thermal and visual comfort maximization of an unconditioned home-office space in Detroit

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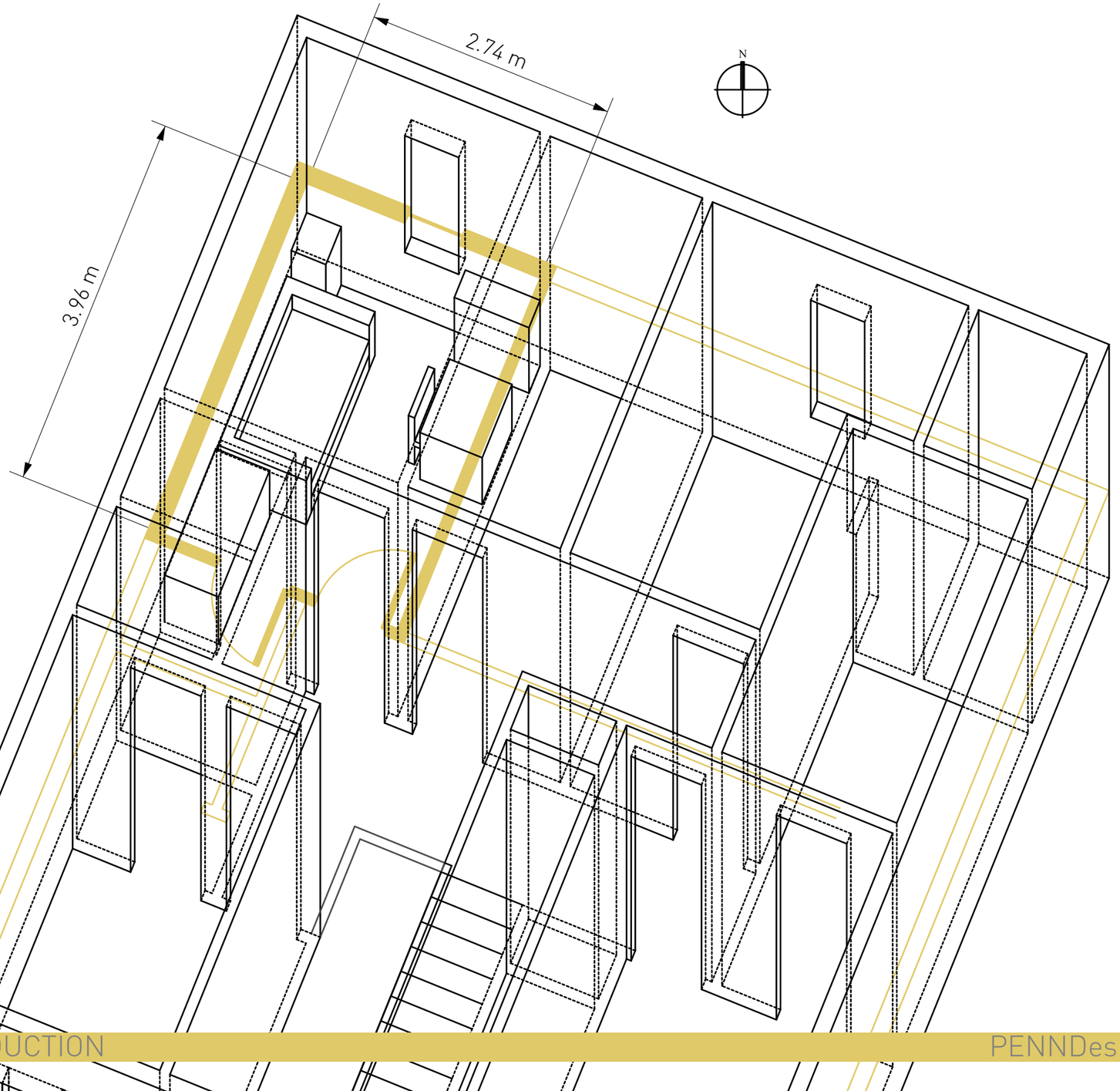
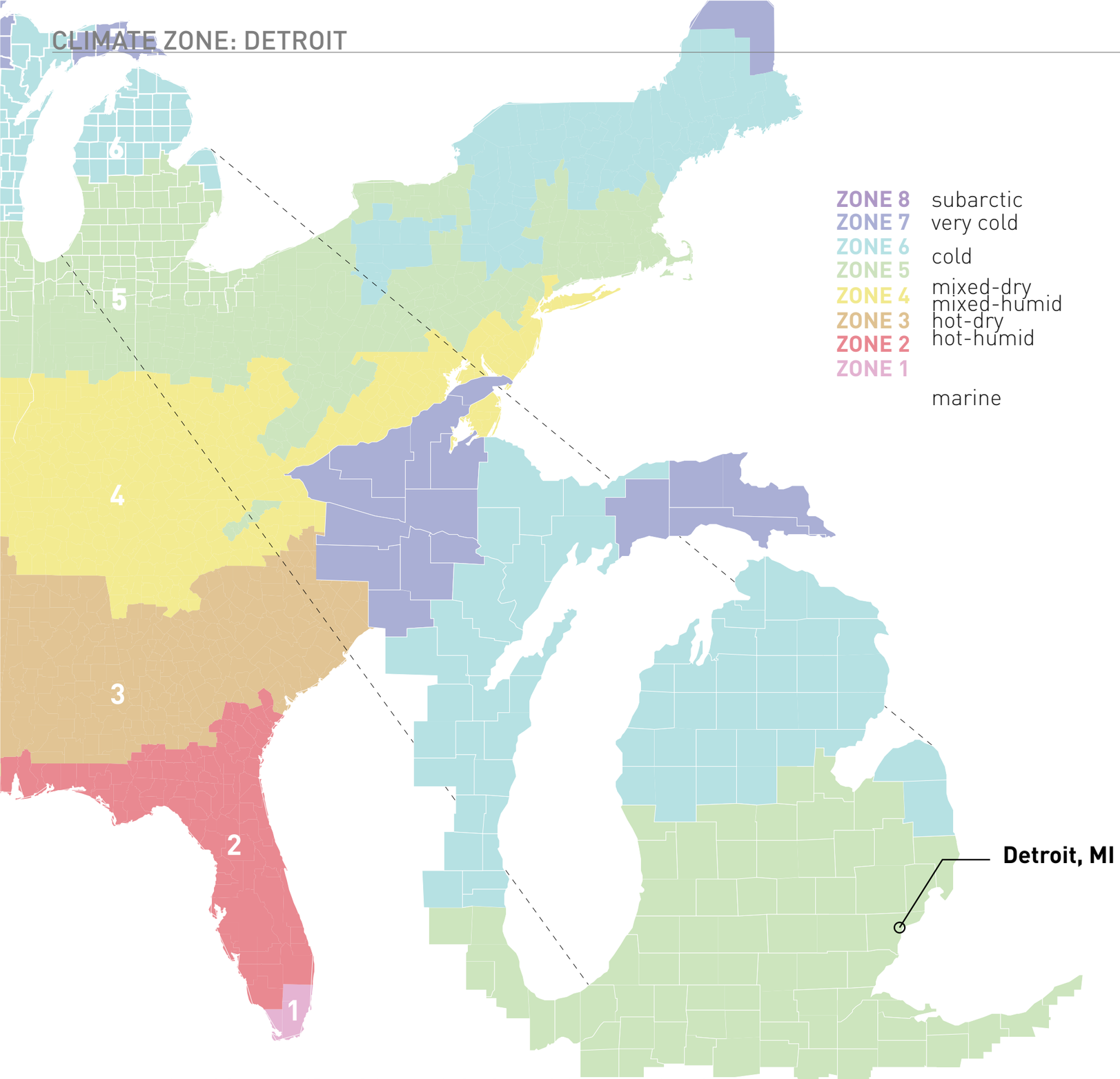


SCENARIO: HOME OFFICE

This project focuses on an existing home office space located in Metro Detroit and seeks to provide maximum hours of comfort for its occupants with no heating and cooling systems, but by redesigning the facade. Different analyses methods taught throughout the semester from the course will be used to analyze the climate, indicate the performance of the existing base case, define design strategies, and ultimately evaluate the performance of the resulting design proposal.

The base case is a home office typical in suburban Metro Detroit. The room sizes 3.96 meters by 2.74 meters (demarcated by the yellow fill on the axon/plan drawing on the left), and has one window on the northeast side of the room. The entire building is rotated in such a way that no exterior window or door directly faces a cardinal direction. The desk is where the main area of focus will be, being the space that will be used the most frequently during occupancy; it is located off-center, on the southeast wall. It is presumed that it cannot be moved.



ZONE 8 subarctic
ZONE 7 very cold
ZONE 6 cold
ZONE 5 mixed-dry
ZONE 4 mixed-humid
ZONE 3 hot-dry
ZONE 2 hot-humid
ZONE 1 marine

LOCATION: Detroit, MI, USA
LATITUDE: 42.33
LONGITUDE: -83.05

WEATHER DATA: USA_MI_Detroit.Metro.Wayne.County.AP.725370_TMY3

CDD: 149.7 degree days
HDD: 3775.65 degree days
Cooling Degree Days (CDD) and Heating Degree Days (HDD) were calculated October 2016 through Ladybug for Grasshopper.

CLIMATE ZONE: 5
CHARACTERISTIC: cold
Detroit is characterized to have a cold climate, which is described as "a region with approximately 5,400 heating degree days (65°F basis) or more and fewer than approximately 9,000 heating degree days (65°F basis)" by the USA Office of Energy Efficiency & Renewable Energy.

