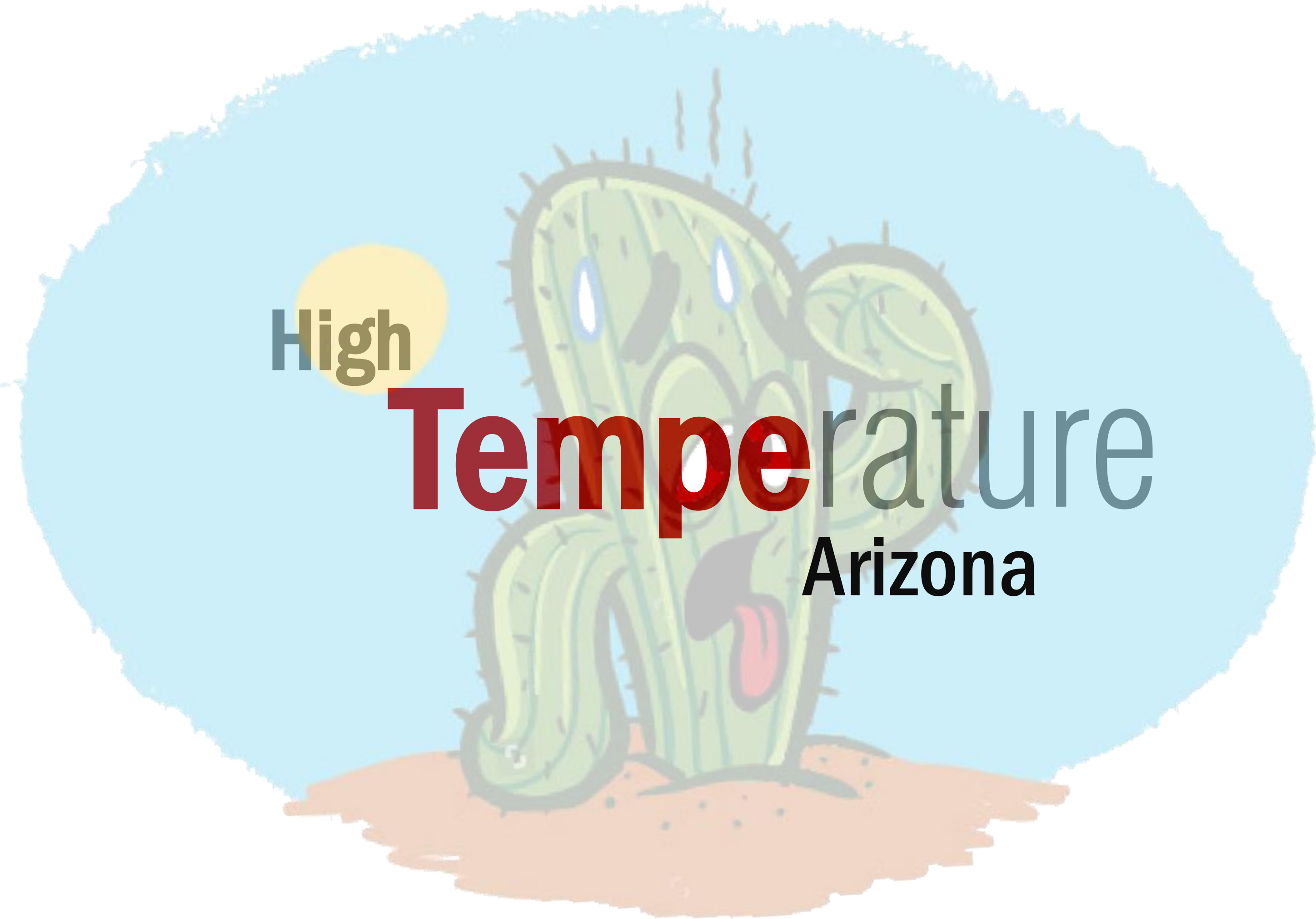
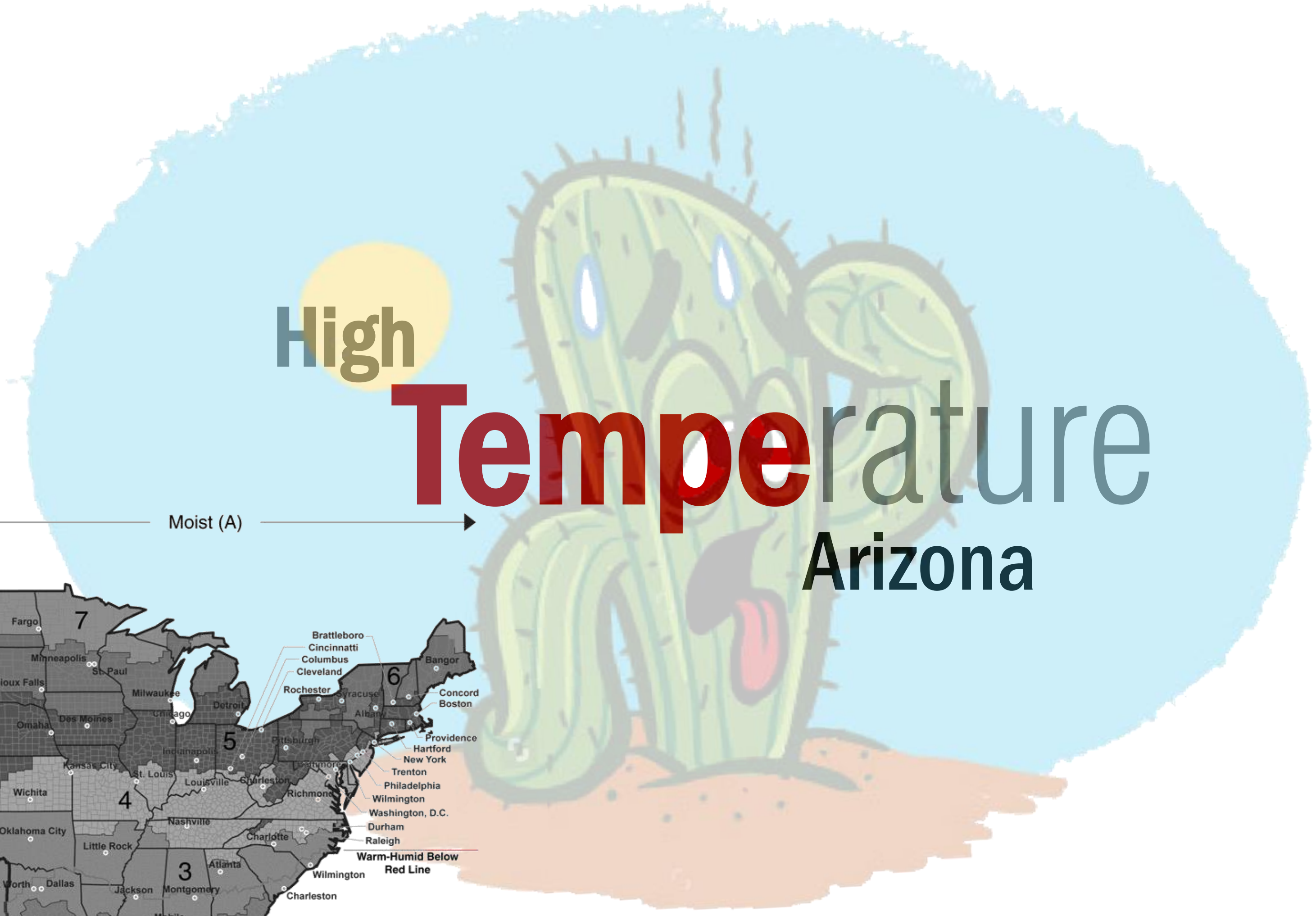
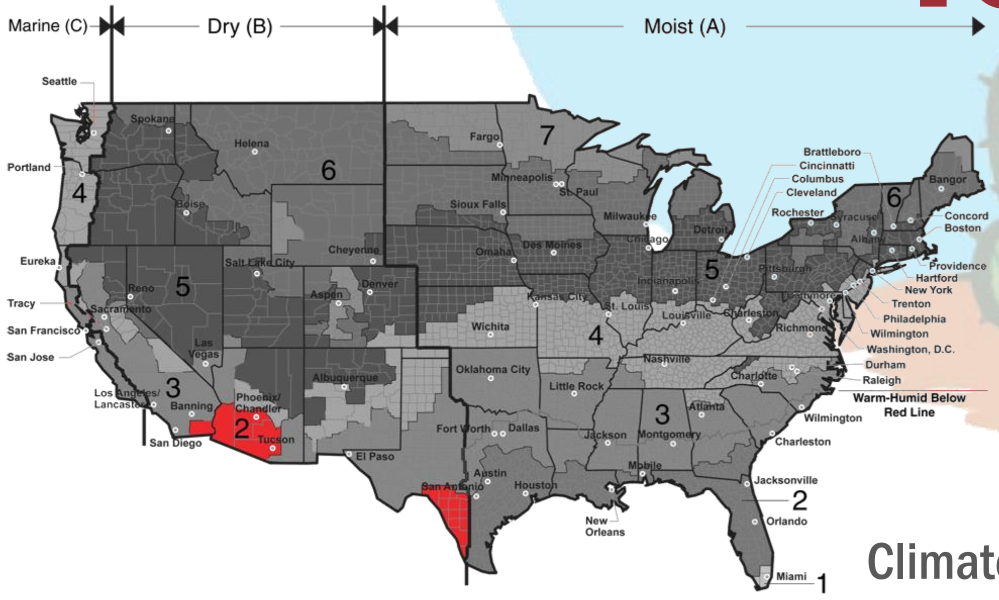


# High Temperature Arizona

Ashish Khemchandani | Pegah Mathur | MEBD Environmental Design Studio

# High Temperature Arizona



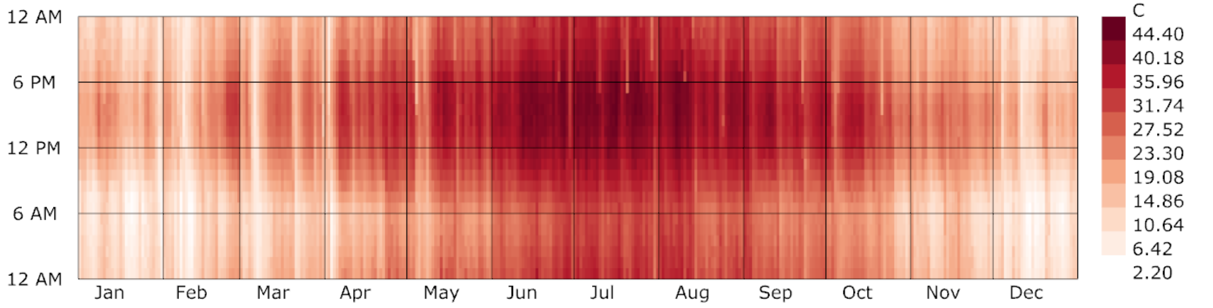



Climate zone: **2B**

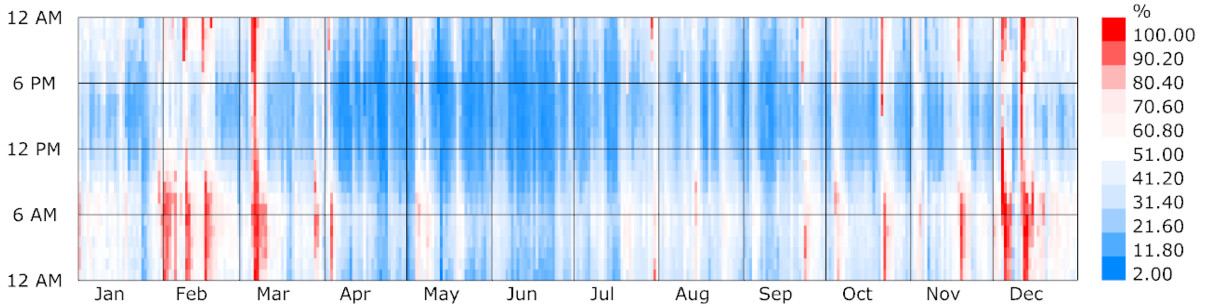
# Weather data

## Observations and conclusions

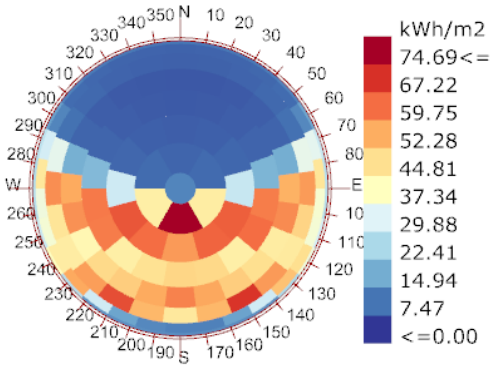
- The dry bulb temperature ranges from an average minimum of about 7˚ C (cold) to the average maximum of over 40˚ C (extremely hot)
- The relative humidity rarely exceeds over 30% over the summer months, therefore it is dry.
- Arizona experiences among the highest levels of radiation in the US with total radiation exceeding 1200 kWh/$m^2$



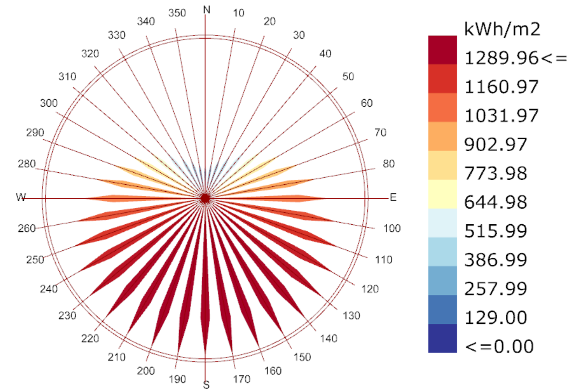
Dry Bulb Temperature (C) - Hourly
Phoenix Sky Harbor Intl Ap_AZ_USA
1 JAN 1:00 - 31 DEC 24:00



Relative Humidity (%) - Hourly
Phoenix Sky Harbor Intl Ap_AZ_USA
1 JAN 1:00 - 31 DEC 24:00



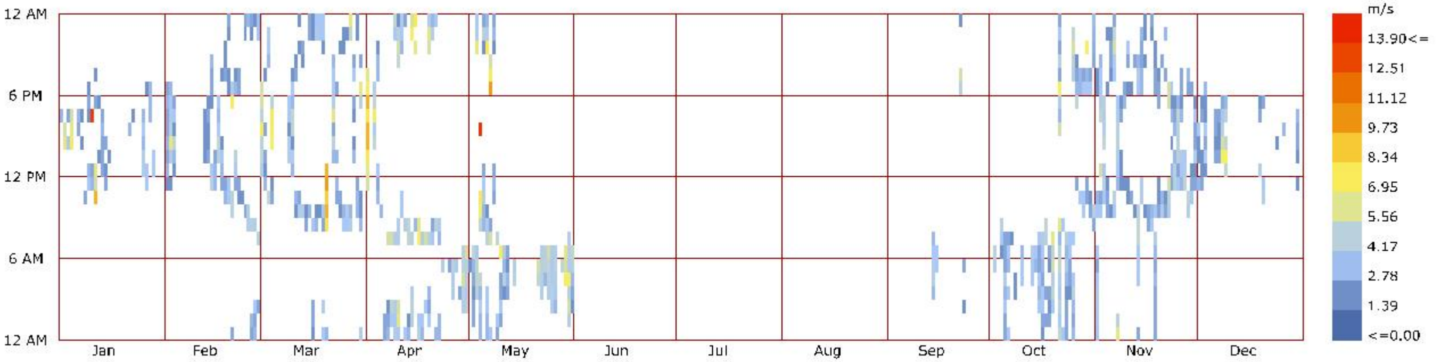
Total Radiation(kWh/m2)
Phoenix_Sky_Harbor_Intl_Ap_AZ_USA
1 JAN 1:00 - 31 DEC 24:00



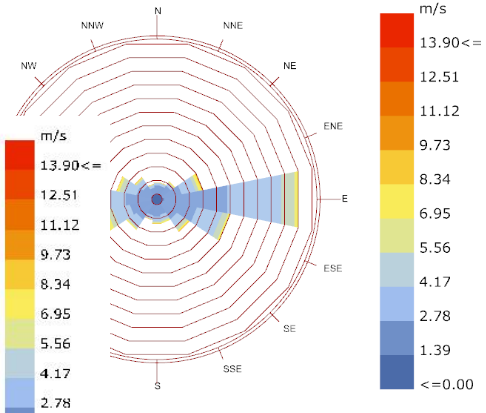
Total Radiation(kWh/m2)
Phoenix_Sky_Harbor_Intl_Ap_AZ_USA
1 JAN 1:00 - 31 DEC 24:00

# Weather data

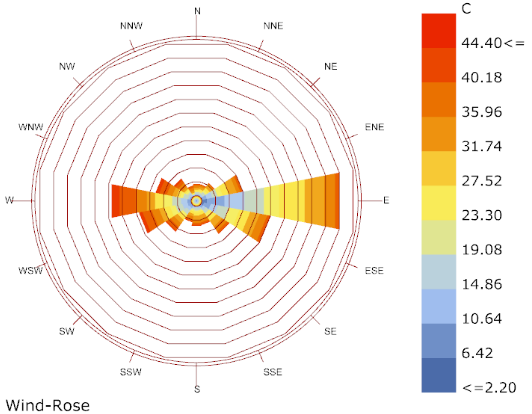
## Observations and conclusions




Wind Speed (m/s) - Hourly
Phoenix Sky Harbor Intl Ap AZ USA
1 JAN 1:00 - 31 DEC 24:00

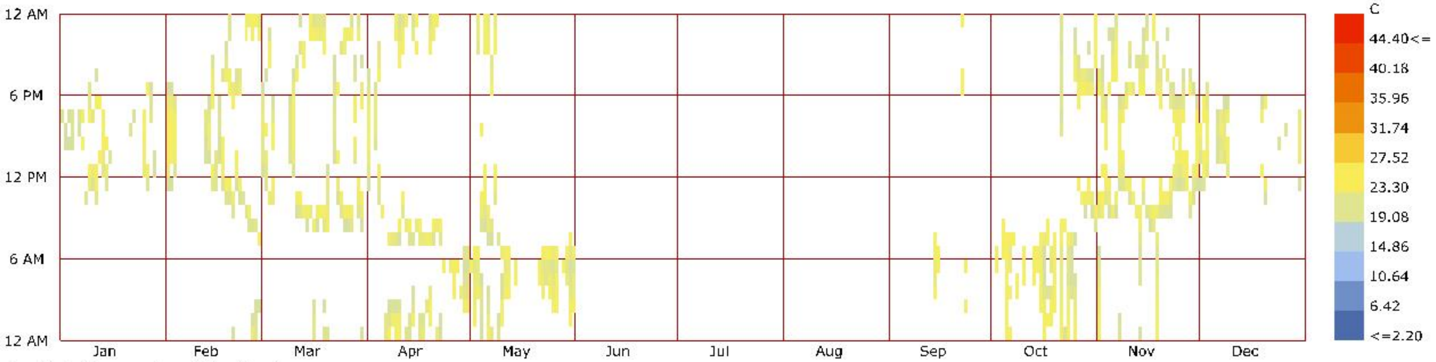



r Intl Ap_AZ_USA
EC 24:00
l Speed (m/s)
of the time = 1058 hours.
ne shows frequency of 2.0%. = 172 hours.

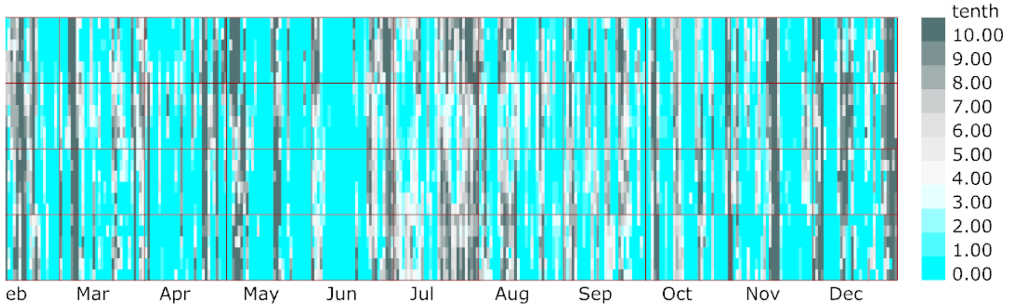



Wind-Rose
Phoenix Sky Harbor Intl Ap_AZ_USA
1 JAN 1:00 - 31 DEC 24:00
Hourly Data: Dry Bulb Temperature (C)
Calm for 12.08% of the time = 1058 hours.
Each closed polyline shows frequency of 2.0%. = 172 hours.

*intense radiation*



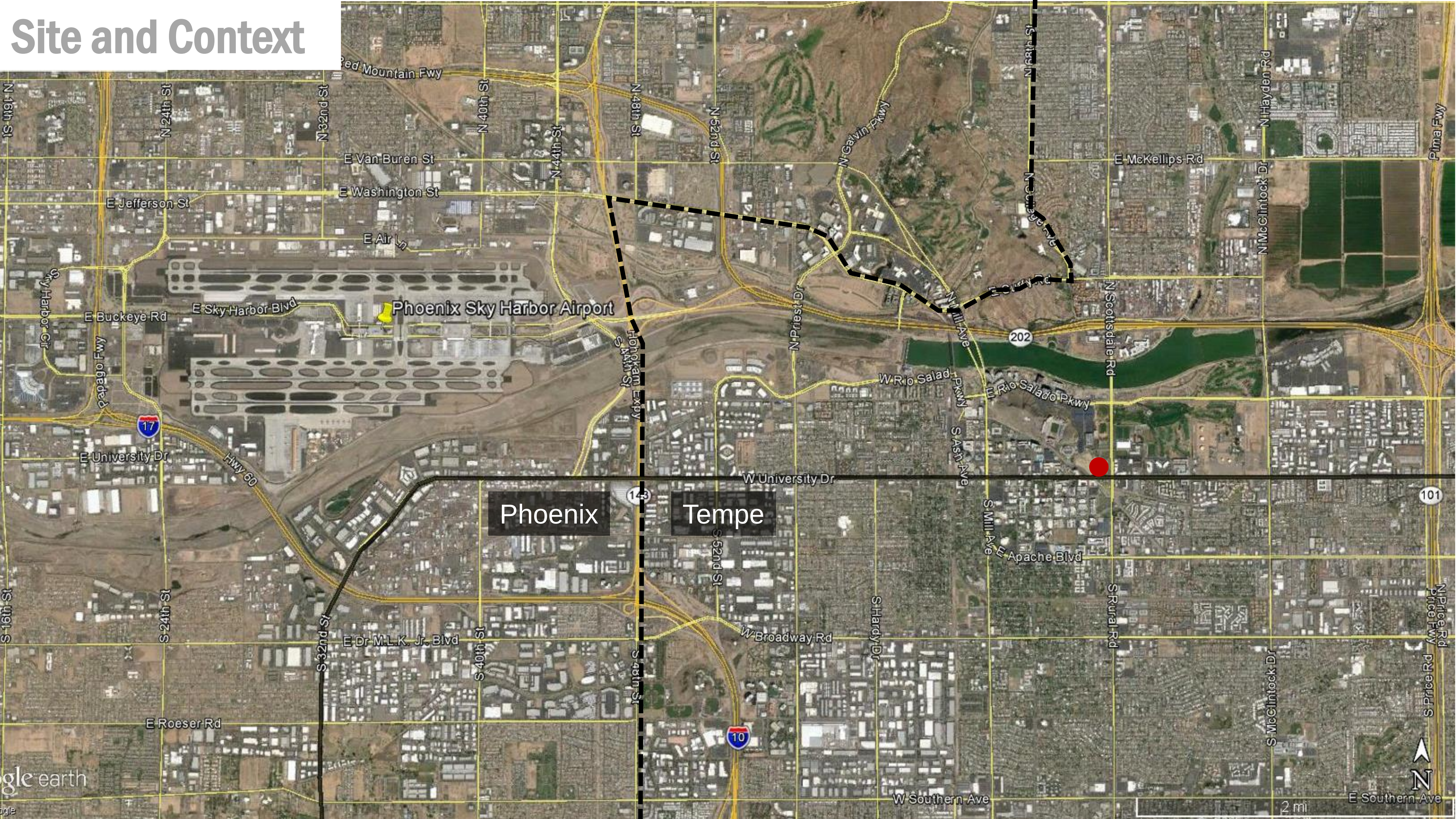

Dry Bulb Temperature (C) - Hourly
Phoenix Sky Harbor Intl Ap AZ USA
1 JAN 1:00 - 31 DEC 24:00



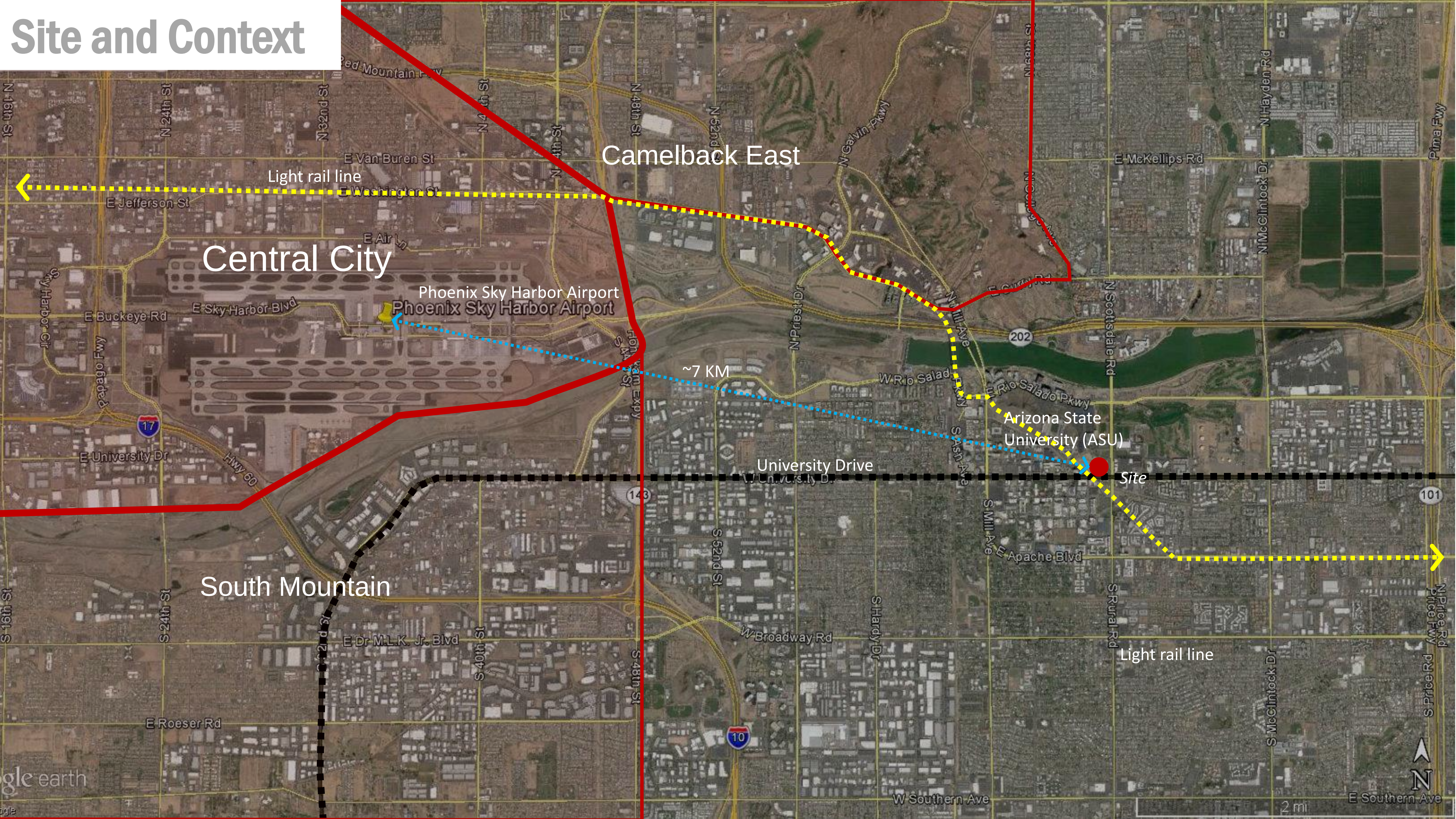

tenth) - Hourly
Intl Ap_AZ_USA
C 24:00

- Natural ventilation hours of the year

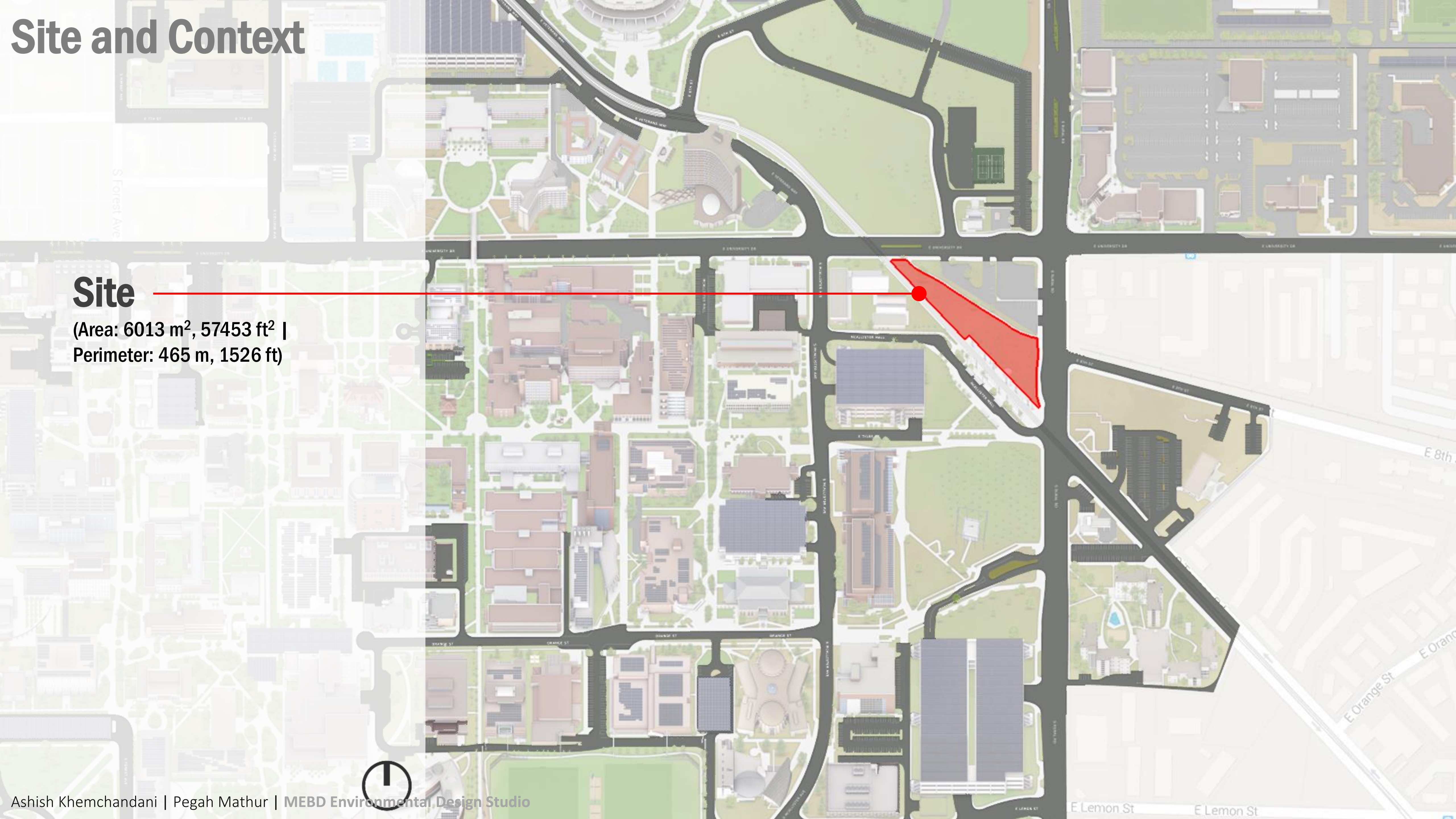
# Site and Context



# Site and Context



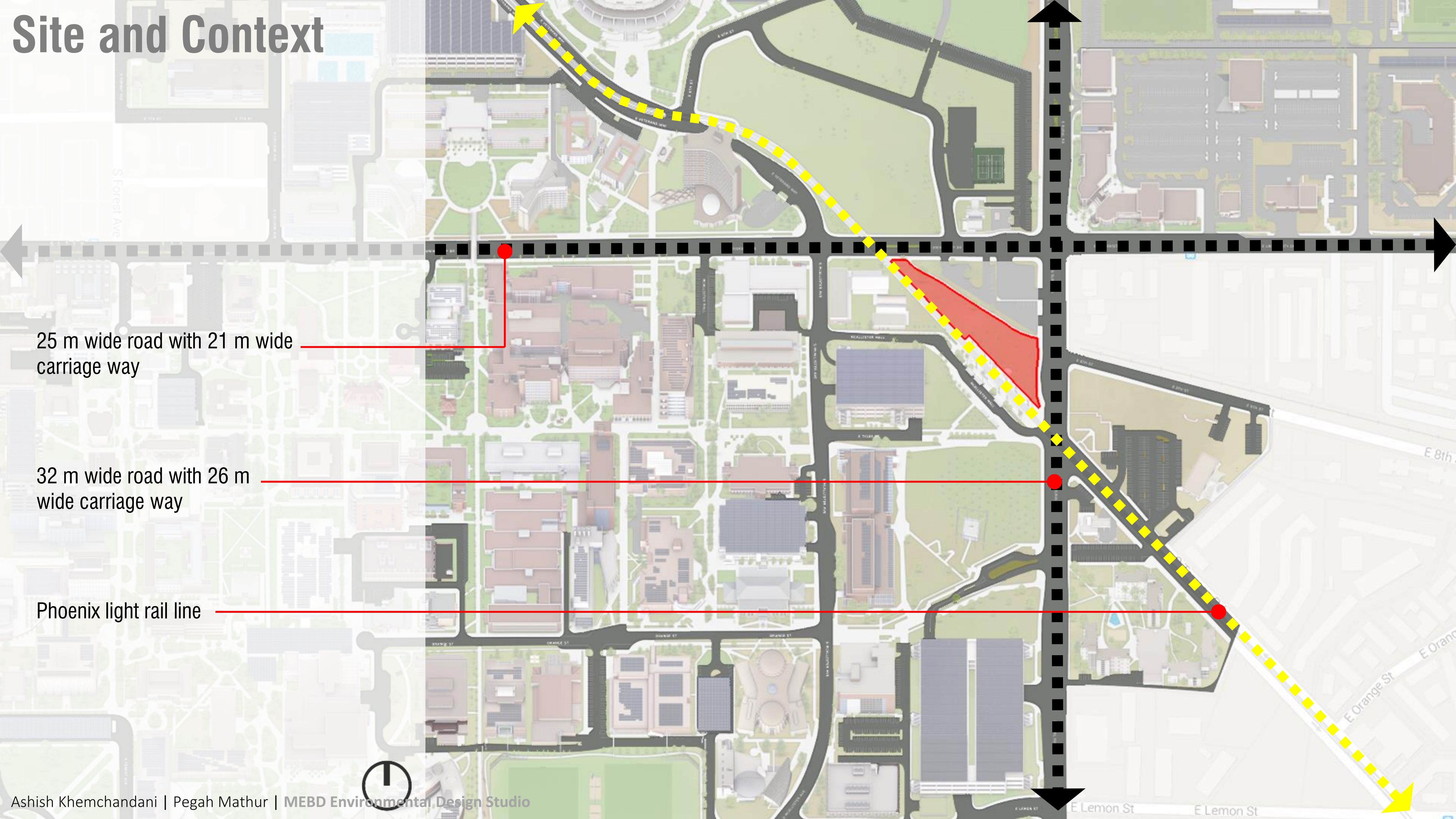
# Site and Context




## Site

(Area: 6013 $m^2$, 57453 $ft^2$ |
Perimeter: 465 m, 1526 ft)

