THERMAL AND VISUAL COMFORT EXPLORATION IN UNCONDITIONED SPACE

FINAL PROJECT REPORT
ARCH-753 Fall 2017

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Project Location: Ardmore, PA

CONTENTS

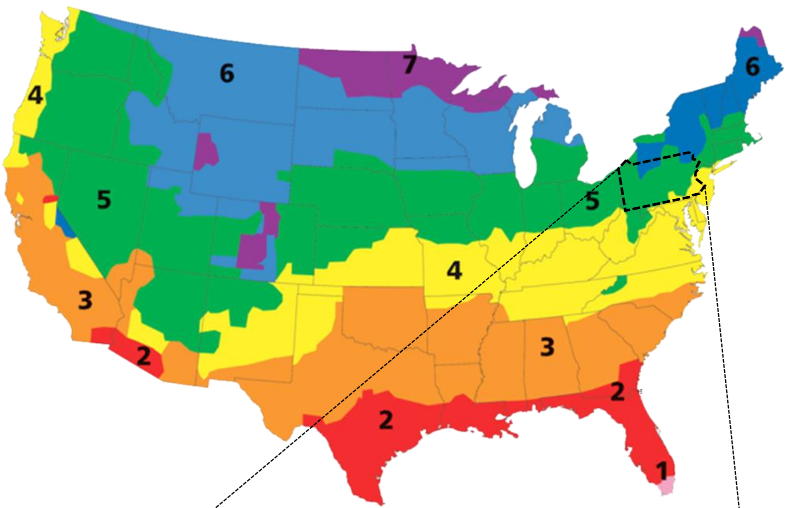
Ⅰ. Target Room Information

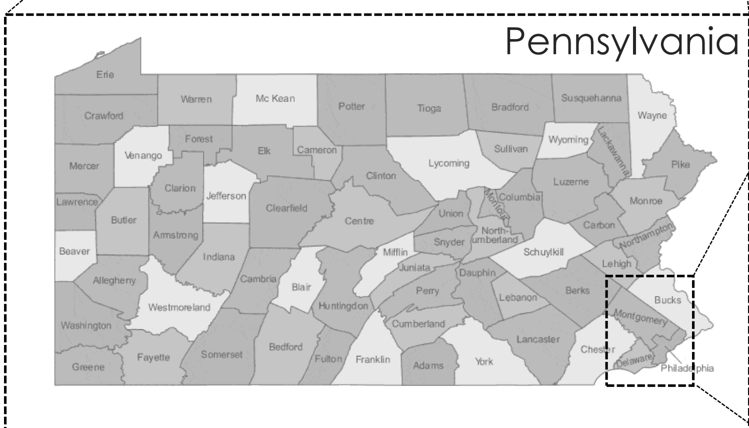
1. General Location Information

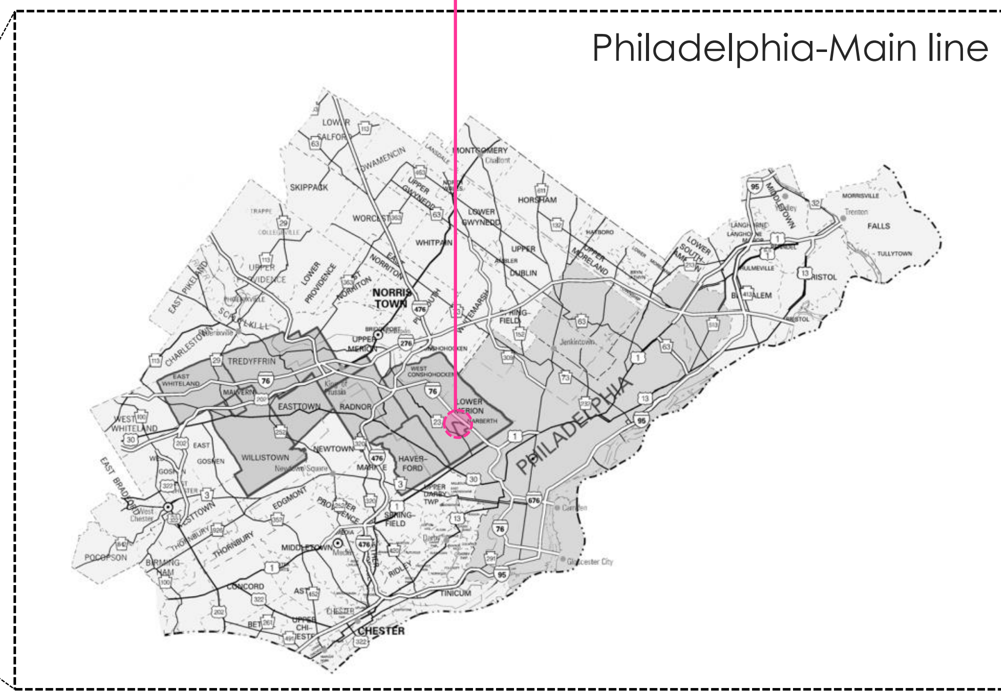
The target room is located in Ardmore, which is one of the suburbs near Philadelphia, and is seven miles away from University of Pennsylvania.
There are 4 distinct seasons, but as we can see heating and cooling degree days below, winter is relatively more critical than summer.

Location: Ardmore, PA
Climate Zone: Zone 4, subtype A

Heating Degree Days: 4052 (2016)
Cooling Degree Days: 1728 (2016)



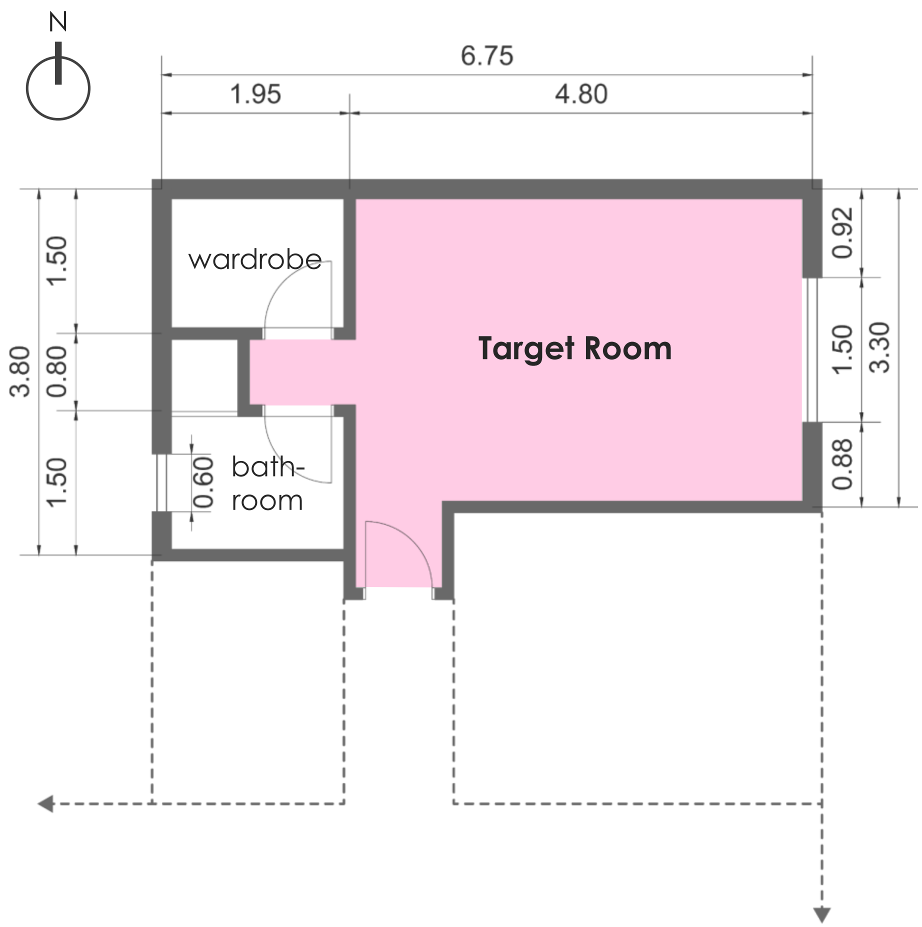




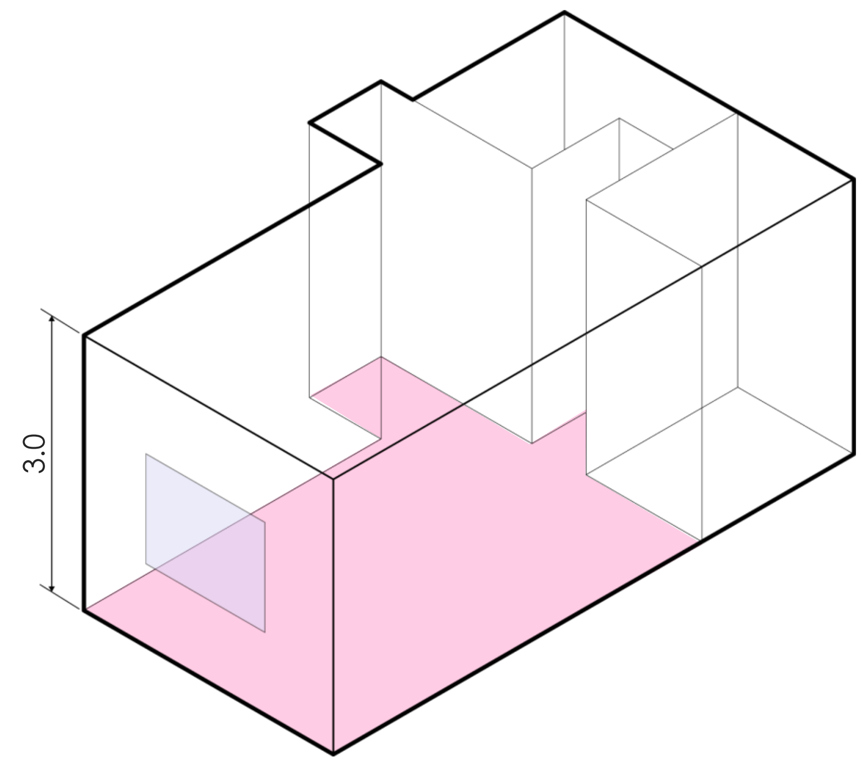
Ⅰ. Target Room Information

2. My Room Plan & 3D Model |

The unit of the target room is on the third floor of the apartment, which is I shaped, 4-storied building. The unit is located at the very right side of the building and the target room is exposed to the outdoor except the south wall. The room has a bathroom and a wardrobe. However, in this design exploration, I focused on the only living area to improve thermal comfort and visual comfort.



unit: meter



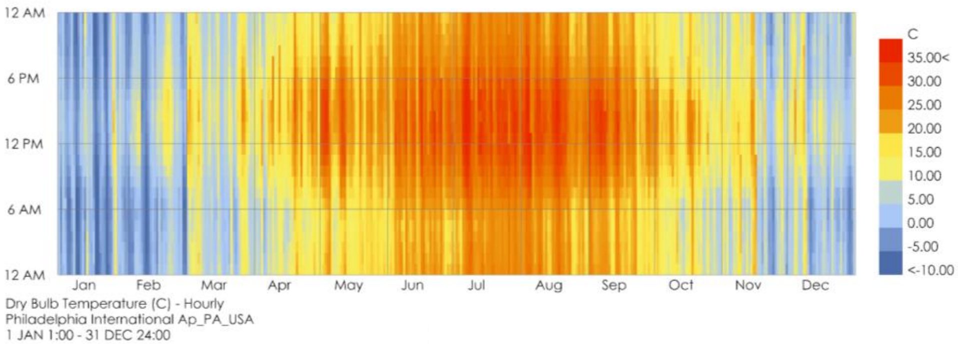
II. Climate Analysis

1. Annual Weather Information |

What type of weather does this location have ?
How many days do people feel comfortable for a year?

