



Bureau of Energy Efficiency



सत्यमेव जयते
Government of India
Ministry of Power



german
cooperation
DEUTSCHE ZUSAMMENARBEIT

giz Deutsche Gesellschaft
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ANGAN

Augmenting Nature by Green Affordable New-habitat

A Courtyard for Revolutionary Change in Building Energy Efficiency

An International Conference on Building Energy Efficiency

9th-11th September, 2019 | Hotel The LaLiT, New Delhi





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Zusammenarbeit (GIZ) GmbH

THIS PRESENTATION WAS SHARED BY

Ms. Swati Puchalapalli

Founder, Terra Viridis, Hyderabad

FOR THE SESSION:

“Analytical Tools to Estimate Building Performance”

DURING ANGAN 2019

Knowledge Partner

teri | THE ENERGY AND
RESOURCES INSTITUTE
Creating Innovative Solutions for a Sustainable Future

Event Partner

TEC INDIA TM
EVENT & BRAND MANAGEMENT CO.

THE ROLE OF SIMULATION TOOLS IN HIGH PERFORMANCE DESIGN – A PRACTITIONER’S PERSPECTIVE

10th September 2019

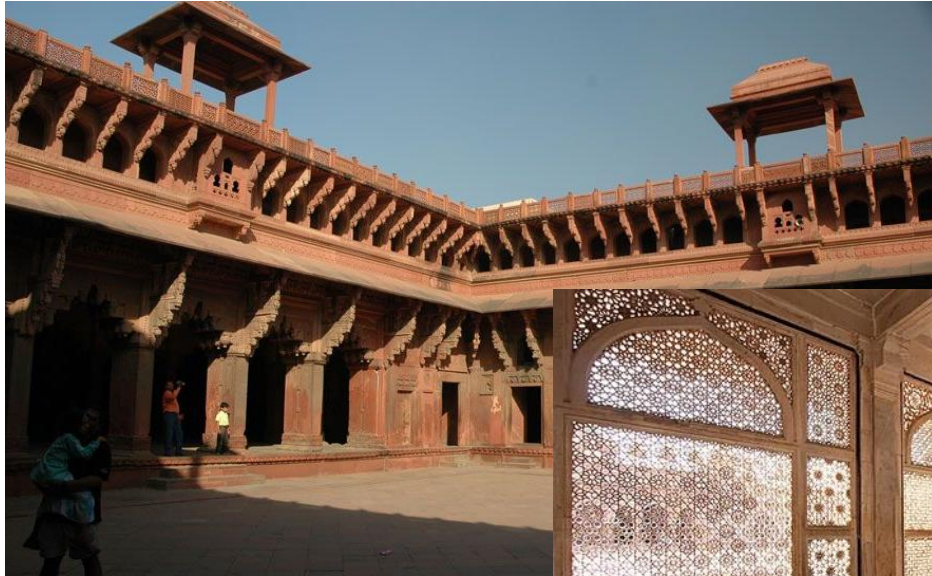
Thematic Track 11 – Analytical Tools to Estimate Building Performance
BEE ANGAN Conference

Swati Puchalapalli
Director, TerraViridis
Director, VeraTatva

High Performance Sustainable Design in India – A 1000+ Year History



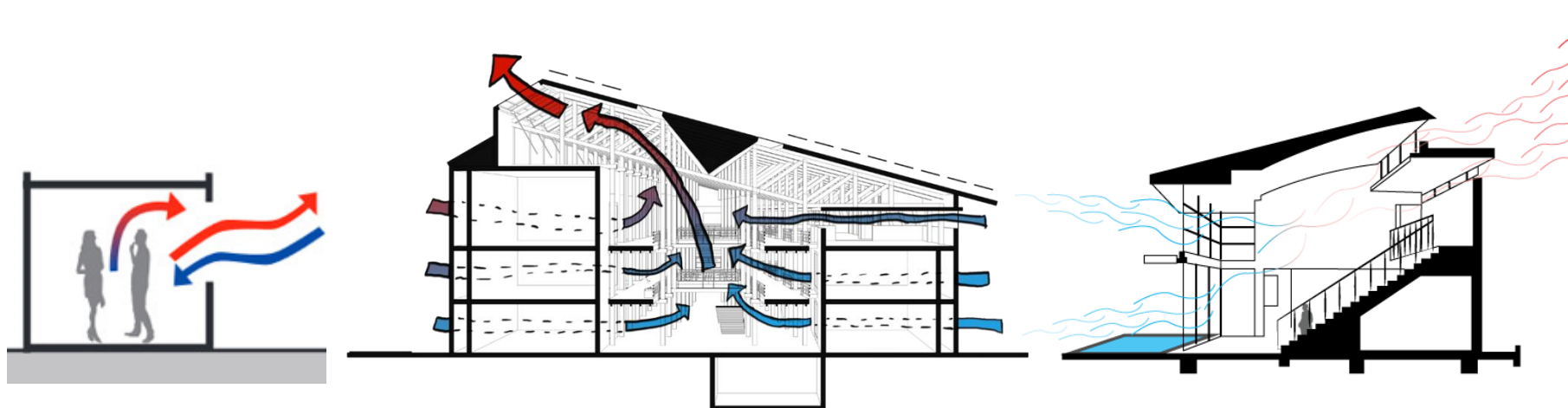
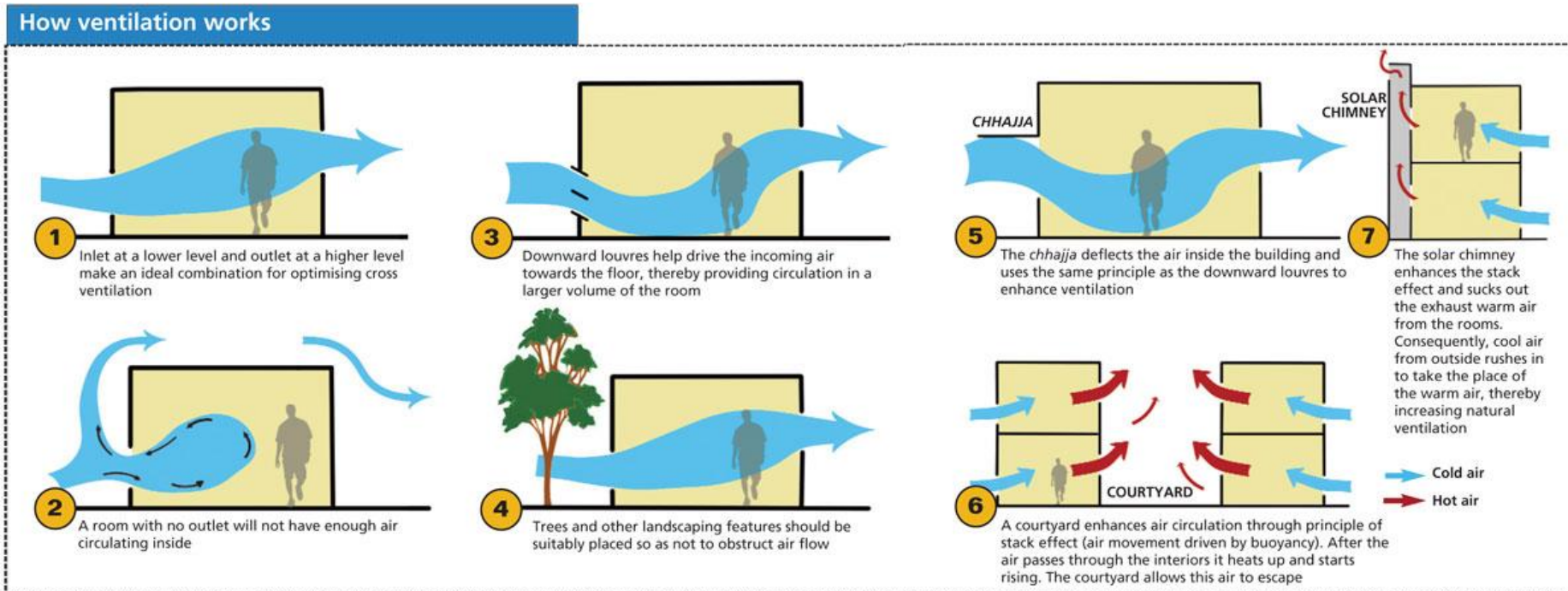
Vernacular Traditions evolved around Climate



Focused on achieving Comfort with minimal active intervention

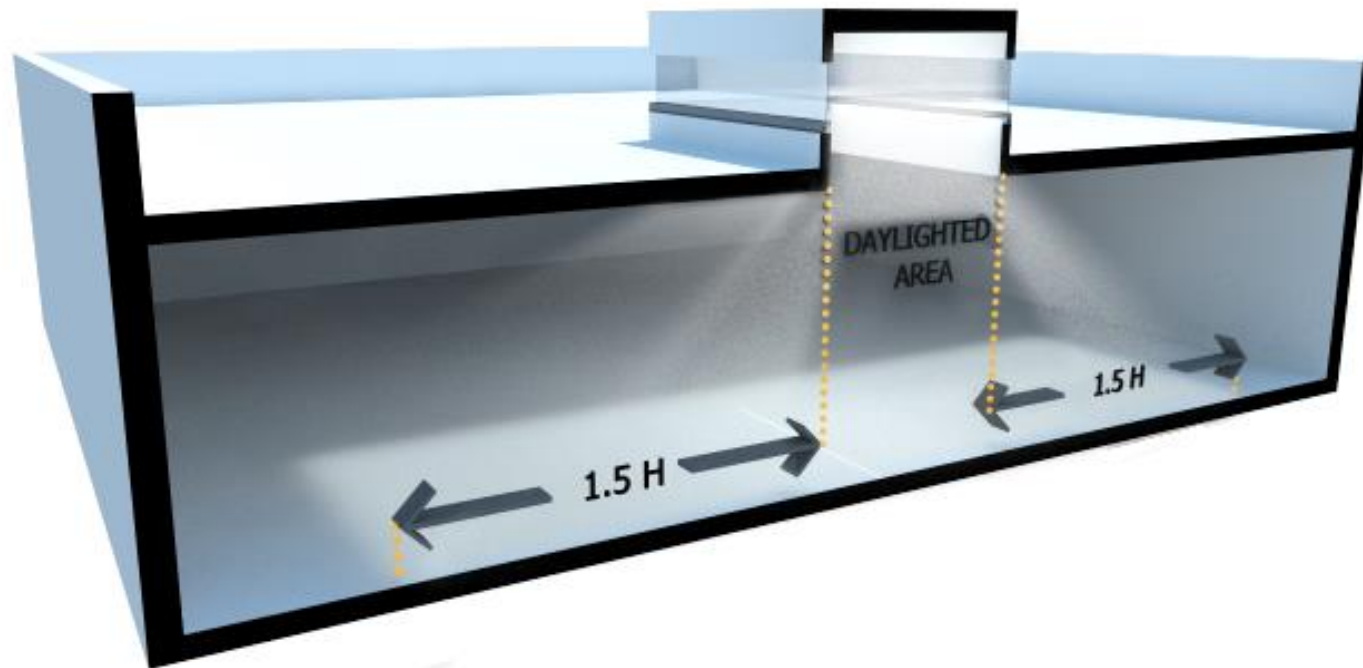
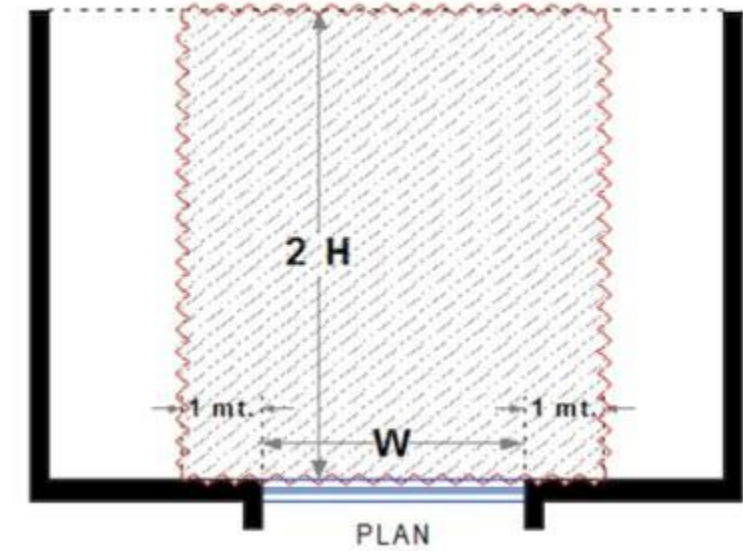
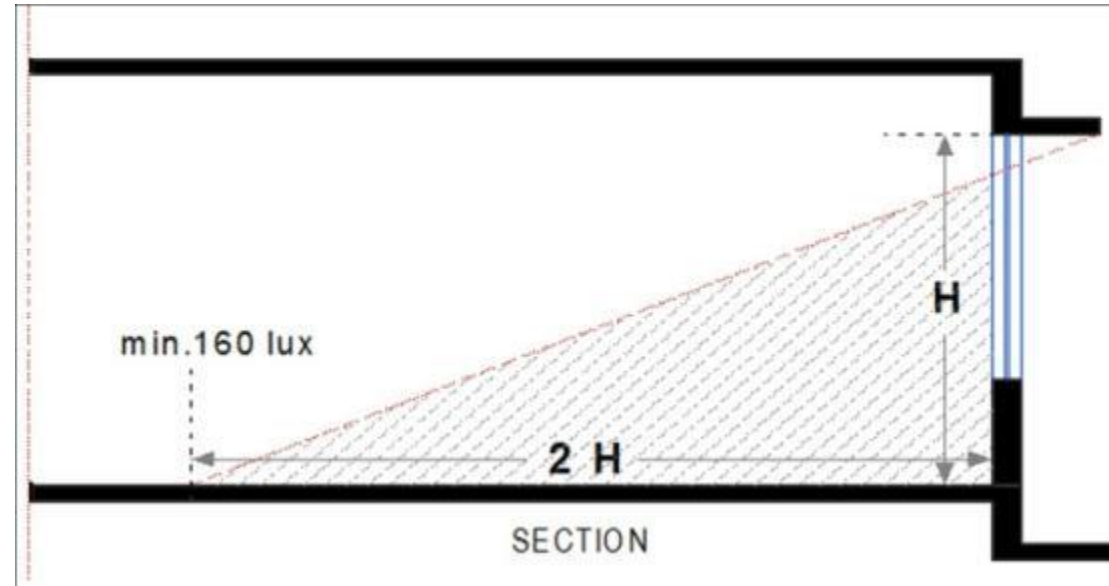


