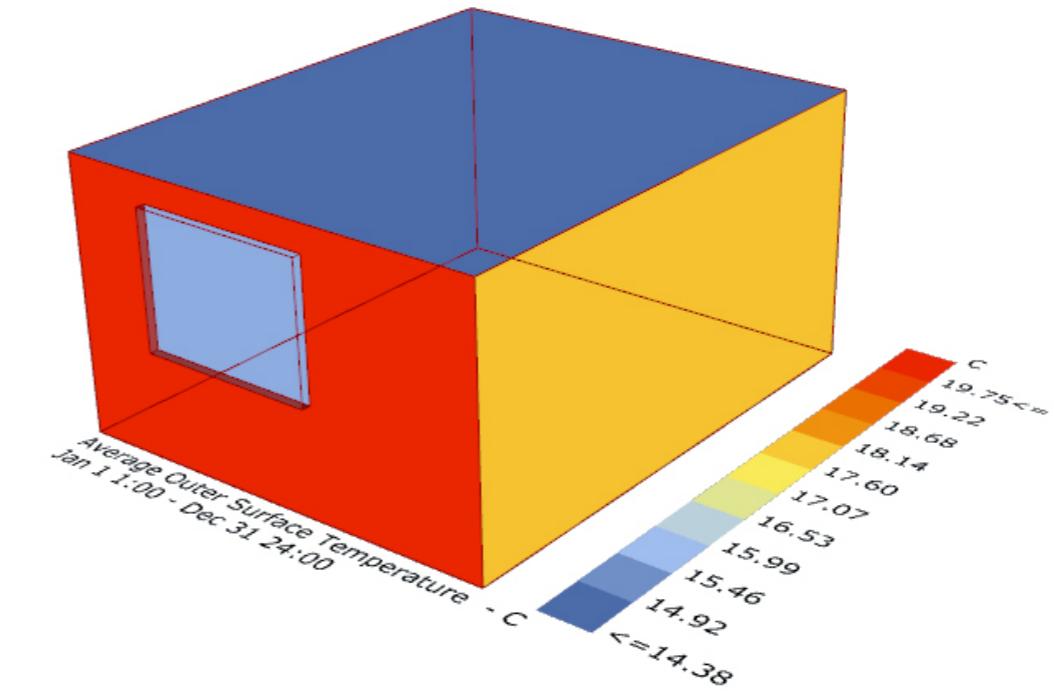
Percentage of Time Comfortable(with natural ventilation) : 48.47

We could see from comparable charts that both of the PMV comfort and adaptive comfort are greatly increased after introducing natural ventilation into the system.