Residential Prescriptive Requirements for Climate Zone 5

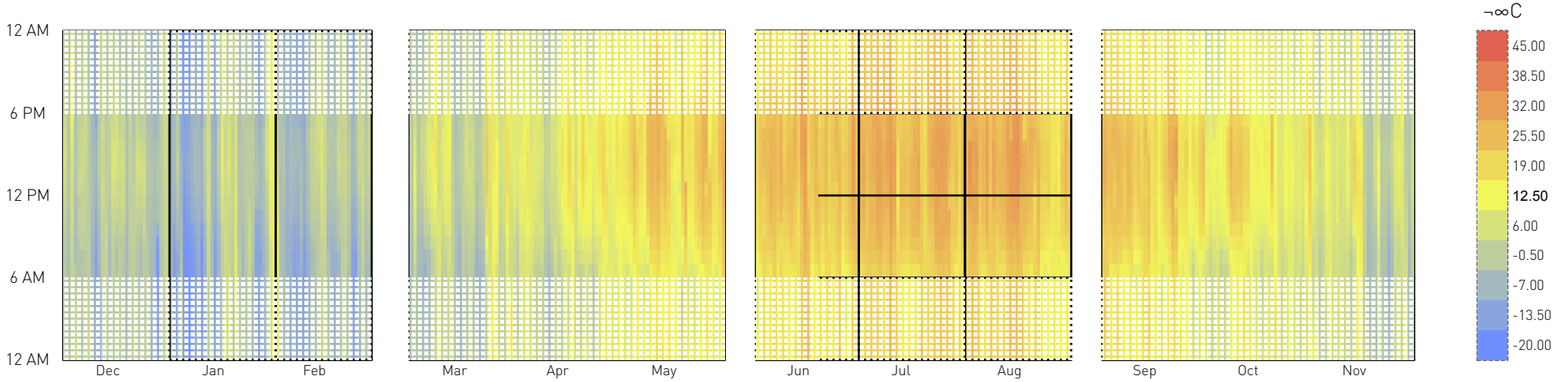
as per 2009 International Energy Conservation Code (IECC) on https://energycode.pnl.gov/EnergyCodeReqs/?state=Michigan

Ceiling R-value	**38**
Wood Frame Wall R-value	**20 or 13+5**
Mass Wall R-value	**13/17**
Floor R-value	**30**
Basement Wall R-value	**10/13**
Slab R-value, Depth	**10, 2 ft**
Crawlspace Wall R-value	**10/13**
Fenestration U-Factor	**0.35**
Skylight U-Factor	**0.60**
Glazed fenestration SHGC	**NR**

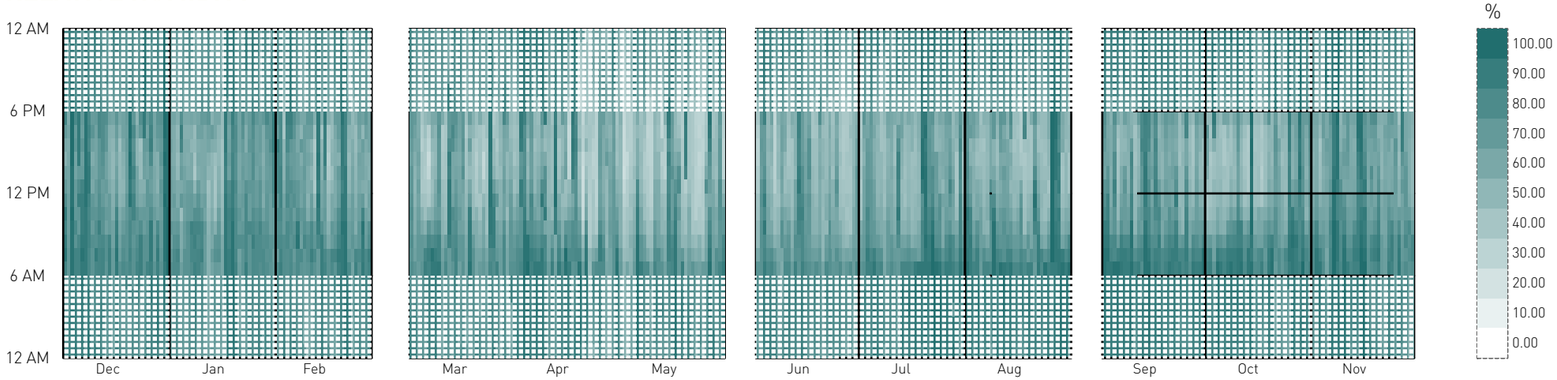
map and data taken from U.S. Department of Energy; Building America Best Practices Series Volume 7.3. August 2015.

WINTER SPRING SUMMER FALL

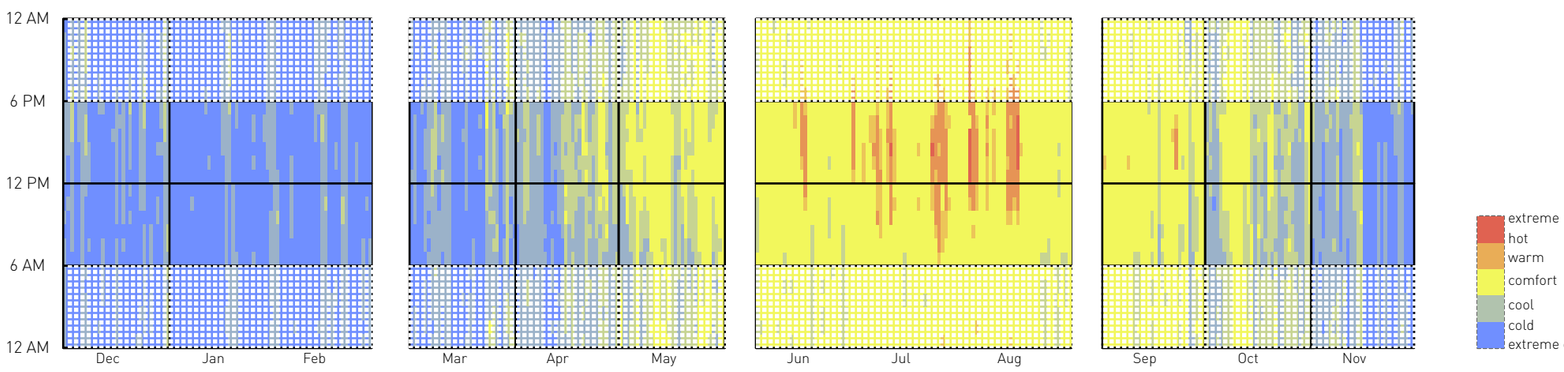
DRY BULB TEMPERATURE



RELATIVE HUMIDITY



OUTDOOR COMFORT



EXTERIOR FACTORS

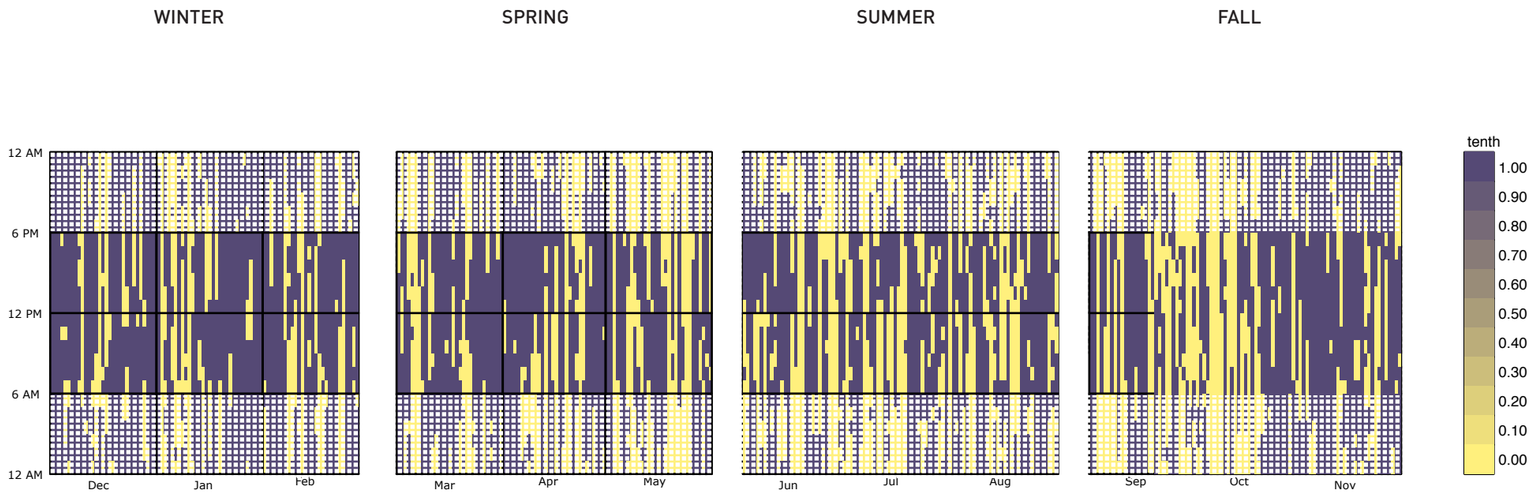
To comprehend the scope of the project, an analysis of the climate in Detroit is necessary. Mapped out on this and the next page are charts and graphs that illustrate exterior factors that characterize the Detroit climate, acquired by using the Detroit Metro Airport EPW data. The following information is shown:

Dry-bulb temperature (DBT) is the temperature of air measured by a thermometer freely exposed to the air but shielded from radiation and moisture. DBT is the temperature that is usually thought of as air temperature, and it is the true thermodynamic temperature. It indicates the amount of heat in the air and is directly proportional to the mean kinetic energy of the air molecules.