Design Principles – Natural Ventilation



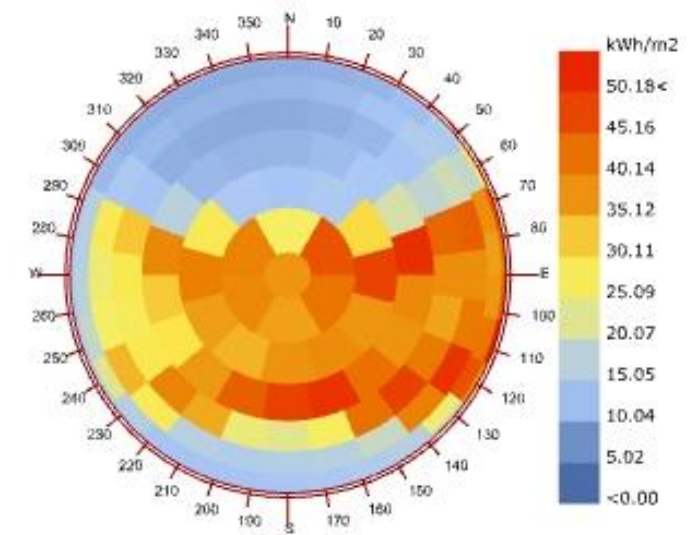
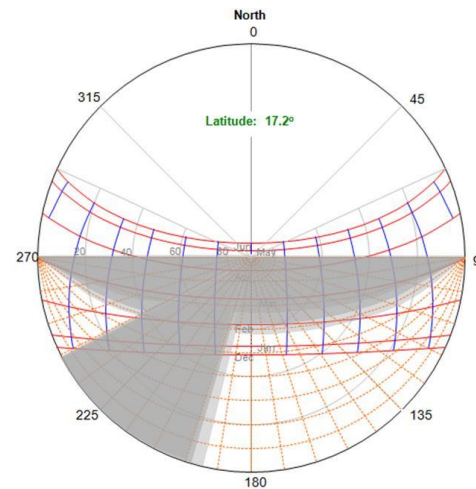
NATURAL VENTILATION

Design Principles – Daylighting in the Buildings

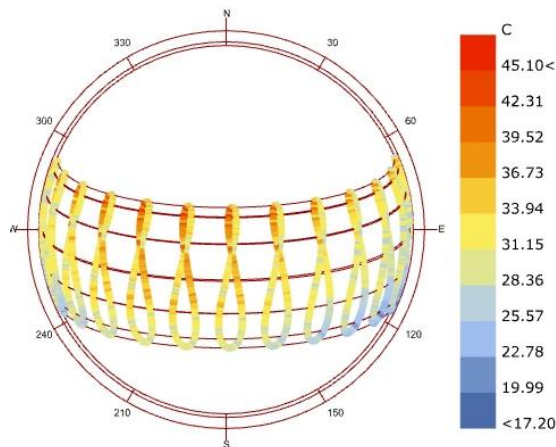


Manual Tools & Calculations

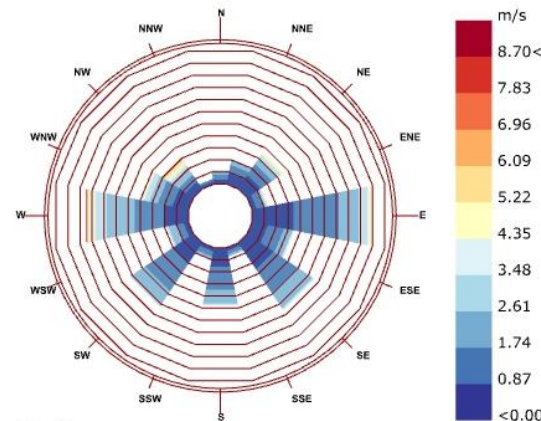
- Climate analysis charts
- Sunpath Diagrams
- Shading Protractors
- Daylight and Radiation overlays
- SHGC calculator (for glazing)
- Daylight Factor Calculations
- Ventilation and stack effect calculators



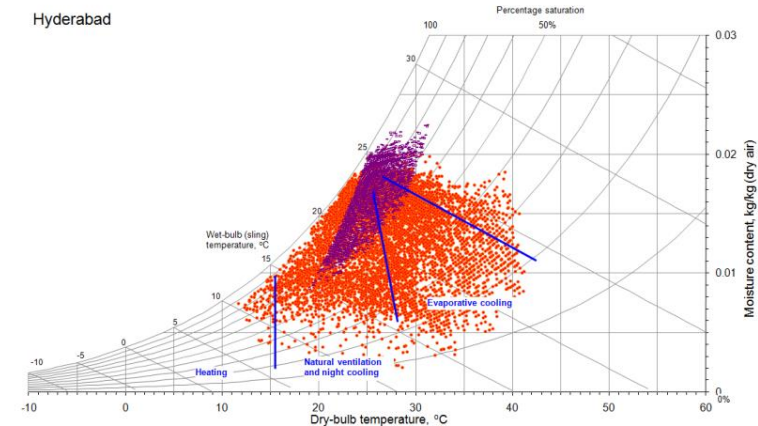
Total Radiation(kWh/m2)
VIJAYAWADA_GANNAVA_IND_2013
1 JAN 1:00 - 31 DEC 24:00



Sun-Path Diagram - Latitude: 16.53
Hourly Data: Dry Bulb Temperature (C)
VIJAYAWADA-GANNAVA_IND

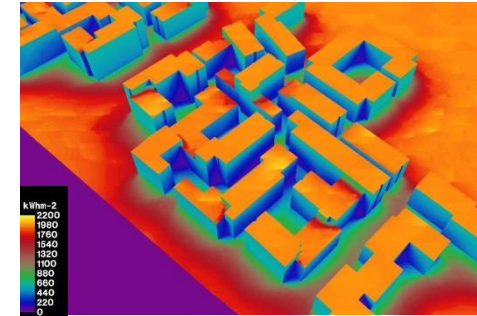


Wind-Rose
VIJAYAWADA-GANNAVA_IND
1 JAN 1:00 - 31 DEC 24:00
Hourly Data: Wind Speed (m/s)
Calm for 41.71% of the time = 3654 hours.
Each closed polyline shows frequency of 1.0%. = 86 hours.

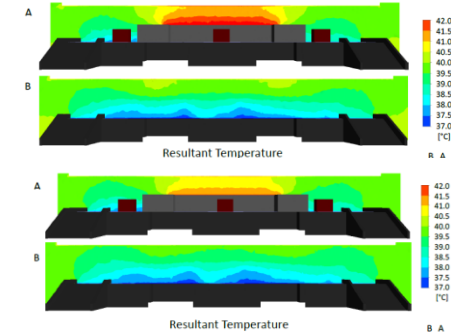


Computer Simulation Programs

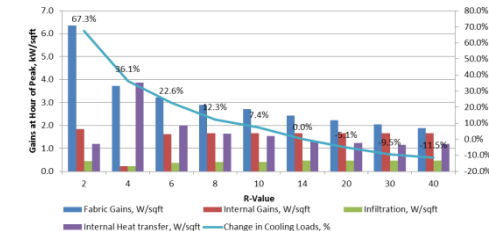
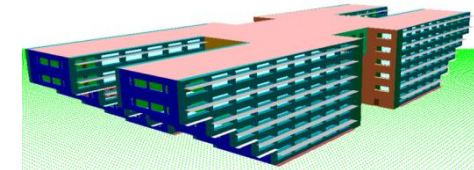
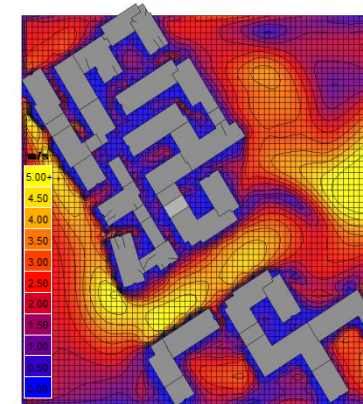
- Irradiation Analysis – DIVA, Ecotect, Grasshopper
- Windflow Analysis – Openfoam, Winflow, CFD, Fluent.....
- Microclimate Analysis – Envimet, UTCI....
- Shading analysis – external shading analysis, solar radiation penetration studies – Ecotect, Sketchup, Vasari...
- Dynamic Thermal Analysis - natural ventilation, comfort conditions, cooling load calculations, eQuest, Design Builder, Espr, TAS, IES....
- Daylight Analysis - daylighting analysis, glare analysis, complex shading and complex daylight enhancing design analysis – Radiance, Daysim, Diva....



