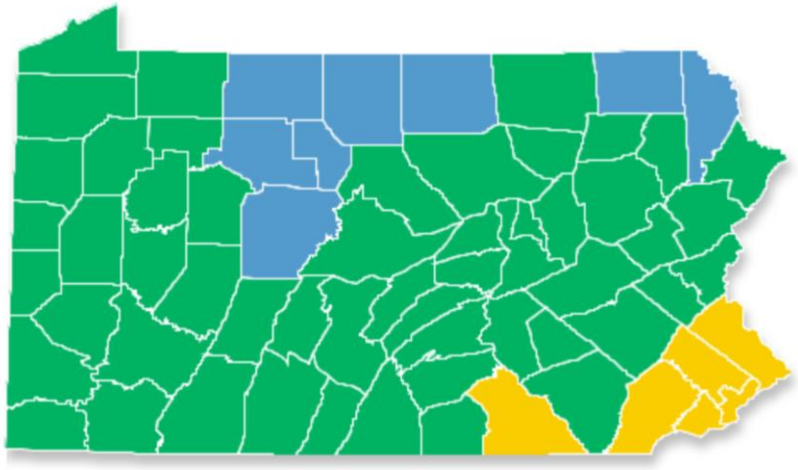
MAXIMIZING THE COMFORT OF AN UNCONDITIONED SPACE

PART 1: STUDYING THE WEATHER OF PHILADELPHIA

Philadelphia, Pennsylvania

Pennsylvania State is located on the North-East of the United States of America. Philadelphia being the capital is located approximately at 40° 0′ 34″ north latitude and 75° 8′ 0″ west longitude.

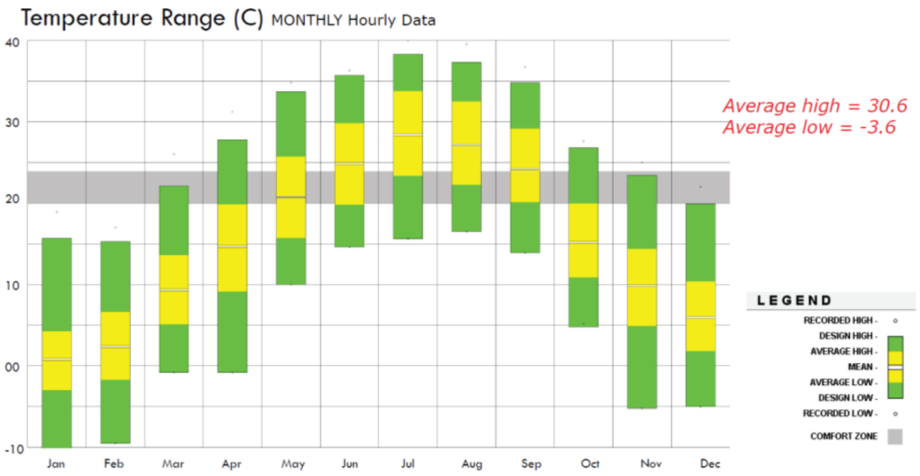
Image Source: maps.google.com



Philadelphia (located in zone 4) has the above zone minimum requirements for residential buildings.
Source:https://energycode.pnl.gov/EnergyCodeReqs/index.jsp?state=Pennsylvania

Climate Zone 4 (Except Marine)

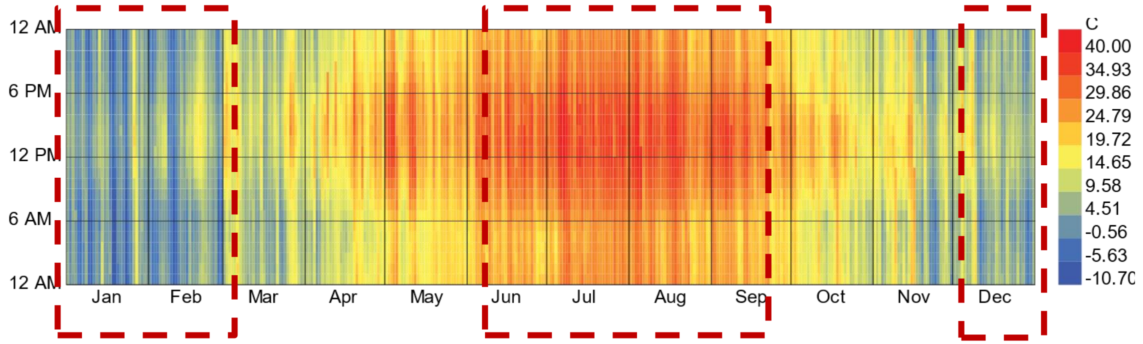
Ceiling R-value	38
Wood Frame Wall R-value	13
Mass Wall R-value [i]	5/10
Floor R-value	19
Basement Wall R-value [c]	10/13
Slab R-value [d], Depth	10, 2 ft
Crawlspace Wall R-value [c]	10/13
Fenestration U-Factor [b]	0.35
Skylight U-Factor [b]	0.60
Glazed fenestration SHGC [b, e]	NR



The graph to the left is from Climate Consultant, which assumes that 20 to 24C is the comfort level. During the entire year the amount of comfortable hours based on looking into Weather data in the graph is very less.

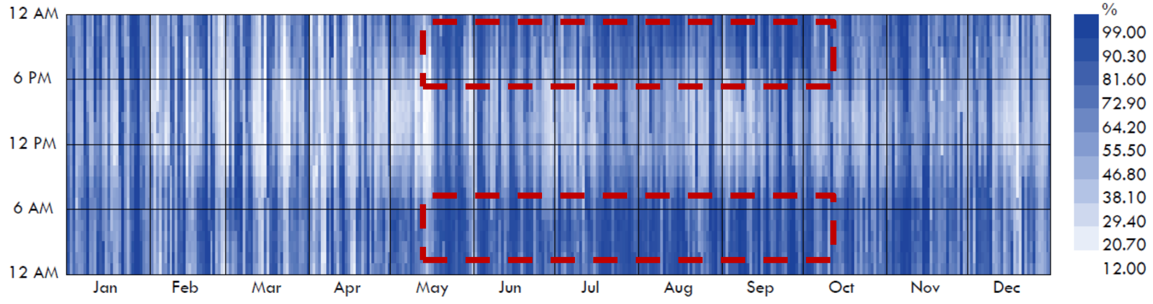
However as shown through this report, there are more factors than just temperature that affect the comfort. Also, since this is outdoor temperature, we cannot solely base our design considerations on this graph.

DRY BULB TEMPERATURE (C) Annual Hourly Data



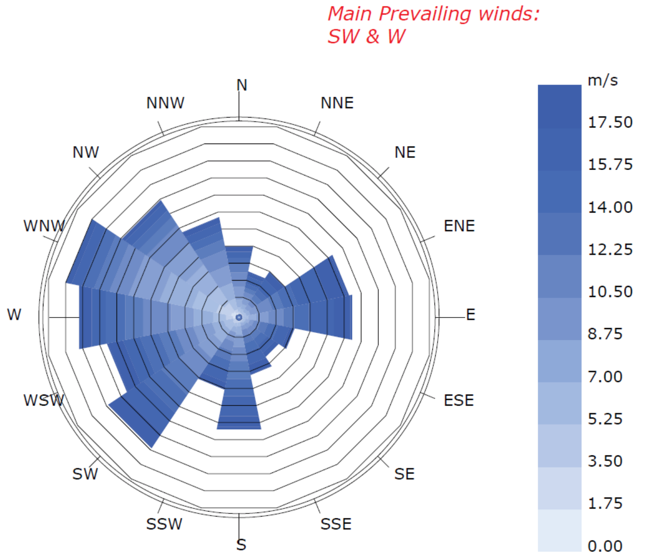
Philadelphia has extreme weather with hot summers ranging from 29-40C and winters ranging from -0 to -10 C. January is the coldest month and July is the hottest month.

RELATIVE HUMIDITY (%) Annual Hourly Data



There is high relative humidity during the night in the summer and fall months with humidity reaching 99%.

WIND ROSE DIAGRAM (m/s) Annual Hourly Data

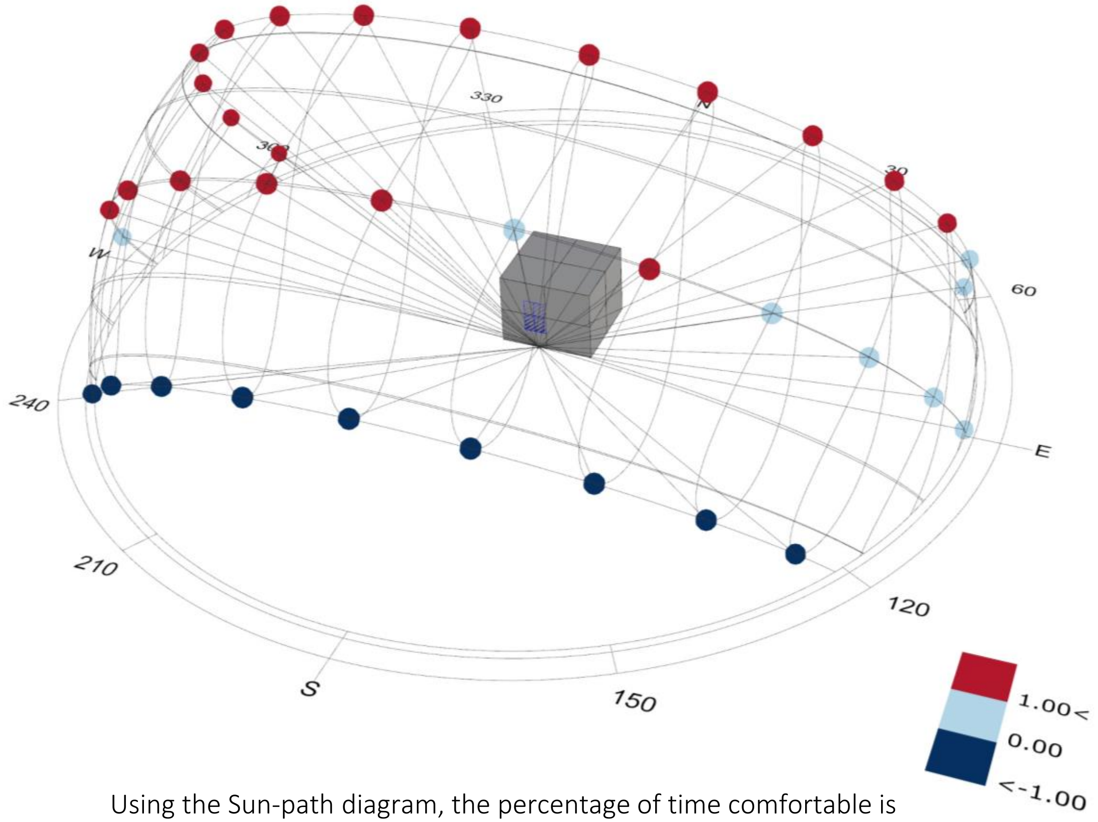


Wind Rose Diagram
ANNUAL Hourly Data: Wind Speed (m/s)

The main prevailing winds are from South-West and West with wind speeds up to 17.5 m/s. Providing windows in the opposite directions based on looking into Weather data inthe wind rose diagram can create a good flow for natural indoor airflow.