# Site and Context



## Microclimate

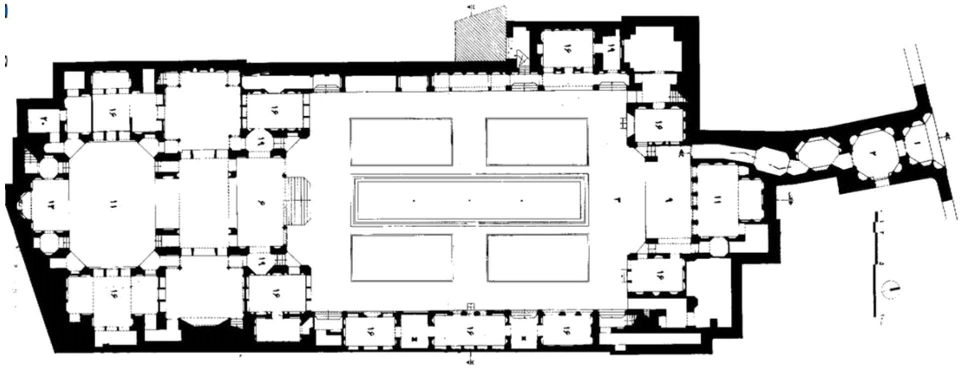
# Passive design in hot and dry climate

Design of a Microclimate

Like a treasure garden

# Passive design in hot and dry climate

## Lower step courtyard

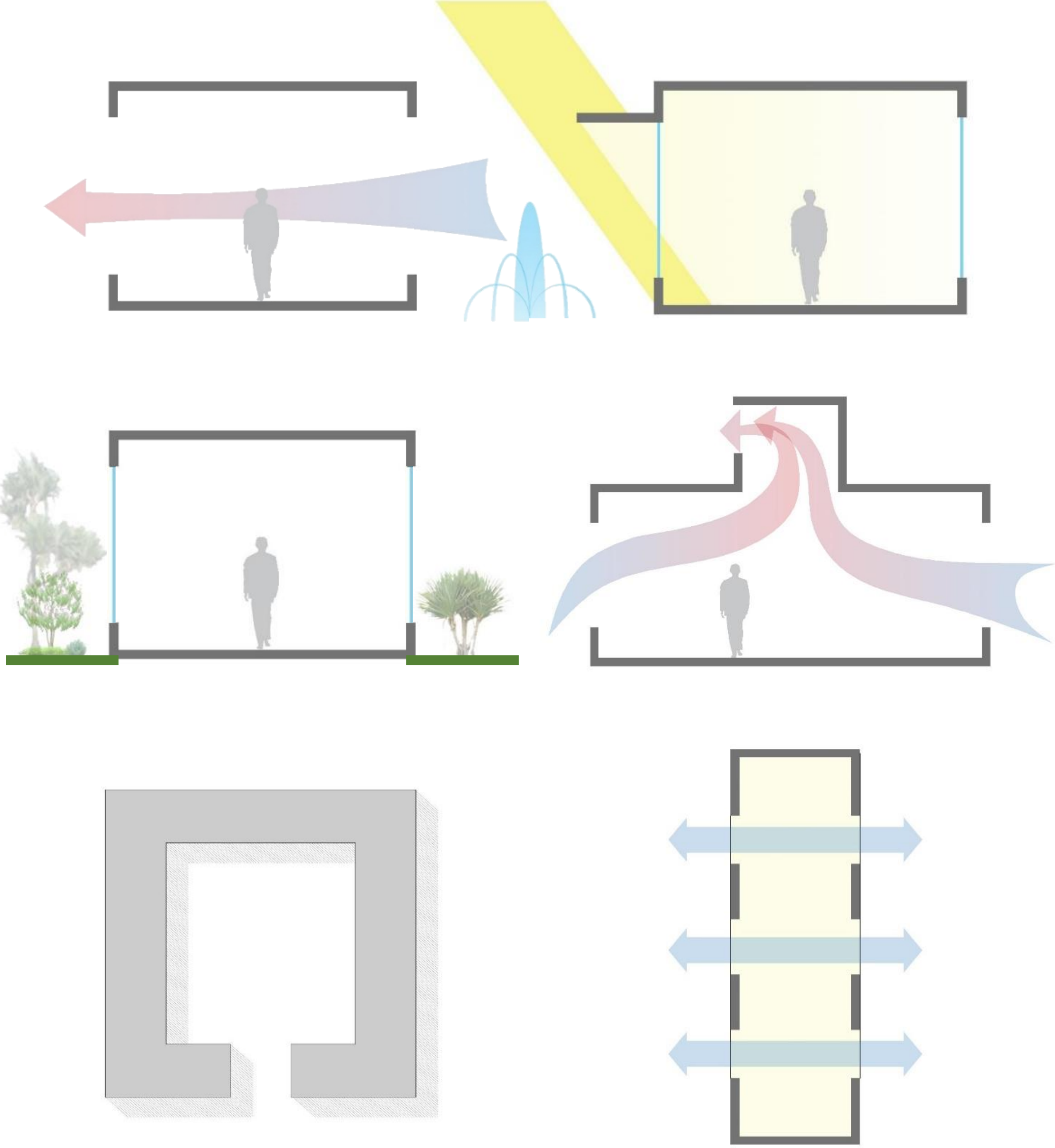



- Reducing thermal conduction
- Cool Environment in summer
- Warm environment in winter

# Rules of thumb

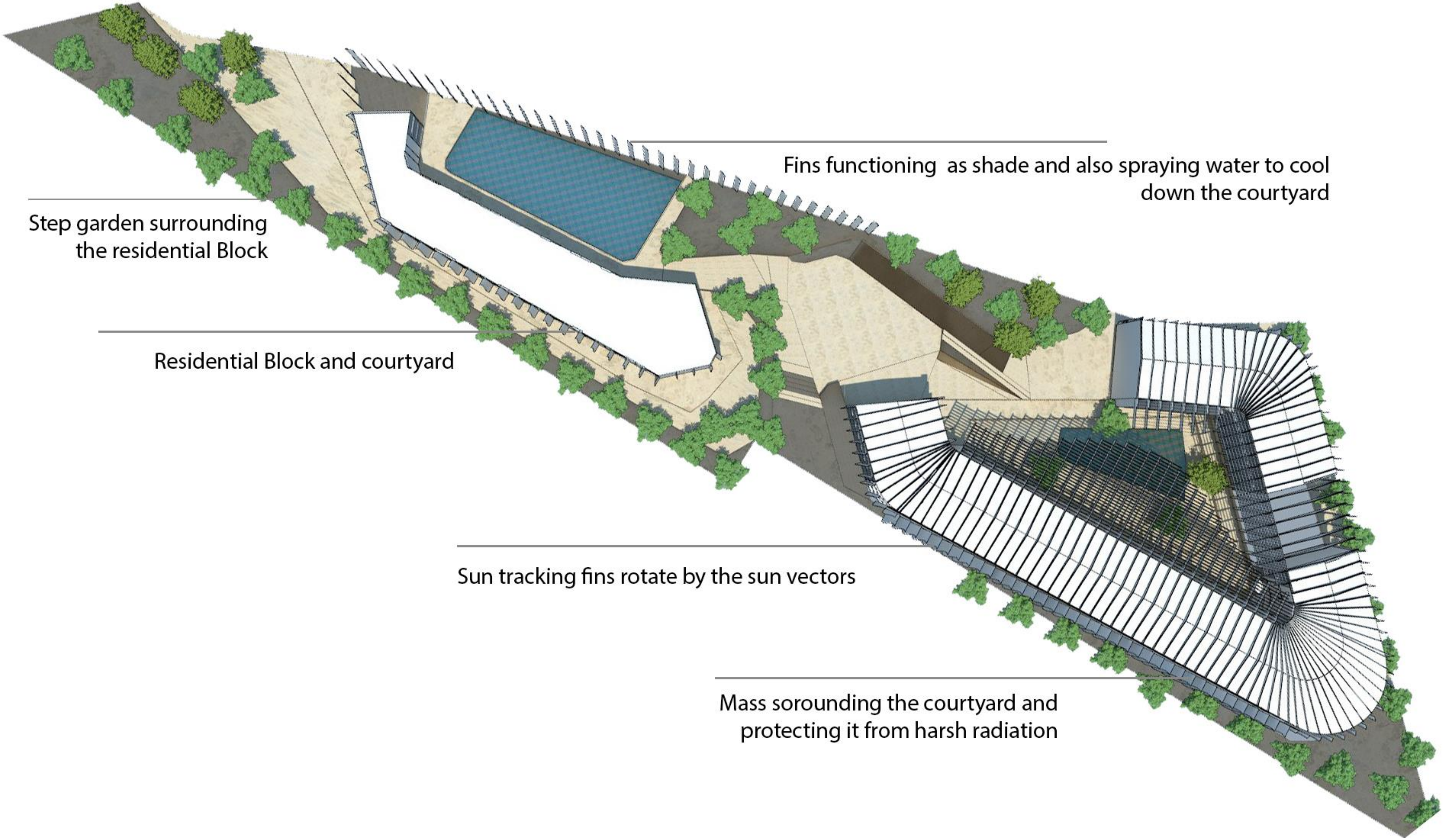
## Feasible passive strategies

- Good natural ventilation can reduce air conditioning in warm but not the hottest days, if combined with some passive cooling technique and shade
- Sparse cloud cover and high radiation levels mean there's good daylight potential but windows and glazing need to be shaded at all times
- Evaporative cooling strategies are feasible to help reduce the temperature considering the low humidity ratios
- Local plantations can help shade walls and improve outdoor microclimate
- Treated courtyard and stack effect to induce ventilation can work in the outdoor and indoor climates
- Long and narrow floor plan to facilitate cross ventilation



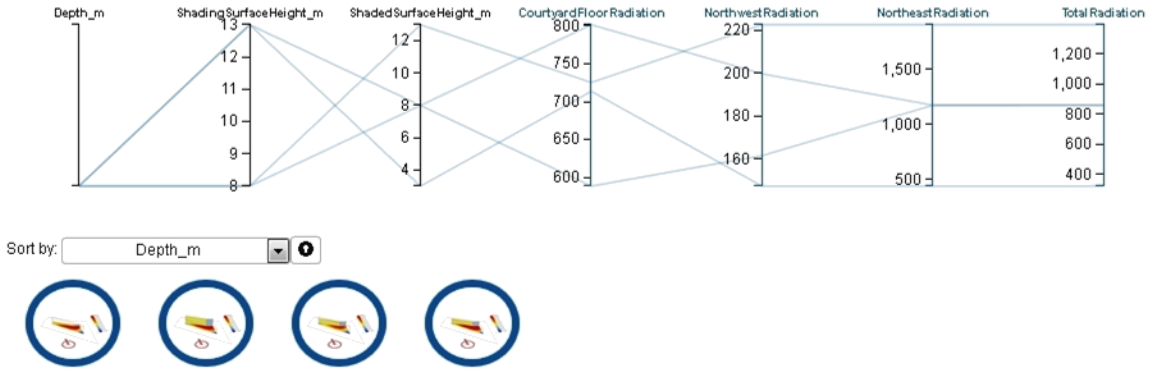
# Site plan

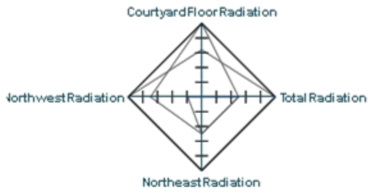
## Narrow double courtyard

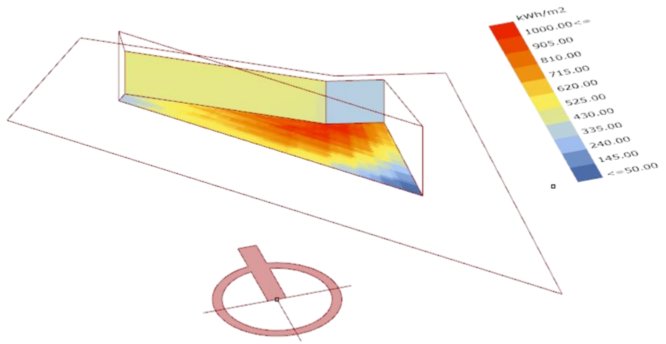


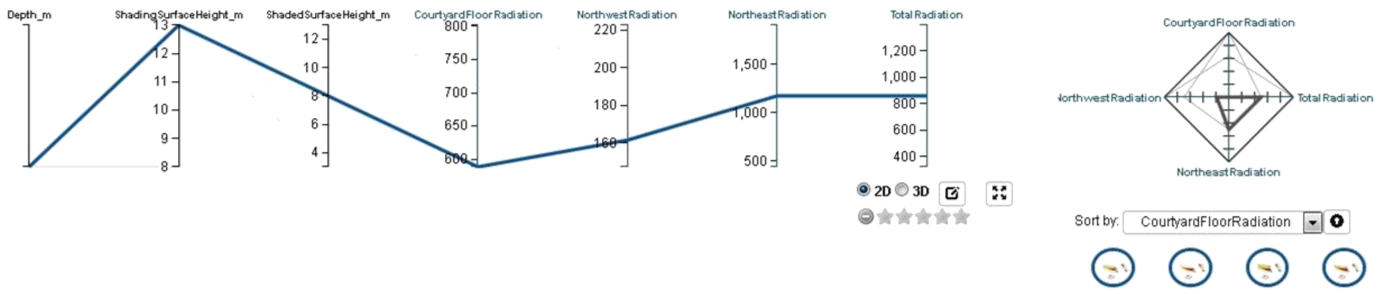
# Form exploration

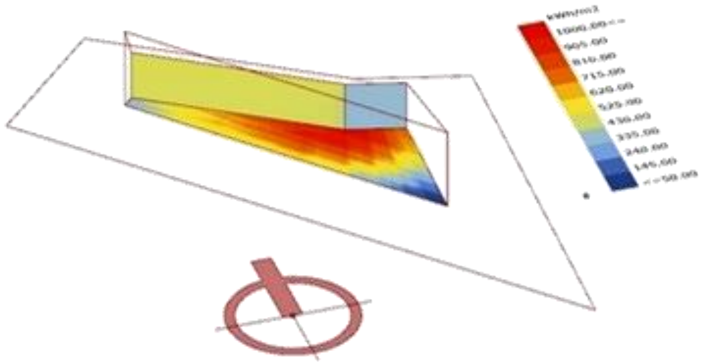
## Exploring the height and depth of the mass



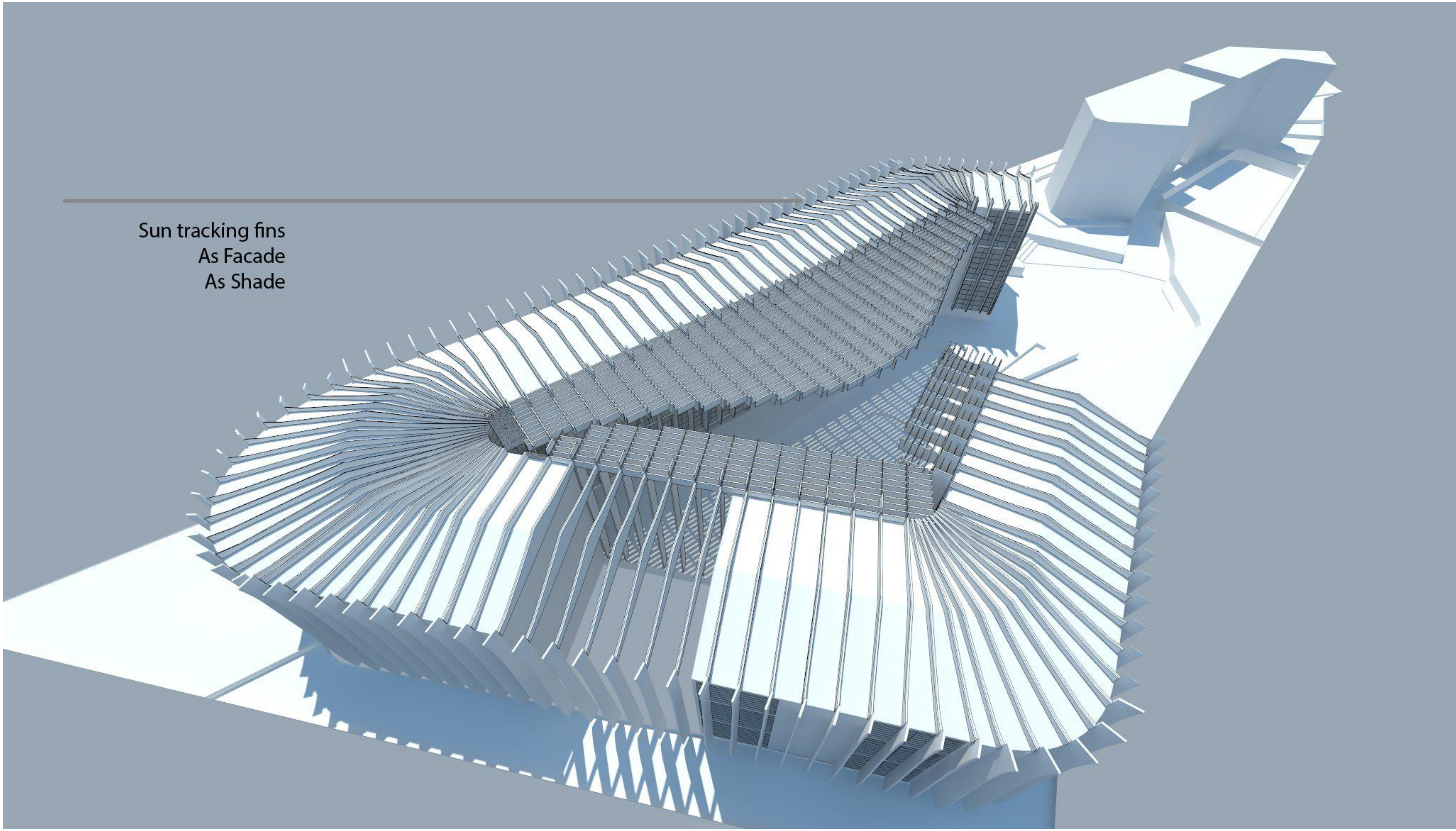



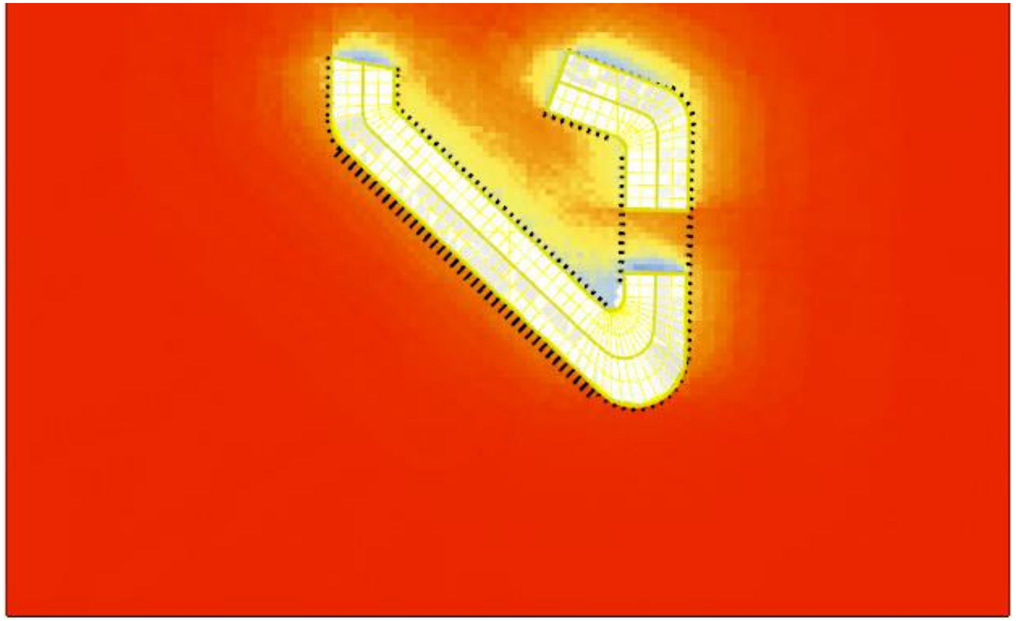



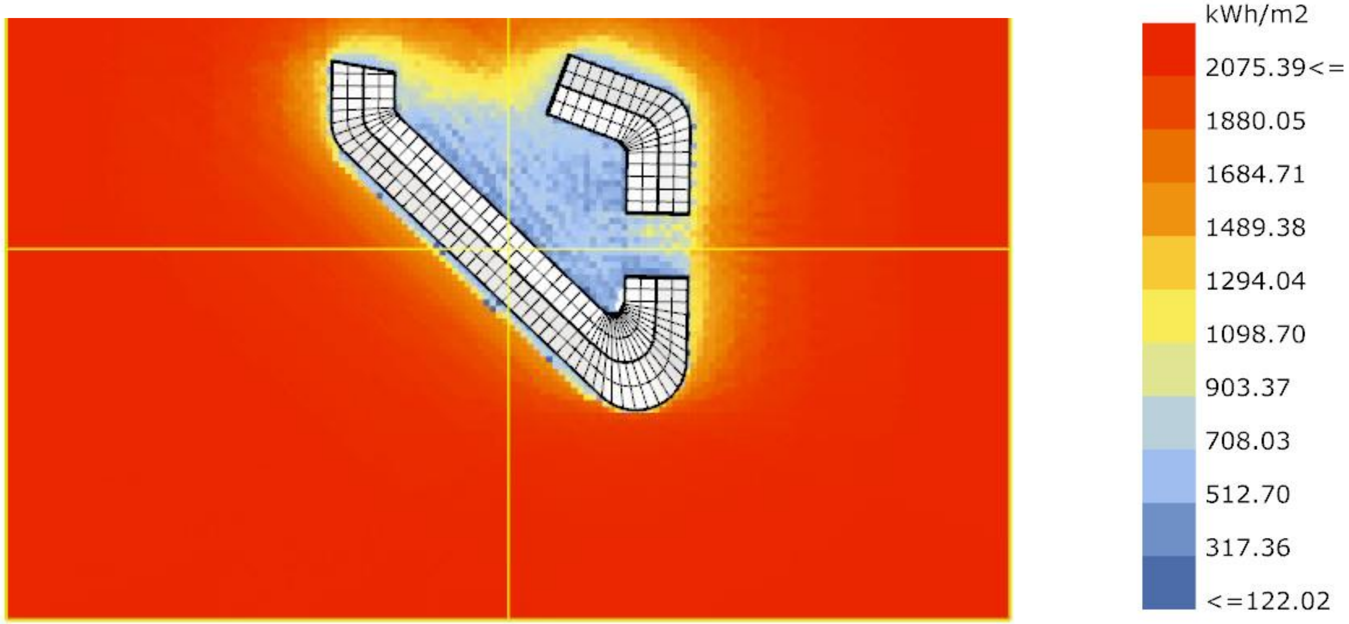
# The Design



# Outdoor comfort

## Radiation and shade in the courtyard






Cumulative radiation analysis

- **Radiation analysis shows how much shade on the courtyard reduces radiation on the courtyard surface.**