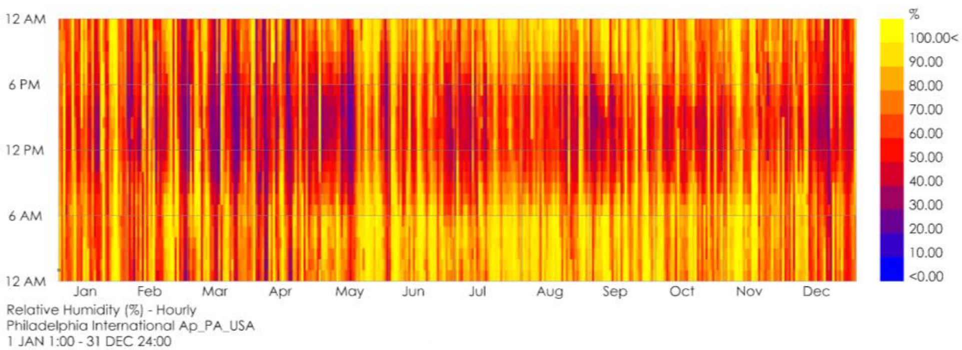
The annual weather of Philadelphia basically has four distinct seasons and has modest and constant Relative Humidity for a year. Except Winter and Summer, people generally can feel comfort.

Annual Outdoor Temperature Chart



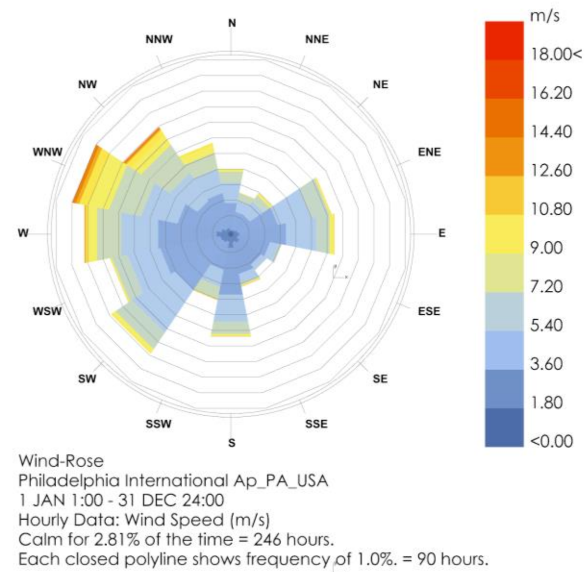
- Highest Temperature 36,7℃
- Lowest Temperature -13.9℃
- Mean Temperature 12℃

Annual Outdoor Relative Humidity Chart

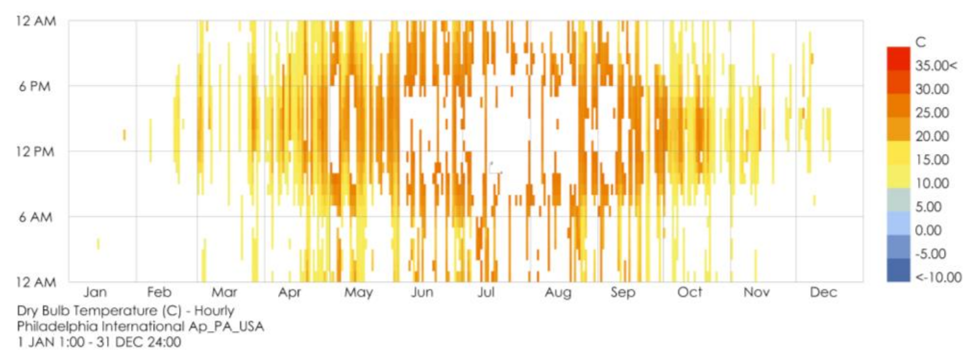


- Highest Relative Humidity 100%
- Lowest Relative Humidity 15%
- Mean Relative Humidity 65%

Annual Wind Rose Analysis



Comfortable Day Chart (Conditioned Chart)

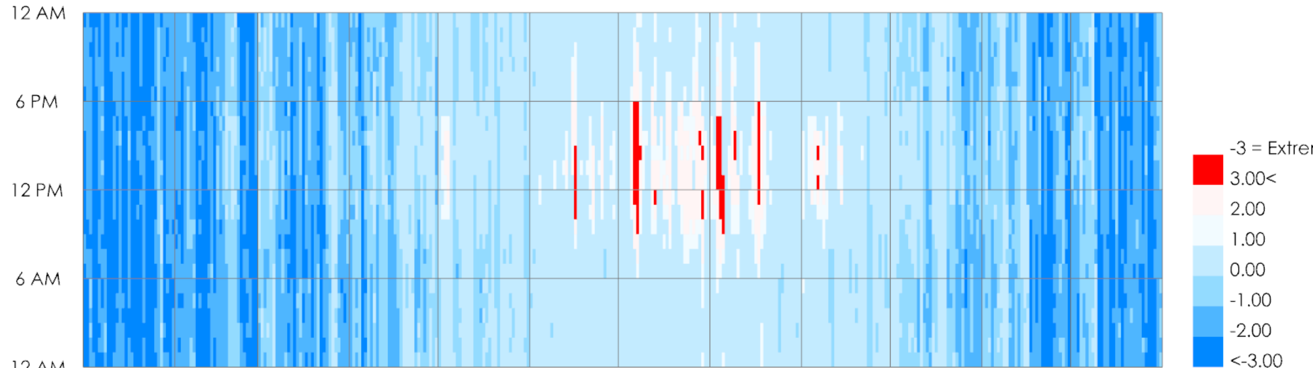


- Condition Setting: 9℃<temp<26 ℃ and Relative Humidity<80%
- Total Hours meets the condition: 26868hrs
- Percentage: 31%

2. Annual Outdoor Comfort Hours Analysis (by Universal Thermal Comfort Index) |

How many days do people feel comfortable for a year? +Using Global Standard

According to the using global standard to assess outdoor comfort, UTCI, people can feel comfort 37.9% of time annually – when fully exposed to sun, and cold stress is much more critical than heat stress.



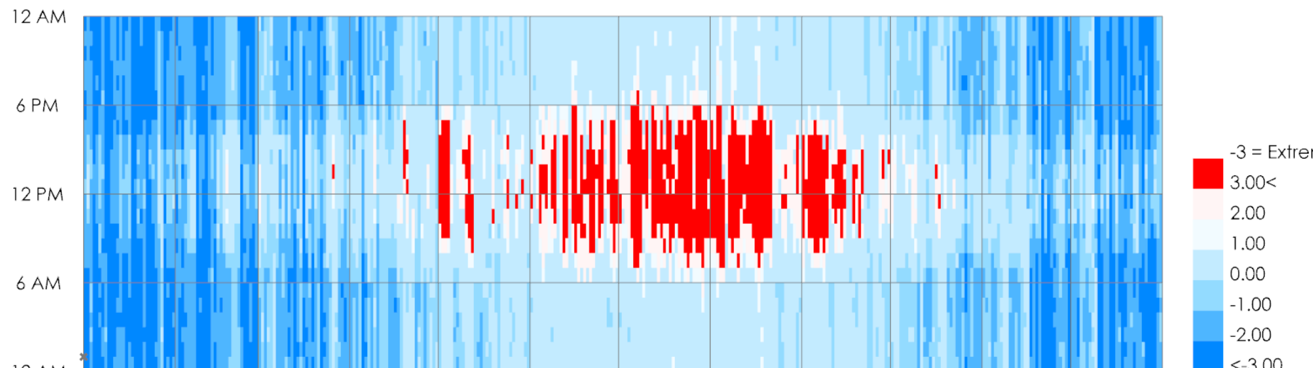
Outdoor Comfort (-3 = Extreme Cold | -2 = Cold | -1 = Cool | 0 = Comfort | 1 = Warm | 2 = Hot | 3 = Extreme Heat) - Hourly
Philadelphia International Ap_PA_USA
1 JAN 1:00 - 31 DEC 24:00

Fully Shaded Outdoor Comfort

Percentage of Comfortable Hours
41.3%

Percentage of Heat Stress(>28 ℃)
3.1%

Percentage of Cold Stress (<0 ℃)
34.3%



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

Solar Adjusted Outdoor Comfort

Percentage of Comfortable Hours
37.9%

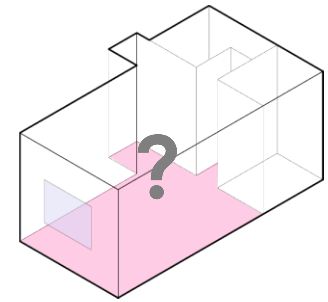
Percentage of Heat Stress(>28 ℃)
12.3%

Percentage of Cold Stress (<0 ℃)
31.2%

Ⅲ. Base-Case Assessment

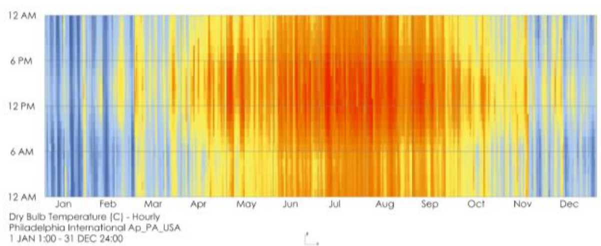
1. Target Room Annual Temperature & Relative Humidity Analysis Ⅰ

What temperature and RH do I feel in my room?
How much difference does it have between indoor and outdoor?



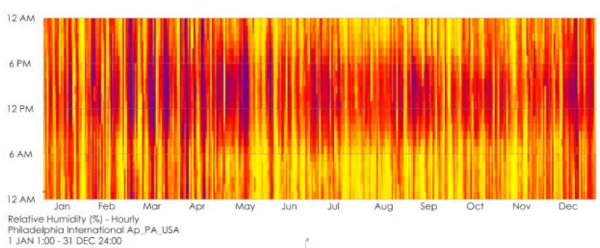
* From here, to analyze the target room, I assumed that there is no operative conditioned system. It means that I only considered passive design factors to explore better sustainable design. Moreover, base-materials of building have used default setting of Honeybee which I used for all simulation.

Annual Outdoor Temperature Chart



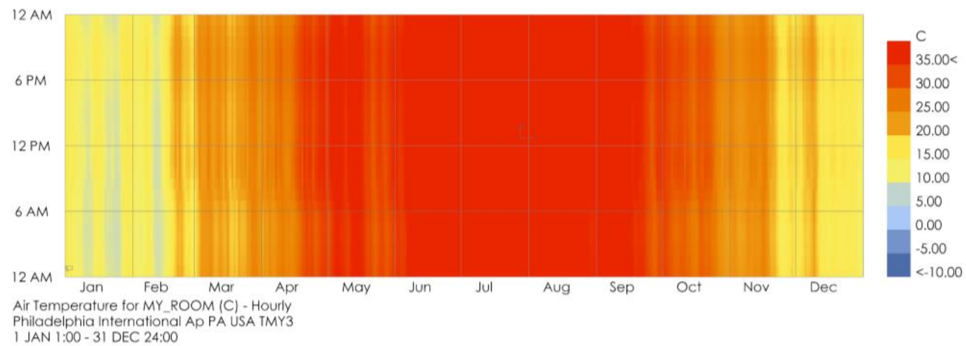
- Highest Temperature 36,7℃
- Lowest Temperature -13.9℃
- Mean Temperature 12℃

Annual Outdoor Relative Humidity Chart



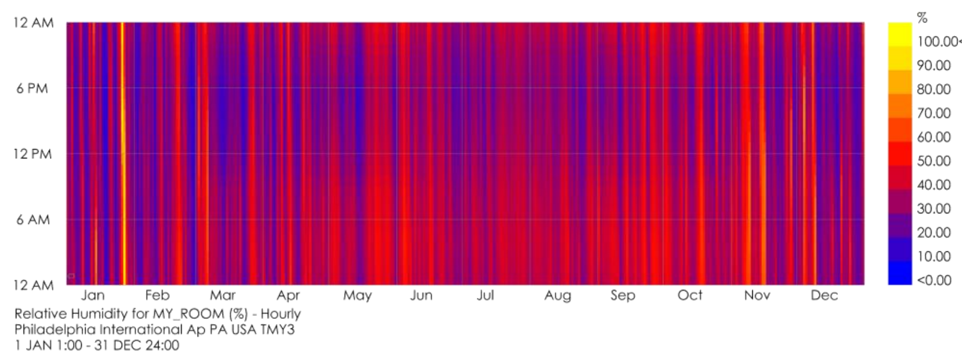
- Highest Relative Humidity 100%
- Lowest Relative Humidity 15%
- Mean Relative Humidity 65%