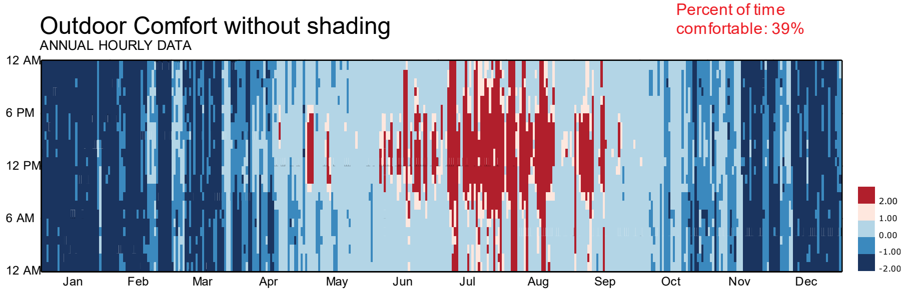
UNDERSTANDING THE CLIMATE OF PHILADELPHIA

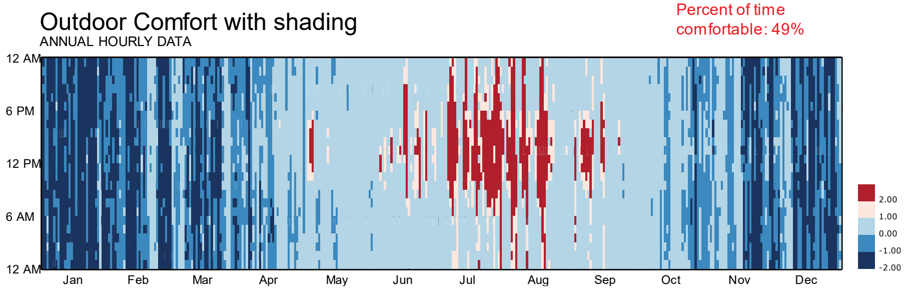
ANNUAL COMFORT ON SUNPATH DIAGRAM



Using the Sun-path diagram, the percentage of time comfortable is plotted. The percent of time comfortable in Philadelphia is 37.34%.

ANNUAL COMFORT WITH & WITHOUT SHADING

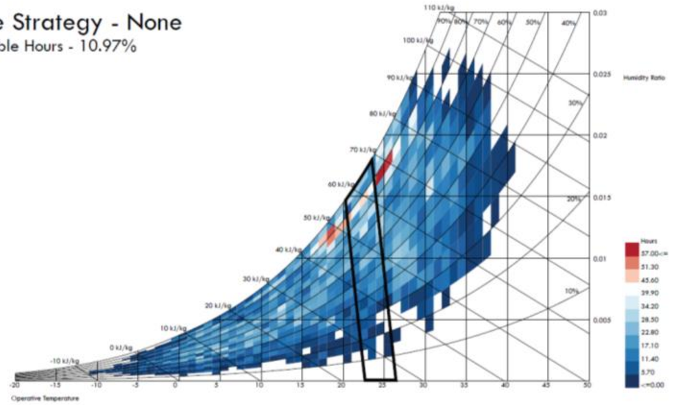




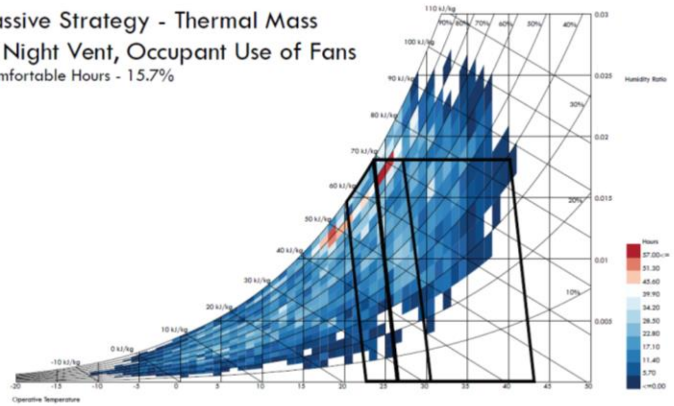
By adding shading, the outdoor comfort increases by about 10%. This shows that removal of solar radiation increased the outdoor comfortable time.

UNDERSTANDING HOW PASSIVE STRATAGIES CAN HELP

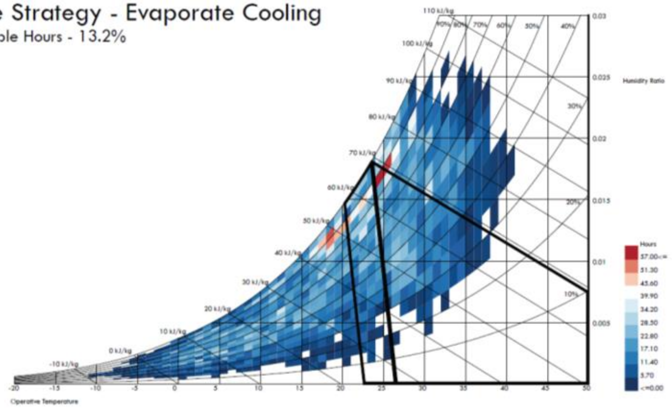
Passive Strategy - None
Comfortable Hours - 10.97%



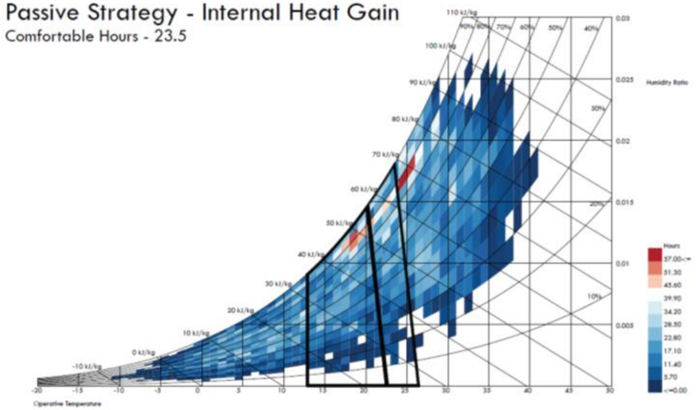
Passive Strategy - Thermal Mass & Night Vent, Occupant Use of Fans
Comfortable Hours - 15.7%



Passive Strategy - Evaporate Cooling
Comfortable Hours - 13.2%



Passive Strategy - Internal Heat Gain
Comfortable Hours - 23.5



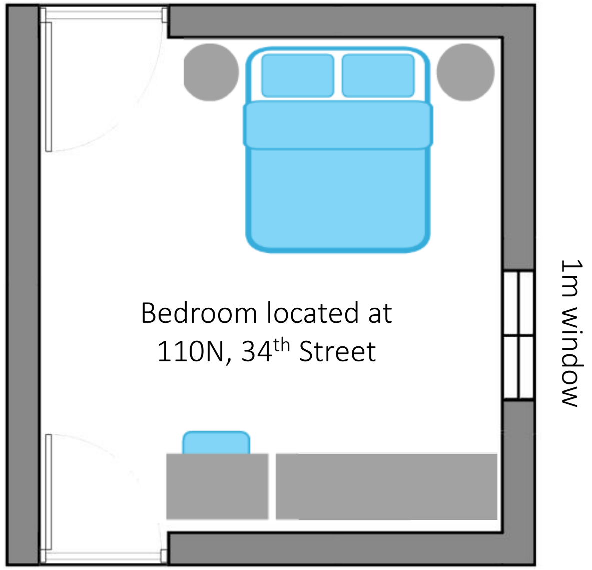
Combining all Passive Strategies
Comfortable Hours - 51.7%

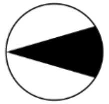
Psychometric charts are used to express various passive strategies such as thermal mass, night vent, use of fans, evaporative cooling and internal heat gain to understand how these small differences can increase the comfort levels of a space in Philadelphia. These strategies can be used to design a space in Philadelphia.

PART 2: MAXIMIZING THE COMFORT OF THE “DREAMROOM”

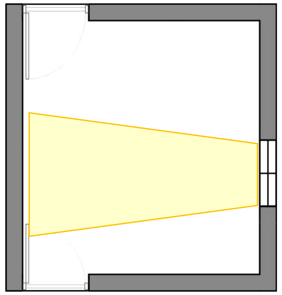
BEDROOM ANALYSIS

PLAN OF THE BEDROOM

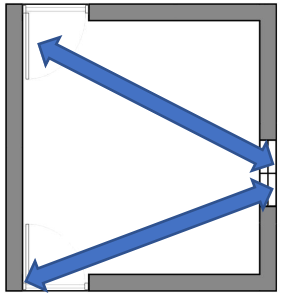




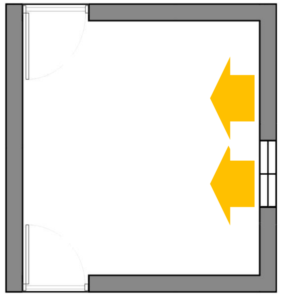
SOME ISSUES OF THE BEDROOM



The bedroom has very limited lighting even during the hot summer months. Every part of the bedroom does not get sufficient lighting.

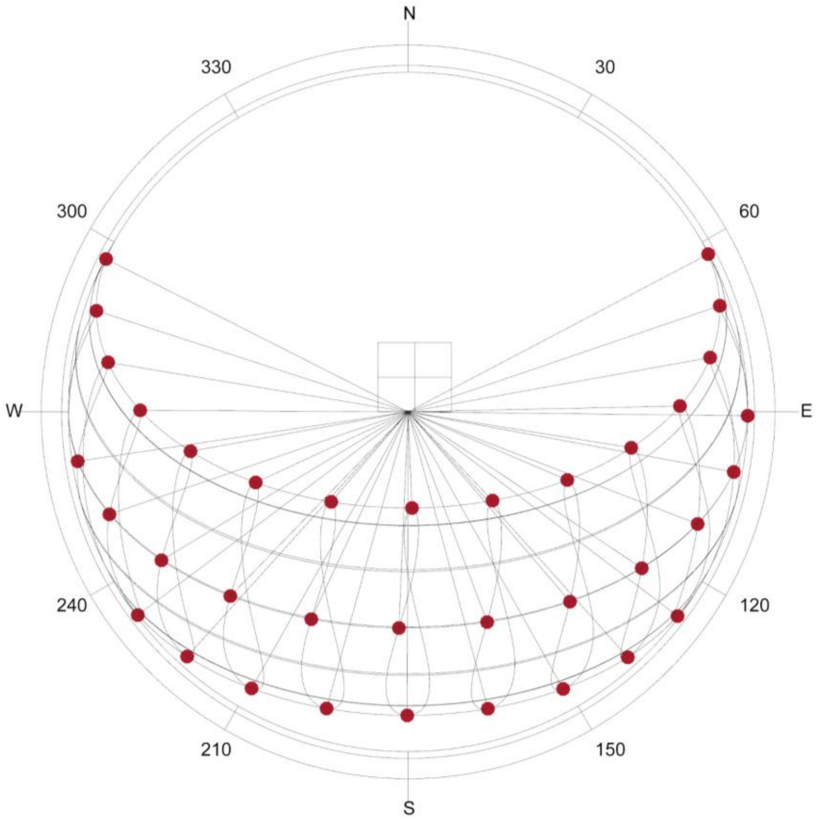


The bedroom does not have any natural indoor airflow making the room completely dependent on HVAC systems.



South facing wall receives a lot of heat during the summer months making it very hot.

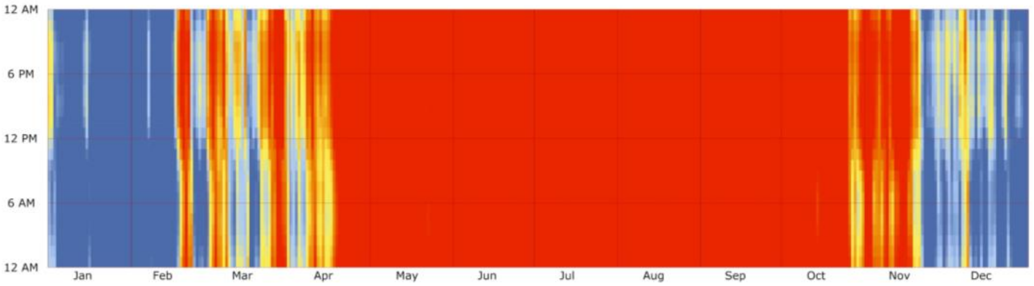
SUNPATH DIAGRAM IN CONTEXT OF THE BEDROOM



The sun angles in the winter are very steep while the sun angles in the summer are very high. Designing a shading system which lets in solar radiation in the winter and stops it in the summer is very crucial to achieve high levels of comfort.