# Outdoor comfort

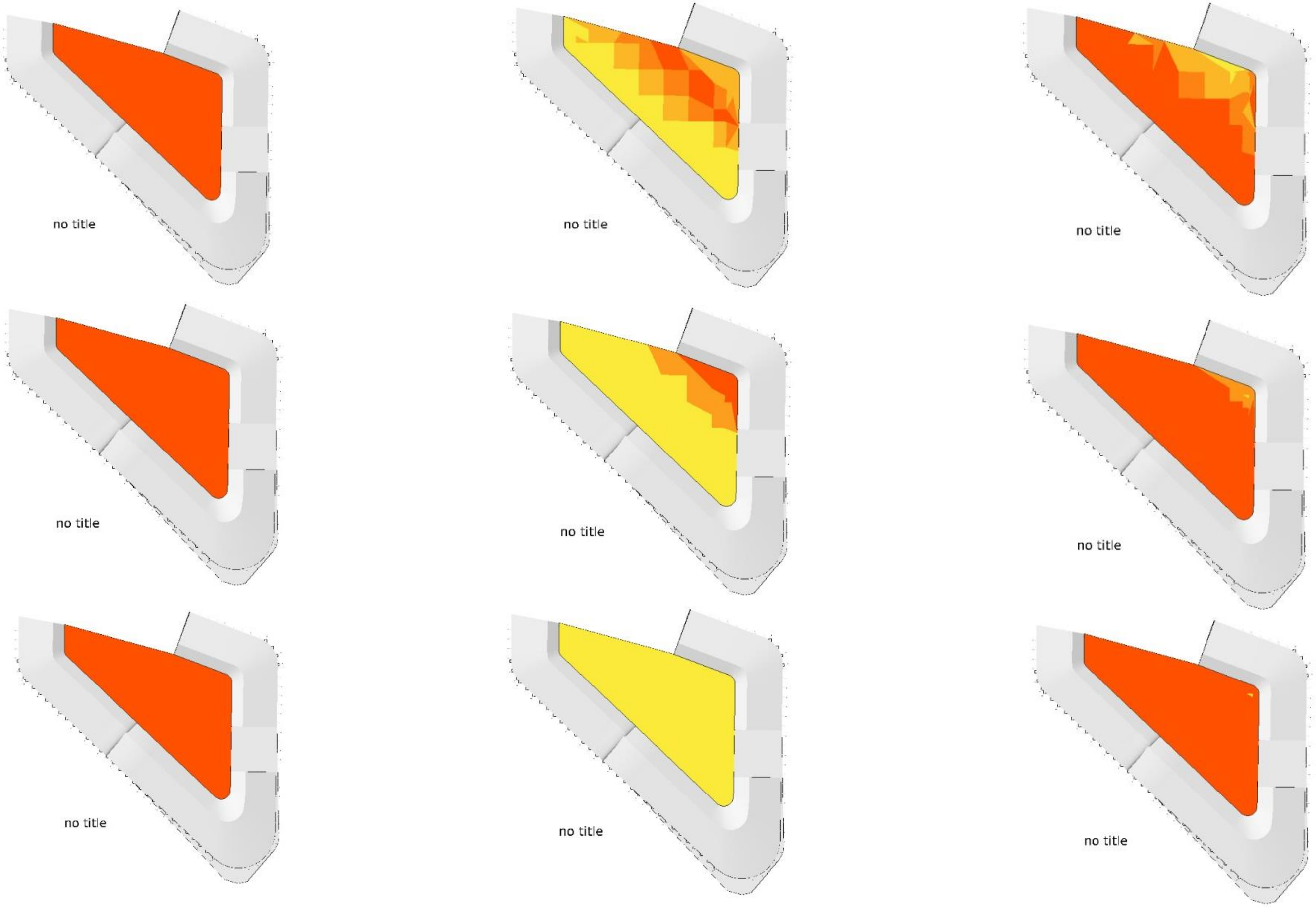
## courtyard

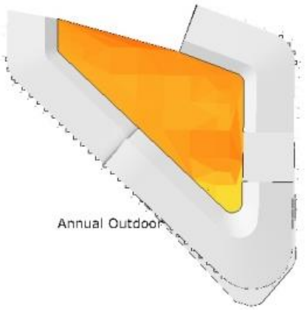
June | Sep | Dec

12-15

9-12

15-17




**Annual 55%**

*Courtyard without shade*

# Outdoor comfort

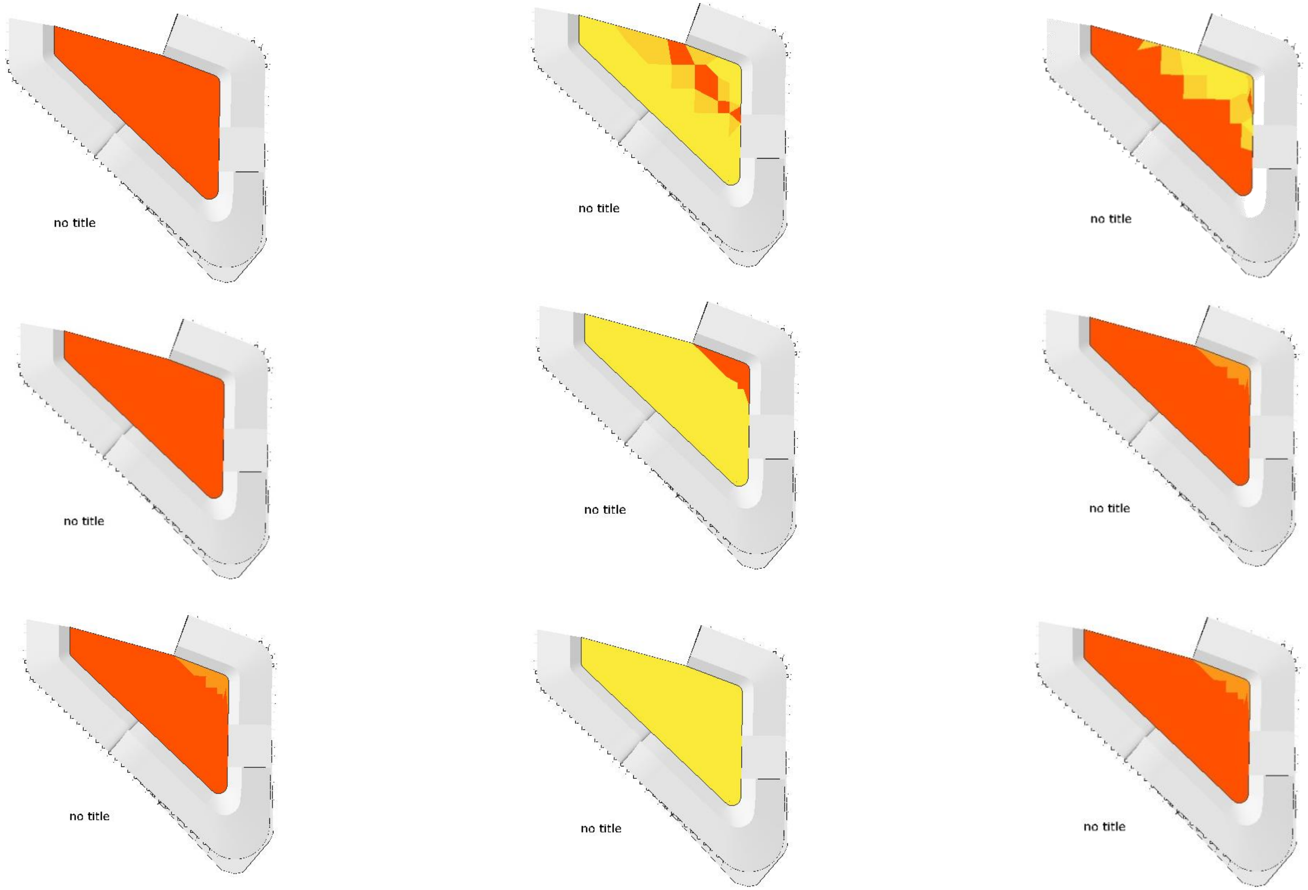
## Courtyard with shade

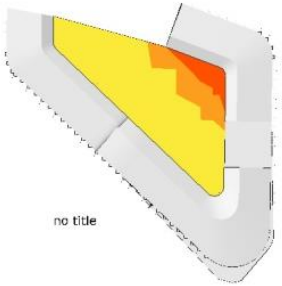
June | Sep | Dec

12-15

9-12

15-17



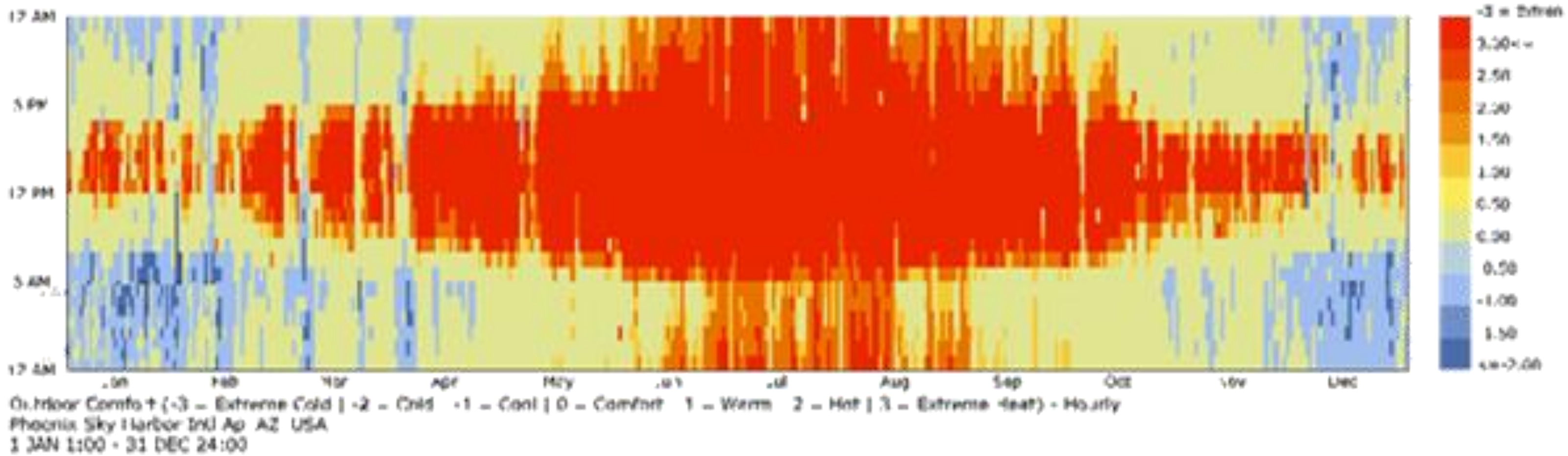




**Annual 65%**

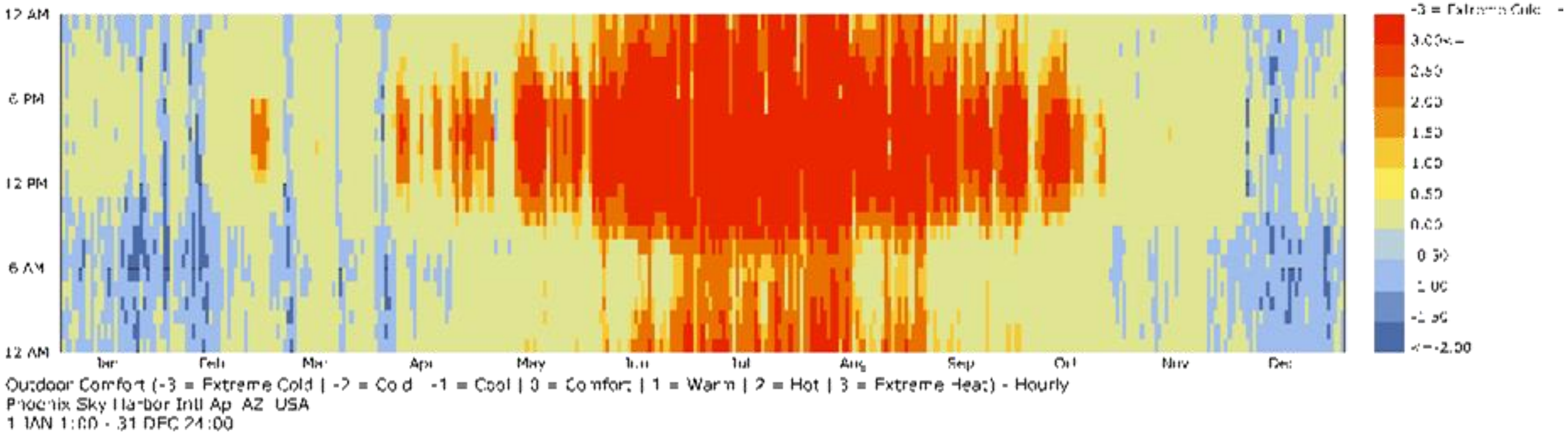
*Courtyard with shade*

# Outdoor comfort

## Why shade is not enough in summer months in outdoor comfort?




**Without Shade**

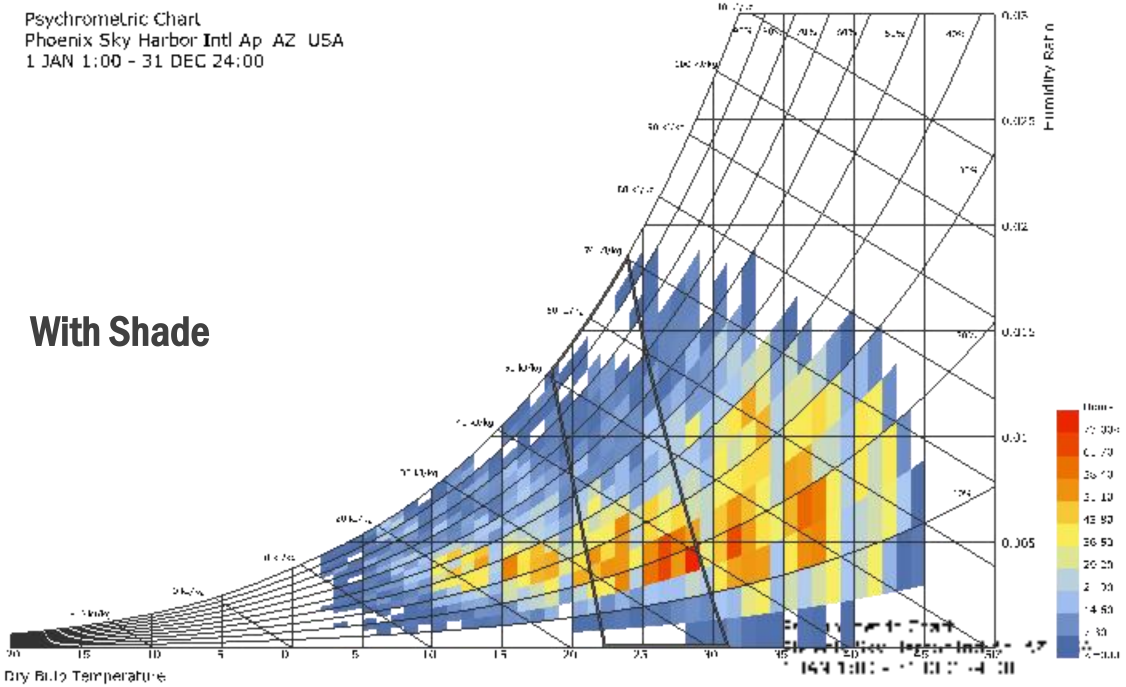



**With Shade**

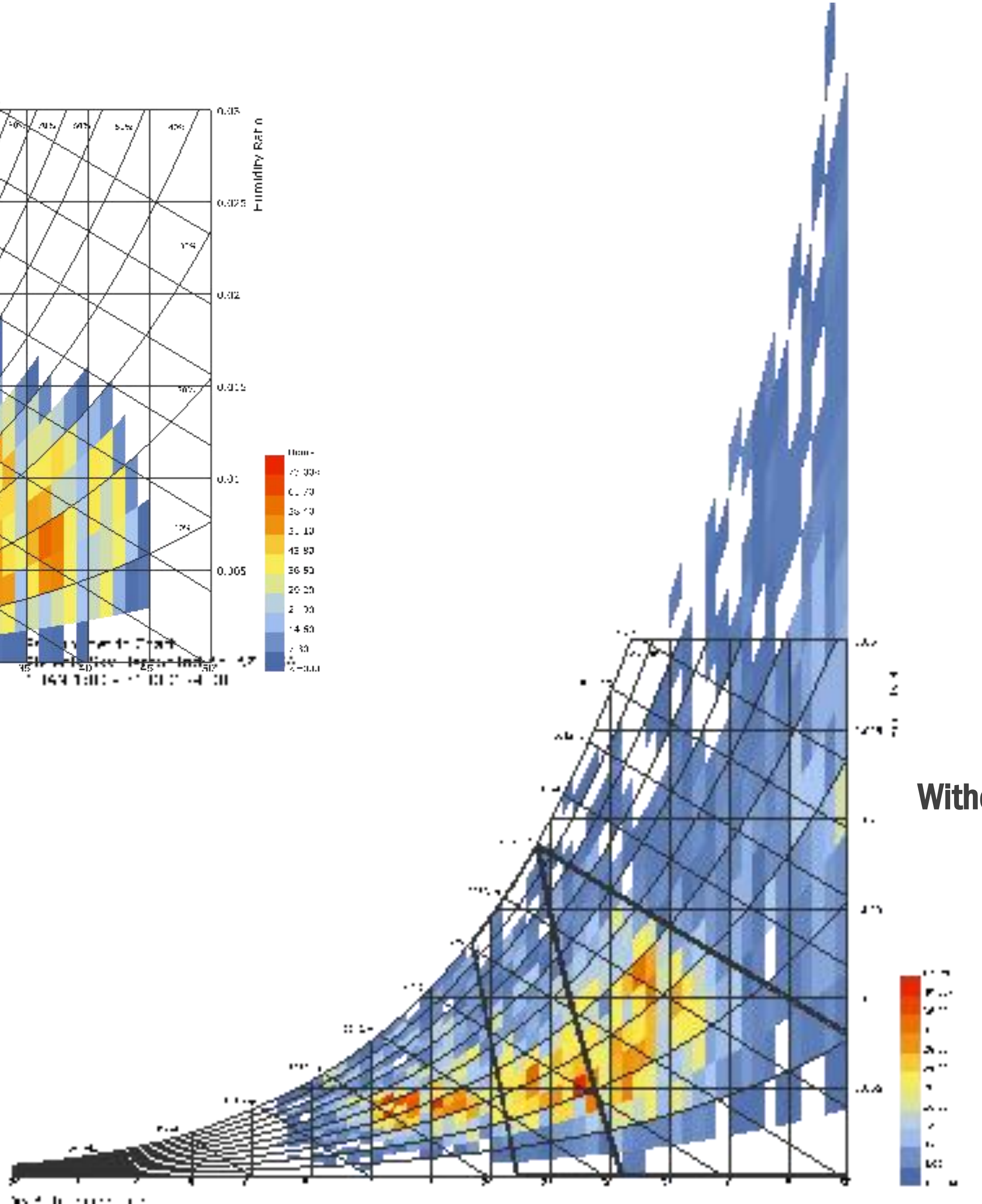
# Outdoor comfort

## Plotting comfort on Psych chart

**With Shade**



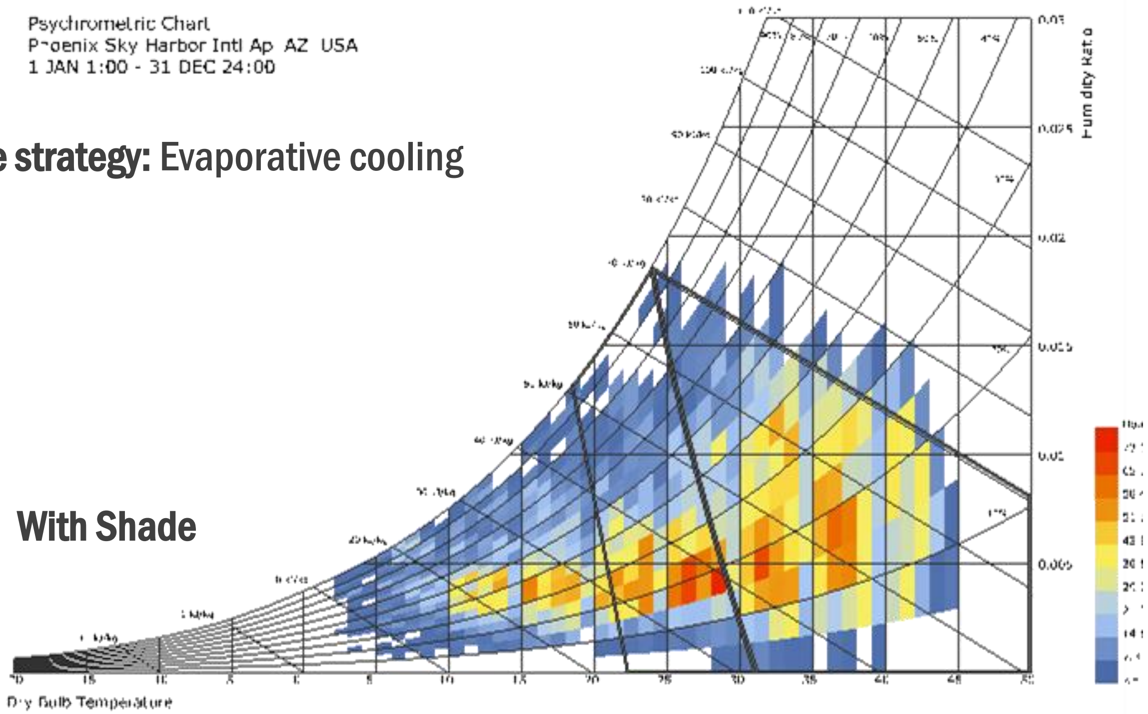

**Without Shade**



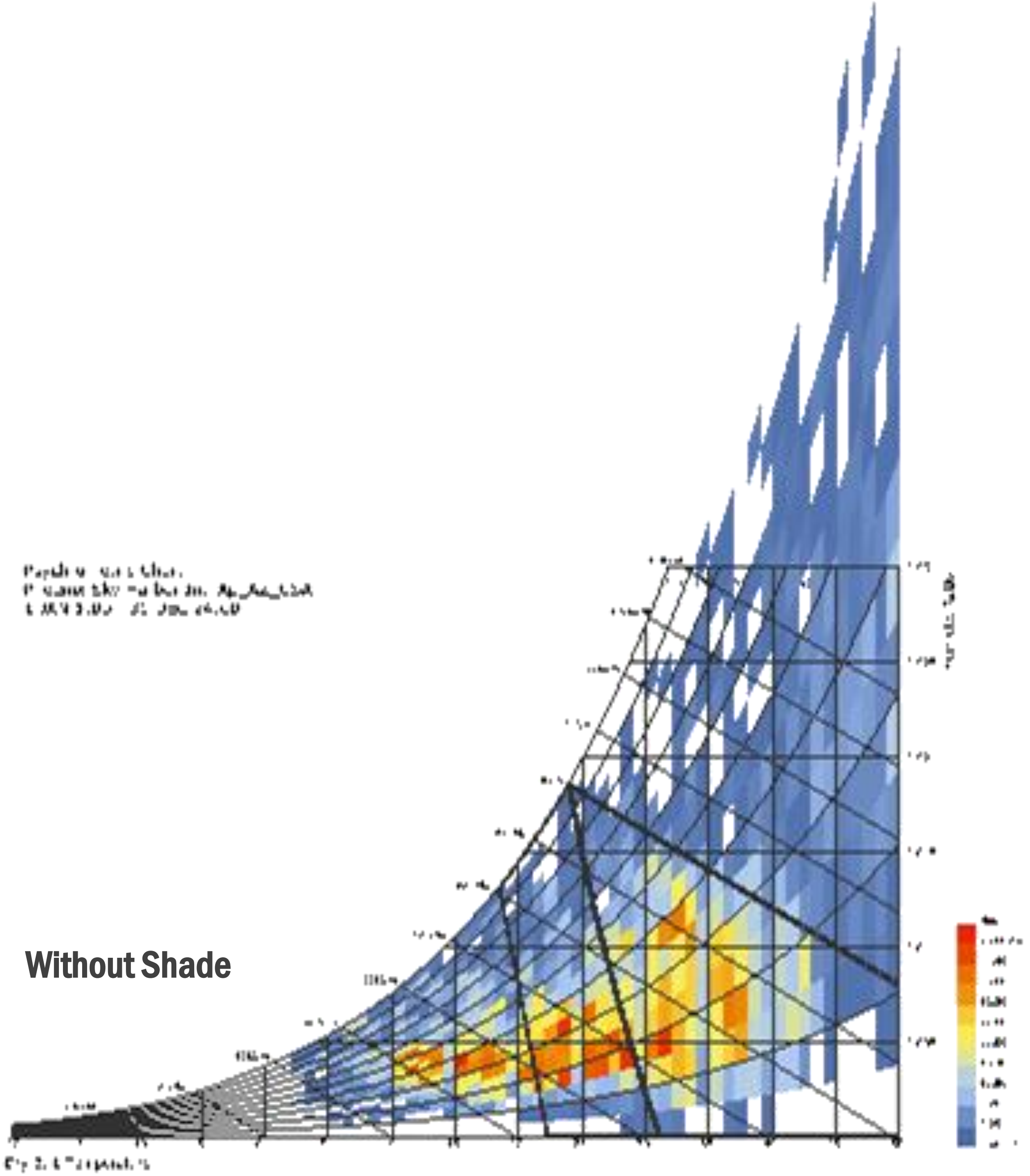
# Outdoor comfort

## Plotting comfort on Psych chart

**Passive strategy:** Evaporative cooling



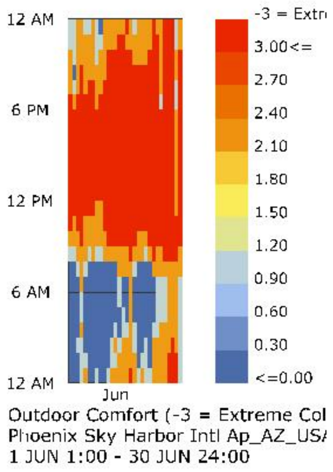

**With Shade**



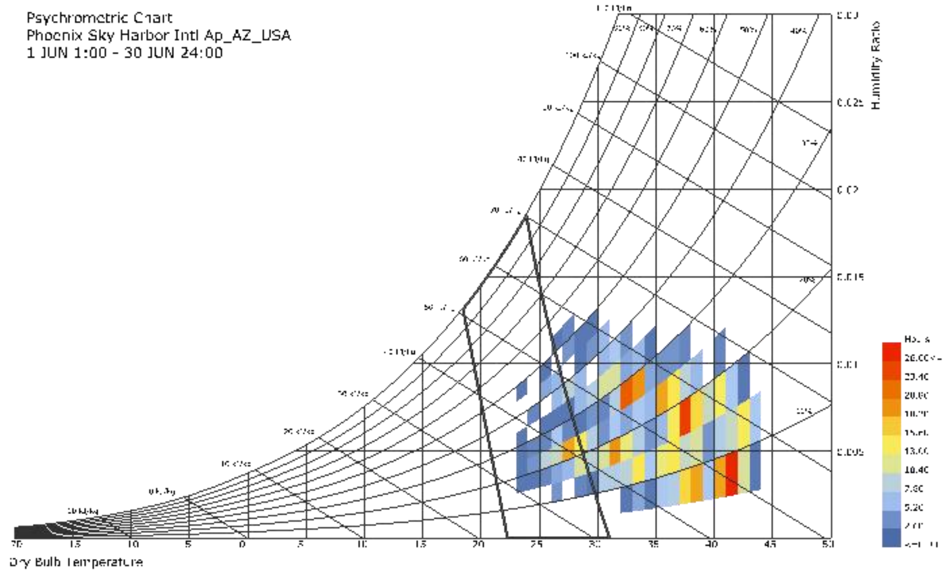
**Without Shade**

# Outdoor comfort

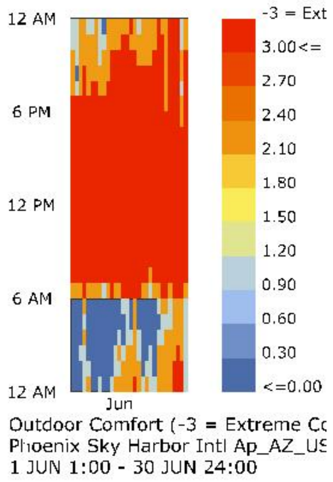
## Plotting comfort on Psych chart



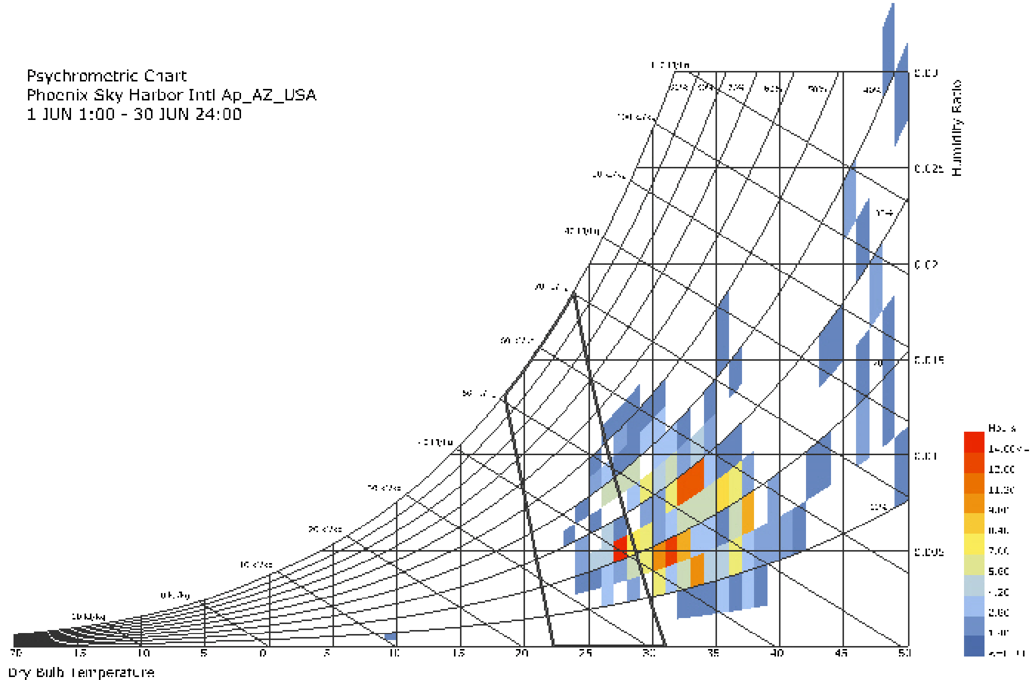

**With Shade**




**June**

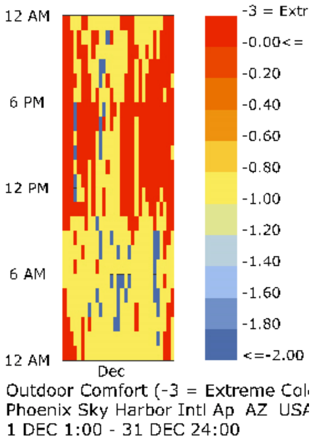



**Without Shade**

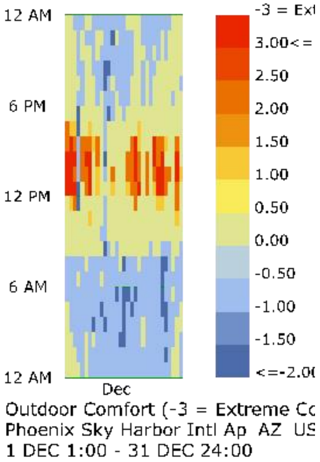


# Outdoor comfort

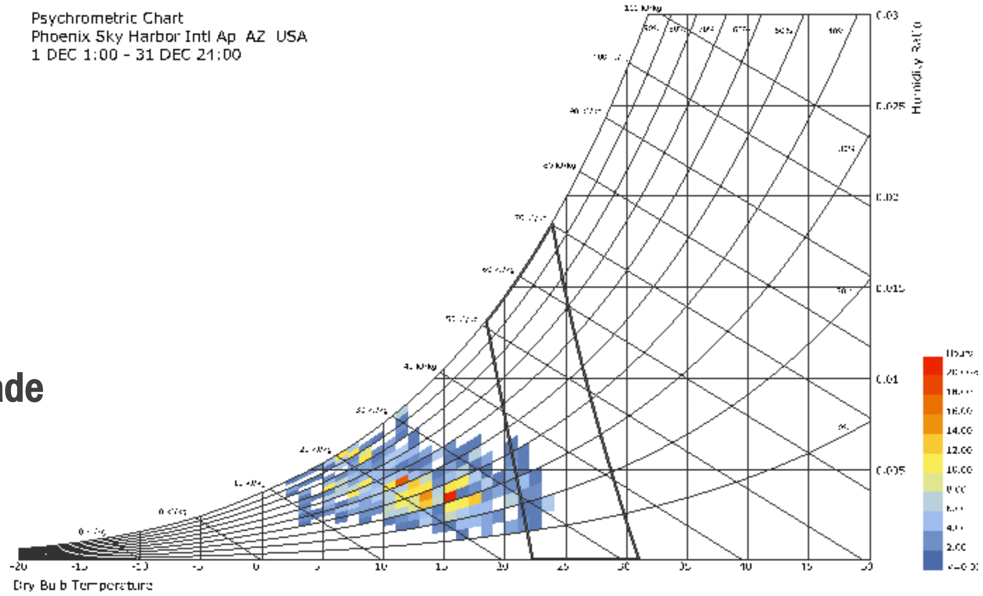
## Plotting comfort on Psych chart



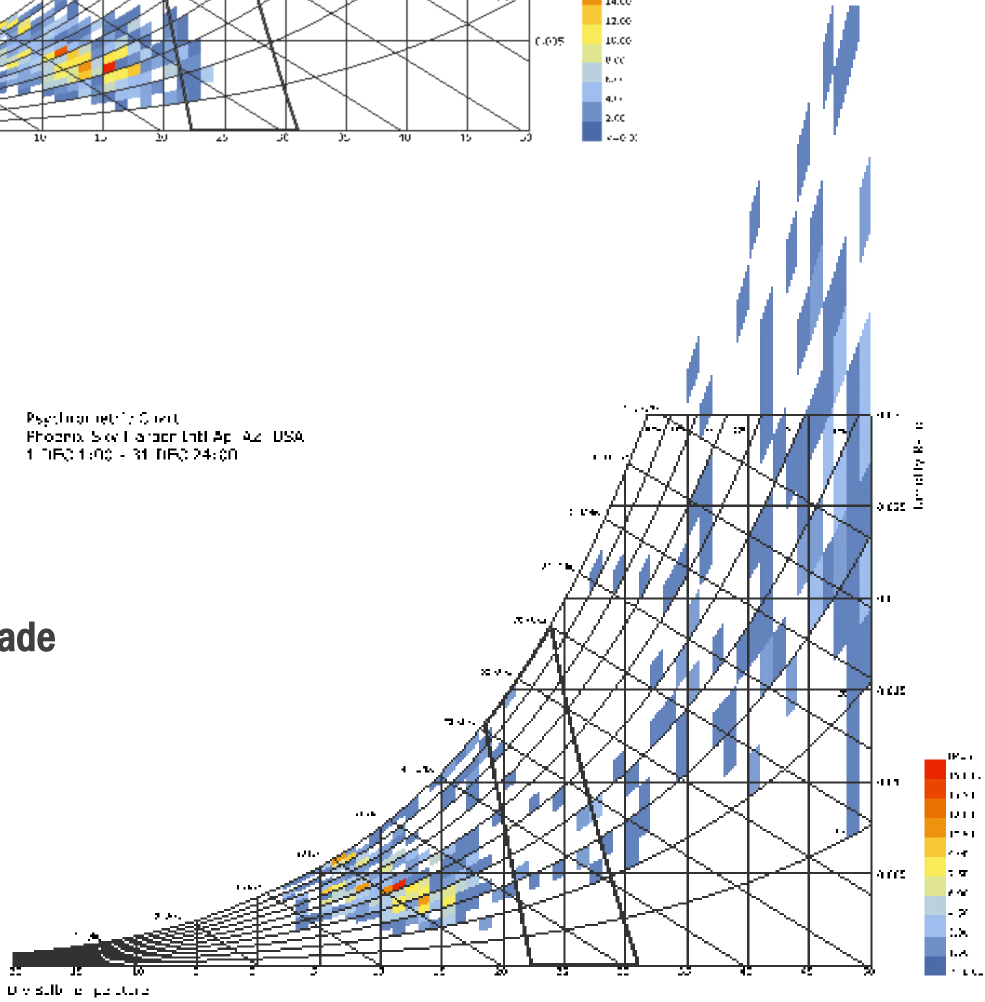

December




With Shade

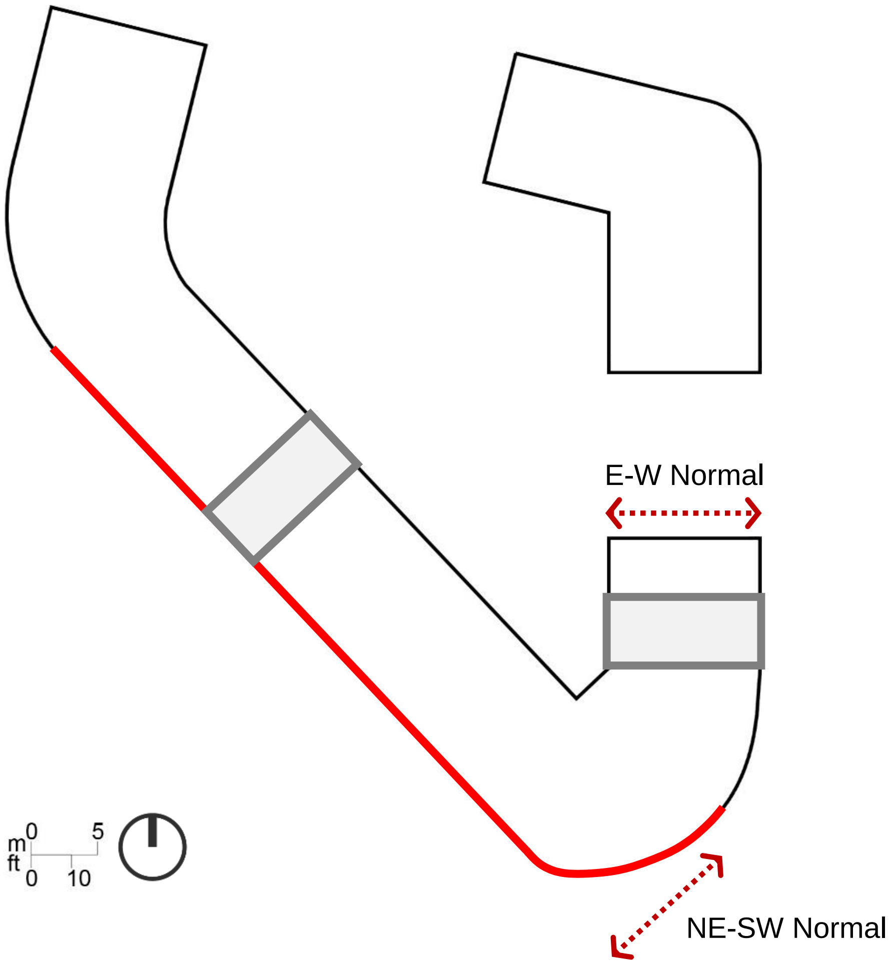


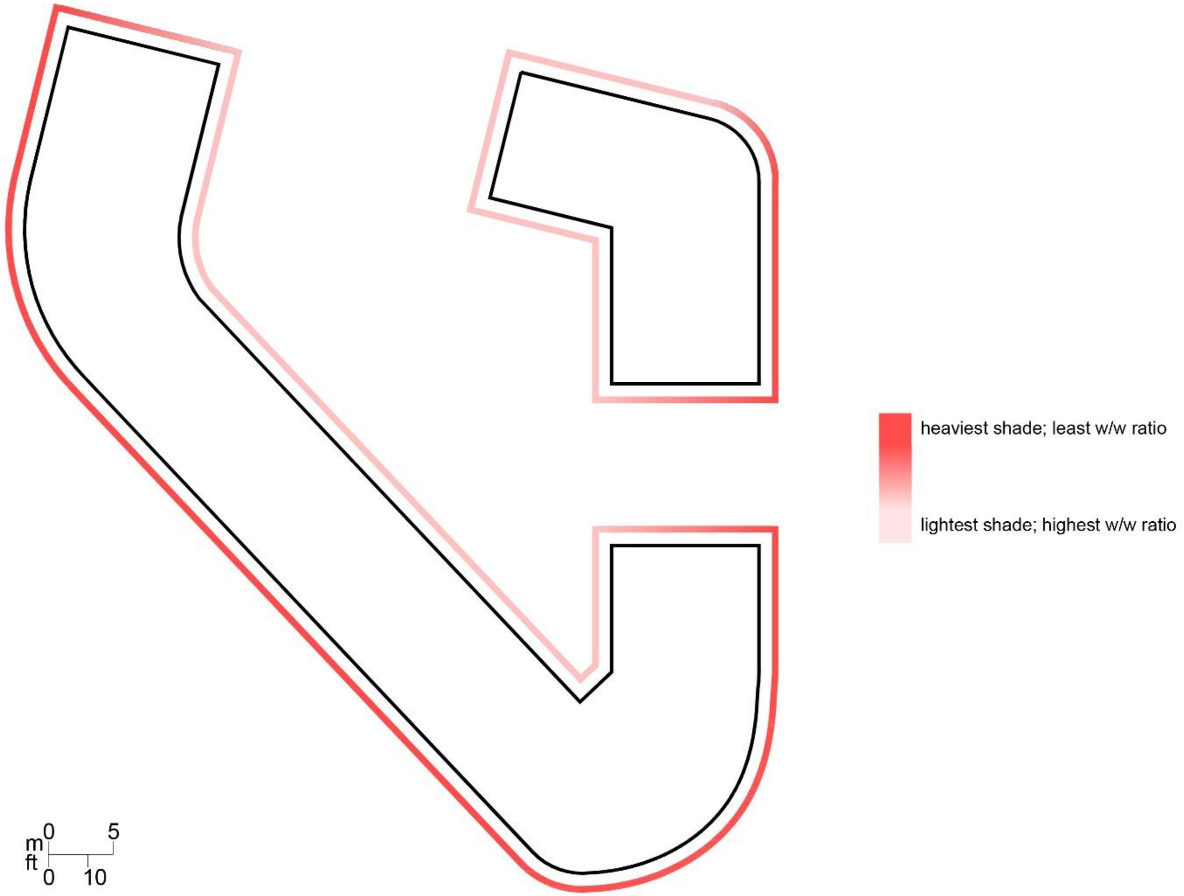

Without Shade



# Optimizing for indoor comfort

## Shade intensity graph and simulation prototype

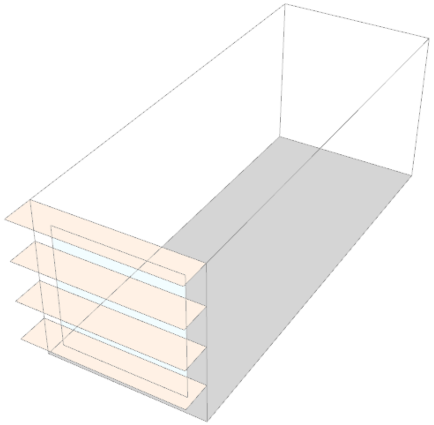


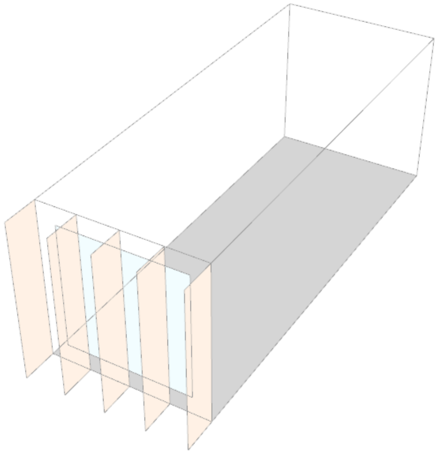

- There are predominantly two different direction normal that the building is oriented to – the NE-SW normal and the E-W normal
- For ease of simulations, a 4 m wide bay for each of the two predominant directions is used to simulate indoor comfort levels