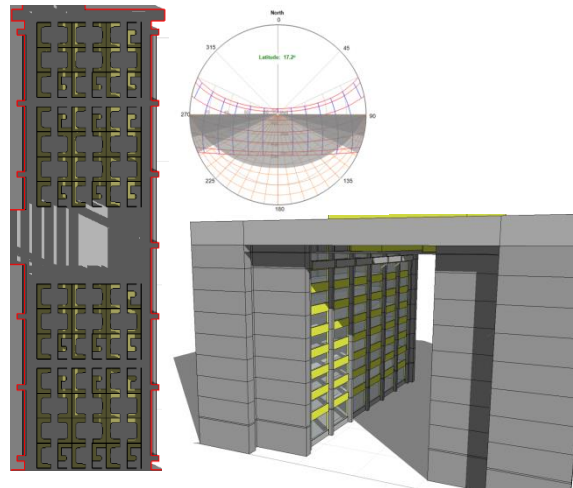
Master planning Studies



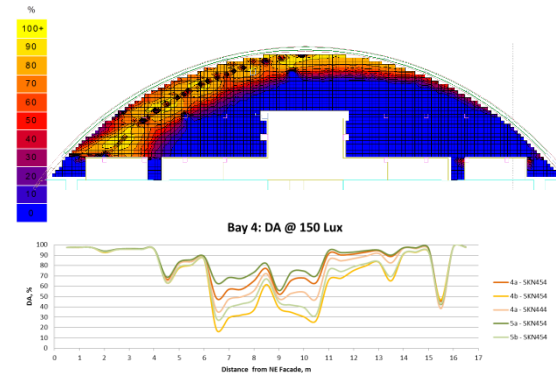
CFD Studies



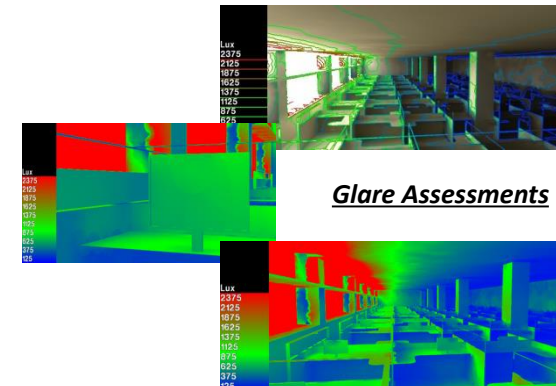
Dynamic Thermal Modelling for Passive Design and Energy Modelling



Shading Studies



Daylight Studies



Glare Assessments

Technology

- Insulation
- Efficient glazing
- Phases change materials
- Efficient HVAC systems
- LED lighting
- Solar PV.....

So much information... So many tools...

1. Learnings from Vernacular Design
2. Passive Design Principles
3. Climate Analysis
4. Design Principles
5. Manual Calculation Tools
6. Simulations and Calculations
7. Codes – ECBC, NBC, ASHRAE, CIBSE
8. Rating System Guidelines – GRIHA, LEED, IGBC, WELL....
9. Thermal Comfort Metrics – IMAC, ASHRAE, CIBSE, NBC

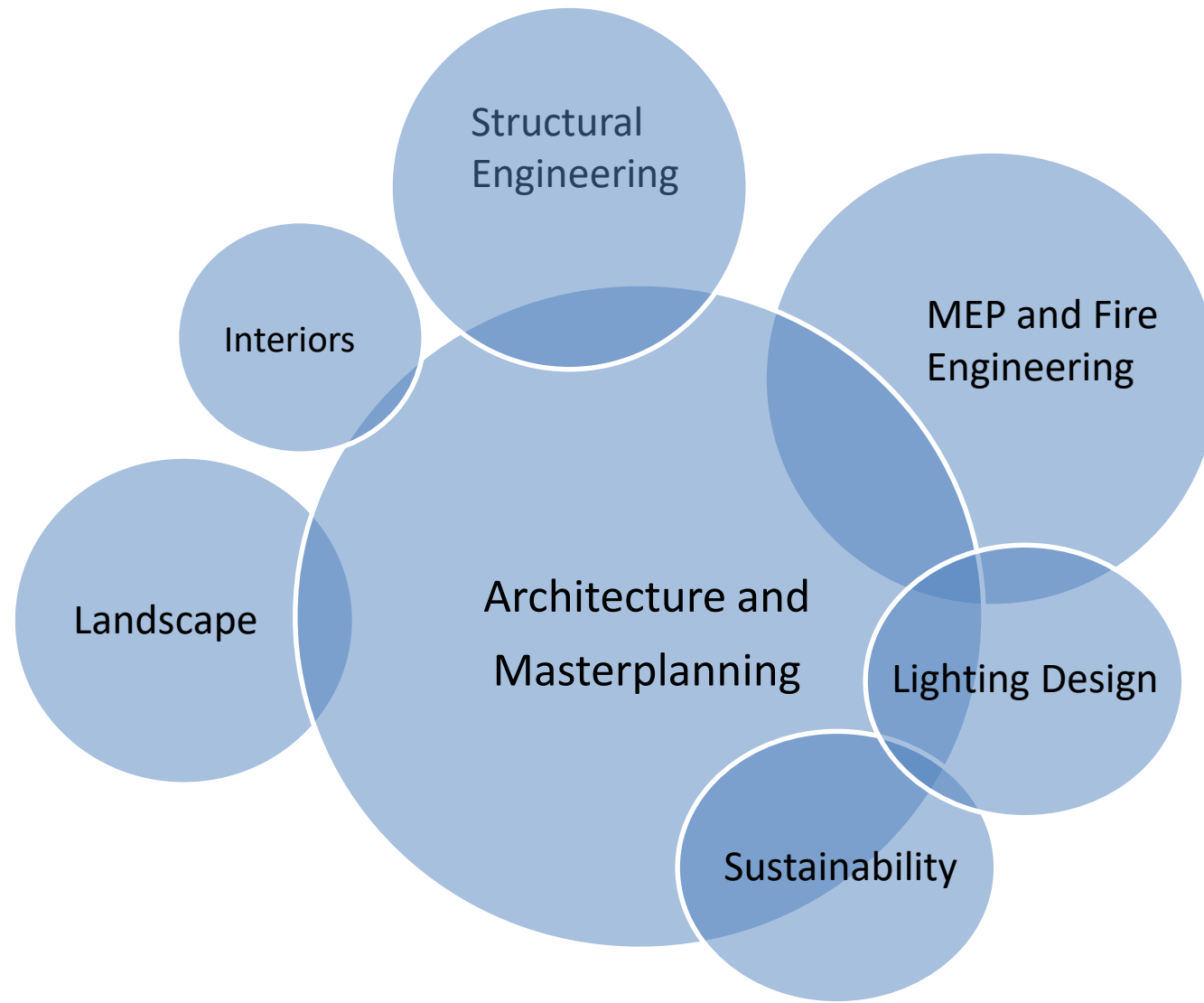
ARE THEY REALLY USEFUL?

WHAT CAN THEY HELP ACHIEVE?

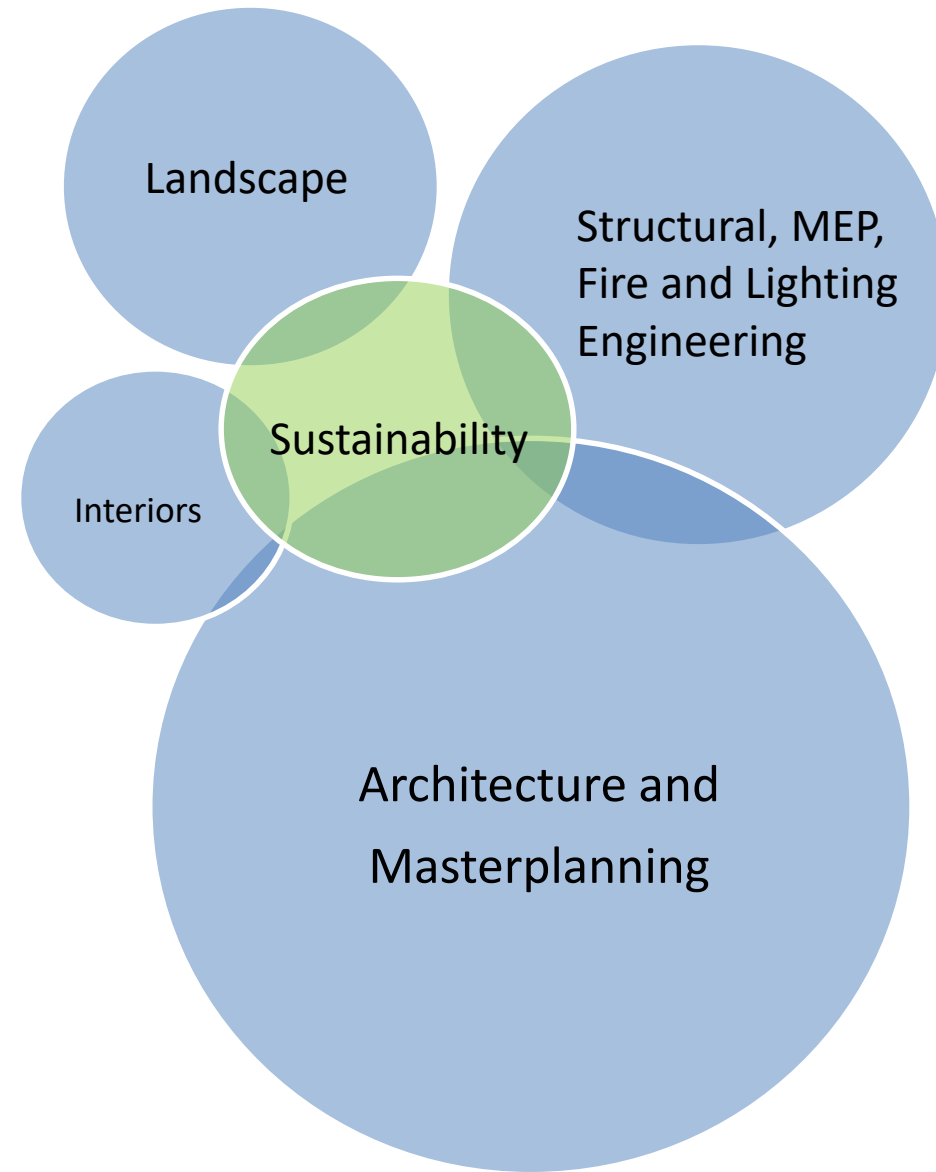
Days of 'The Master Builder' are gone!!



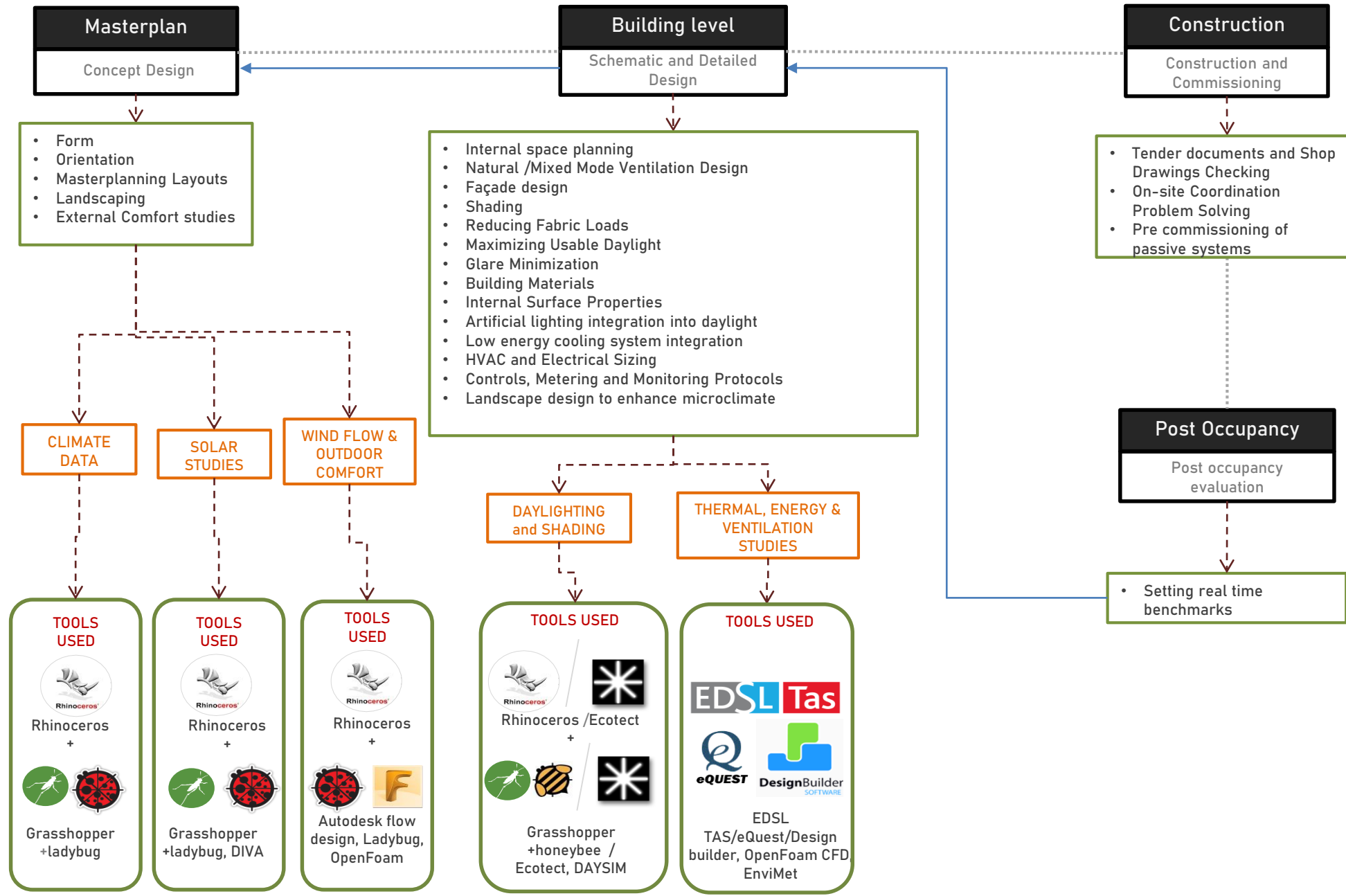
IT'S A TEAM EFFORT.