Annual Target Room Temperature Chart



- Highest Temperature 46.6 ℃ (▲ 9.9 ℃)
- Lowest Temperature 6.2 ℃ (▲ 20.1 ℃)
- Mean Temperature 27 ℃ (▲ 15 ℃)

Annual Target Room Relative Humidity Chart



- Highest Relative Humidity 100% (=)
- Lowest Relative Humidity 8% (▼ 7%)
- Mean Humidity 34% (▼ 31%)

Ⅲ. Base-Case Assessment

2. Target Room Annual Indoor Comfort Analysis |

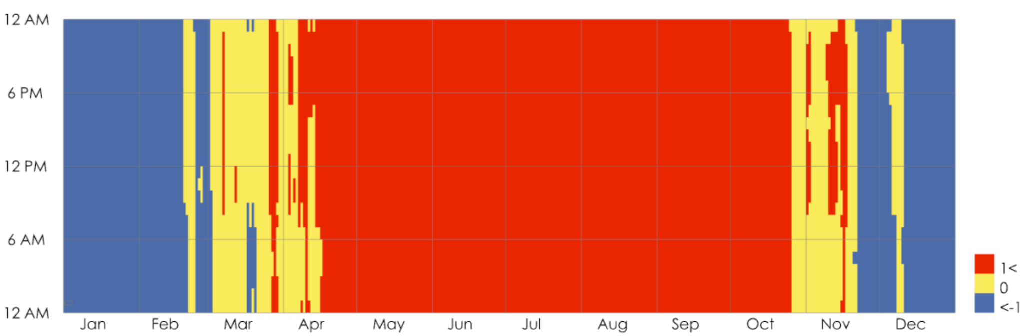
How many days can I feel comfortable in my room?
What standard do I use for Indoor Comfort Analysis? – Adaptive Comfort

* To figure out the indoor comfort, I used the adaptive comfort model.
PMV(Predicted Mean Vote) model is the oldest and the most recognized thermal comfort models, but this model is based on air-conditioned buildings and does not directly related with outdoor condition. On the other hand, Adaptive Model is developed based on the idea that occupant dynamically interact with indoor and outdoor condition, and this model is generally applied for non-mechanical systems buildings
In this exploration, since I assumed that the space as an unconditioned space and focused on interaction between indoor and outdoor condition, I used Adaptive Comfort for indoor comfort assessment.

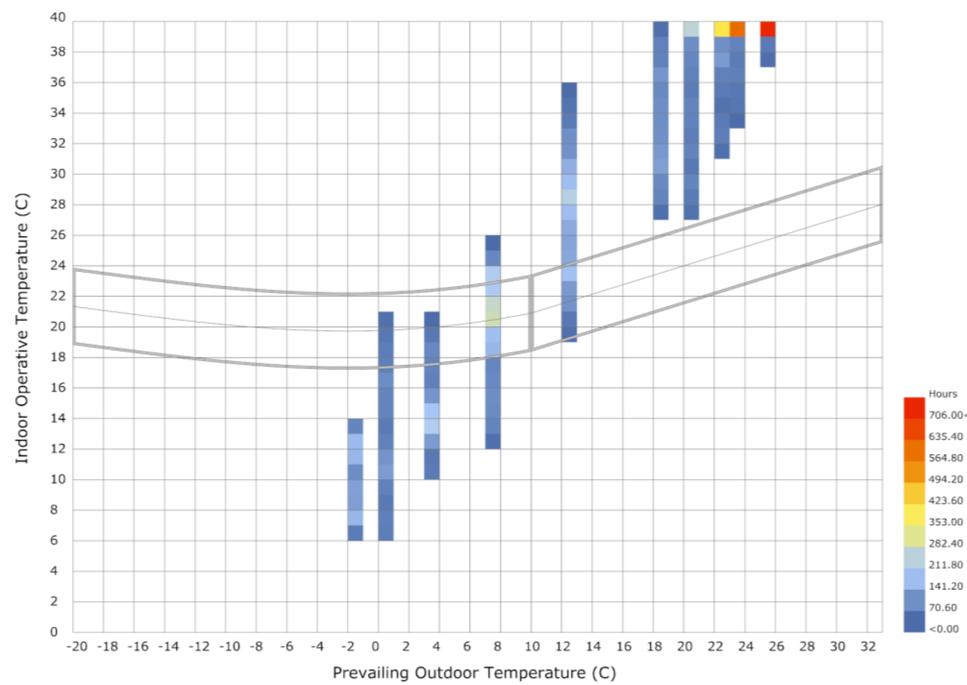
Adaptive Comfort Analysis

*No apply natural ventilation
Exterior wall R-VALUE: 2.18
Window U-VALUE: 2.37

% comfortable time 17.3%
Hot stress 57.3%
Cold stress 25.4%



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



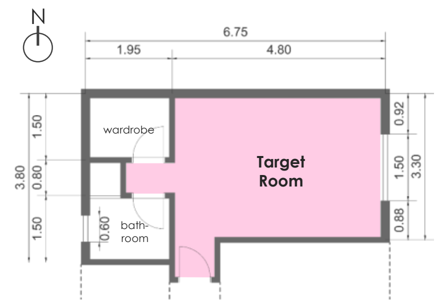
Adaptive Chart
Philadelphia International Ap_PA_USA
1 JAN 1:00 - 31 DEC 24:00

Ⅲ. Base-Case Assessment

3. Target Room Daylight Analysis - 1) Point-in-time Illuminance & Glare Probability Analysis Ⅰ

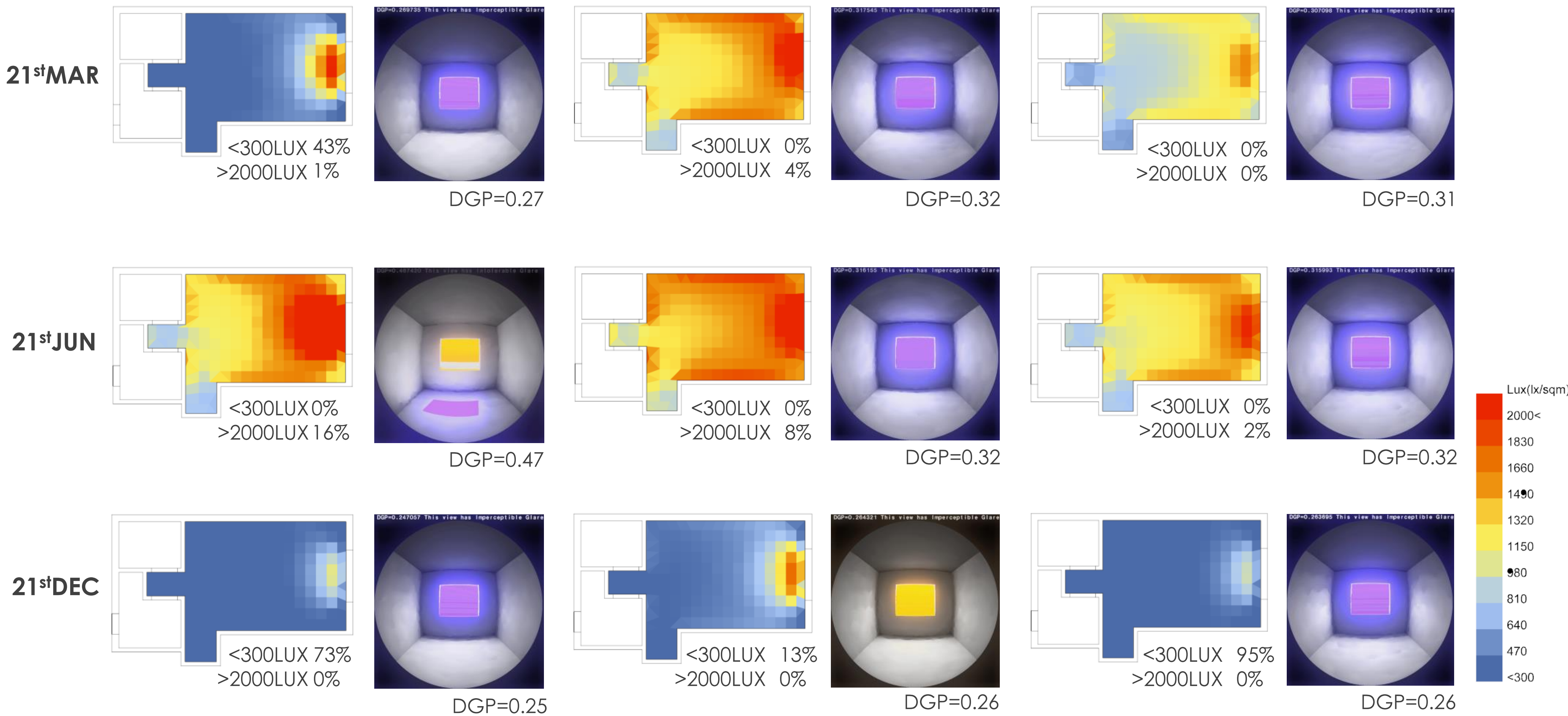
How much daylight does the room receive in different time?

The room is deep, and there is only one window on the east side. As the analysis results are shown below, sufficient sun light do not come evenly inside through this window. Except June, the room does not provide enough daylight during the day, and glare probability is also imperceptible during most of days.



Floor Plan (Unit: m)

9AM 12PM 3PM

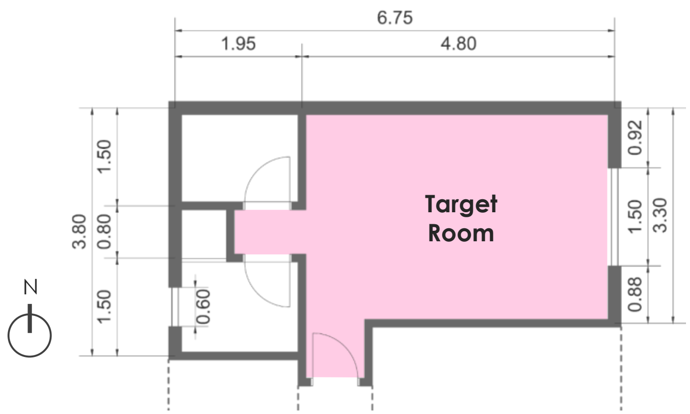


Ⅲ. Base-Case Assessment

4. Target Room Daylight Analysis - 2) Varying Annual Illuminance Analysis |

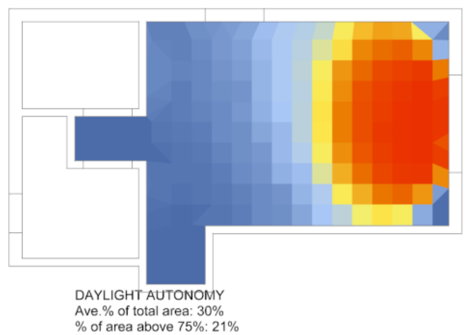
What about annual illuminance analysis? Do different analysis models make different result?

By running different illuminance analysis, I tried to figure out the difference and the common from the result. I set a 300lux as a threshold for DA and CDA. Since all models have different logic, the result shows the difference, but all result show the left side of the target room needs more daylight. Moreover, since UDI can figure out illuminance level over the threshold, I select UDI for annual illuminance analysis.