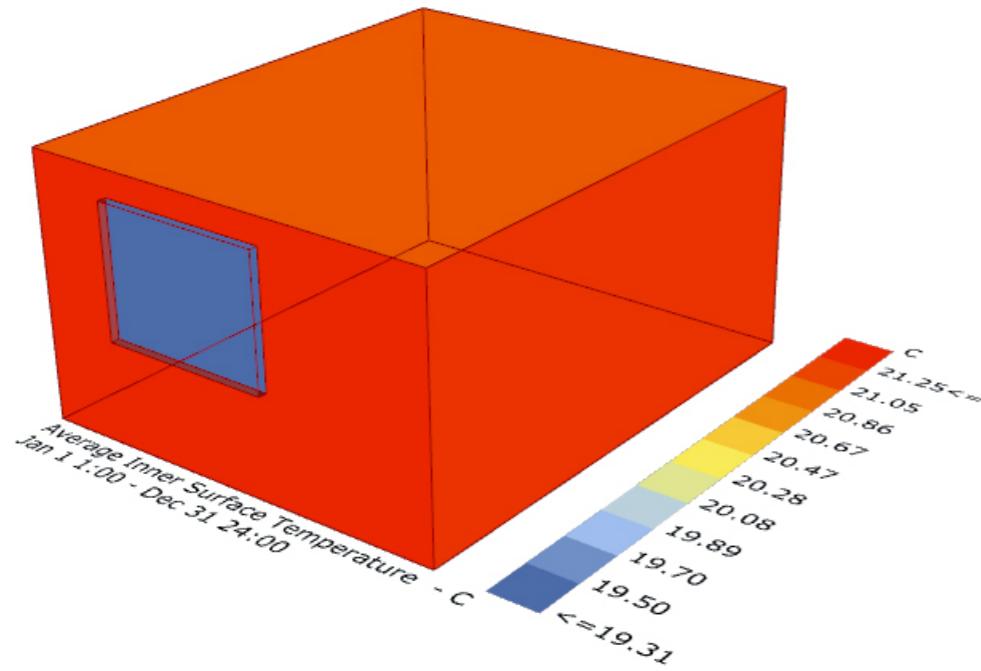
Energy Simulation



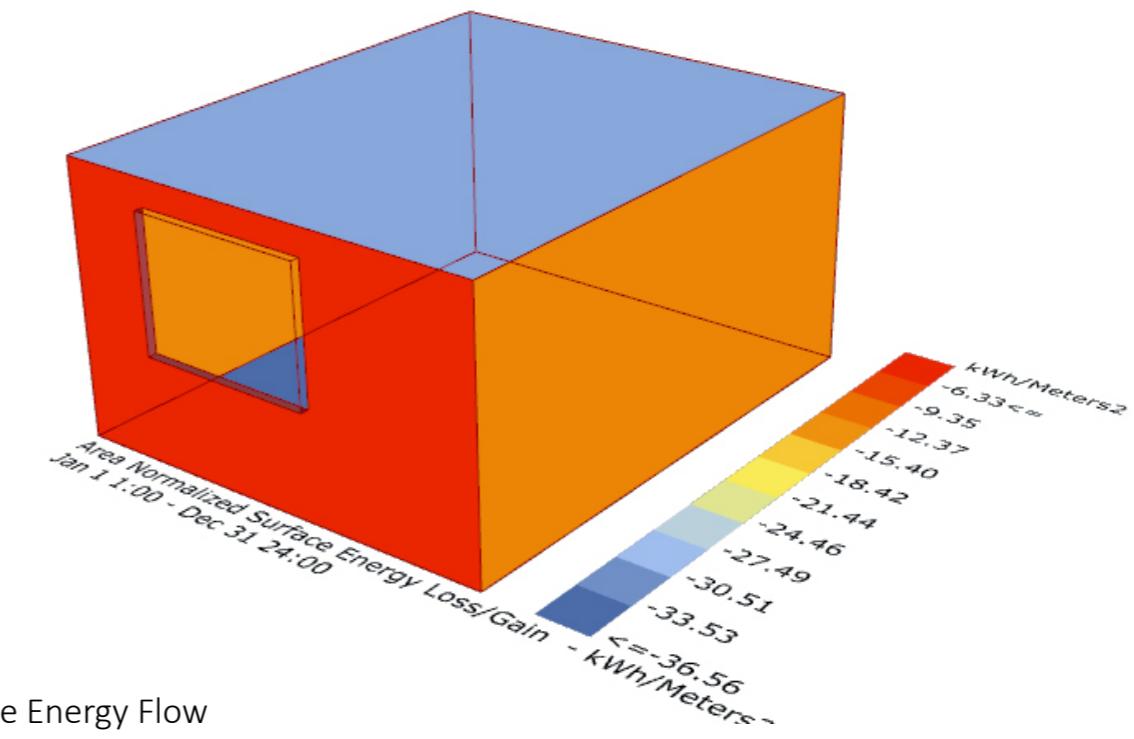
Surface Energy



Surface Outdoor Temperature



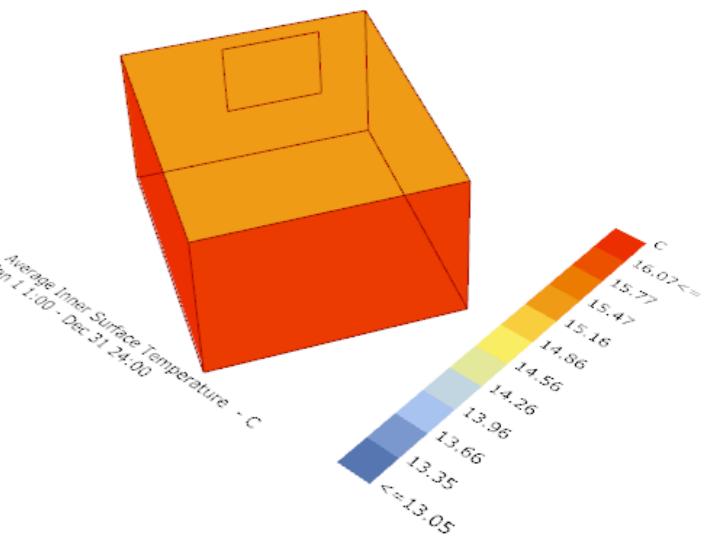
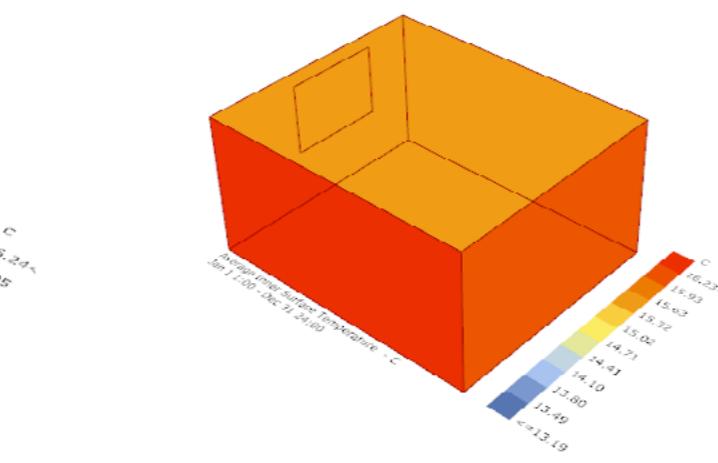
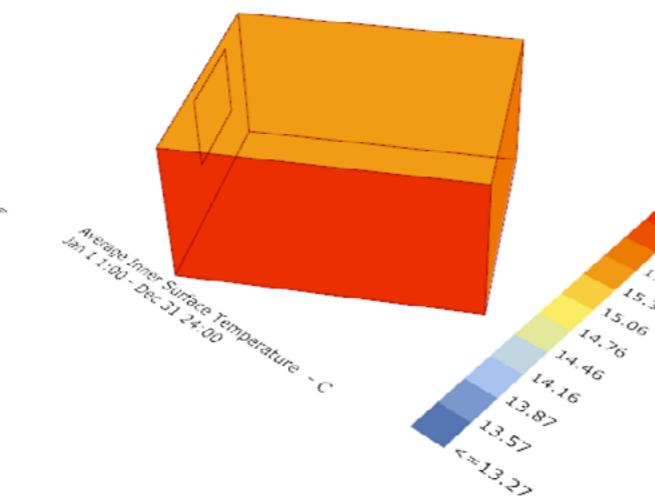
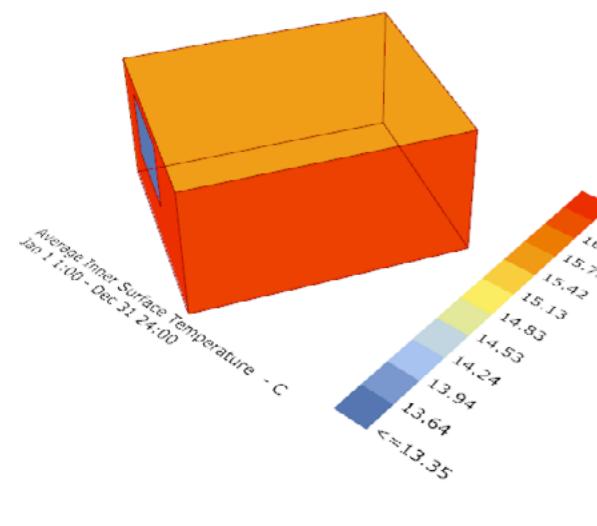
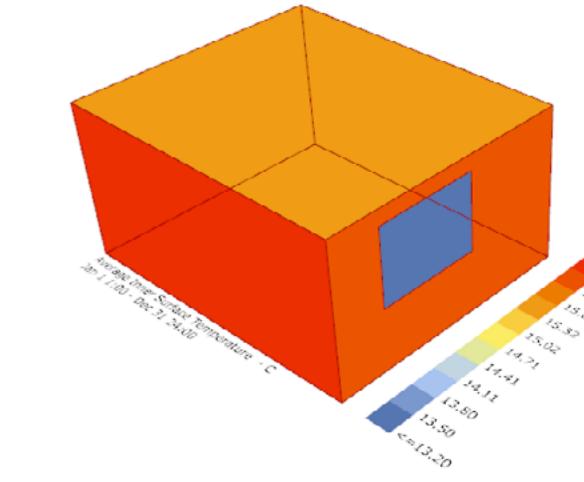
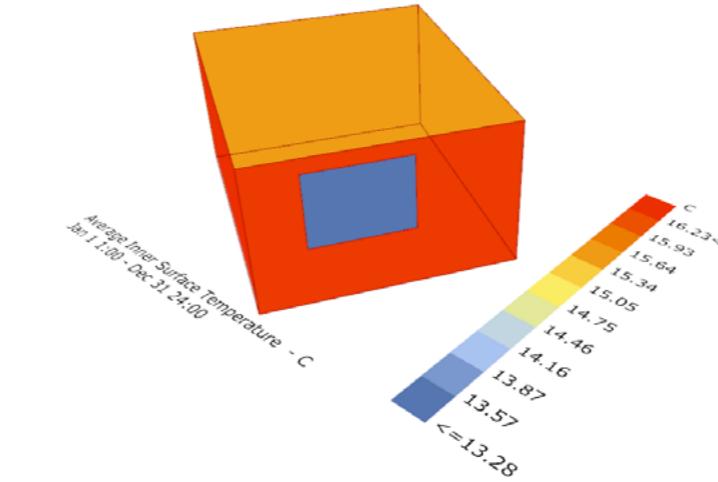
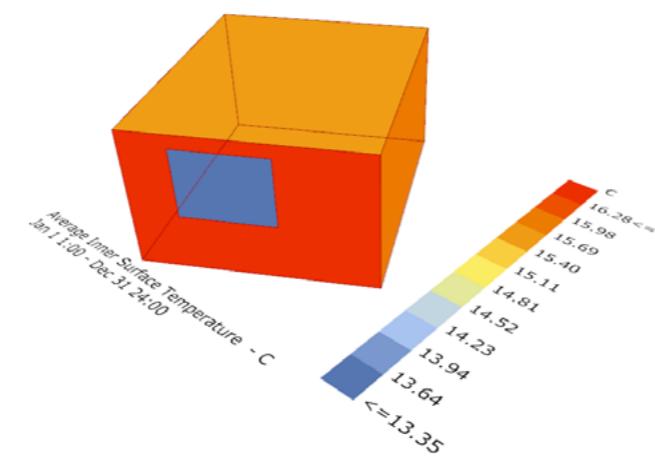
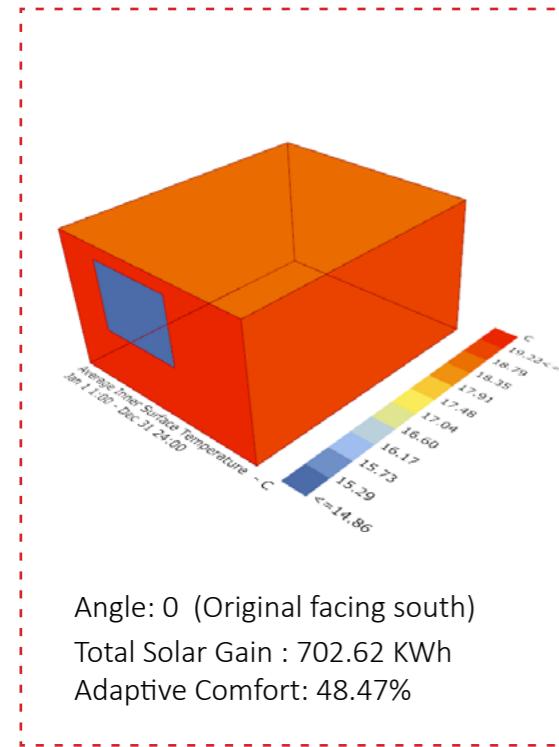
Surface Indoor Temperature



