Tempe, AZ

Multi-criteria decision making

The primary concern in this climate is identified as heat stress in most hours of the year which have been addressed using various strategies based on rules of thumb, the local context and climate and subsequent simulation results.

Microclimate was the initial concept as Passive design strategy in hot and dry climate and a very good example of Microclimate was Persian garden. we were inspired by the idea of Persian garden which is like a treasure garden in hot and dry climate.

The main design idea was to use courtyard to shade the outdoor space by mass, and going deeper into the ground to block the radiation. The main elements of Persian garden are applied in the design of site plan and the whole design is inspired of it.

Optimum shading was critical to block the harsh radiation, and rotating fins which are tracking sun are functioning as not to let the sun vectors touch the glass.

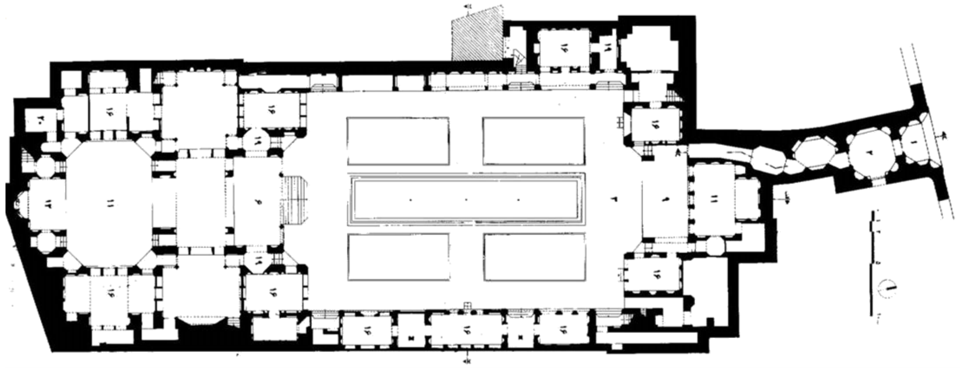
Analyzing the natural ventilation charts showed that there weren't many hours during the year when the use of natural ventilation was feasible unless the air was cooled down.

To cool down the air we designed a microclimate and took the cooled air into the building to passively cool the indoor spaces.
Solar chimneys are designed to take the hot air out of the building and create air flow.

Analysis also showed there are hours in months of summer when shade is not enough to create comfortable spaces, therefore other strategies based on psychrometric charts were added such as evaporative cooling (pool and spraying water) and night flushing.

Design inspirations – Stepped courtyards of the Persian gardens

Fig. 1, 2: Illustrative example of the Persian Courtyards in hot and dry climates



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

Rules of thumb applicable for the context

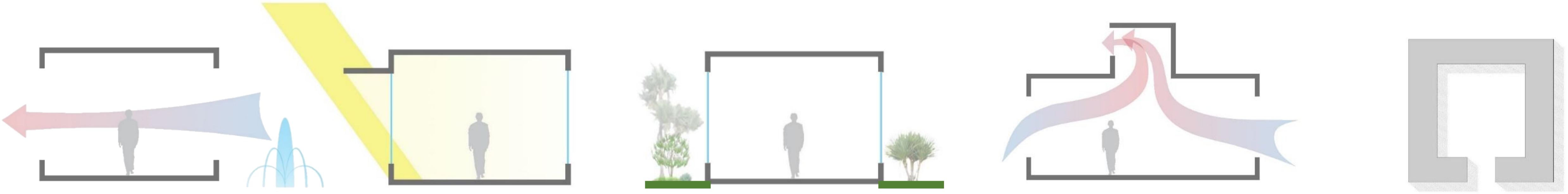


Fig. 3: (L to R) Ventilation with evaporative cooling, Daylighting, Shade through plantation, Stack effect and Courtyard

Weather data

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.

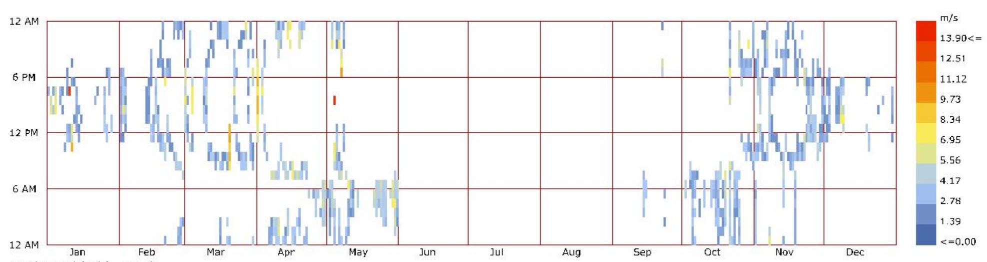
Arizona experiences among the highest levels of radiation in the US with total radiation exceeding 1200 kWh/m2

The wind speed is typically low and rarely exceeding 4 m/s with gusts of wind exceeding 40°C in temperature

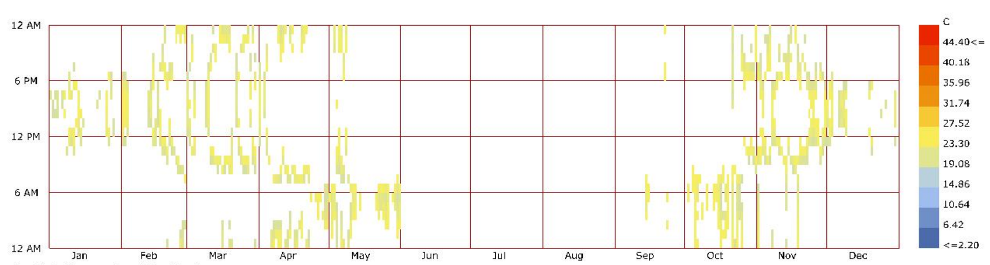
Being a desert, the Phoenix metro region experiences sparse rainfall averaging about 200 mm (~8") annually. Therefore the skies are mostly clear

Summary: Harsh sun, low humidity, low wind speed, less water and intense radiation

To be Design for cooling

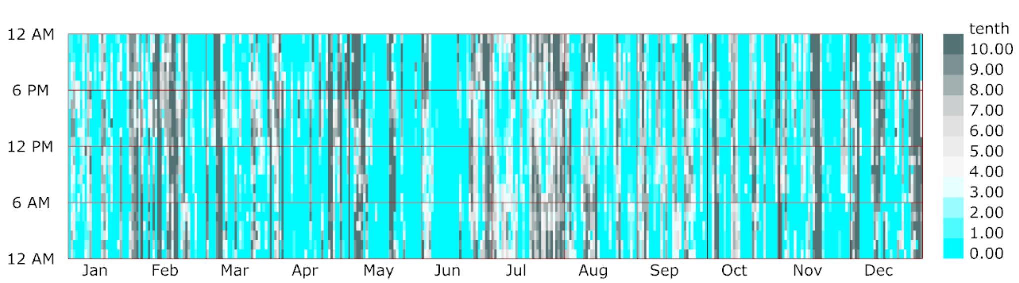


Wind Speed (m/s) - Hourly
Phoenix Sky Harbor Intl Ap AZ USA
1 JAN 1:00 - 31 DEC 24:00

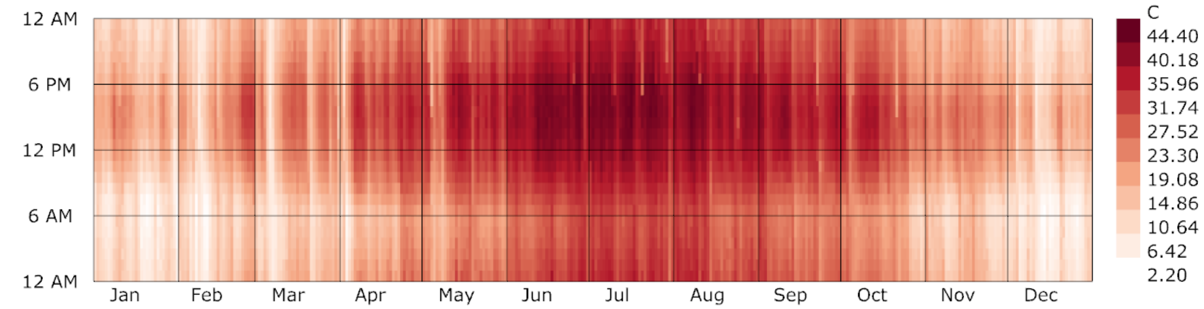


Dry Bulb Temperature (C) - Hourly
Phoenix Sky Harbor Intl Ap AZ USA
1 JAN 1:00 - 31 DEC 24:00

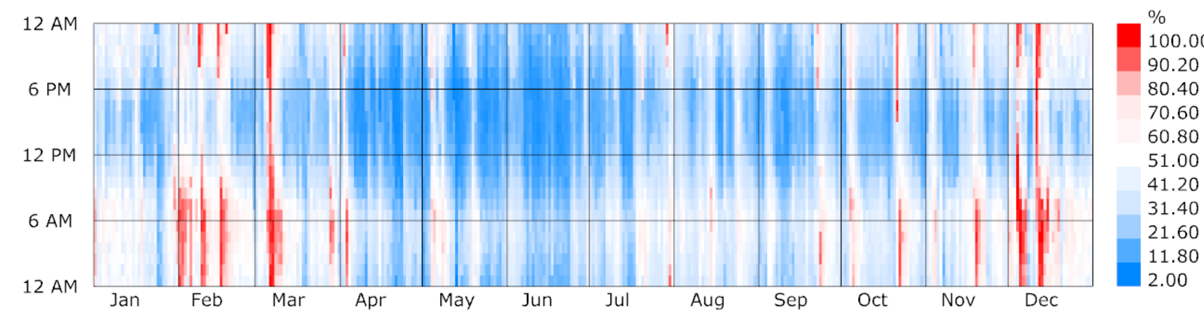
Fig. 4,5: (L to R) The wind speed that falls within the comfortable dry-bulb temperature range in the region



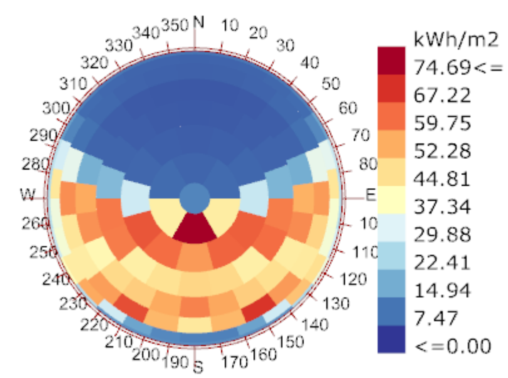
Total Cloud Cover (tenth) - Hourly
Phoenix Sky Harbor Intl Ap_AZ_USA
1 JAN 1:00 - 31 DEC 24:00



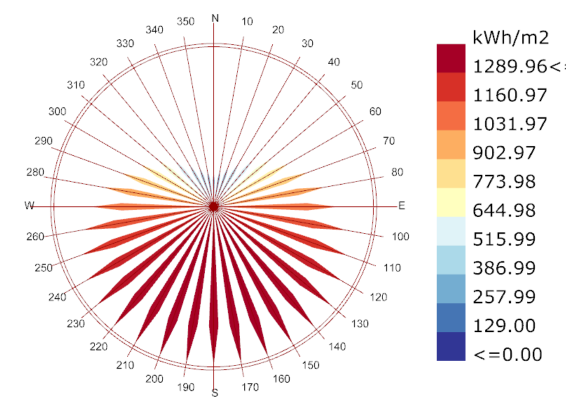
Dry Bulb Temperature (C) - Hourly
Phoenix Sky Harbor Intl Ap_AZ_USA
1 JAN 1:00 - 31 DEC 24:00



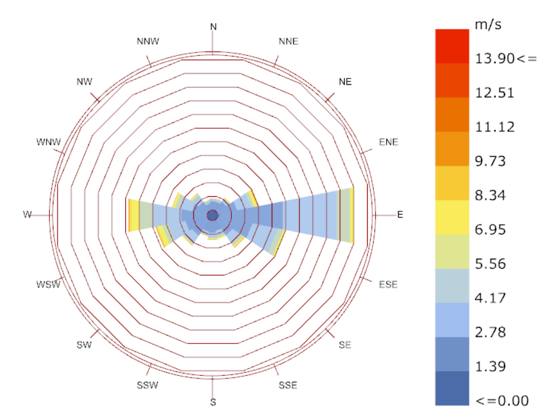
Relative Humidity (%) - Hourly
Phoenix Sky Harbor Intl Ap_AZ_USA
1 JAN 1:00 - 31 DEC 24:00



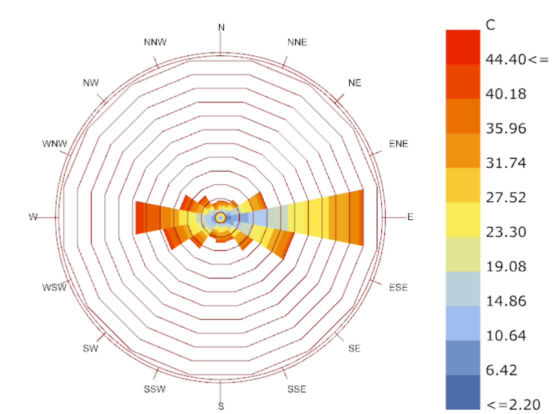
Total Radiation(kWh/m2)
Phoenix_Sky_Harbor_Intl_Ap_AZ_USA
1 JAN 1:00 - 31 DEC 24:00



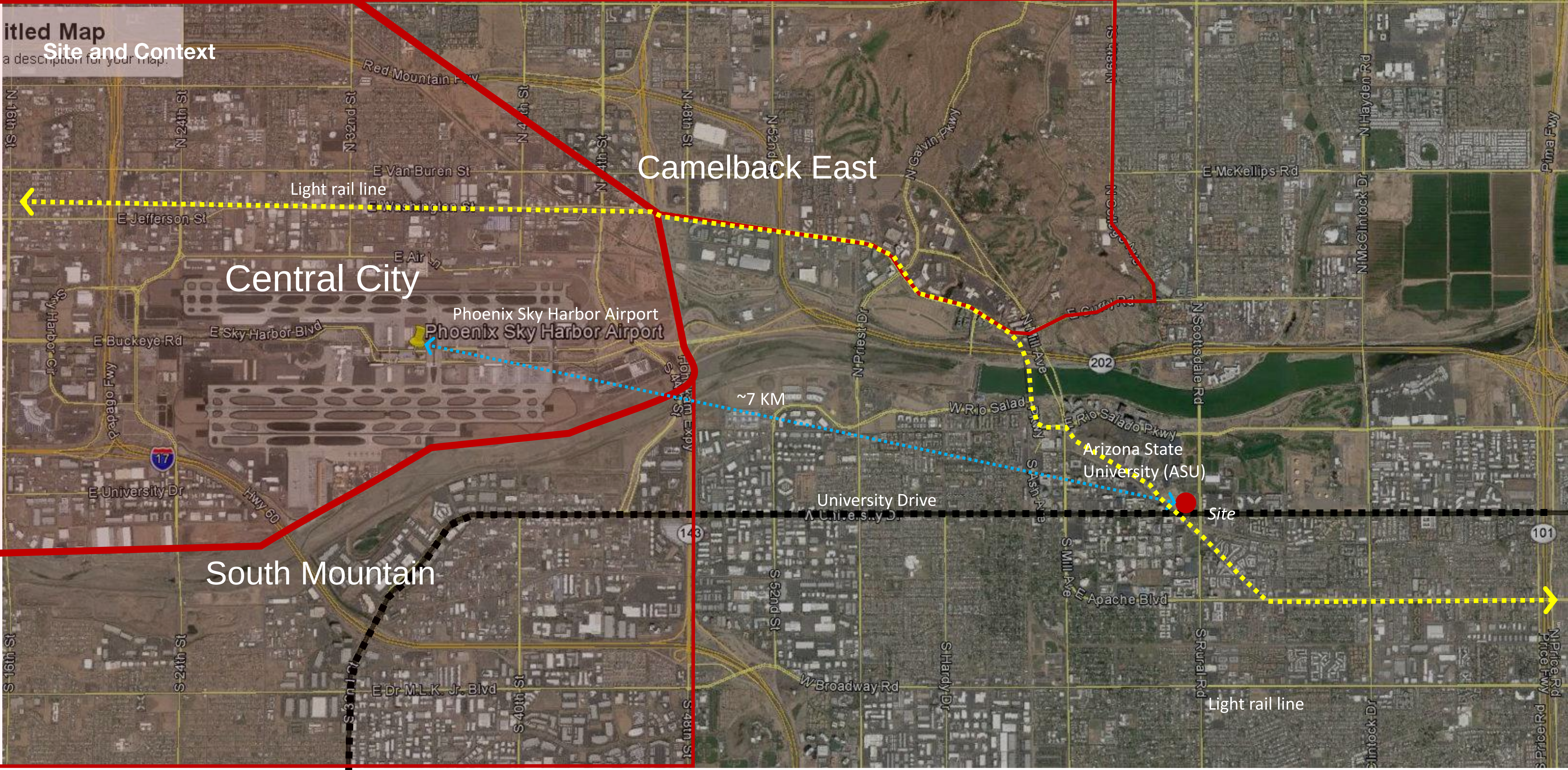
Total Radiation(kWh/m2)
Phoenix_Sky_Harbor_Intl_Ap_AZ_USA
1 JAN 1:00 - 31 DEC 24:00