# Optimizing for indoor comfort

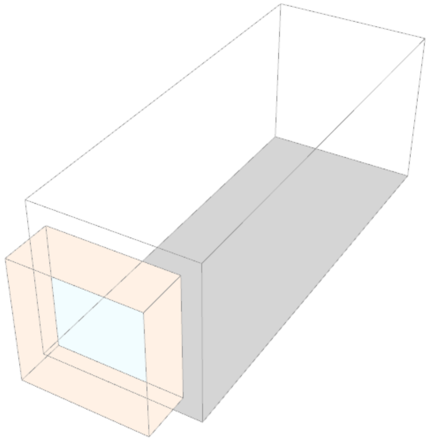
## Various shading strategies experimented with



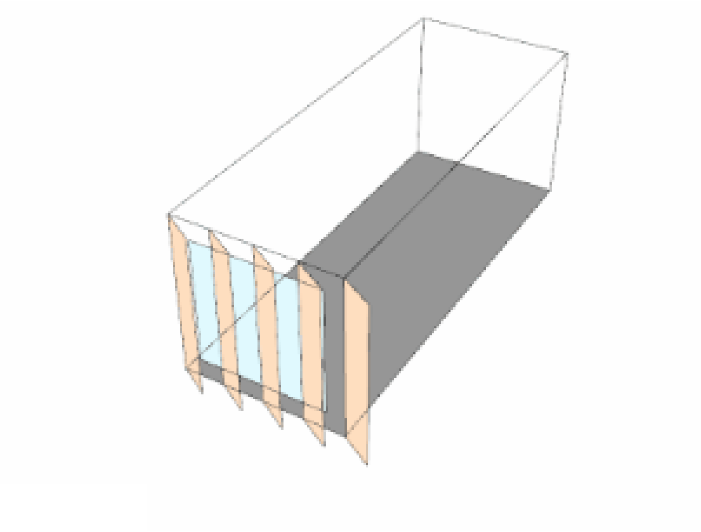
1. Louvers



2. Fins



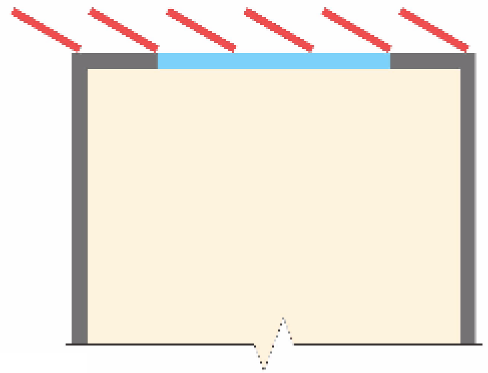
3. Box shades



**4. Dynamic fins**

# Shading strategies and WWR

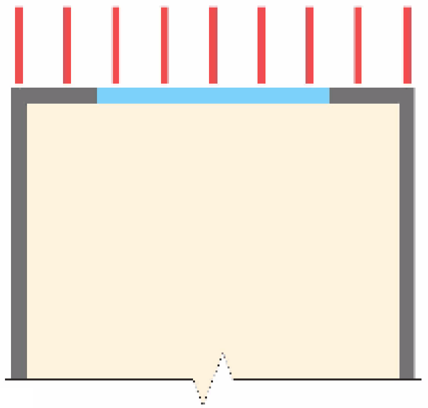
## Parameters employed to determine the optimal fins



1. Angle of fins

# Shading strategies and WWR

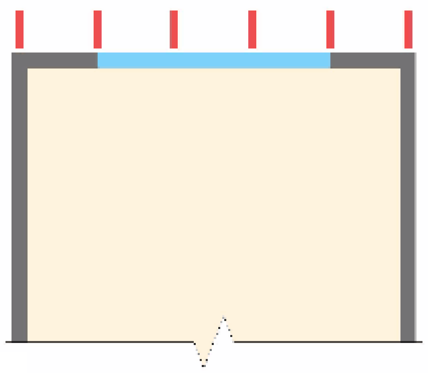
## Parameters employed to determine the optimal fins



2. Distance between the fins

# Shading strategies and WWR

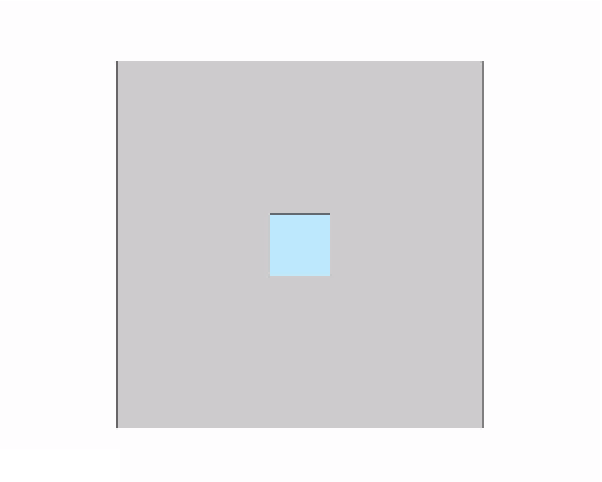
## Parameters employed to determine the optimal fins



3. Depth of fins

# Shading strategies and WWR

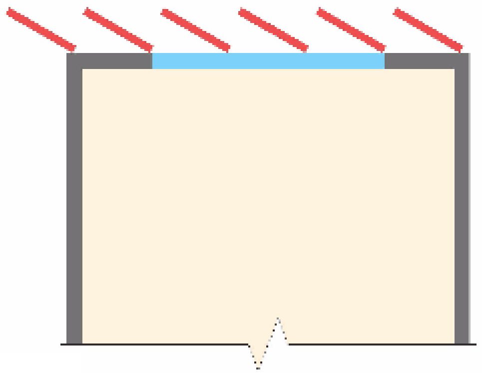
## Parameters employed to determine the optimal fins



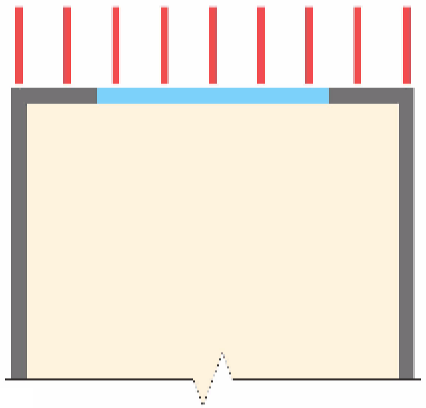
4. Window/ wall ratio

# Shading strategies and WWR

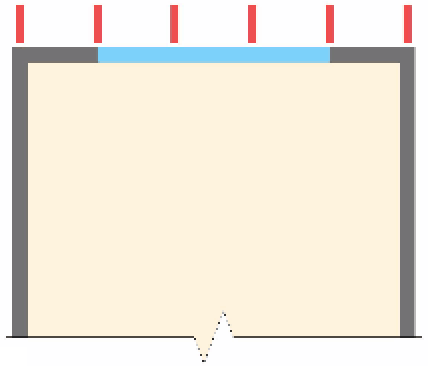
## Parameters employed to determine the optimal fins



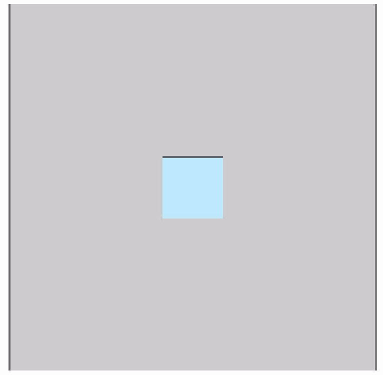
1. Angle of fins



2. Distance between the fins



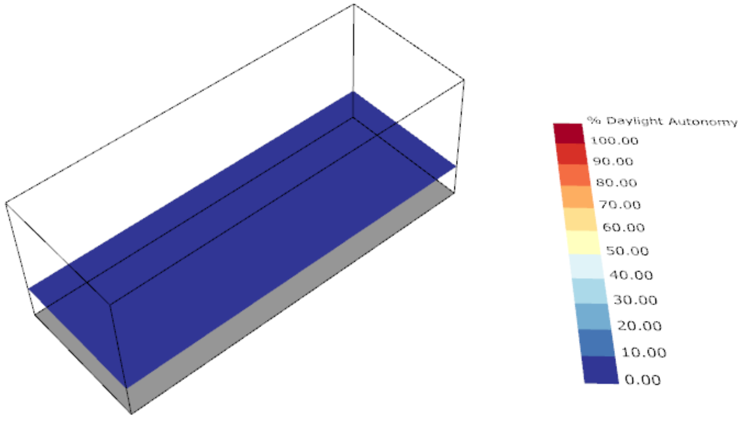
3. Depth of fins



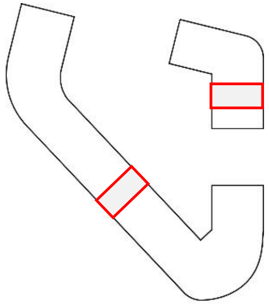
4. Window/ wall ratio

# Indoor comfort

## Establishing a base case



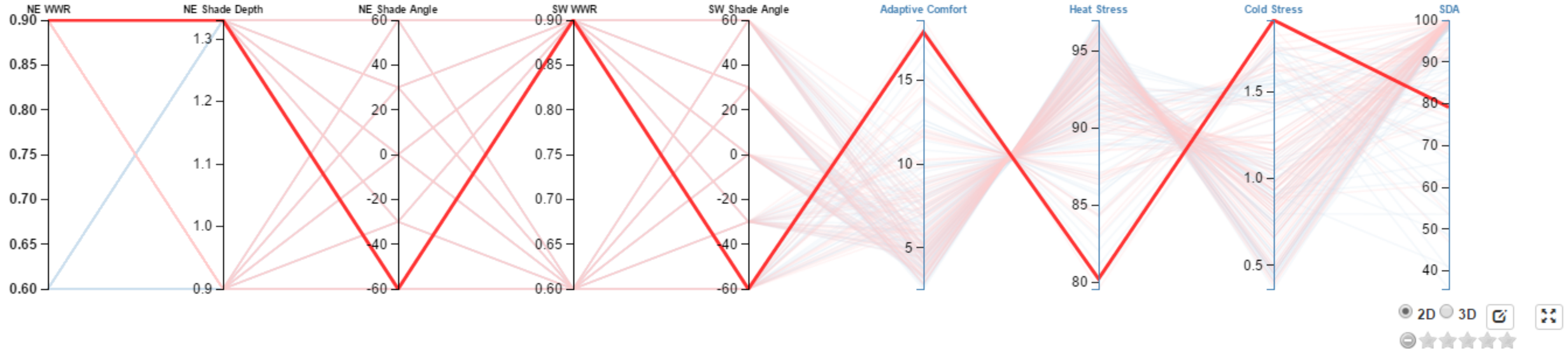

Adaptive comfort: 38.139269% | sDA: 0.00

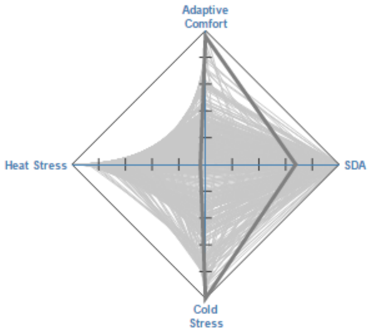


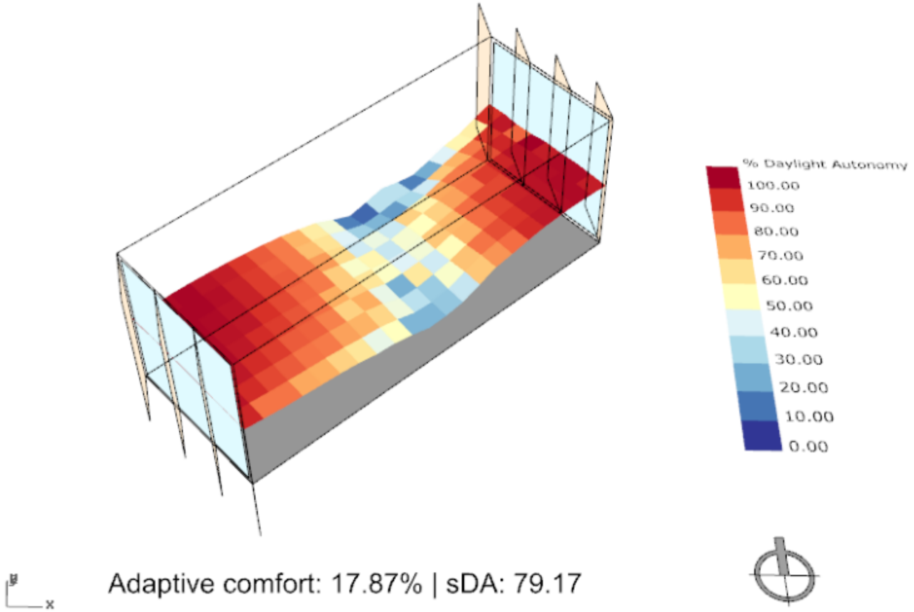
- Establish a base case in the SW-NE normal, the most heated and critical direction, check the level of comfort without any heating by radiation

# Indoor comfort

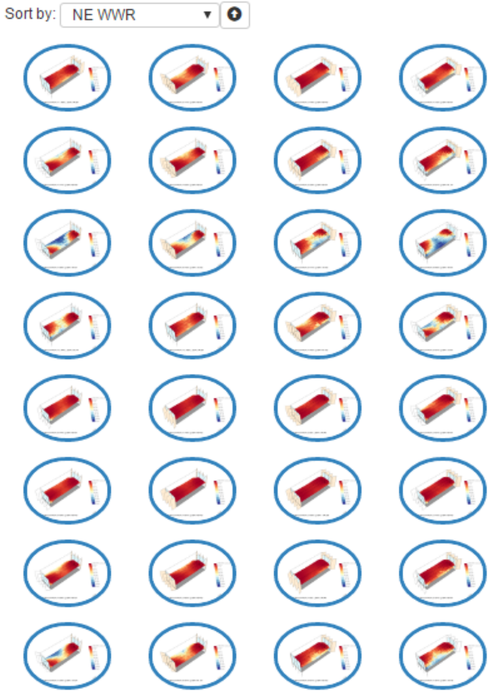
## Determining the best parameters – NE-SW normal



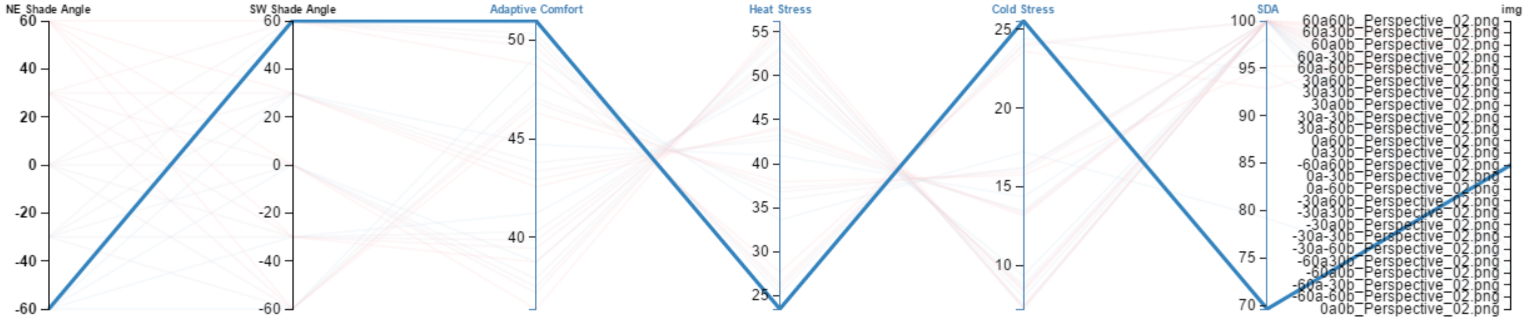

Adaptive comfort: 17.87% | sDA: 79.17

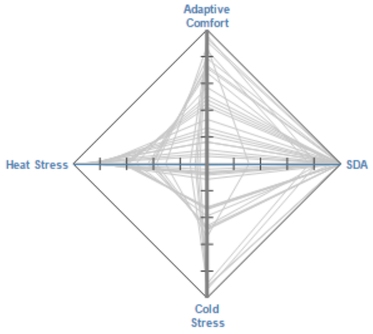


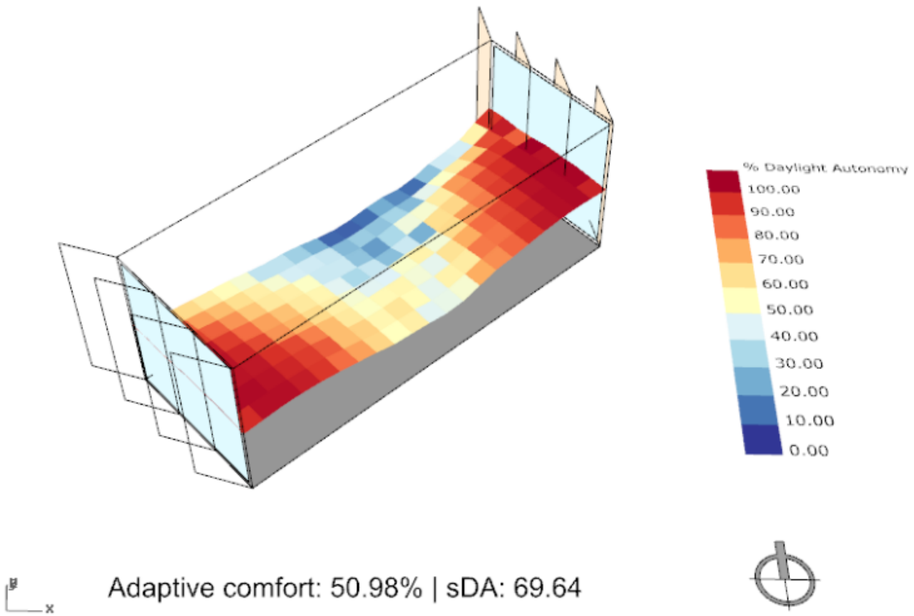

- **The best shading parameters and window/wall ratio are decided based on the adaptive comfort and daylight autonomy parameters of the summer months**

# Indoor comfort

## Determining the best parameters – NE-SW normal



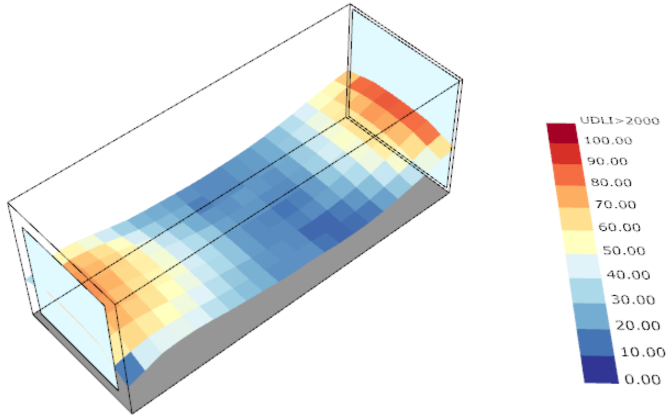




Adaptive comfort: 50.98% | sDA: 69.64

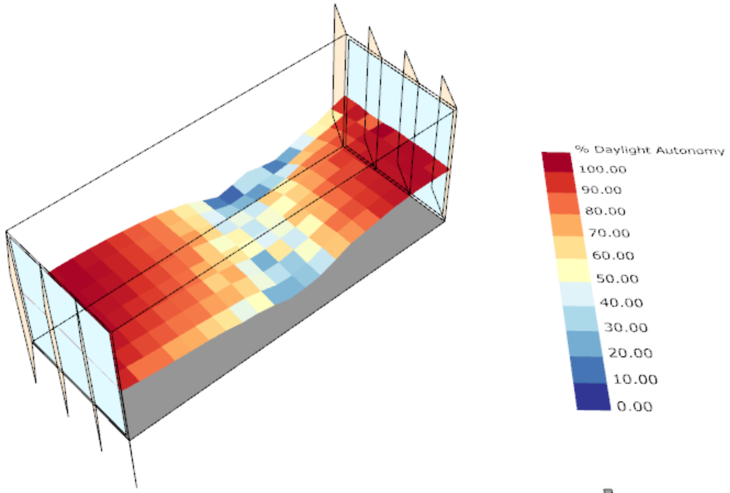

- The best shading parameters and window/wall ratio are decided based on the adaptive comfort and daylight autonomy parameters of the summer months
- Once the ideal WWR and the fin depth are decided, a simulation for the winter months informs the ideal fin angle for best comfort

# Indoor comfort

## Comparing results

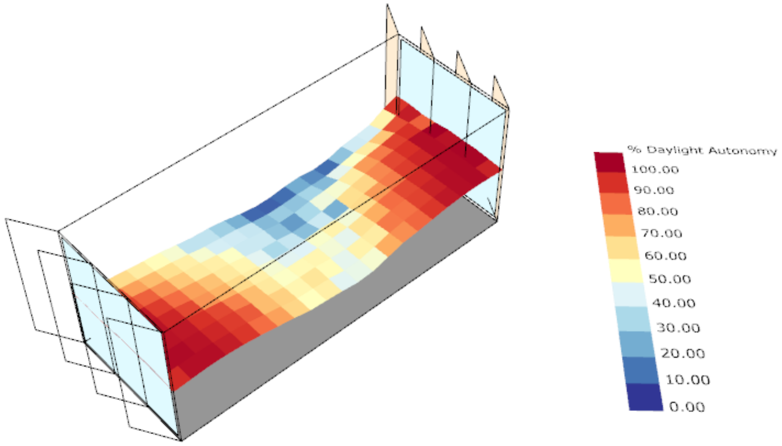



Adaptive comfort: 13.755708% | sDA: 100.00




Adaptive comfort: 17.87% | sDA: 79.17

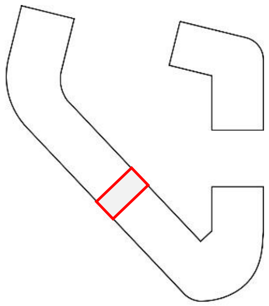
Summer




Adaptive comfort: 50.98% | sDA: 69.64

Winter

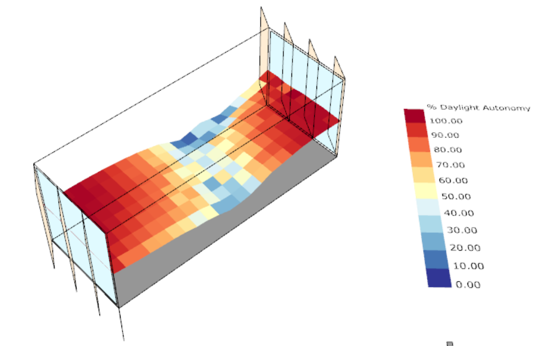
Average annual adaptive comfort: **34.45%**



- **Establish a base case in the SW-NE normal, the most heated and critical direction, check the level of comfort without any heating by radiation**
- **Check the increase in comfort based exclusively on shading: an increase of 20.7%**

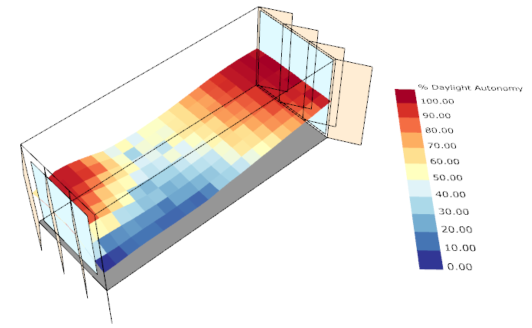
# Indoor comfort

## Various results and observations



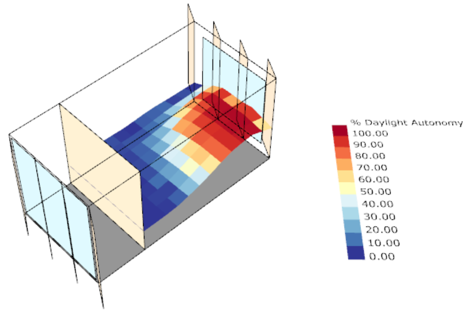

Adaptive comfort: 17.87% | sDA: 79.17

Summer



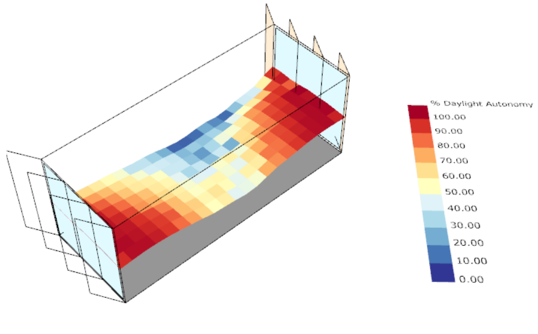

Adaptive comfort: 14.14% | sDA: 62.50

Summer



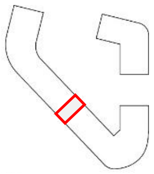

Adaptive comfort: 18.4% | sDA: 32.65

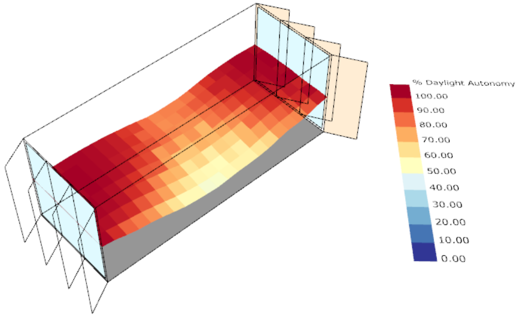
Summer




Adaptive comfort: 50.98% | sDA: 69.64

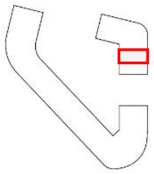
Winter

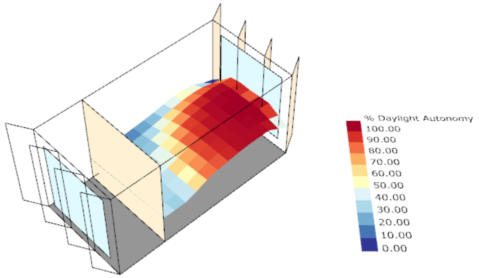





Adaptive comfort: 50.87% | sDA: 98.81

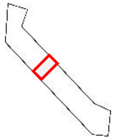
Winter





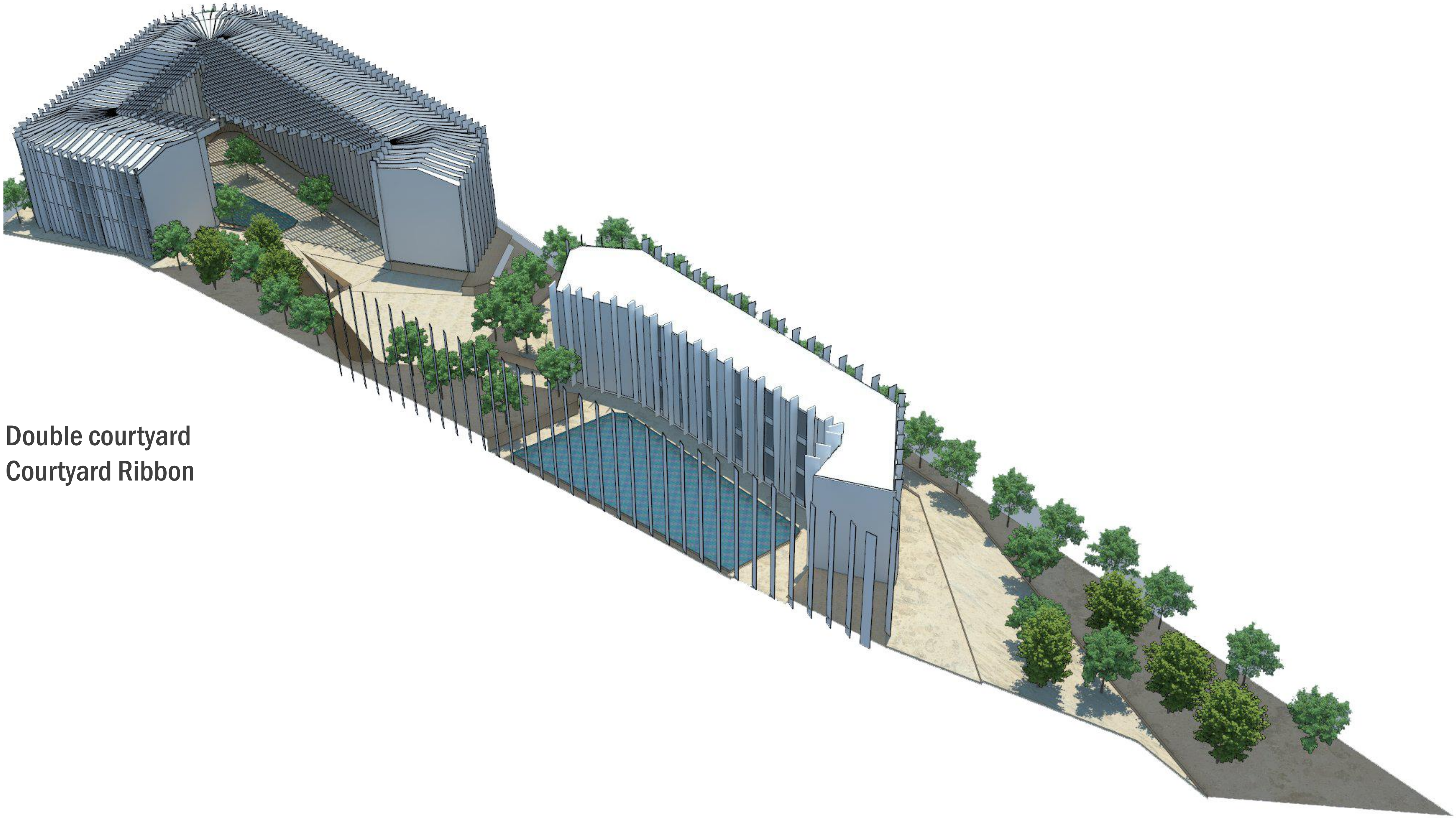

Adaptive comfort: 36.81% | sDA: 56.12

Winter



- A higher window/wall ratio to harness more daylight is feasible as long as the glazing is shaded.
- There is a clear trade-off between daylight and comfort autonomy, which can be partially addressed if the shades are dynamic
- Cross ventilation increases indoor comfort as long as the ventilation is controlled and subject to a comfortable outdoor temperature