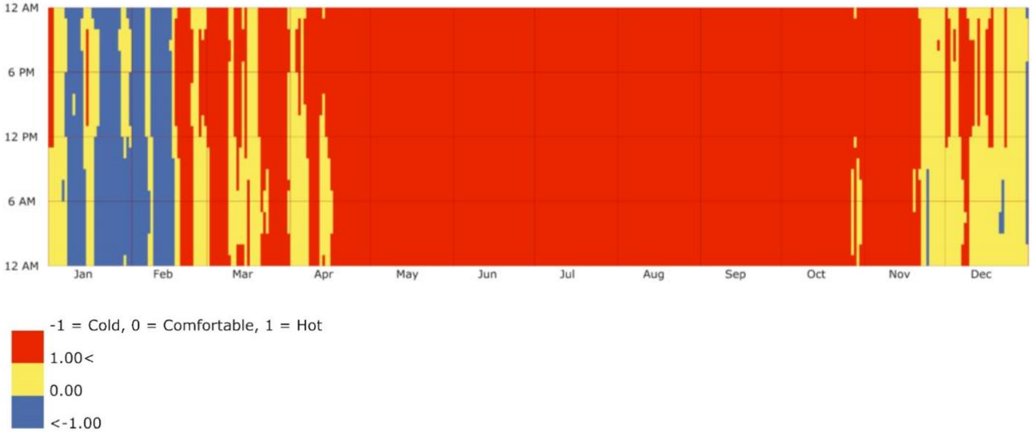
PREDICTED MEAN VOTE FOR BEDROOM

% Comfortable Hours: 13.53

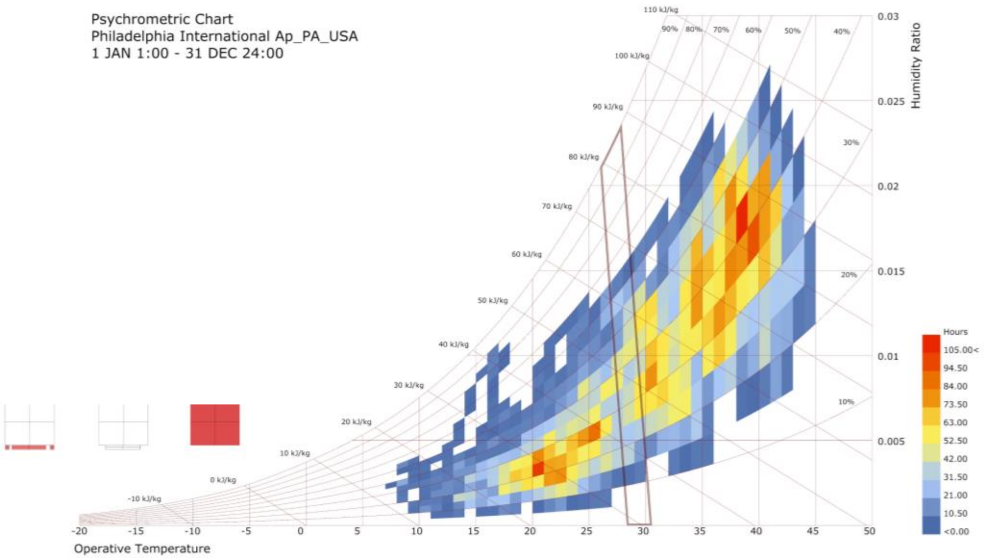


ADAPTIVE COMFORT FOR BEDROOM

% Comfortable Hours: 17.06

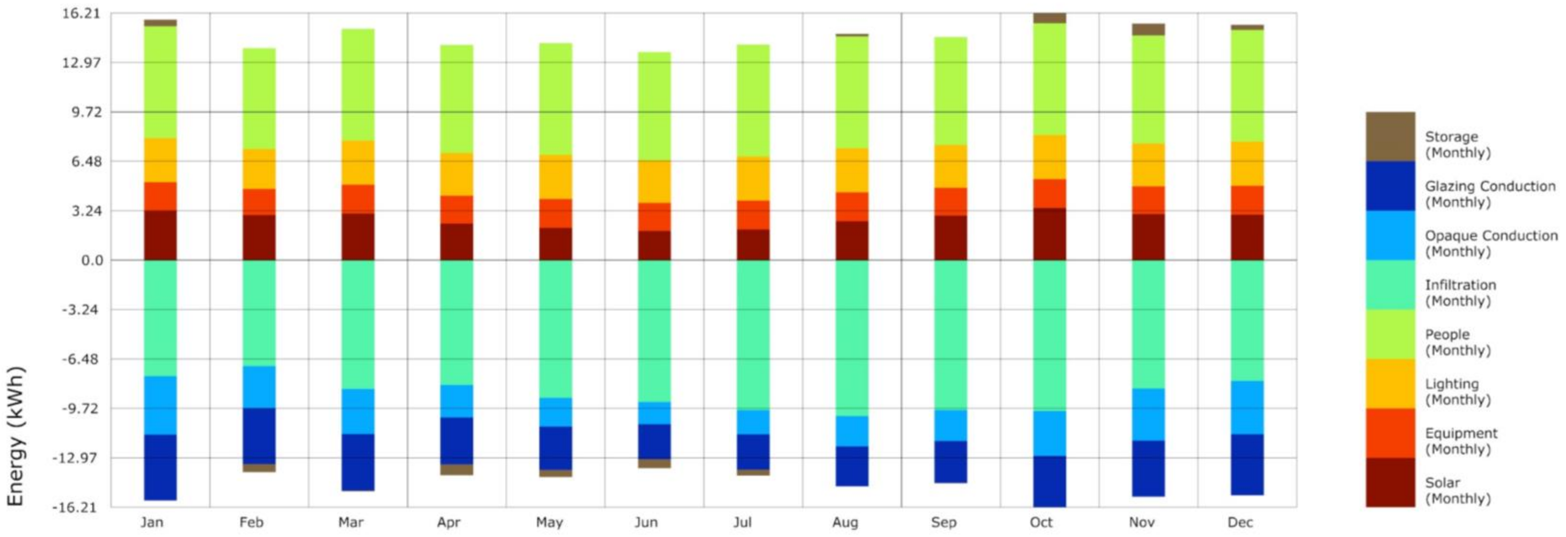


PSYCHROMETRIC CHART



% HOURS COMFORTABLE: 17.06%

ENERGY BALANCE CHART

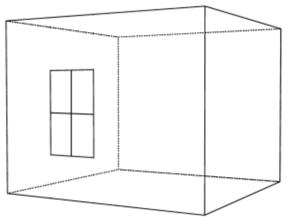


A basic Energy balance chart was done to understand the loads of the bedroom currently. Based on looking into simulation data a few strategies can be applied to make the space more comfortable.

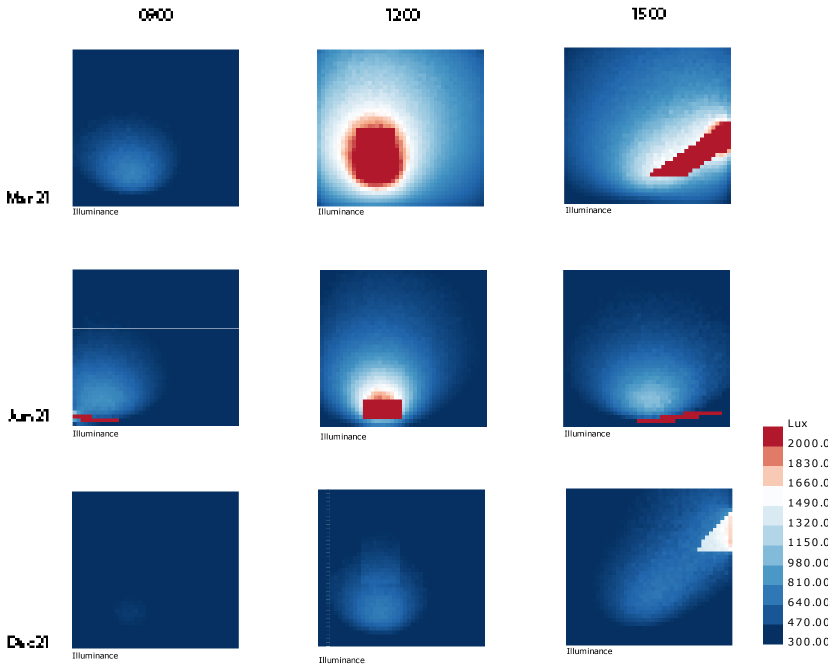
Based on looking into simulation data in the energy balance chart, the following aspects needs to be developed to improve the comfort of the bedroom.

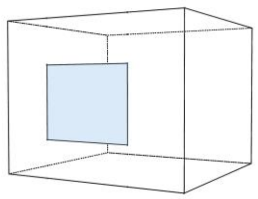
1. Glazing design
   - Shading devices
2. Adding natural indoor airflow
3. Zone loads
   - Infiltration rate
   - Equipment load
   - No of people
   - Lighting load
4. Occupancy Schedules
5. Change in the construction materials