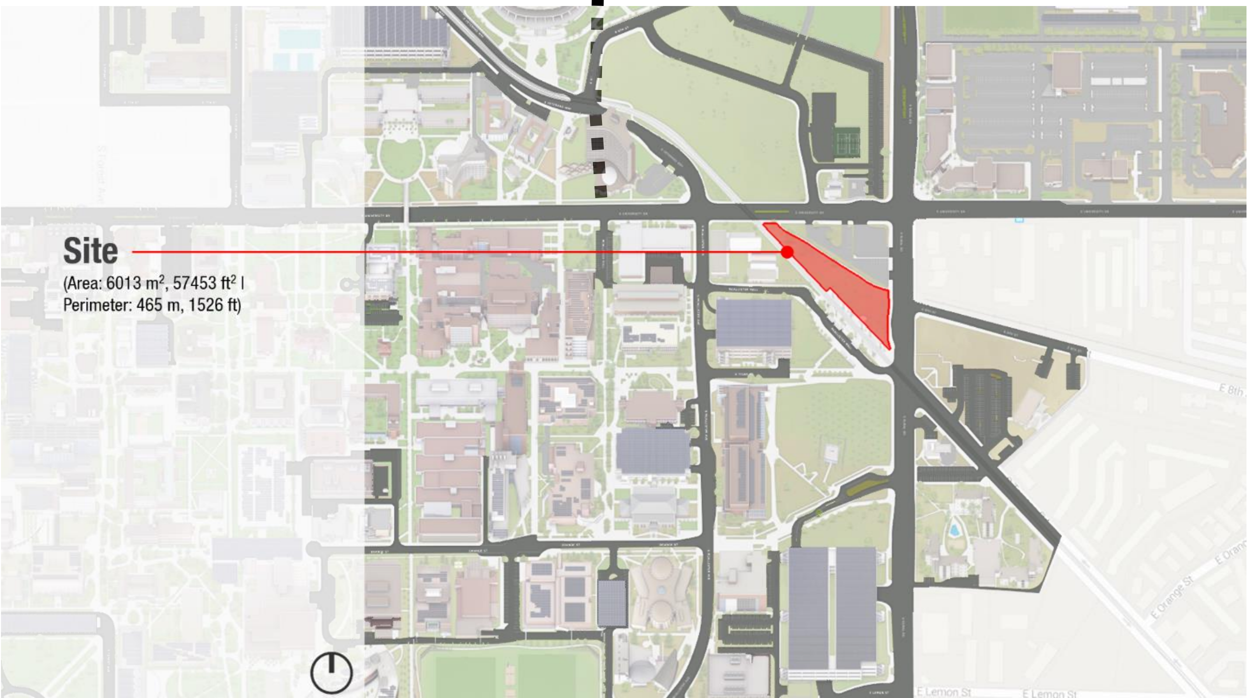


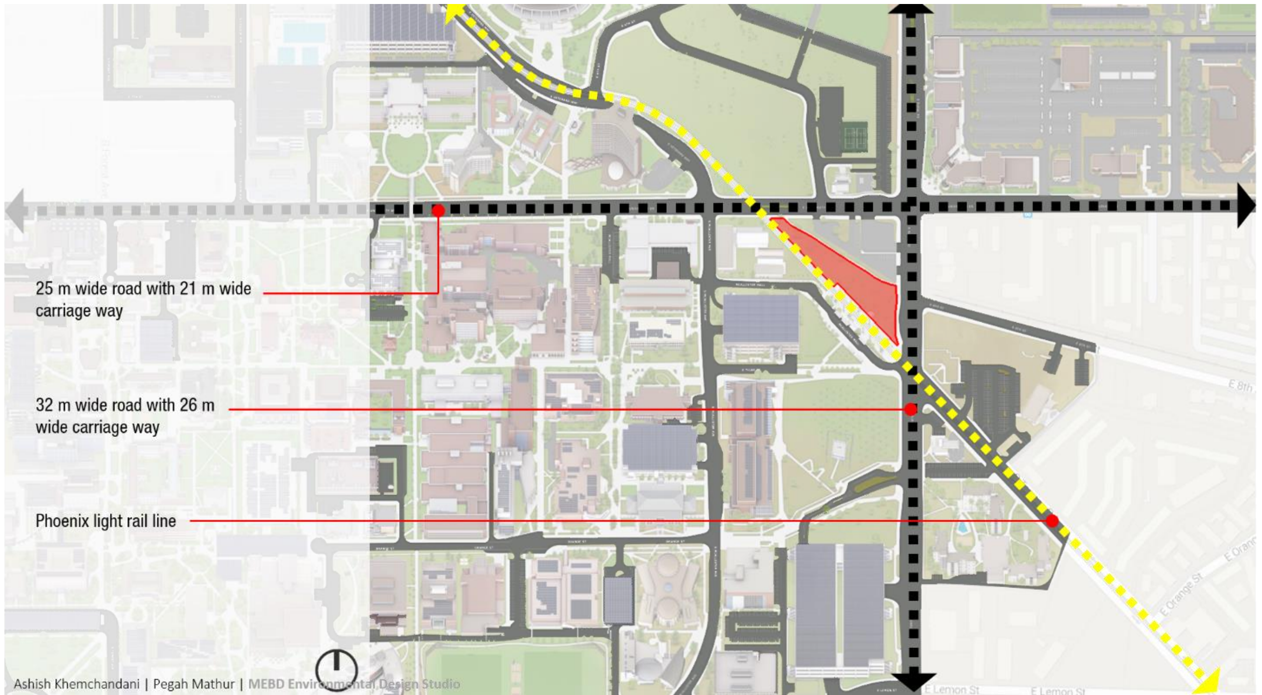
Wind-Rose
Phoenix Sky Harbor Intl Ap_AZ_USA
1 JAN 1:00 - 31 DEC 24:00
Hourly Data: Wind Speed (m/s)
Calm for 12.08% of the time = 1058 hours.
Each closed polyline shows frequency of 2.0%. = 172 hours.



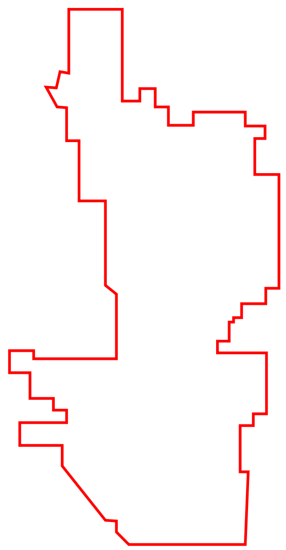
Wind-Rose
Phoenix Sky Harbor Intl Ap_AZ_USA
1 JAN 1:00 - 31 DEC 24:00
Hourly Data: Dry Bulb Temperature (C)
Calm for 12.08% of the time = 1058 hours.
Each closed polyline shows frequency of 2.0%. = 172 hours.


itled Map
Site and Context
a description for your map.
Camelback East
Central City
South Mountain
Light rail line
Phoenix Sky Harbor Airport
~7 KM
Arizona State University (ASU)
University Drive
Site
Light rail line
E Van Buren St
E Jefferson St
E Washington St
E Air Ln
E Sky Harbor Blvd
E Buckeye Rd
E University Dr
Red Mountain Fwy
E McKellips Rd
W Rio Salado Pkwy
E Rio Salado Pkwy
E Apache Blvd
W Broadway Rd
E Dr M.L.K. Jr. Blvd
N Scottsdale Rd
S Rural Rd
N Hayden Rd
N McClintock Dr
S Mill Ave
S Hardy Dr
N Priest Dr
Pima Fwy
Papago Fwy
Hwy 60
202
143
101
17


Site
(Area: 6013 m², 57453 ft² | Perimeter: 465 m, 1526 ft)

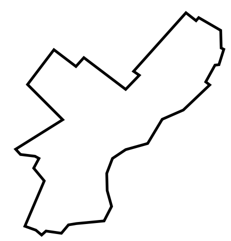

25 m wide road with 21 m wide carriage way
32 m wide road with 26 m wide carriage way
Phoenix light rail line
Ashish Khemchandani | Pegah Mathur | MEBD Environmental Design Studio

Analyzing the site and context



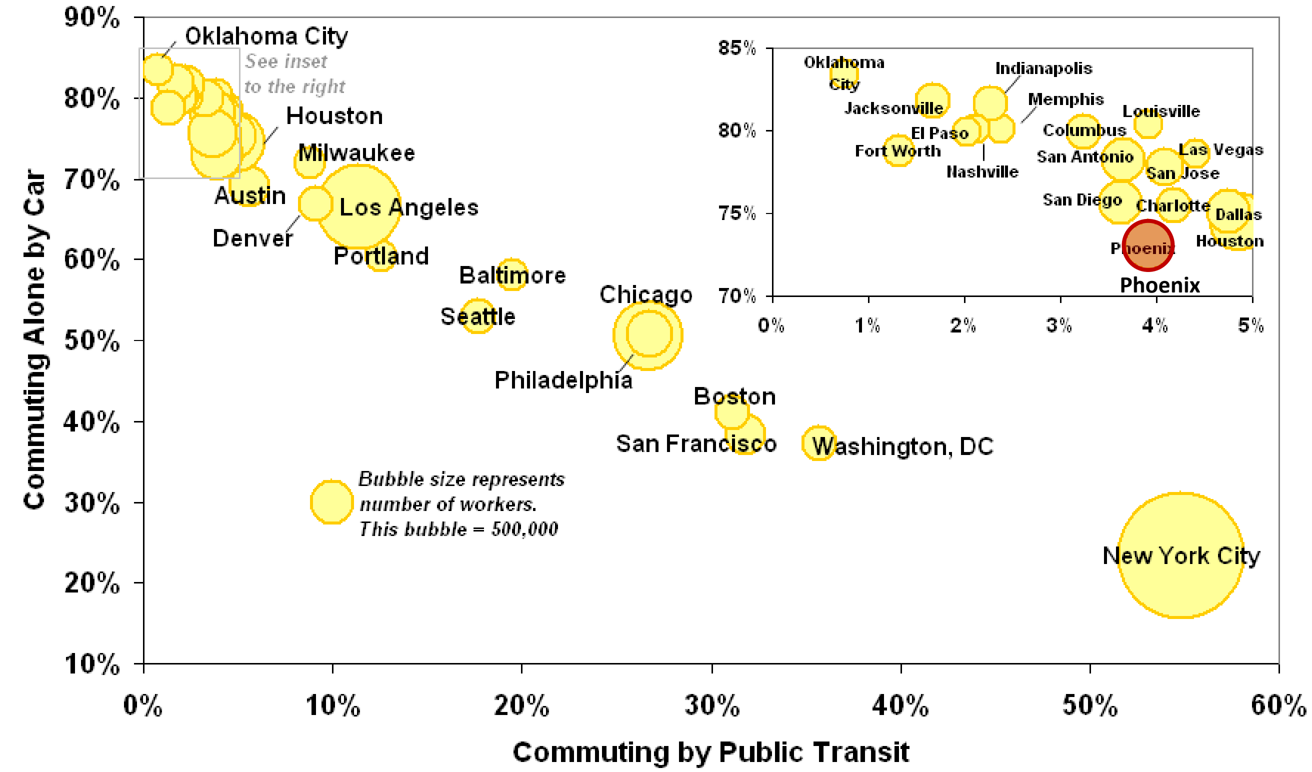
Phoenix, AZ

Area: 517.948 sq mi
Population: 14,45,632
Density: 2,967.59/ sq mi

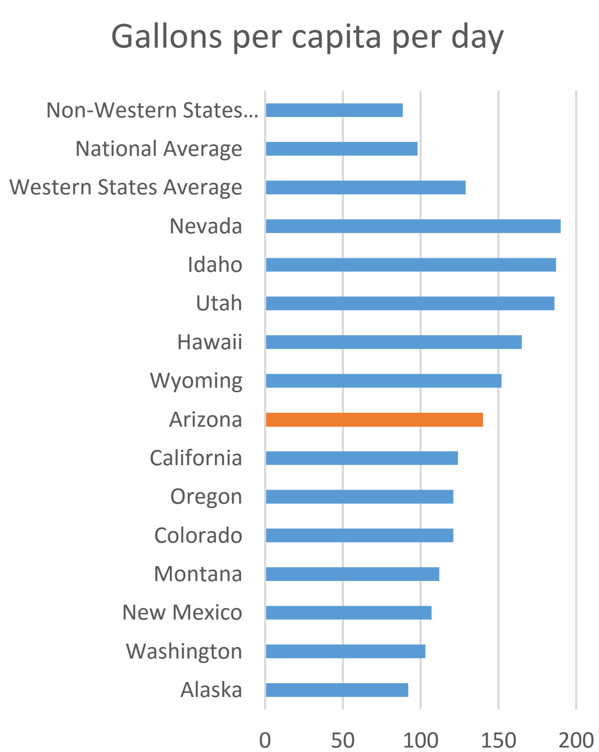


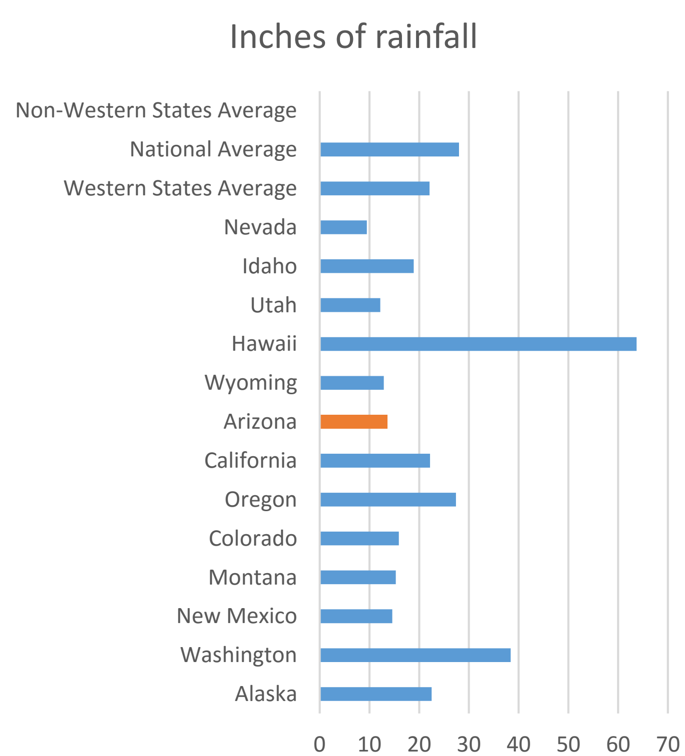
Philadelphia, PA

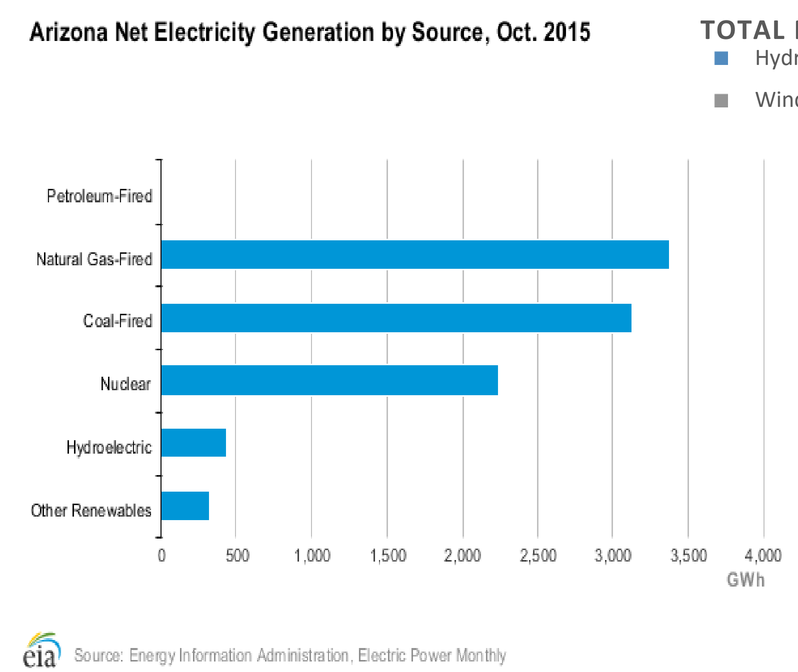
Area: 141.6 sq mi
Population: 15,60,297
Density: 11,635/ sq mi

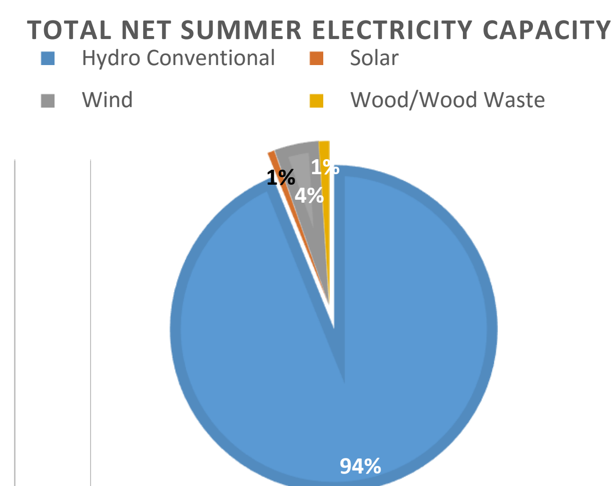


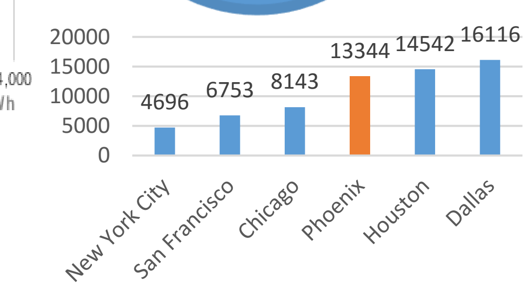
- **Population density:** Disproportionately high! Above, a comparison of Phoenix with Philadelphia, a city with similar population with a to-scale profile indicates an idea of the wide urban sprawl of the Phoenix metro-region.
- **Transport:** Use of public transport is relatively uncommon in the Phoenix region, over 70% people travel alone by car and less than 4% use mass transit.