Sustainability overlaps with every other Team Member

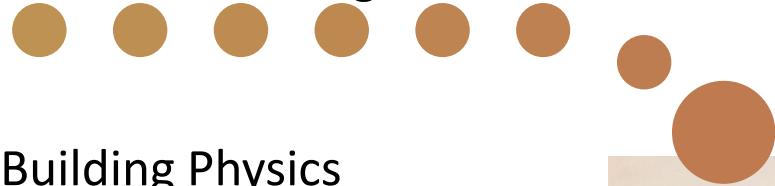


Simulation Tools Bridge the Gap – Numbers can Talk!



Simulation Tools help in..

Vernacular Design



Building Physics Principles



Engineering



Technology



The design development from start to finish

1. Combining design with technology most effectively
2. Identifying problem areas and helping to solve them
3. Optimising the design



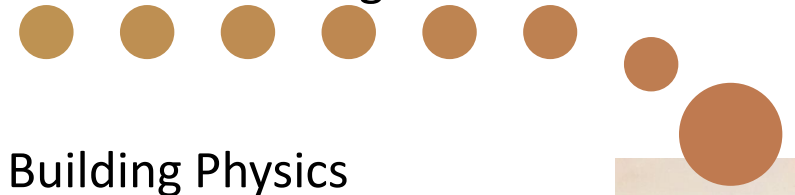
Project: Amaravati High Court
Architects: Foster + Partners, AHC

Simulation Tools help in..

The design of High Performance Buildings with ambitious energy consumption targets

30kWh/sqm/annum – Institutional Building
75kWh/sqm/Annum – Office Buildings

Vernacular Design



Building Physics Principles



Engineering



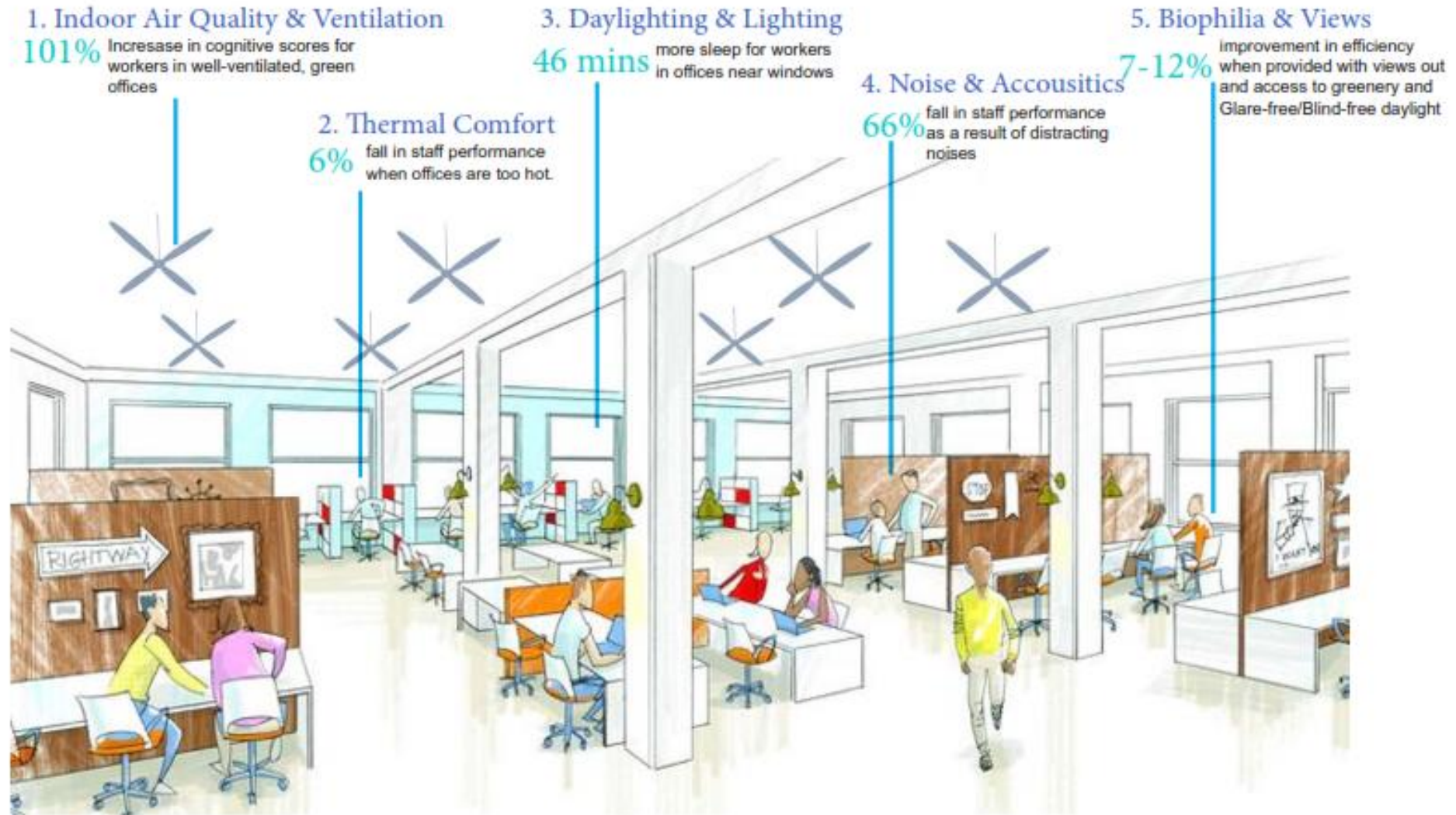
Technology



And Achieve Net Zero Energy Targets

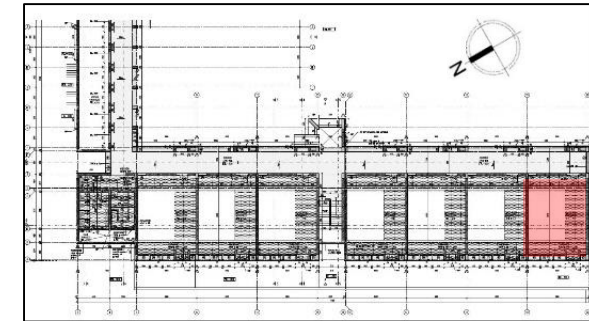
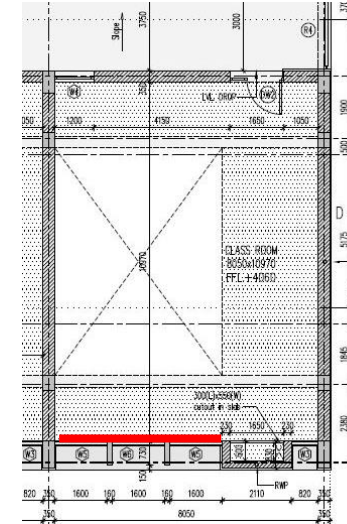
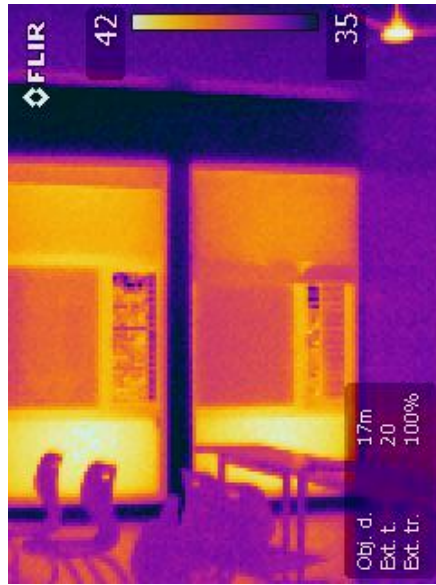
*Project: Amaravati High Court
Architects: Foster + Partners, AHC*

High Performance Without Considering Comfort....



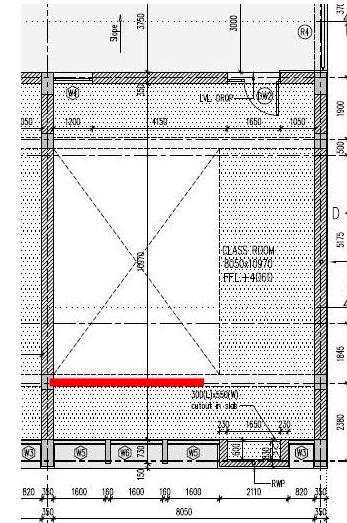
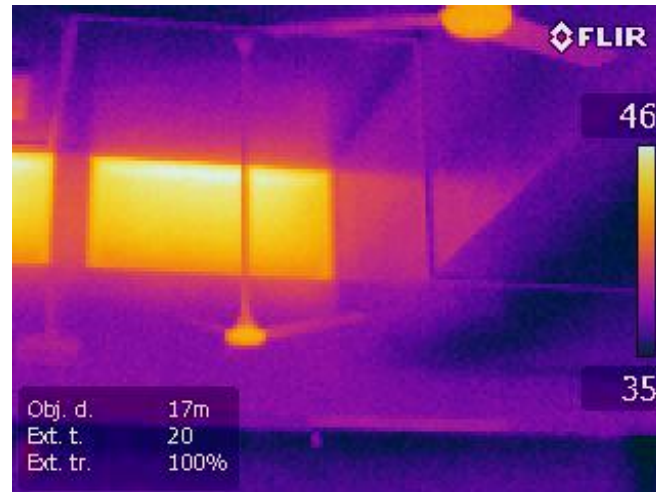
SENIOR CLASSROOM – THERMAL STUDY

External Wall
12 PM



	Internal	External
Temperature	34.7°	36.7°
Humidity	33%	27%
Daylight	220 lx	8084 lx

Clearstory

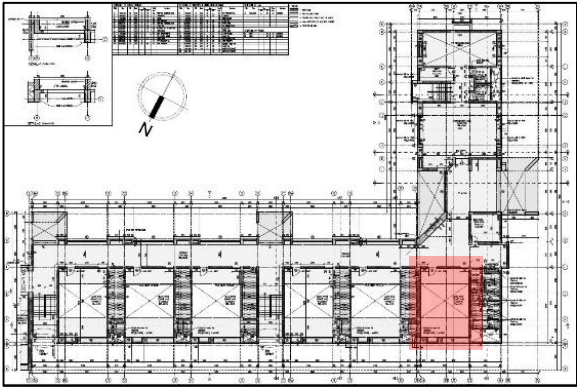
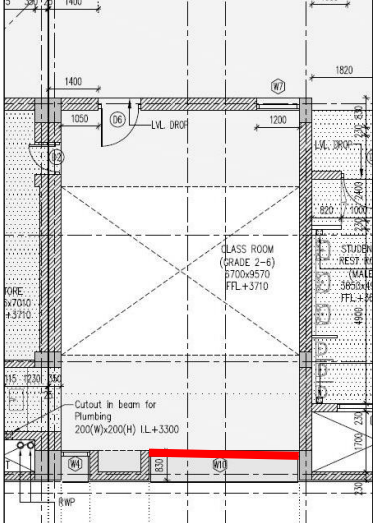
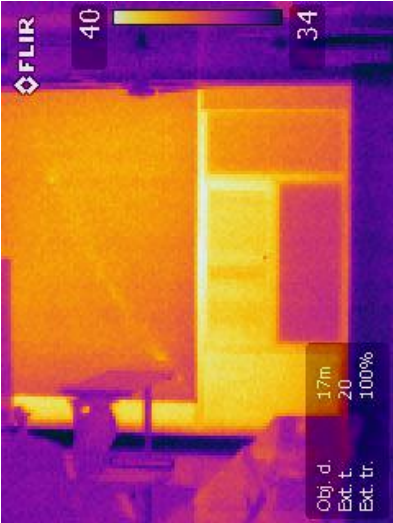