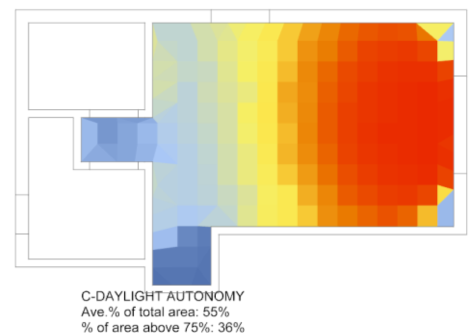
Floor Plan (Unit: m)

| Daylight Autonomy



Average % of total area
30%

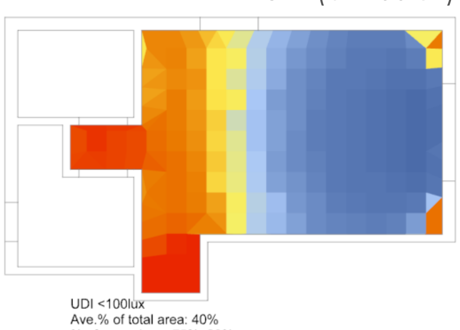
| Continuous Daylight Autonomy



Average% of total area
55%

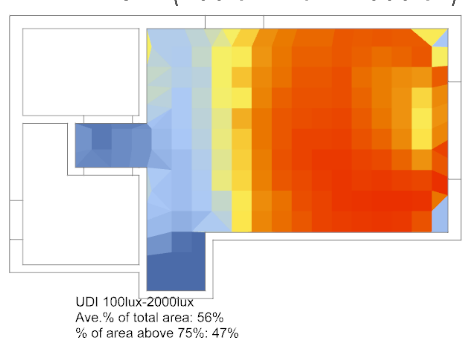
| Useful Daylight Illuminance (UDI)

UDI (a<100lux)



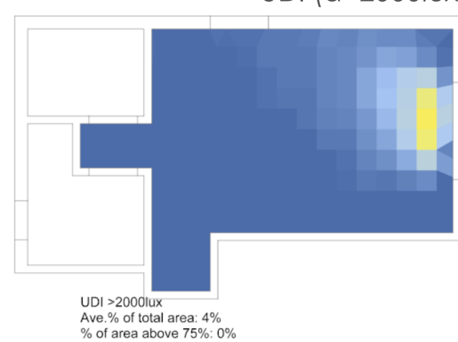
22% Of area meets UDI<100lux
For over 75% of time

UDI (100lux<=a<=2000lux)

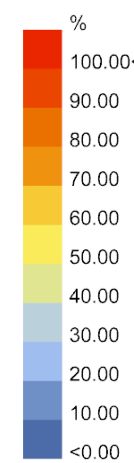


47% Of area meets UDI 100lux<2000lux
For over 75% of time

UDI (a>2000lux)

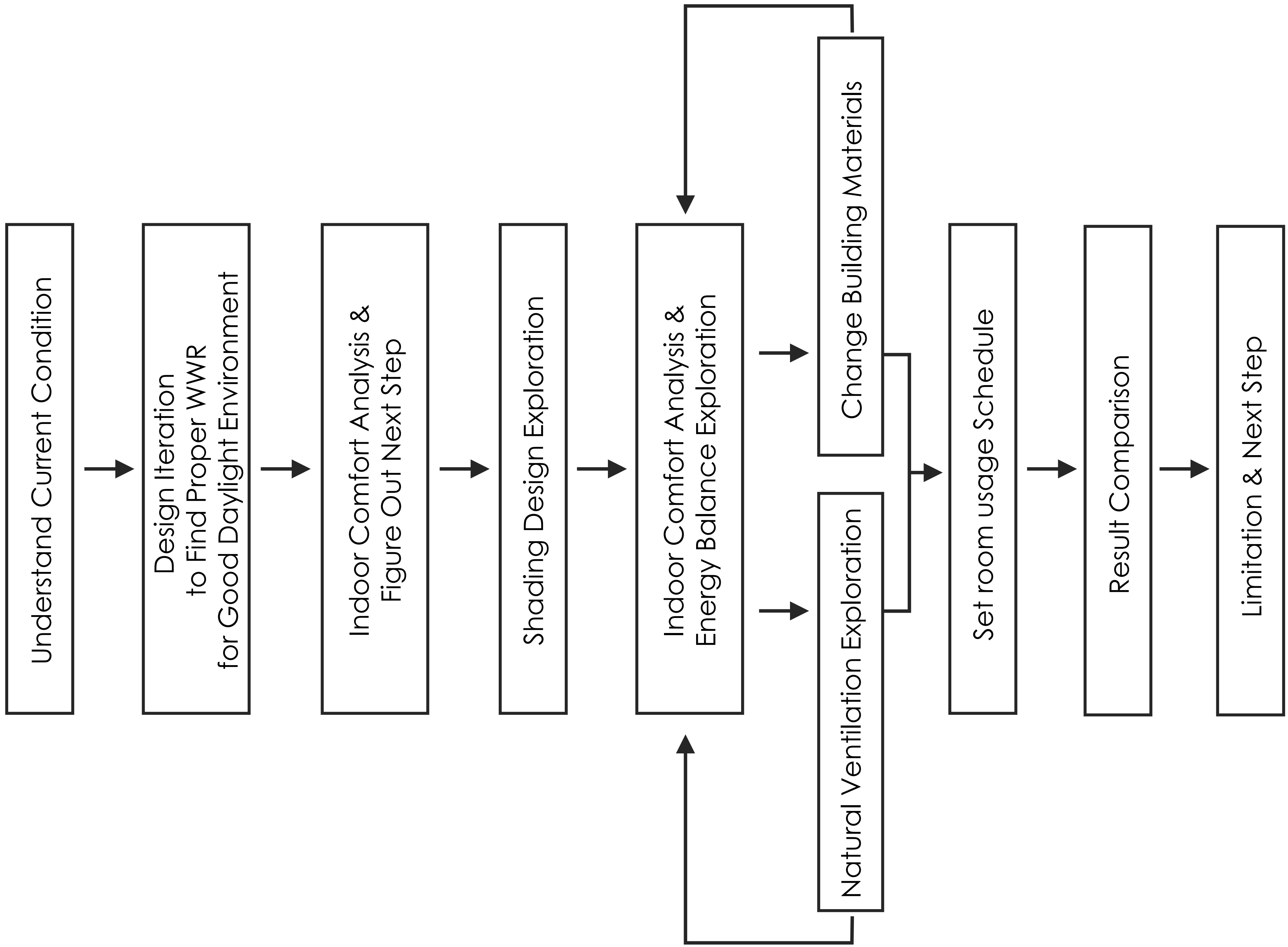


0% Of area meets UDI >2000lux
For over 75% of time



Ⅳ. Discussion and Design Proposals

Process of Design Exploration |

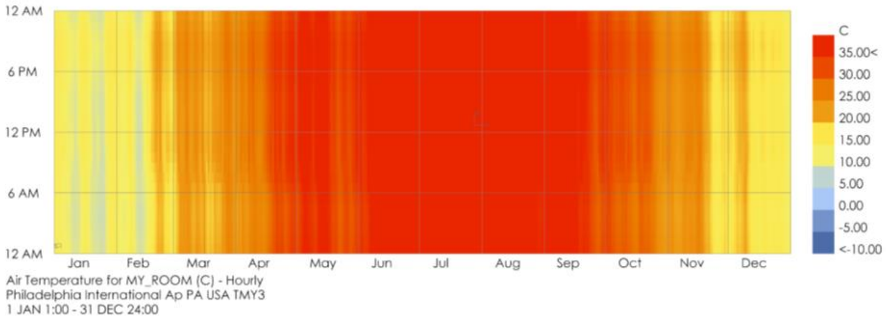


Ⅳ. Discussion and Design Proposals

Step 1. Understand Current Condition of Target Room

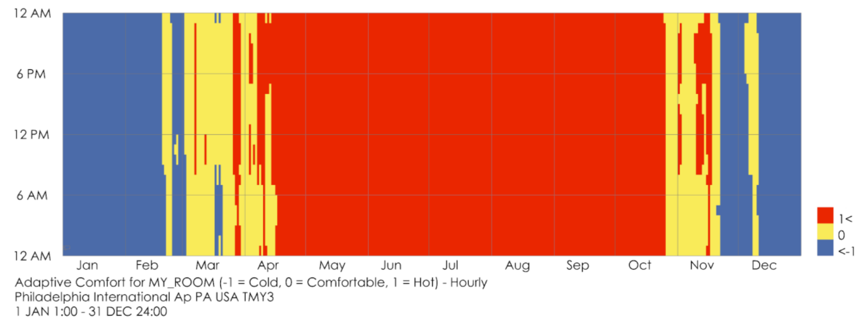
1. The target room gets critical heat stress.

Annual Target Room Temperature Chart



- Highest Temperature 46.6 ℃ (▲ 9.9 ℃ than outside)
- Lowest Temperature 6.2 ℃ (▲ 20.1 ℃ than outside)
- Mean Temperature 27 ℃ (▲ 15 ℃ than outside)

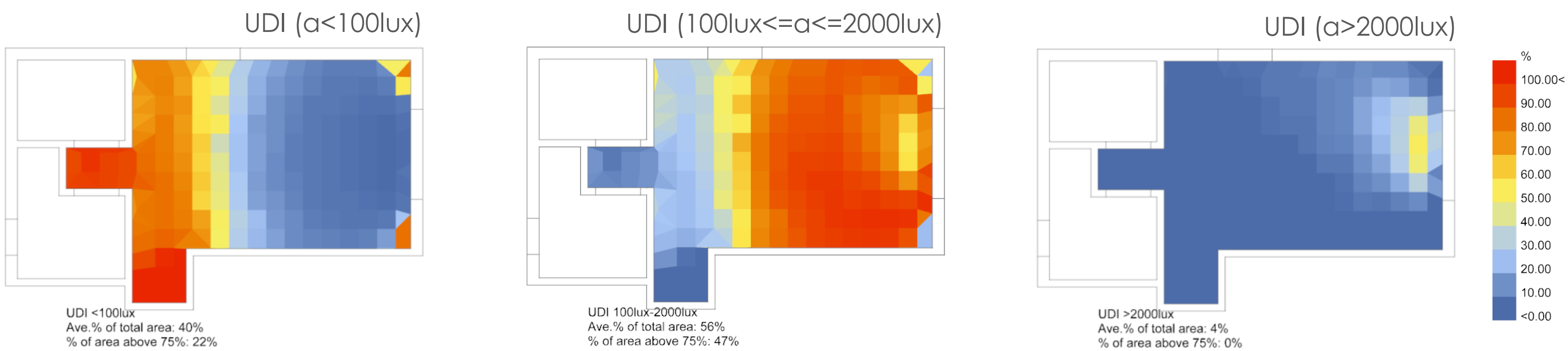
Indoor Comfort Analysis



% comfortable time 17.3%
Hot stress 57.3%
Cold stress 25.4%

2. The target room has under-lit problem and it requires to adjust

Annual Daylight Analysis



22% Of area meets UDI<100lux
For over 75% of time

47% Of area meets UDI 100lux<2000lux
For over 75% of time

0% Of area meets UDI >2000lux
For over 75% of time

Main goal of this design exploration is to improve both visual comfort and thermal comfort Without support of mechanical system.