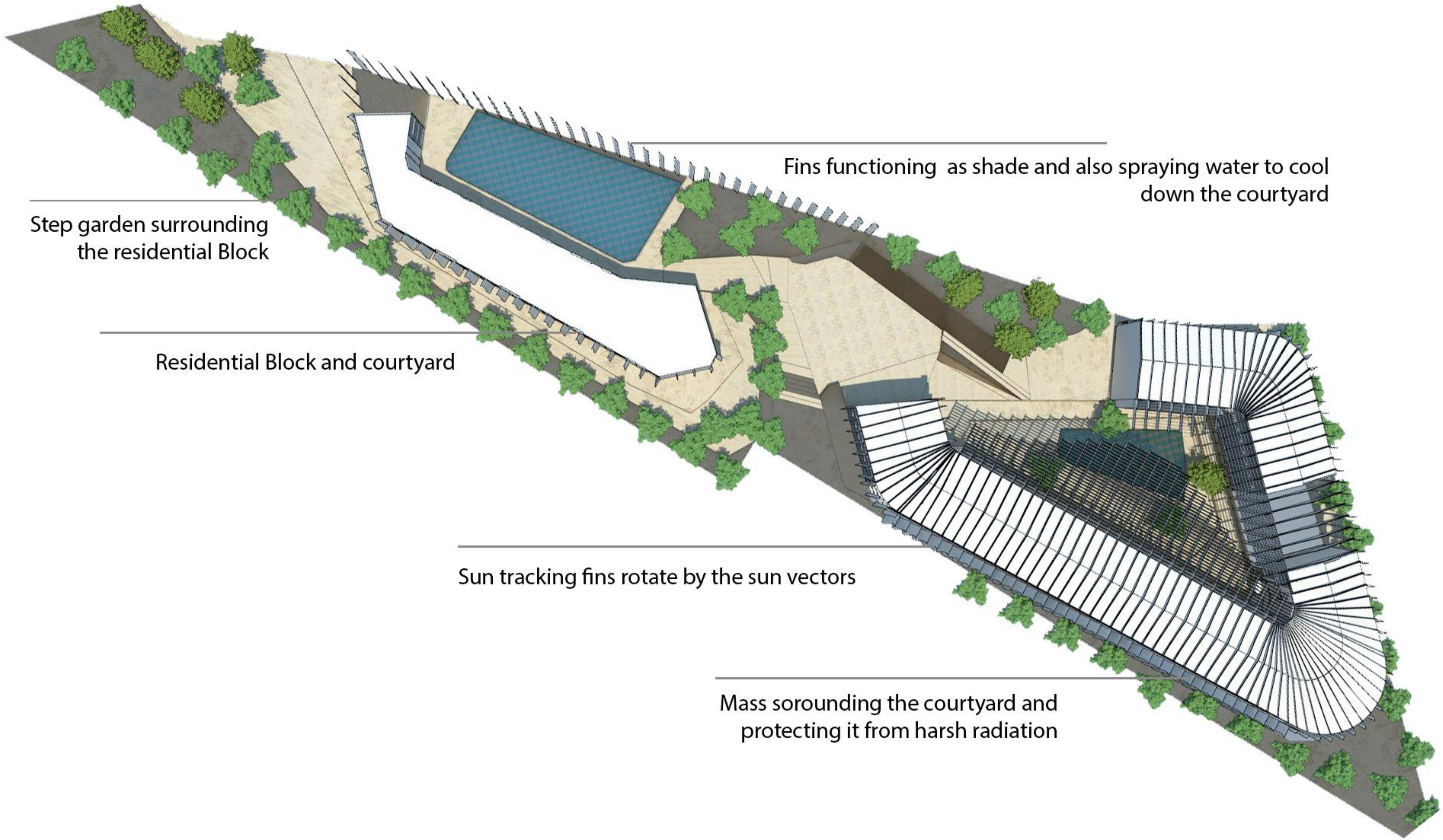




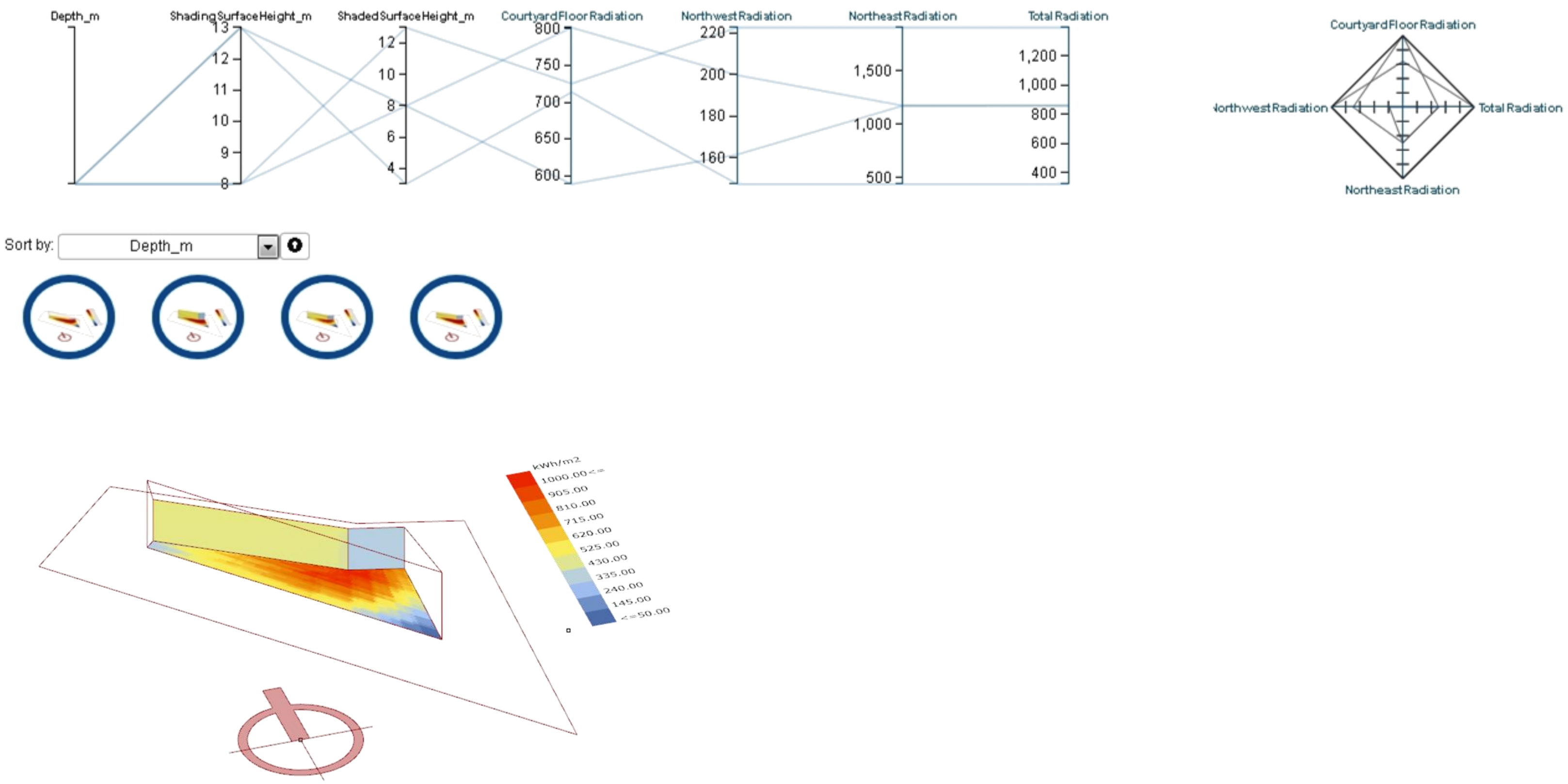


- **Water use:** Arizona mostly being a desert receives less rainfall than the national average, but the average per capita water consumption is higher than the national average. Most water used is in Irrigation.
- **Energy generation:** Arizona reserves among the highest solar potential in the country but the primary source of energy remains fossil fuels. Further more, the Phoenix energy demand outweighs other major cities such as New York and Chicago.

Site Plan


Fins functioning as shade and also spraying water to cool
down the courtyard
Step garden surrounding
the residential Block
Residential Block and courtyard
Sun tracking fins rotate by the sun vectors
Mass sorounding the courtyard and
protecting it from harsh radiation

Exploration of form based on outdoor comfort



Changing the height of the building modified the nature of the courtyard radiation and improved outdoor comfort of the courtyard

Radiation and shade in the courtyard

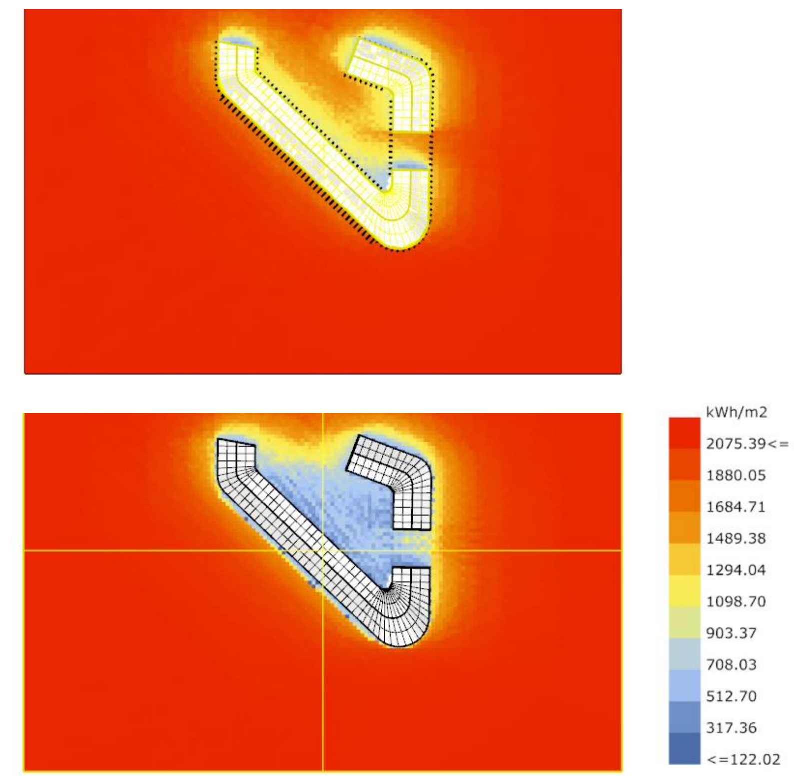
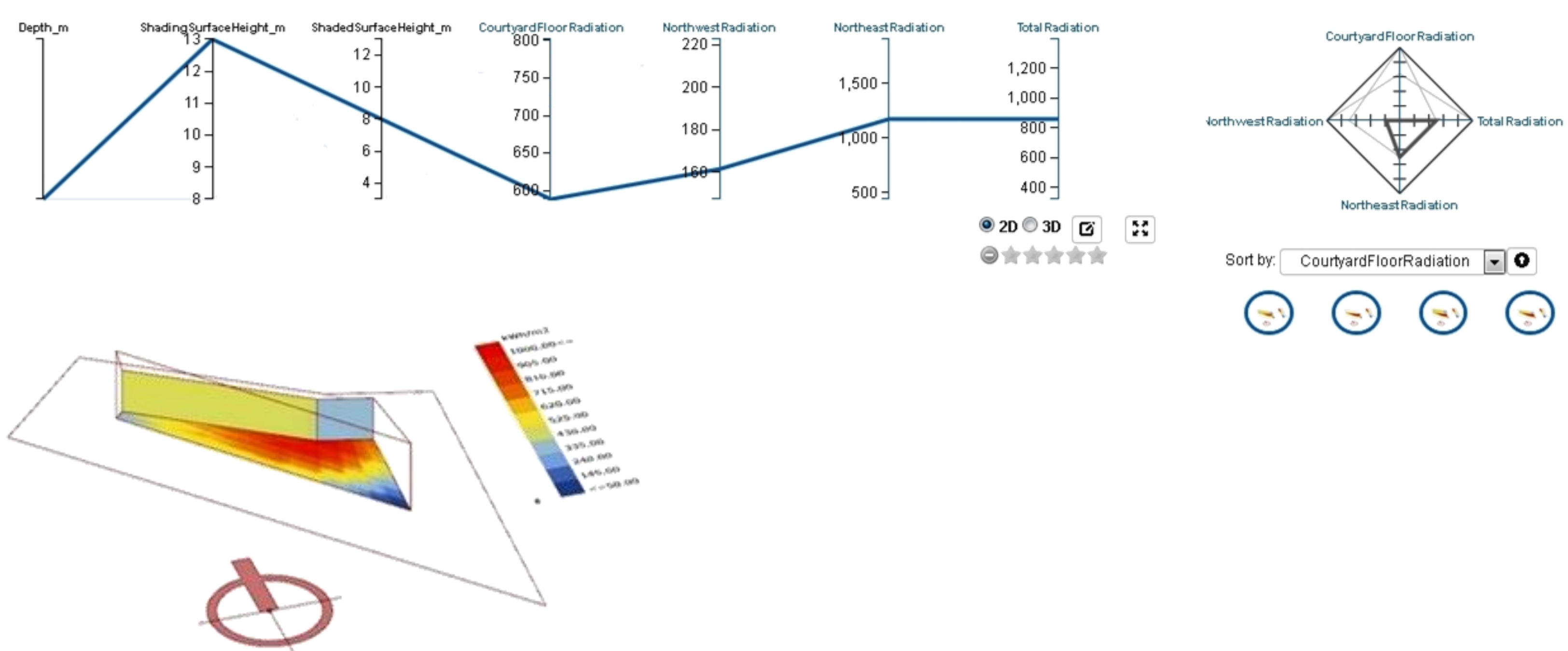


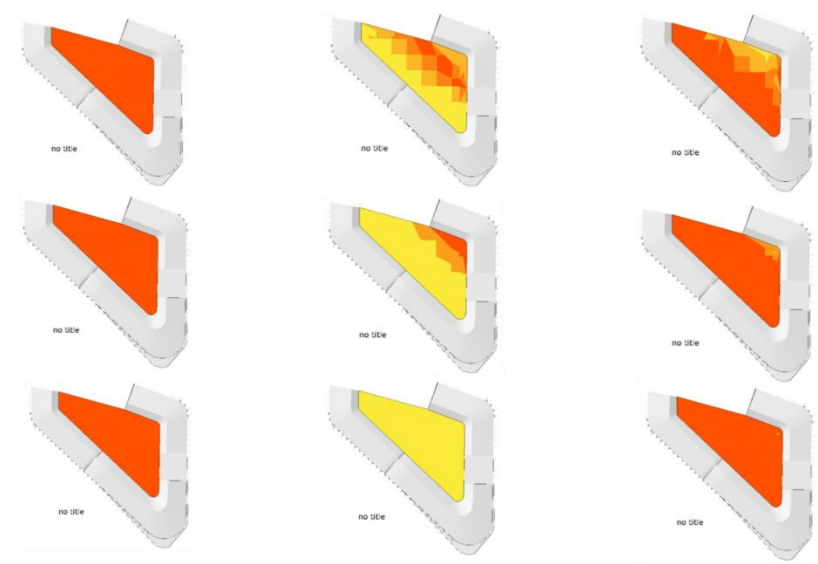
Fig. 9: Radiation analysis shows how much shade on the courtyard reduces radiation on the courtyard surface.