Opaque Energy Flow

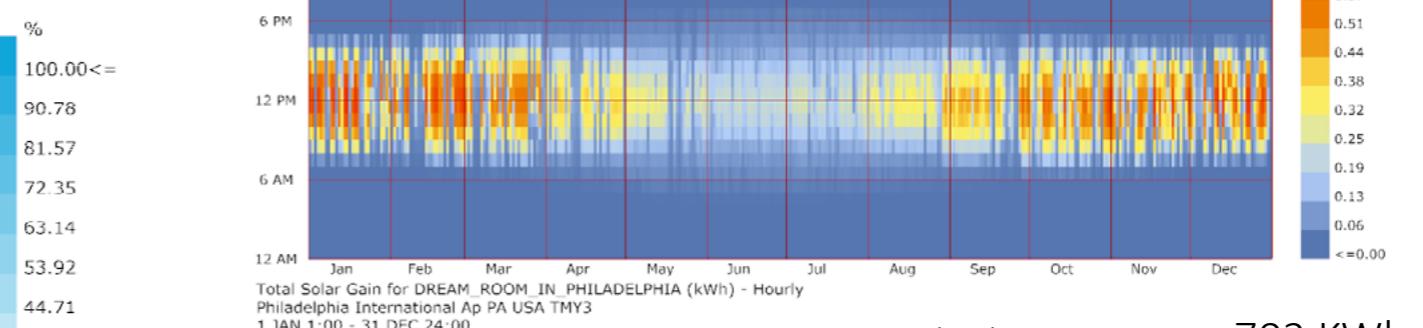
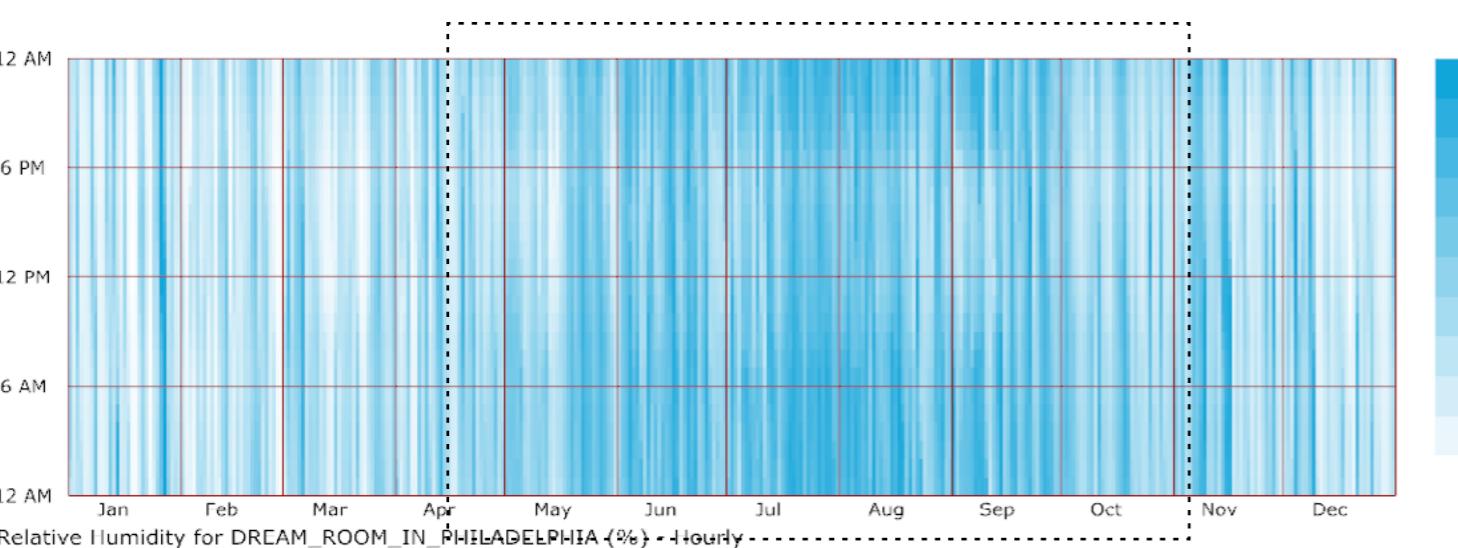
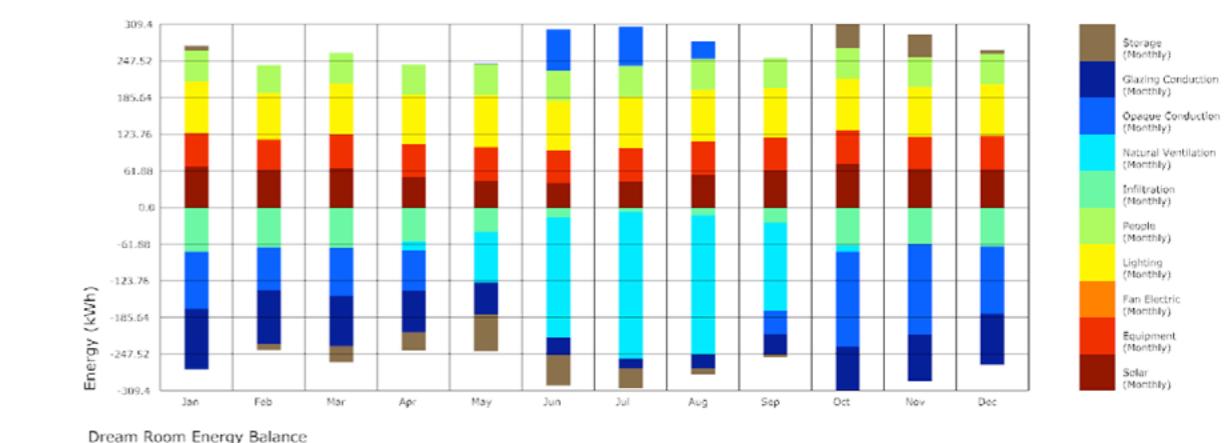
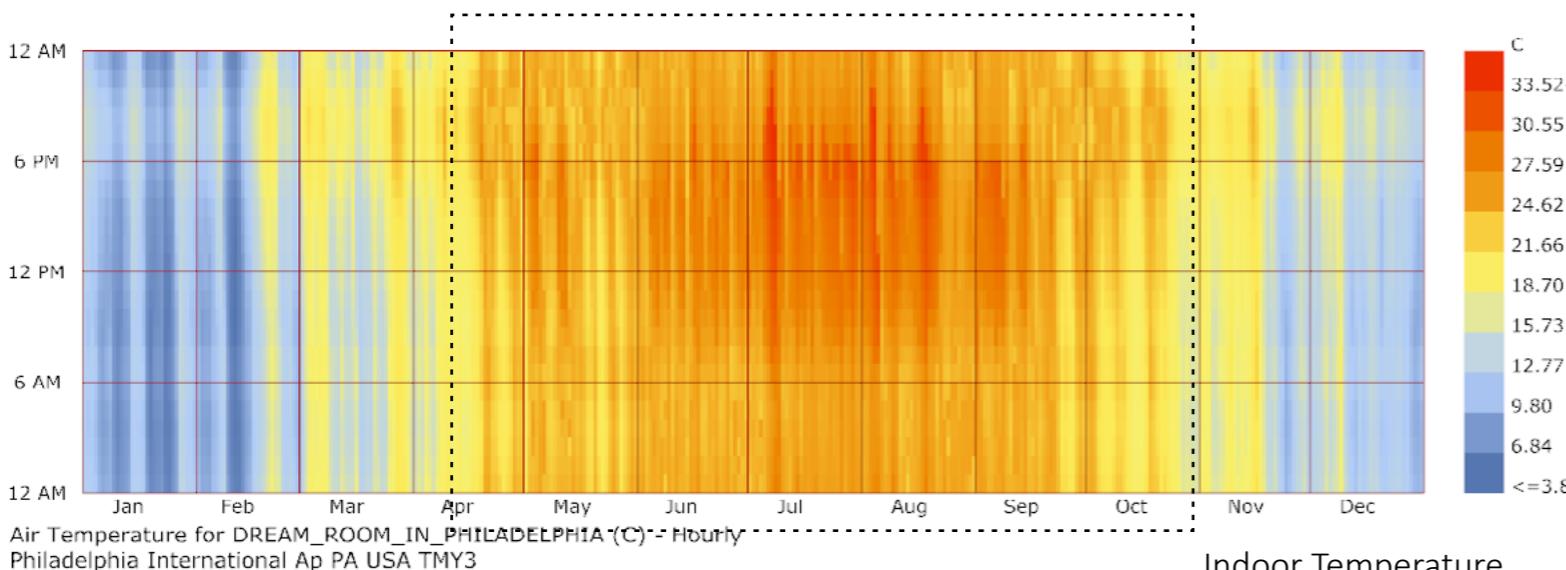
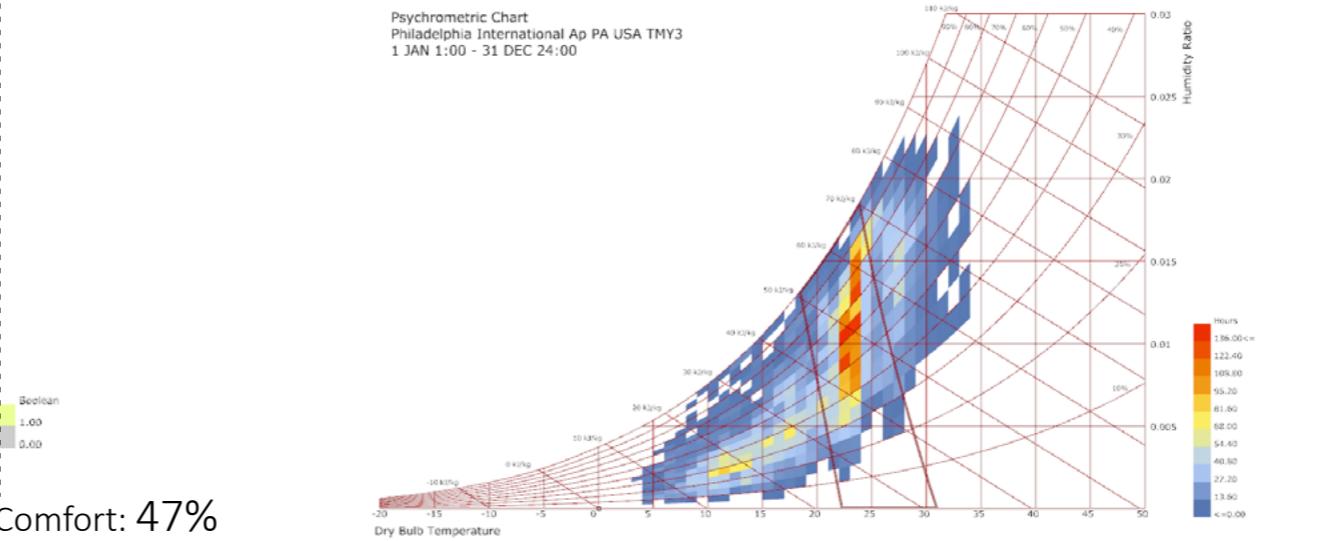
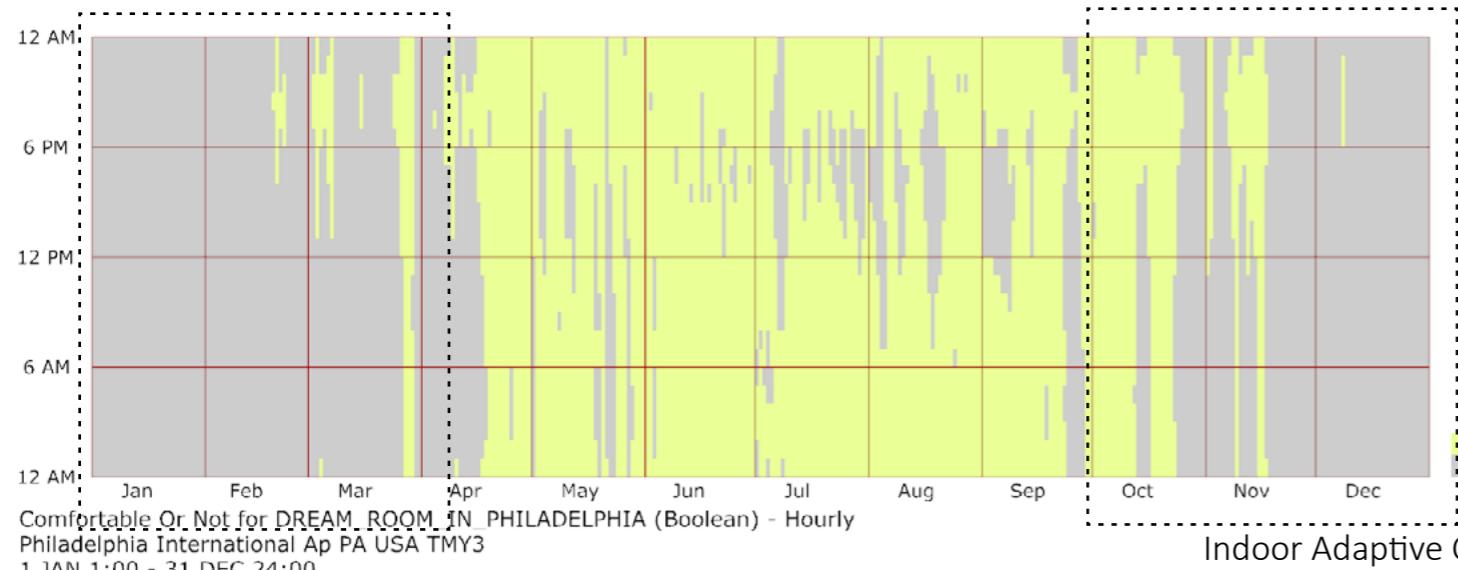
Orientation

Indoor Surface Temperature
Total Solar Gain
Adaptive Comfort



8 energy simulations have been executed with different orientations to test if orientation was going to help to increase indoor temperature, and total solar heat gain, adaptive comfort were tested as well. The original angle which face directly to the south, has the maximum total solar gain and highest adaptive comfort rate. Thus, the original orientation would be kept for the next step modification.

Indoor Factors



Total Solar Energy Gain: 702 KWh

Indoor Relative Humidity

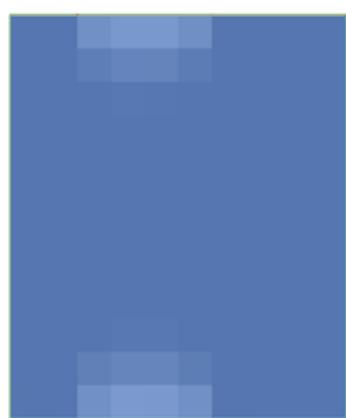
There is high ratio of heat stress and relative humidity during summer time. Besides, from January to February, there is also a strong cold stress which lead to the low comfortable time in the dream room. Next step will try to increase the opening ratio to increase evaporation and also introduce more daylight time in the room.

Increase Glazing Ratio

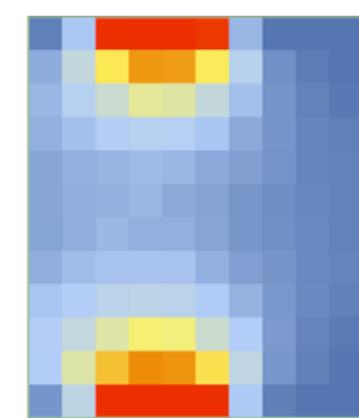
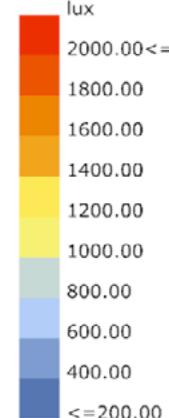
Current Ratio: 20 %

Test Ratio: 40%

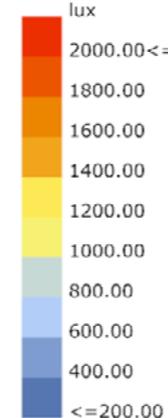
Adding another 20% openings on the northern part of the room to Increase the daylight condition in the dream room and also the ventilation rate.