BEDROOM ANALYSIS with PROPOSED DESIGN

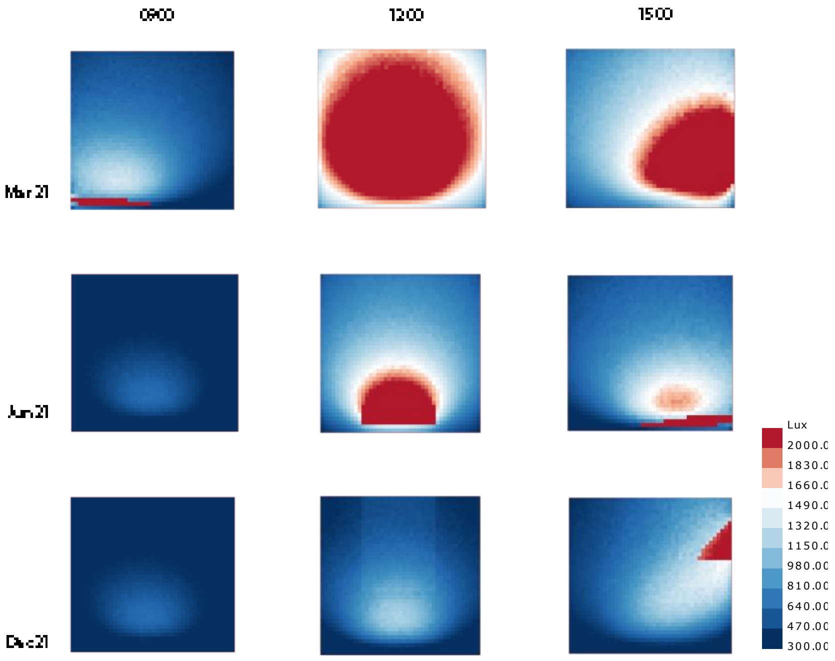


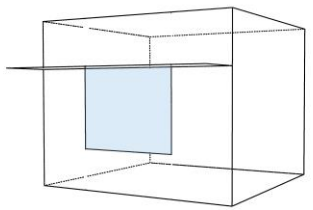
BASELINE
SIZE OF WINDOW: 1m



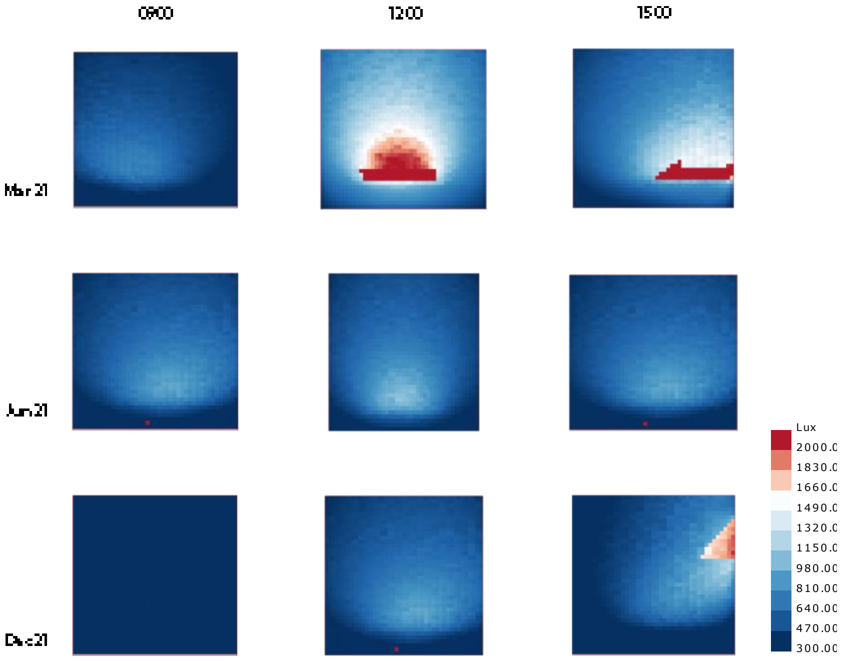


SIZE OF WINDOW: 2m

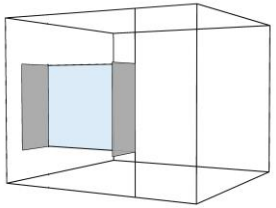




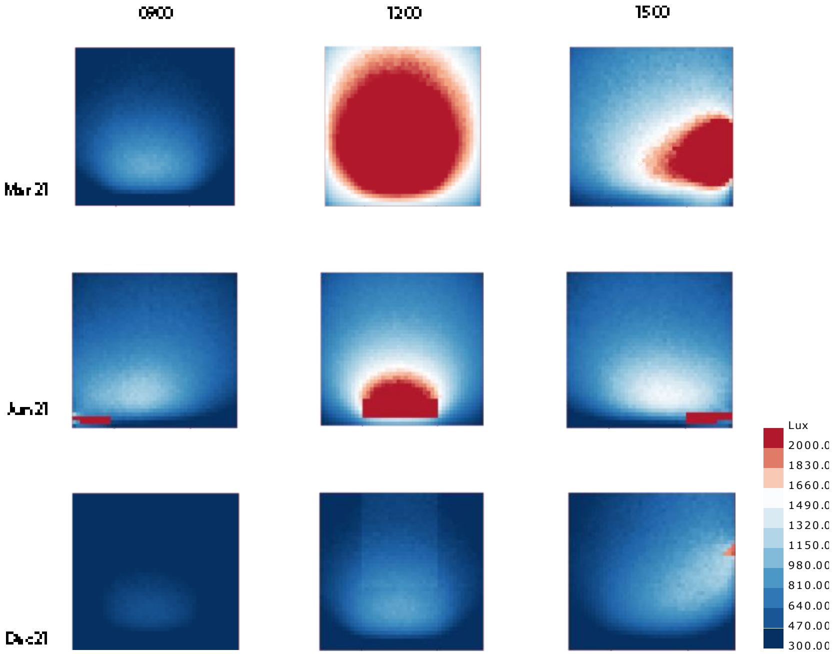
SIZE OF WINDOW: 2m
HORIZONTAL SHADING: 1m

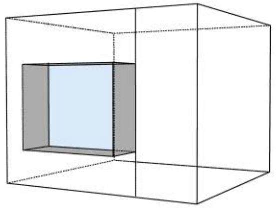


BEDROOM ANALYSIS with PROPOSED DESIGN

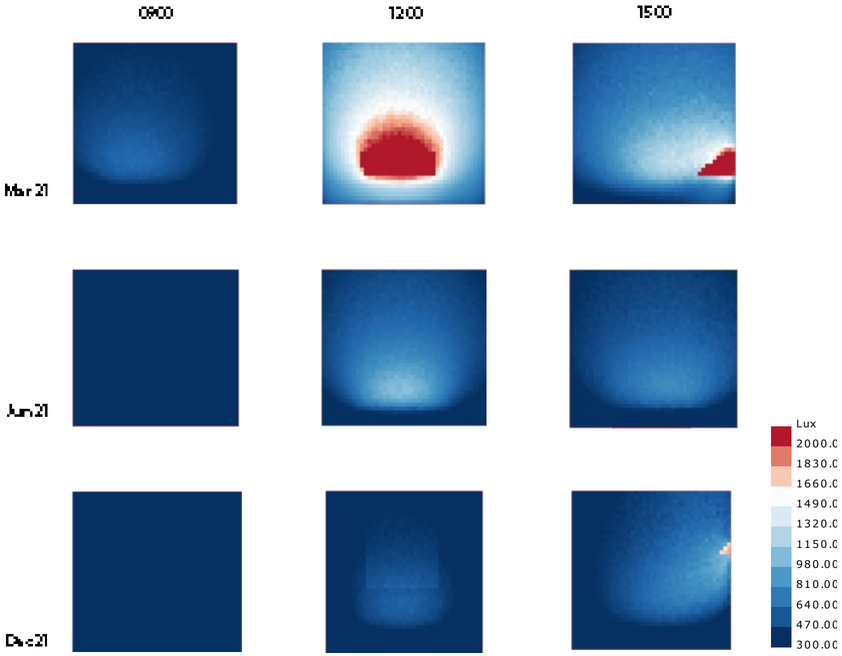


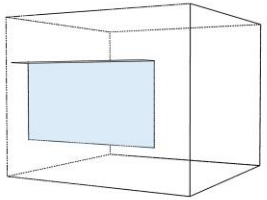
SIZE OF WINDOW: 2m
VERTICAL SHADING: 0.75m



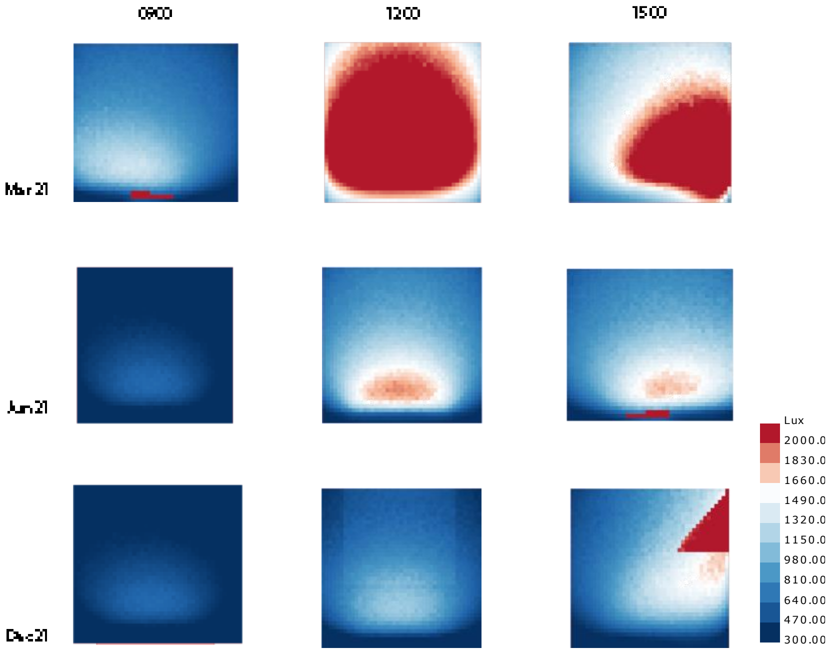


SIZE OF WINDOW: 2m
VERTICAL & HORIZONTAL SHADING: 0.75m

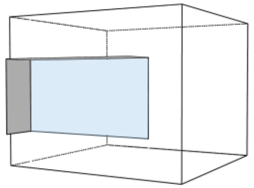




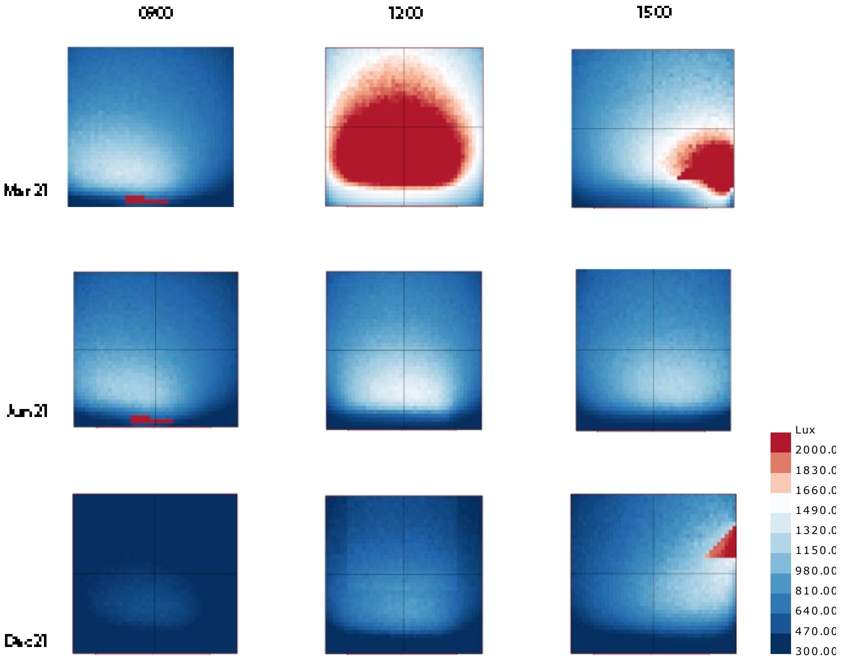
SIZE OF WINDOW: 3m
HORIZONTAL SHADING: 0.5m

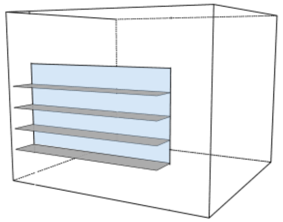


BEDROOM ANALYSIS with PROPOSED DESIGN

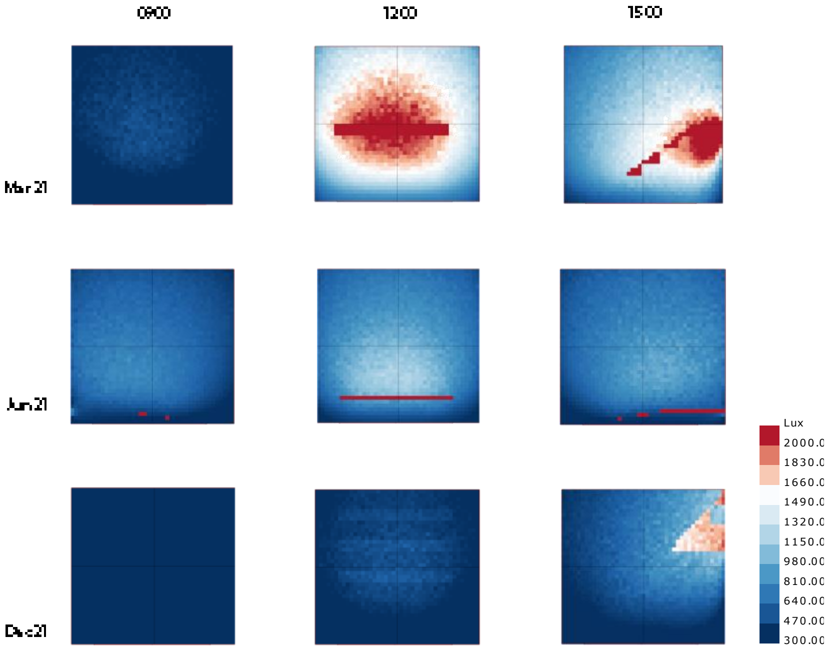


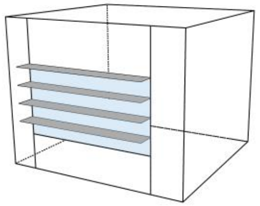
SIZE OF WINDOW: 3m
VERTICAL & HORIZONTAL SHADING: 0.75m