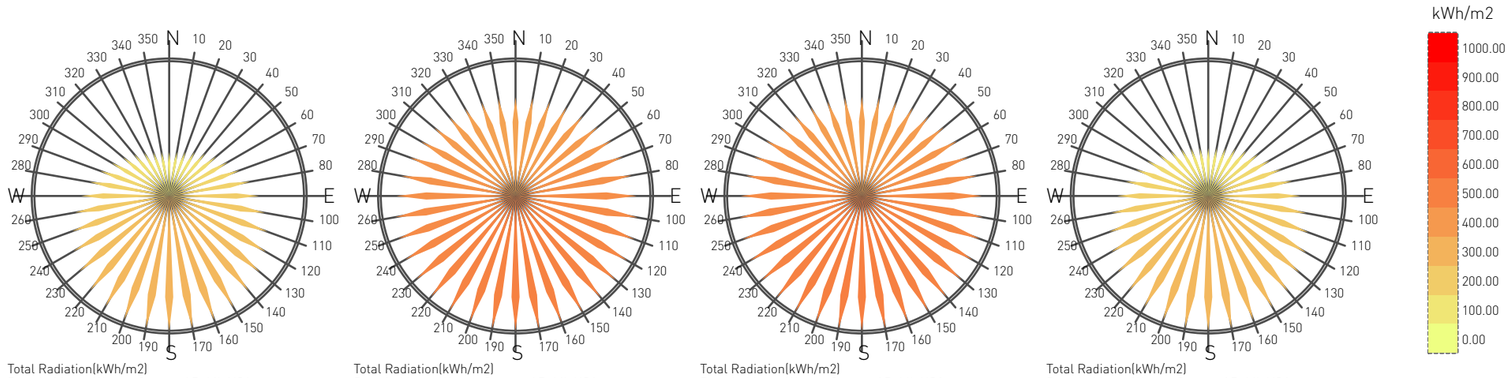
Relative humidity (abbreviated RH) is the ratio of the partial pressure of water vapor to the equilibrium vapor pressure of water at the same temperature. Relative humidity depends on temperature and the pressure of the system of interest.

Outdoor comfort based on the **Universal Thermal Climate Index**, (UTCI), defined as the air temperature (Ta) of the reference condition causing the same model response as actual conditions. The offset, i.e. the deviation of UTCI from air temperature, depends on the actual values of air and mean radiant tem- perature (Tmrt), wind speed (va) and humidity, expressed as water vapour pressure (vp) or rela- tive humidity (RH).

The figures on this page plot out annual Detroit weather to demonstrate temperature and humidity patterns typical of the four seasons experienced there. The bottom chart maps out temperature in the context of comfort. On all of the charts the time period between roughly 6 PM and 6 AM is faded in order to flesh out the typical occupation hours at the home office.



Total Cloud Cover (tenth) - Hourly
Detroit Metro Wayne County AP_MI_USA
1 JAN 1:00 - 31 DEC 24:00

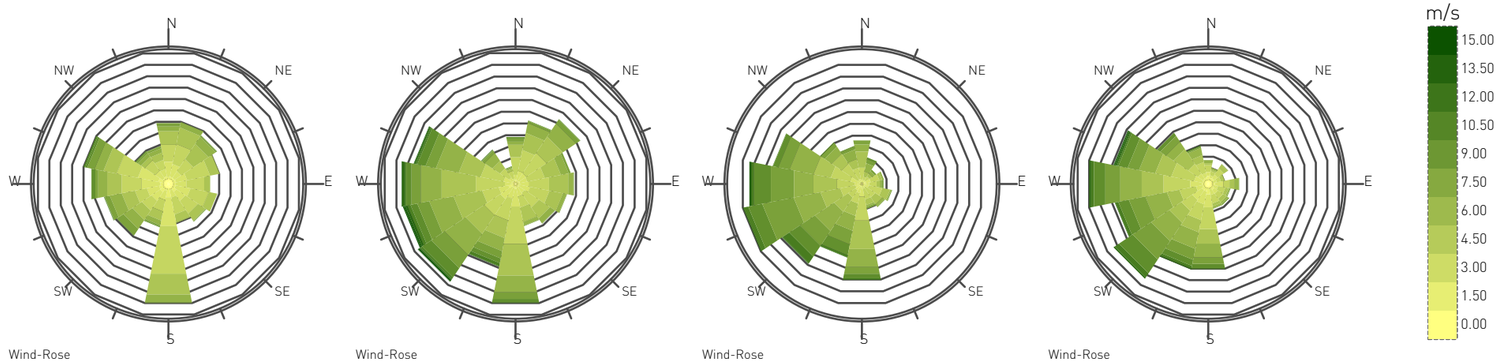


Total Radiation(kWh/m2)
Detroit_Metro_Wayne_County_AP_MI_USA
21 DEC 1:00 - 21 MAR 24:00

Total Radiation(kWh/m2)
Detroit_Metro_Wayne_County_AP_MI_USA
21 MAR 1:00 - 21 JUN 24:00

Total Radiation(kWh/m2)
Detroit_Metro_Wayne_County_AP_MI_USA
21 JUN 1:00 - 21 SEP 24:00

Total Radiation(kWh/m2)
Detroit_Metro_Wayne_County_AP_MI_USA
21 SEP 1:00 - 21 DEC 24:00



Wind-Rose
Detroit Metro Wayne County AP_MI_USA
21 JUN 1:00 - 21 SEP 24:00
Hourly Data: Wind Speed (m/s)
Calm for 8.65% of the time = 193 hours.
Each closed polyline shows frequency of 1.2%. = 26 hours.

Wind-Rose
Detroit Metro Wayne County AP_MI_USA
21 MAR 1:00 - 21 JUN 24:00
Hourly Data: Wind Speed (m/s)
Calm for 2.51% of the time = 56 hours.
Each closed polyline shows frequency of 1.0%. = 22 hours.

Wind-Rose
Detroit Metro Wayne County AP_MI_USA
21 DEC 1:00 - 21 MAR 24:00
Hourly Data: Wind Speed (m/s)
Calm for 1.79% of the time = 39 hours.
Each closed polyline shows frequency of 1.3%. = 28 hours.

Wind-Rose
Detroit Metro Wayne County AP_MI_USA
21 SEP 1:00 - 21 DEC 24:00
Hourly Data: Wind Speed (m/s)
Calm for 7.56% of the time = 167 hours.
Each closed polyline shows frequency of 1.3%. = 28 hours.

OTHER CONTRIBUTING FACTORS

Besides temperature, other factors pertaining to climate play a large role in the overall comfort of an individual be they inside or outside. The charts on this page show elemental factors that could have major effects on the design of comfort of a residential space: radiation, wind, and sky coverage.

Just like the previous page, the charts are more or less separated by season to demonstrate the typical patterns of these months. The variance of the graphs per season indicates the importance of considering things like orientation and context in the design process.

SKY/CLOUD COVER

The ratio of how much the sky is covered by clouds over the course of the year is boiled down and reduced to two basic values/situations: 0 and 1, cloudy and sunny, respectively.

RADIATION

It ought to be considered that half a year, 6 months at a time, radiation chiefly comes from the Soutern direction. This becomes a quite important factor when considering the location of egress and windows, in terms of heat and light.

WIND SPEEDS

Detroit does receive a substantial amount of wind at various speeds across all seasons, particularly coming from the southwest direction. It may be due to Detroit's position being lakefront. This factor should be taken into consideration along with temperature and radiation since the combination of these elements would make a bigger impact on the comfort design, especially for the possibility of integrating natural ventilation.

CLIMATE OBSERVATIONS

Based on the information mapped out on the climate analysis charts, one can observe that certain problems are likely to arise due to the climate of Detroit, such as the amount of radiation and sunlight received due to the orientation of the building (sun paths), the range in average outdoor temperature across all the seasons, the amount of wind received from different directions (taking into account that Detroit is a lakeside city).

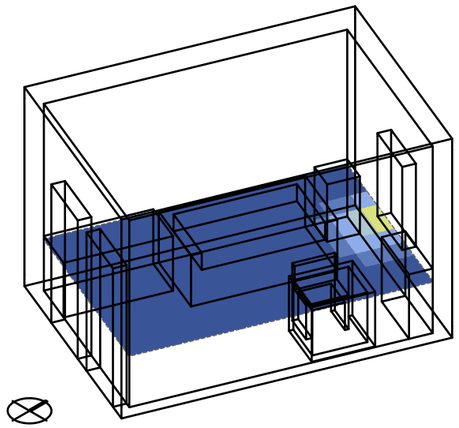
In the next few pages, the base case of the existing home office will be analyzed in terms of performance through daylighting and energy simulations, based on its climate context. These simulations are run through Ladybug and Honeybee.