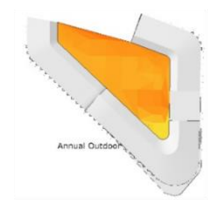


Courtyard with and without shade

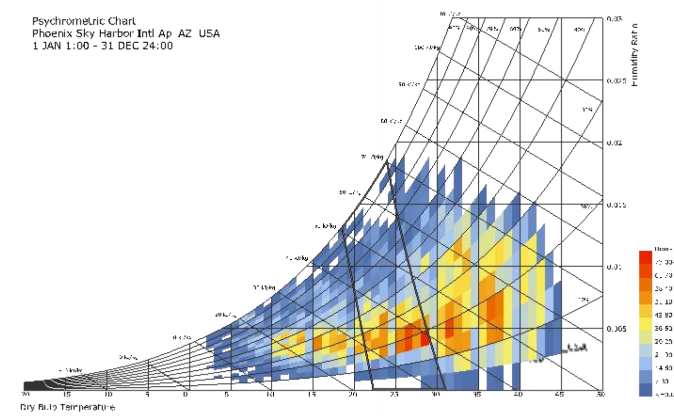
June | Sep | Dec

12-15
9-12
15-17

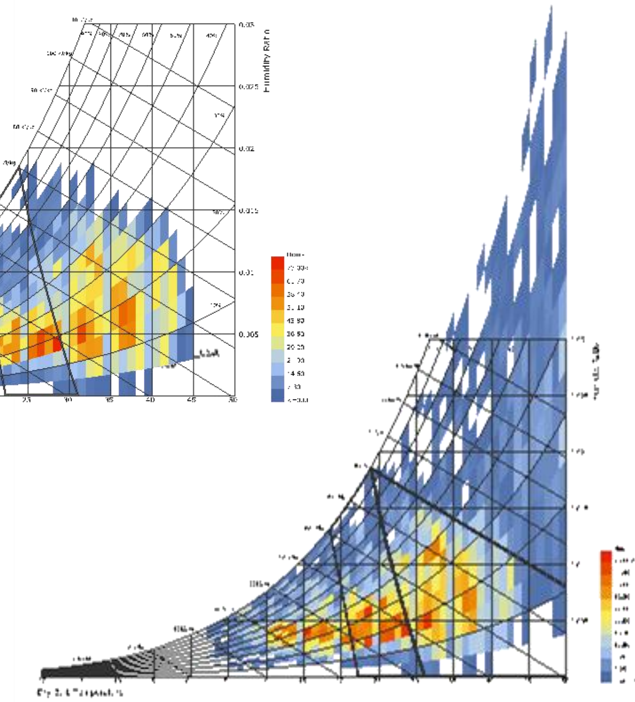




Annual **55%**



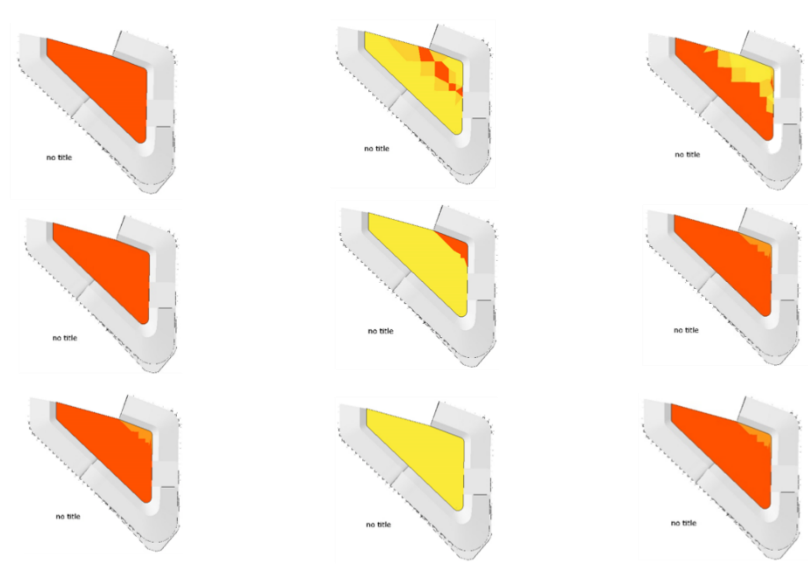
With Shade

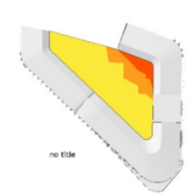


Without Shade

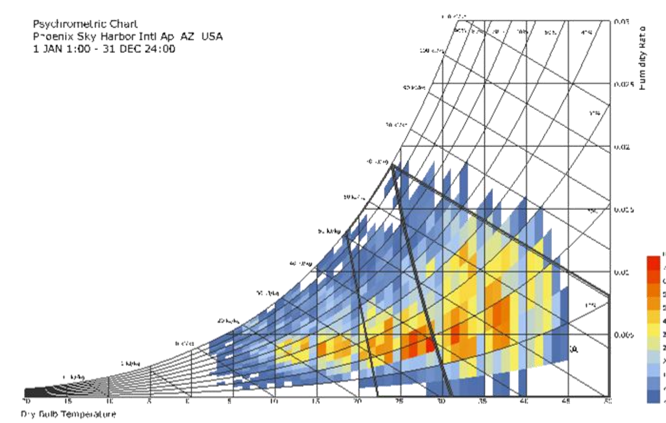
June | Sep | Dec

12-15
9-12
15-17

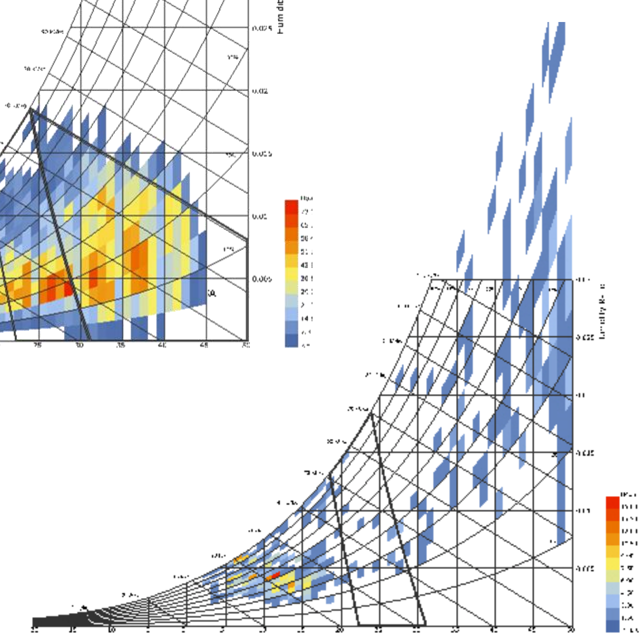




Annual **65%**

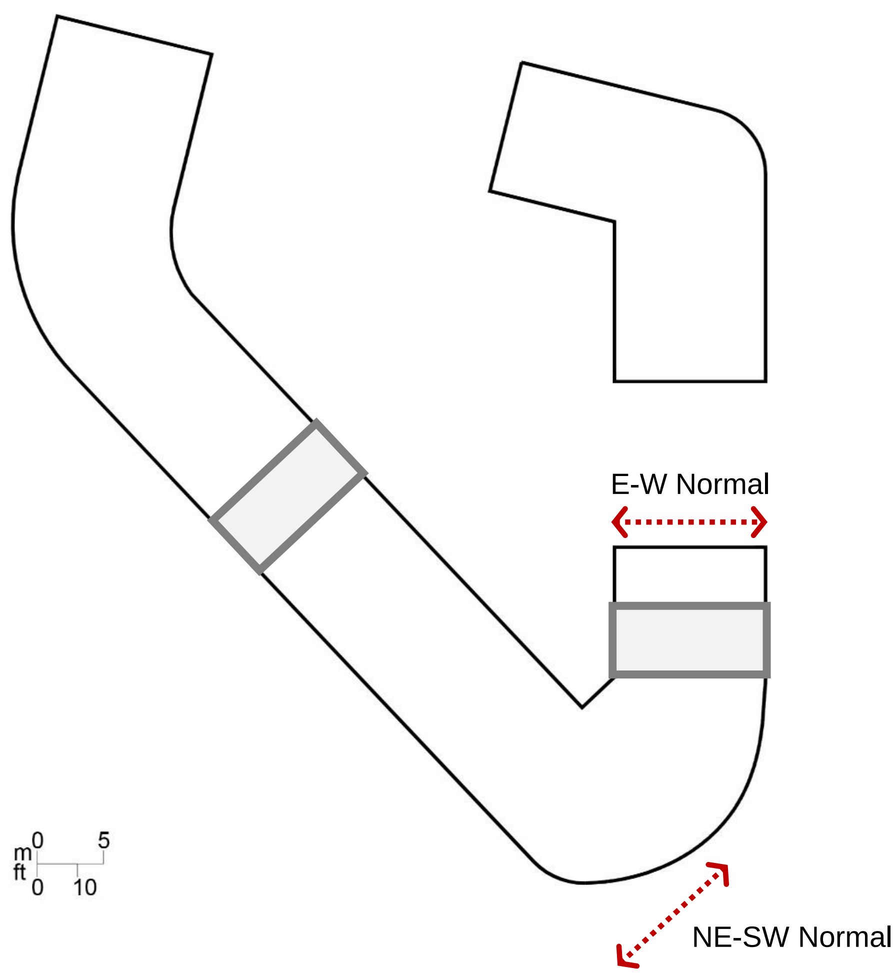


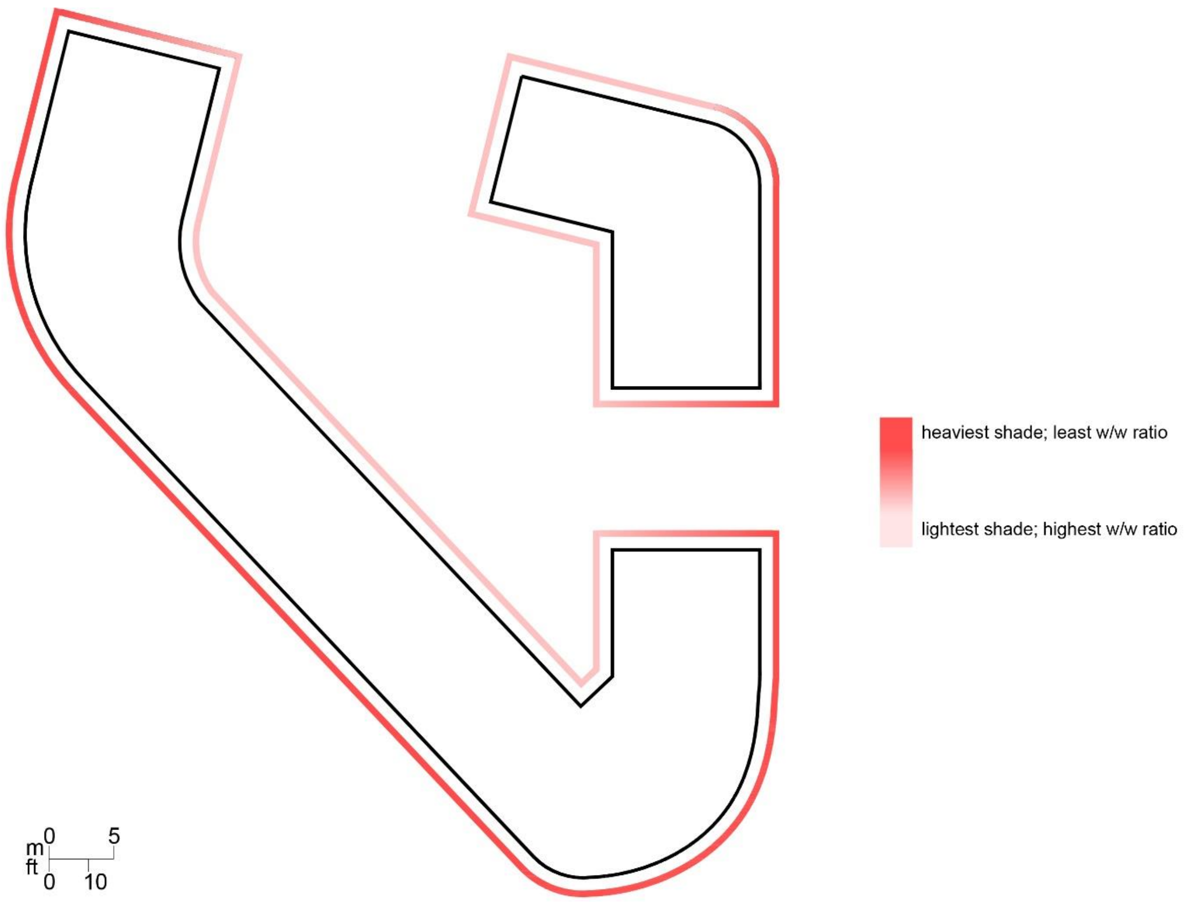
With Shade



Without Shade

Strategies employed for indoor comfort





- 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

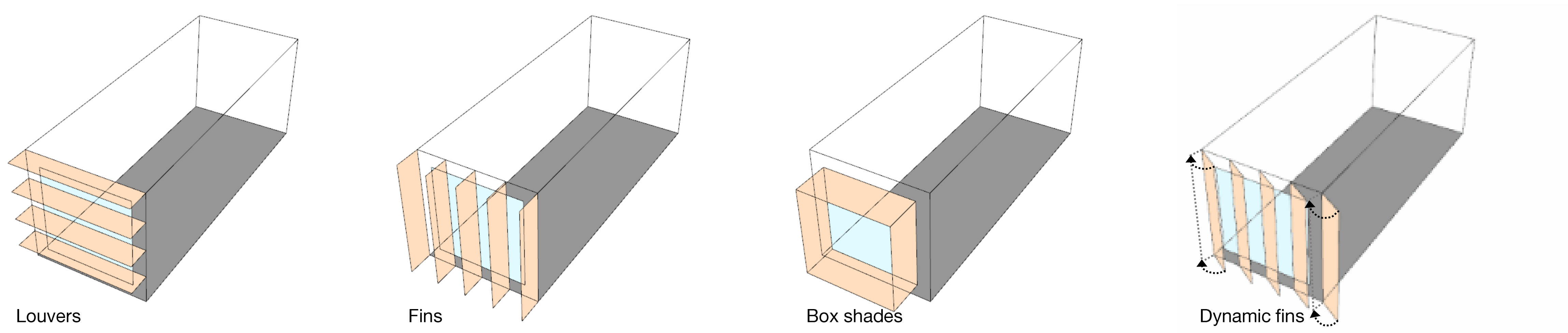
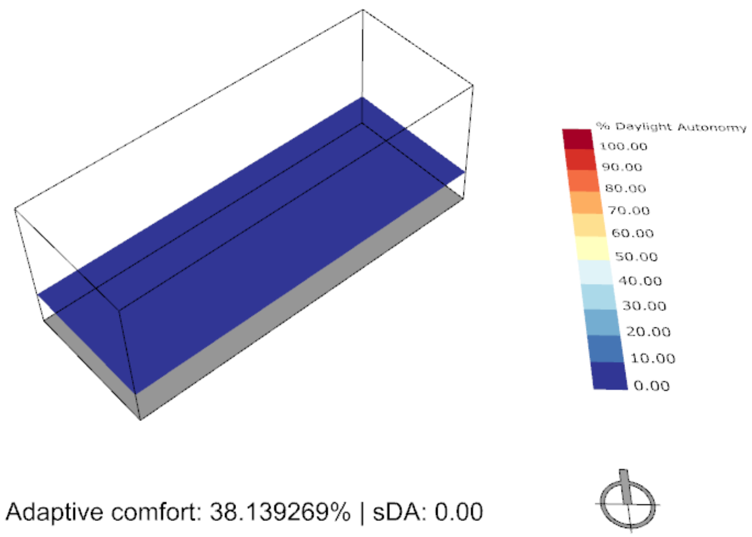
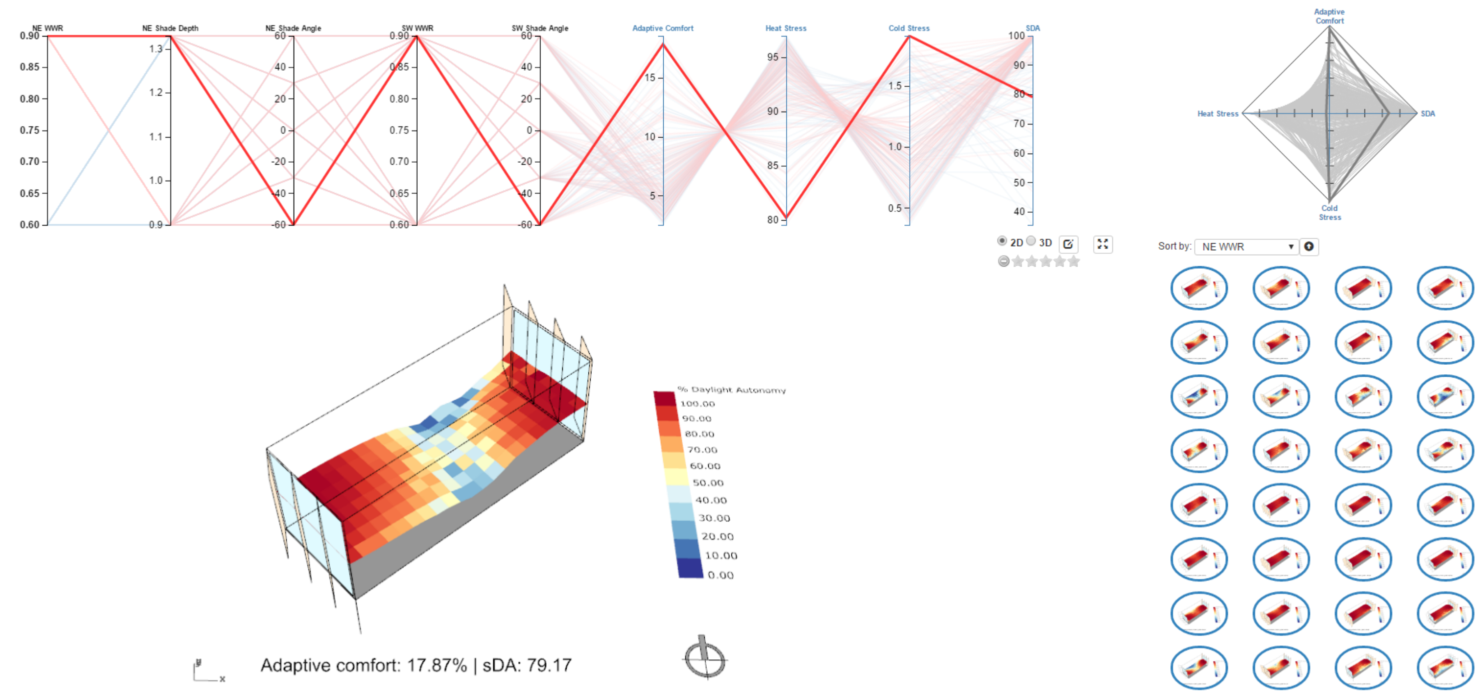


Fig. 10: Various shading strategies experimented with

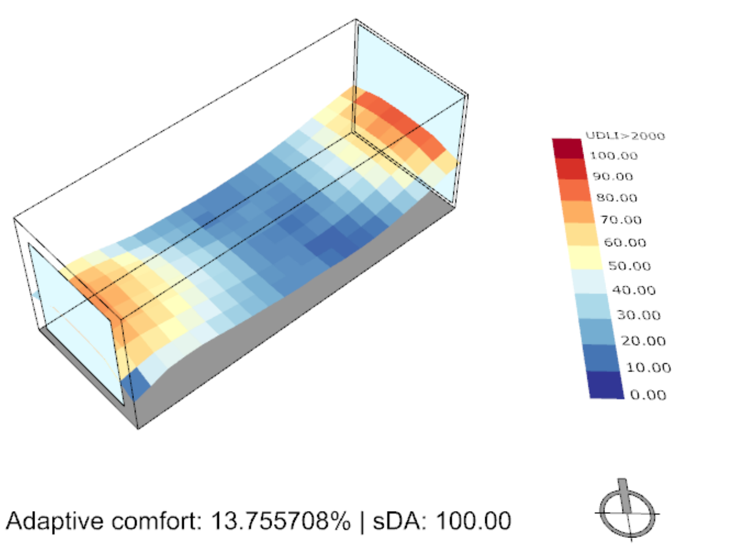
Indoor comfort



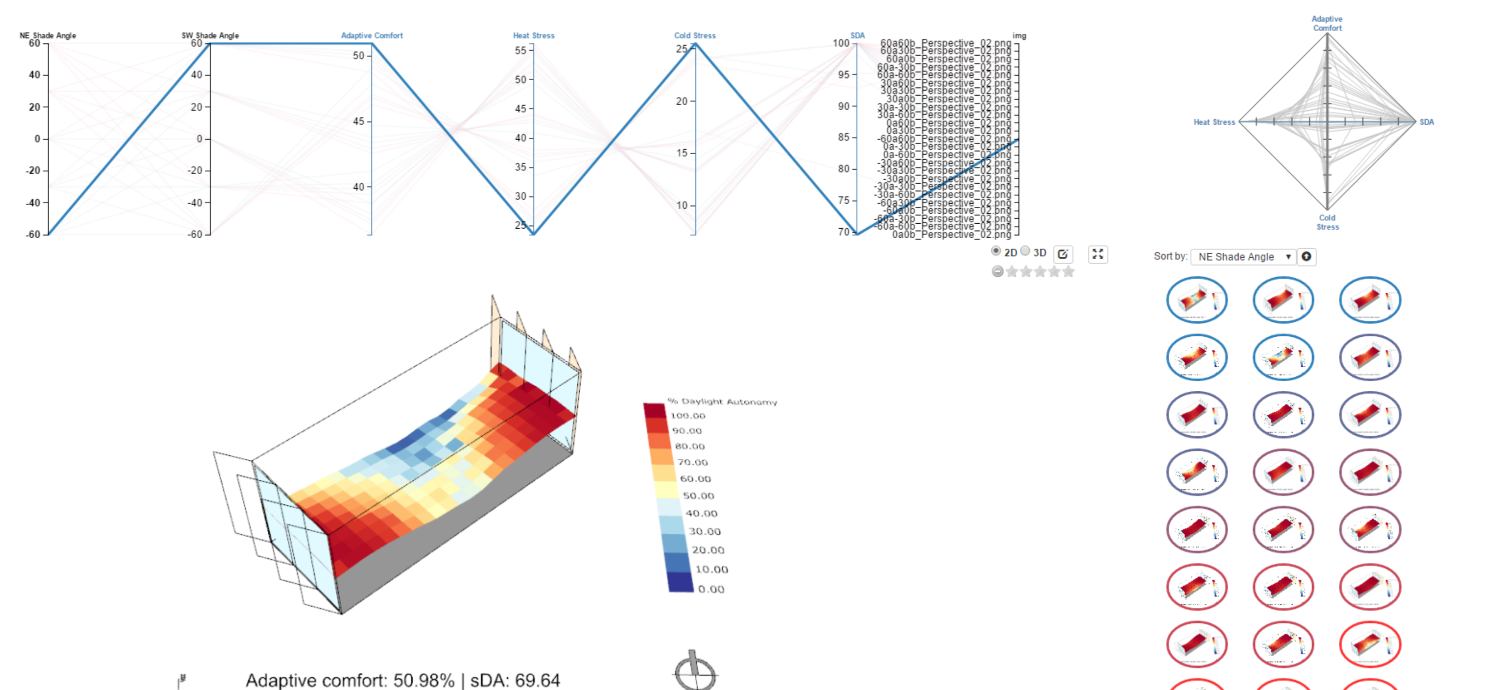
The base case



SW normal bay, summer



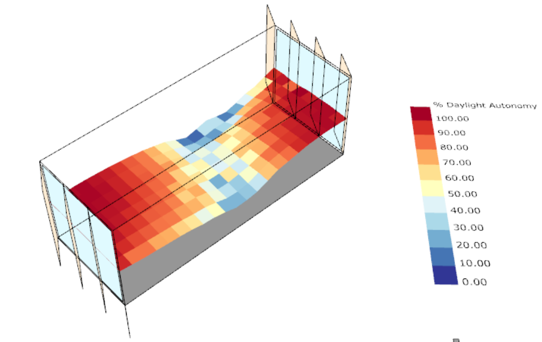
Comfort levels without shade



SW normal bay, winter

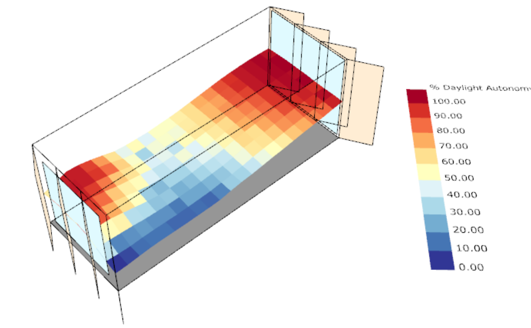
Average annual adaptive comfort: **34.45%**