Ⅳ. Discussion and Design Proposals

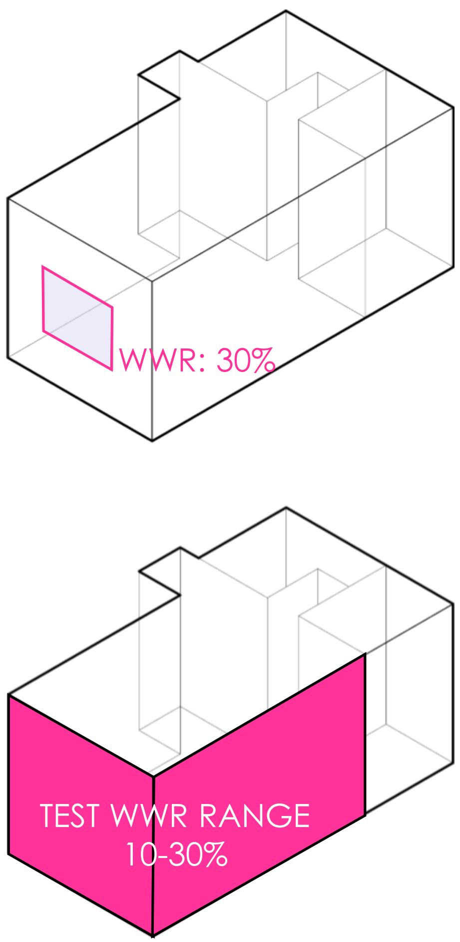
Step 2. Improve Visual Comfort through window design iteration |

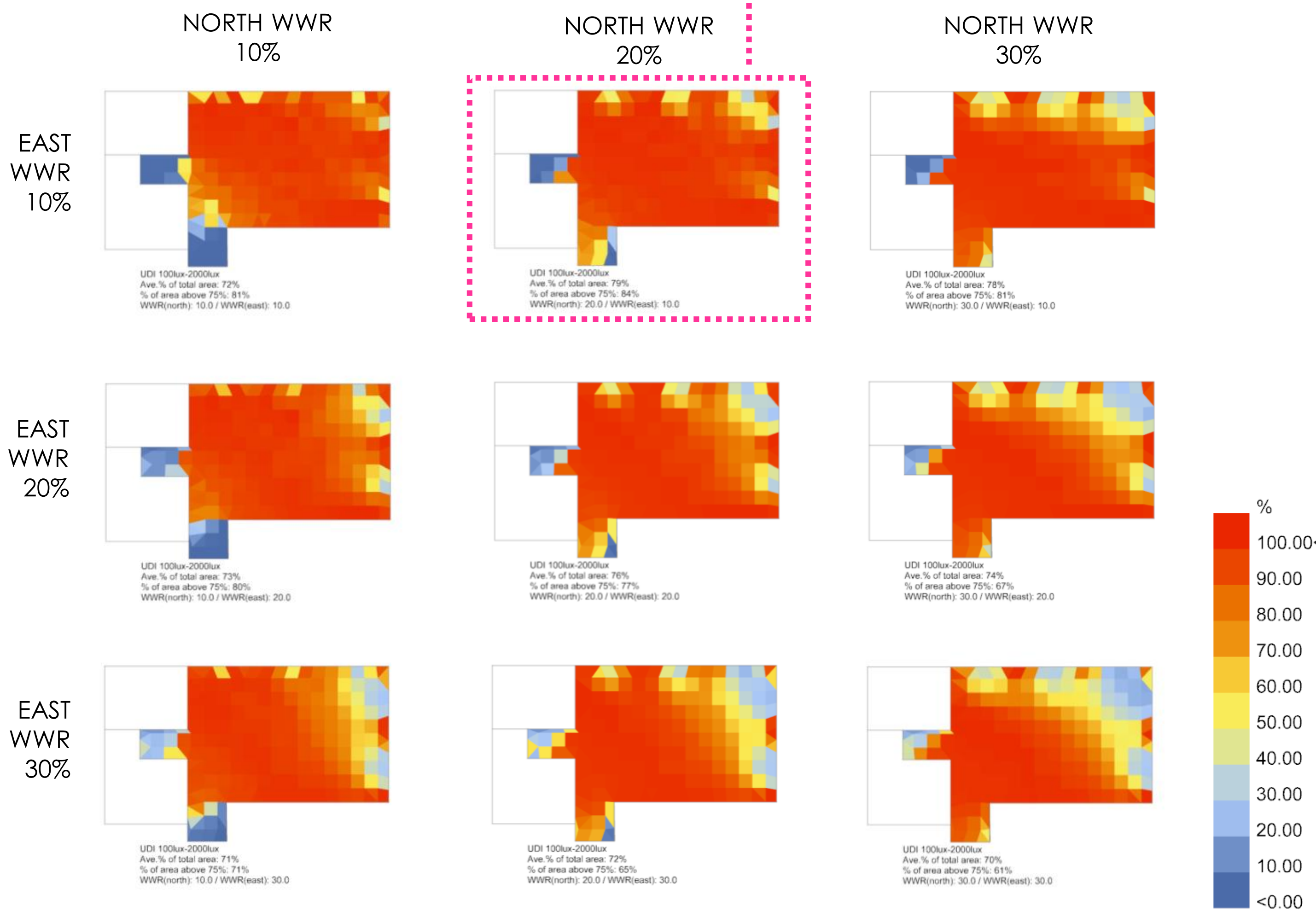
1. Evaluation of UDI upon Window-to-Wall Ratio no North and East Facade

The room has both east and north façades. To optimize UDI from the previous proposed design, geometry of the room has been changed. WWR of north and east façade has a specific range, 10%-30%, since the WWR of the original window facing the east is around 30%. If the WWR is above 30%, there would be over-lit, and daylight will not be provided evenly due to the depth of the room. For these reasons, UDI is evaluated upon the WWR of the north side and the east.

BEST RESULT
WWR(north): 20%
WWR(east): 10%

84% Of area meets UDI<100lux
For over 75% of time



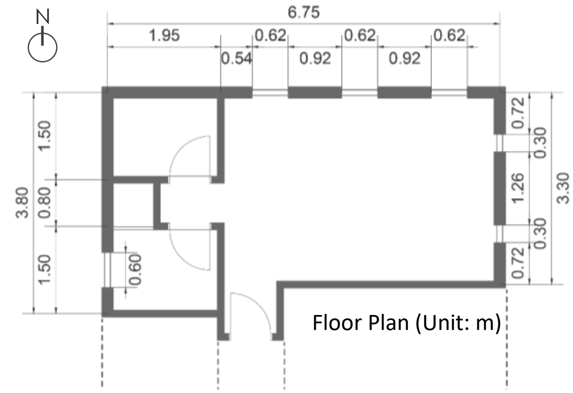


IV. Discussion and Design Proposals

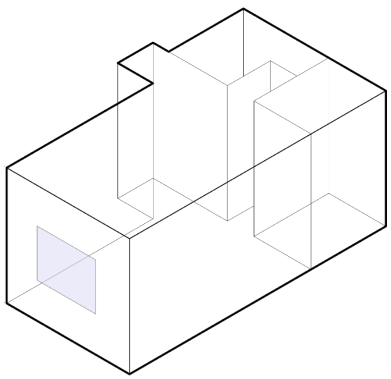
Step 2. Improve Visual Comfort through window design iteration

2. Result Comparison

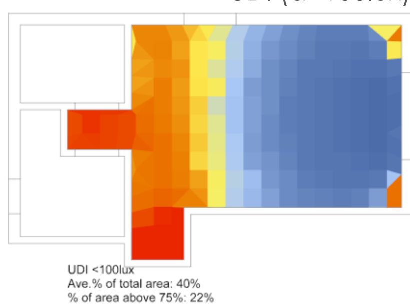
The room now has sufficient daylight. However, since the room still has a few over-lit, next step is to reduce over-lit with shading devices.



Useful Daylight Illuminance (UDI)



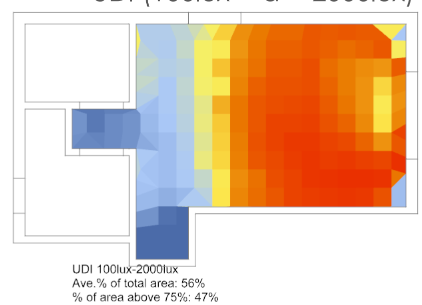
UDI (a<100lux)



22%

Of area meets UDI<100lux
For over 75% of time

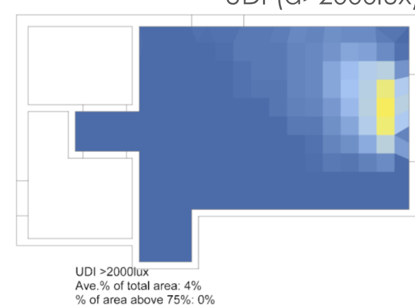
UDI (100lux<=a<=2000lux)



47%

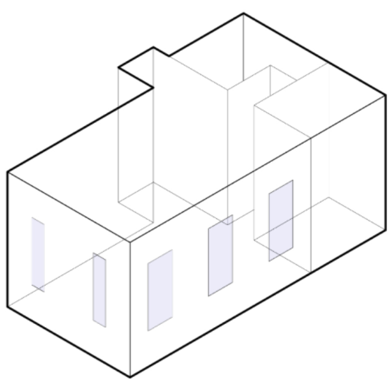
Of area meets UDI 100lux<2000lux
For over 75% of time

UDI (a>2000lux)



0%

Of area meets UDI >2000lux
For over 75% of time

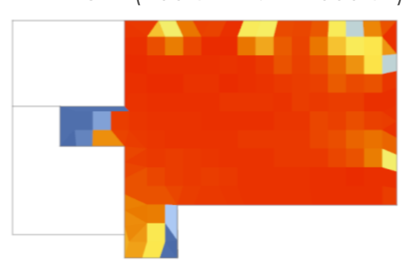


UDI (a<100lux)

5%

Of area meets UDI<100lux
For over 75% of time

UDI (100lux<=a<=2000lux)



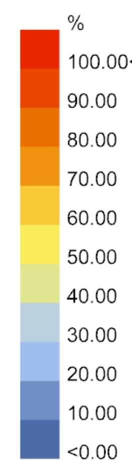
84%

Of area meets UDI 100lux<2000lux
For over 75% of time

UDI (a>2000lux)

0%

Of area meets UDI >2000lux
For over 75% of time

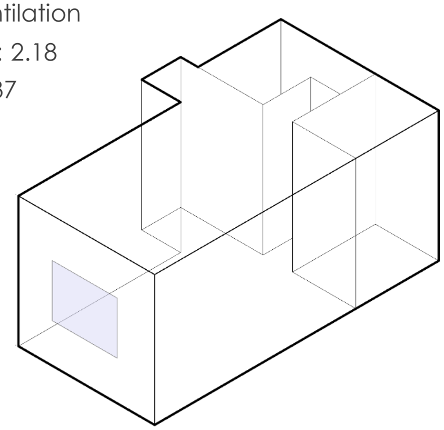


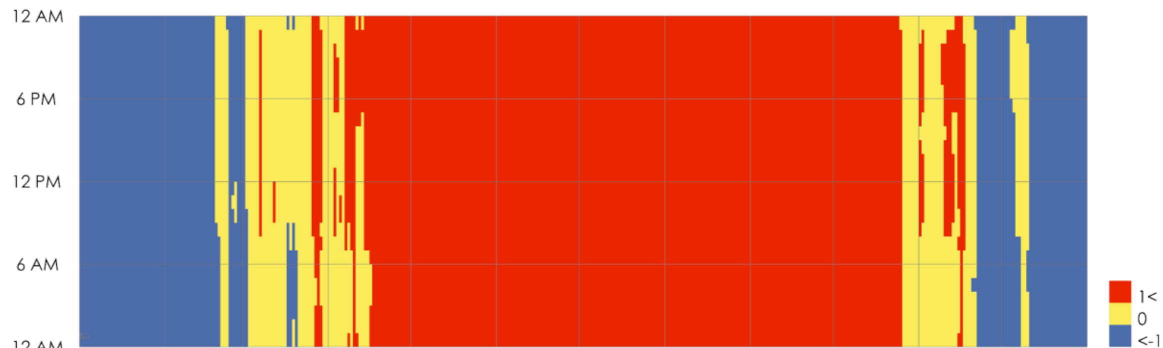
Step 3. Design Check Iteration (1)

Adaptive Comfort Chart Comparison and Next Step

Although the target room has evenly sufficient daylight, indoor comfort becomes slightly worsen than before. Following step is the process to reduce heat stress and cold stress as well.