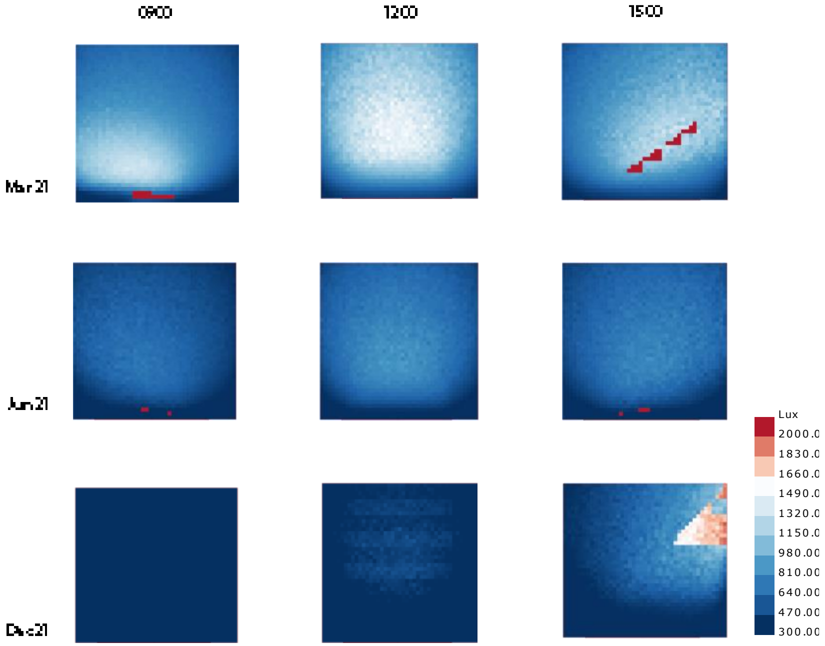


SIZE OF WINDOW: 3m
HORIZONTAL SHADING: 0.75m

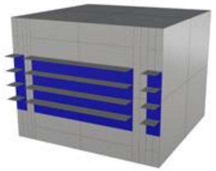




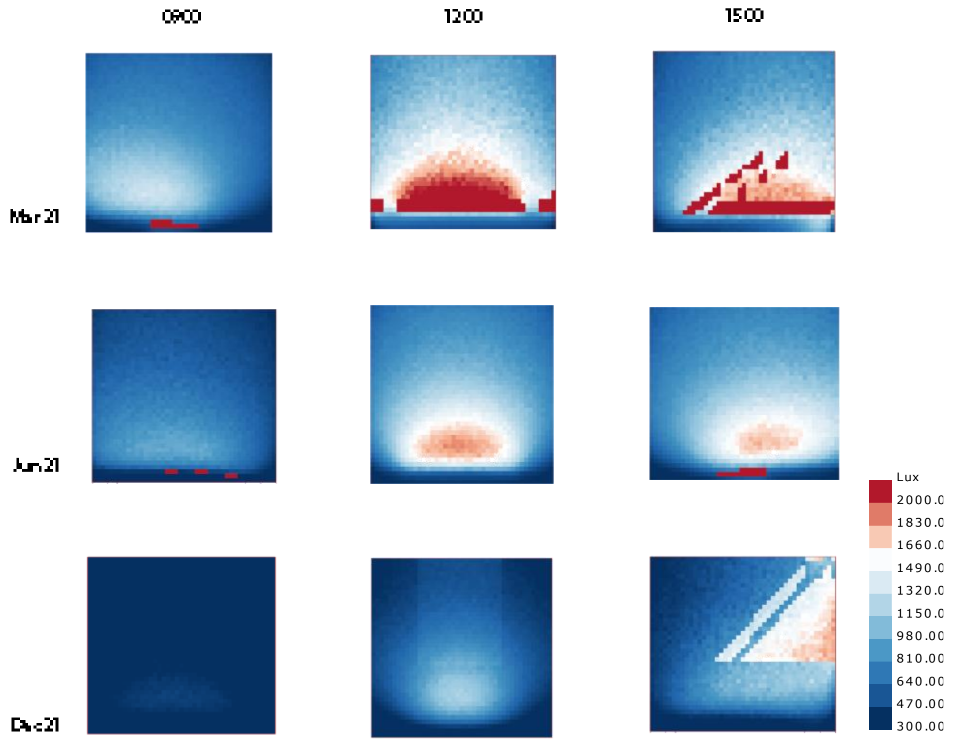
SIZE OF WINDOW: 3m
HORIZONTAL SHADING: 0.75m



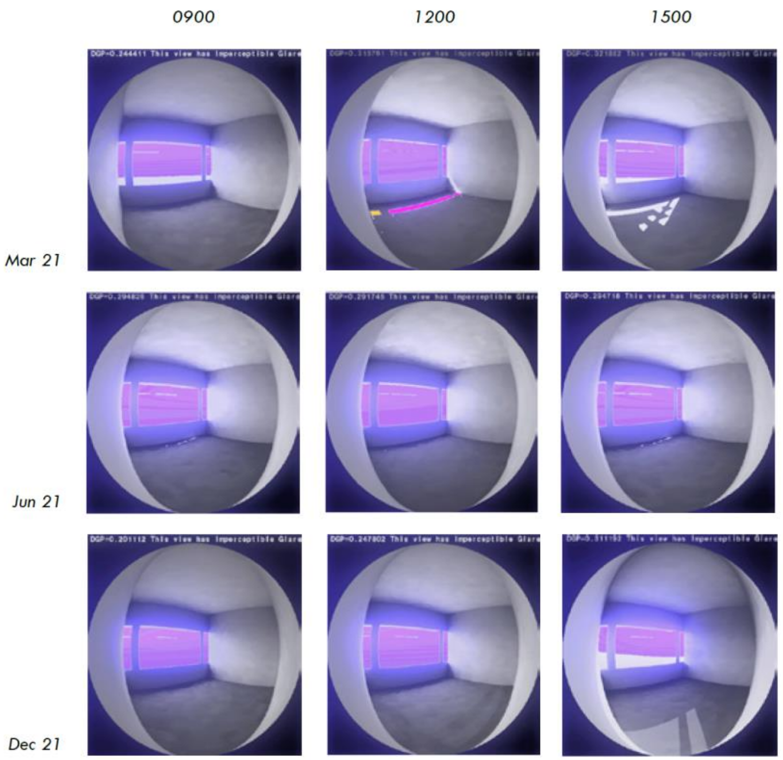
FINAL PROPOSED WINDOW AND SHADING DESIGN



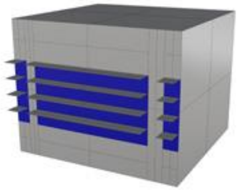
SIZE OF WINDOWS: 0.25m; 3m; 0.25m
HORIZONTAL SHADING: 0.25m



Two small windows are added to increase the daylighting of the rooms. This gives proper lighting and the louvres protect from high illuminance levels.

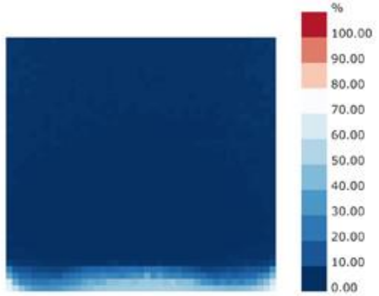


For the new proposed design, the glare levels for all shown situations are less than 0.35 DGP . This shows that they are all imperceptible glare which is acceptable.

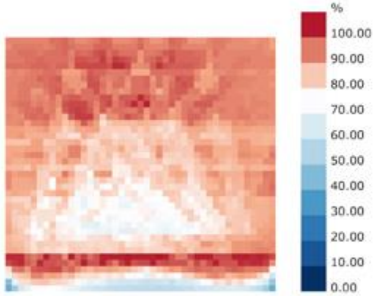


SIZE OF WINDOW: 3m; 0.25m
HORIZONTAL SHADING: 0.5m

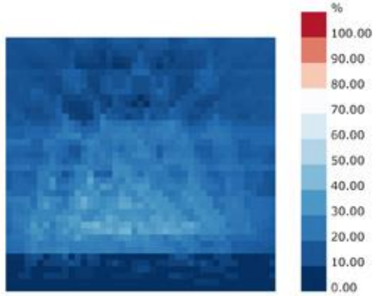
Occupancy Hours: 9am to 3pm
Glass: Single Pane; lower transmittance



% Useful Daylight Illuminance
>100 Lux

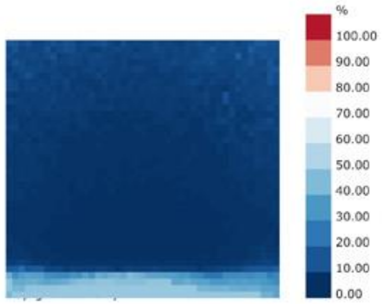


% Useful Daylight Illuminance
100-2000 Lux

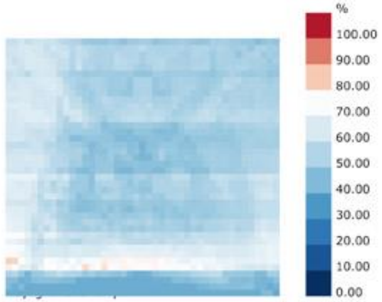


% Useful Daylight Illuminance
2000 Lux

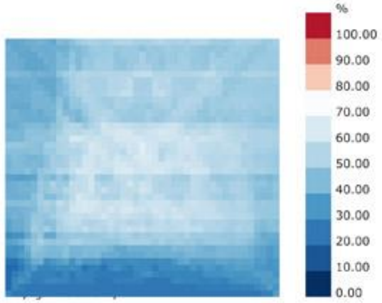
Occupancy Hours: 9am to 3pm
Glass: Double Pane; higher transmittance



% Useful Daylight Illuminance
>100 Lux



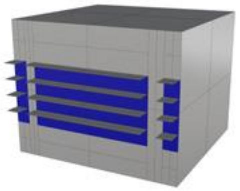
% Useful Daylight Illuminance
100-2000 Lux



% Useful Daylight Illuminance
2000 Lux

Increasing the transmittance of the walls, ceiling and changing the glass to double pane (although double pane doesn't contribute to the increase) showed that only 40-60% of UDI falls in the category of 100- 2000 Lux because the amount of UDI above >2000 Lux is high.

Step 1. Shading Design



SIZE OF WINDOW: 3m; 0.25m
HORIZONTAL SHADING: 0.5m

Based on looking into the analysis done in the previous slides, the glazing was increased and a shading system was designed to protect the bedroom from summer heat and have increased radiation in the winter.

The final design analysis is shown in pages 11 and 12.