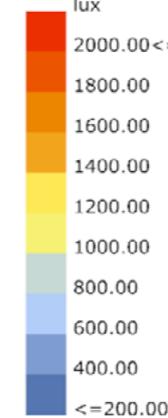
21 March 9:00 am



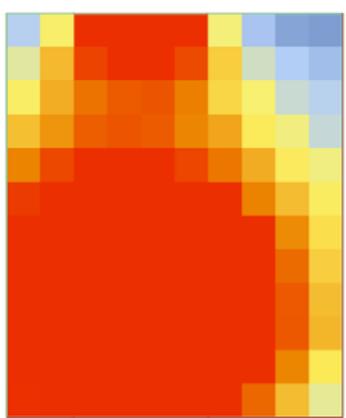
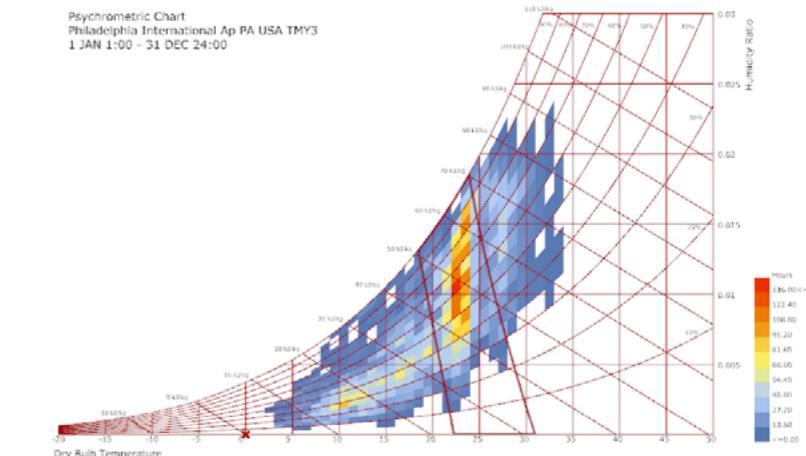
21 June 9:00 am



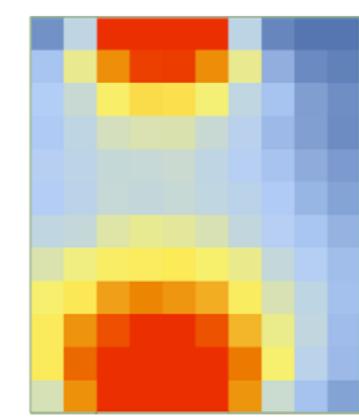
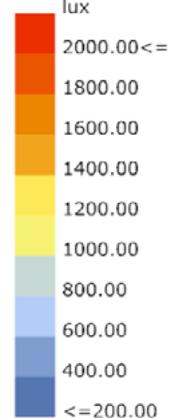
21 Dec 9:00 am



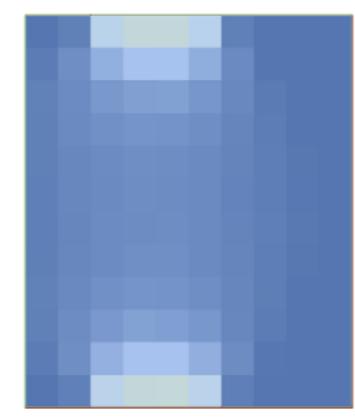
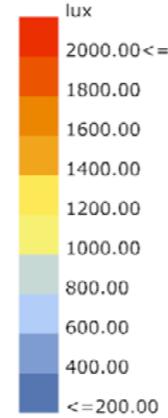
Psychrometric Chart
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00



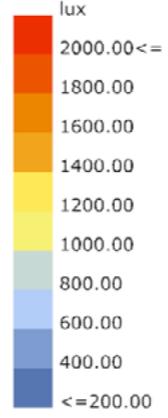
21 March 12:00 am



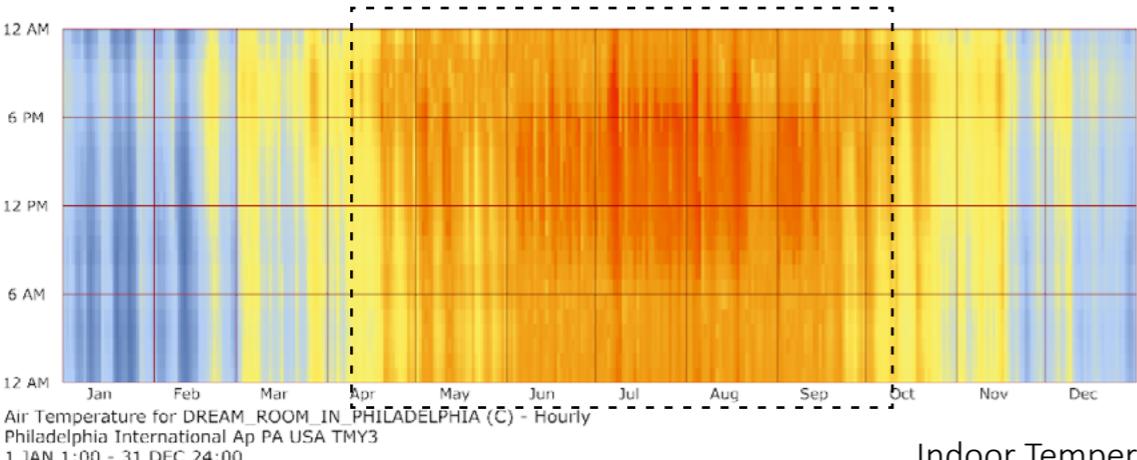
21 June 12:00 am



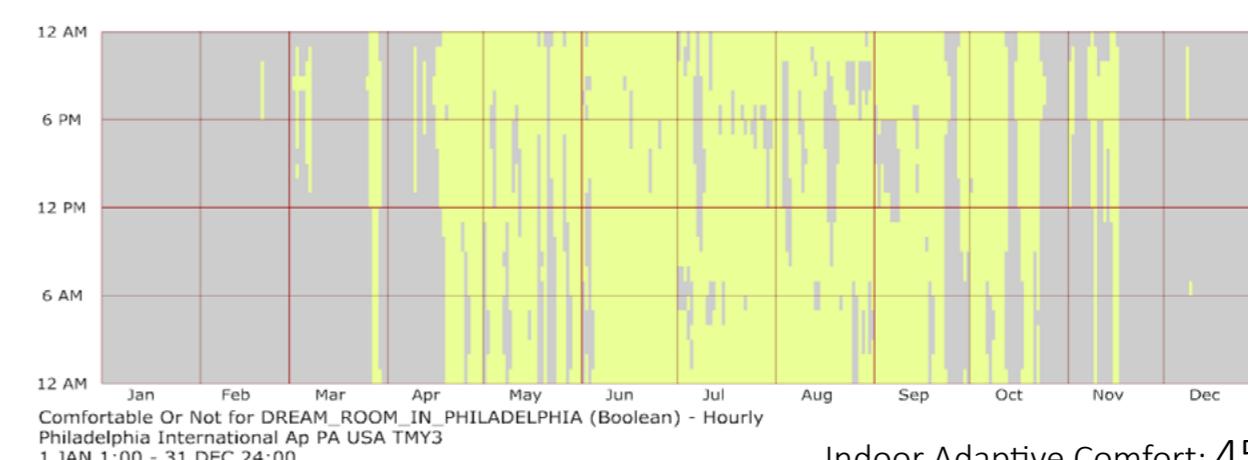
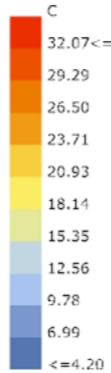
21 Dec 12:00 am



Total Solar Gain: 947.27 KWh



Indoor Temperature

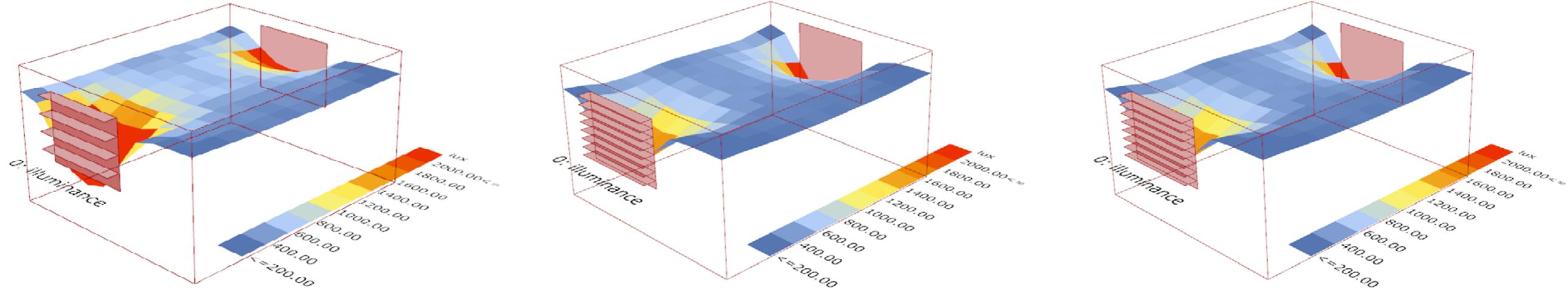


Indoor Adaptive Comfort: 45%

Comfortable Or Not for DREAM_ROOM_IN_PHILADELPHIA (Boolean) - Hourly
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00

By adding openings at the northern wall, the general indoor adaptive comfort ratio is increased. The total solar gain is also increased during winter time. However, there is still glare issues during the daytime at the southern part of the room. Besides, the high temperature period is increased during summer time. Next step would try to decrease the glare issues by adding shades on the south window.