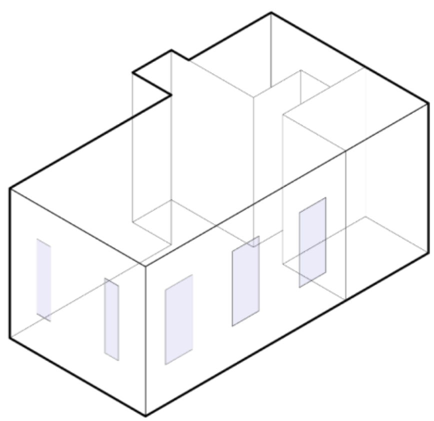
*No apply natural ventilation
Exterior wall R-VALUE: 2.18
Window U-VALUE: 2.37

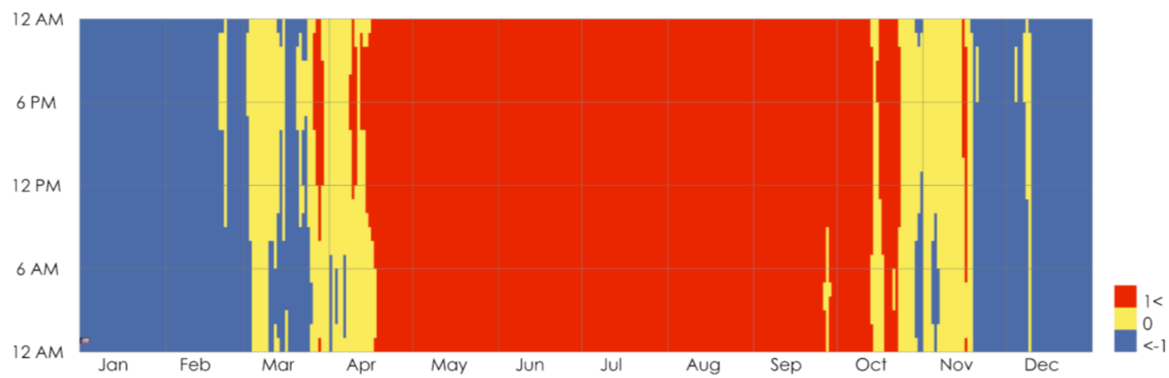




Adaptive Comfort for MY_ROOM (-1 = Cold, 0 = Comfortable, 1 = Hot) - Hourly
Philadelphia International Ap PA USA TMY3
1 JAN 1:00 - 31 DEC 24:00

% comfortable time 17.3%
Hot stress 57.3%
Cold stress 25.4%





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

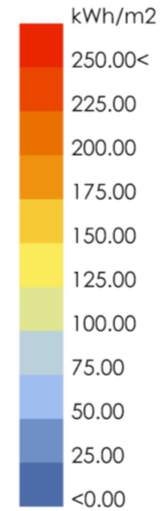
% comfortable time 16.3%
Hot stress 52.7%
Cold stress 31.0%

Ⅳ. Discussion and Design Proposals

Step 4. Shading Design Exploration

Strategy to block sunlight during summer and to reduce over-lit problem

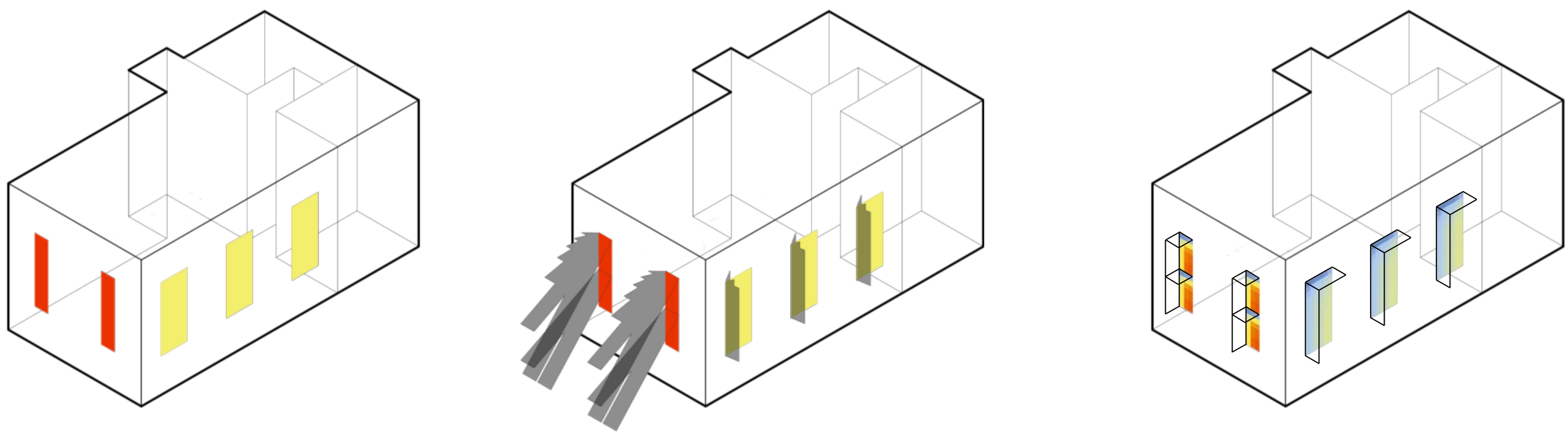
In this step, I tried to block sunlight during summer and allow to come sunlight inside during winter to reduce cold stress. To achieve this goal, I analyzed sun angle during summer, especially the highest sun angle which is June, and figure out the area to block these sun vectors.



Understanding of Current Solar Irradiation (June-August)

Figure out the area to Block the highest sun angle (June)

Propose Shading Design With unified design language



Ⅳ. Discussion and Design Proposals

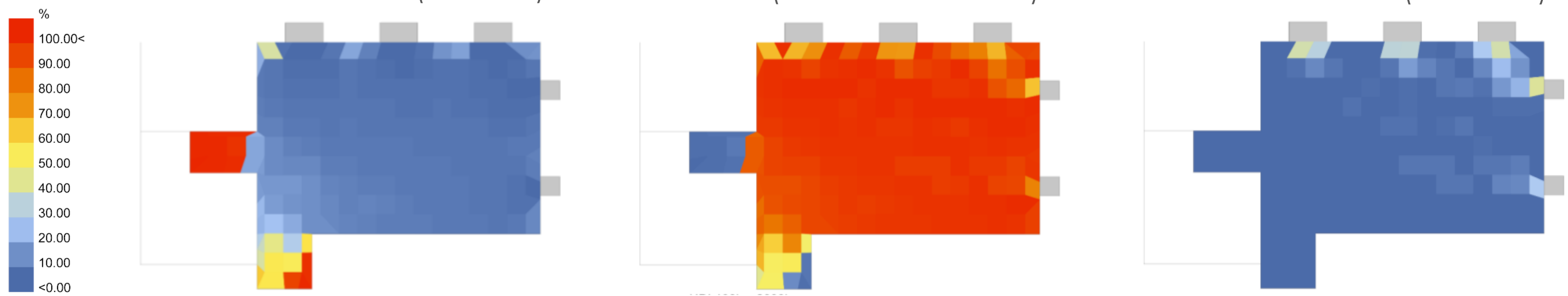
Step 5. Design Check Iteration (2)

Figure Out the Next Step through Mid Design Check

Although I tried to reduce only the hot stress, cold stress also has increased because of shading.
Thus, I admitted the limitation of the process, and then start to find other method to improve indoor comfort.

Useful Daylight Illuminance

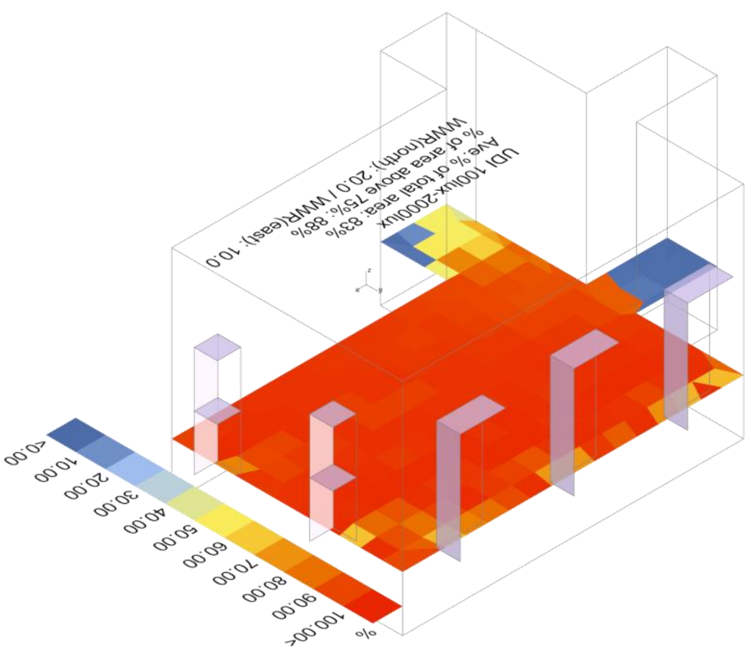
UDI (a<100lux) | UDI (100lux<=a<=2000lux) | UDI (a>2000lux)



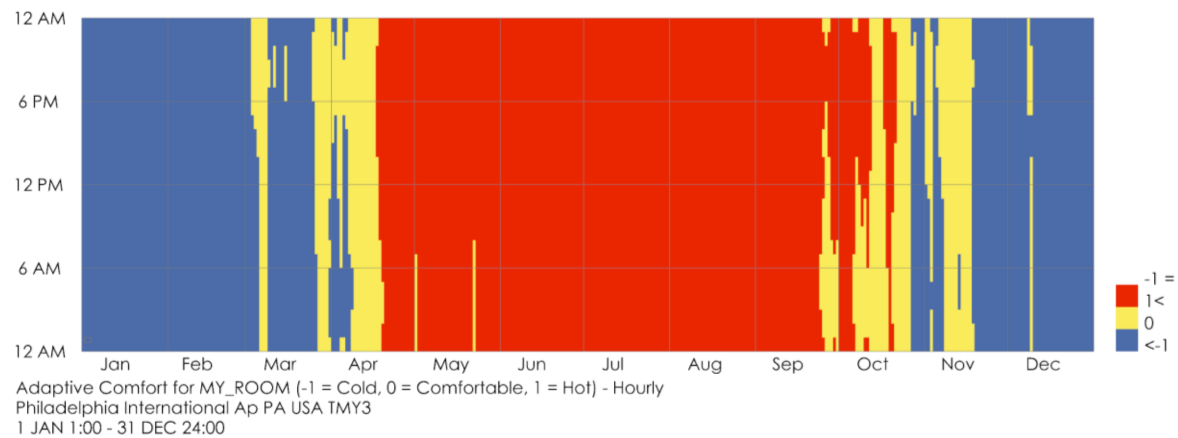
5%(=)
Of area meets UDI<100lux
For over 75% of time

88%(▲4%)
Of area meets UDI 100lux<2000lux
For over 75% of time

0%(=)
Of area meets UDI >2000lux
For over 75% of time



Indoor Comfort Analysis



% comfortable time 15.1% (▼1.2%)
Hot stress 47.7% (▼5%)
Cold stress 37.0% (▲6%)