Step 2. Natural Indoor Airflow

The simulation was set up such that in the summers, the windows would be opened if the temperature outside it greater than the inside. During winter, the windows will be opened if the temperature outside is more than the temperature inside.

Min Indoor Temperature : 24C
Max Outdoor Temperature: 28C

Step 3. Zone Loads

Infiltration Rate: Tight building: 0.0001 m3/s per m2
No of people: 0.03 ppl/m2
Equipment Load: 4 W/m2
Lighting Density per Area: 8 W/m2

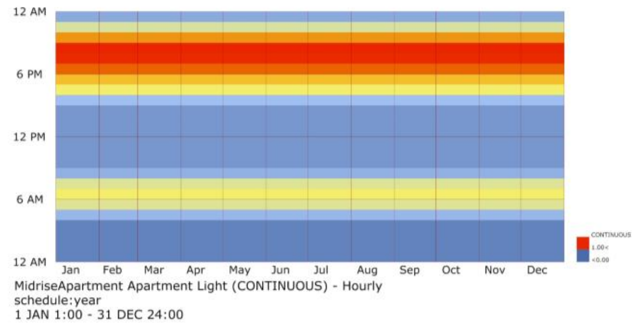
Having higher lighting density and equipment load adds to the internal gain which helps keep the bedroom warm in winter.

Step 4. Occupancy Schedule

Occupancy schedule: Mid Rise Apartment Light

Although the occupants of the current bedroom are both working, the above schedule was selected for the sake of the analysis of the bedroom.

The schedule incorporates all days and all times of the year.



Step 5. Change of Materials

The materials were changed to increase the comfort of the bedroom.

Roof: Highly Insulated with R-value of 34.4

Wall: **Highly Insulated with** R-value of 34.4

Floor: **Highly Insulated with R-value of 34.4**

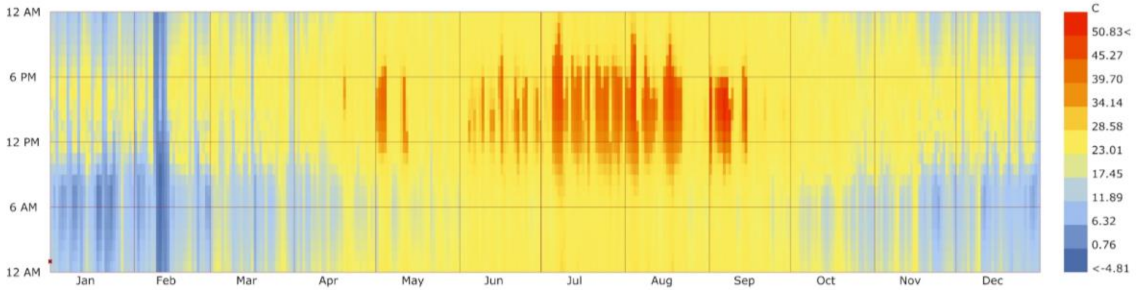
Glazing:
A four pane window with low-e coating was included in the simulations.
U-value of 1 & SGHC of 0.39

ANALYSIS OF THE BEDROOM AFTER IMPLEMENTING THE STRATEGIES

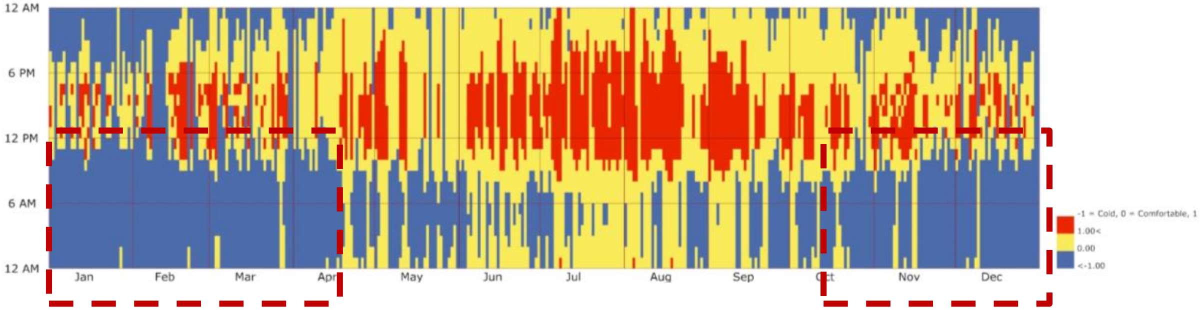
	Adding Shading Design	Shading Design & Adding Natural Indoor Airflow	Shading Design, natural indoor airflow & Adding Infiltration rates, lighting and occupancy schedule
LOW R-VALUES	HOURS COMFORTABLE: 18.41% Hours Hot: 60.6% Hours Cold: 21.0% Low R-is essentially the thermal resistance which means low R-values do not prevent heat insulation. Hence the during the summer, all the heat enters the room especially from the south wall and the glazing. It also get's incredibly cold in the winters because there is not enough insulation to store the heat.	HOURS COMFORTABLE: 22.78% Hours Hot: 47.7% Hours Cold: 29.5% Introducing natural indoor airflow increases the comfort of the bedroom. However since the R-value is very low, the natural indoor airflow doesn't reduce the heat as much as expected.	HOURS COMFORTABLE: 43.31% Hours Hot: 16.3% Hours Cold: 40.3% By adding the infiltration and schedules, the comfort rises because the simulation is considering the fact that the bedroom is only occupied for some percentage of the time during the day. Hence the rest of the time is not given high importance.
HIGH R-VALUES	HOURS COMFORTABLE: 20.46% Hours Hot: 69.6% Hours Cold: 9.8% Increasing the R-values increases the thermal resistance of the material. Hence the material or insulation has high conductivity wherein, it absorbs a lot of the heat and stores it. While the shading device restricts some of the direct heat through the glazing, the heat still enters through the walls.	HOURS COMFORTABLE: 70.73% Hours Hot: 12.2% Hours Cold: 17.0% Indoor airflow makes the space very comfortable especially in the summer because natural airflow makes the bedroom cooler when the windows are opened with respect to the temperature outside. During winter, the program is configured such that the windows are automatically open if the temperature outside is greater than inside.	**HOURS COMFORTABLE: 75.11%** **Hours Hot: 11.9% Hours Cold: 12.9%** Reducing the infiltration means that during the summer, it doesn't add to the heat of the bedroom. The equipment in the bedroom was also modified to make sure there isn't too much heat in the bedroom. Adding sensors in the bedroom based on occupancy schedule means that the light is only on when there isn't enough daylight. The summers mostly has enough daylight so the lighting heat is not generated. However during winters, more light is required hence lighting heat can help keep the room warm.

LOW R-VALUES with Shading Design, natural indoor airflow & Infiltration rates, lighting and occupancy schedule

INDOOR TEMPERATURE

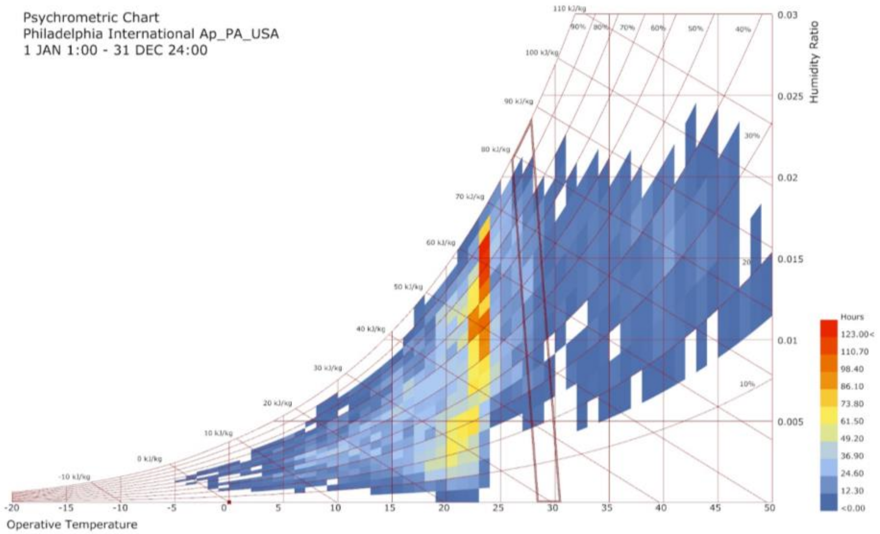


ADAPTIVE COMFORT



% of cold hours is high

PSYCHROMETRIC CHART



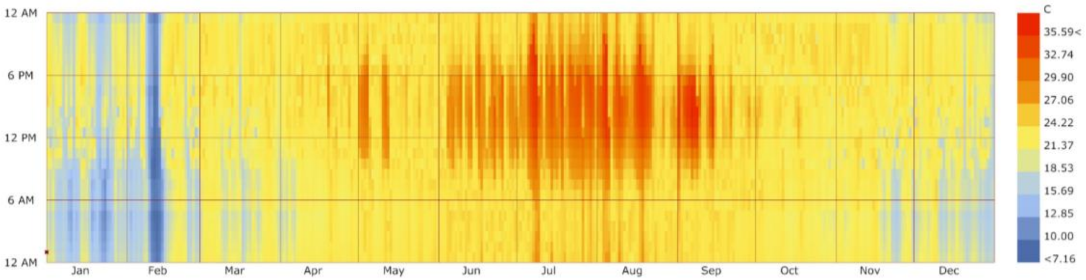
% HOURS COMFORTABLE: 43.31%

% Hours Hot: 16.3%

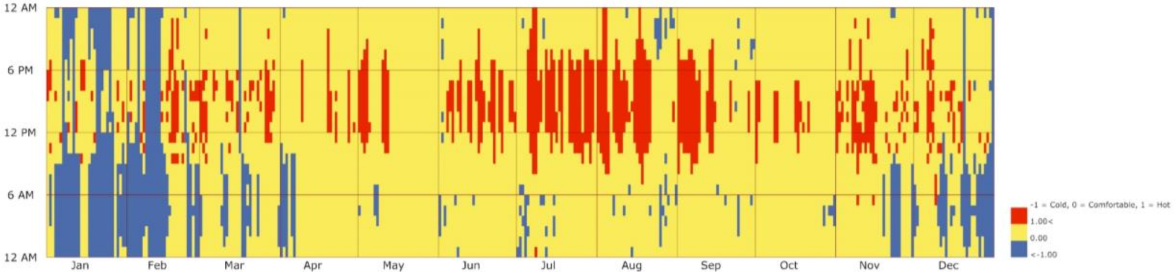
% Hours Cold: 40.3%

HIGH R-VALUES with Shading Design, natural indoor airflow & Infiltration rates, lighting and occupancy schedule

INDOOR TEMPERATURE

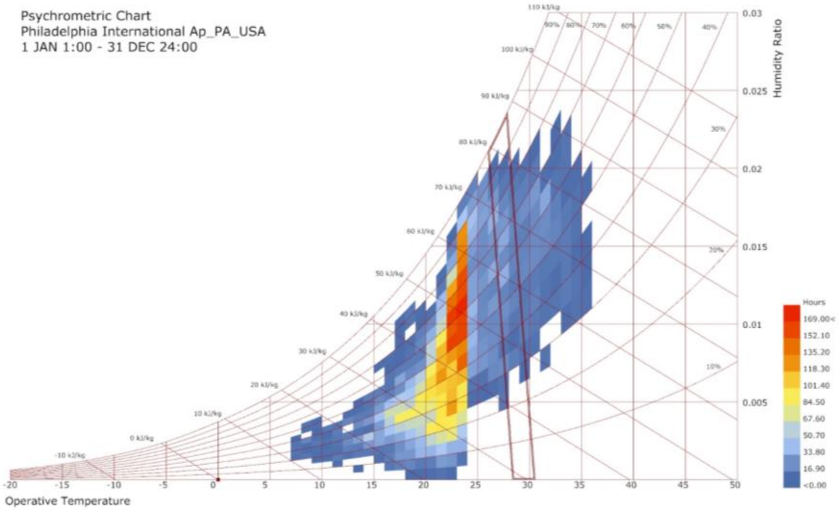


ADAPTIVE COMFORT



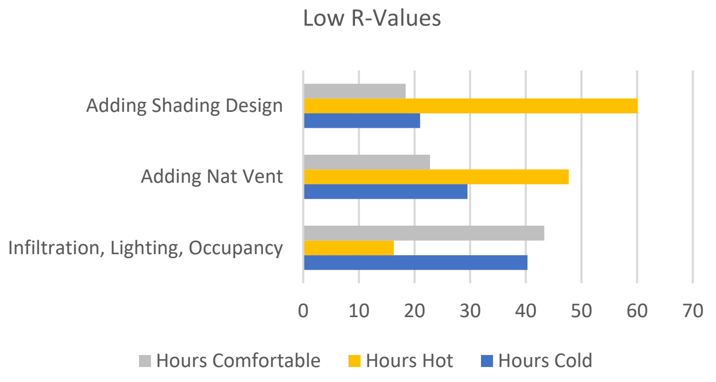
Based on looking into Weather /simulation data in the previous analysis done, the comfort of the bedroom was increased from 17% to 75% using simple strategies as shown in the previous slide.