Adding Shades



21 March 12:00 am

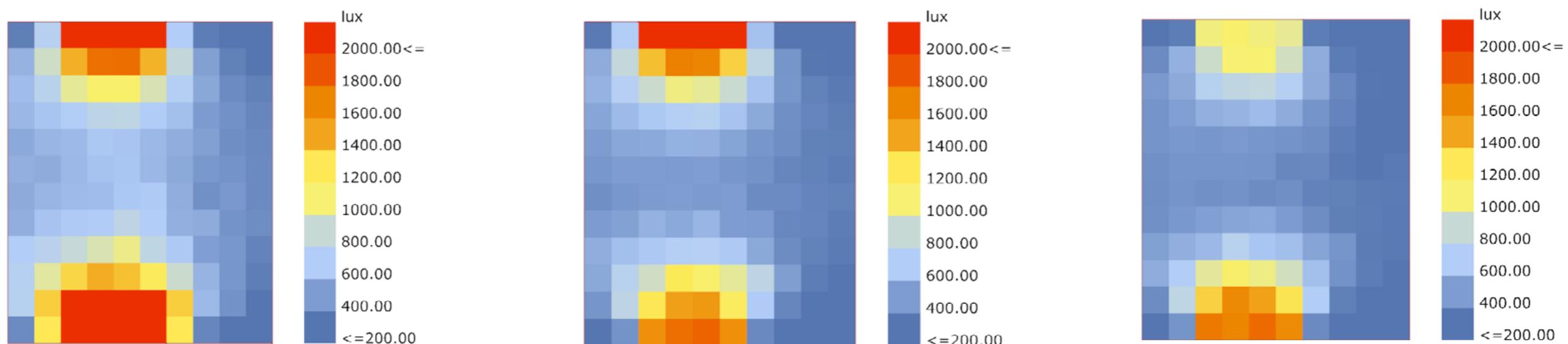
Shades Depth: 0.3
Number of Shades: 4

21 March 12:00 am

Shades Depth: 0.3
Number of Shades: 8

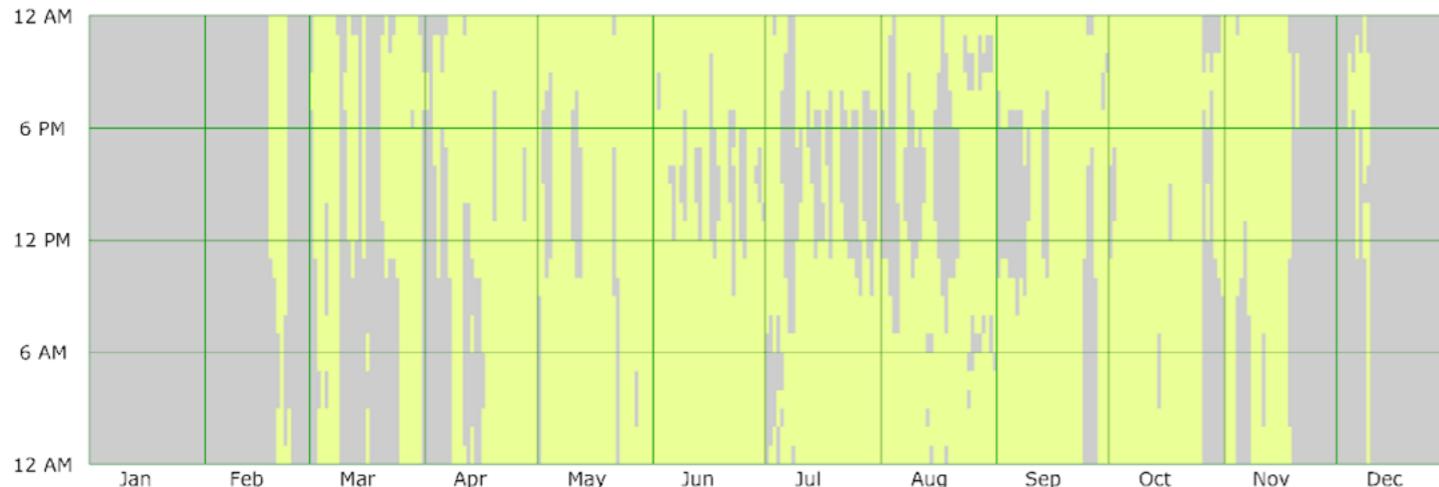
21 March 12:00 am

Shades Depth: 0.3
Number of Shades: 8 (South) 4 (North)

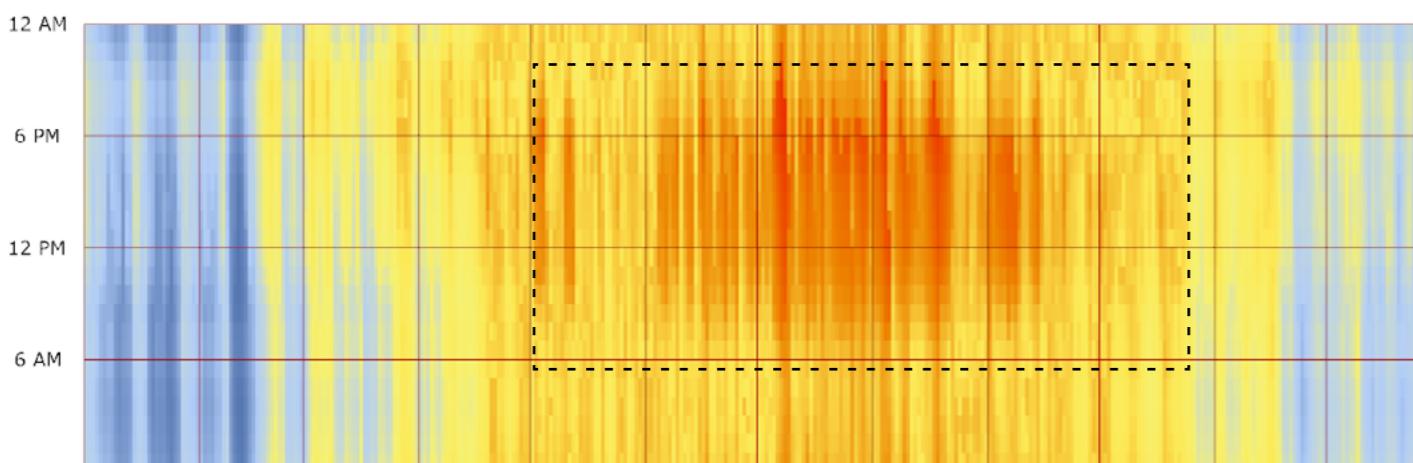
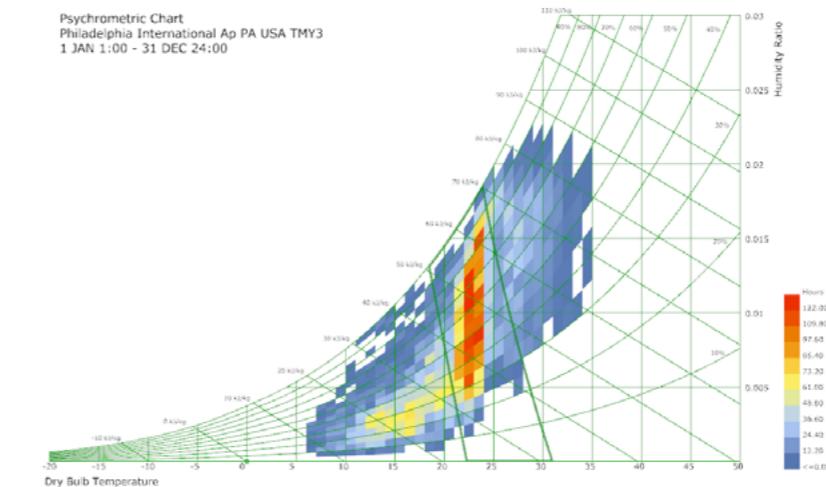


By adding different ratio of shades on both the southern and northern openings according to its glare problems, the general daylight condition in the dream room is greatly increased. Thus, adding proper shades during certain time in the summer time can help get desirable daylighting.

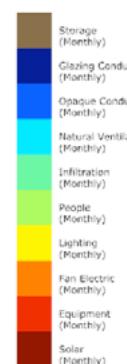
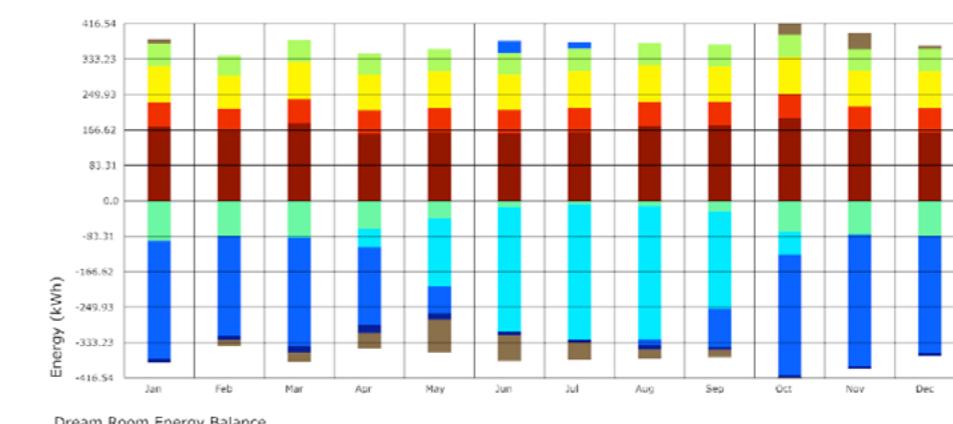
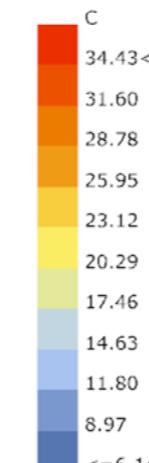
Construction Material



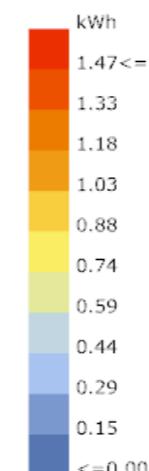
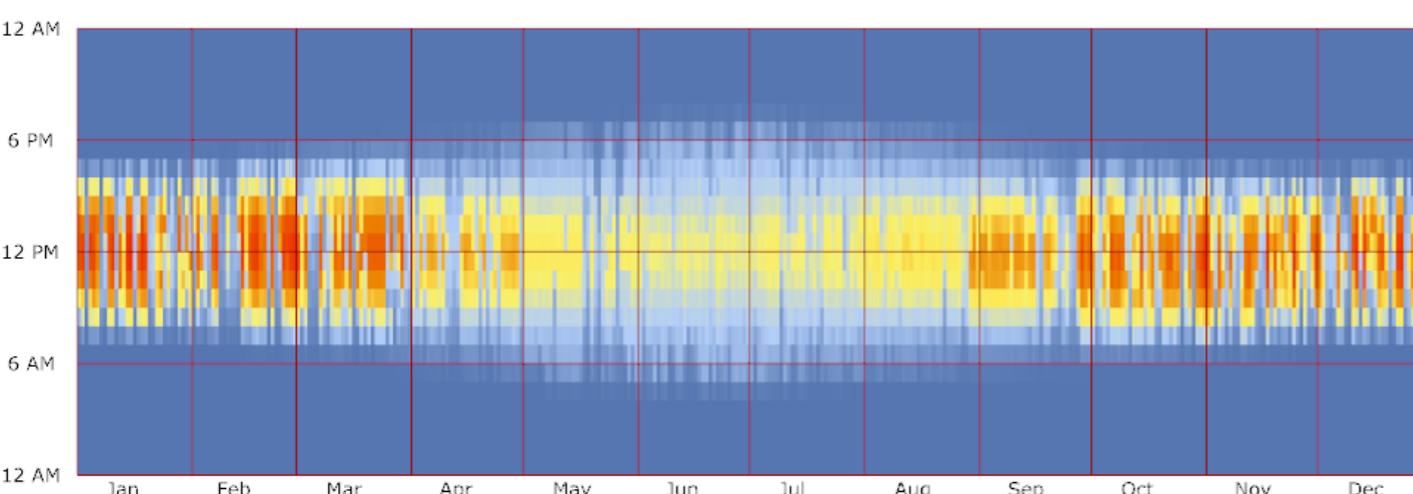
Indoor Adaptive Comfort: 57%



Indoor Temperature



Energy Balance



Total Solar Energy Gain: 2099 KWh

Modify Factor: Glazing

Test:

Low-E Double Glazing SC = 0.6

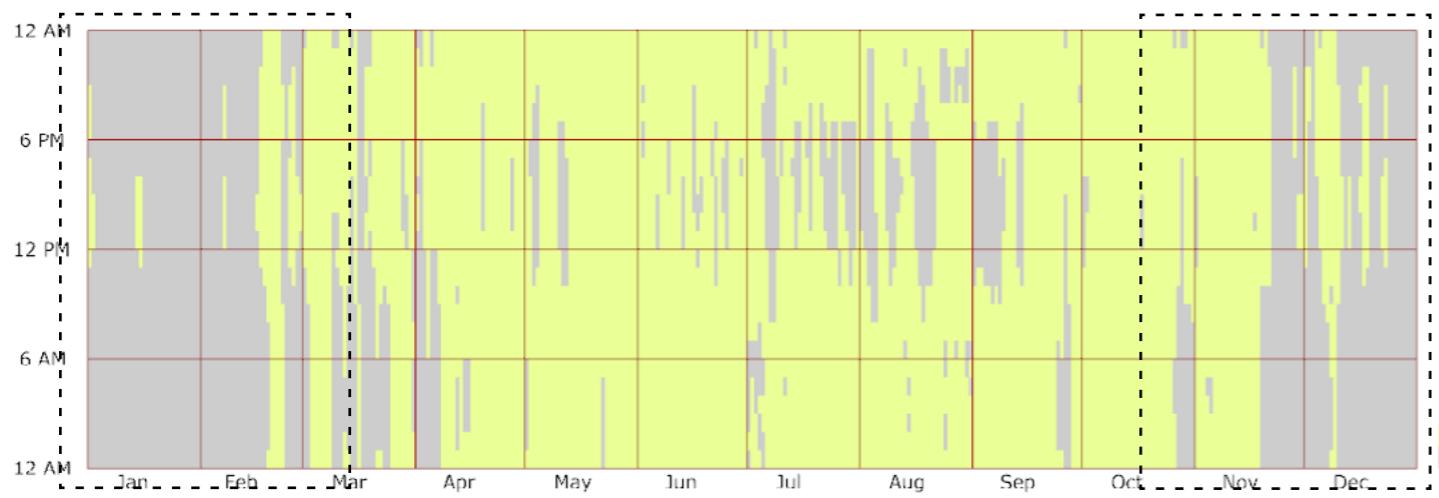
VT : 0.73

SHGC : 0.6

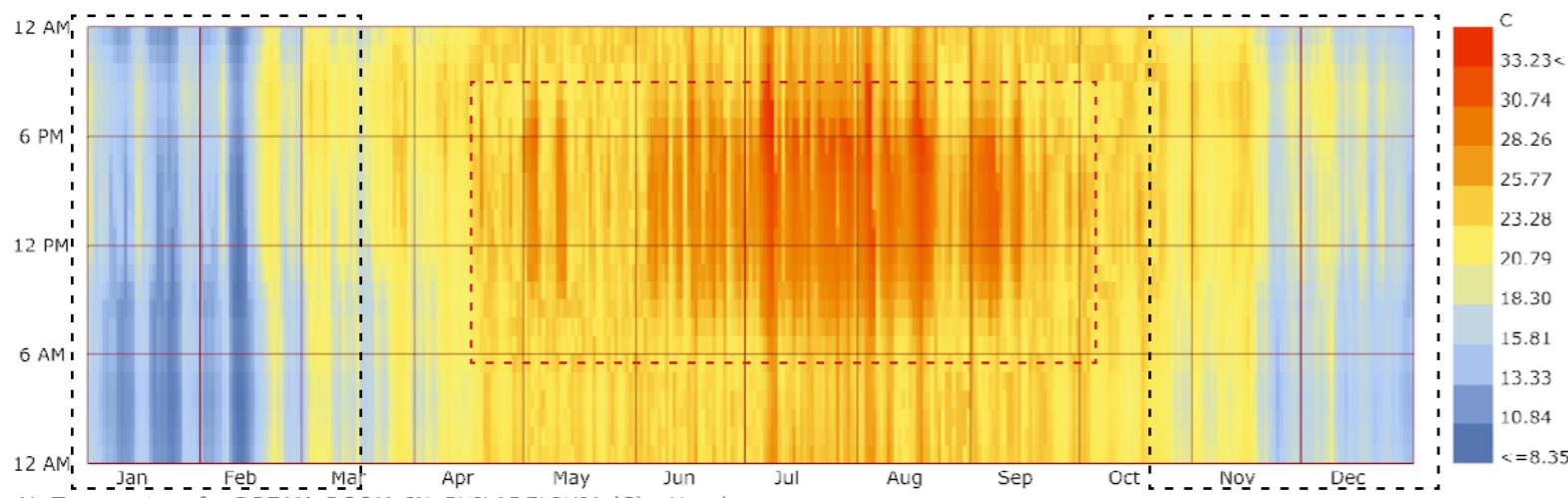
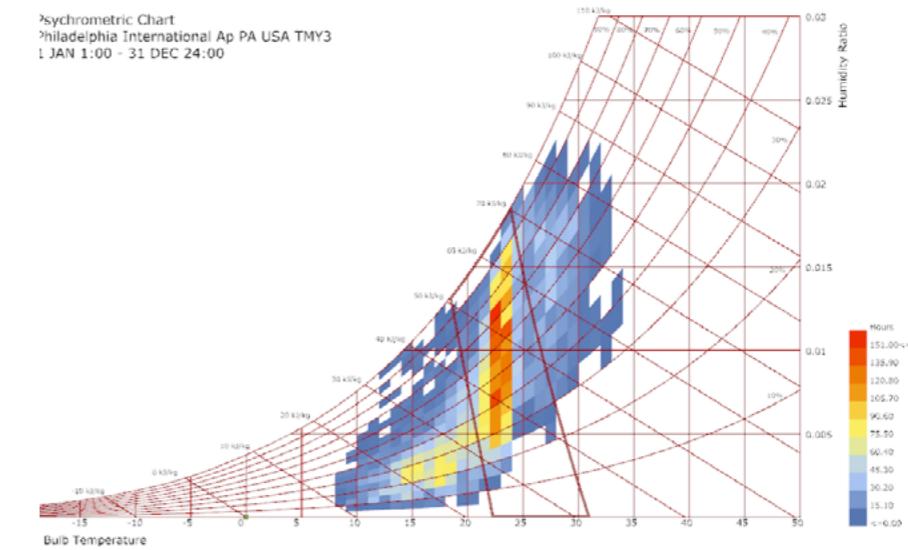
U : 0.37

There is about 10% increase of the indoor adaptive comfort after changing the glazing material to higher performance Low-E double glazing. Next step would still try to modify other construction materials to get a more desirable comfort condition in the room.