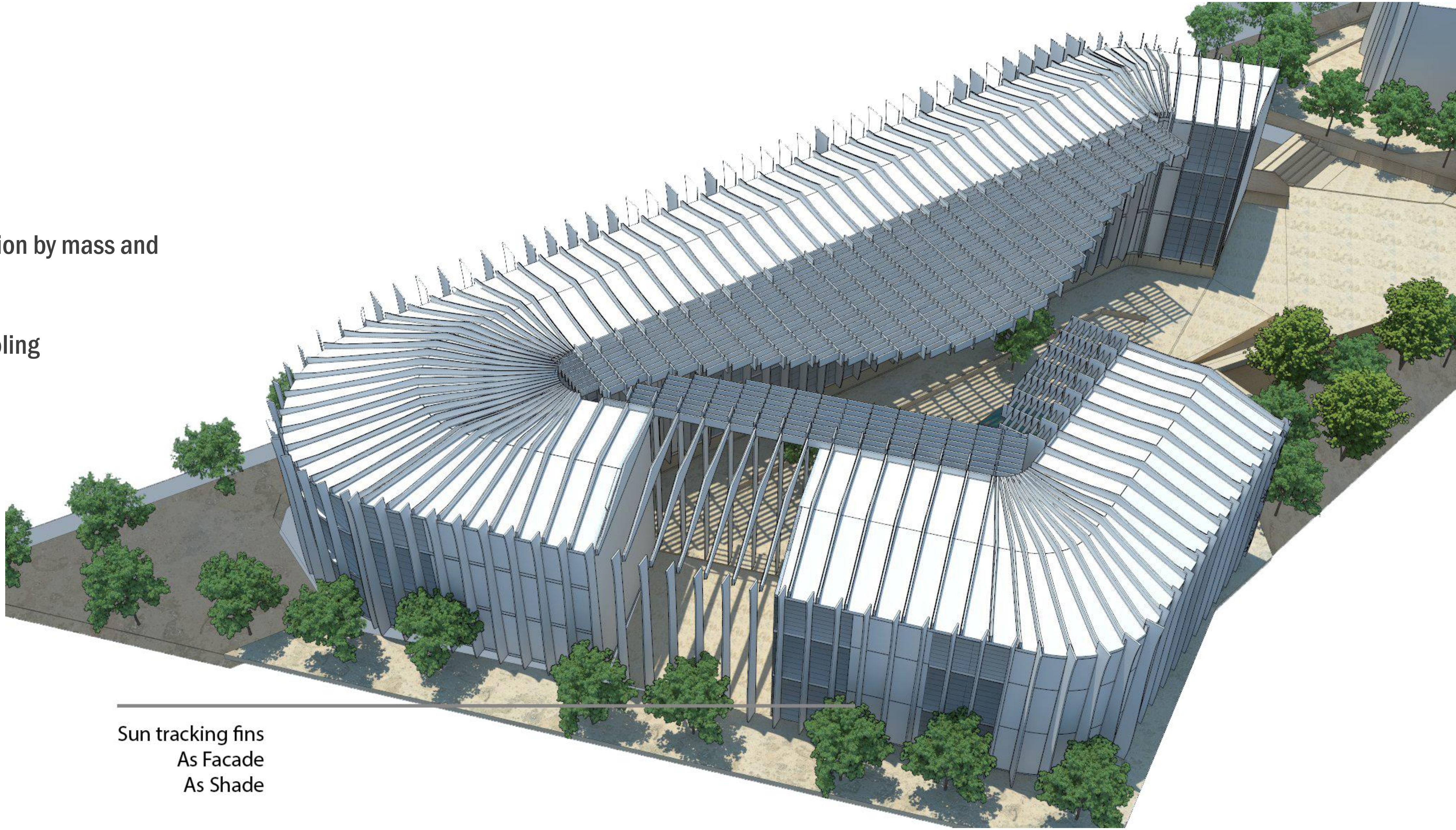
# Design details



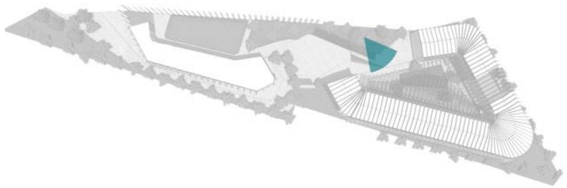
Double courtyard
Courtyard Ribbon

# Design details

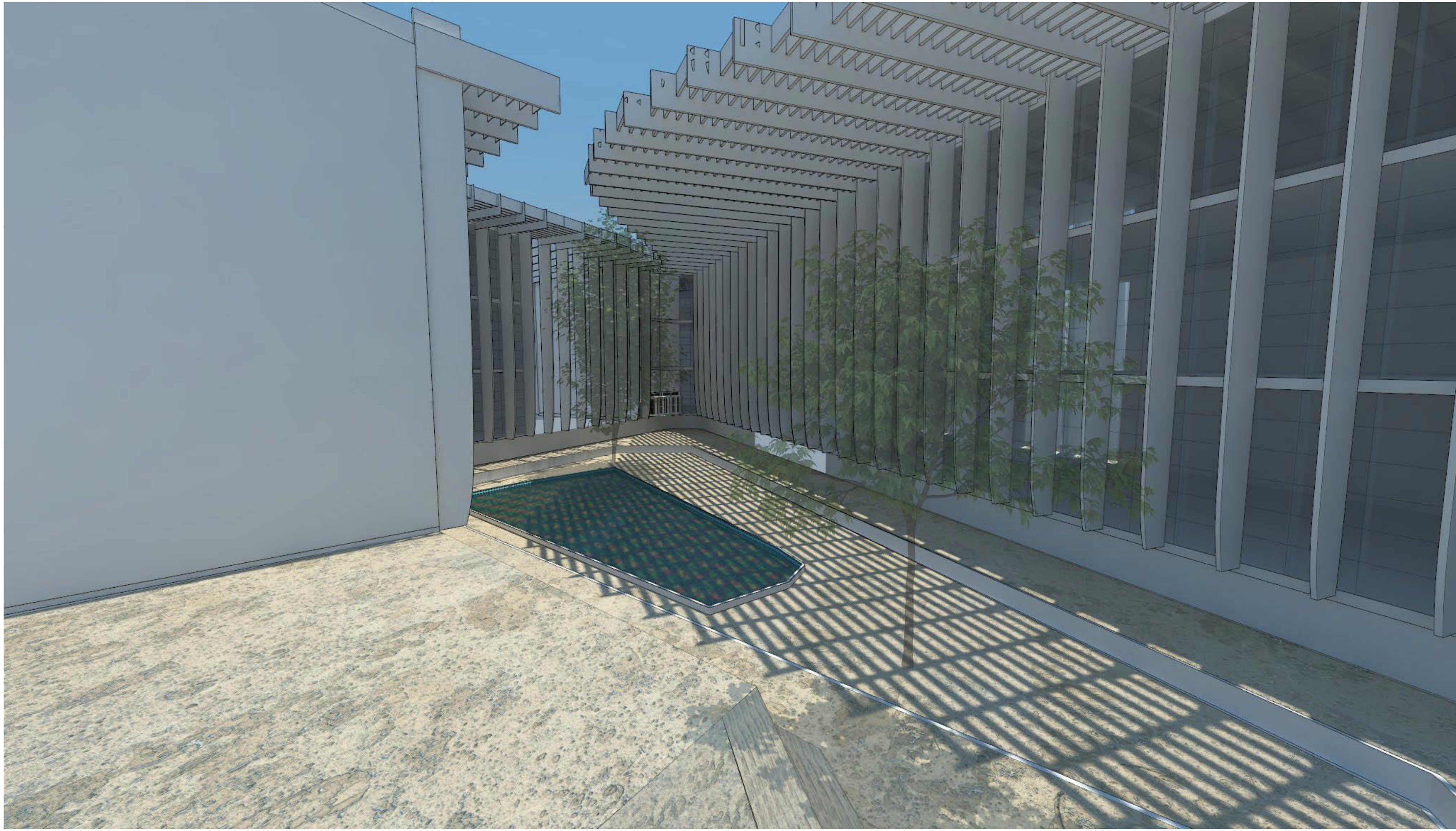
- Blocking radiation by mass and shade
- Microclimate
- Evaporative cooling



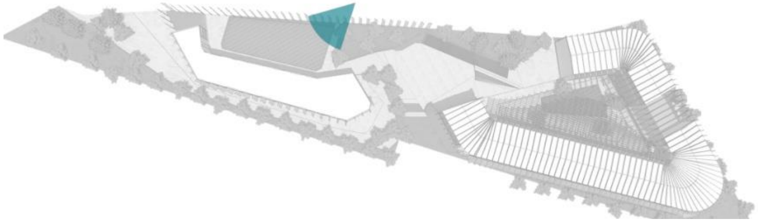
# Design details



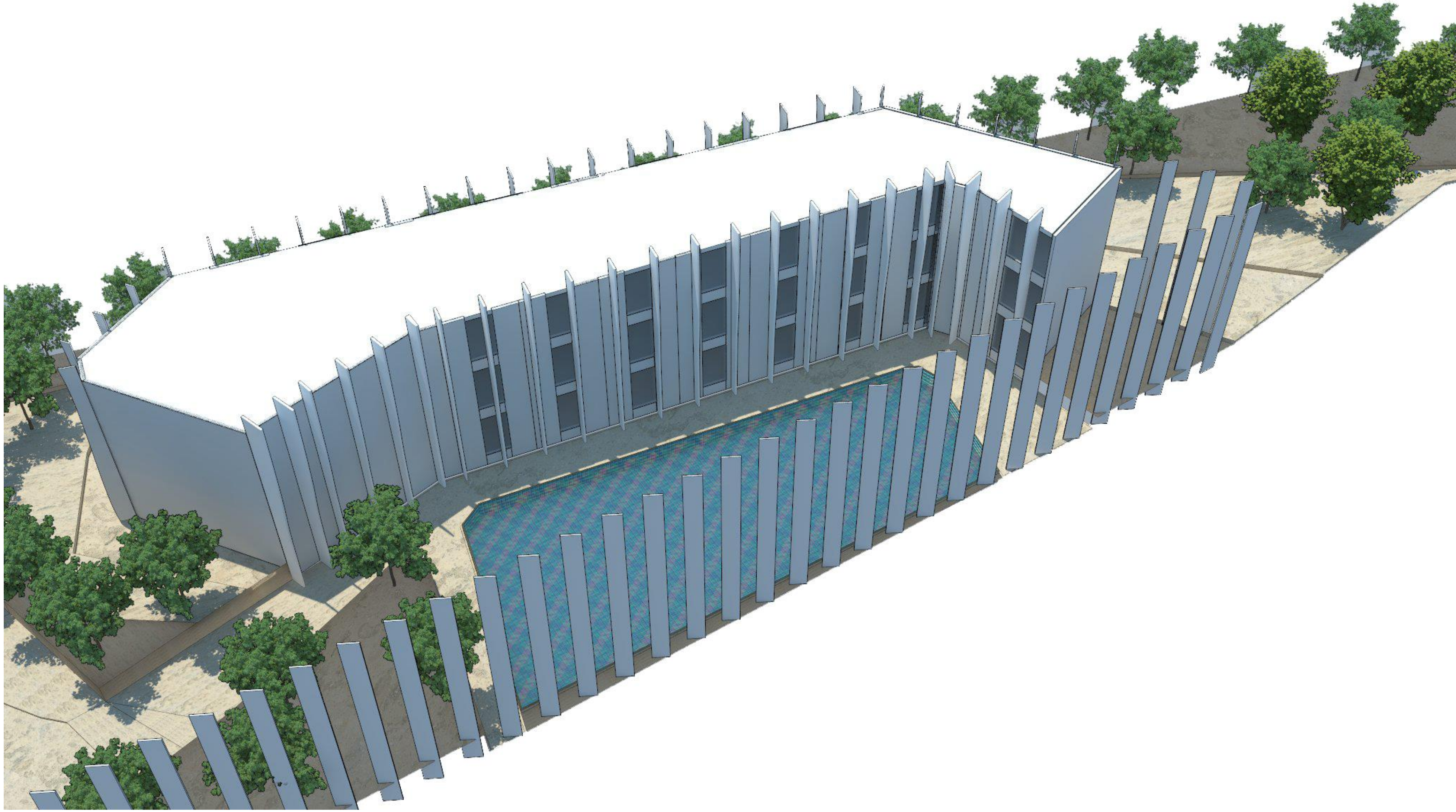
Cooling down the air in outdoor space by Microclimate



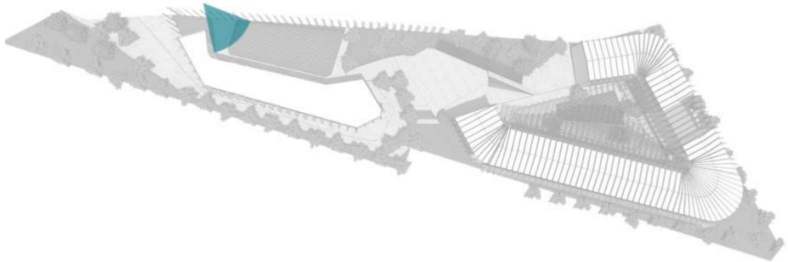
# Design details



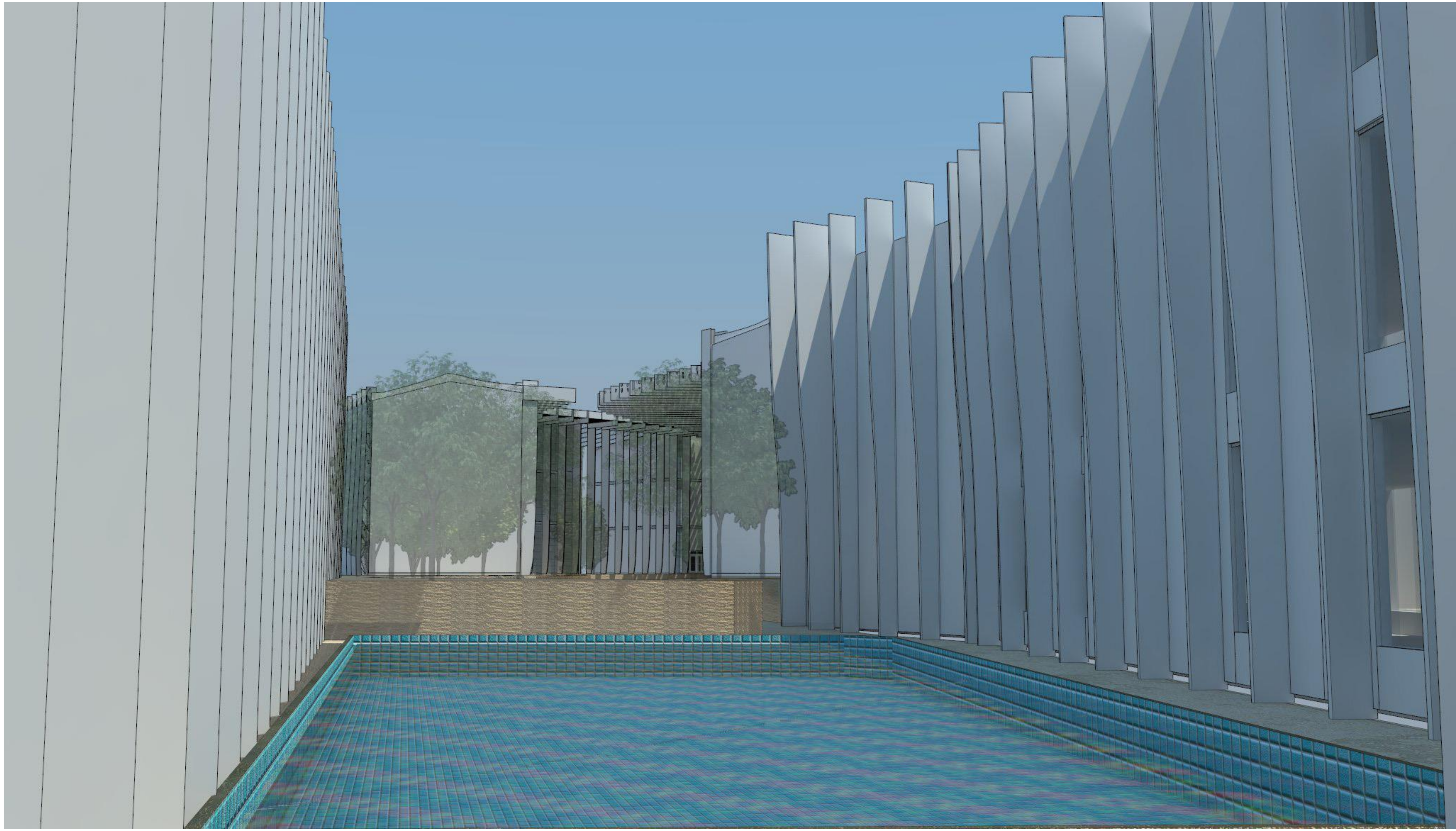
Fins Spraying water and enclosing and shading the residential courtyard



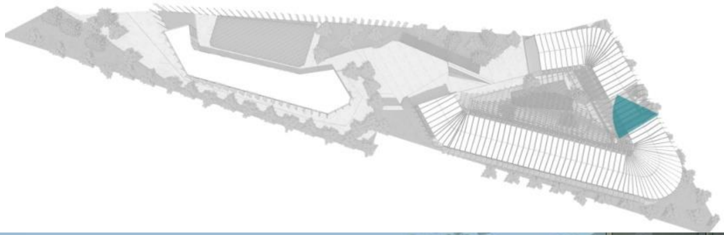
# Design details

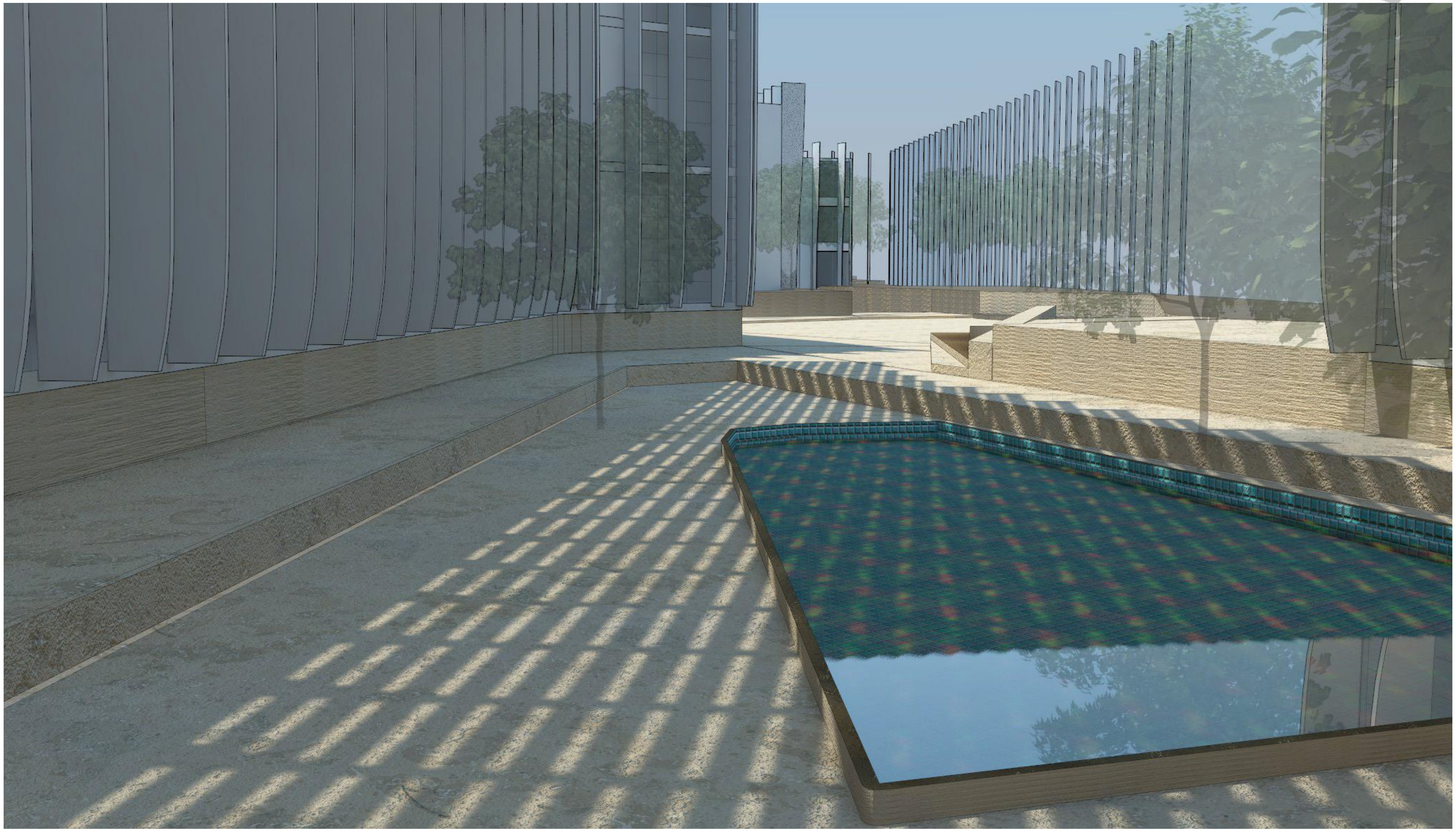


Private residential courtyard



# Design details

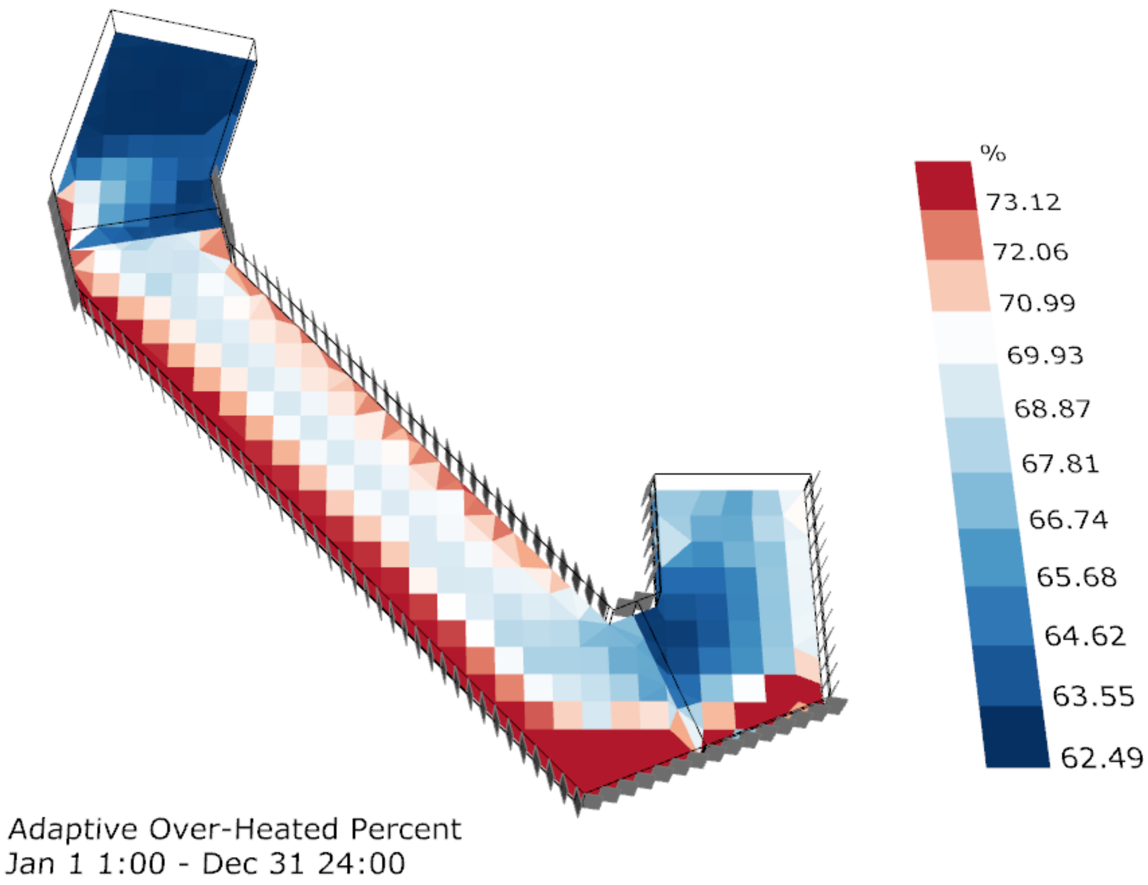


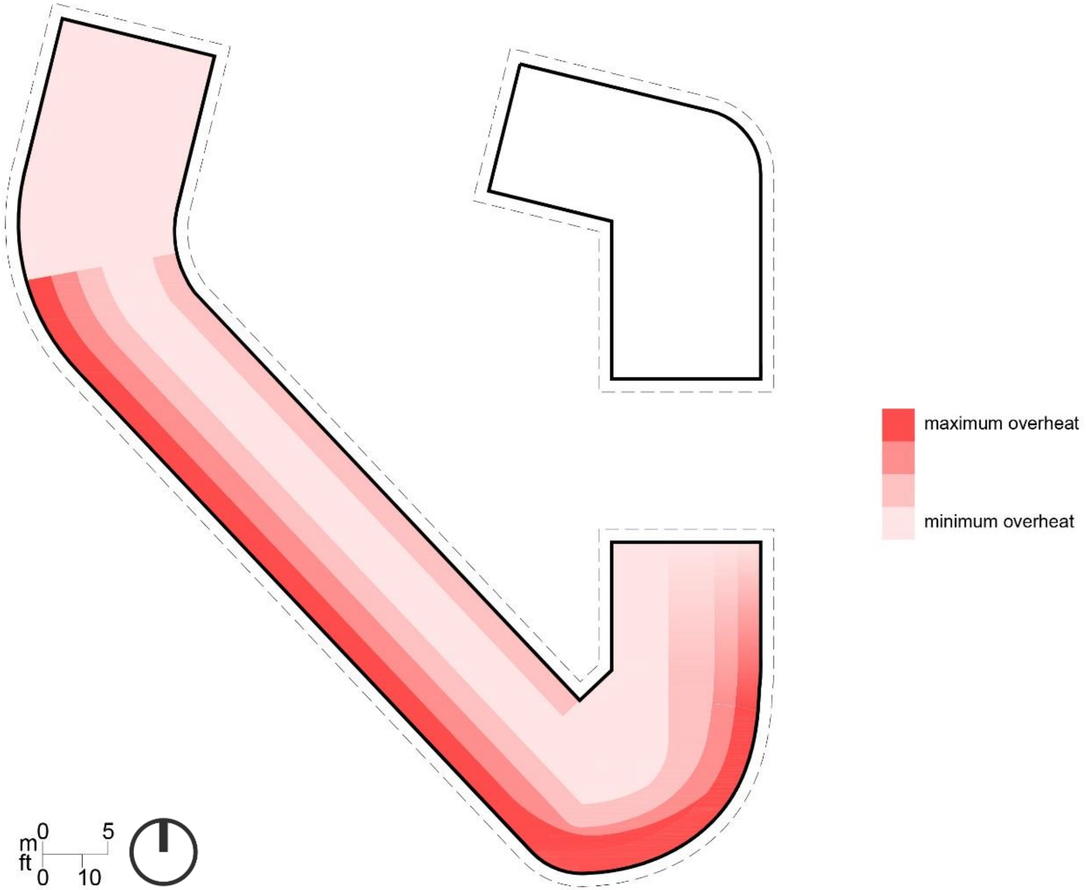


Considering privacy for the residential courtyard by site design and blocks locating

# Formulating the indoor layout

## Applying the outcome of the determined fins

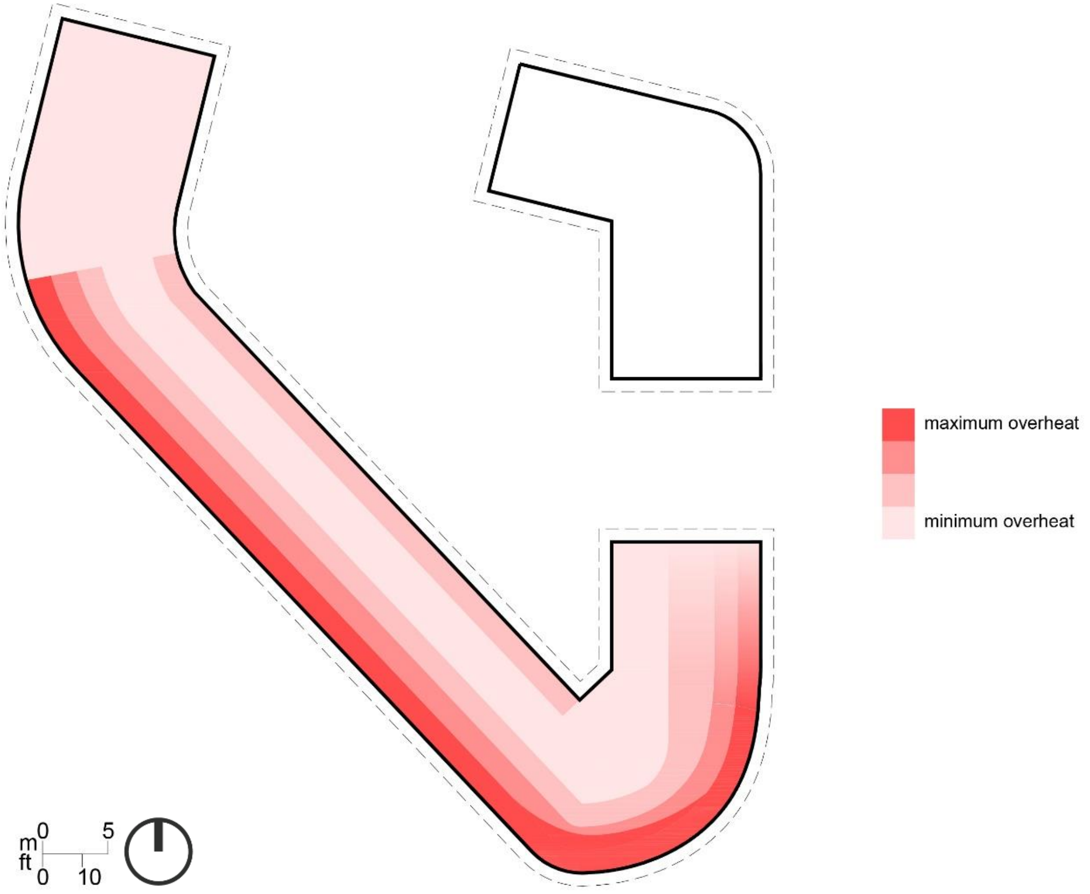


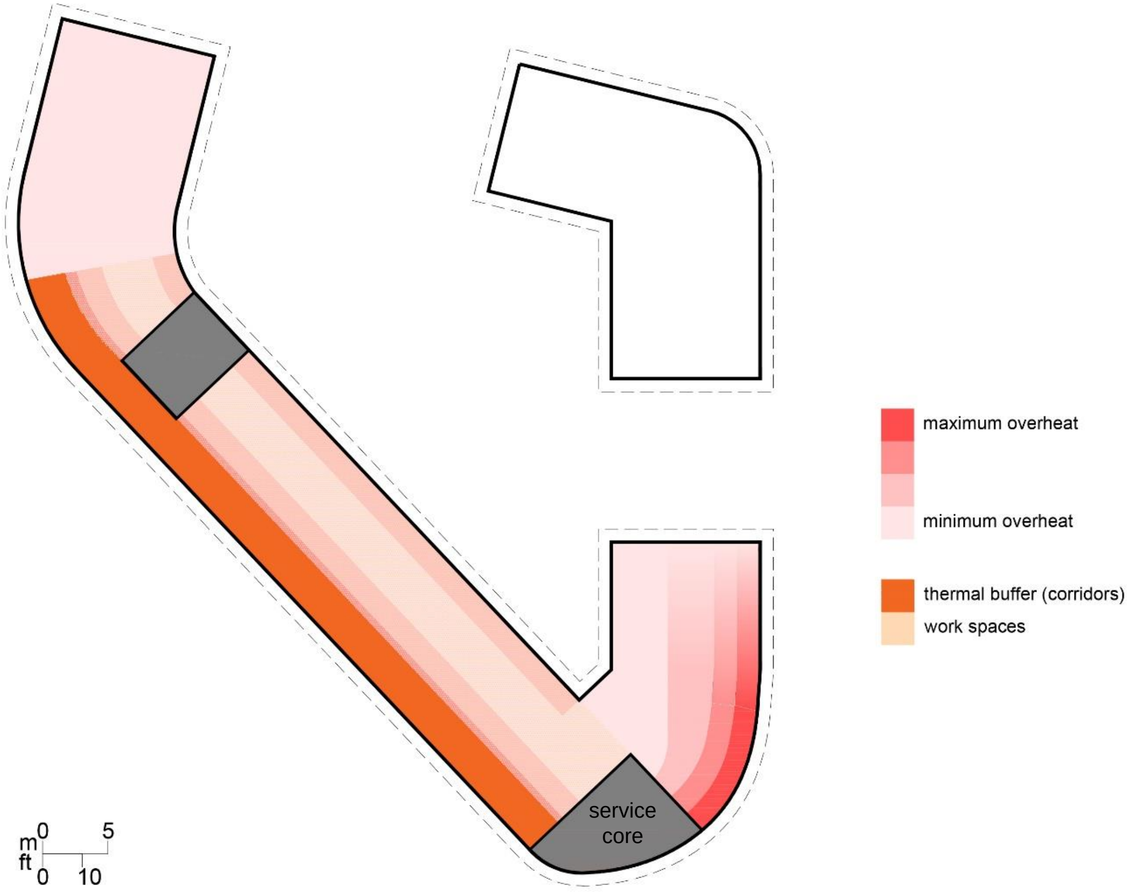




- **The overheated area is closest to the area subjected to the highest radiation**

# Formulating the indoor layout

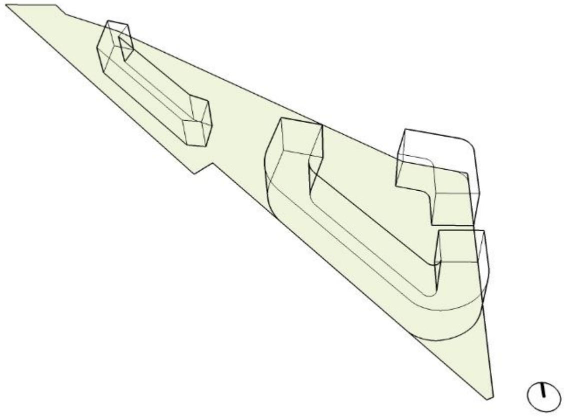
## Organizing spaces as per the indoor environment



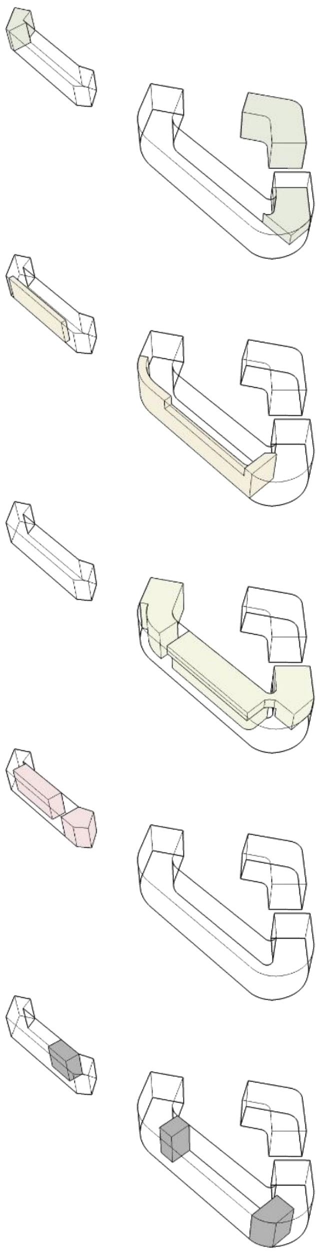




- The overheated area is closest to the area subjected to the highest radiation
- The area closest to the south-west wall and glazing is utilized as corridors and circulation spaces and acts as a thermal buffer.