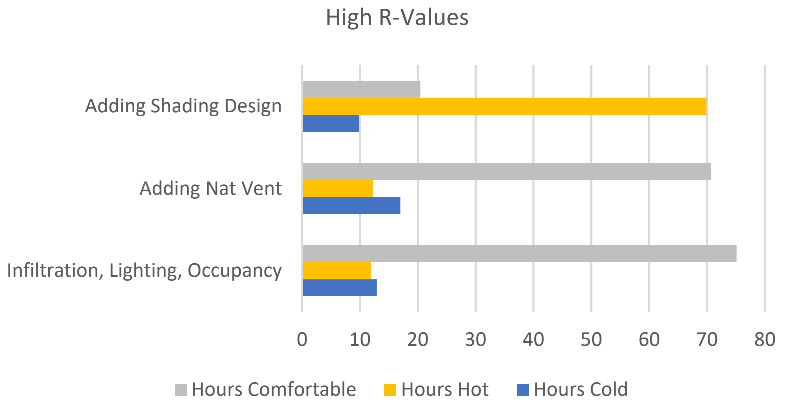
PSYCHROMETRIC CHART

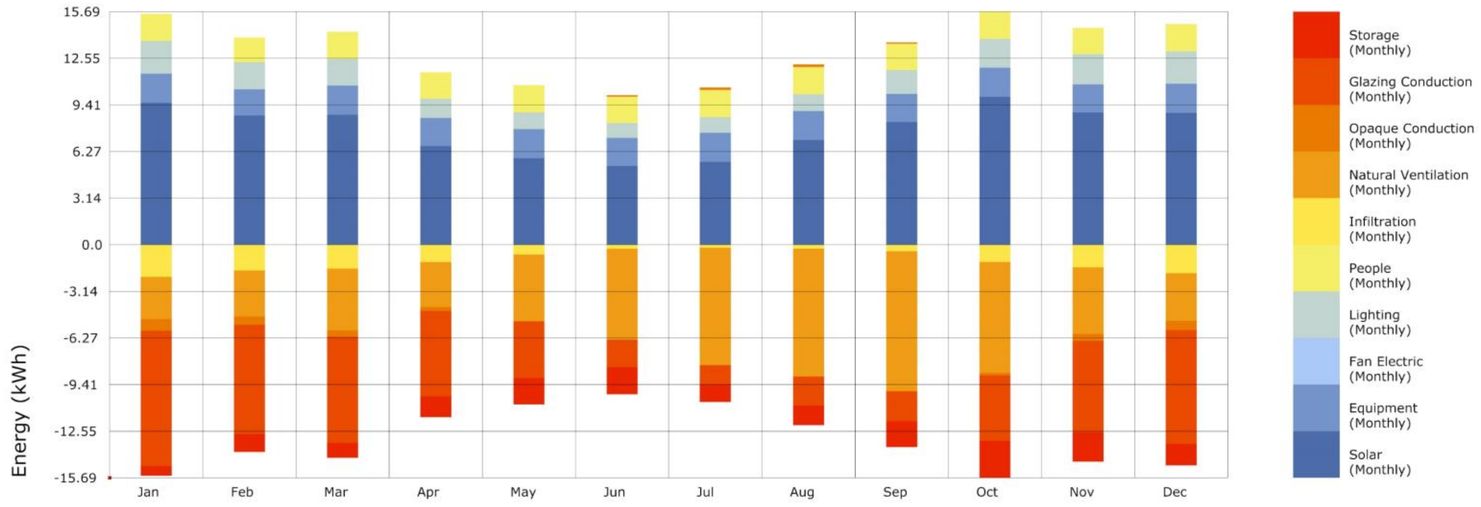


% HOURS COMFORTABLE: 75.11%
% Hours Hot: 11.9%
% Hours Cold: 12.9%

SOME OBSERVATIONS DURING THE SIMULATIONS







GLAZING CONDUCTION contributed highly to the amount energy loss based on the looking at the energy balance chart.

Initially glazing material used: U-value of 1.0 & SGHC of 0.39

However by decreasing the U-value the glass will reflect heat making the home better insulated. The Solar Heat Gain Coefficient is the amount of solar heat that enters the house. Hence higher SHGC is required in Philadelphia so that during winter, natural heat is allowed in. This reduces the heating loads substantially.

Hence a new glazing material was setup!

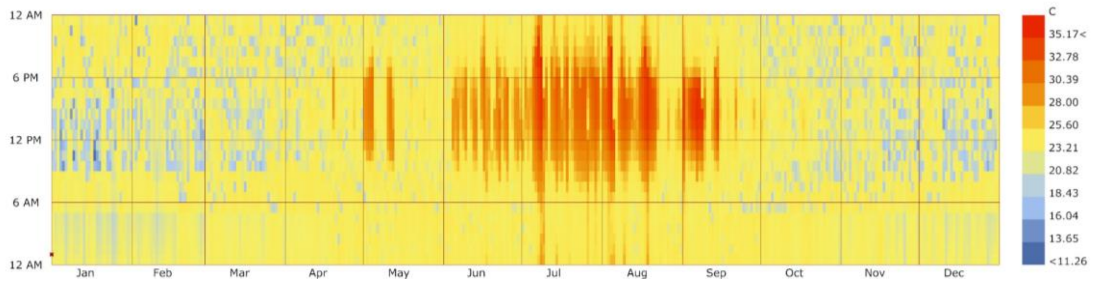
NATURAL VENTILATION also contributes to the energy loss for the bedroom. This could be mainly because when the windows are opened, heat is lost from the inside to the outside or vice versa.

INTERNAL GAINS such as lighting, occupancy and equipment helped the room be comfortable substantially. especially during the winter.

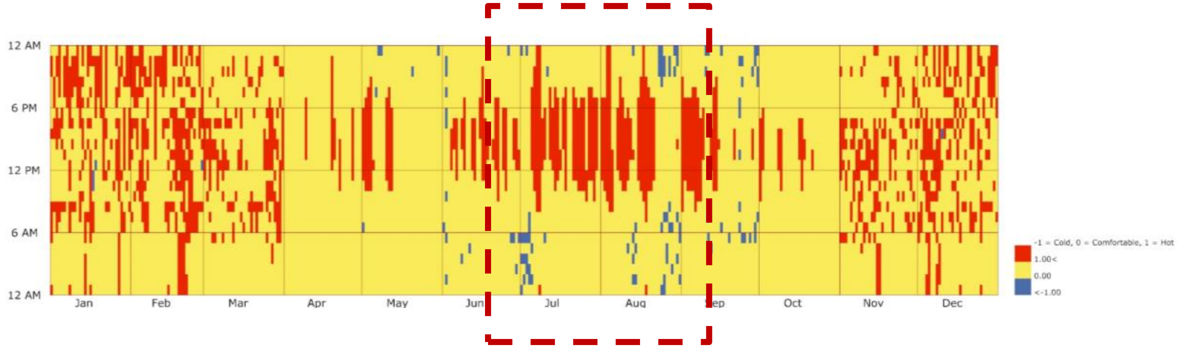
Increasing the SGHC Value and Decreasing the U-value

U-value: 0.5 and SGHC: 0.4

INDOOR TEMPERATURE

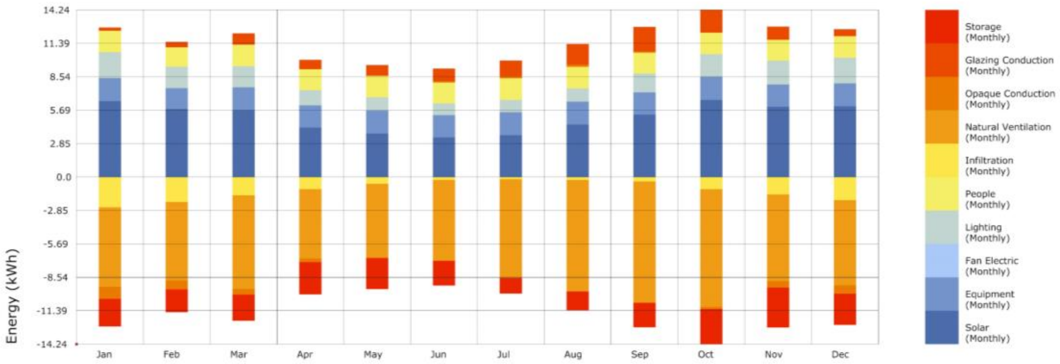


ADAPTIVE COMFORT



% of hot hours is high

ENERGY BALANCE CHART



Glazing conduction has decreased

% HOURS COMFORTABLE: 79.2%

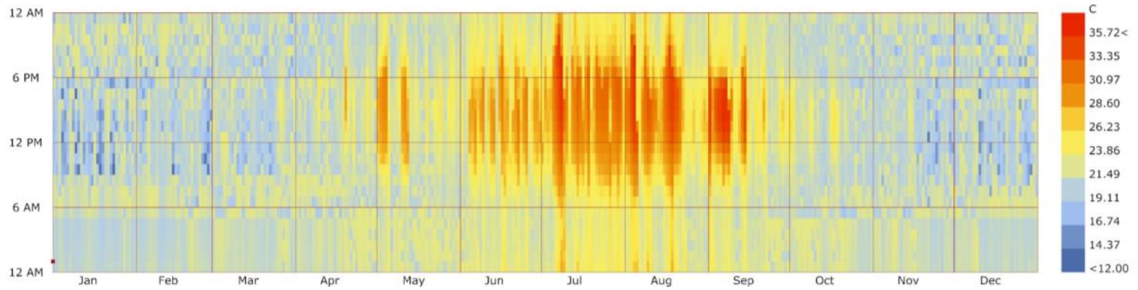
% Hours Hot: 19.47%

% Hours Cold: 1.3%

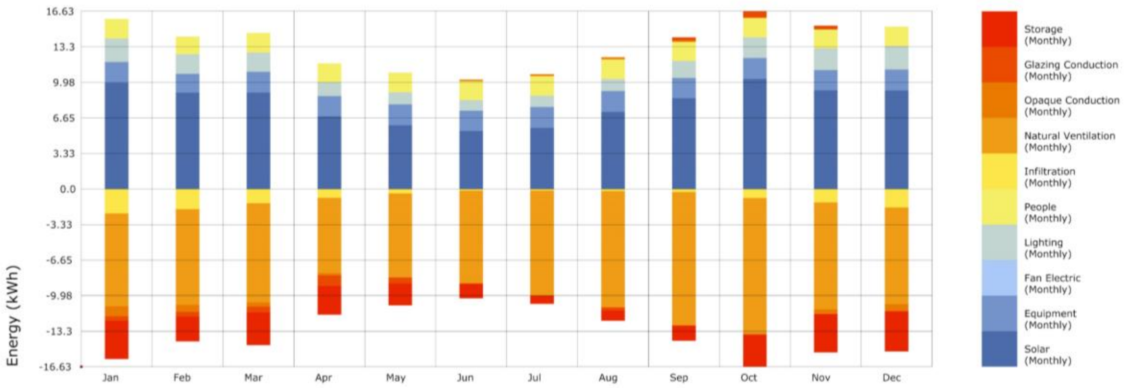
Changing the natural ventilation factors