Project: Aga Khan Academy Retrofit

JUNIOR CLASSROOM – THERMAL STUDY

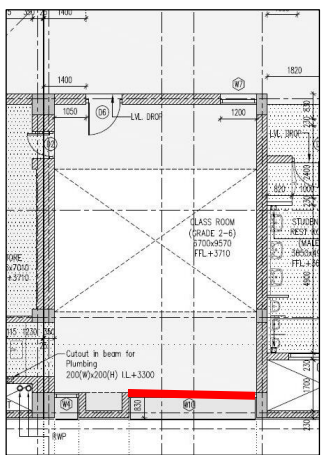
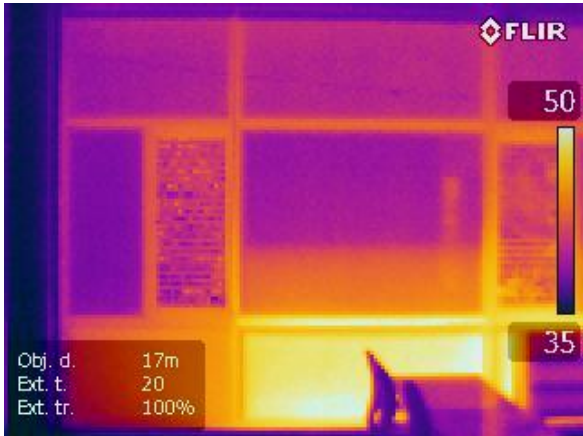
External Wall

10 AM



	Internal	External
Temperature	34.3°	34.4°
Humidity	40%	31%
Daylight	315 lx	2600 lx