# Program



Site = 6013 m$^2$



- Exhibition space
- Reception and lobby
- Recreation spaces

1157.25 m$^2$

- Corridors and passages

665.74 m$^2$

- Laboratories
- Offices
- Class rooms
- Meeting rooms
- Library

2060.87 m$^2$

- Apartments
- Dormitories

693.63 m$^2$

- Elevators
- Stair shafts
- Restrooms
- Mechanical

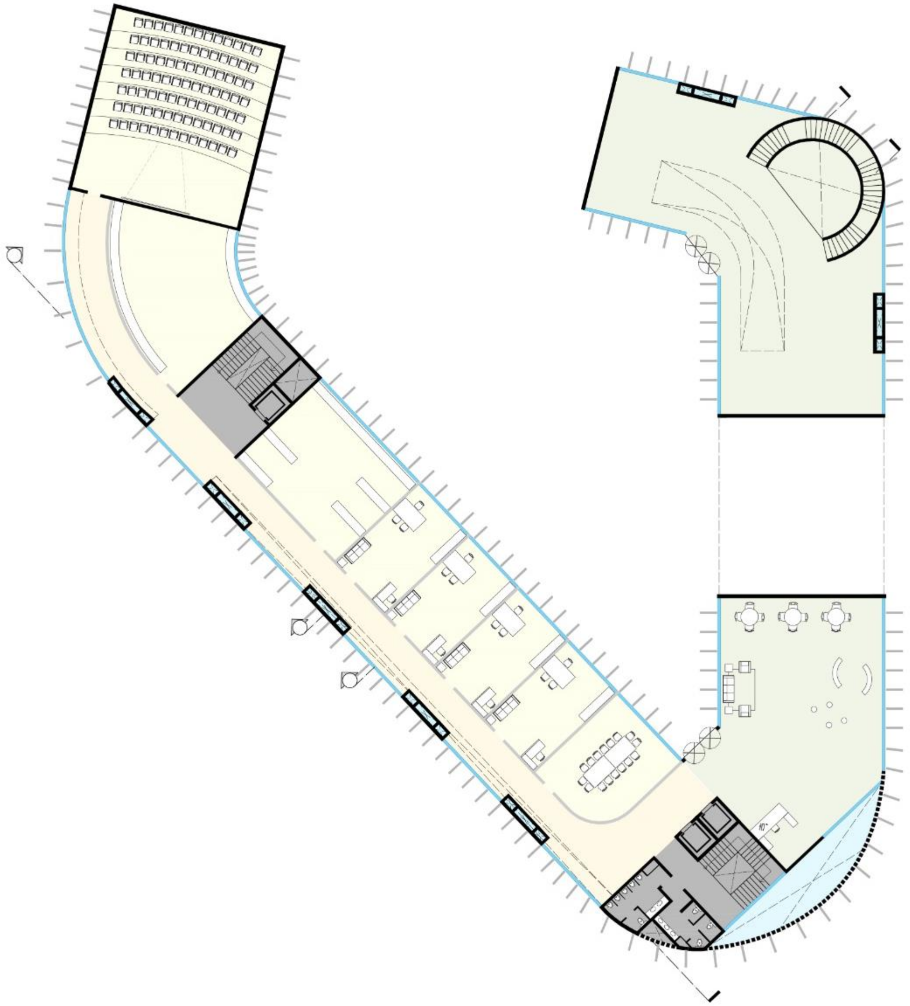
506 m$^2$

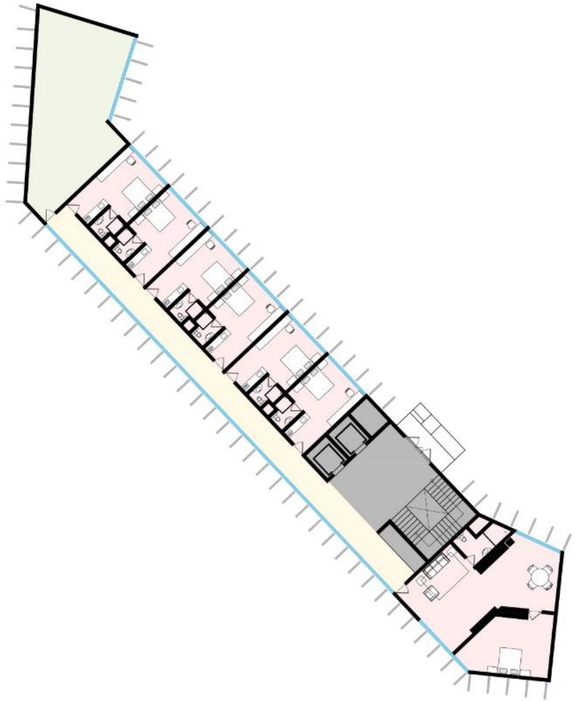
5083.5 m$^2$
(54718.33 sq ft)

Public spaces
Corridors and circulation
Work spaces
Residential spaces
Service cores

# Layouts

## Floor plans – Ground floor





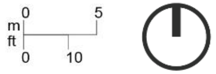
Public spaces

Corridors and circulation

Work spaces

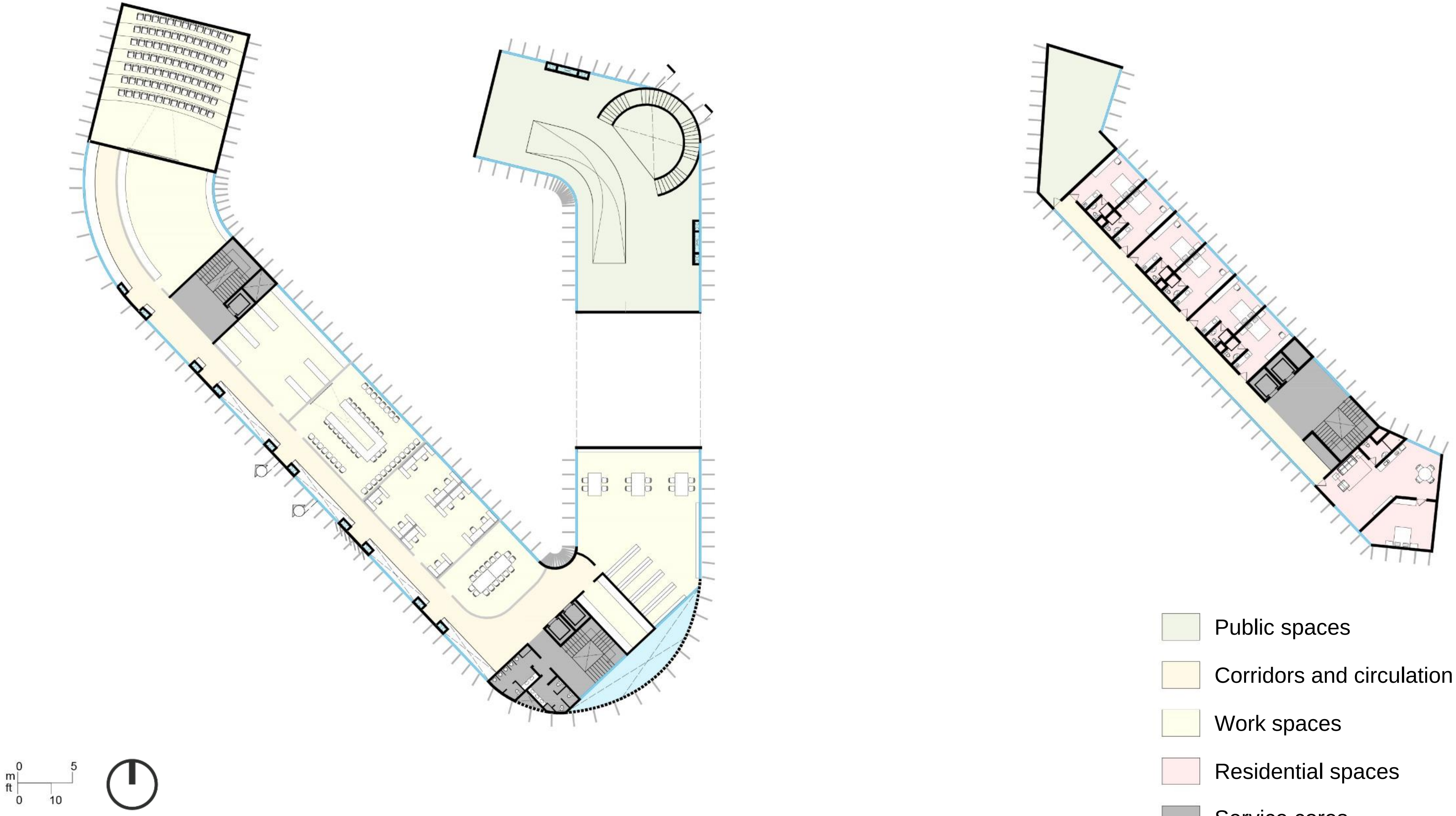
Residential spaces

Service cores



# Layouts

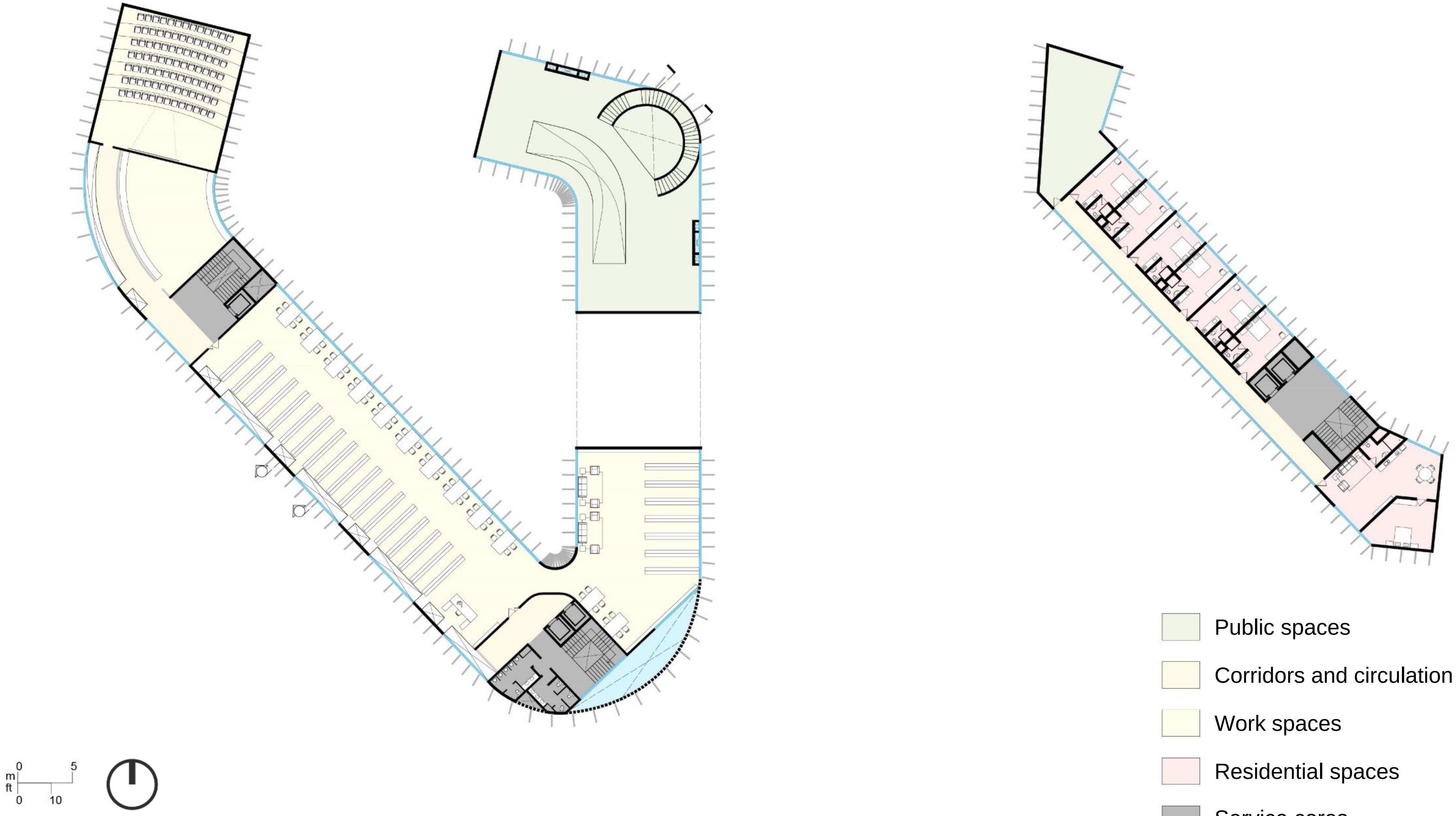
## Floor plans – First floor




- Public spaces
- Corridors and circulation
- Work spaces
- Residential spaces
- Service cores

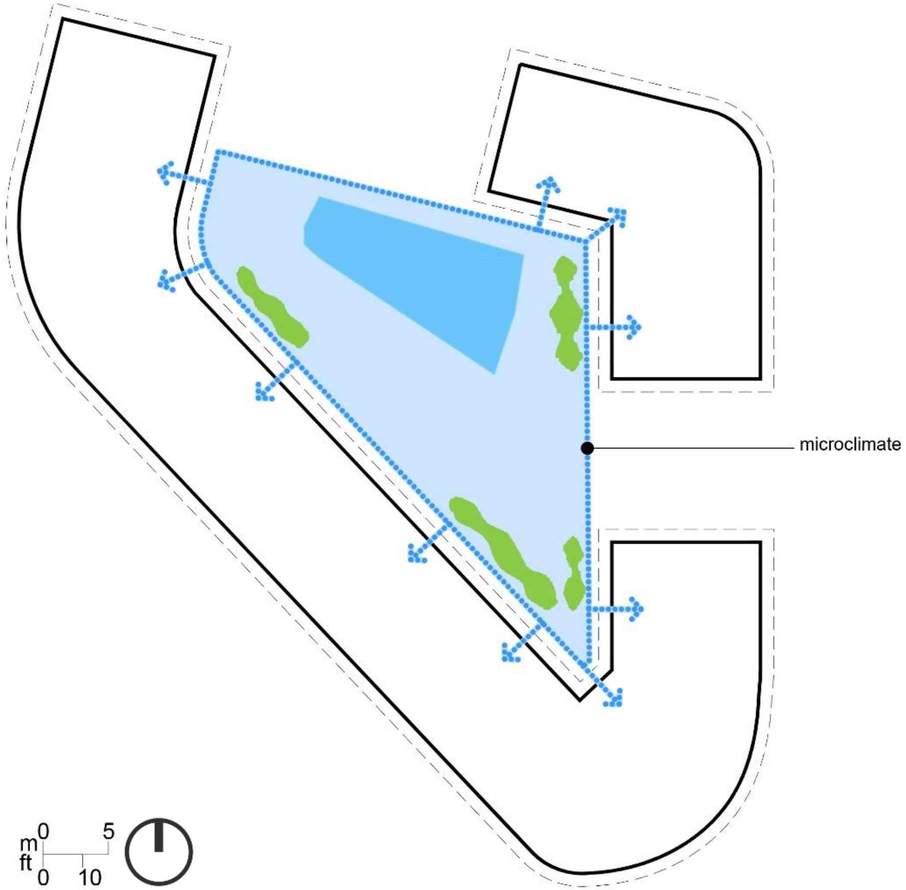
# Layouts

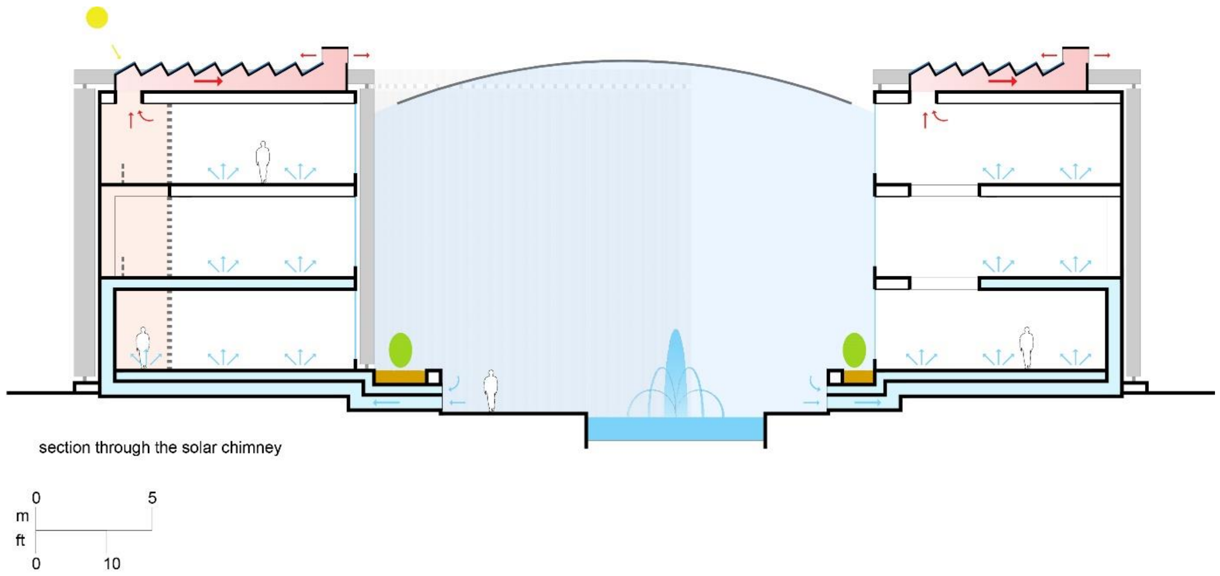
## Floor plans – Second floor

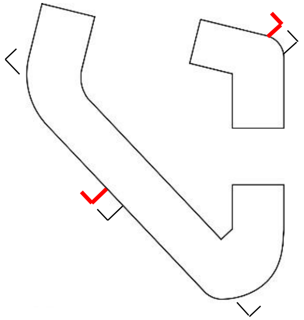


# The microclimate

## Outdoor micro-climate



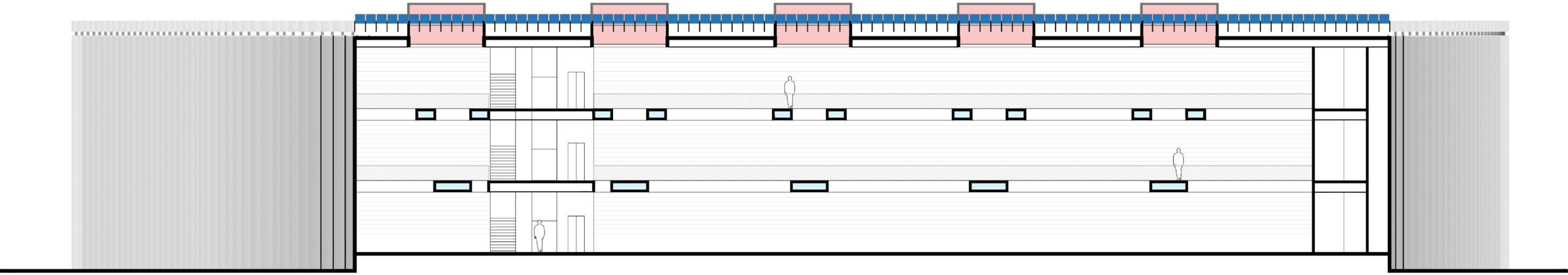



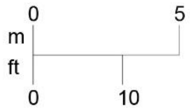



- The microclimate used for the outdoors could be harnessed to cool the indoor spaces

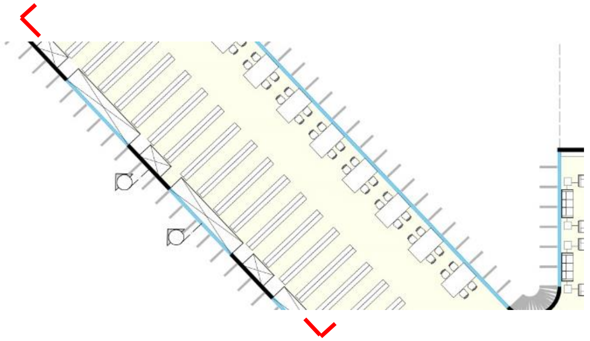
# The microclimate

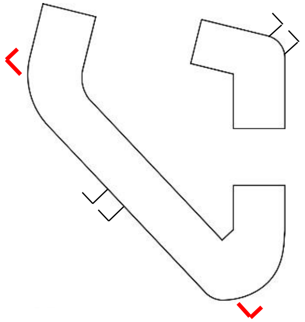
## Longitudinal section





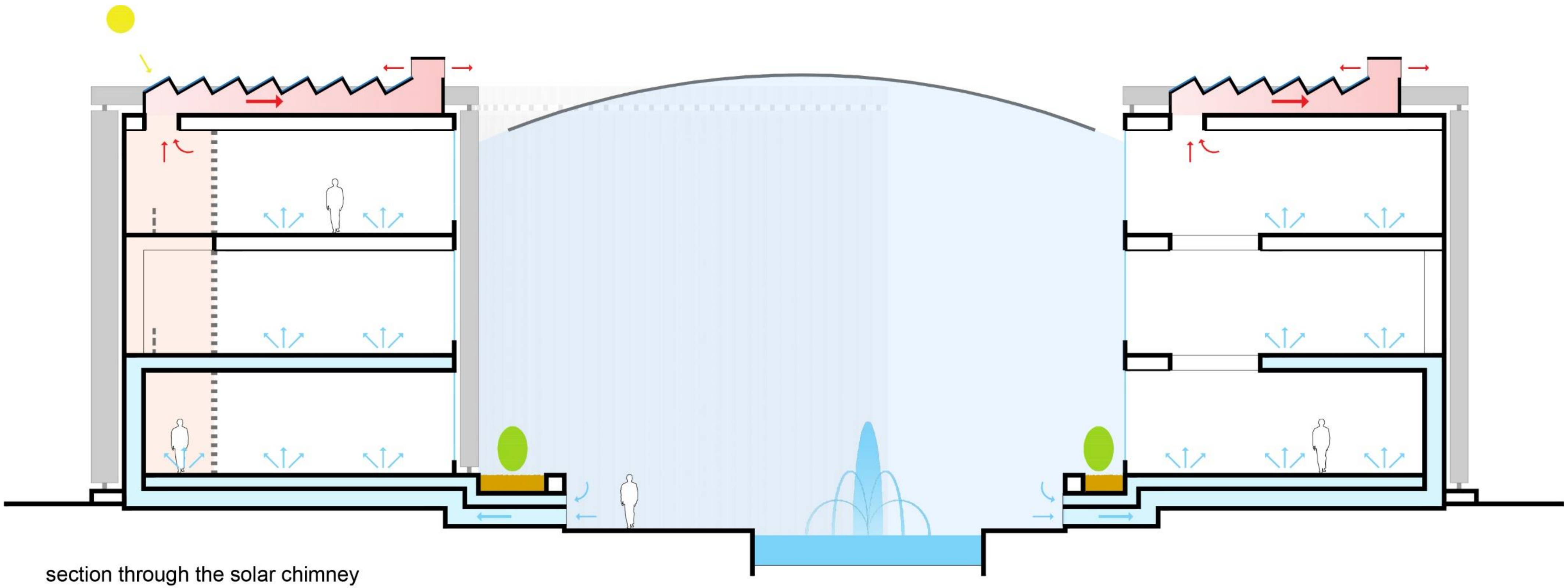

- Section cuts through the space directly below the solar chimney inlet



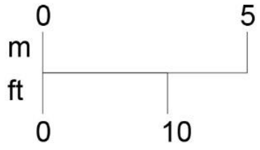


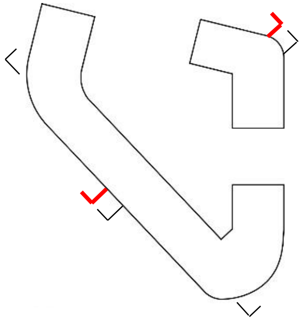
# The microclimate

## Cross section through the courtyard and solar chimney



section through the solar chimney

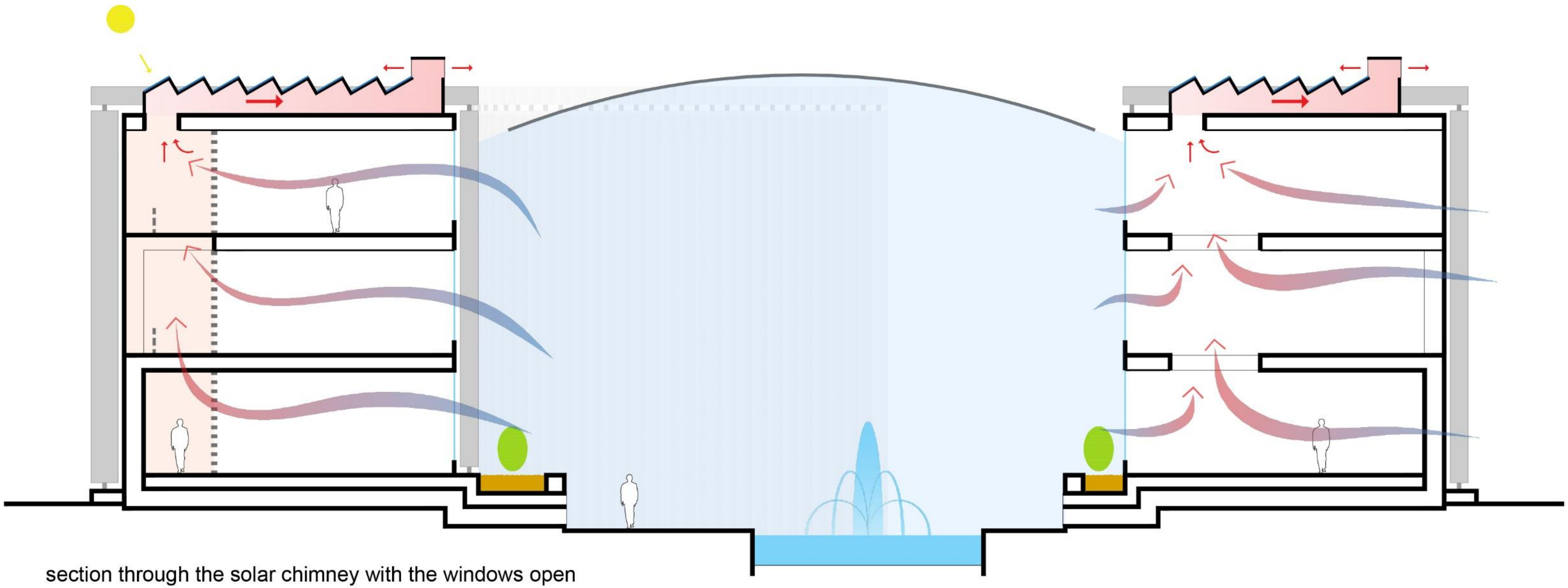


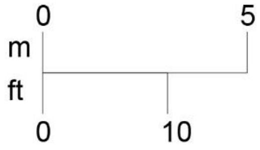
- Using an array of solar chimneys to induce ventilation of the air that is cooled down in the courtyard
- The roof-top PV panels can double up to generate the required heat for the solar chimney

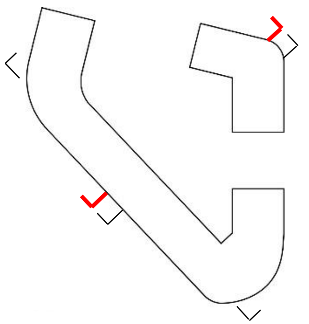
# The microclimate

## Cross section through the courtyard and solar chimney



section through the solar chimney with the windows open

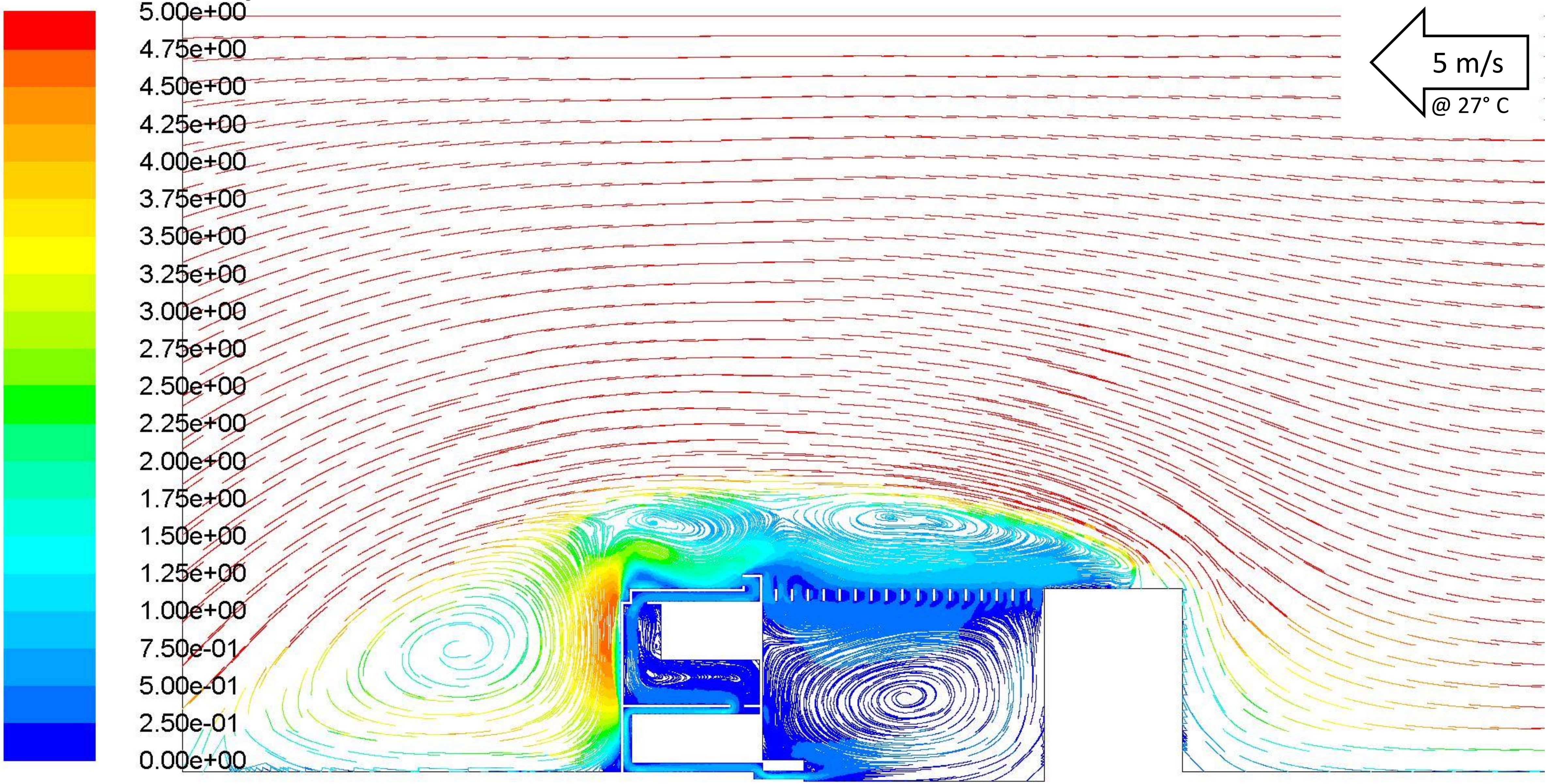


- The windows could open during the winter and the air inlet would stop functioning