Indoor comfort – Various results and observations



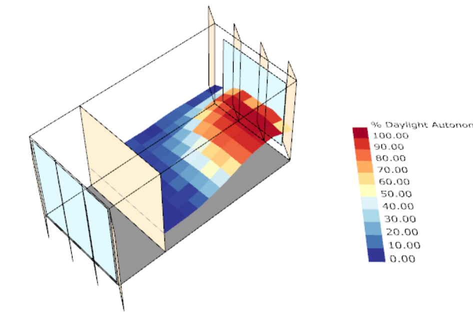
Adaptive comfort: 17.87% | sDA: 79.17

Summer



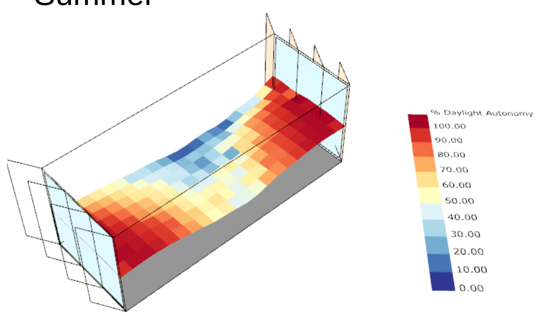
Adaptive comfort: 14.14% | sDA: 62.50

Summer



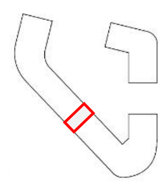
Adaptive comfort: 18.4% | sDA: 32.65

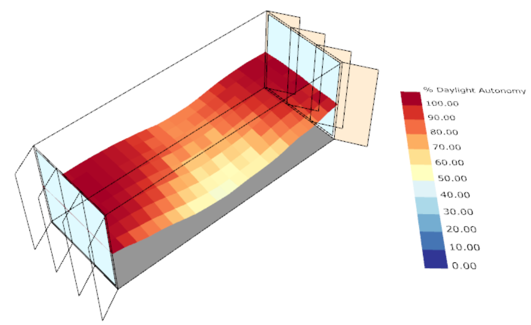
Summer



Adaptive comfort: 50.98% | sDA: 69.64

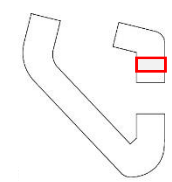
Winter

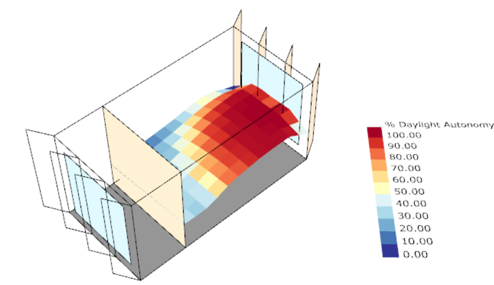




Adaptive comfort: 50.87% | sDA: 98.81

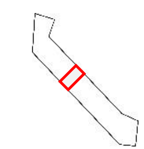
Winter





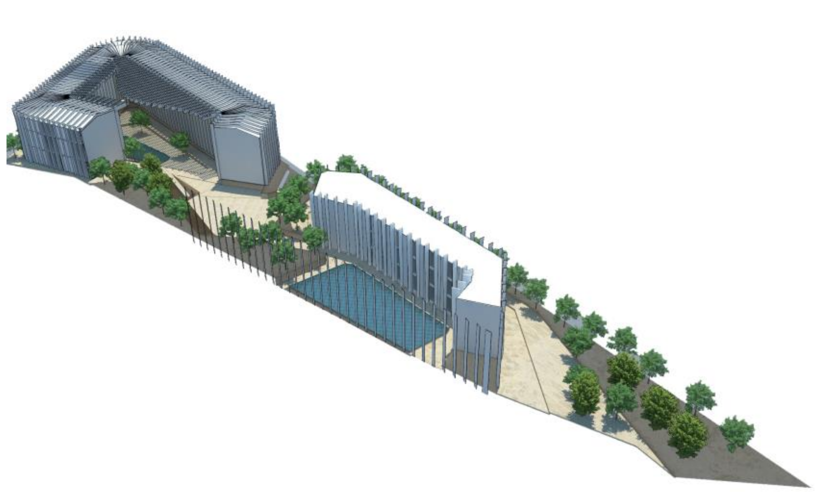
Adaptive comfort: 36.81% | sDA: 56.12

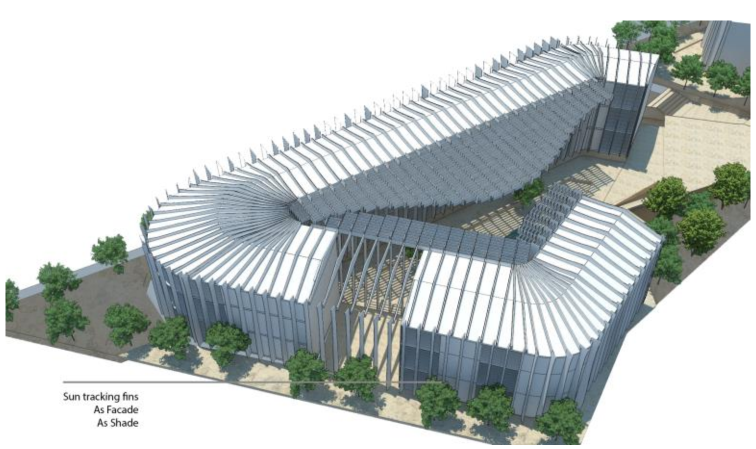
Winter

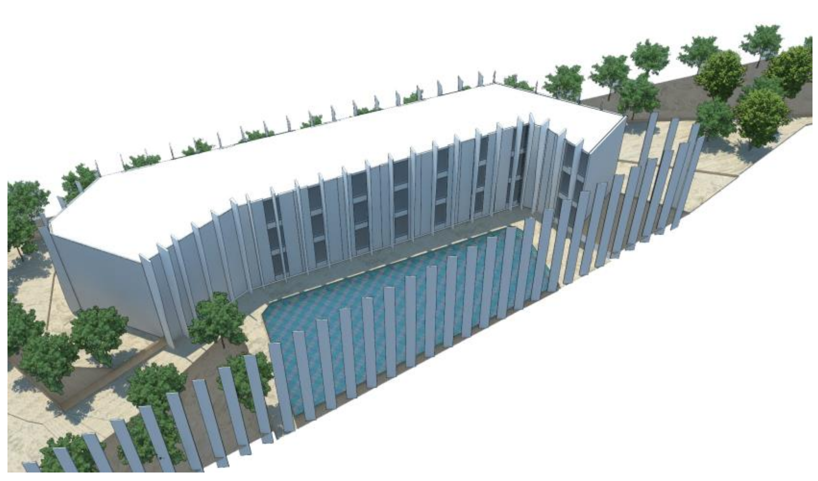


- A higher window/wall ratio to harness more daylight is feasible as long as the glazing is shaded.
- There is a clear trade-off between daylight and comfort autonomy, which can be partially addressed if the shades are dynamic
- Cross ventilation increases indoor comfort as long as the ventilation is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

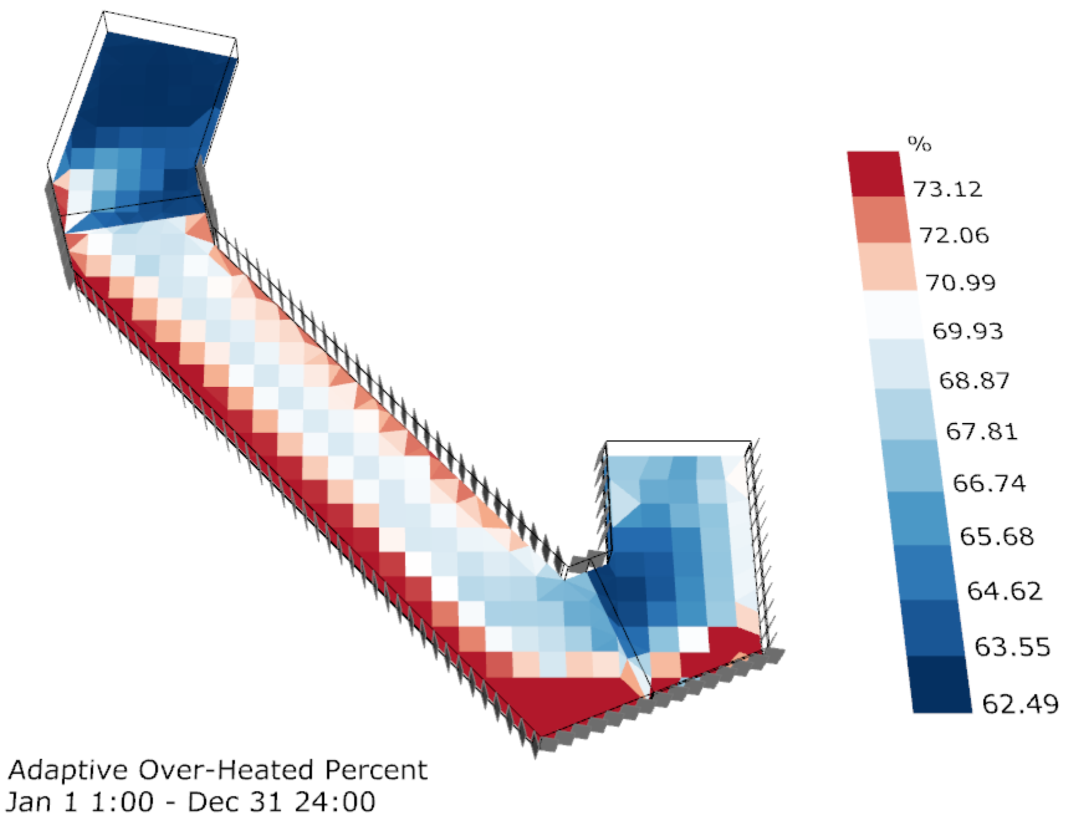
Design details

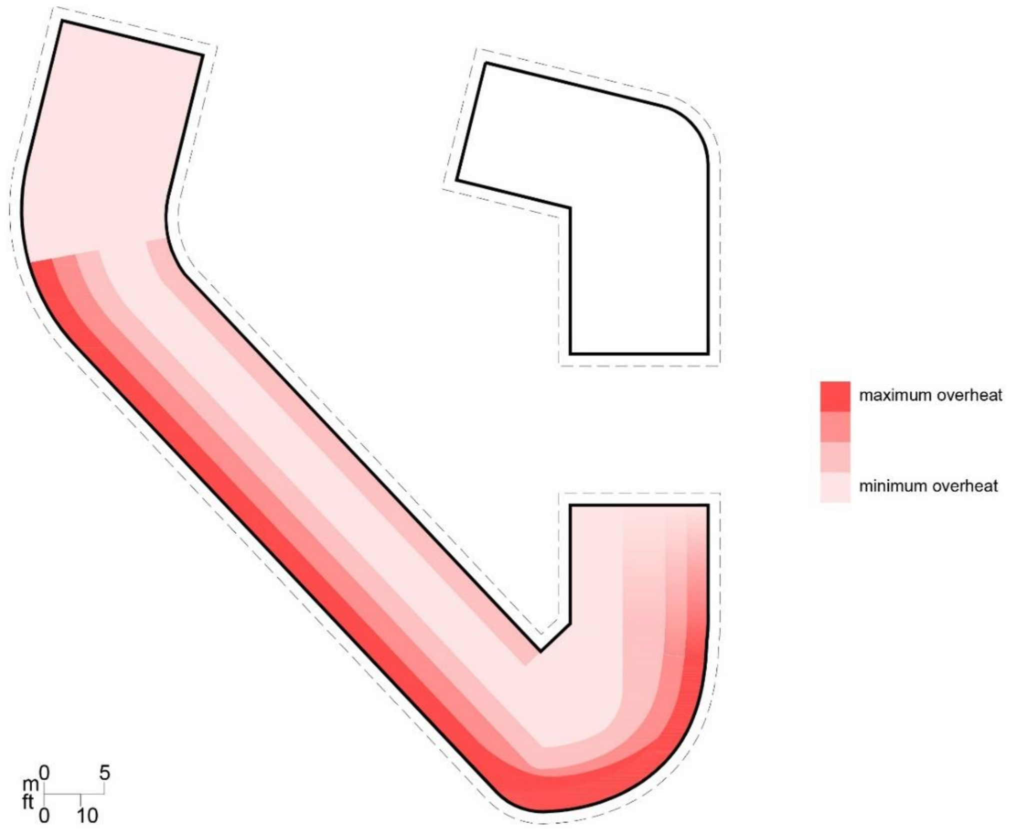




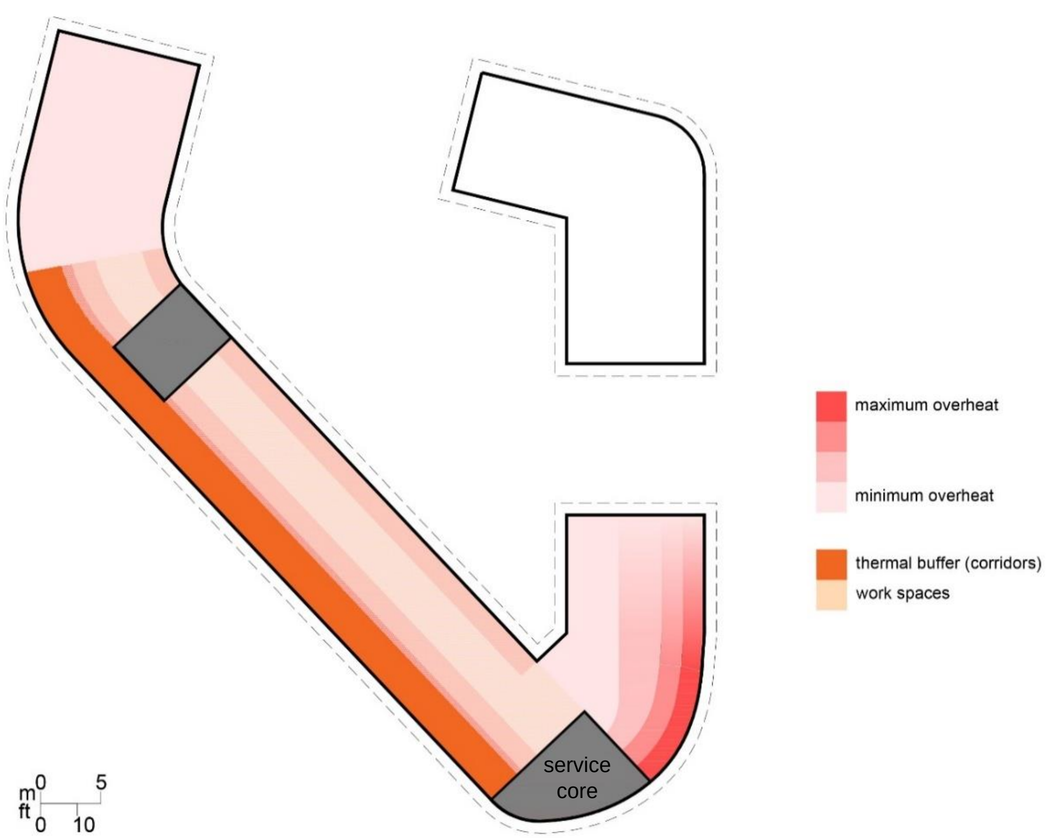


Formulation the indoor layout



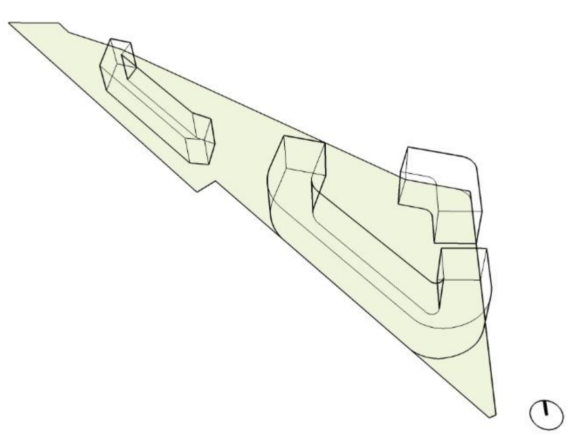


- The overheated area is closest to the area subjected to the highest radiation

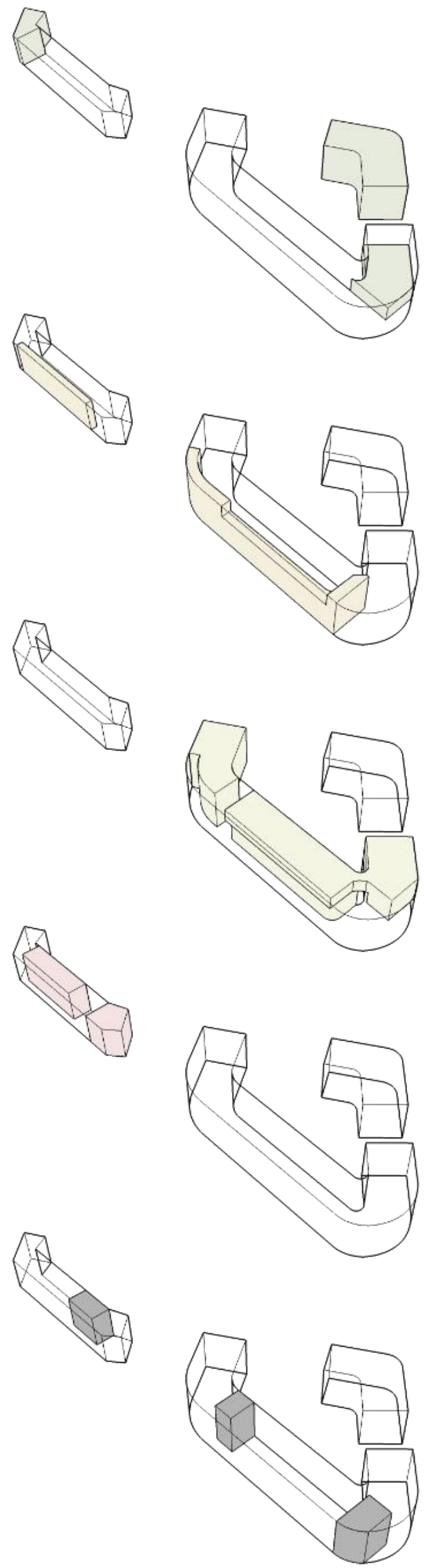


- The service core and the passages and corridors are placed in the areas subject to highest heat-gain with the work and occupied spaces pushed indoors

Formulation the indoor layout



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

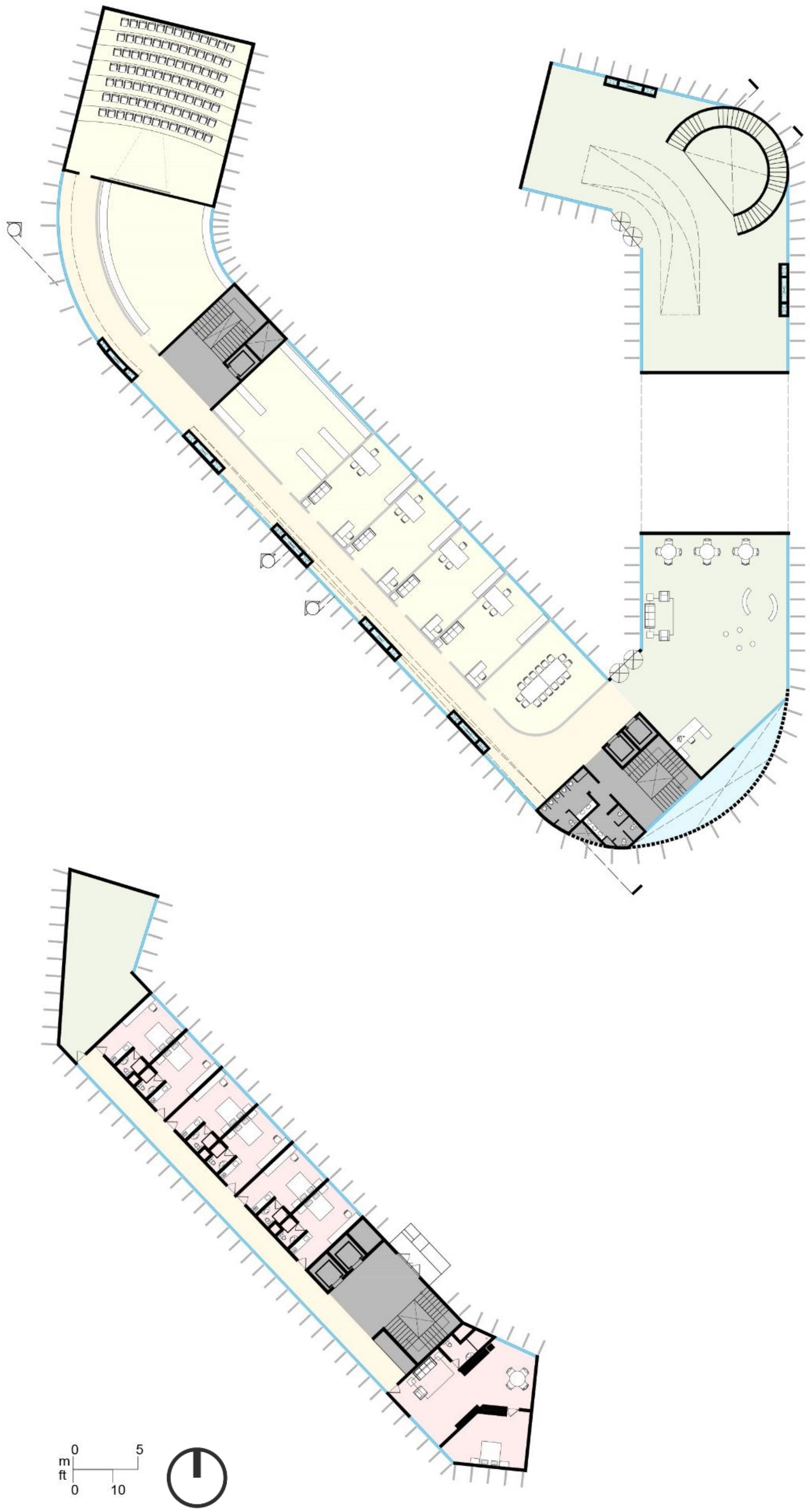
- Elevators
- Stair shafts
- Restrooms
- Mechanical