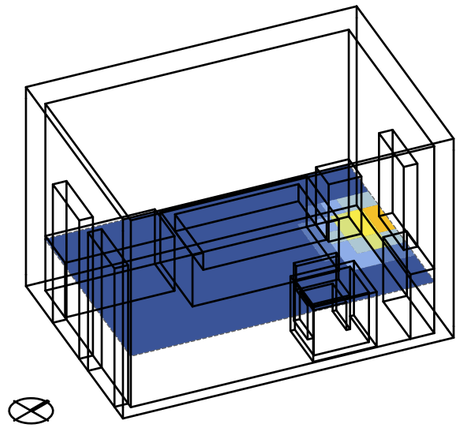
9:00

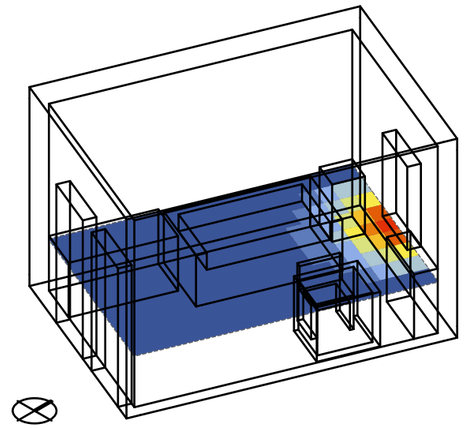
12:00

15:00

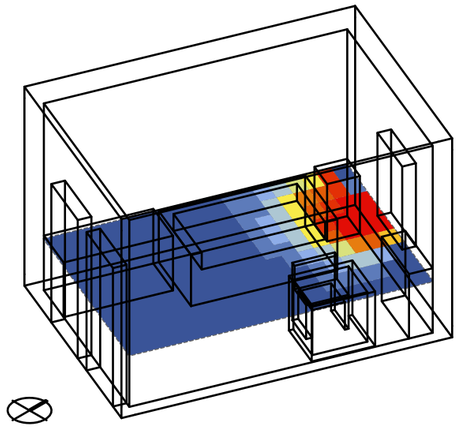
21 MARCH

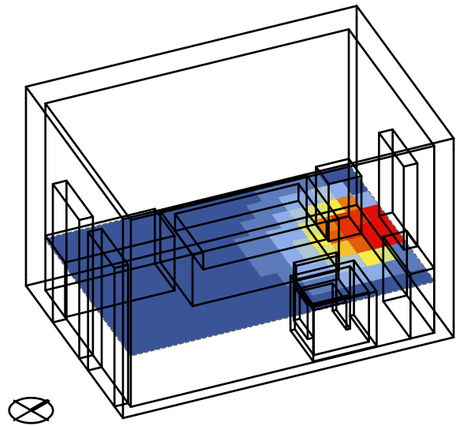


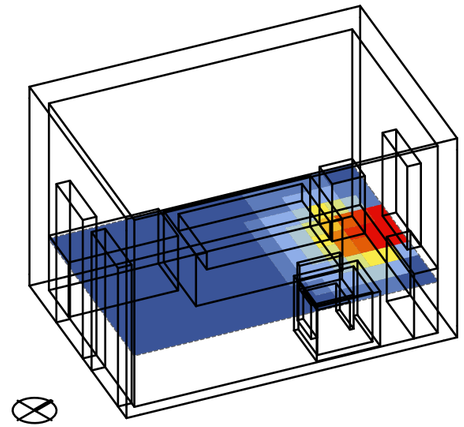




21 JUNE







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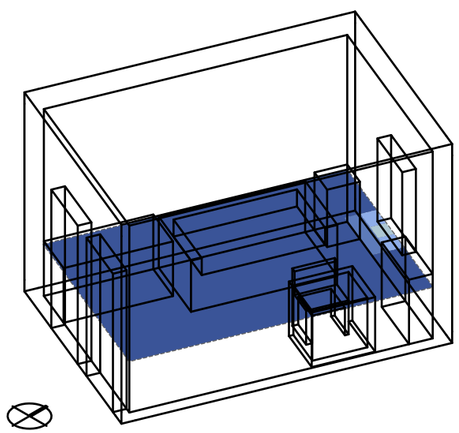
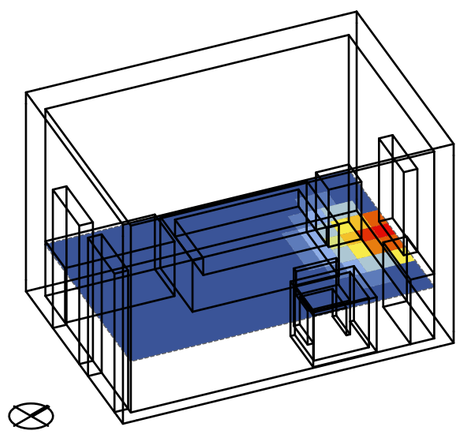
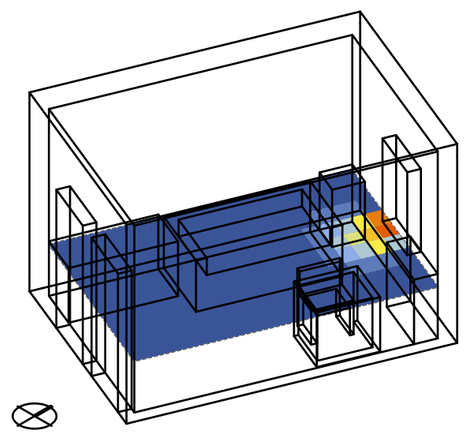
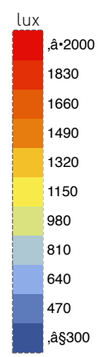






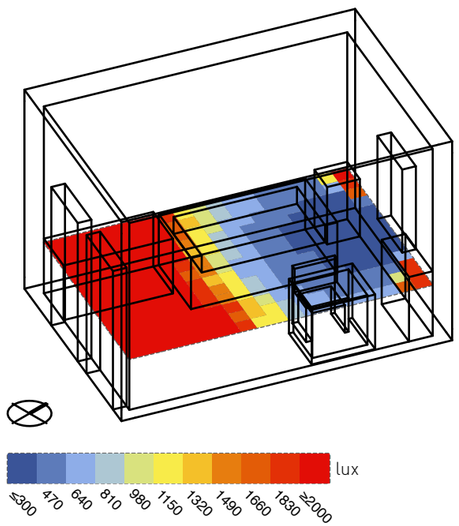


ANALYZING DAYLIGHT QUALITY

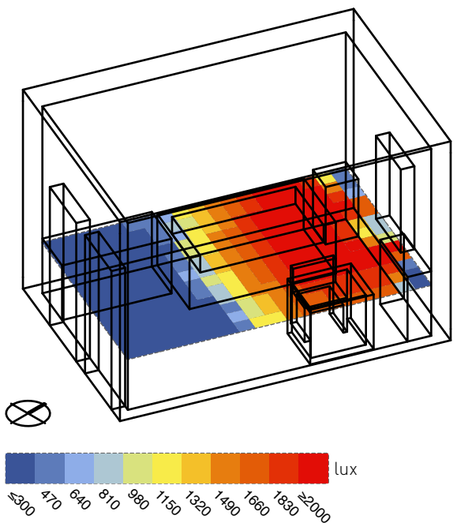
To illustrate how much daylight comes into this space, a 3d model of the space is constructed out of surfaces, distinguishing window material from opaque material; then using Ladybug and Honeybee in conjunction, skies are simulated for the location and tested with the 3d model for a specific set of days and times in order to evaluate the existing daylight quality of the base case. The existing daylight quality of the base case can be seen in the charts on the left; values over 2000 lux implies potential glare and values below 300 implies a lack of daylighting.