Ⅳ. Discussion and Design Proposals

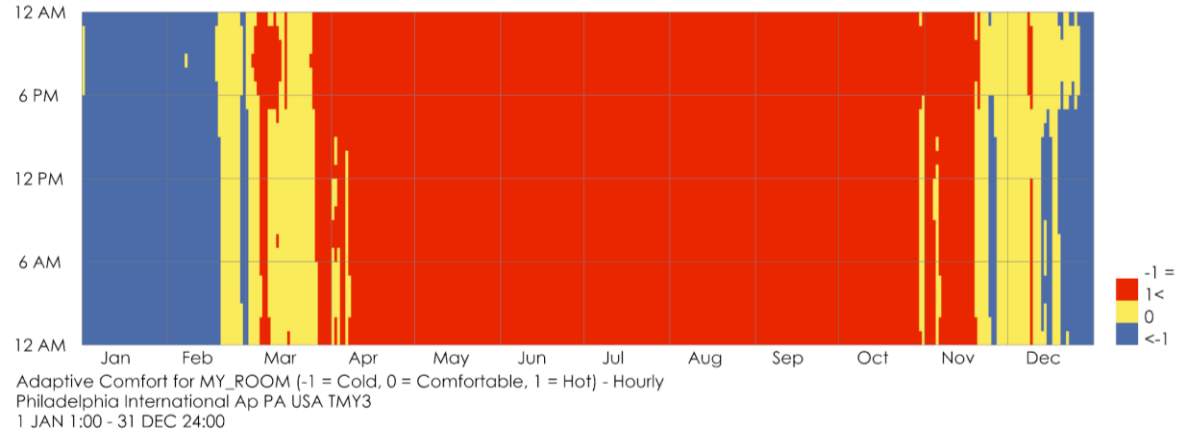
Step 6. Change Building Materials

Increase Heat Buffer to Reduce Cold Stress

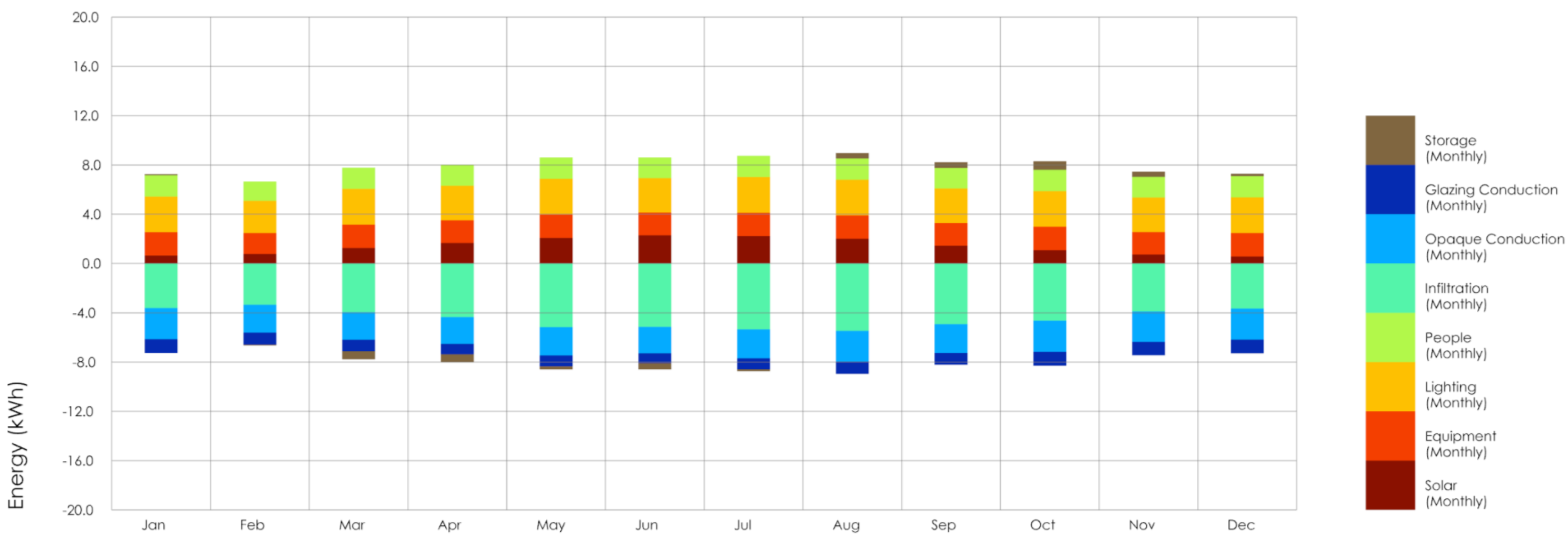
First, I changed the building materials to make a well-insulated room. The room achieved dramatically reduced cold stress, but heat stress simultaneously increased. Next step is to reduce the heat stress with natural ventilation.

Baseline	New Properties
Exterior wall R-VALUE: 2.18	**Exterior wall R-VALUE: 4.74**
Window U-VALUE: 2.37	**Window U-VALUE: 0.5**
	Window SHGC: 0.37
	Window VT: 0.56

Indoor Comfort Analysis | *No apply natural ventilation



% comfortable time 15.8% (▲0.7%)
Hot stress 65.9% (▲18.2%)
Cold stress 18.3% (▼18.7%)



Ⅳ. Discussion and Design Proposals

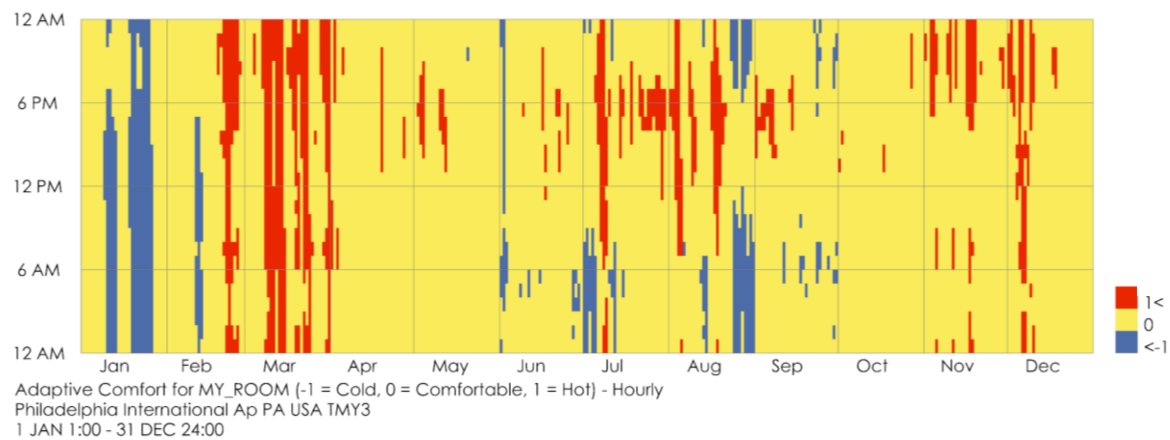
Step 7. Application of Natural Ventilation Exploration

Natural Ventilation is Critical Strategy to reduce Heat Stress

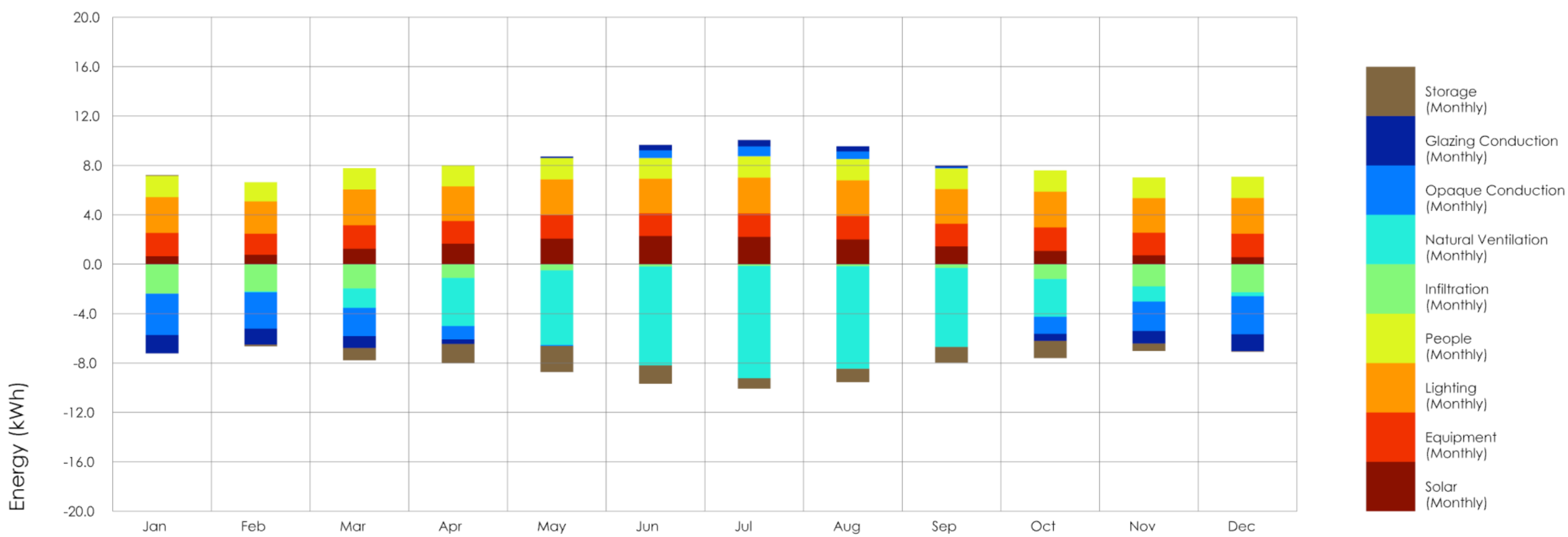
Natural ventilation is useful strategy to overcome thermal comfort problem in unconditioned building. However, the building does not consider HVAC, standard of the range of natural ventilation does not work properly in the target room. I tried to adjust numerous time to find the best range of natural ventilation, but I could not tell that this was the best range.

Minimum Indoor Temp. for Nat.Ventilation: 23 ℃
Maximum Indoor Temp. for Nat.Ventilation: 34 ℃
Minimum outdoor Temp. for Nat.Ventilation: 10 ℃
Maximum outdoor Temp. for Nat.Ventilation: 27 ℃
Infiltration Rate: 0.0001

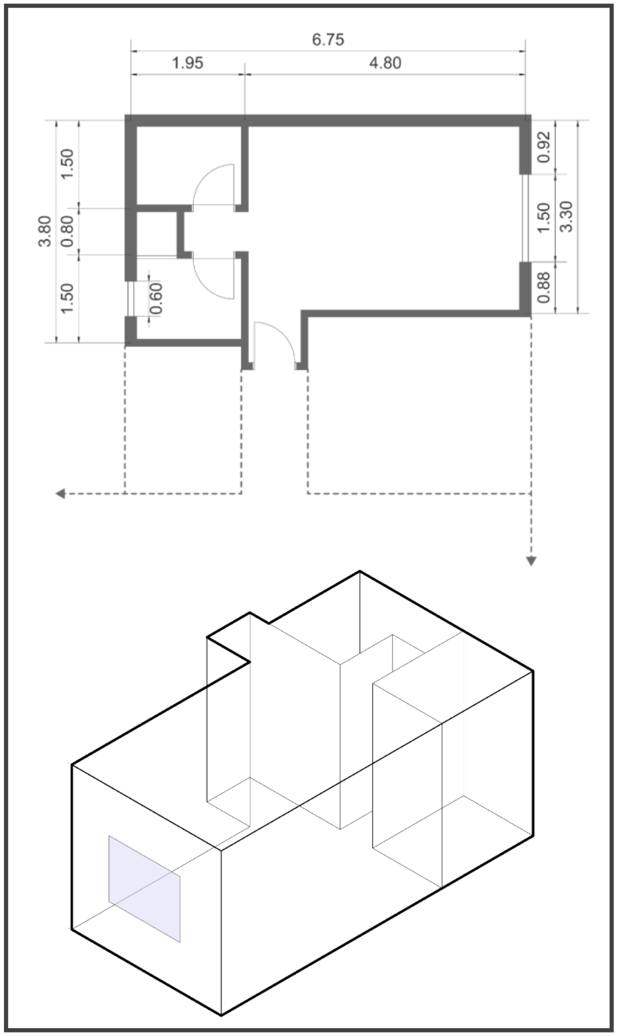
Indoor Comfort Analysis

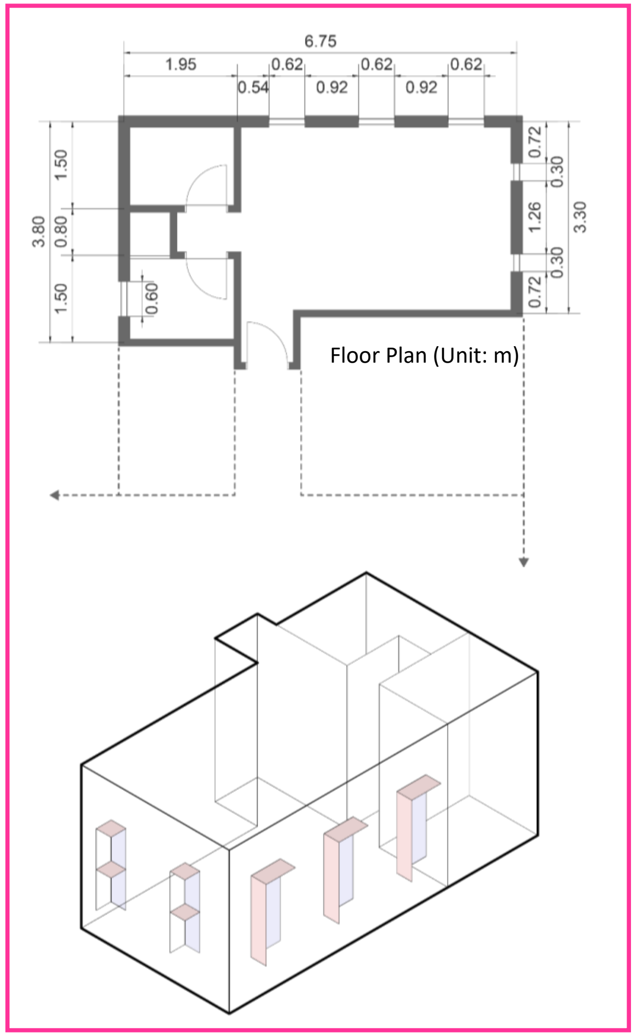


% comfortable time 83.3% (▲67.5%)
Hot stress 10.4% (▼47.7%)
Cold stress 6.3% (▼12%)