506 m^2

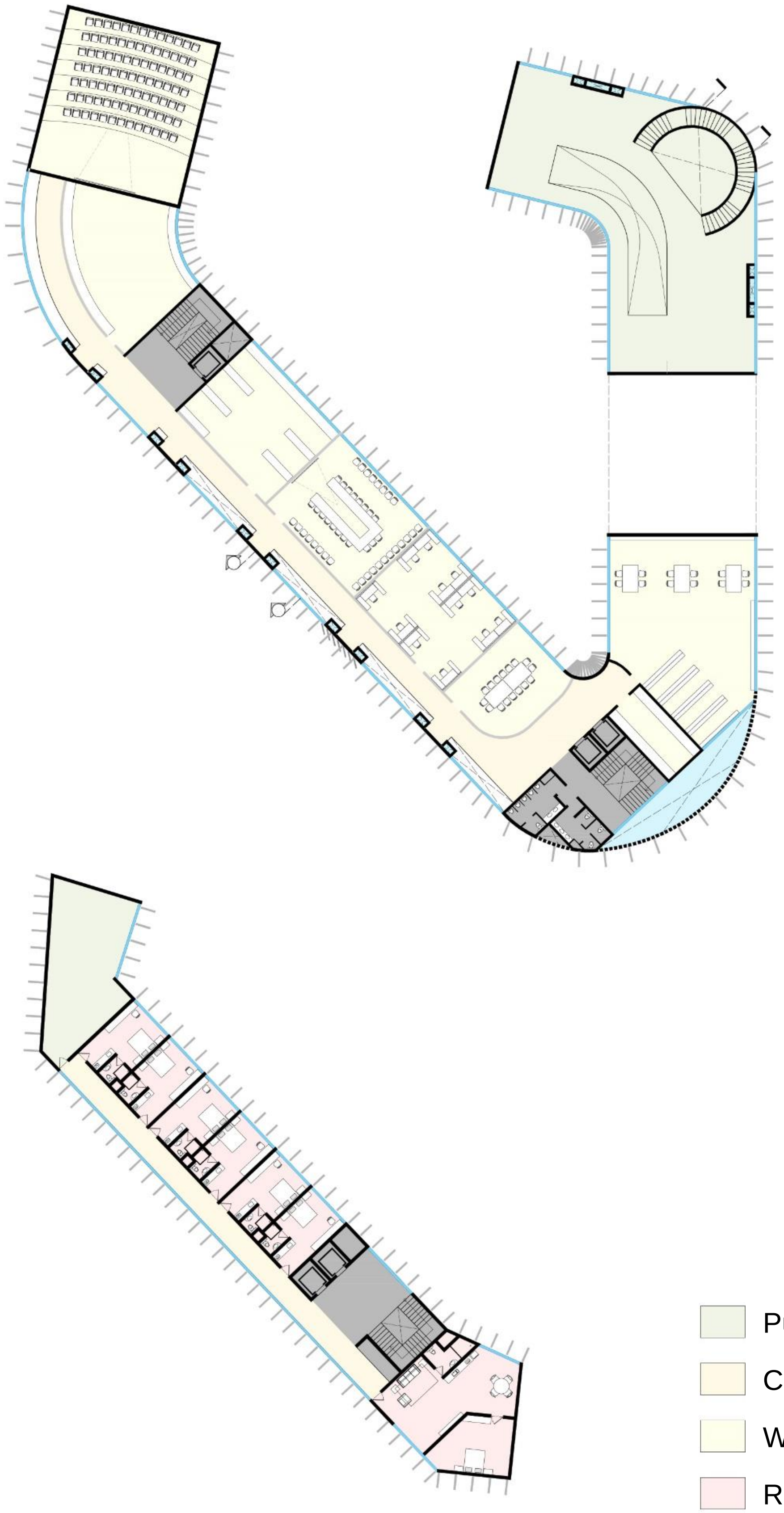
5083.5 m^2
(54718.33 sq ft)

Public spaces
Corridors and circulation
Work spaces
Residential spaces
Service cores

Layouts



Ground floor plan



First floor plan

Public spaces

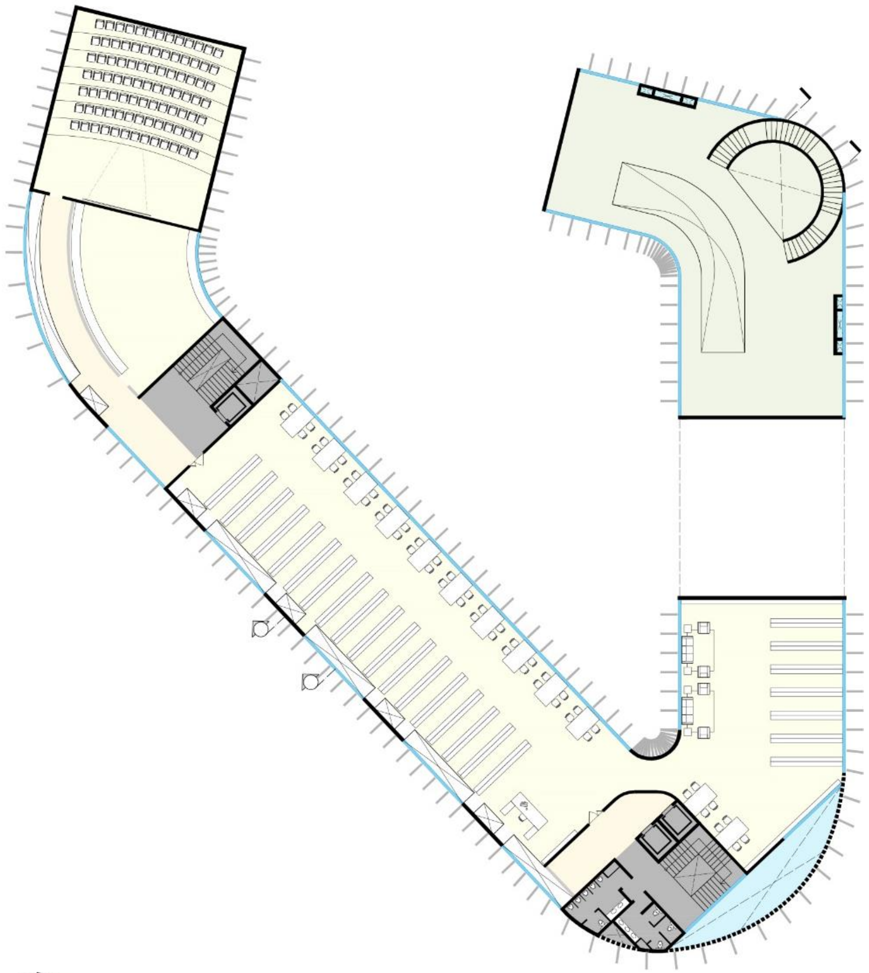
Corridors and circulation

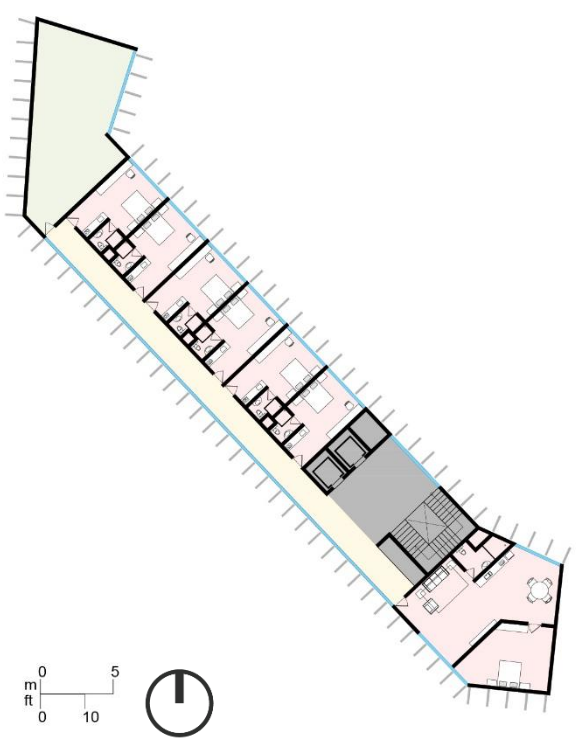
Work spaces

Residential spaces

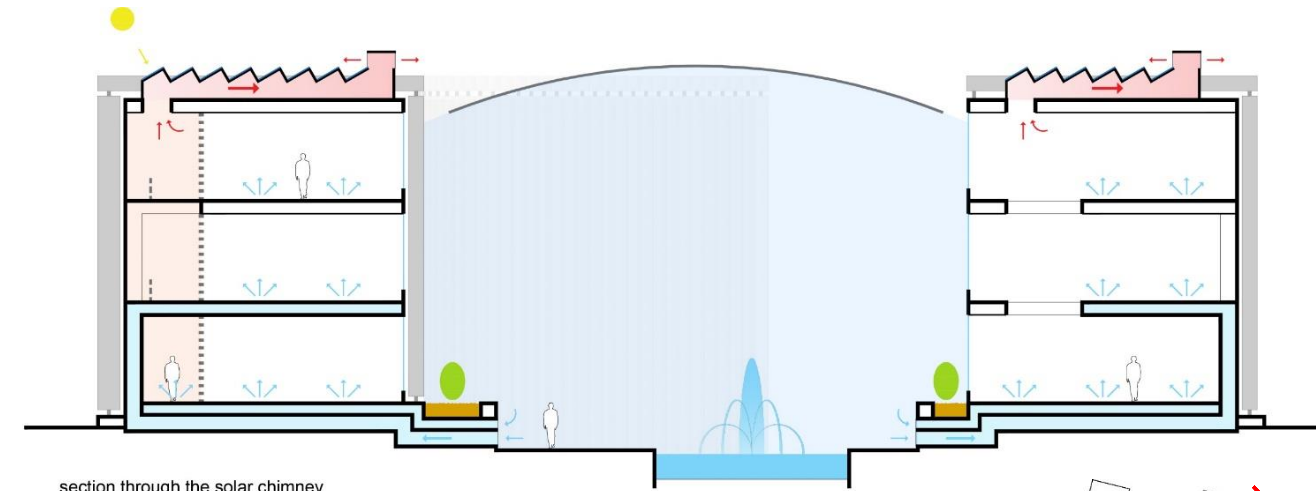
Service cores

Layouts

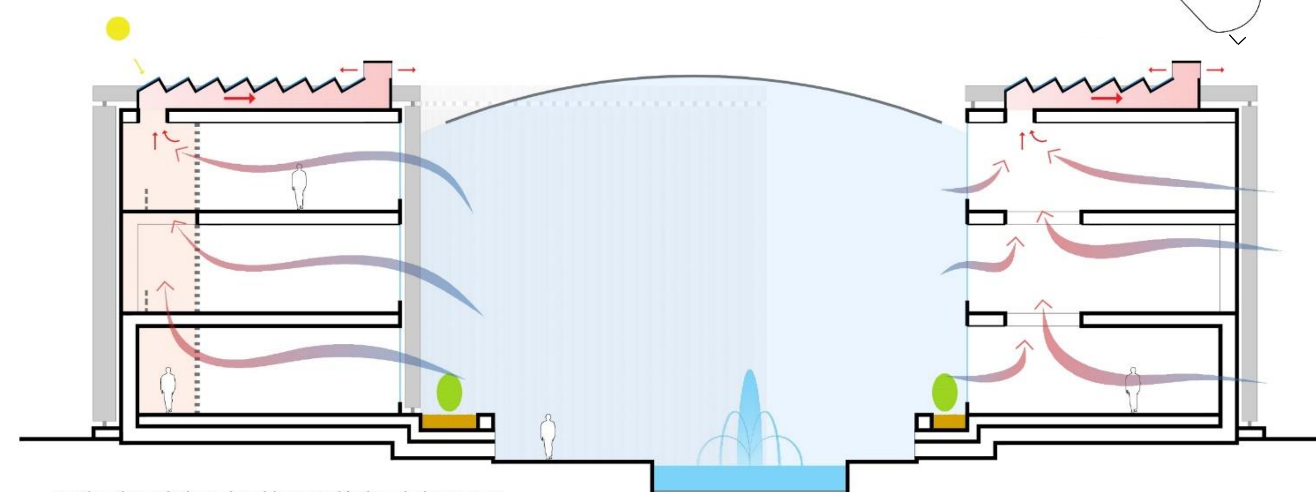




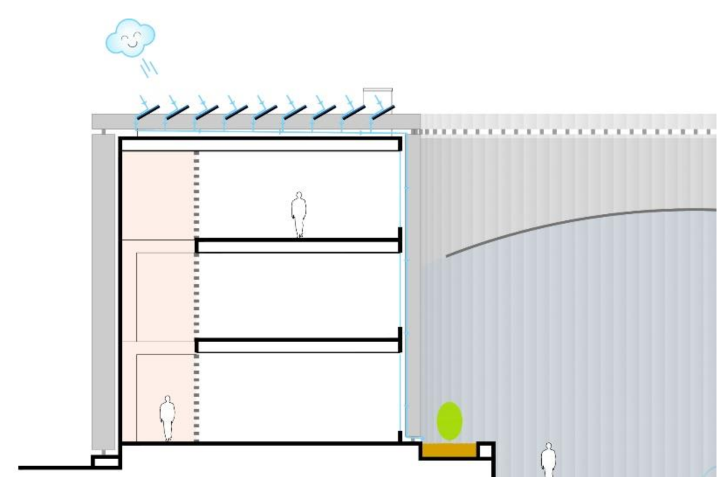
Second floor plan



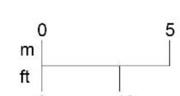
section through the solar chimney



section through the solar chimney with the windows open

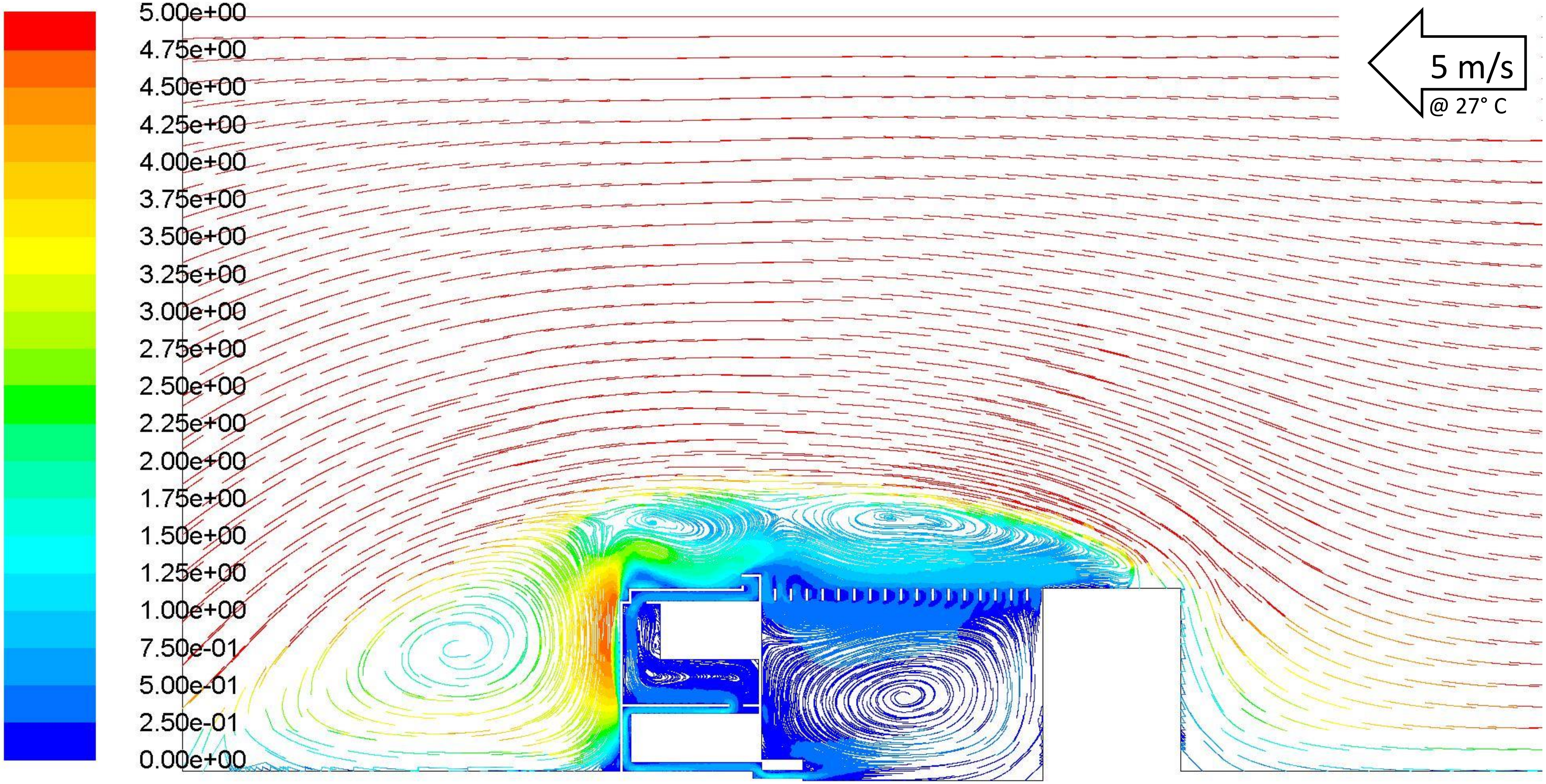


section not through the solar chimney



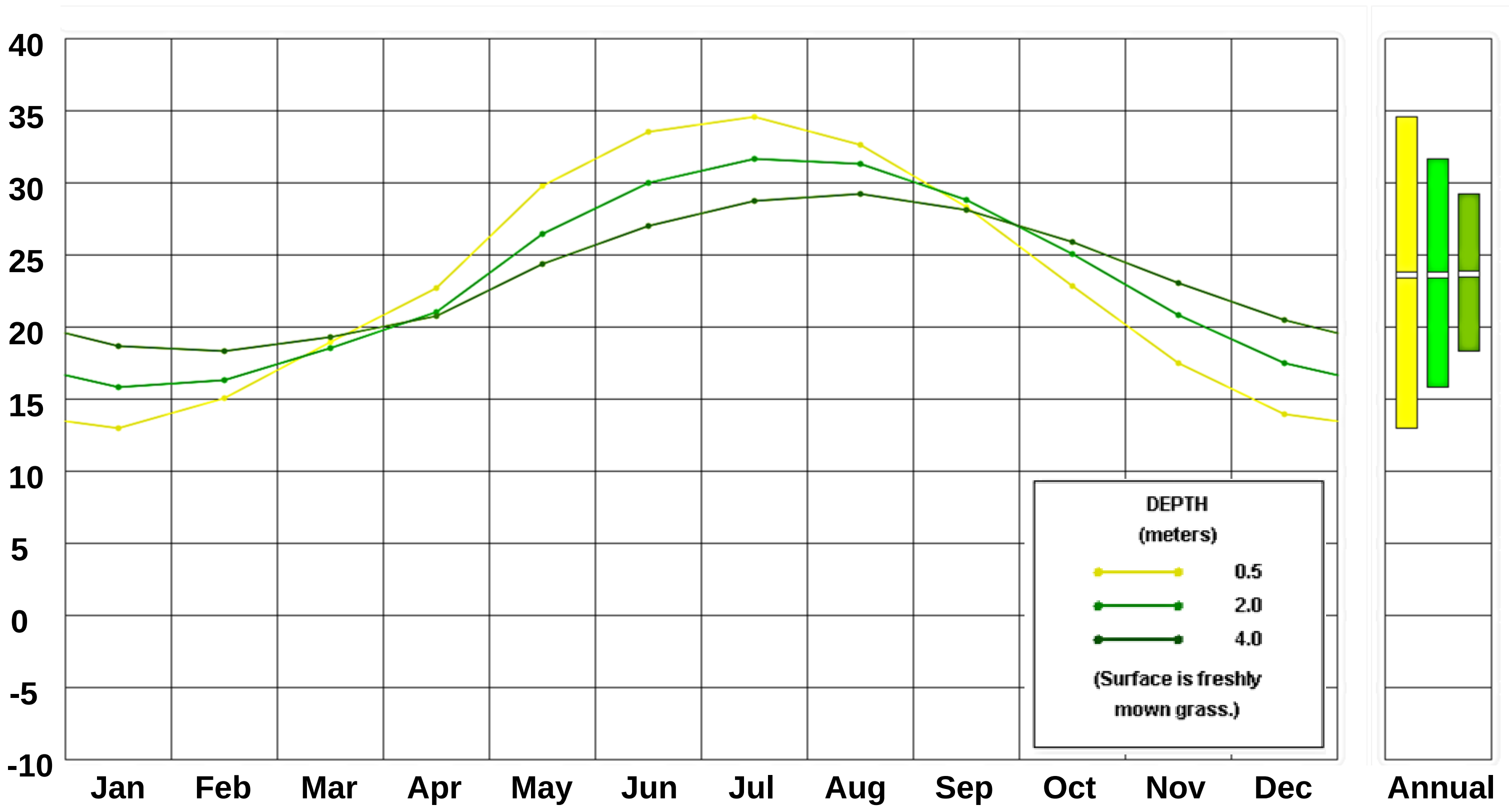
- Public spaces
- Corridors and circulation
- Work spaces
- Residential spaces
- Service cores