ANNUAL DAYLIGHT

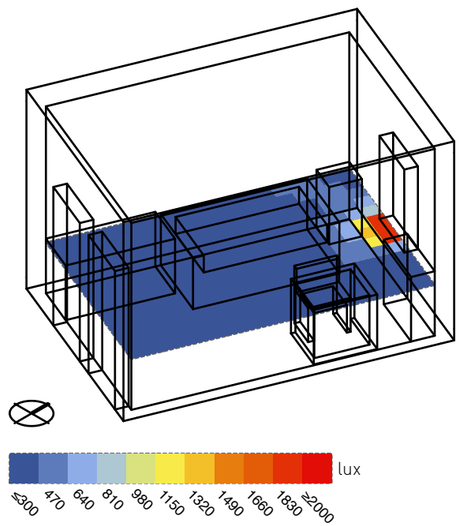
UDI ≤ 100

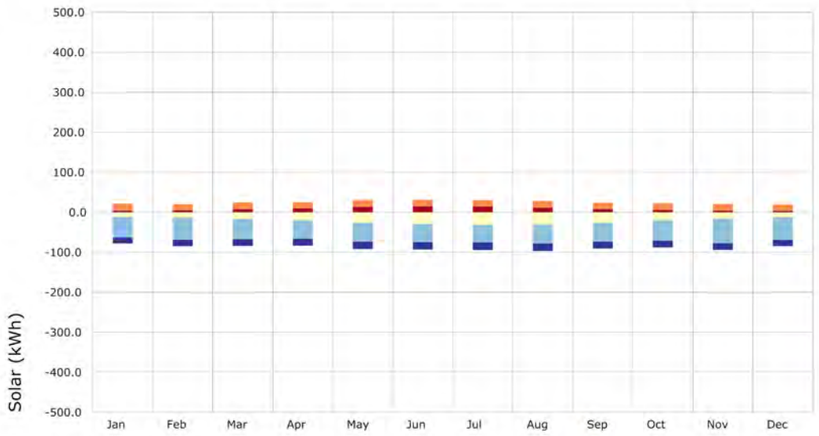


100 <= UDI <= 2000

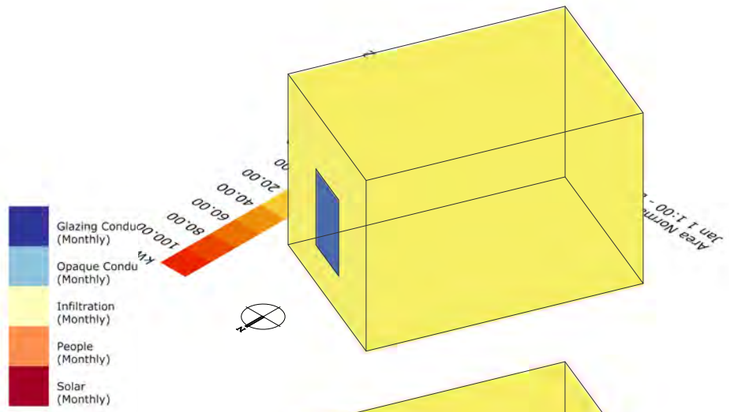


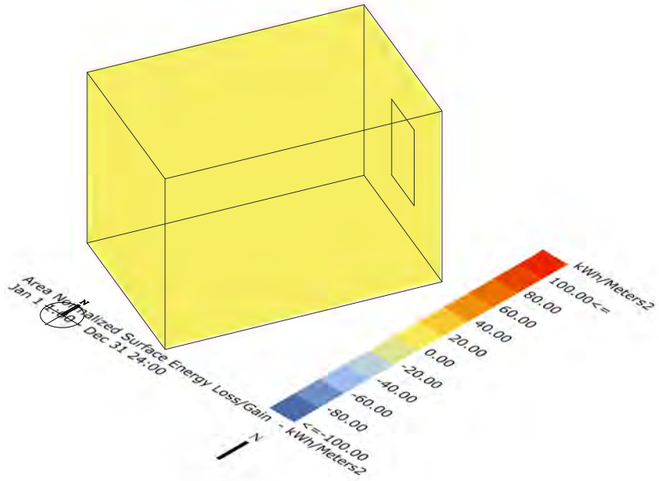
UDI ≥ 2000

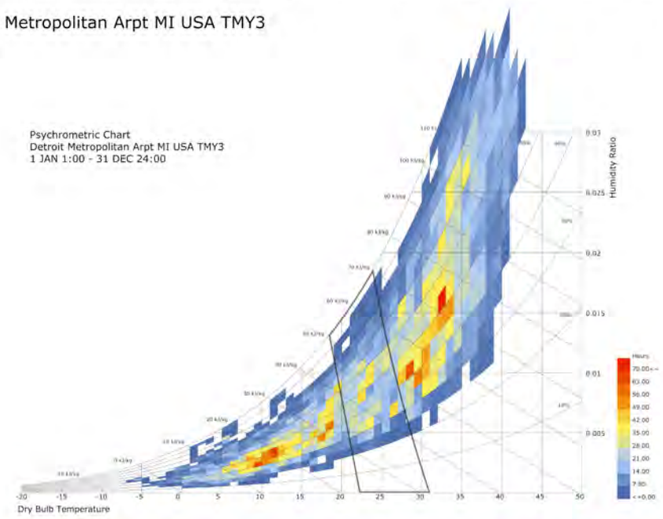


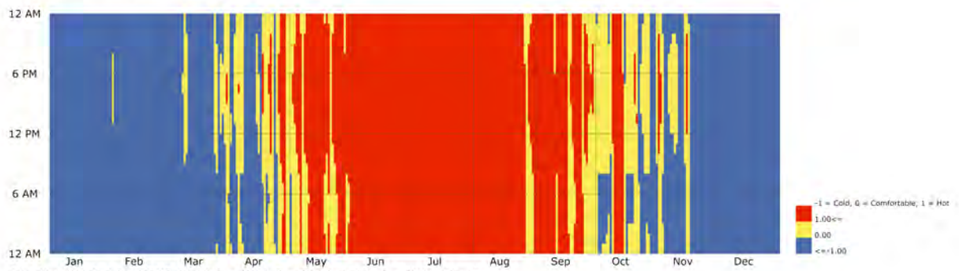


Detroit Metropolitan Arpt MI USA TMY3









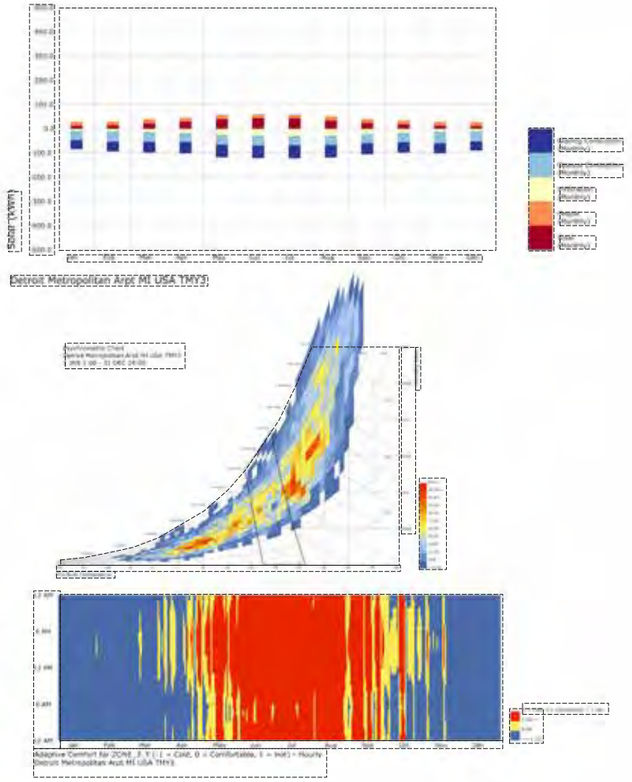
Adaptive Comfort for ZONE_3_T (-1 = Cold, 0 = Comfortable, 1 = Hot) - Hourly
Detroit Metropolitan Arpt MI USA TMY3
1 JAN 1:00 - 31 DEC 24:00

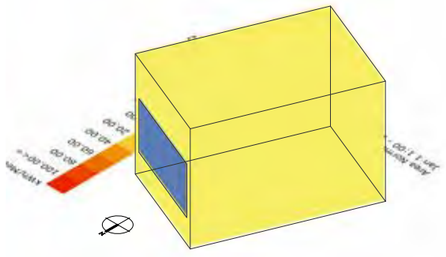
ENERGY SIMULATION

The results of the energy simulation analysis is such that overall comfort comes out to be 16.32%, the percentage of the time that is too hot to be comfortable is 39.41% and for cold is 44.27%.

MAJOR DESIGN ISSUES THAT NEED TO BE ADDRESSED WITH THE BASE CASE

Based on the information plotted on the previous charts, one can conclude that daylighting is problematic such that the amount the entire room receives for the majority of the year is insufficient, and the frequency of the room condition of the room being cold as opposed to being hot is 10% higher.





comfort:

15.11%

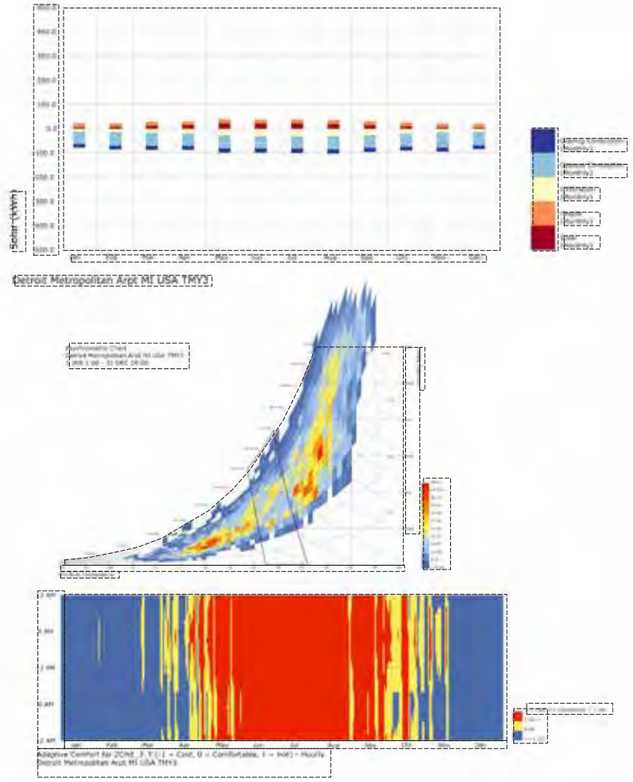
hot:

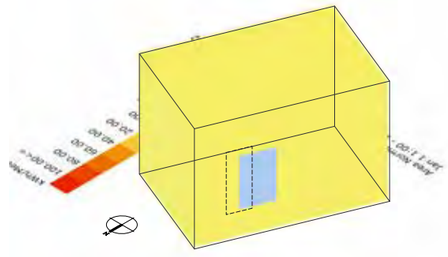
36.04%

cold:

48.85%

case w1_
larger window





comfort:

15.82%

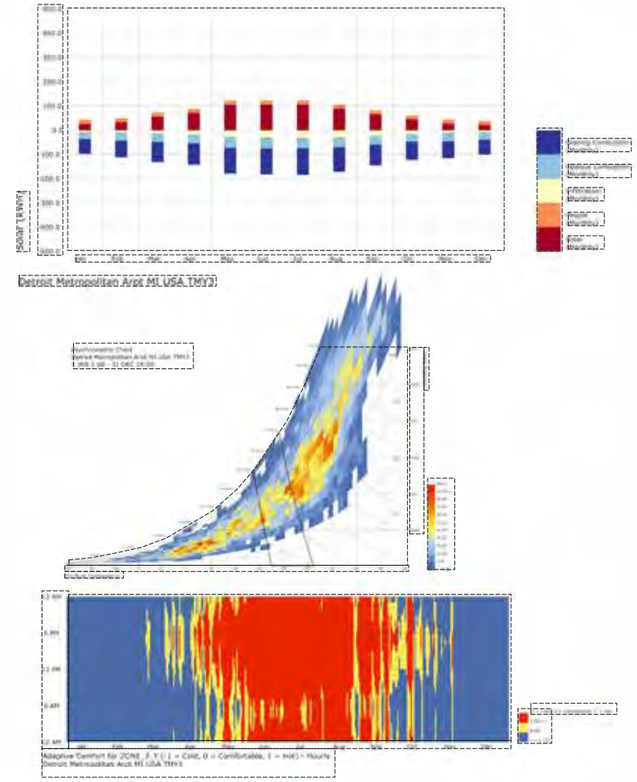
hot:

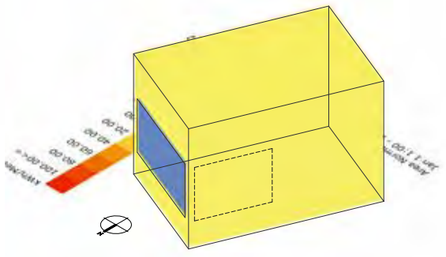
41.02%

cold:

43.16%

case w2_
window location change





comfort:

13.98%

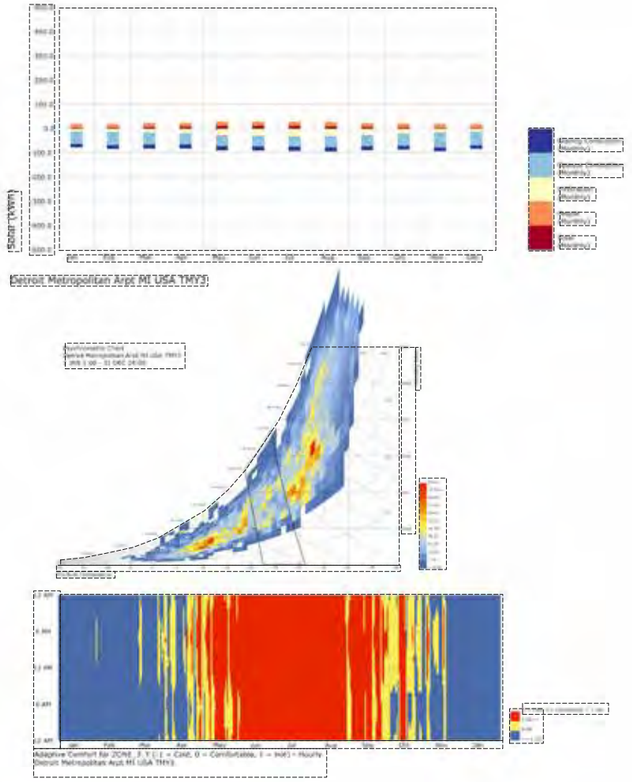
hot:

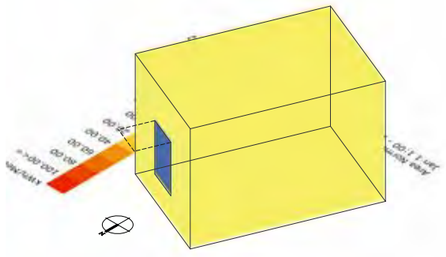
35.54%

cold:

50.48%

case w3_
size + location





comfort:

16.34%

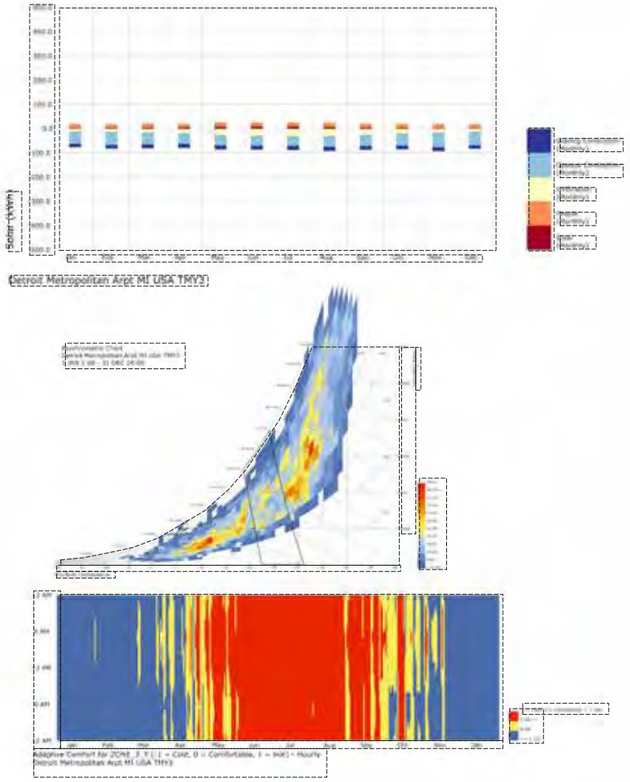
hot:

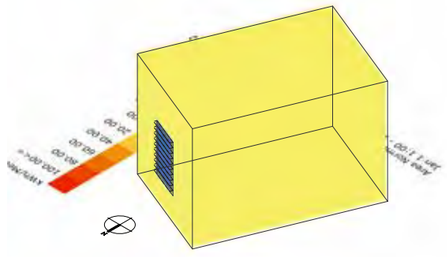
39.11%

cold:

44.55%

case b1_
light shelf





comfort:

16.59%

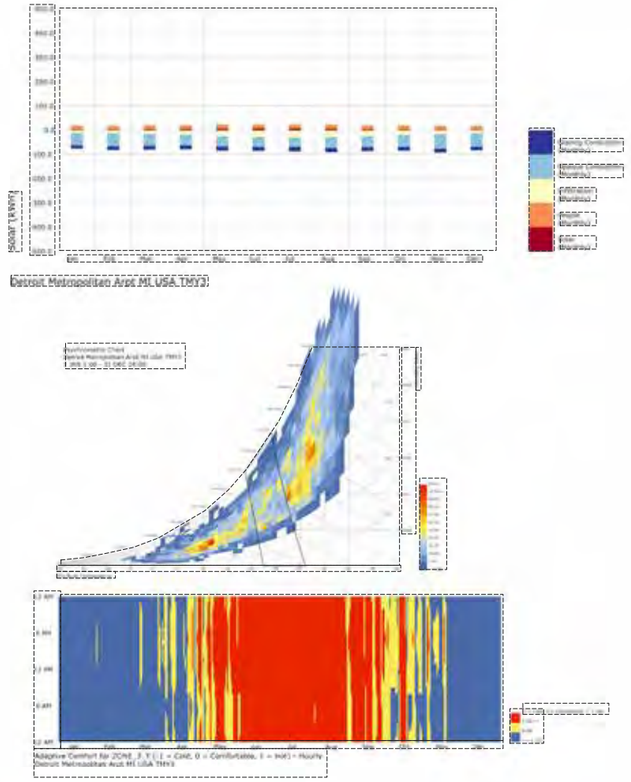
hot:

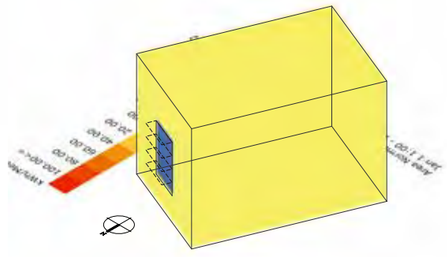
38.56%

cold:

44.85%

case b2_
regular blinds





comfort:

16.72%

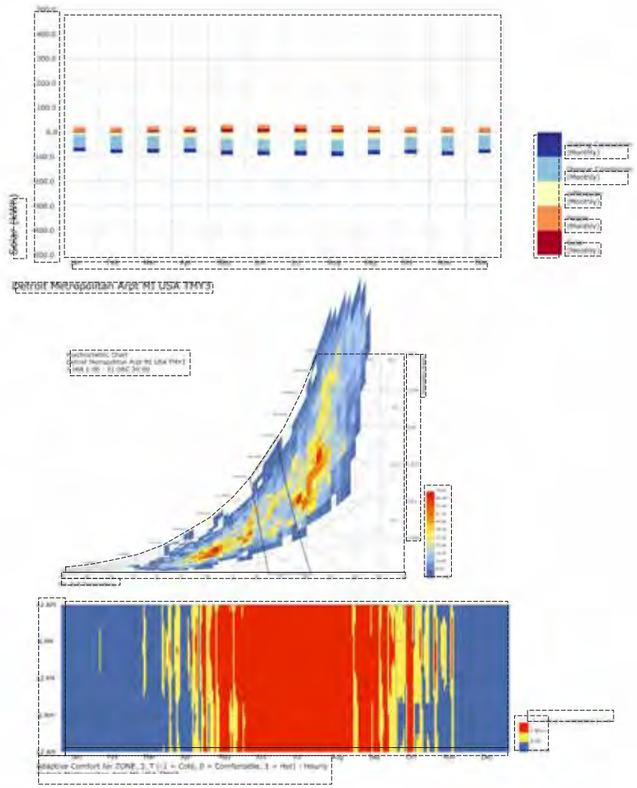
hot:

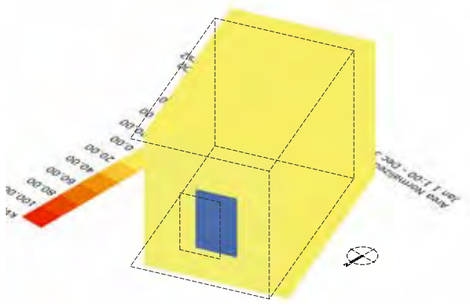
38.05%

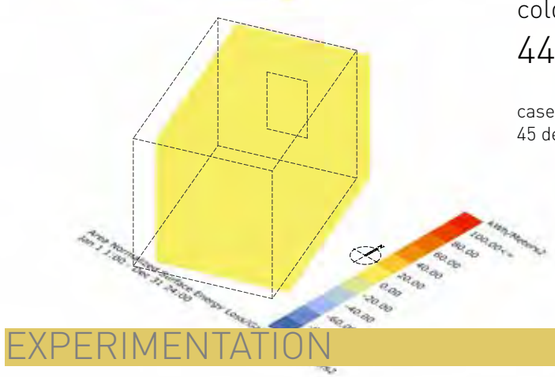
cold:

45.23%

case b3_
middle case







comfort:

16.11%

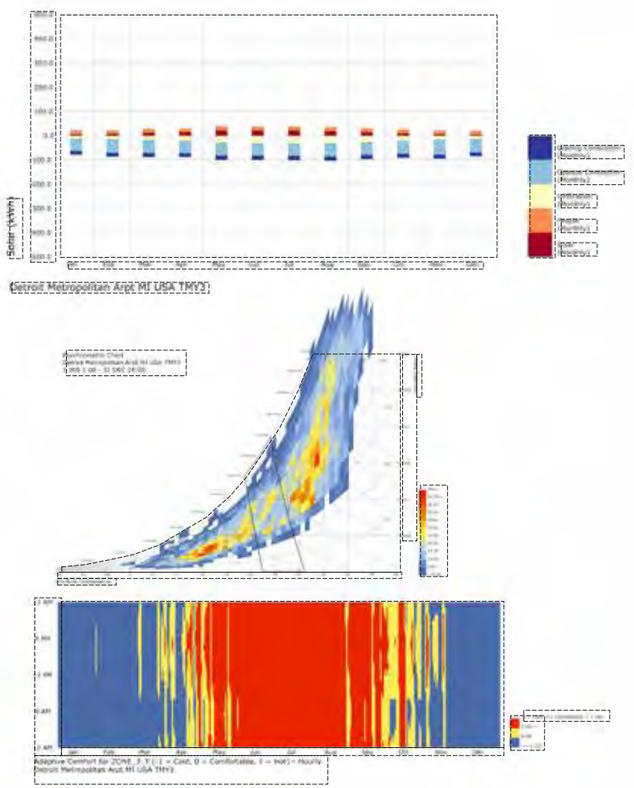
hot:

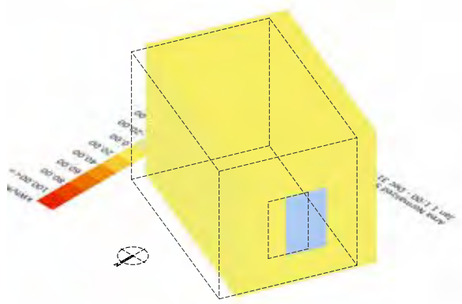
39.55%

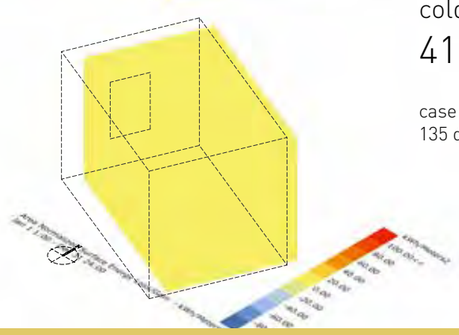
cold:

44.34%

case r1_
45 degrees







comfort:

15.47%

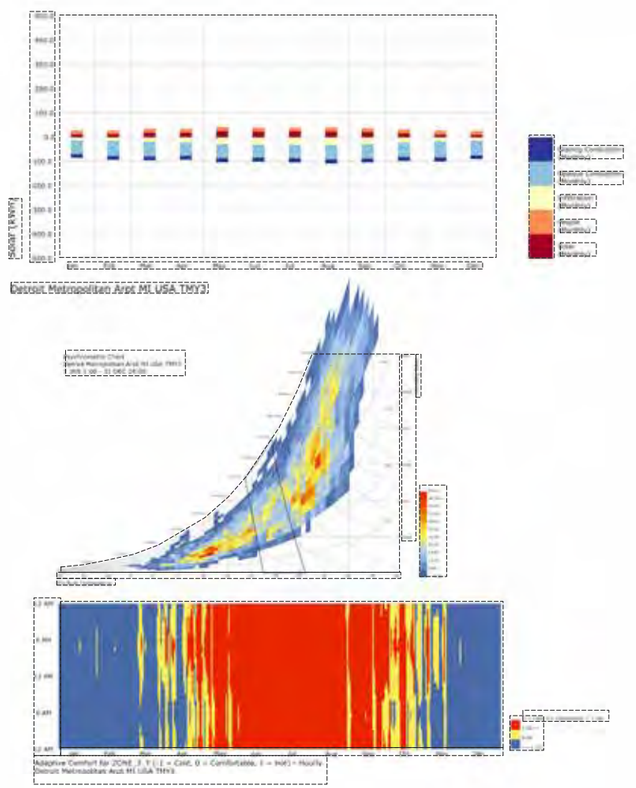
hot:

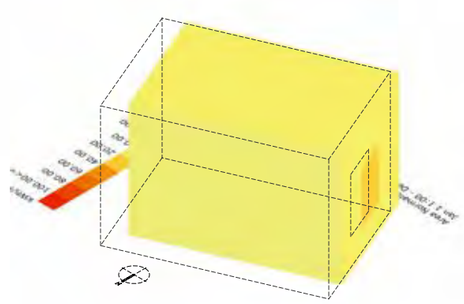
43.18%

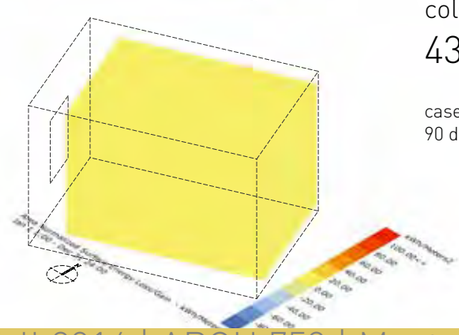
cold:

41.35%

case r2_
135 degrees







comfort:

15.82%

hot:

41.82%

cold:

43.15%

case r1_
90 degrees

GENETICS APPROACH

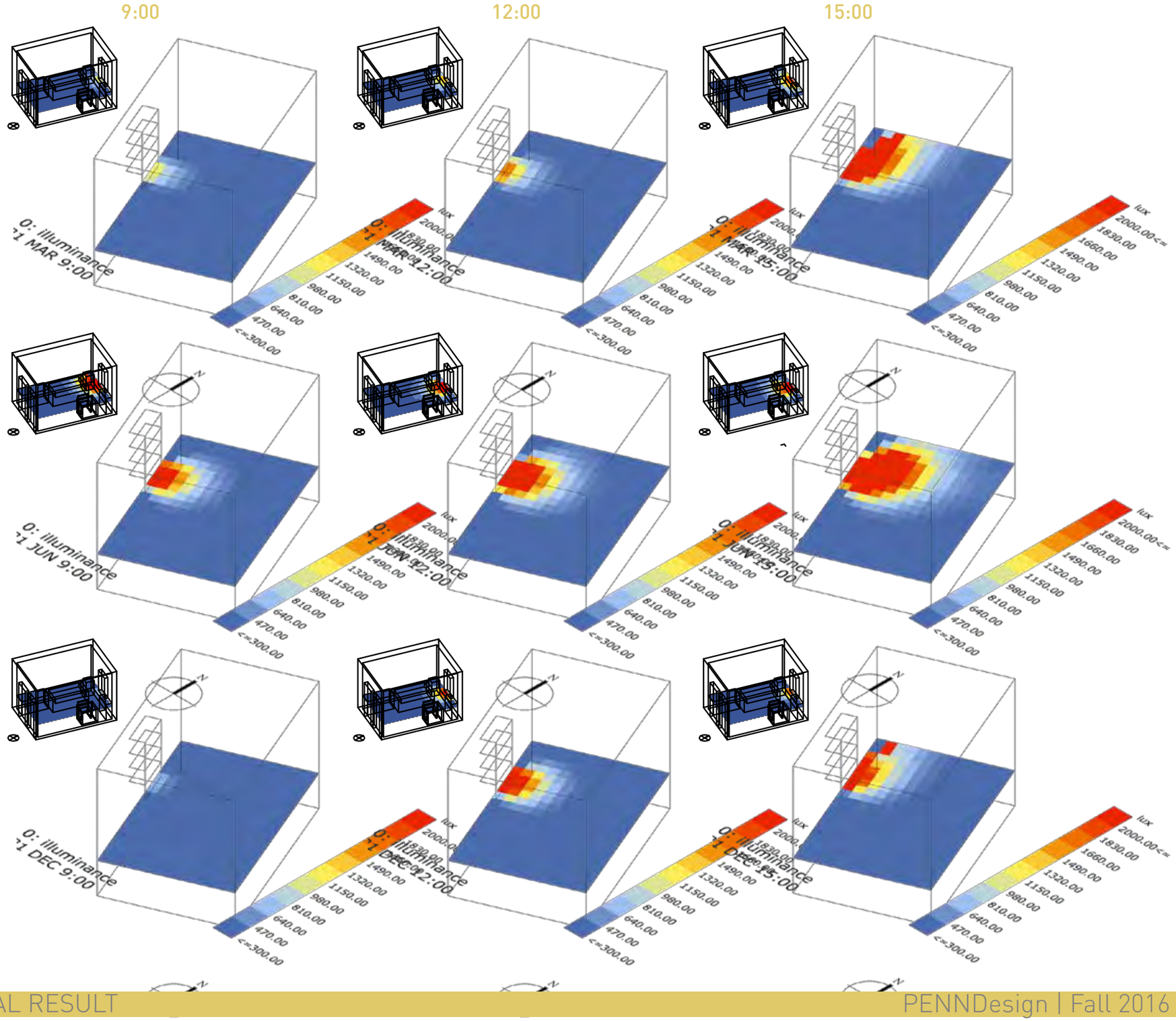
The method in which this study undergoes more or less follows the theory of natural selection, in which traits of a single category are taken side by side and based on which trait has better results, it will be the one inherited by the new design. In this case, the same energy simulations are run while keeping all but one aspect of the design constant; three instances of window sizing, rotation, and blind applications are tested. Whichever change ends up with the best results is then matched up against the base case.