Min Indoor Temp for Nat Vent: 22C
Max Outdoor Temp for Nat Vent: 30C

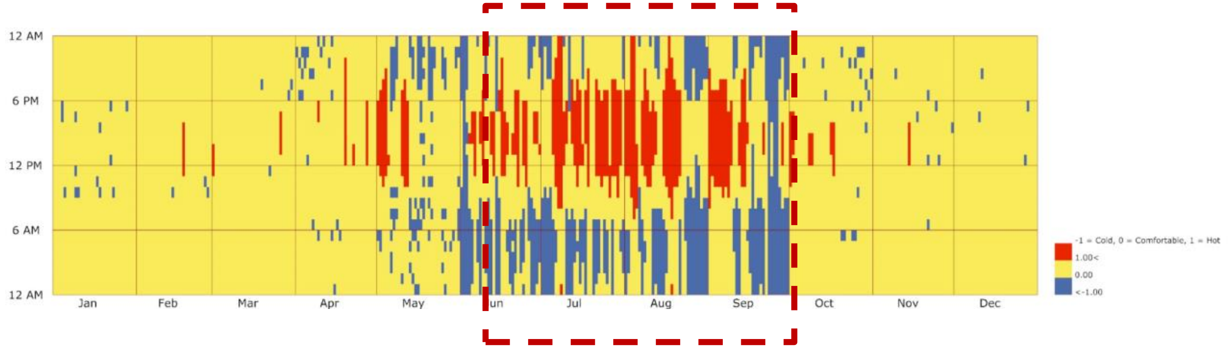
INDOOR TEMPERATURE



ENERGY BALANCE CHART



ADAPTIVE COMFORT



% of hot hours is reduced

% HOURS COMFORTABLE: 80.37%
% Hours Hot: 7.87%
% Hours Cold: 11.7%

THE END RESULT

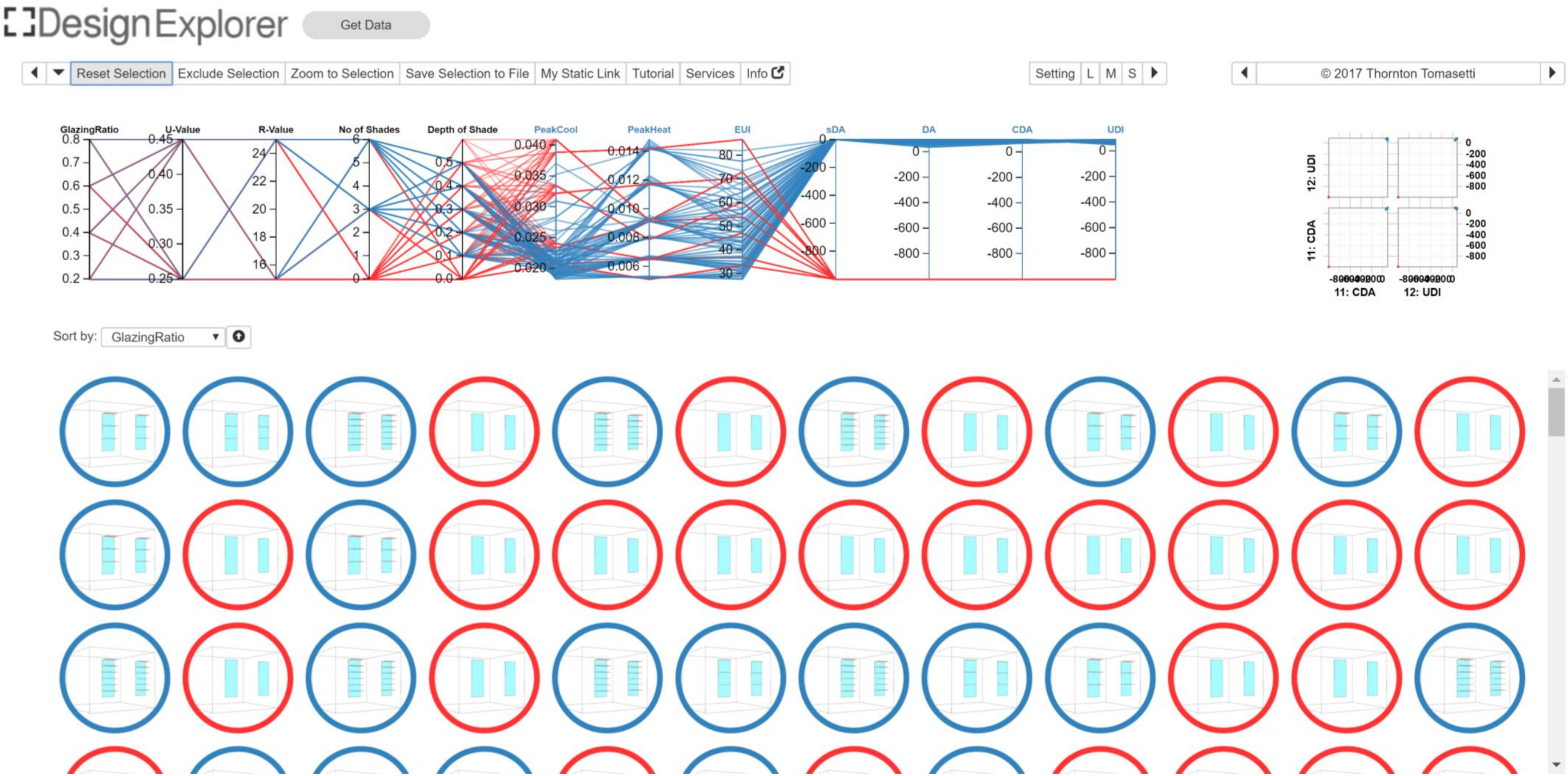
Increasing the R-value of the structure played a major role in increasing the comfort of the bedroom. Higher R-values means the insulating power of the material was greater.

The energy balance chart showed how the strategies have been incorporated into the bedroom. Controlling the amount of solar heat gain through glazing and natural indoor airflow were other two major factors which helped further the goal.

The comfort has not reached a complete 100% . Although in reality, it is impossible to achieve 100% comfort, more strategies such as night vent and evaporative cooling could add to the comfort level. However, based on the unstructured method of reaching maximum comfort, some data could have been lost in the process. The bedroom could have been more controlled starting with better initial design proposals.

PART 3: EXPLORING OTHER WAYS OF FINDING THE SOLUTION

http://tt-acm.github.io/DesignExplorer/?ID=HSNvWM



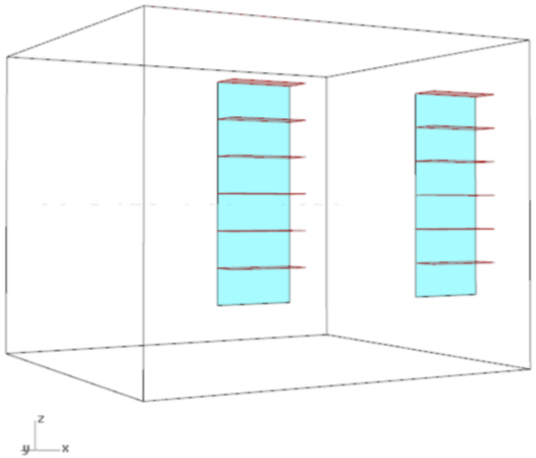
DESIGN EXPLORER

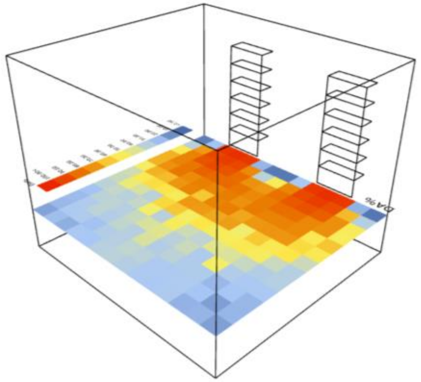
Design Explorer is a valuable tool in analyzing data, and understanding all the aspects of every option. The same bedroom was used with south facing window to find most suitable glazing ratio, U-value, Daylight Autonomy, etc.

This however is conditioned space taking into account the heating and cooling loads based on the geometry of the glazing.

BEDROOM ANALYSIS – DESIGN EXPLORER

SUITABLE OPTION 1



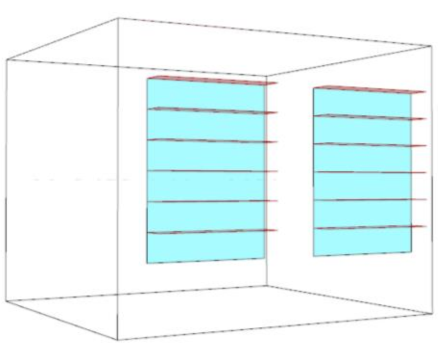


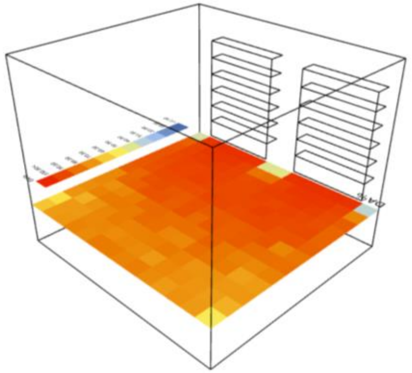
Attributes

GlazingRatio : 0.2
U-Value : 0.25
R-Value : 15
No of Shades : 6
Depth of Shade : 0.3
PeakCool : 0.018711
PeakHeat : 0.005286
EUI : 28.33554
sDA : 0.456044
DA : 49.172061
CDA : 77.64566
UDI : 82.65347
Rating : 0

This option is quite suitable for the bedroom. Although the daylight autonomy is lower, the overall EUI of the bedroom is much lower than other options.

SUITABLE OPTION 2





Attributes

GlazingRatio : 0.4
U-Value : 0.25
R-Value : 15
No of Shades : 6
Depth of Shade : 0.3
PeakCool : 0.019428
PeakHeat : 0.006658
EUI : 35.268236
sDA : 0.978022
DA : 81.395454
CDA : 92.3501
UDI : 83.843444
Rating : 0

This option has high daylight autonomy, low u-values and has a glazing ratio of 0.4. This option is quite well-suited for the design of this bedroom.

THE END RESULT

Although the solution in Part 2 worked well, it was based on my assumptions on what would be a good glazing and shading design for the bedroom. The use of Design Explorer can be beneficial by understanding all the different aspects of the bedroom, the amount of glazing required, the number of shades, the depth of the shades, the r values and u-values, etc. This study can help to think of every alternate solution possible and it can be easily mapped out using this system.

However, this system can be used only as an initial design of the bedroom. Further studies (like the kind done in Part 2) needs to be done in order to understand the comfort levels of this space. This part was done to understand the scope of decisions that can be made using this system.