Outdoor ventilation



- 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`

Annual average ground temperature and wet bulb temperature



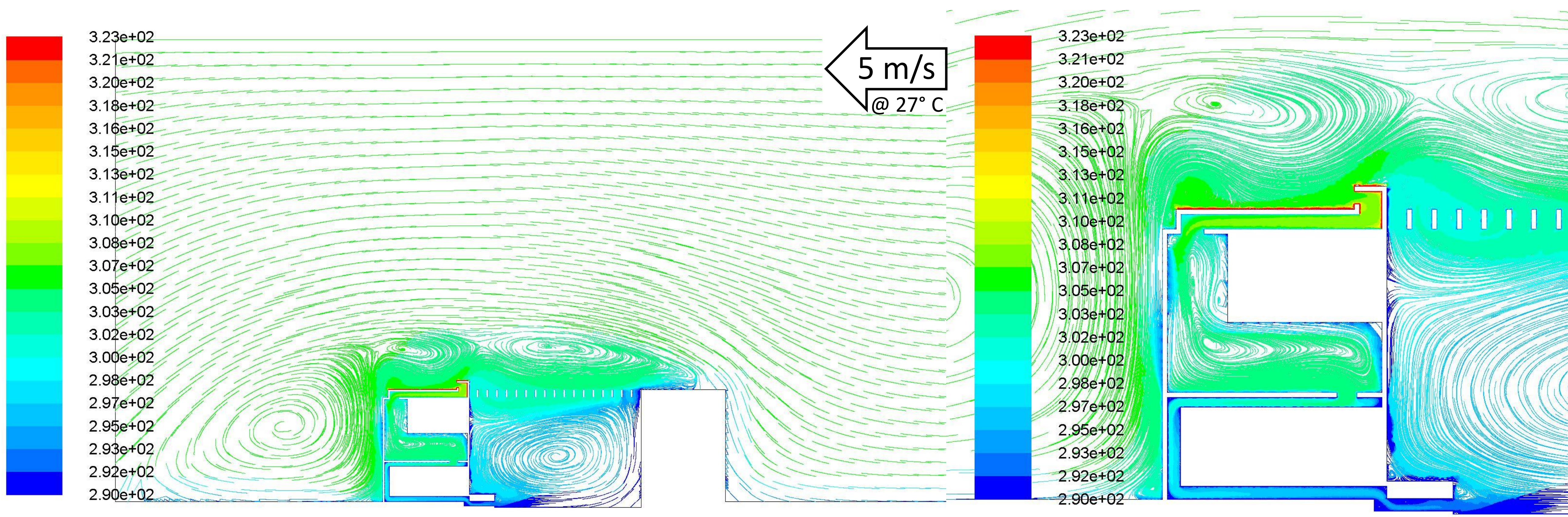
Maximum Average Wet Bulb

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

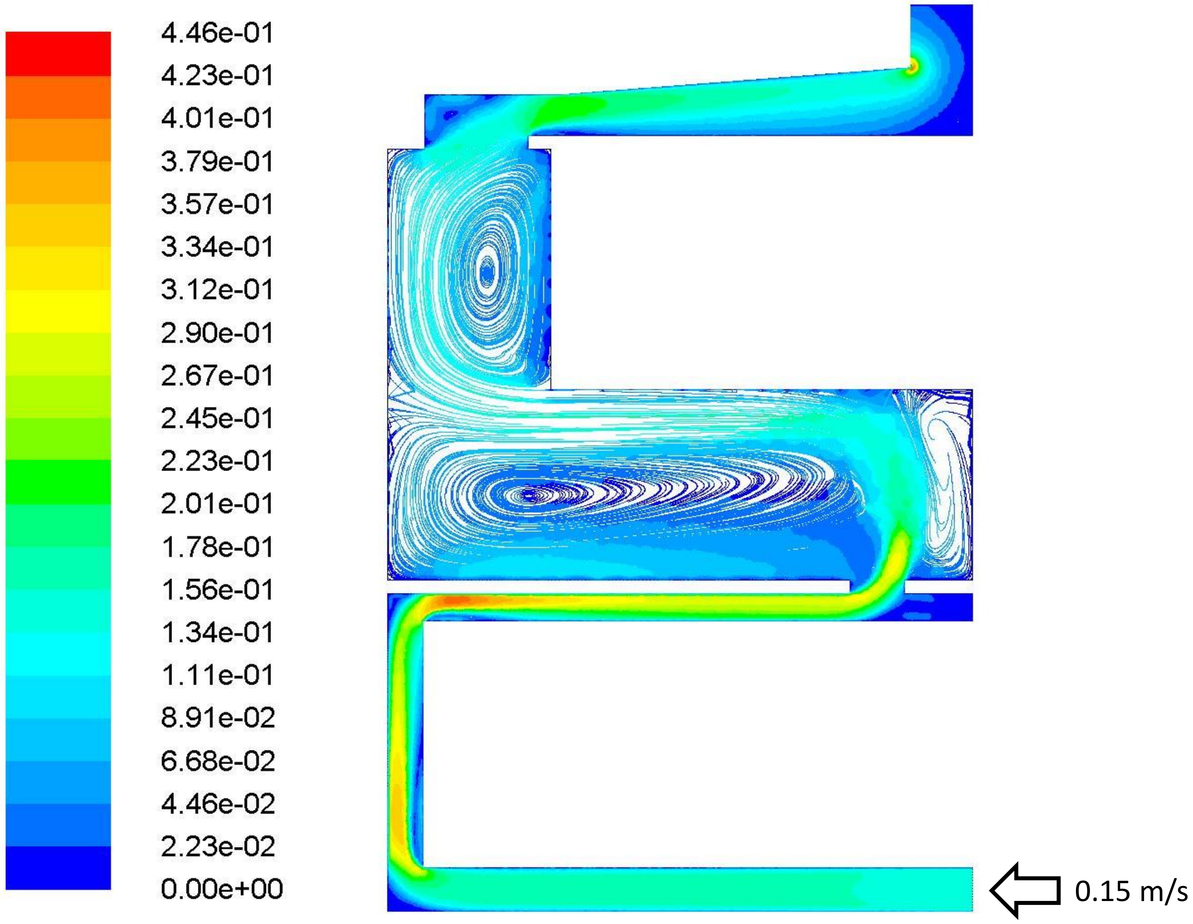
In Fahrenheit

* source: TiggrWeather

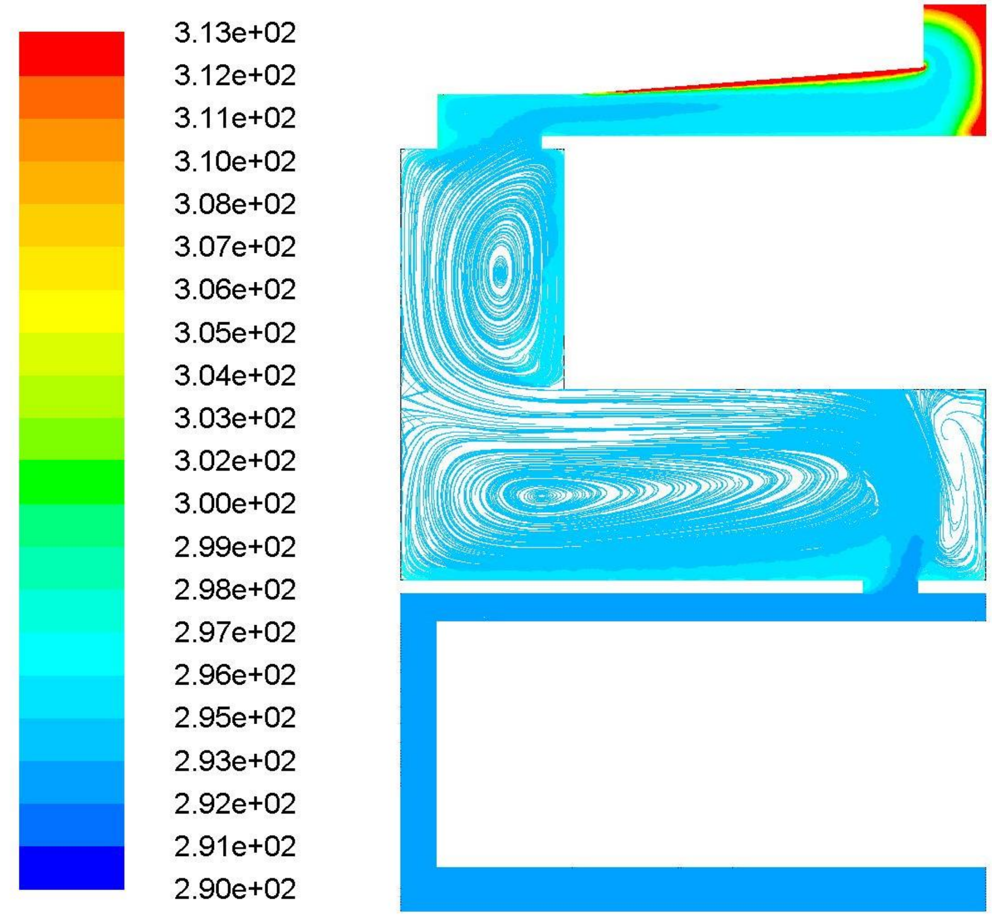
- The average ground temperature at a depth of 0.5 m ranges from about 34°C to 13°C. Therefore, in the summer months ground source cooling will prove insufficient
- The wet-bulb temperature in the hottest months ranges from 20°C to 25°C



Indoor ventilation

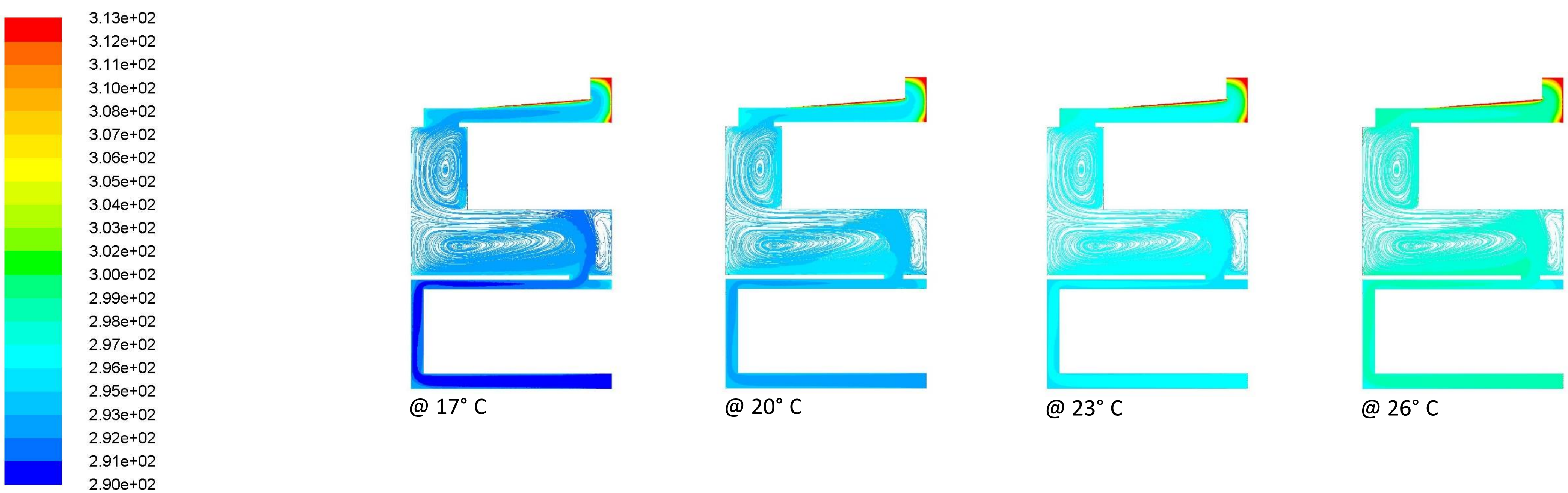


Air velocity in m/s

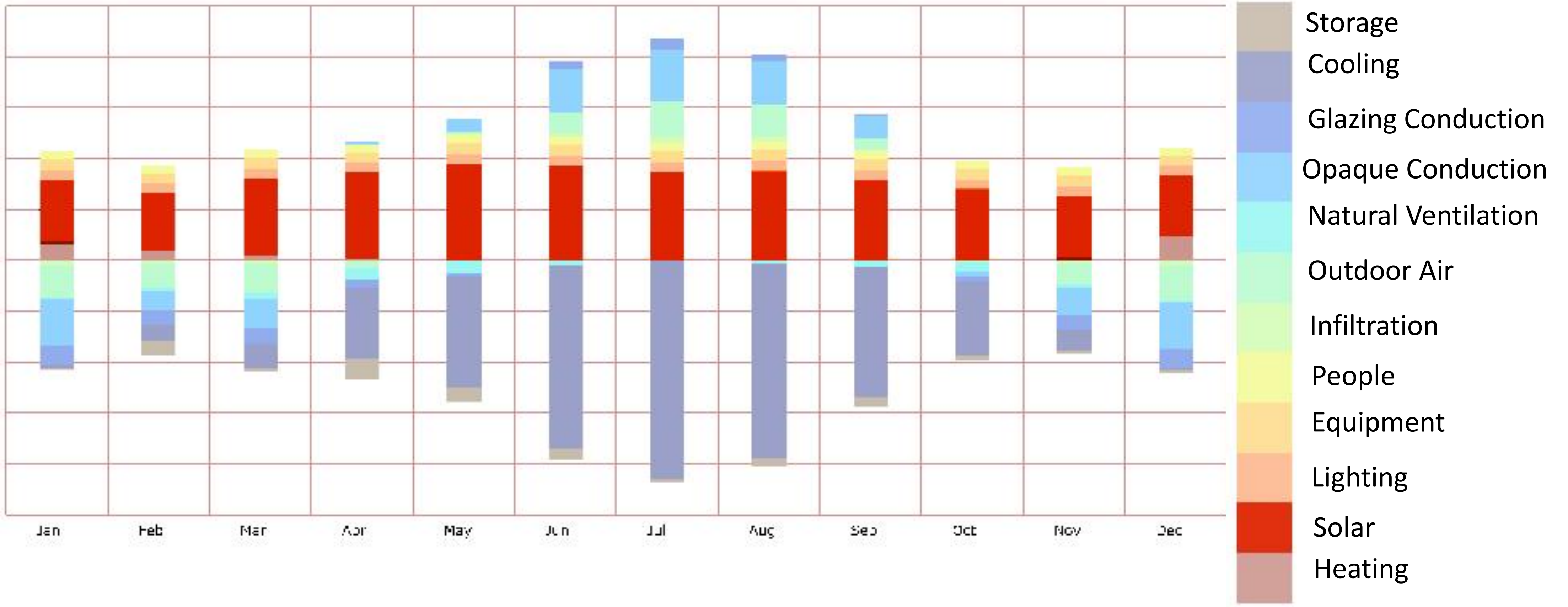


Air temperature in K

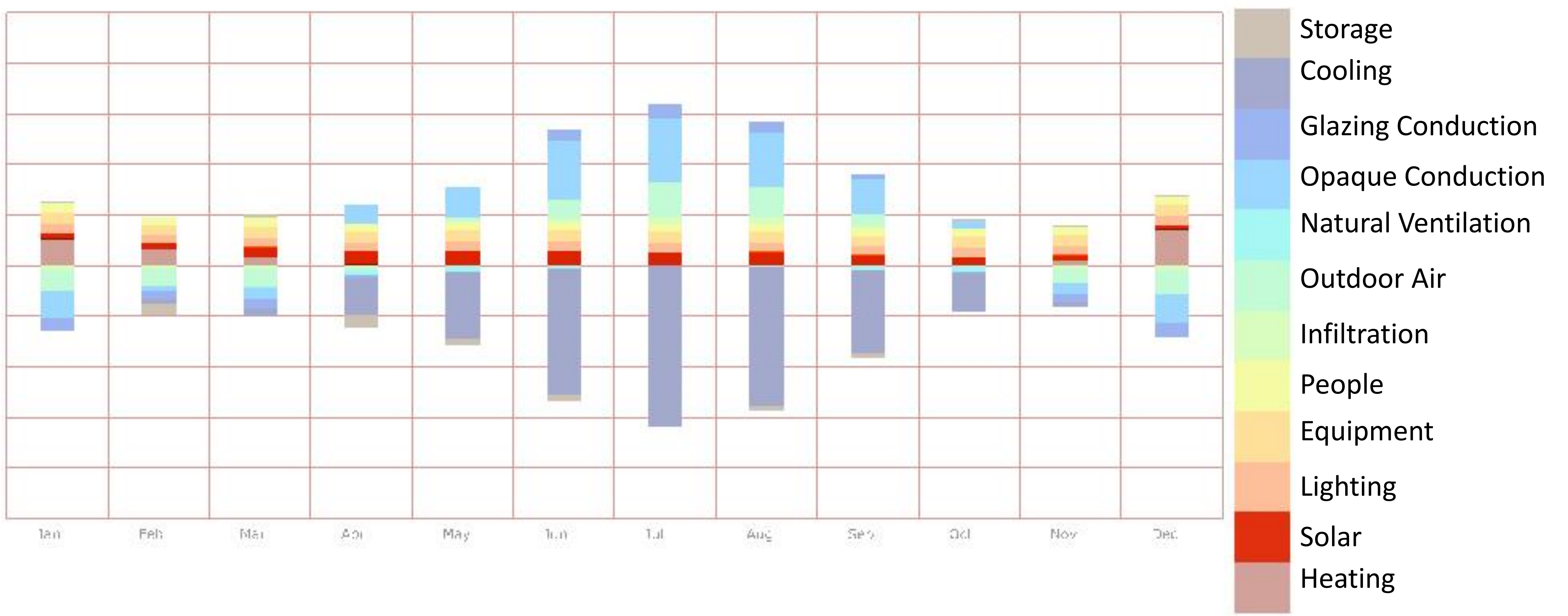
- However, if the air is misted and the temperature gets closer to the average June wet-bulb temperature at 17°C, the indoor air reaches an average 23-24°C with a minimal air draft.