Ⅴ. Final Design Assessment





Exterior wall R-VALUE: 4.74

Window U-VALUE: 0.5

Window SHGC: 0.37

Window VT: 0.56

Min Indoor Temp. for Nat.Ventilation: 23 ℃

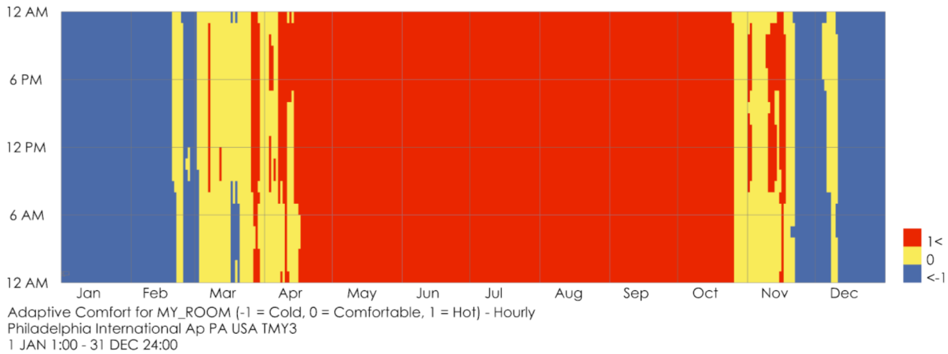
Max Indoor Temp. for Nat.Ventilation: 34 ℃

Min outdoor Temp. for Nat.Ventilation: 10 ℃

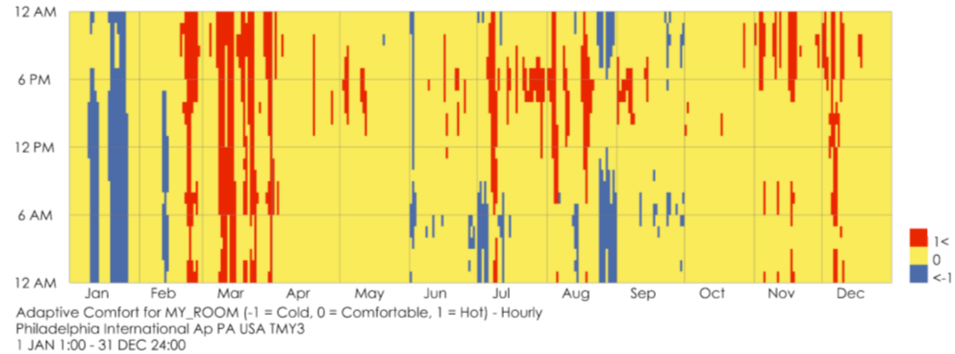
Max outdoor Temp. for Nat.Ventilation: 27 ℃

V. Final Design Assessment

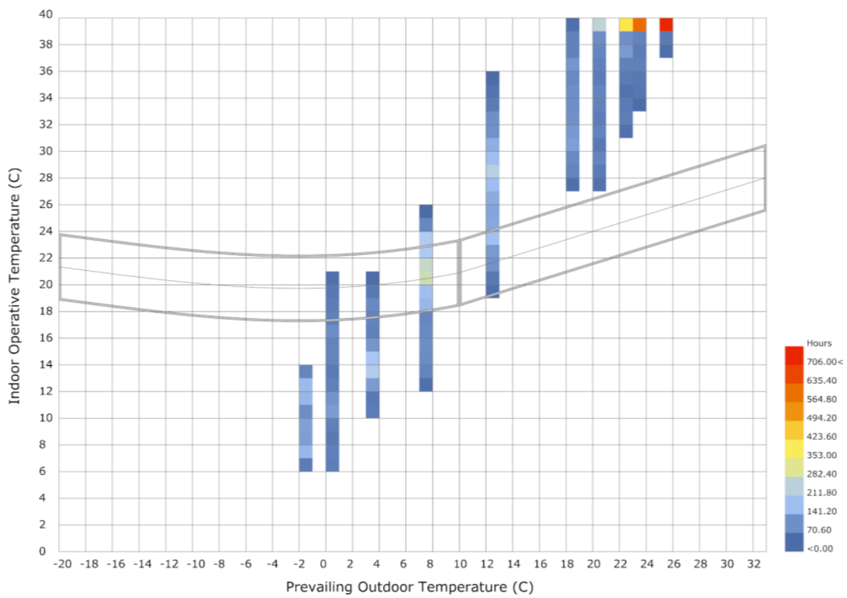
Indoor Thermal Comfort Comparison



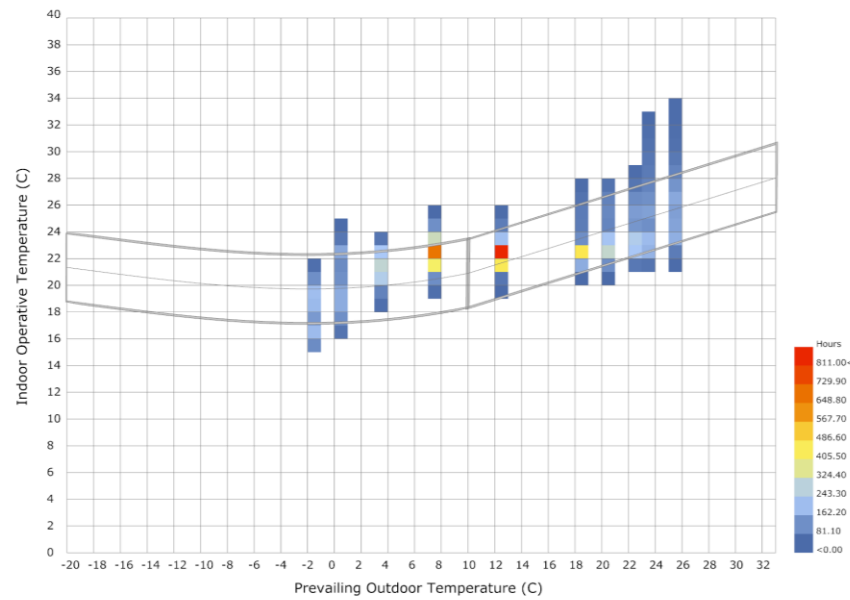
% comfortable time 17.3%
Hot stress 57.3%
Cold stress 25.4%



% comfortable time 83.3% (▲66%)
Hot stress 10.4% (▼46.9%)
Cold stress 6.3% (▼19.1%)



Adaptive Chart
Philadelphia International Ap_PA_USA
1 JAN 1:00 - 31 DEC 24:00



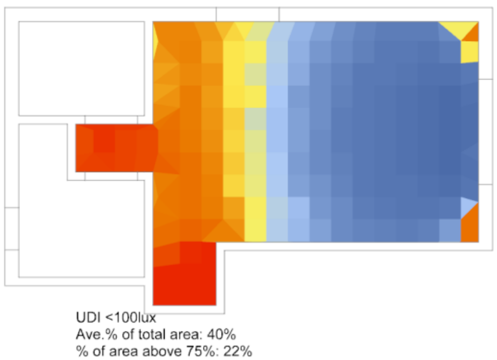
Adaptive Chart
Philadelphia International Ap_PA_USA
1 JAN 1:00 - 31 DEC 24:00

V. Final Design Assessment

Indoor Visual Comfort Comparison

Useful Daylight Illuminance

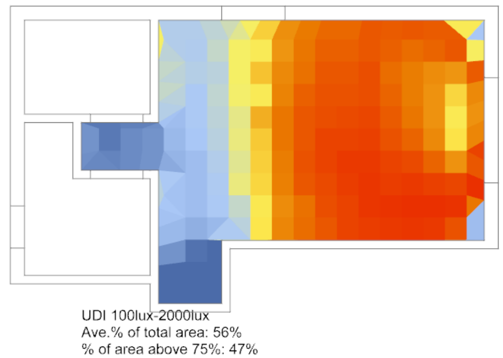
UDI (a<100lux)



22%

Of area meets UDI<100lux
For over 75% of time

UDI (100lux<=a<=2000lux)



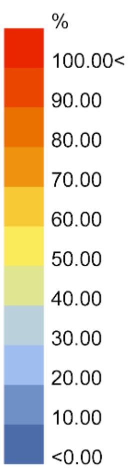
47%

Of area meets UDI 100lux<2000lux
For over 75% of time

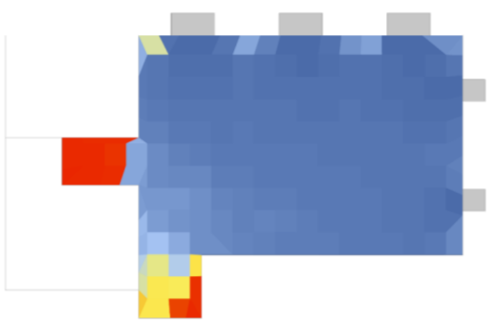
UDI (a>2000lux)

0%

Of area meets UDI >2000lux
For over 75% of time



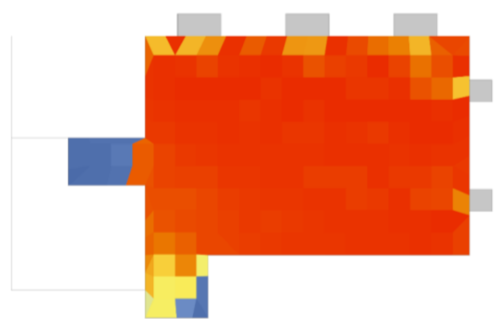
UDI (a<100lux)



5%(▼17%)

Of area meets UDI<100lux
For over 75% of time

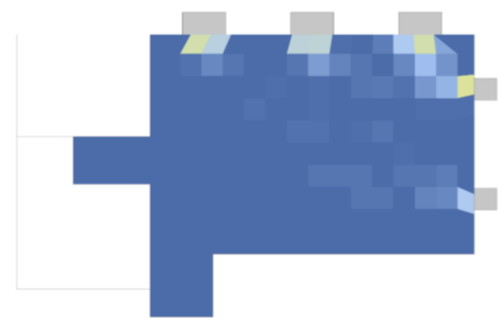
UDI (100lux<=a<=2000lux)



88%(▲41%)

Of area meets UDI 100lux<2000lux
For over 75% of time

UDI (a>2000lux)



0%(=)

Of area meets UDI >2000lux
For over 75% of time

VI. Conclusion

Conclusion

By completing this paper, I have learned how to use the simulation, what principle each simulation model has, and good opportunity to learn what process I need to design sustainable building. Although I have achieved good result from this paper, I met numerous limitations during the process. Here are the limitations which I got and will be the next step to understand deeply about a building performance simulation.

Limitation & Next Step

1. Limitation of Lineage Process

2. Limitation of Shading Design
   : How can I consider simultaneously both of Horizontal and Vertical Shading?
   : Difficult to meet not only minimize solar insolation during summer but also maximize during winter

3. Limitation of understanding of adaptive comfort chart

4. What if I try to replace wardrobe and toilet?