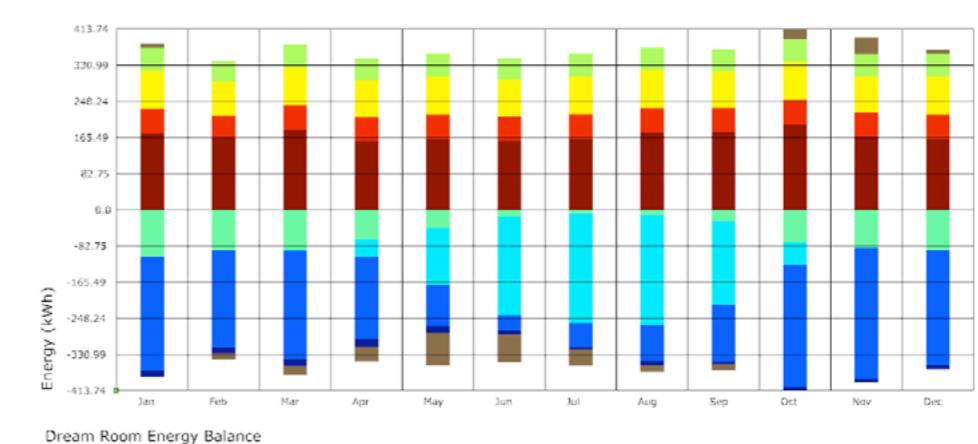
Construction Material



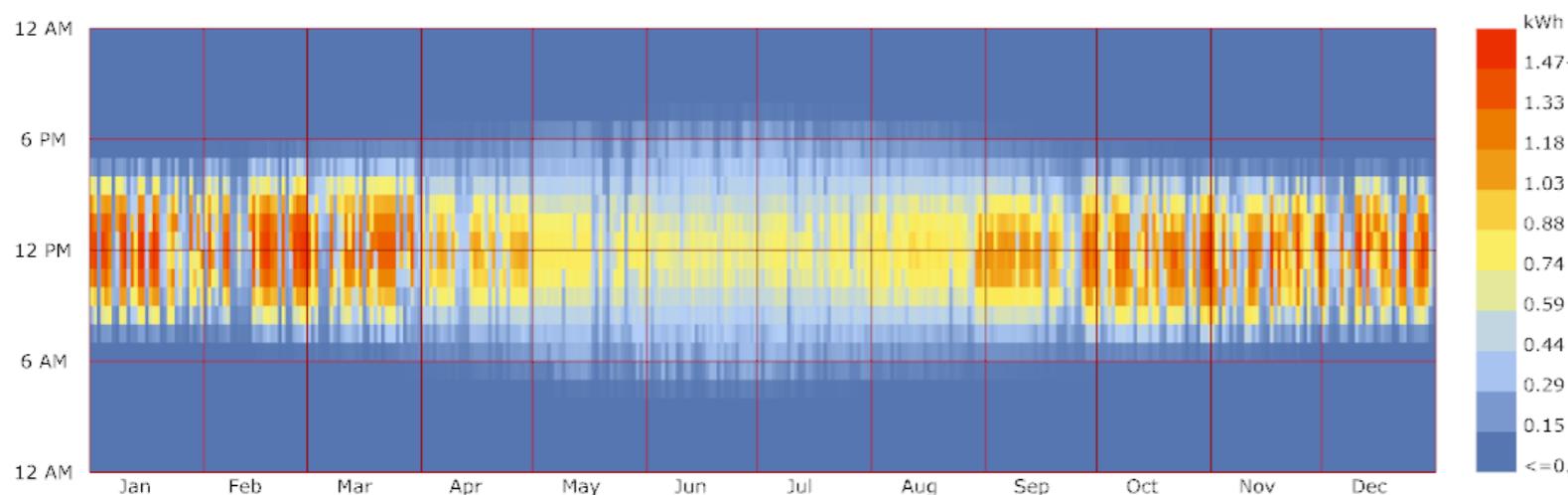
Indoor Adaptive Comfort: 67%



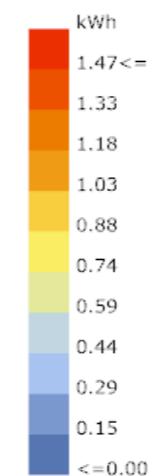
Indoor Temperature



Energy Balance



Total Solar Energy Gain: 2038 Kwh

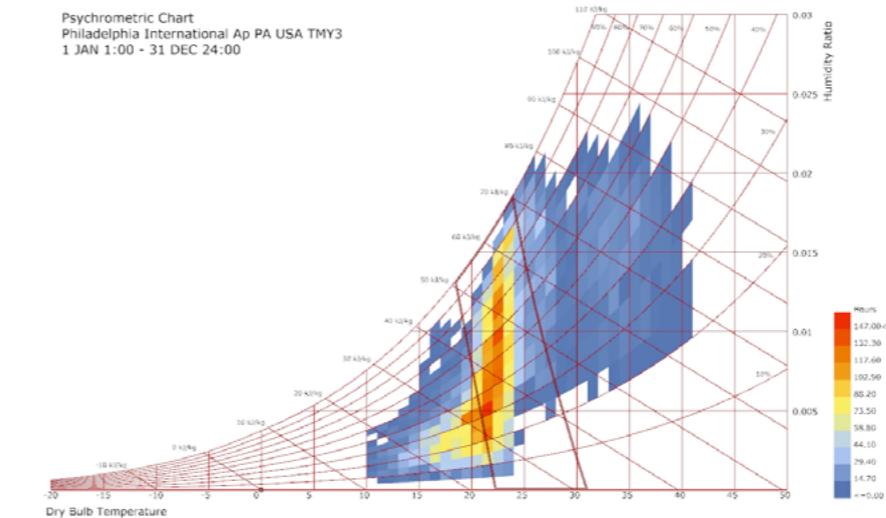
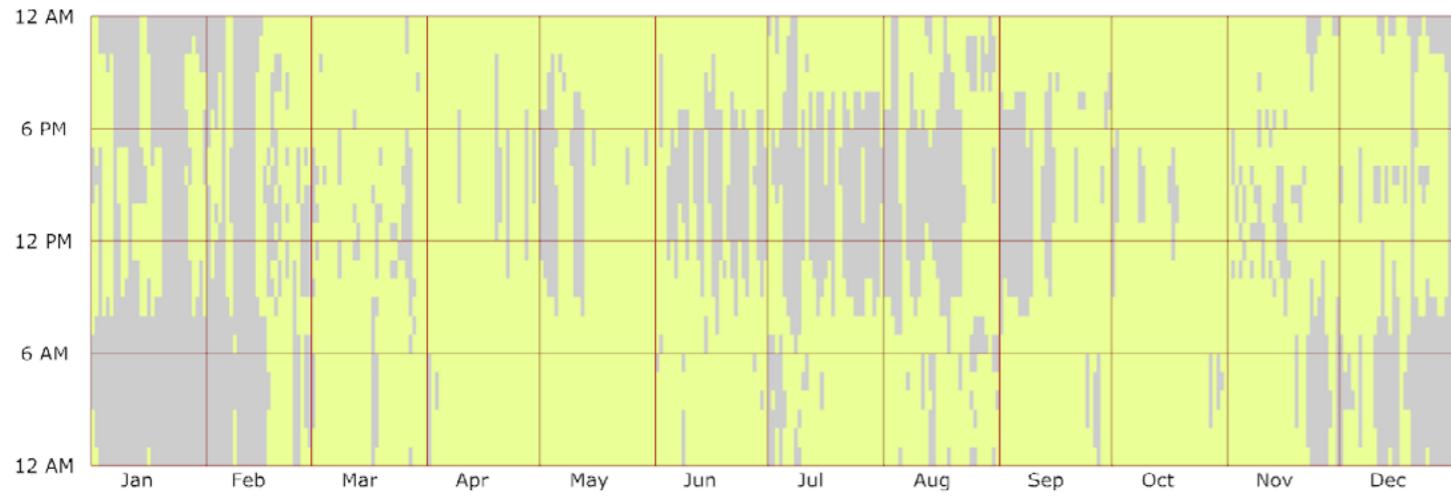


Modify Factor: Wall

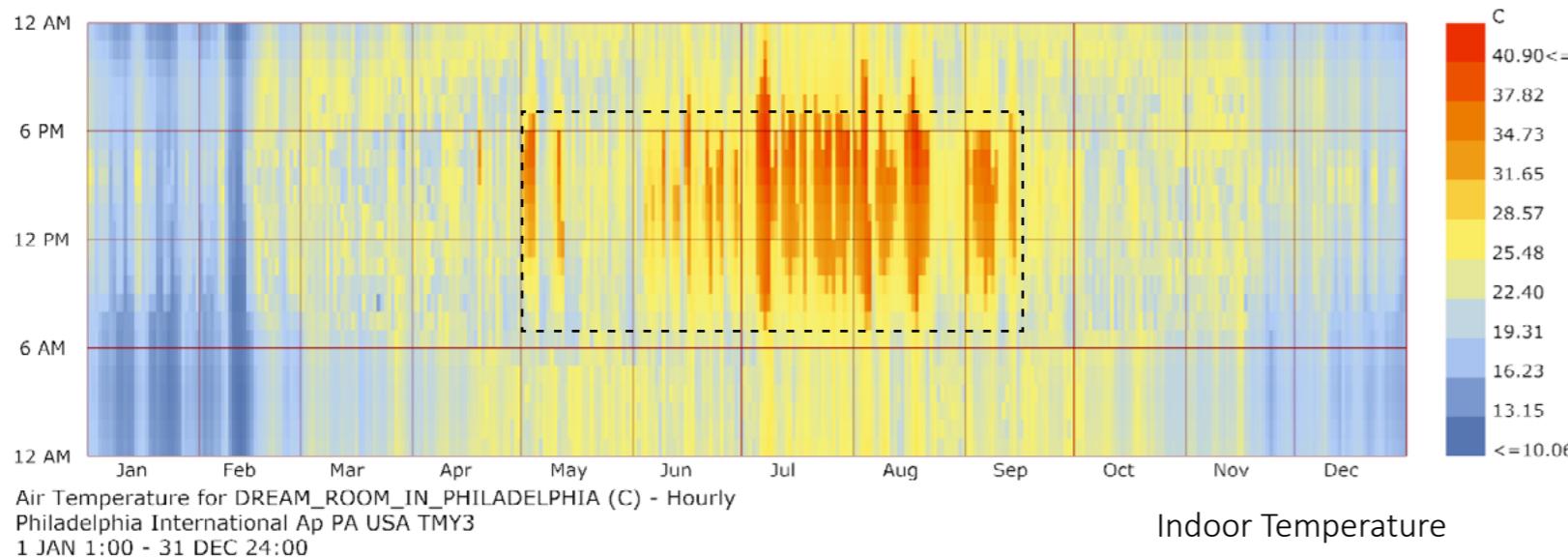
Test:
1 IN Stucco
8 IN Concrete HW
Wall Insulation 40
1/2 IN Gypsum

There is another 10% increase of indoor adaptive comfort rate after changing wall material. The comfortable time during winter time is increased as the building envelop help keep more heat inside the room. However, there is still a lot heat stress from April to September, Next Step would try to decrease temperatures by adding more openings to the room.

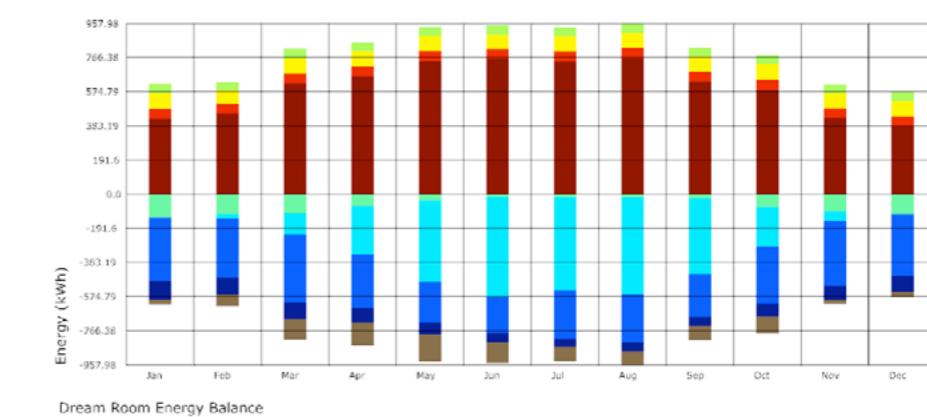
Increase Opennings



Indoor Adaptive Comfort: 72%

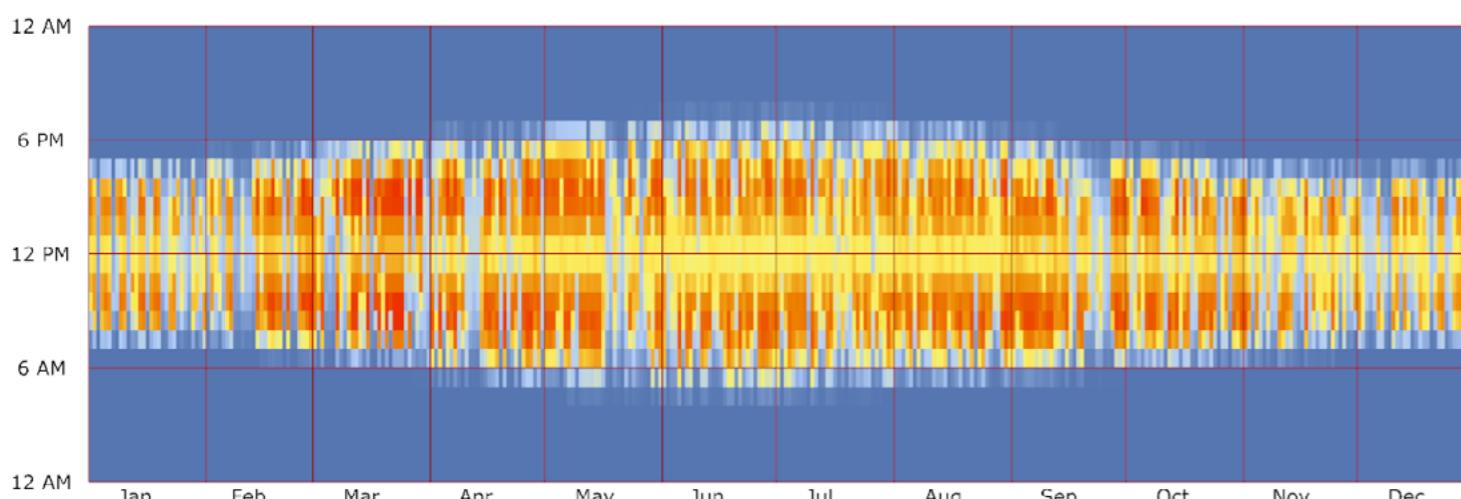


Indoor Temperature

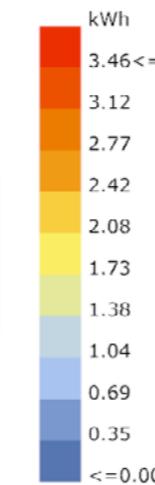


Energy Balance

- Storage (Monthly)
- Glazing Conduction (Monthly)
- Opaque Conduction (Monthly)
- Natural Ventilation (Monthly)
- Infiltration (Monthly)
- People (Monthly)
- Lighting (Monthly)
- Fan Electric (Monthly)
- Equipment (Monthly)
- Solar (Monthly)



Total Solar Energy Gain: 7186 KWh



Modify Factor: Glazing

Test:

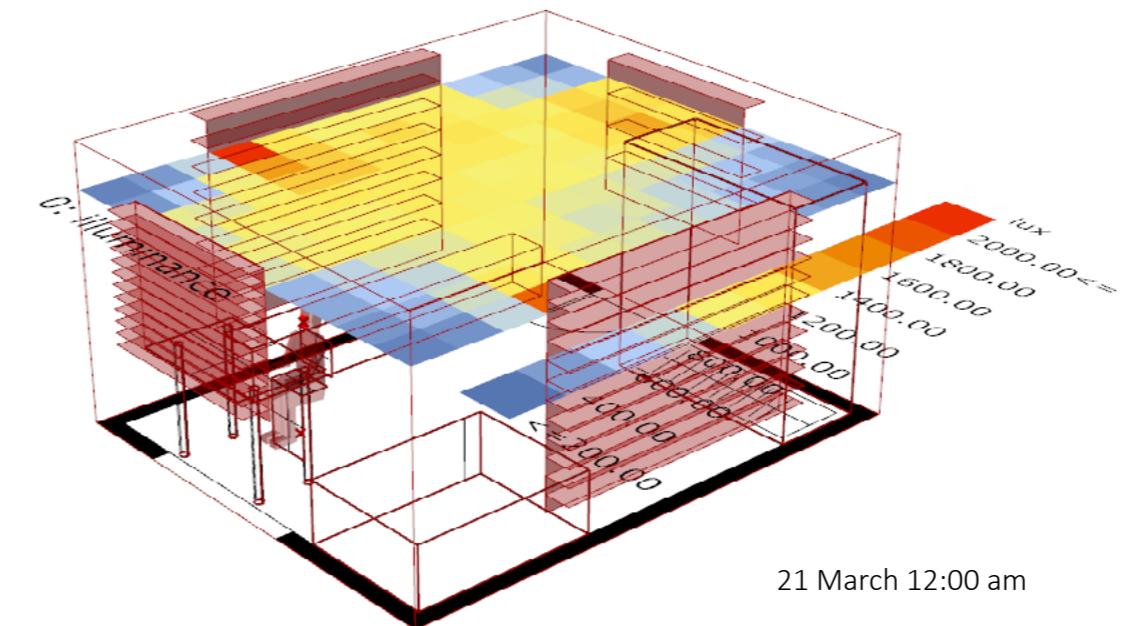
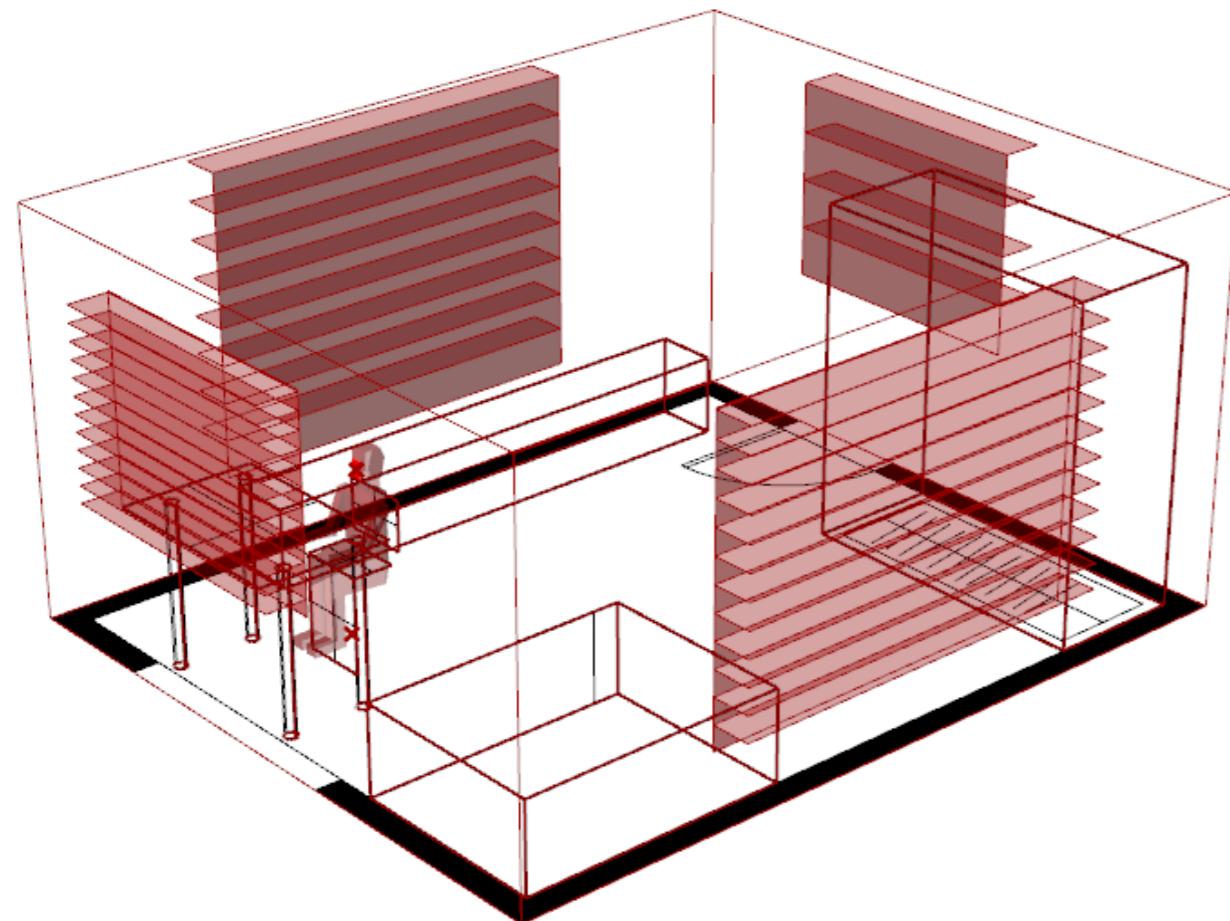
North Glazing Ratio: 20%

West Glazing Ratio: 40%

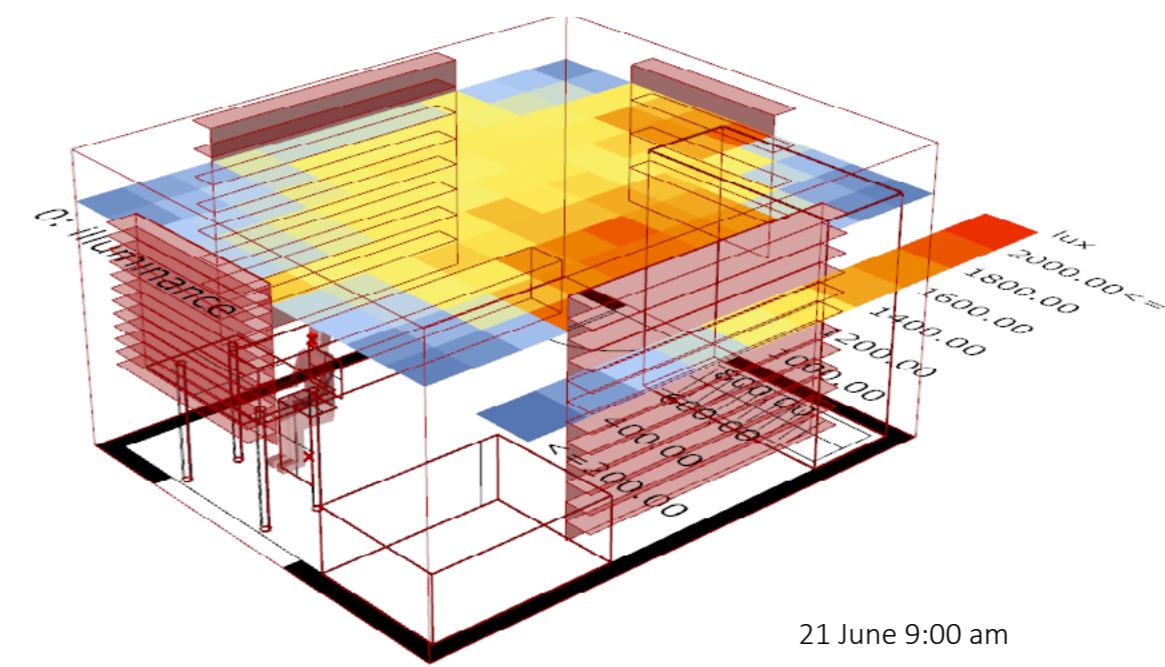
East Glazing Ratio: 40%

There is about 5% increase of the indoor adaptive comfort after adding more openings on the west and east direction. From the wind frequency chart, we could know that there is high ratio of west to east wind through the whole year. The openings in this direction help decrease the high temperature a lot during the summer time. But there is still high temperature during the daytime from June to September. As the main occupation hour is from 8pm to 8am during night, the modified result is acceptable .

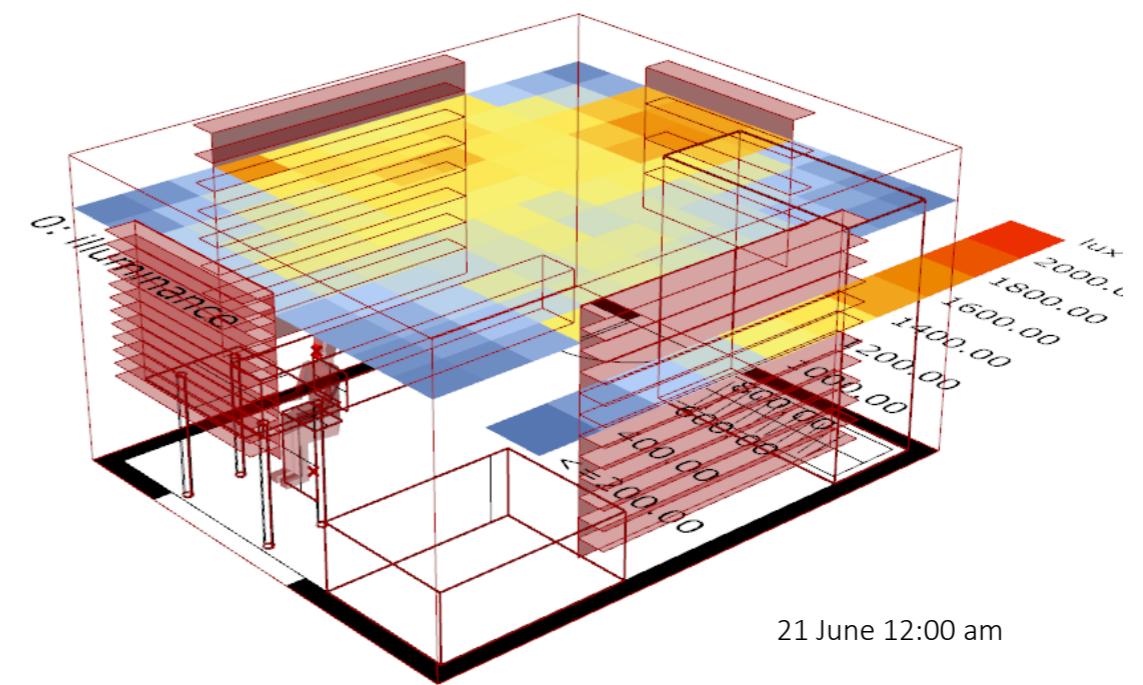
Adding Shades to New Openings



21 March 12:00 am



21 June 9:00 am



21 June 12:00 am