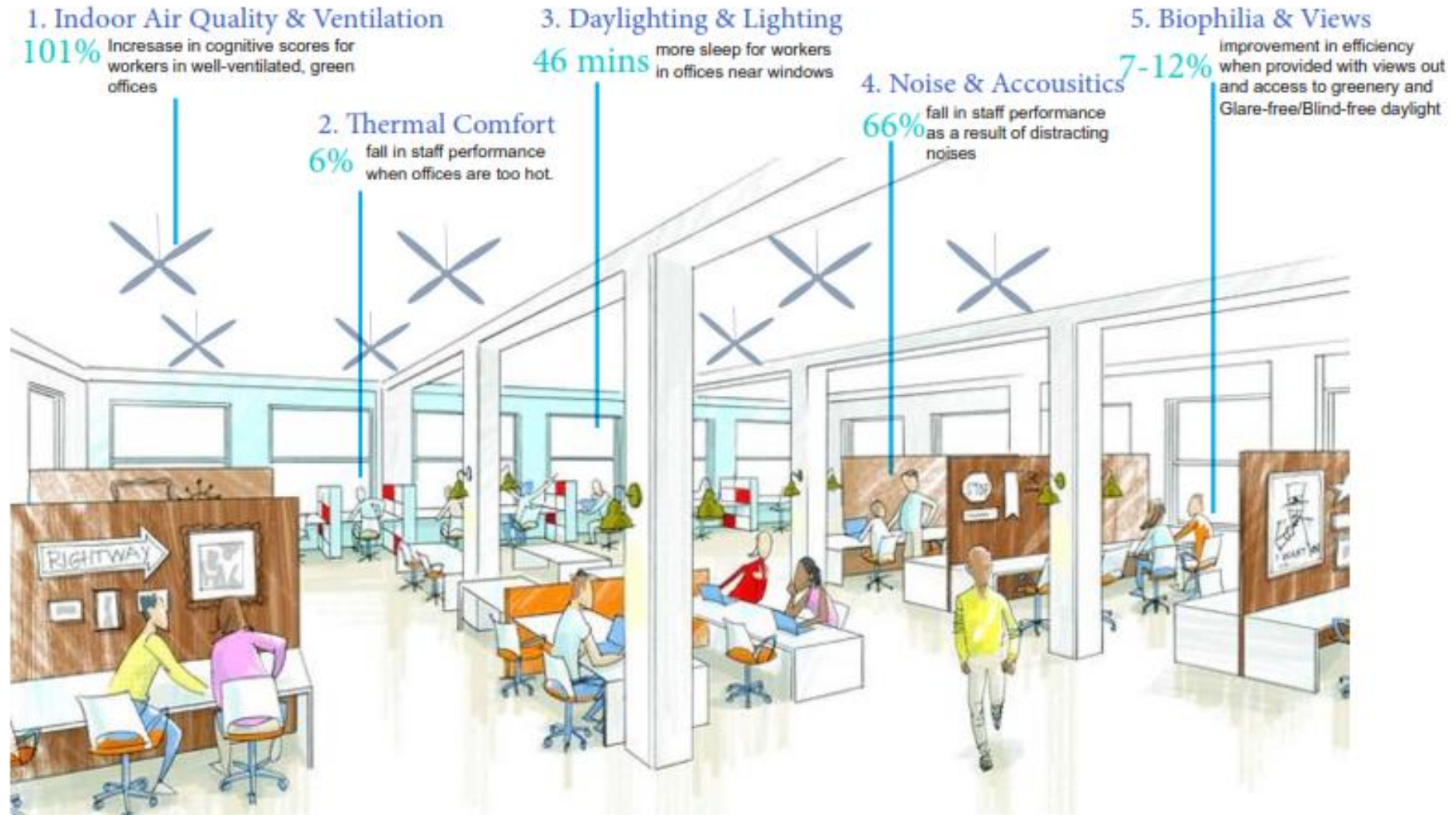
2.30 PM



	Internal	External
Temperature	34.7°	36°
Humidity	32%	23%
Daylight	500 lx	4850 lx

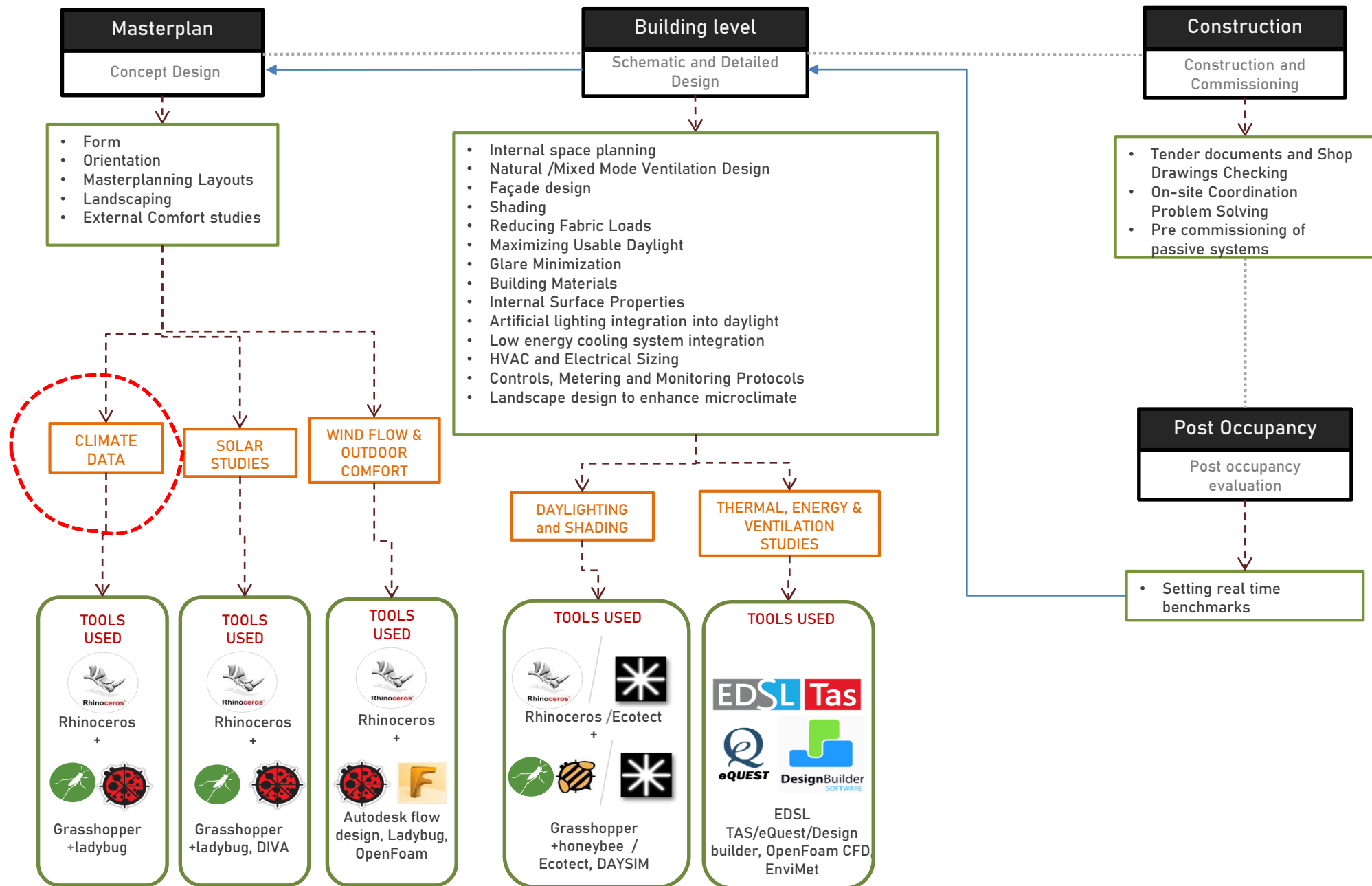
Project: Aga Khan Academy Retrofit

High Performance Without Considering Comfort...is a wasted Opportunity

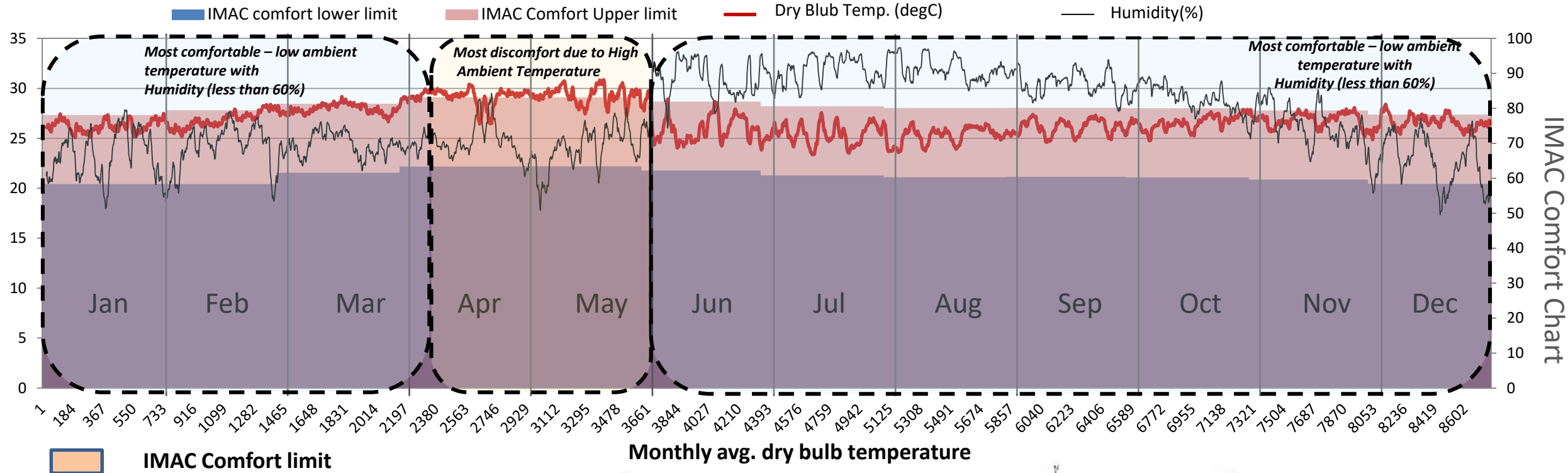


SIMULATION TOOLS THAT HELP WITH COMFORT ASSESSMENT

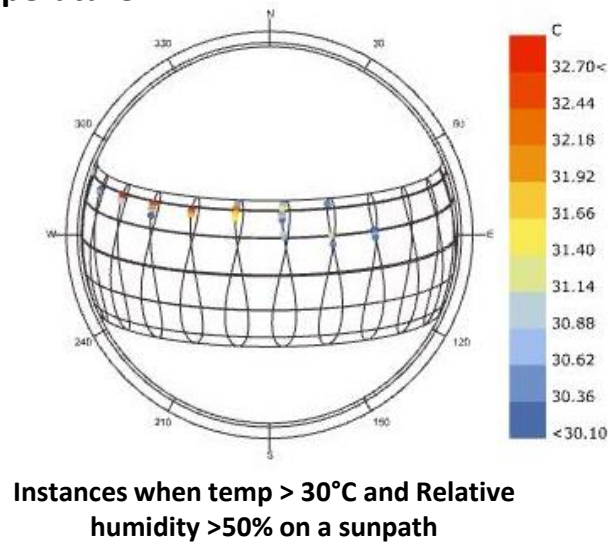
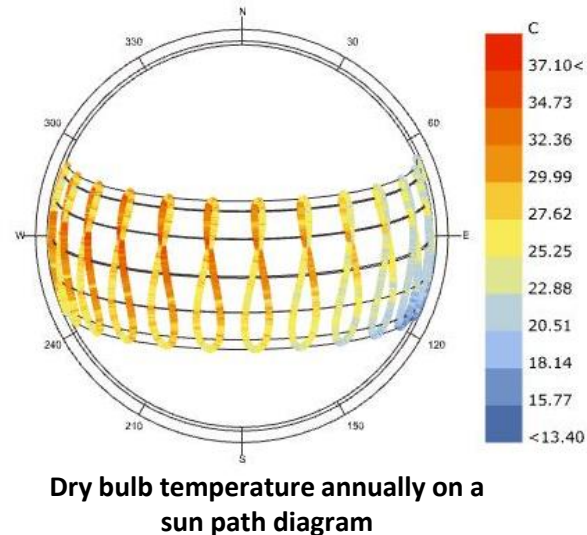
Early Design Stage – Climate Analysis



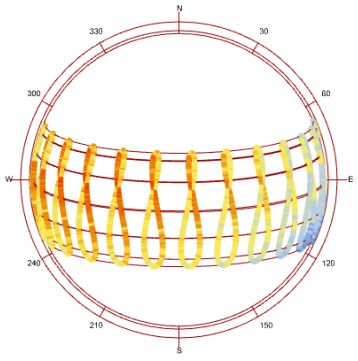
Climate Analysis – Ambient conditions



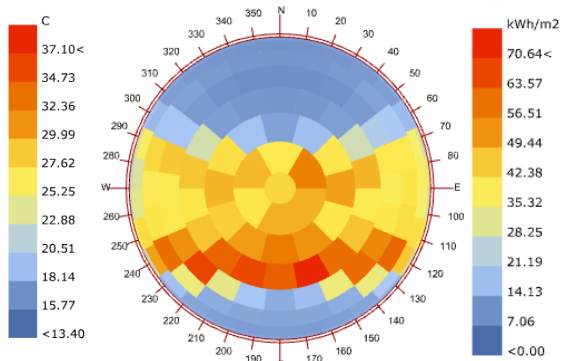
- 86% of the year is comfortable
- Max IMAC threshold temp. – 29.1c
- Discomfort hours as per IMAC is for one month only when ambient temperatures go above 32 deg C



Climate Analysis – Solar Intensity and Wind



Sun-Path Diagram - Latitude: 12.97
Hourly Data: Dry Bulb Temperature (C)
BANGALORE_KARNATAKA_IND



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

Solar Radiation Distribution at Bengaluru

1. Intensity of solar radiation is higher pre-noon compared to post noon. However ambient temperature is higher post noon compared to pre noon.
2. Intensity of solar radiation is high 9am to 4pm (From April to June)
3. As it is very cloudy, the intensity of radiation is the least during monsoons (July to Sep)
4. The intensity increases again post monsoon from October to March. However, the intensity is high from around 10 am to 3pm.

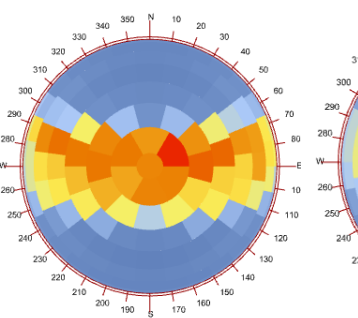
Solar control and shading requirement

Based on the combination of solar intensity and ambient temperatures, effective solar shading is required from

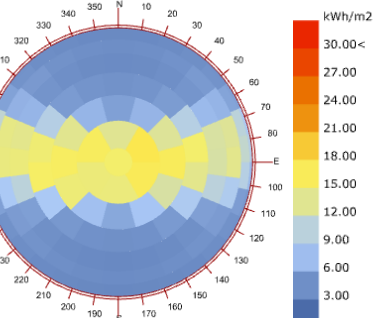
- 9am to 4pm in from Mid March to Mid September
- 10am to 3pm from Mid September to Mid March

Wind flow at Bengaluru

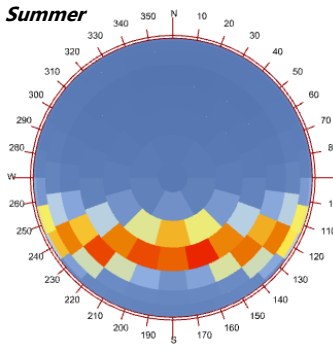
Windflow is primarily from east and west in Bangalore and quite consistent through out the year.



Total Radiation(kWh/m2)
BANGALORE_KARNATAKA_IND
1 MAR 1:00 - 30 JUN 24:00

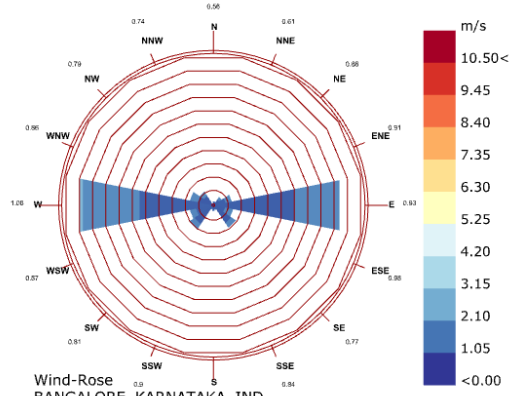


Total Radiation(kWh/m2)
BANGALORE_KARNATAKA_IND,
1 JUL 1:00 - 30 SEP 24:00

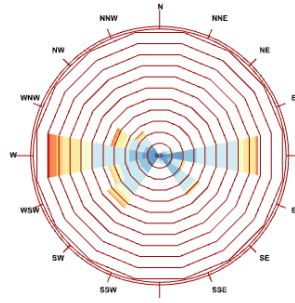


Total Radiation(kWh/m2)
BANGALORE_KARNATAKA_IND,
1 OCT 1:00 - 28 FEB 24:00

Winter

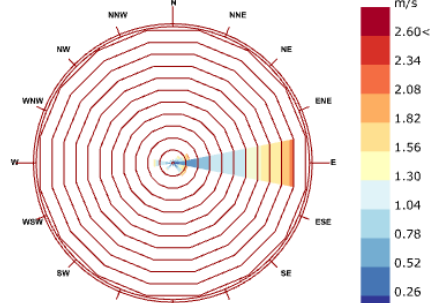


Wind-Rose
BANGALORE_KARNATAKA_IND
1 JAN 1:00 - 31 DEC 24:00
Hourly Data: Wind Speed (m/s)
Calm for 5.01% of the time = 439 hours.
Each closed polyline shows frequency of 2.9%. = 257 hours.



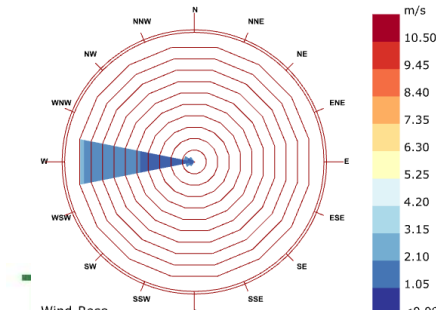
Wind-Rose
BANGALORE_KARNATAKA_IND
1 MAR 1:00 - 30 JUN 24:00

Summer



Wind-Rose
BANGALORE_KARNATAKA_IND
1 OCT 1:00 - 28 FEB 24:00

Monsoon



Wind-Rose
BANGALORE_KARNATAKA_IND
1 JUL 1:00 - 30 SEP 24:00
Hourly Data: Wind Speed (m/s)

- During the SW monsoons, it is predominantly from the west.
- During NE monsoon, the wind direction changes to East and wind speeds are fairly high
- During the winter months, the direction shifts to E, however the wind speeds are fairly low.
- In summers, the wind direction ranges from W, SW and E.

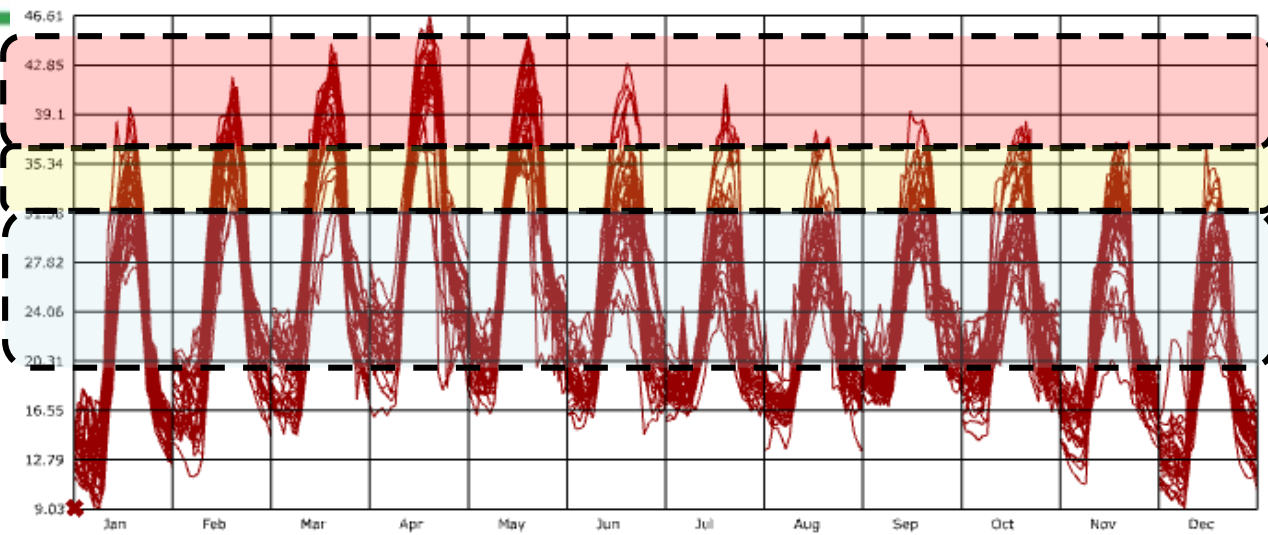
Orienting for wind and enhancing natural ventilation at Bengaluru

Given the varying wind direction and consistent winds through out the year, the following strategies have to be employed to enhance natural ventilation