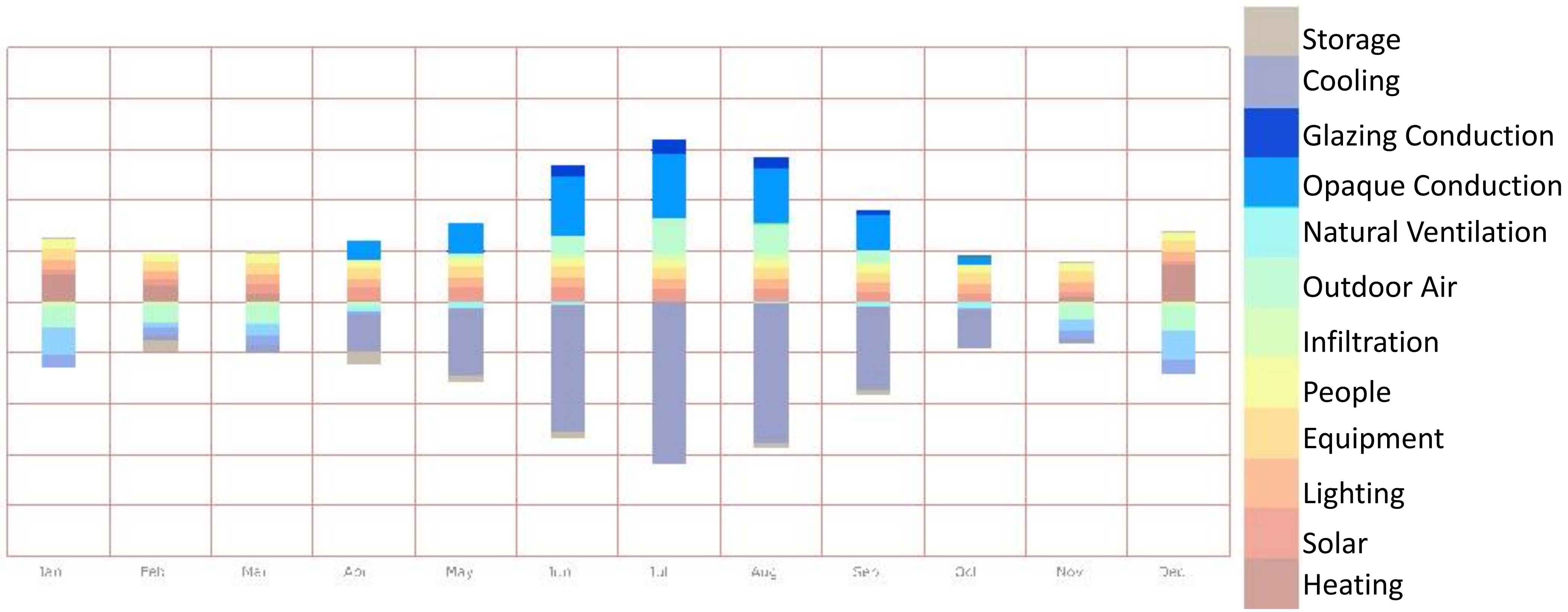
Monthly energy load balance



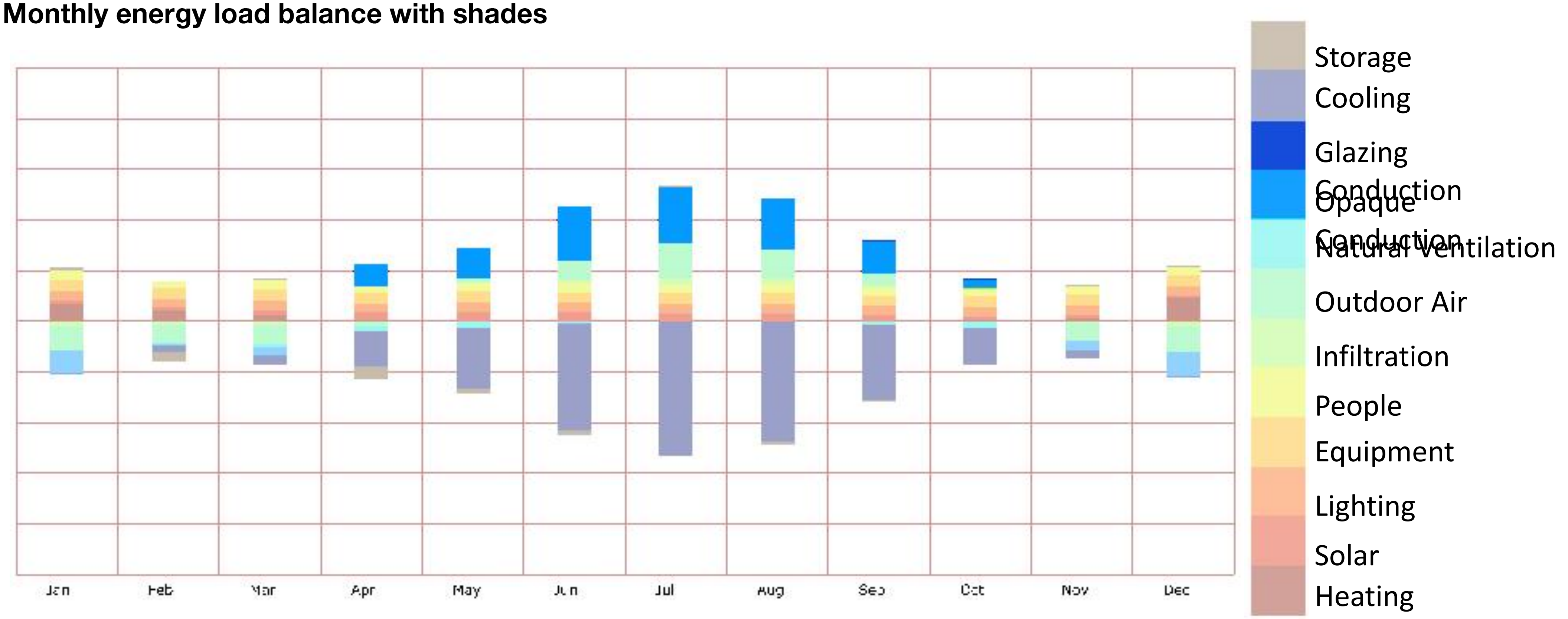
Monthly energy load balance with shades



Monthly energy load balance

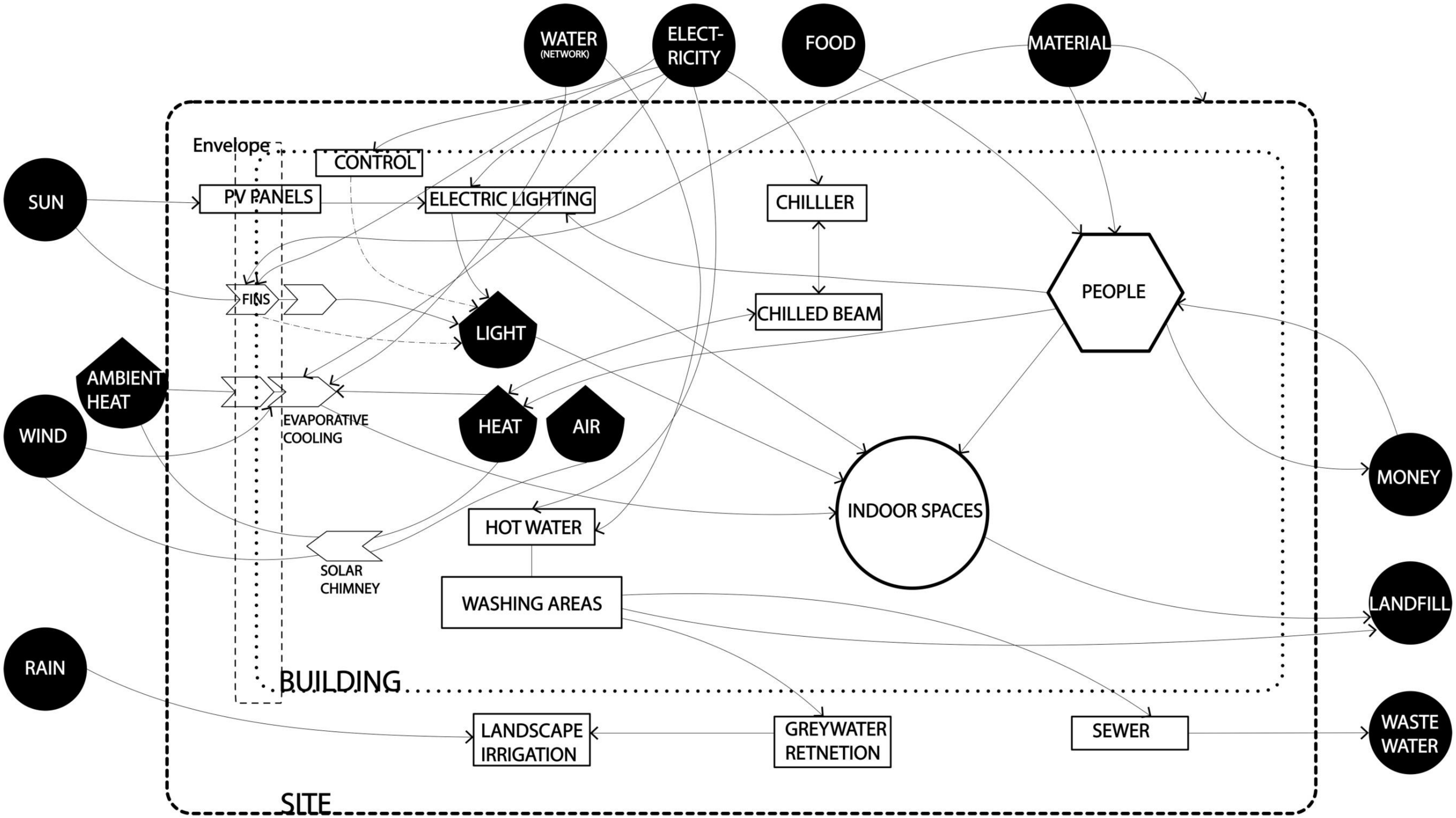


Monthly energy load balance with shades

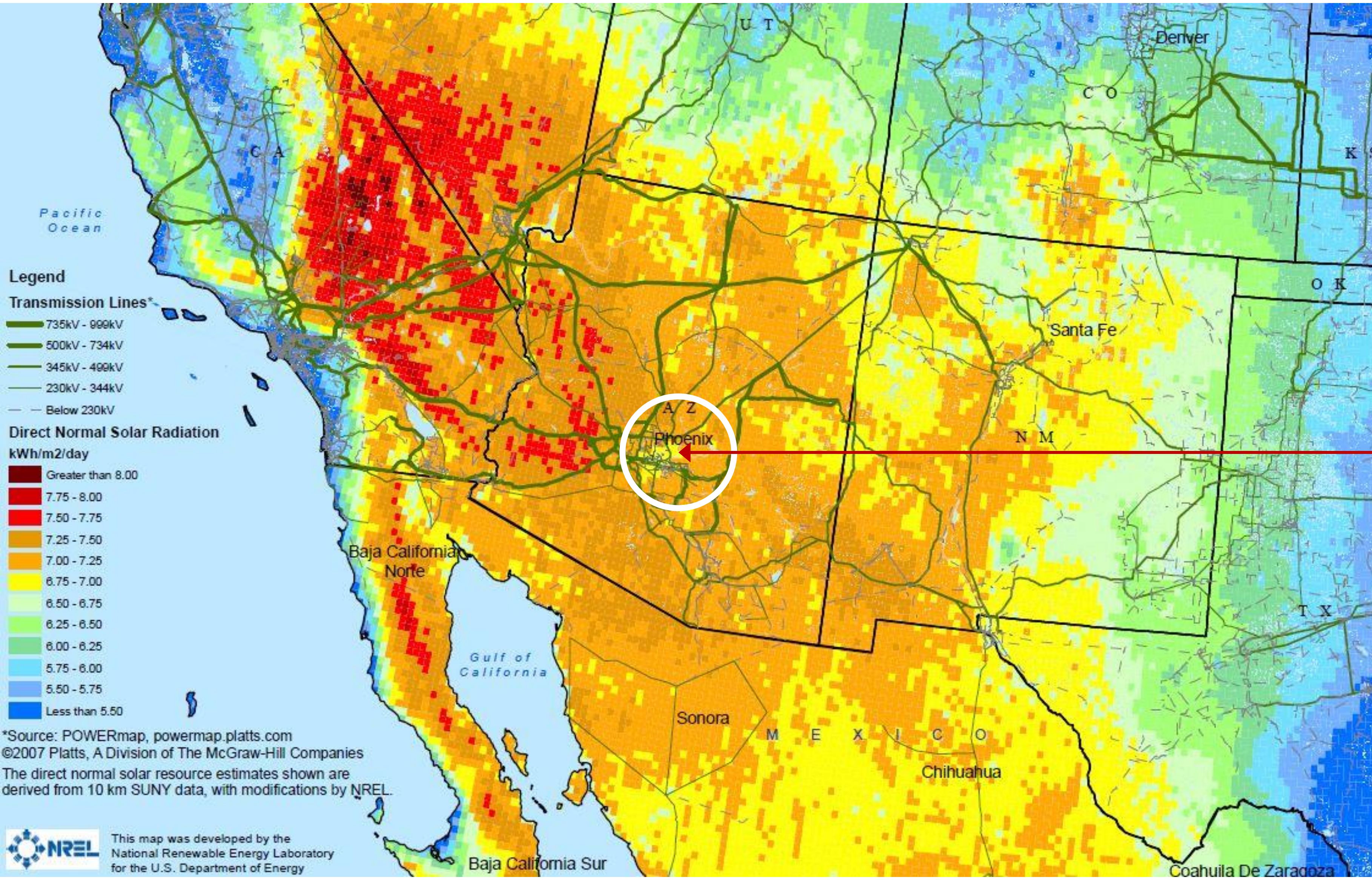


- Changing Materials of roof, walls, floor and thermochromic glass show slightly reduces opaque conduction and glazing conduction also reduces solar gain.

Emergy Diagram



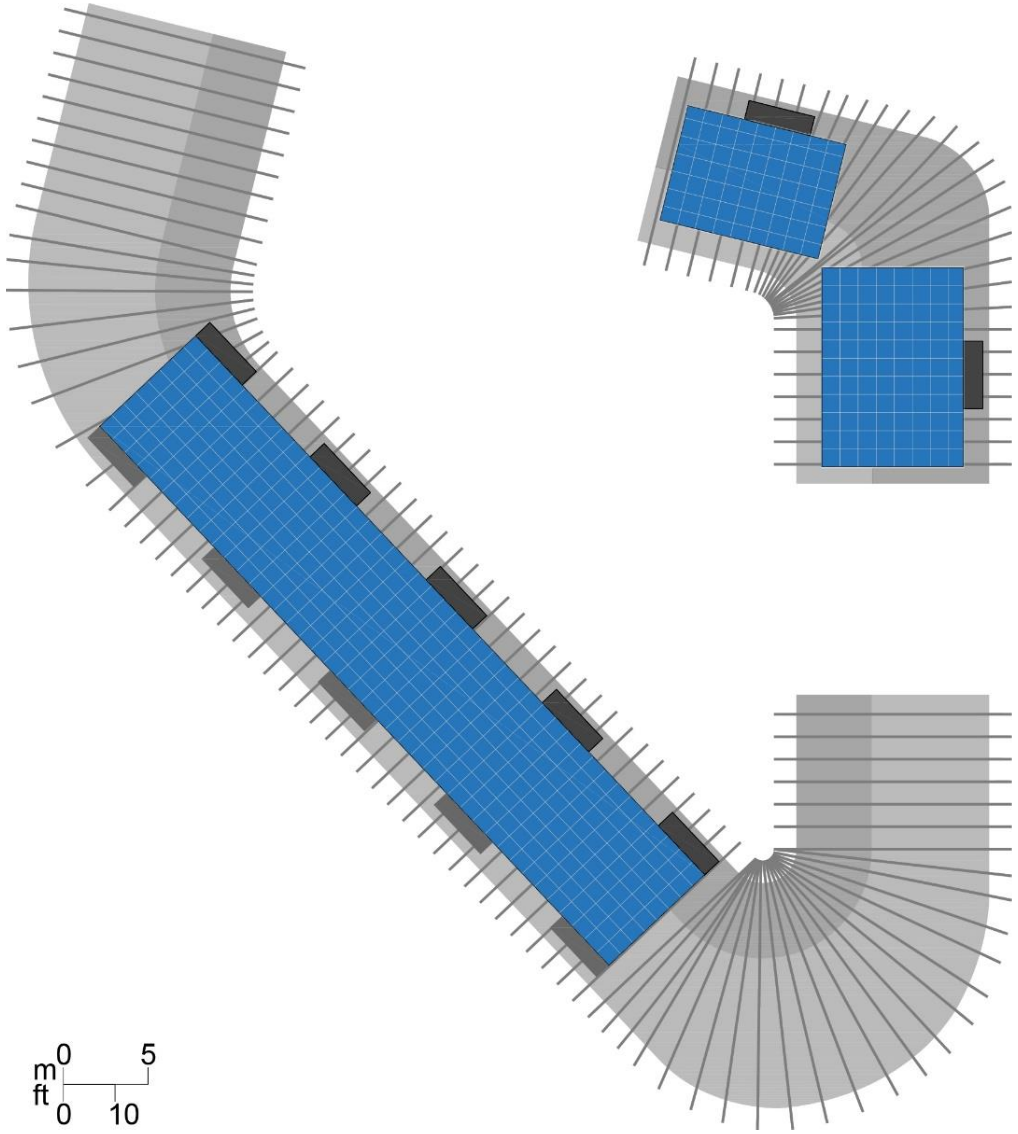
Solar potential and PV

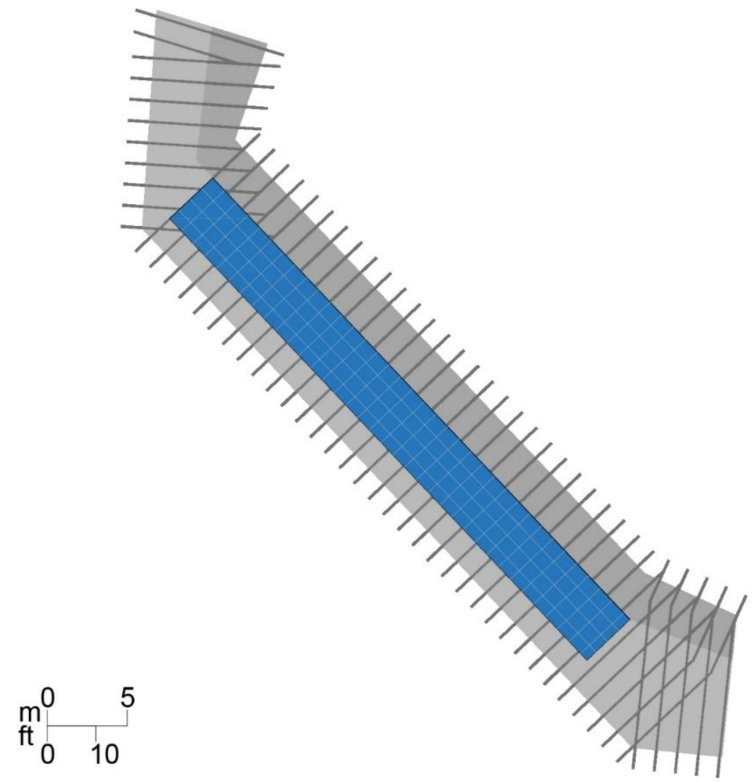


6.75-7.25 kWh/m2

Regional solar potential map

Solar potential and PV





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

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

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

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