9:00
12:00
15:00

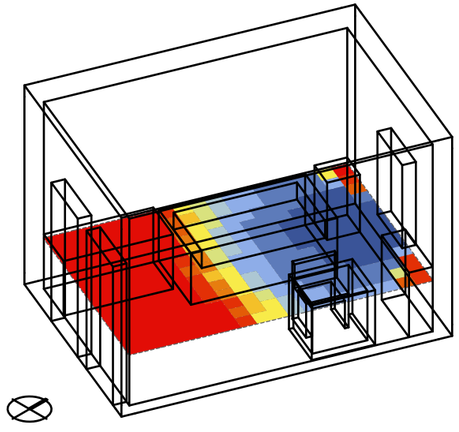
21 MARCH

21 JUNE

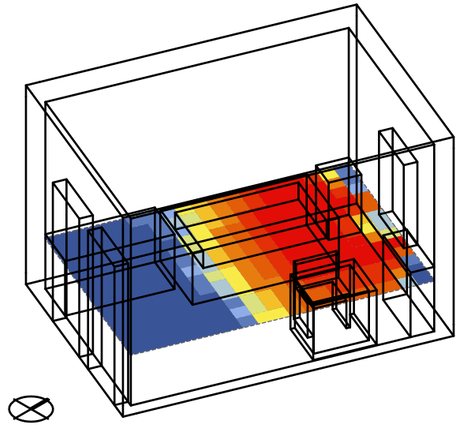
21 DECEMBER



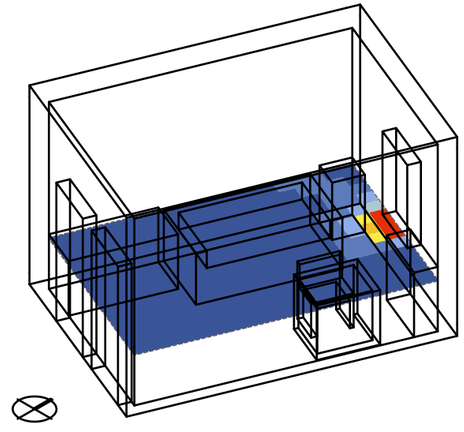
UDI ≤ 100

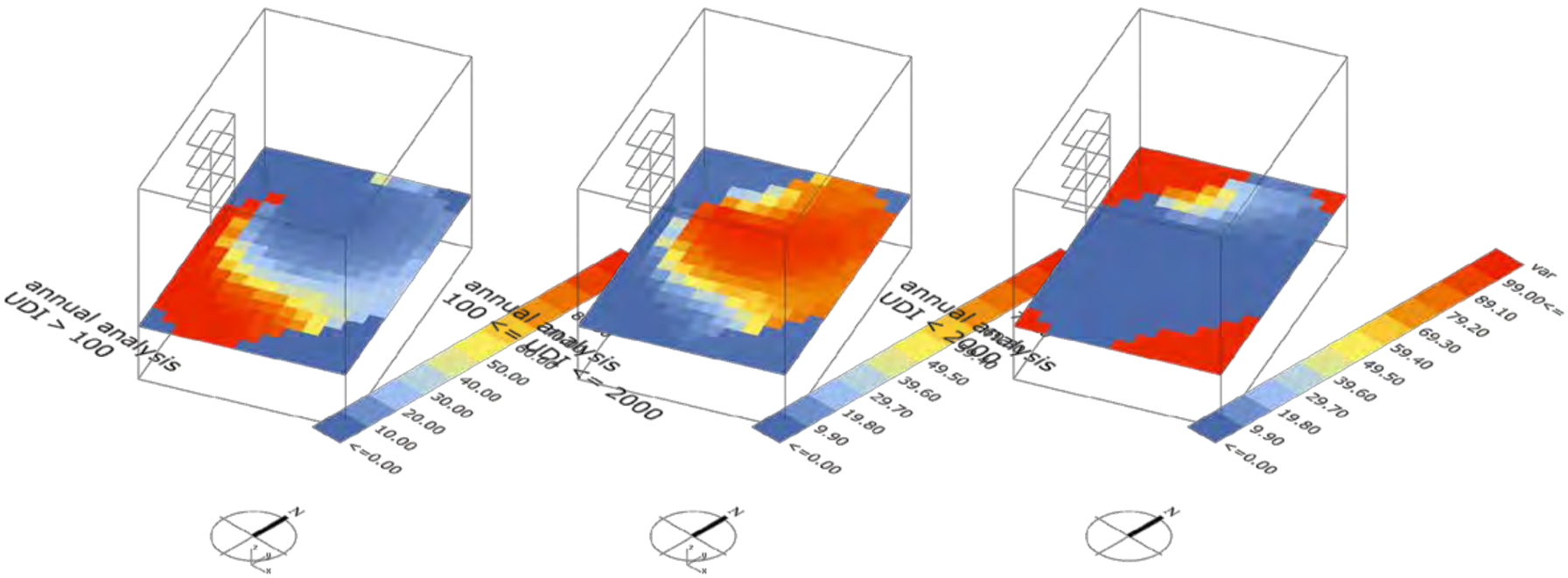


100 <= UDI <= 2000

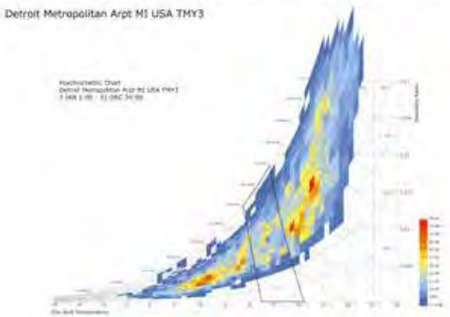


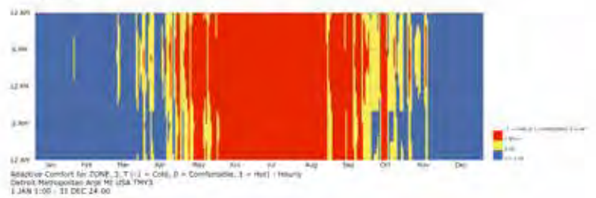
UDI ≥ 2000



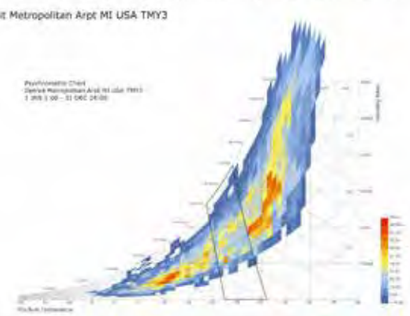


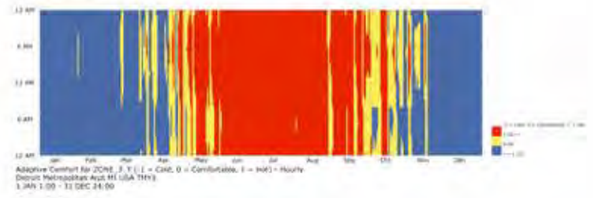
Detroit Metropolitan Arpt MI USA TMY3





Detroit Metropolitan Arpt MI USA TMY3





The end result, after combining all of the "victorious" traits are: 45 degree rotation, 4 blinds that are 0.3 m deep,and moving the location of the window to the middle of the NE wall instead.

The resulting data shows a +.28% rise in overall comfort, a +0.21% rise in heat, and a -0.49% drop in coldness.

While this intervention is successful in terms of providing comfort in colder situations, it does fail in that heat stress is heightened. A large shortcoming of this particular application of the genetics approach is the lack of traits tested: testing only three of each characteristic does not suffice for an effective design.

Two other huge errors in this process is (1) seen in modelling; the results would be more descriptive and accurate to the real situation if elements such as wall thickness and construction types had been accounted for; (2) seen in calibration of data results; had the case study results been more controlled, better observations and ultimately better initial design proposals might have been more effective.