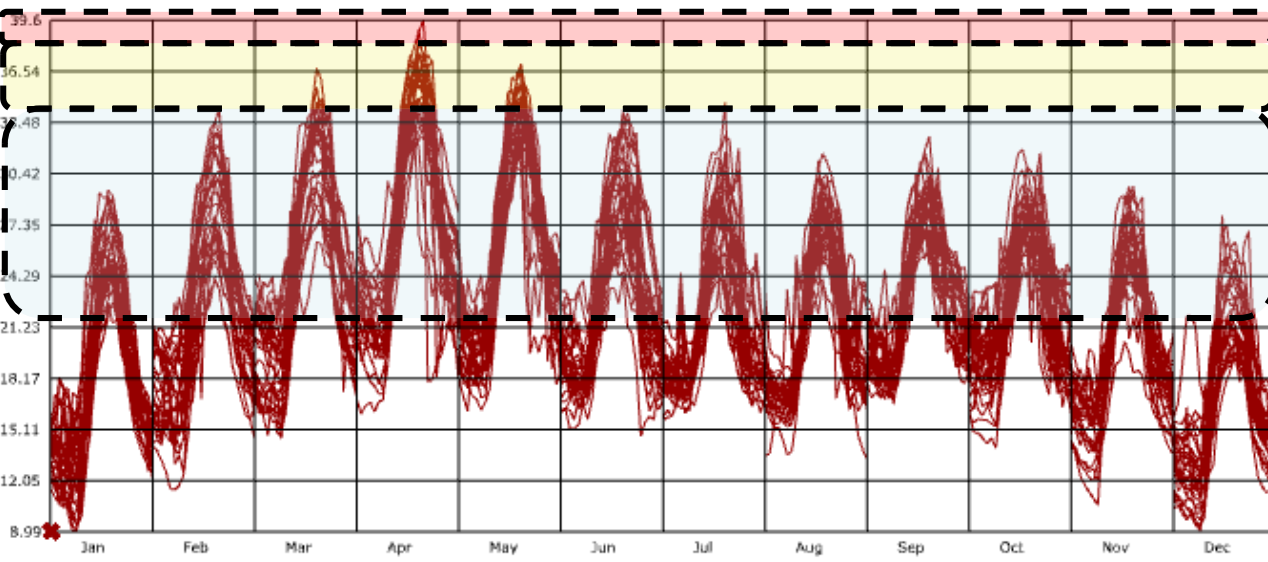
1. Orient to catch both West, East as well as SW breezes.
2. Provide for stack ventilation along with cross ventilation to help enhance natural ventilation through out the year

Climate Analysis – PET Temperature

Under Direct sun & shaded conditions



Hourly PET temperature Under direct sun (Max 46.6c)



Hourly PET temperature Under Shaded outdoor Condition (Max 39.6 – Min 12c)

Hot conditions(PET >38c)
 Warm conditions(PET>34)

PET Body characteristic Input Conditions –

- **Age** – 25 yr.
- **Weight** – 60kg
- **Body position** – Standing
- **Clothing insulation** – summer cloths
- **Activity duration** – 180 minutes
- **Metabolic rate** – 1.6

PET Levels -

- **Category -4 (<14c)** – Very Cold
- **Category -3 (14c-18c)** –Cold
- **Category -2 (18c-22c)** – Cool
- **Category -1 (22c-26c)** – Slightly cool
- **Category 0 (26c-30c)** – Comfortable

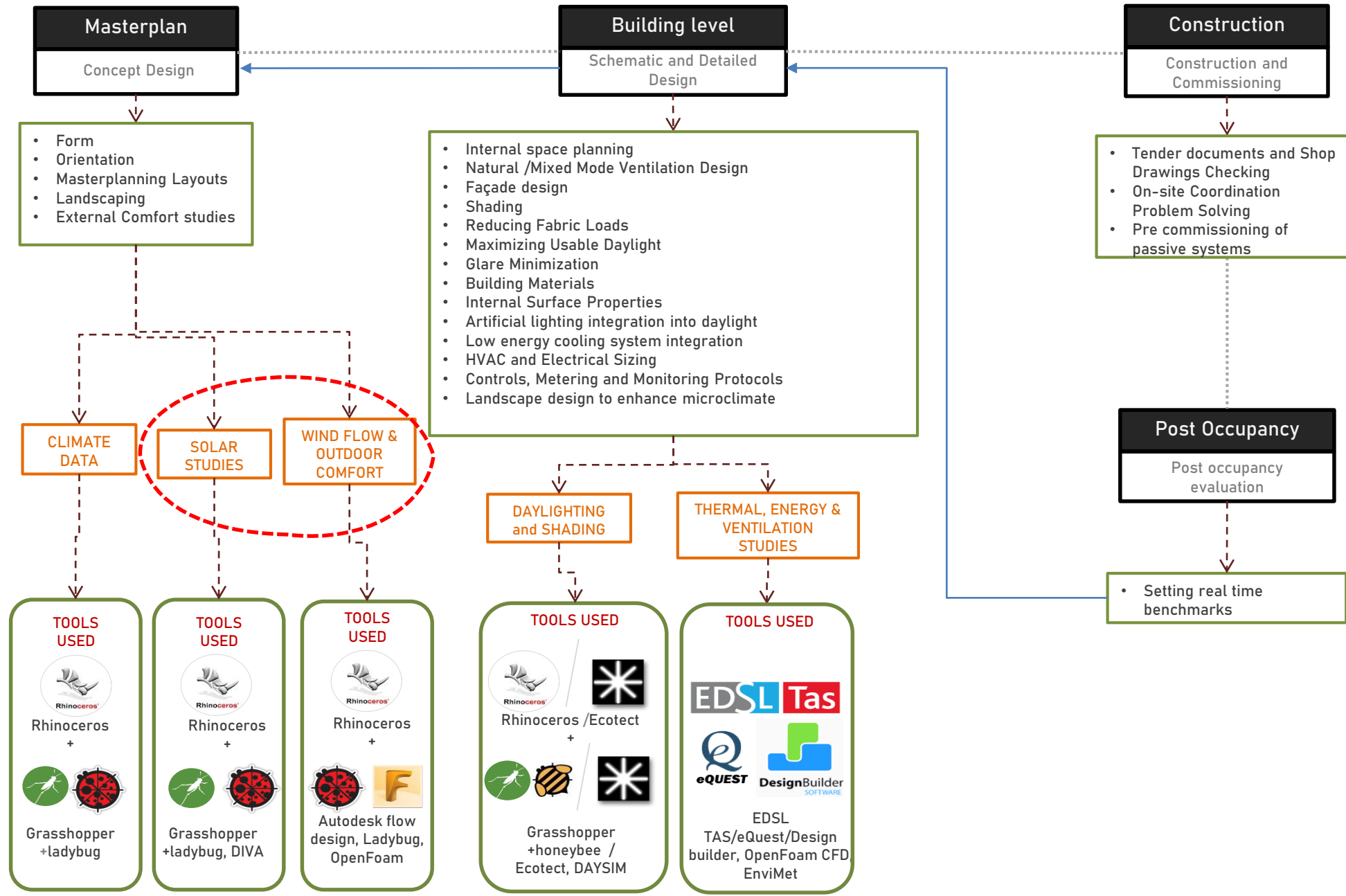
PET Levels -

- **Category 1 (30c-34c)** – Slightly warm
- **Category 2 (34c-38c)** – Warm
- **Category 3 (38c-42c)** – Hot
- **Category 4 (>42)** – Very Hot

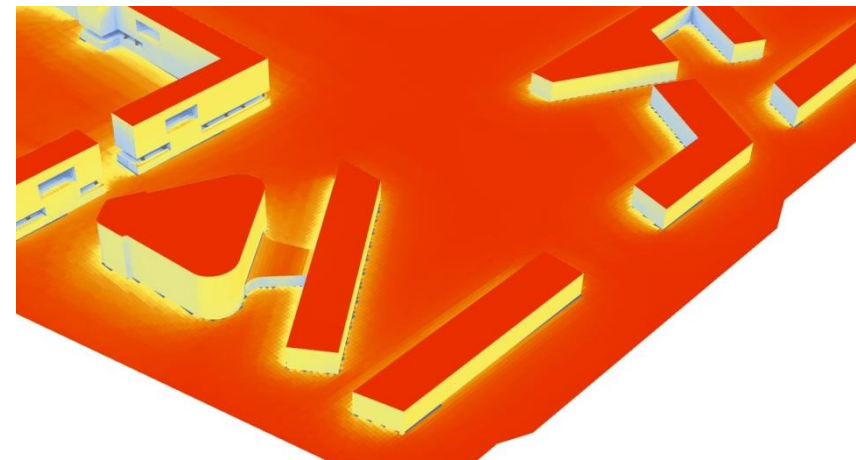
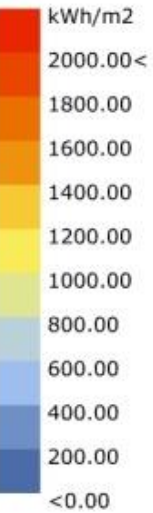
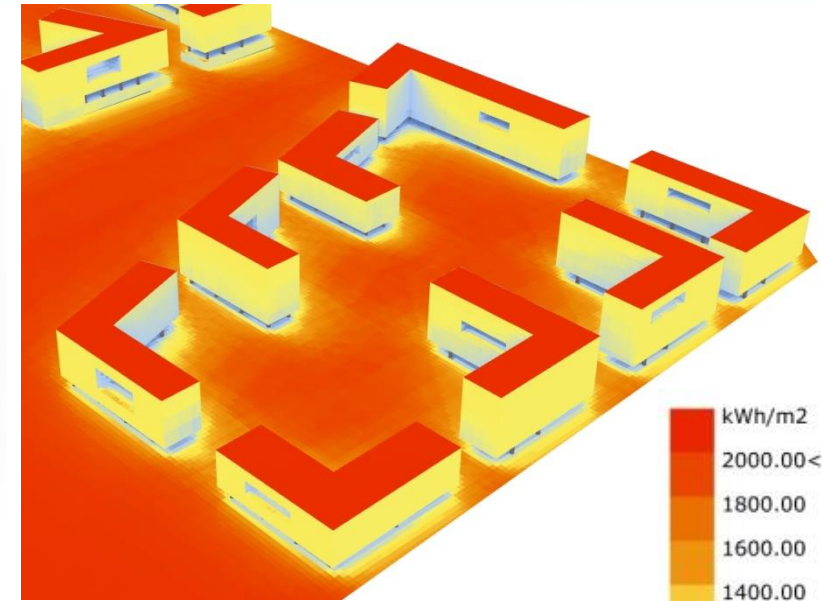
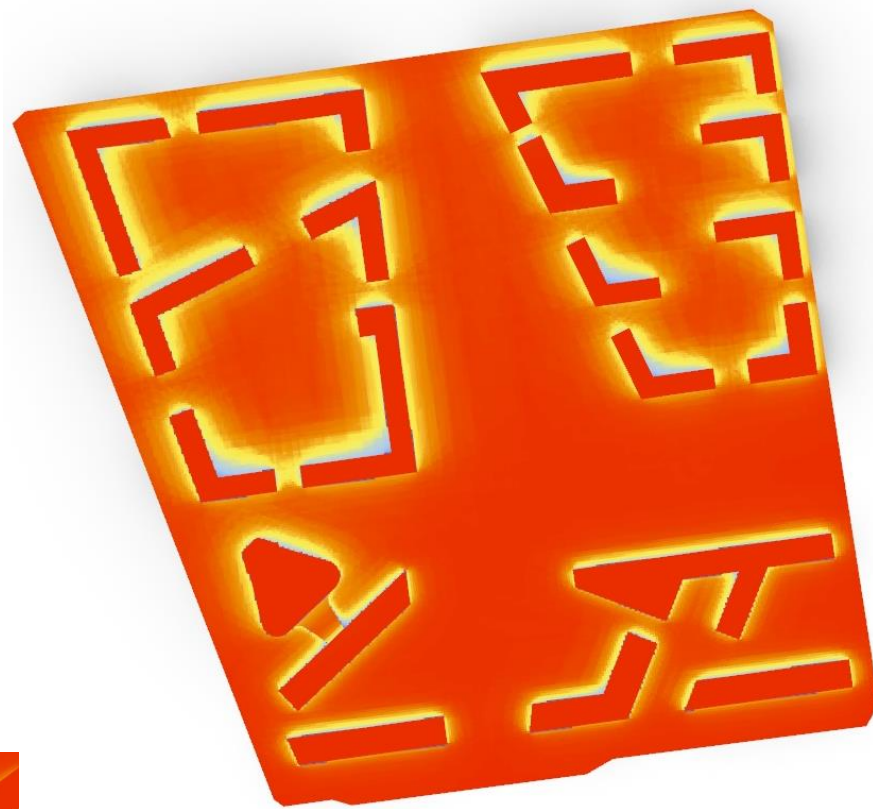
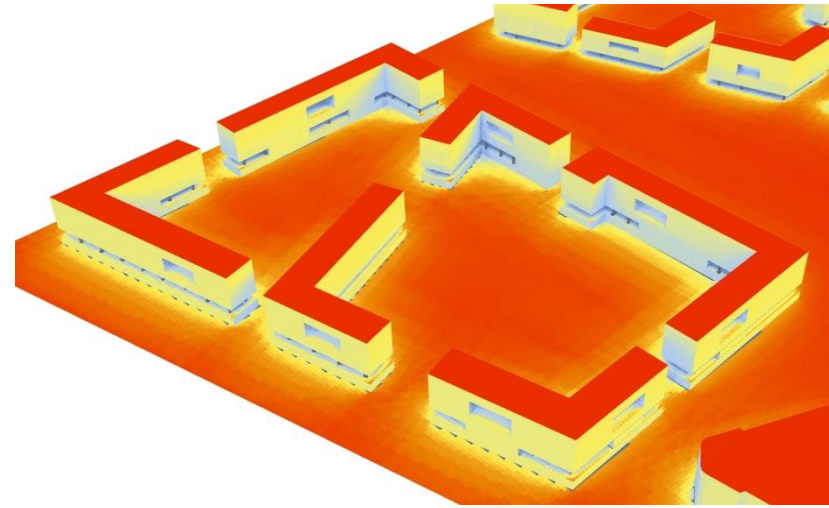
Observations