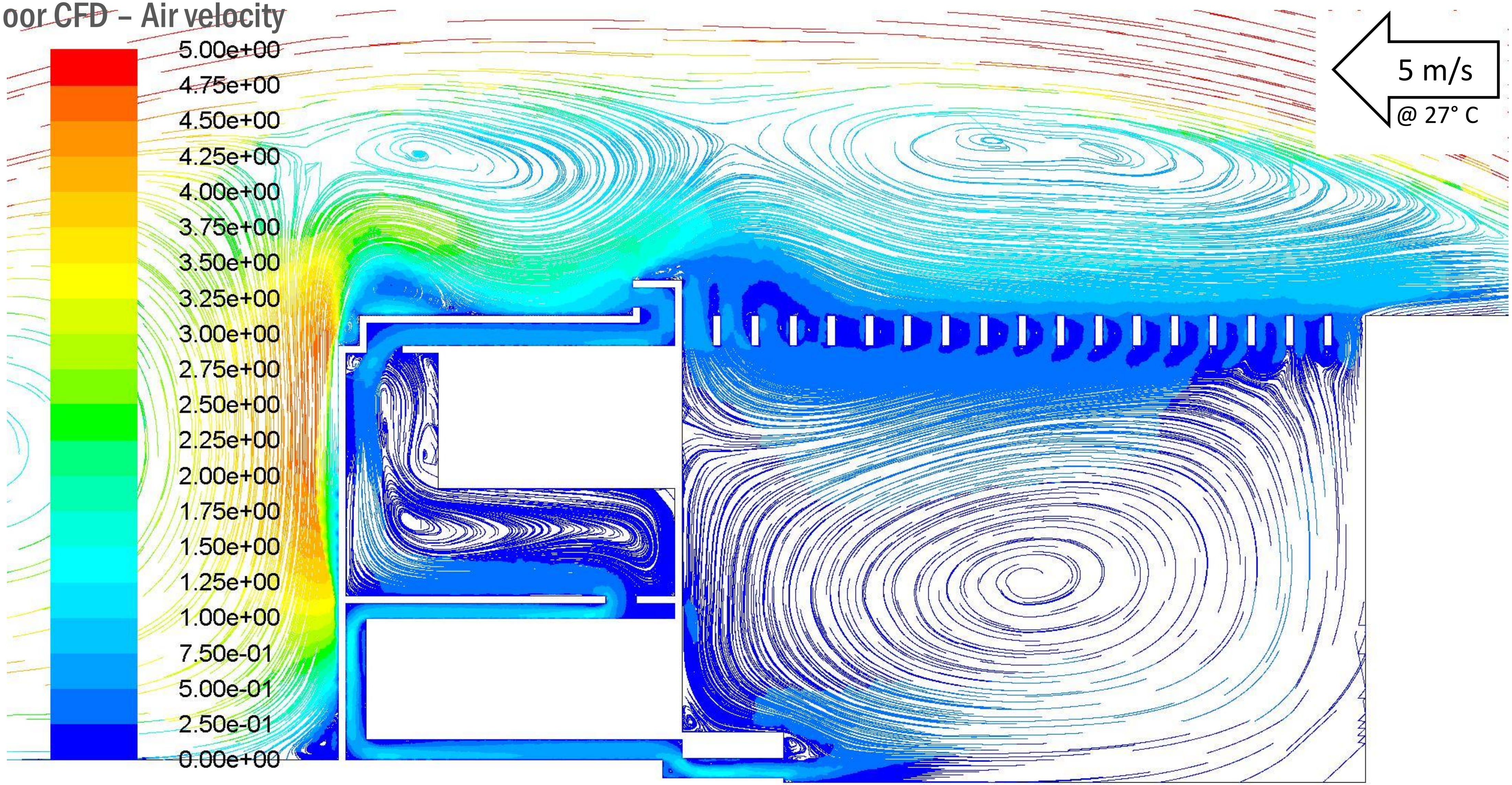
# Indoor ventilation

## Outdoor CFD – Air velocity



# Indoor ventilation

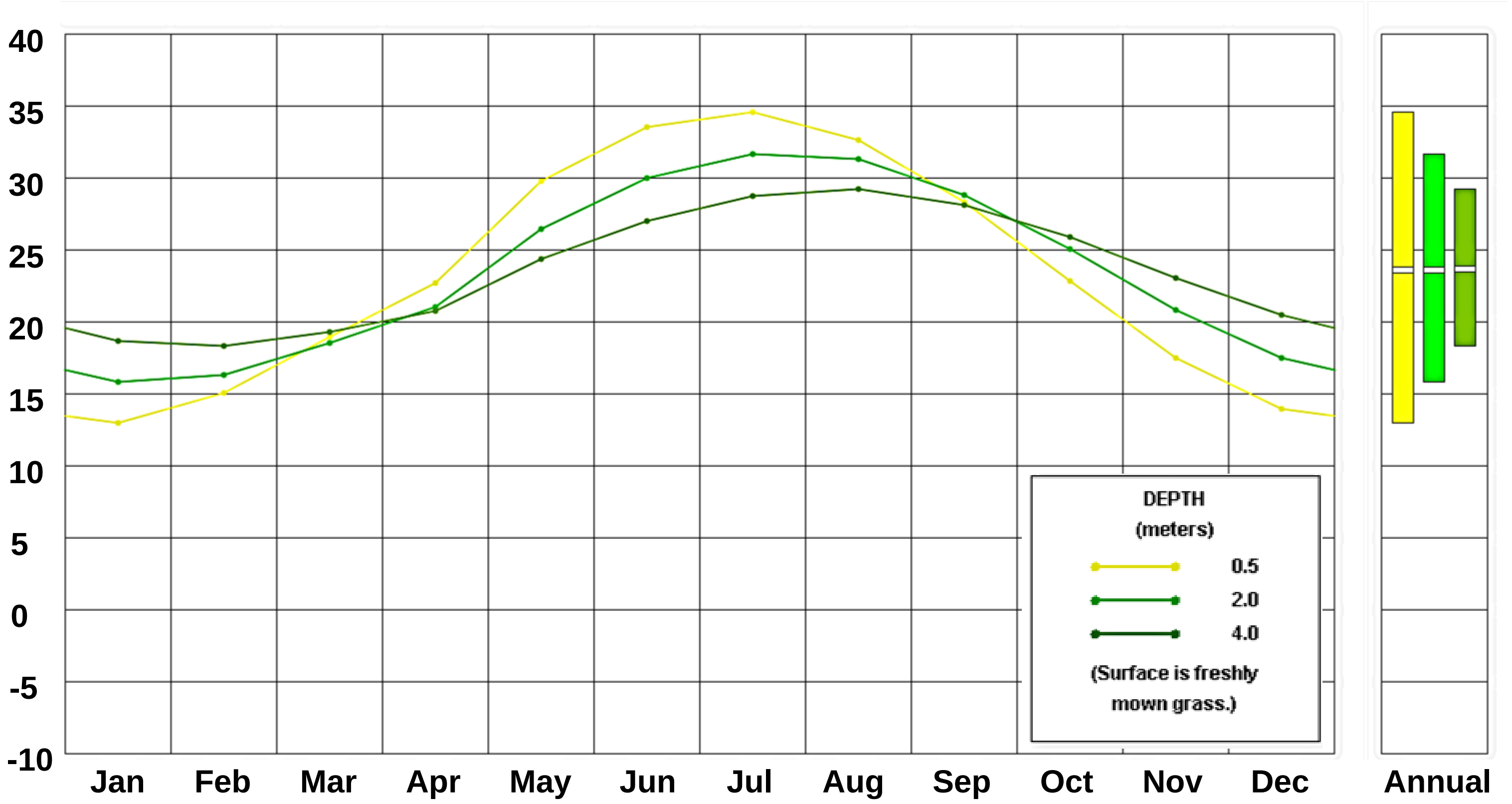
## Outdoor CFD – Air velocity




- The buildings around the courtyard create significant turbulence and the wind speed drops from 5 m/s to less than 0.25 m/s
- The temperature differential between the Solar chimney and the cool microclimate air successfully induces ventilation

# Indoor ventilation

## Annual average ground temperature and wet bulb temperature




| Maximum Average Wet Bulb | | | | | | | |
|---|---|---|---|---|---|---|---|
| Date | May | Jun | Jul | Aug | Sep | Oct | Year |
| 2016 | 59.3* | --- | --- | --- | --- | --- | 60.2* |
| 2015 | 63.2 | 73.7 | 72.7 | 75.6 | 72.6 | 66.2 | 75.6* |
| 2014 | 64.4 | 68.3 | 74.0 | 74.3 | 74.2 | 66.9 | 74.3 |
| 2013 | 66.4 | 72.9 | 77.2 | 75.8 | 74.5 | 59.8 | 77.2* |
| 2012 | 61.2 | 70.3 | 75.8 | 76.3 | 74.4 | 62.6 | 76.3* |
| 2011 | 62.6 | 70.0 | 74.8 | 74.2 | 72.7 | 65.9 | 74.8 |
| 2010 | 60.1 | 69.8 | 75.3 | 75.1 | 72.4 | 67.7 | 75.3 |
| 2009 | 65.0 | 70.2* | 74.1 | 71.6 | 70.7* | 61.8 | 74.1* |
| 2008 | 63.4 | 68.8 | 73.8 | 73.2 | 71.3 | 61.1 | 73.8 |
| 2007 | --- | --- | 76.4 | 77.1* | 73.7* | 70.2 | 77.1* |
| 2006 | 64.9 | 71.0 | 77.3* | 75.4* | 73.3 | 69.2 | 77.3* |
| Max | 66.4 | 73.7 | 77.3 | 77.1 | 74.5 | 70.2 | 77.3 |

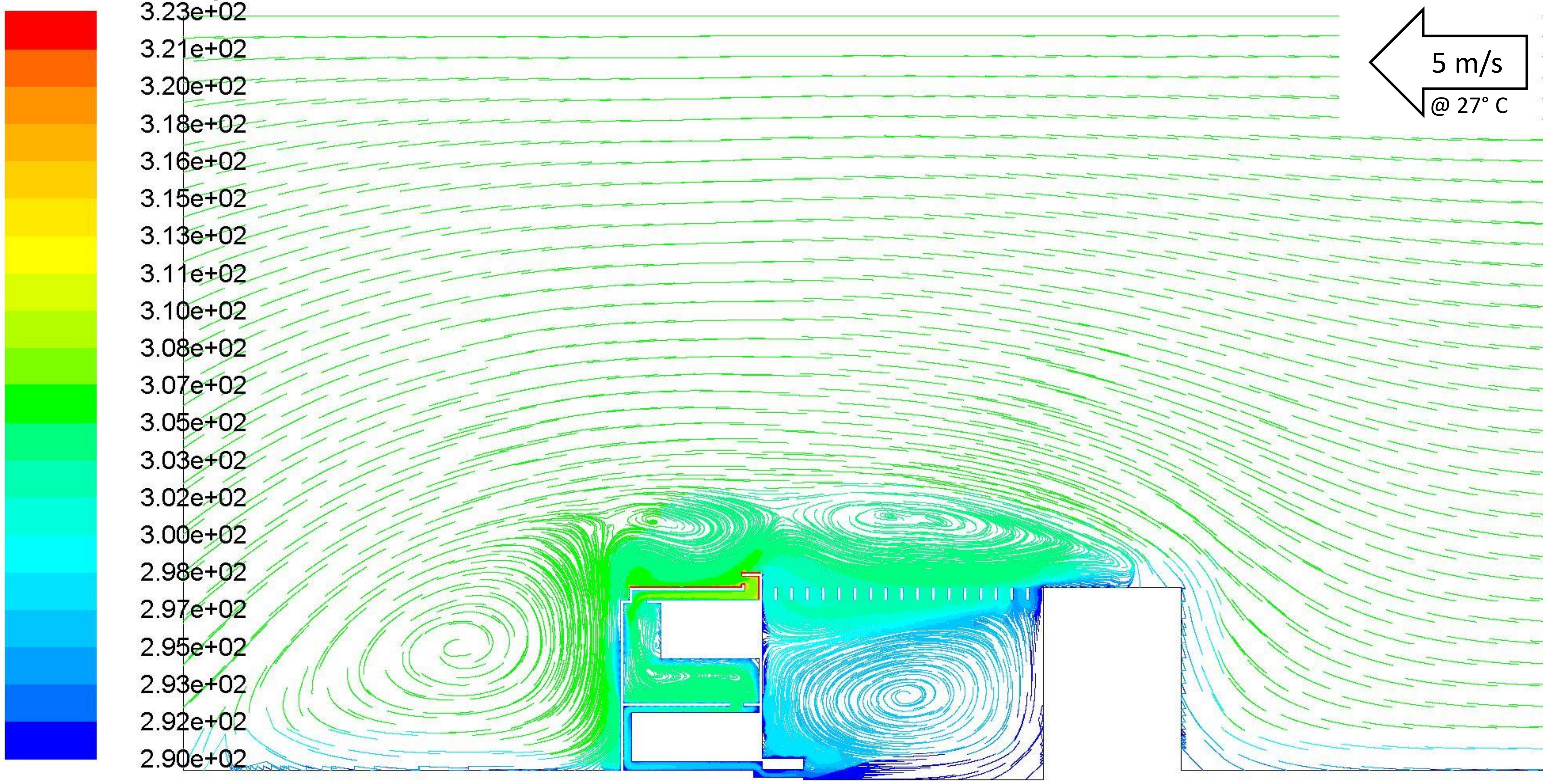
*In Fahrenheit*

* source: TiggrWeather

- The average ground temperature at a depth of 0.5 m ranges from about 34˚ C to 13˚ C. Therefore, in the summer months ground source cooling will prove insufficient
- The wet-bulb temperature in the hottest months ranges from 20˚ C to 25˚ C

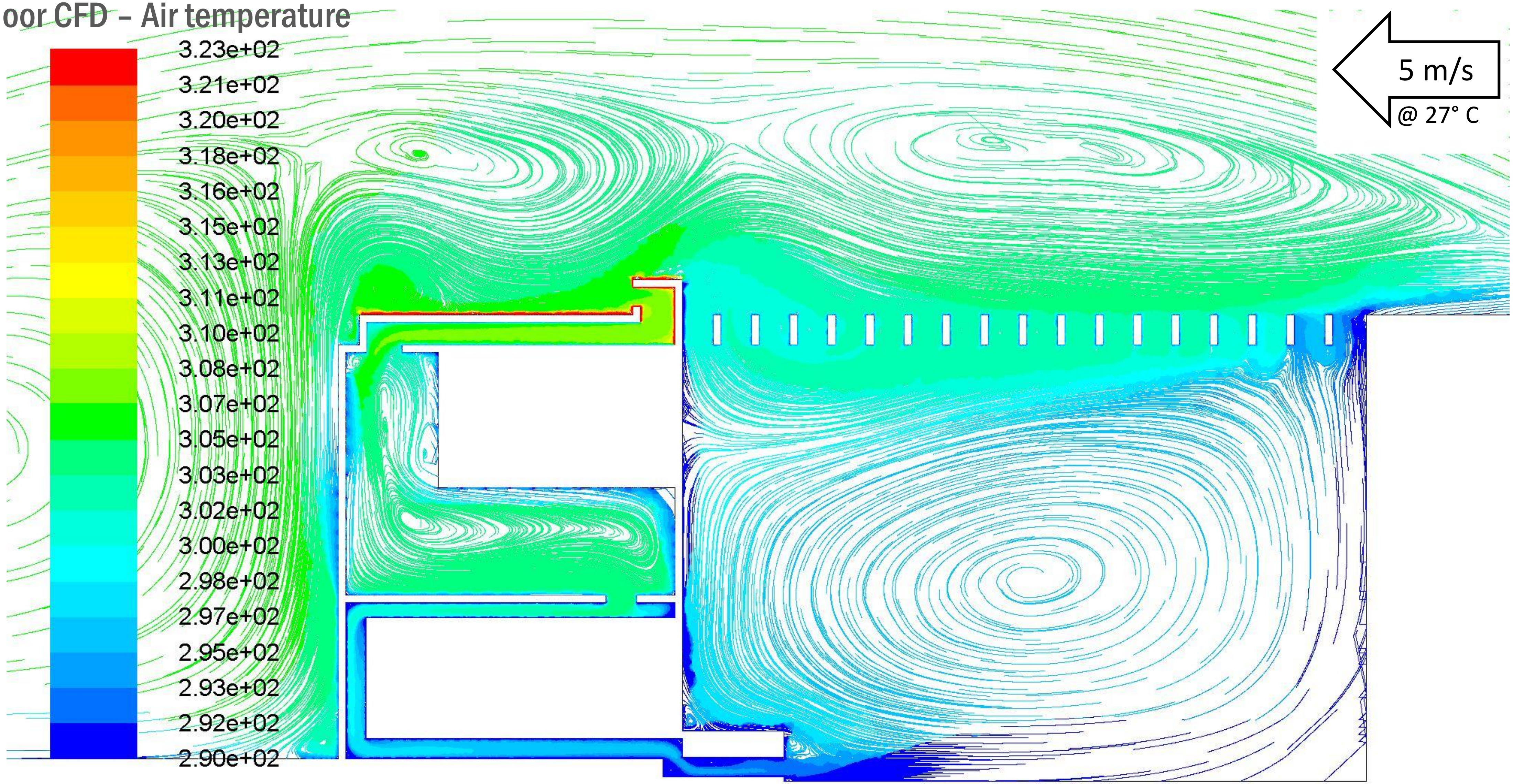
# Indoor ventilation

## Outdoor CFD – Air temperature



# Indoor ventilation

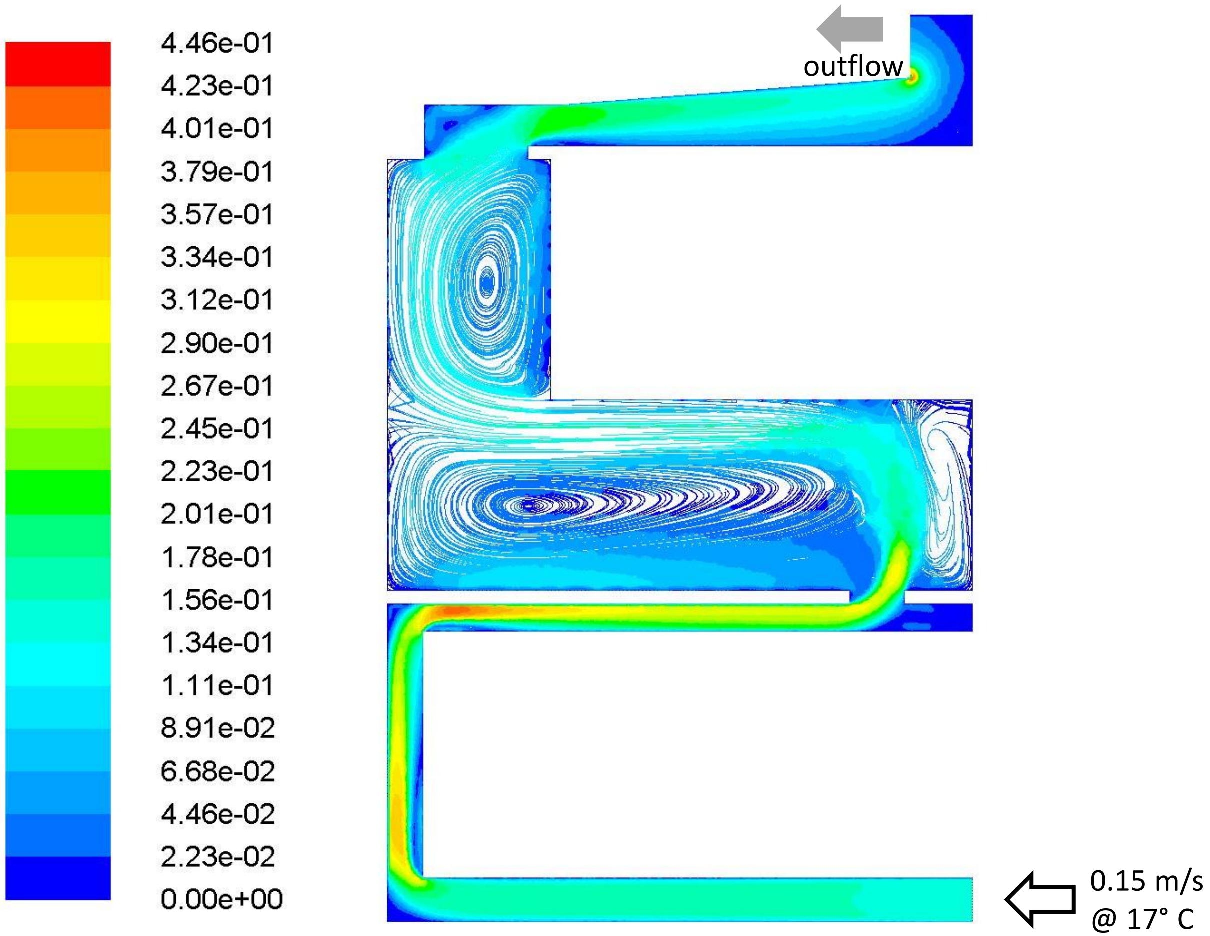
## Outdoor CFD – Air temperature



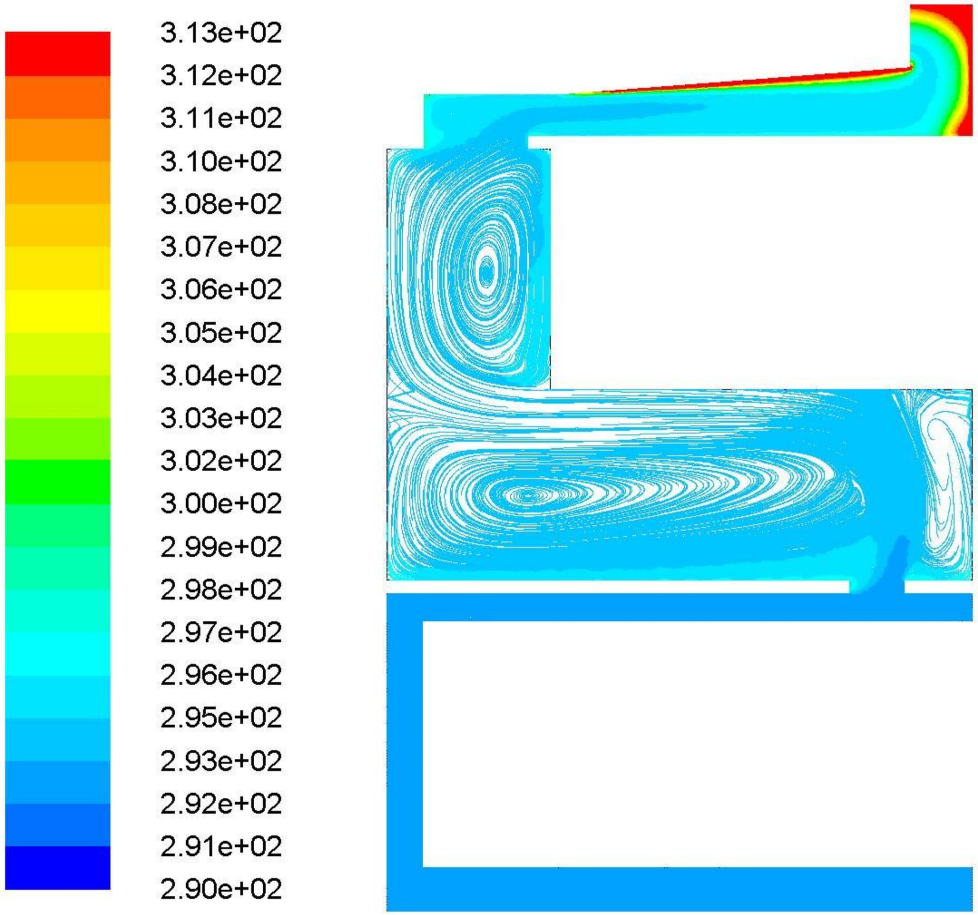

- Even with the evaporative cooling in the courtyard, the indoor air temperature rises to over 30° C in the indoor spaces. Misting the air at the inlet is required.

# Indoor ventilation

## Indoor CFD – Air velocity and temperature




Air velocity in m/s

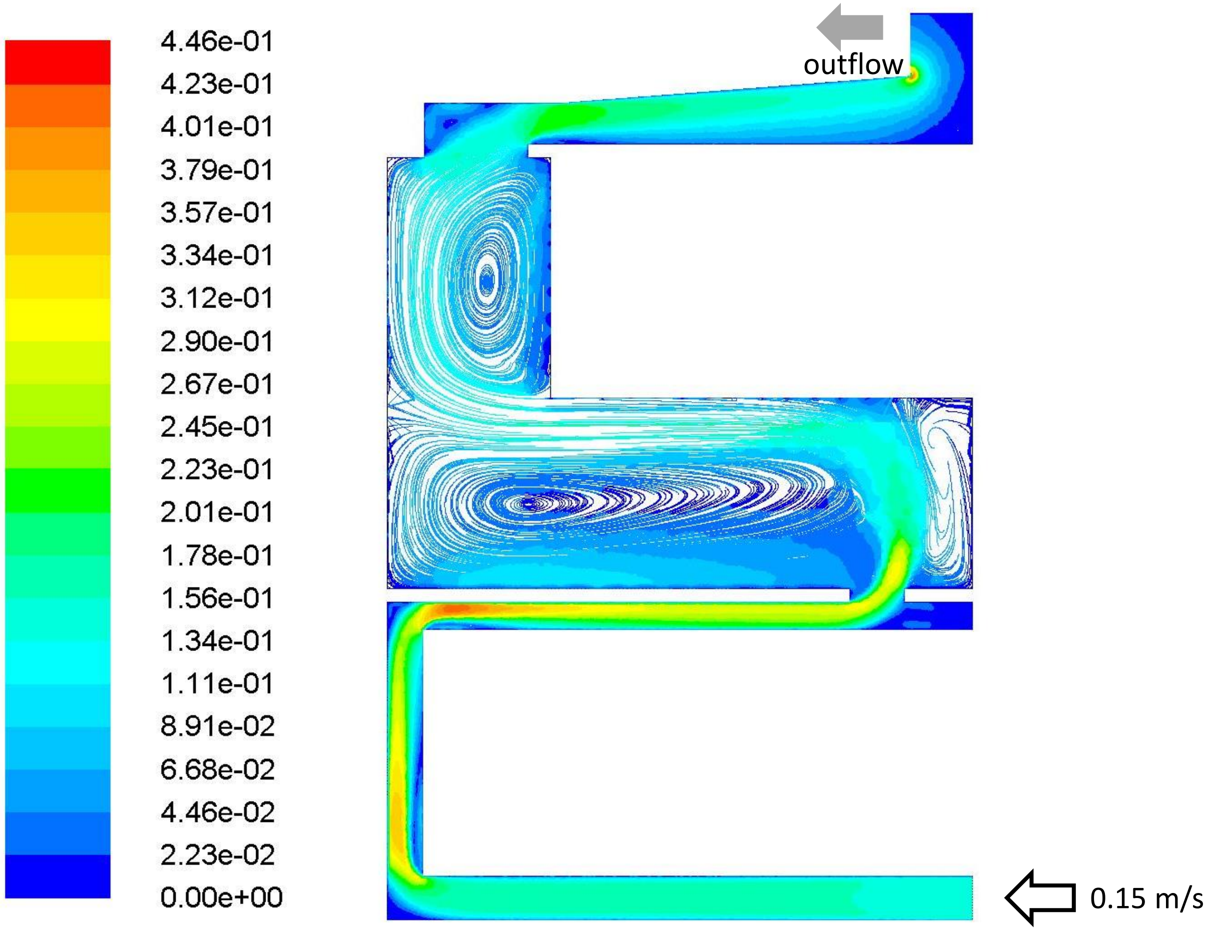



Air temperature in K

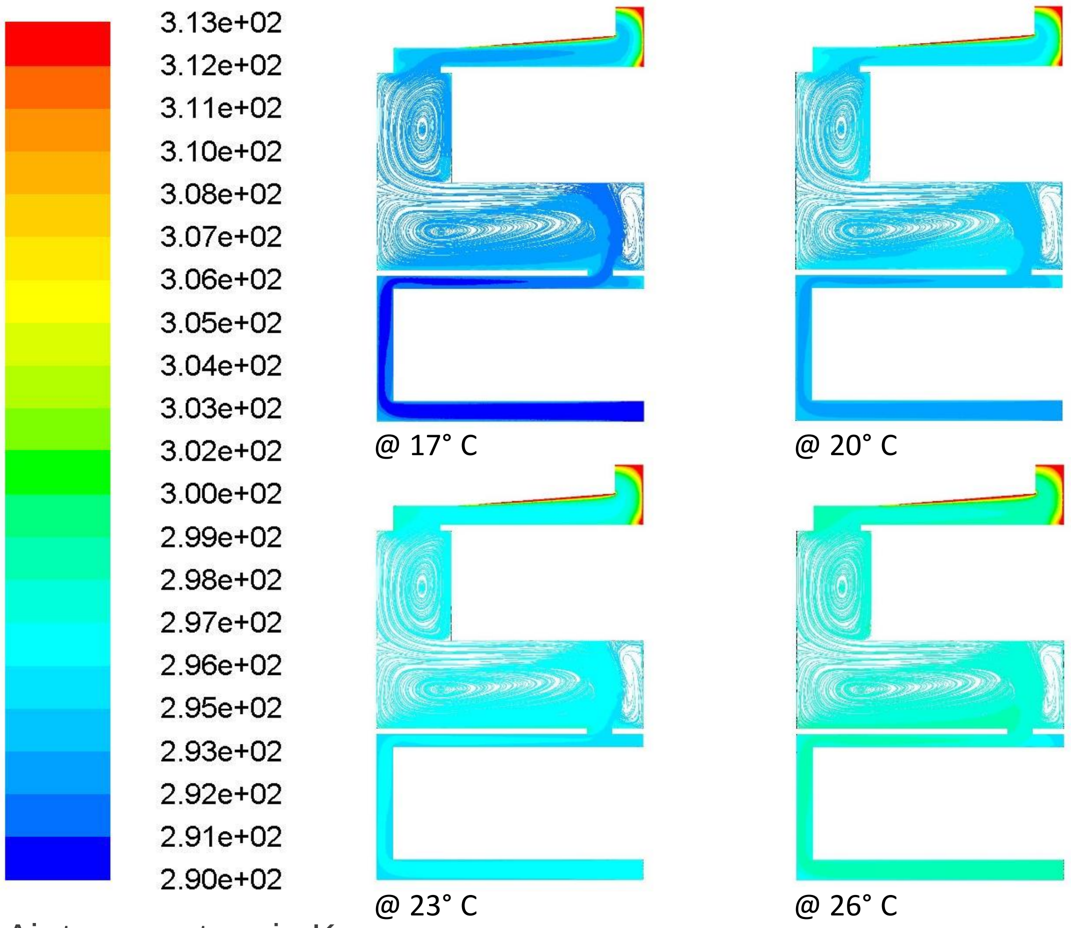
- **However, if the air is misted and the temperature gets closer to the average June wet-bulb temperature at 17° C, the indoor air reaches an average 23-24° C with a minimal air draft.**

# Indoor ventilation

## Indoor CFD – Air velocity and temperature




Air velocity in m/s

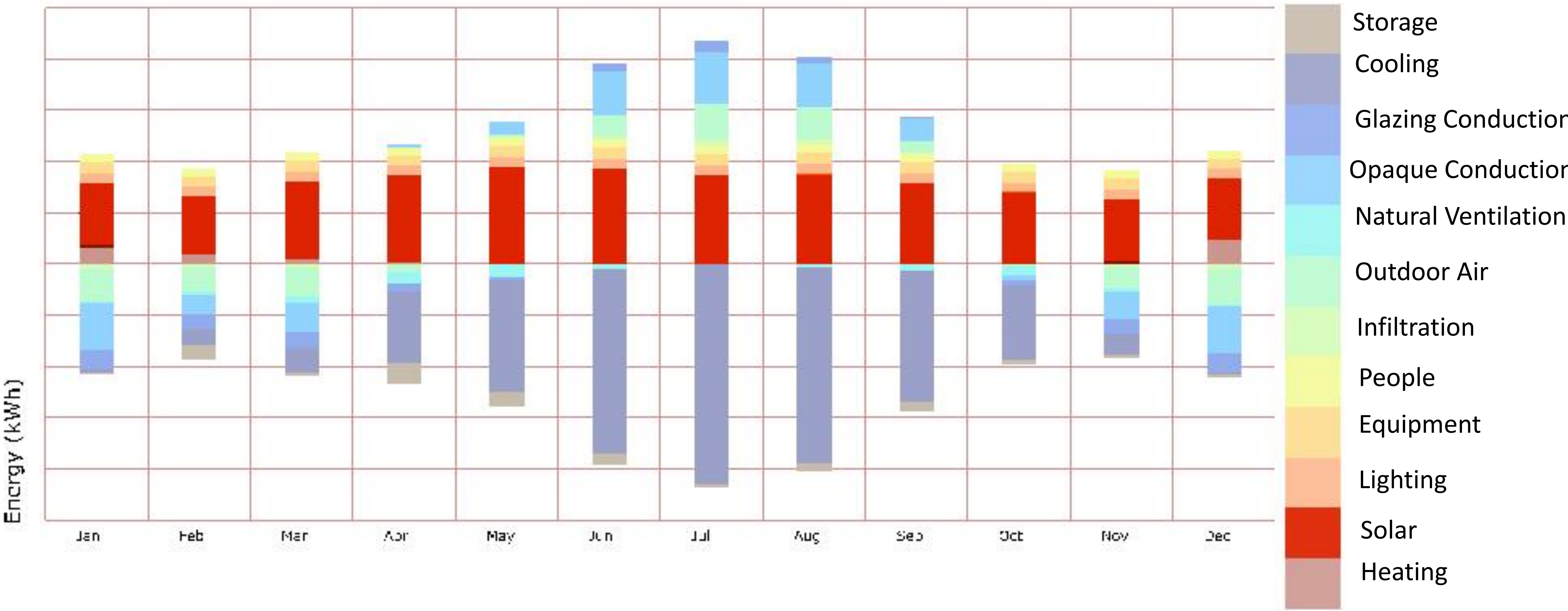



Air temperature in K

- **Indoor air temperature at various wet-bulb temperatures assuming the air temperature reaches close to the wet-bulb upon misting.**

# Energy balance

## Monthly balance




No shade

No shade

The most heat load is created by Solar Gain.

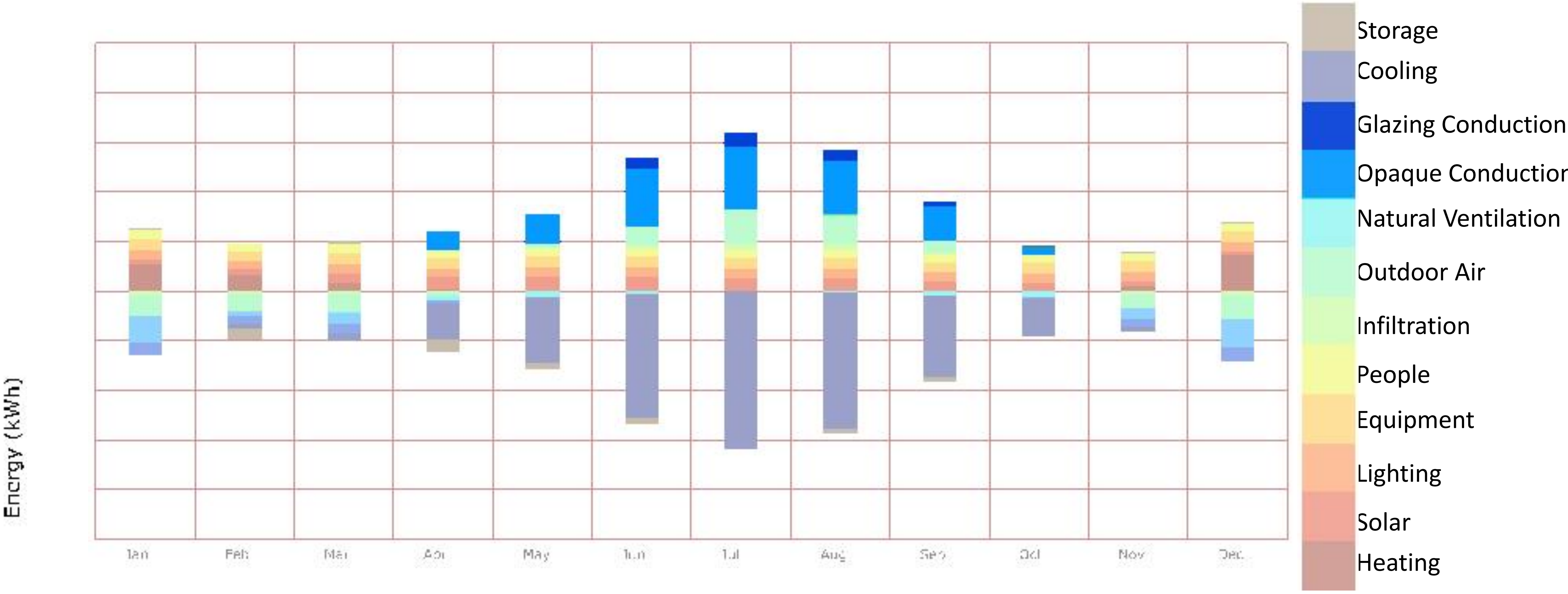
# Energy balance

## Shades


Applying shade on glazed surfaces, reduces the heat load created by solar gain and shows that it has been moved to opaque conduction and outdoor air in three months of summer.

# Energy balance

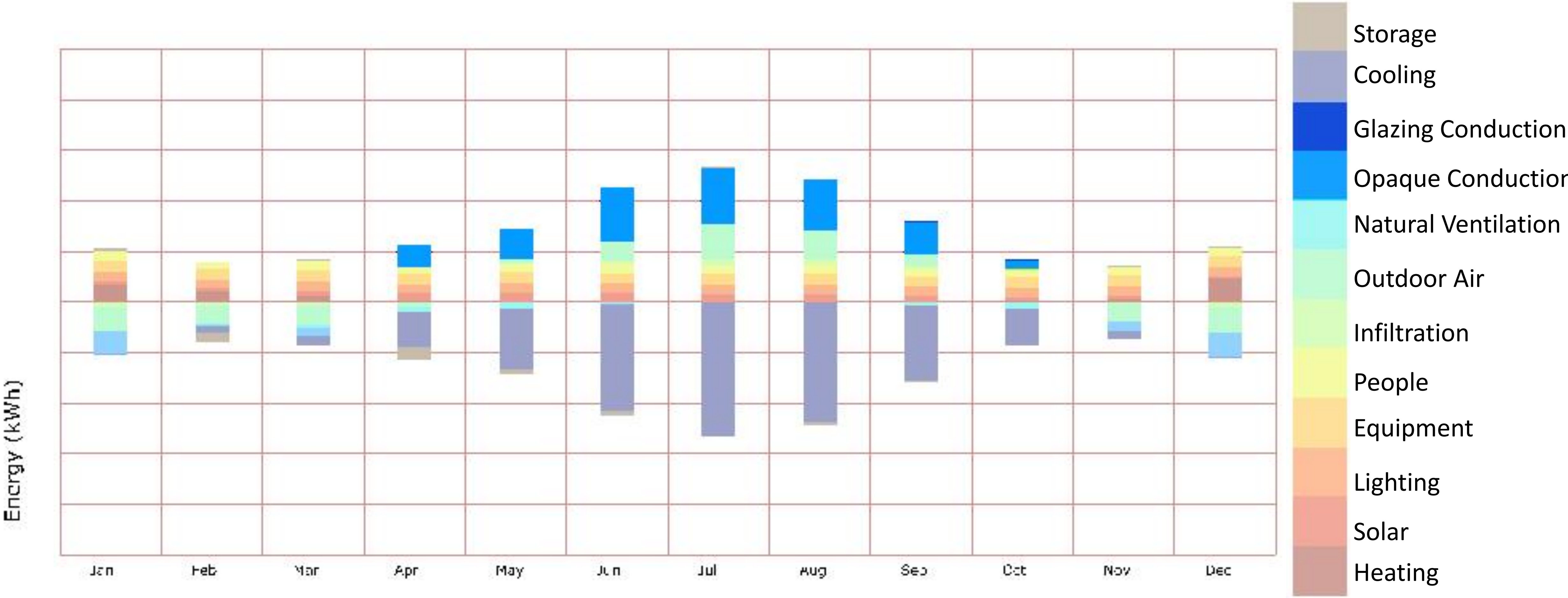
## Opaque and glazing conduction




Glazing and opaque conduction loads can be reduced by changing the material.

# Energy balance

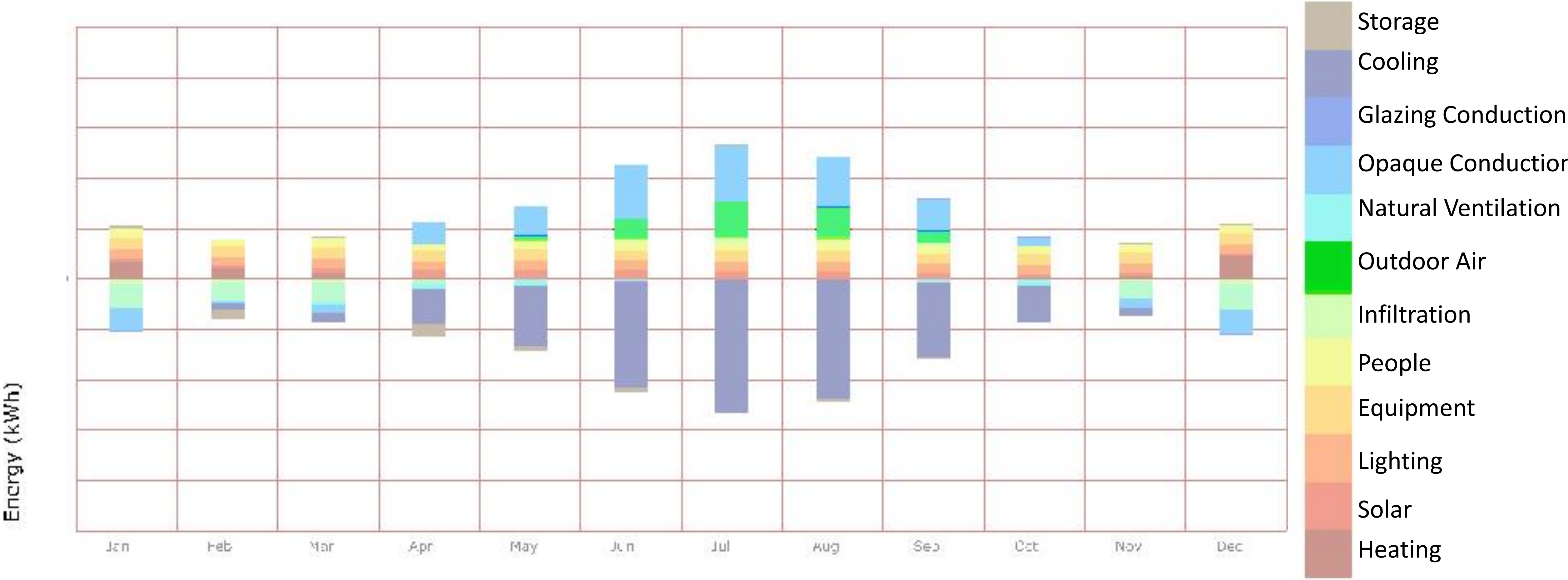
## Materials change




Changing Materials of roof, walls, floor and thermochromic glass show slightly reduces opaque conduction and glazing conduction also reduces solar gain.

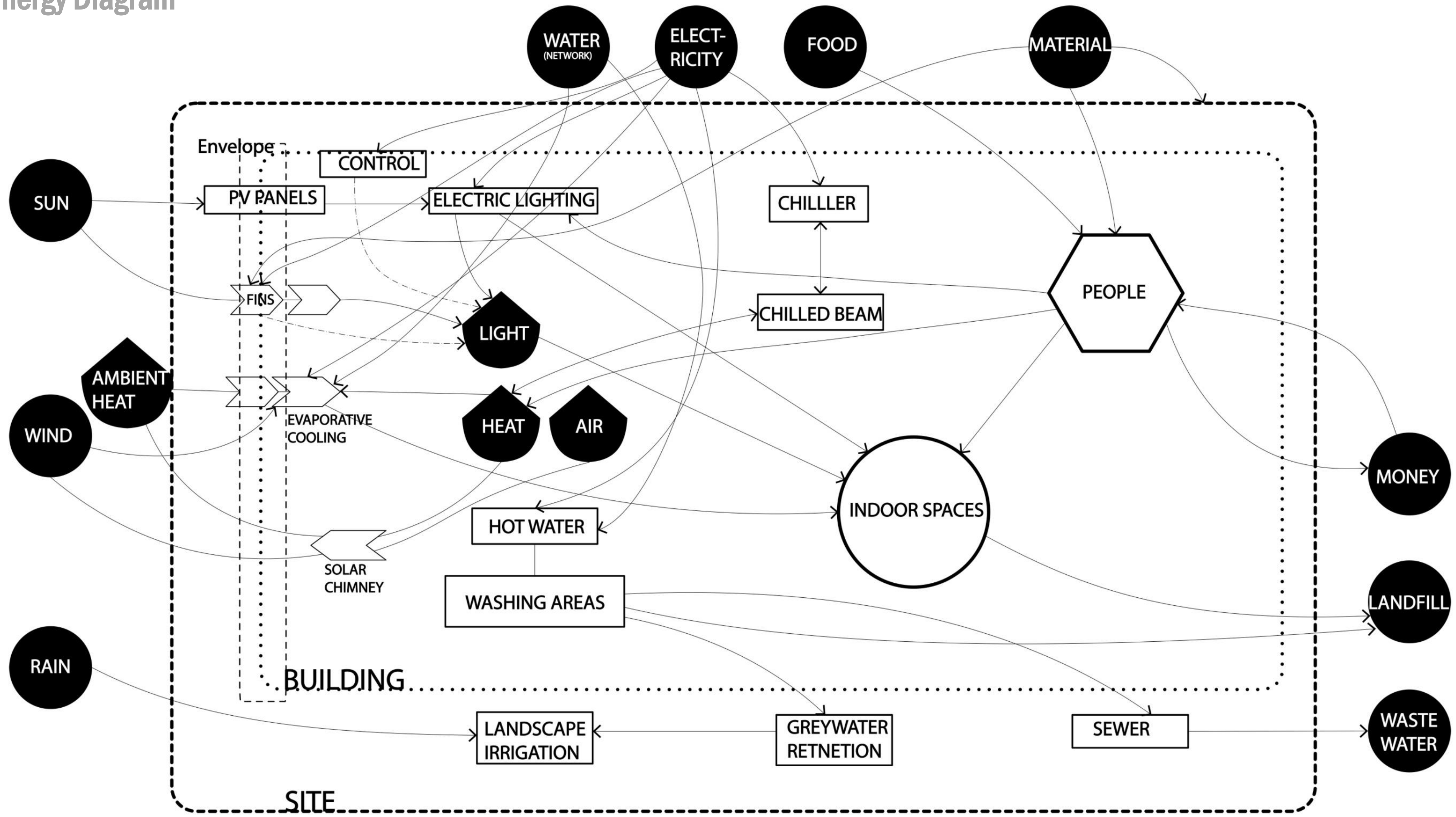
# Energy balance

## Outdoor air



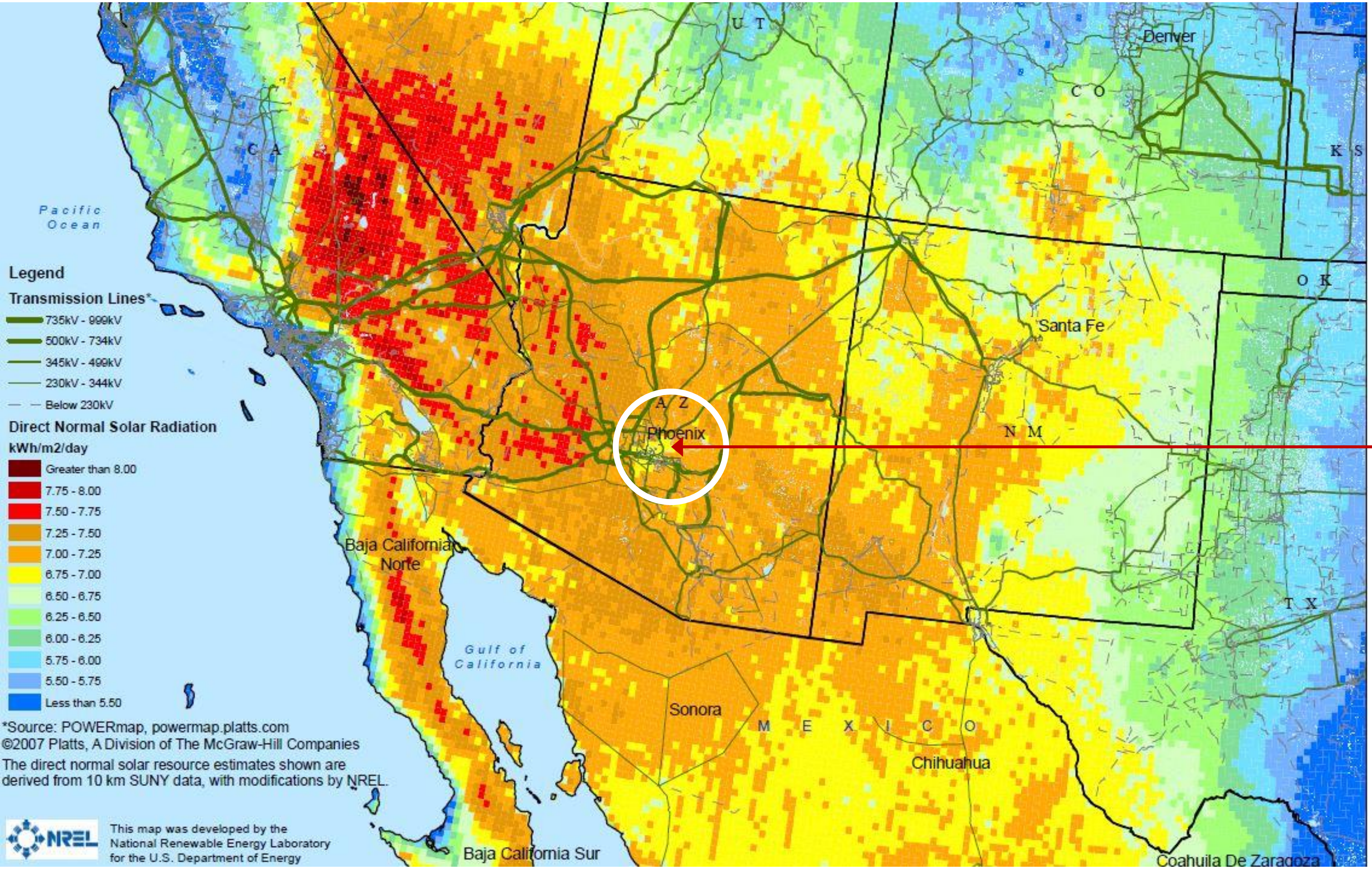

The Loads of Outdoor Air adding to the heat produced shows that In three months of June, July and August, due to the very hot outdoor air, loads on HVAC system is more than other months.

# Emergy Diagram



# Solar potential and PV

## Regional solar potential map




6.75-7.25 kWh/m2

# Solar potential and PV

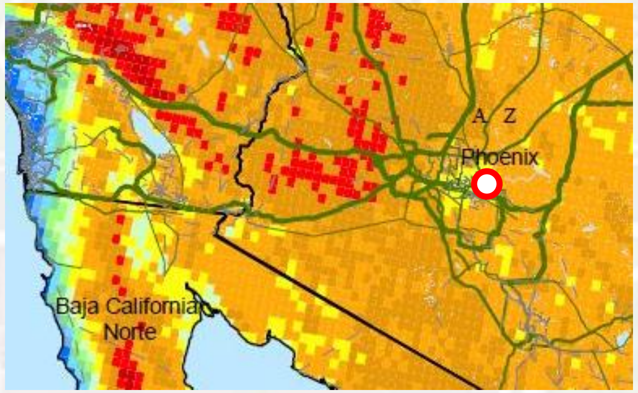
# Solar potential and PV

## Median energy requirement for a similar building


Median Energy requirement for 2B climate zone: 131 kBtu/sqft/year or **413.25 kWh/m2/year**

# Solar potential and PV

## Site solar potential




6.75-7.25 kWh/m$^2$/day

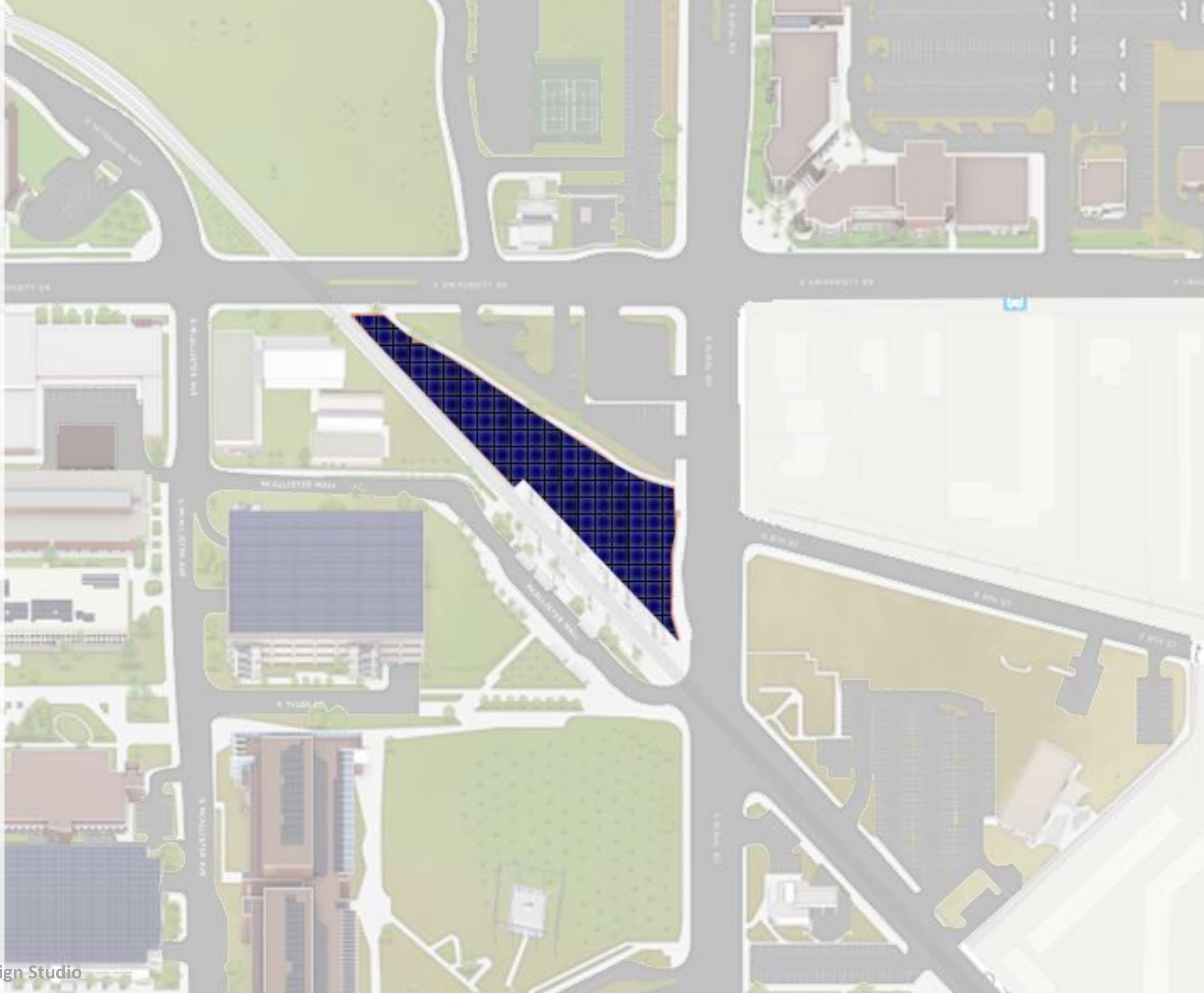
= 2464-2646 kWh/m$^2$/Y

= 344.96-370.44 Wh/m$^2$ for a 140W peak output PV cell

Hours of sun in Phoenix region = 3872; % sunshine = 85

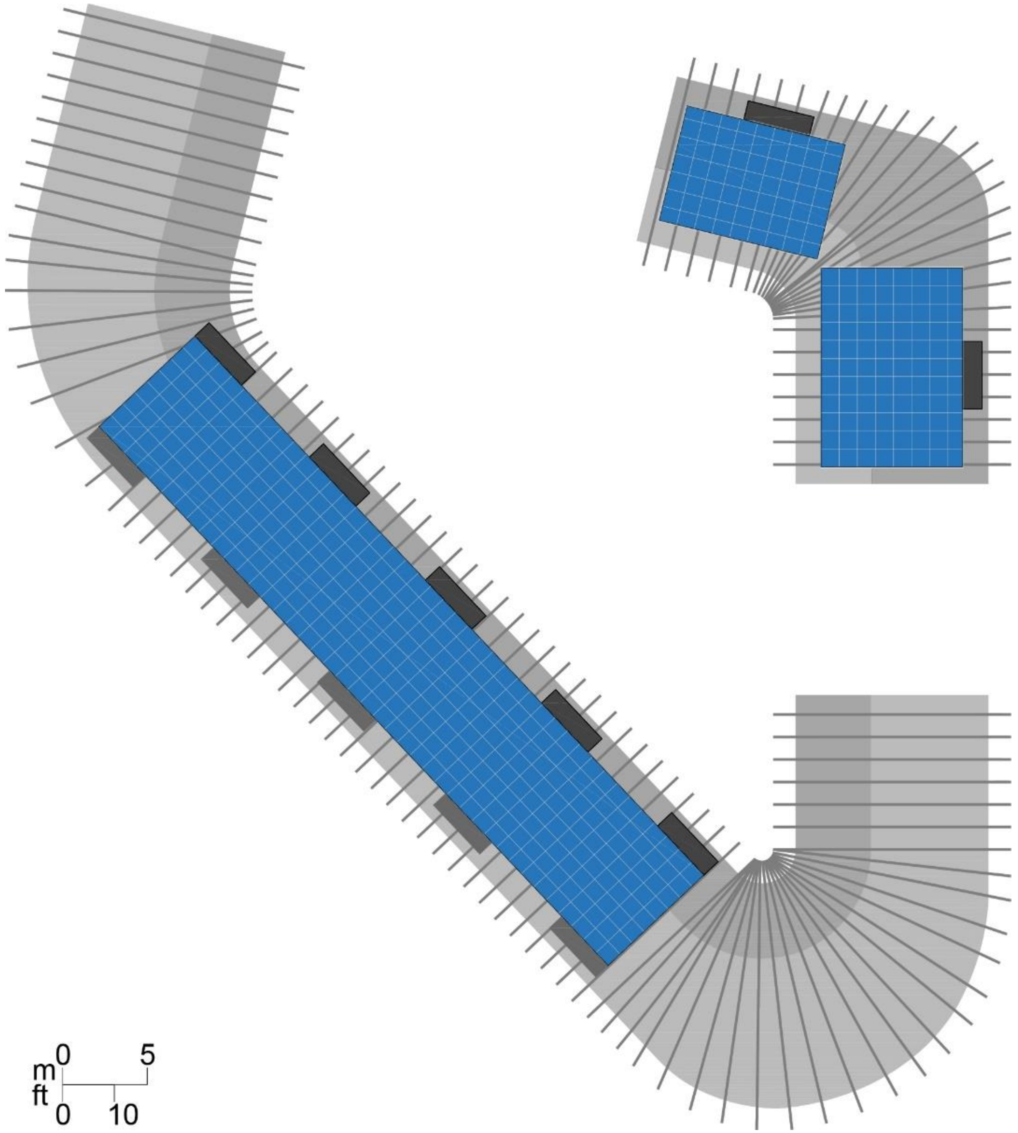
**Total capacity = 1135-1218.9 kWh/m$^2$/Y**

**Median requirement: 413.25 kWh/m$^2$/Y**



# Solar potential and PV

## Roof-top Photovoltaic panels




PVWatts Calculator

**RESULTS** **138,753 kWh per Year ***

| Month | Solar Radiation ( kWh / $m^2$ / day ) | AC Energy ( kWh ) | Energy Value ( $ ) |
|---|---|---|---|
| January | 4.64 | 9,061 | 926 |
| February | 5.35 | 9,304 | 951 |
| March | 6.18 | 11,698 | 1,196 |
| April | 7.56 | 13,518 | 1,382 |
| May | 7.76 | 14,061 | 1,437 |
| June | 7.99 | 13,442 | 1,374 |
| July | 7.46 | 13,018 | 1,330 |
| August | 7.38 | 12,939 | 1,322 |
| September | 7.13 | 12,191 | 1,246 |
| October | 5.99 | 10,957 | 1,120 |
| November | 5.23 | 9,669 | 988 |
| December | 4.52 | 8,894 | 909 |
| Annual | 6.43 | 138,752 | $ 14,181 |

**Location and Station Identification**

| | |
|---|---|
| Requested Location | phoenix |
| Weather Data S | 5.2 mi |
| Latitude | |
| Longitude | |

**PV System Sp**

DC System Size

Module Type

Array Type

Array Tilt

Array Azimuth

System Losses

Inverter Efficie

DC to AC Size R

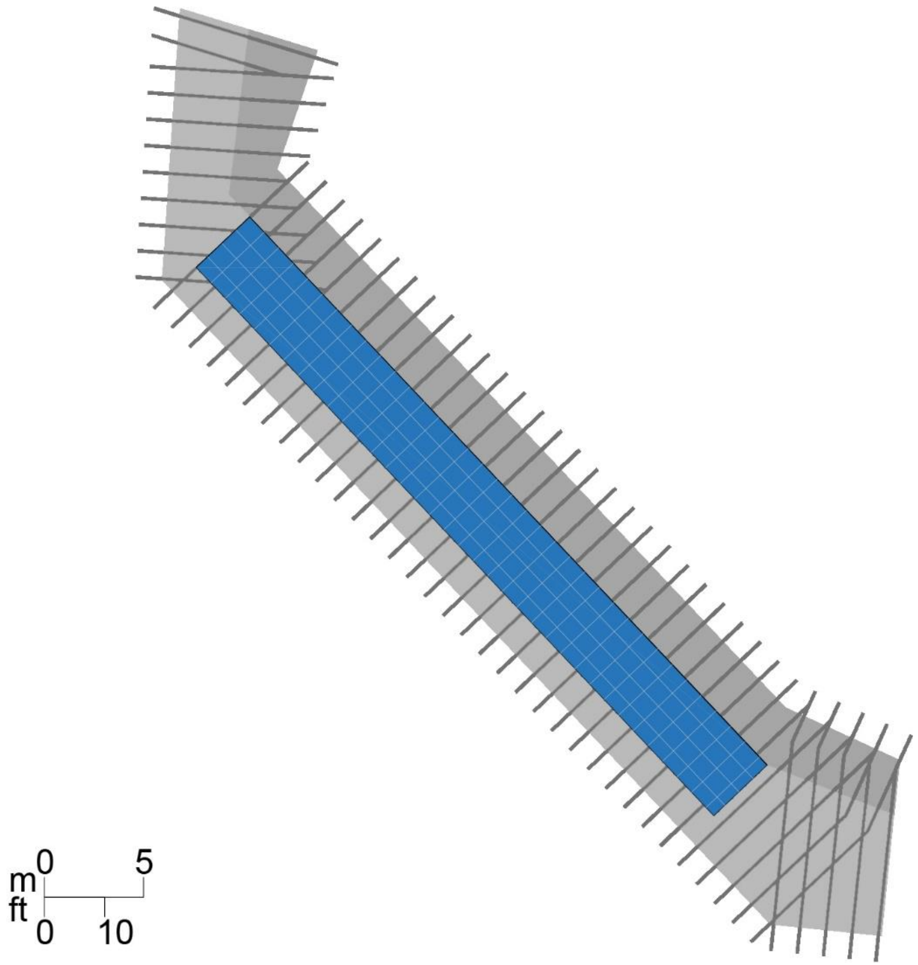
**Initial Econom**

| | |
|---|---|
| Average Cost of Electricity Purchased from Utility | 0.10 $/kWh |
| Initial Cost | 3.30 $/Wdc |
| Cost of Electricity Generated by System | 0.16 $/kWh |

**Building area: 4269 $m^2$**
**PV area: 507 $m^2$**
**Energy produced:**
**~32.5 kWh/$m^2$**
**Energy produced if the entire roof was harnessed:**
**~91.13 kWh/$m^2$**

# Solar potential and PV

## Roof-top Photovoltaic panels – residential wing




PVWatts Calculator

**RESULTS** **38,653 kWh per Year ***

*System output may range from 36,716 to 39,515kWh per year near this location.*

| Month | Solar Radiation ( kWh / m$^2$ / day ) | AC Energy ( kWh ) | Energy Value ( $ ) |
|---|---|---|---|
| January | 4.64 | 2,524 | 302 |
| February | 5.35 | 2,592 | 310 |
| March | 6.18 | 3,259 | 390 |
| April | 7.56 | 3,766 | 450 |
| May | 7.76 | 3,917 | 468 |
| June | 7.99 | 3,745 | 448 |
| July | 7.46 | 3,626 | 434 |
| August | 7.38 | 3,605 | 431 |
| September | 7.13 | 3,396 | 406 |
| October | 5.99 | 3,052 | 365 |
| November | 5.23 | 2,694 | 322 |
| December | 4.52 | 2,478 | 296 |
| Annual | 6.43 | 38,654 | $ 4,622 |

**Location and Station Identification**

| | |
|---|---|
| Requested Location | phoenix |
| Weather Data | 2 mi |
| Latitude | |
| Longitude | |

**PV System S**

| | |
|---|---|
| DC System Siz | |
| Module Type | |
| Array Type | |
| Array Tilt | |
| Array Azimuth | |
| System Losse | |
| Inverter Efficie | |
| DC to AC Size | |

**Building area: 1338 m$^2$**
**PV area: 141 m$^2$**
**Energy produced:**
**~28.9 kWh/m$^2$**
**Energy produced if the entire roof was harnessed:**
**~91.27 kWh/m$^2$**

**Initial Econo**

| | |
|---|---|
| Average Cost of Electricity Purchased from Utility | 0.12 $/kWh |
| Initial Cost | 3.30 $/Wdc |
| Cost of Electricity Generated by System | 0.16 $/kWh |

That’s all we have…

# Thanks!