- Under direct sun very hot conditions starts from Feb to June, while intensity is higher in March to May.
- Under Shaded Outdoor conditions From March to May prevails warm conditions.
- Maximizing shaded path ways along with soft scaping can reduce mean radiant temperature at outdoor conditions.
- During Mar-May humidity levels are lower (<30%) - Humidification through water elements (fountains, waterbodies) can reduce ambient air temperature aiding comfort in outdoor conditions.

Early Design Stage - Masterplanning

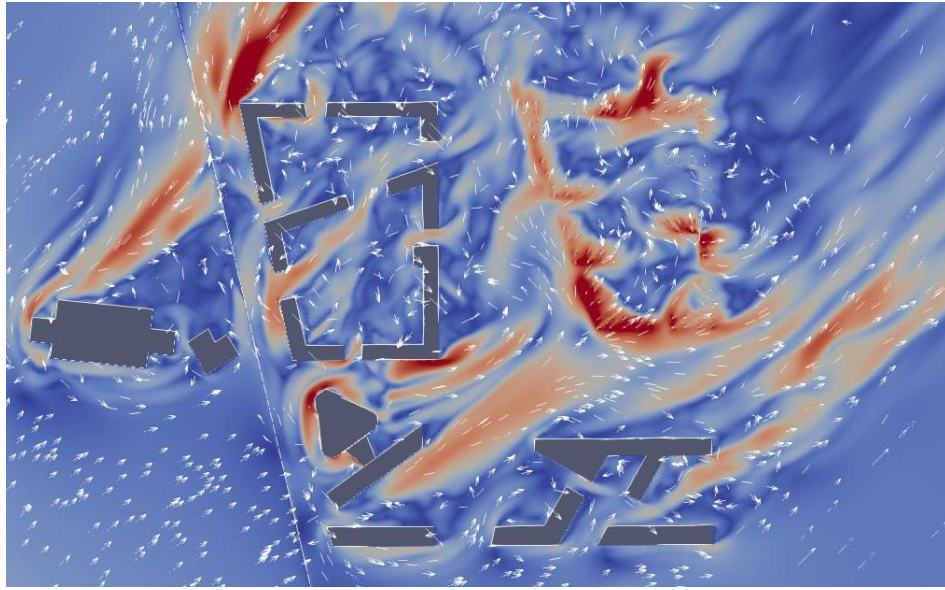


Irradiation studies for Option 4B

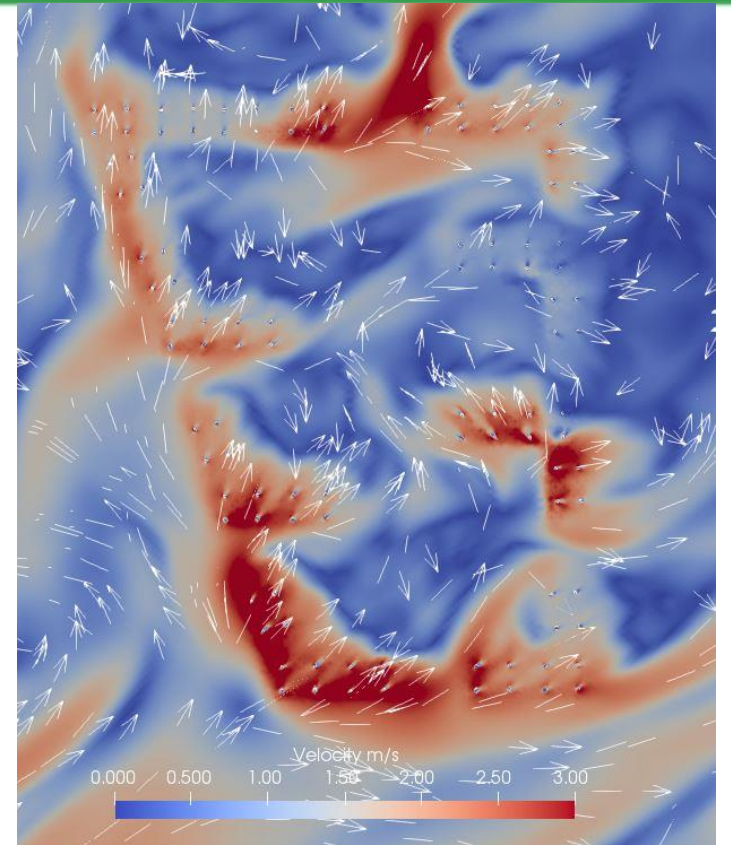


Project: IIPE
Architects: Architect Hafeez Contractor

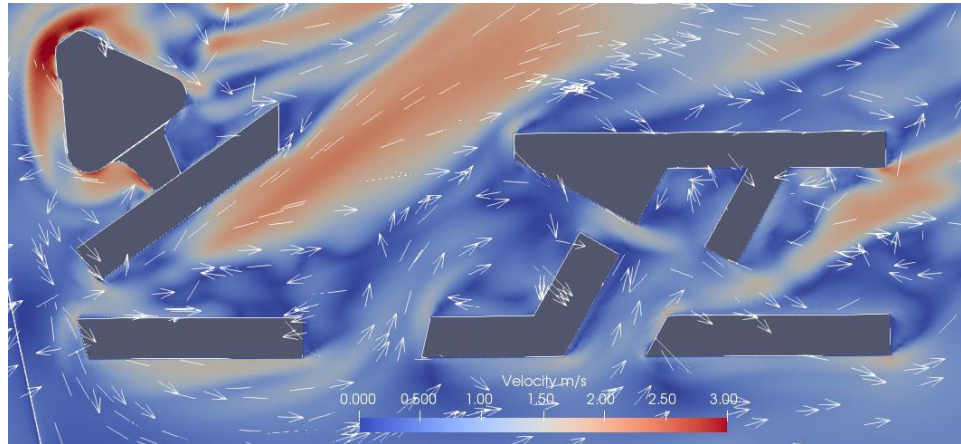
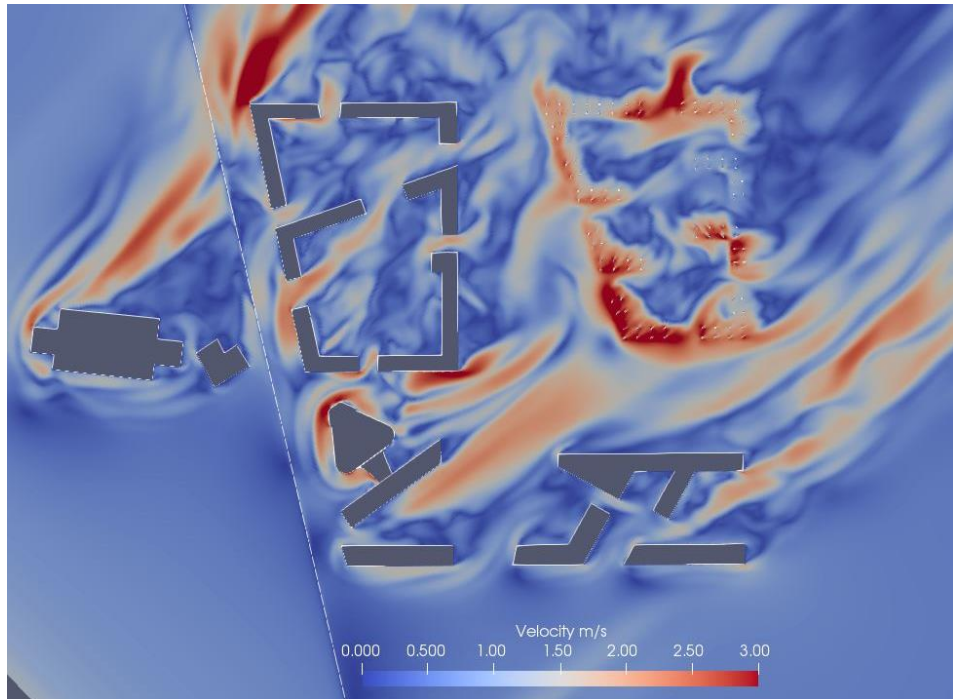
Ventilation studies For South West-Option 4B (1.8m)



Point of interest (a)

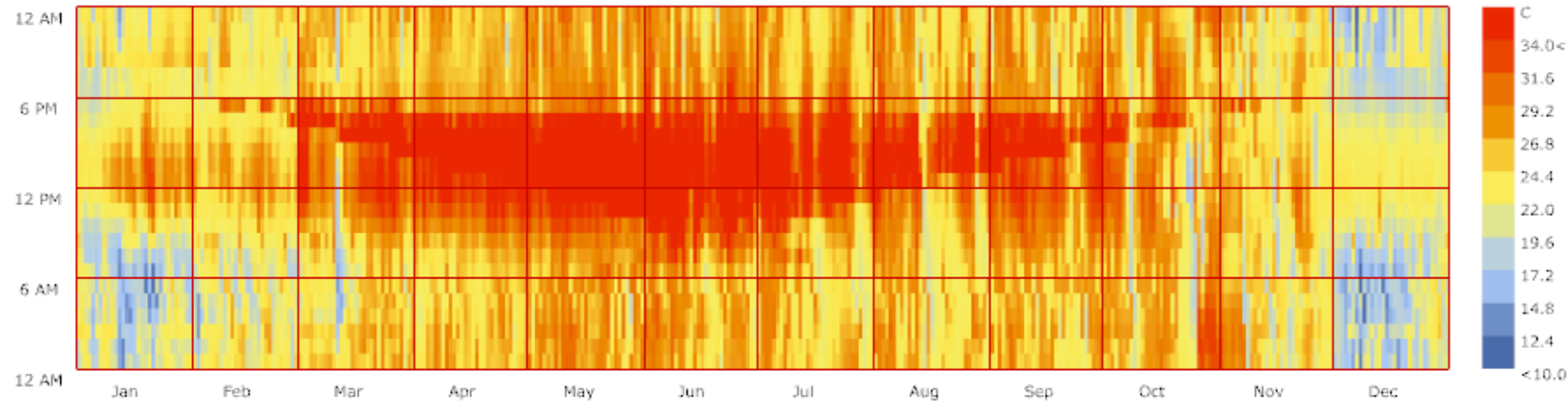


Point of interest (b)



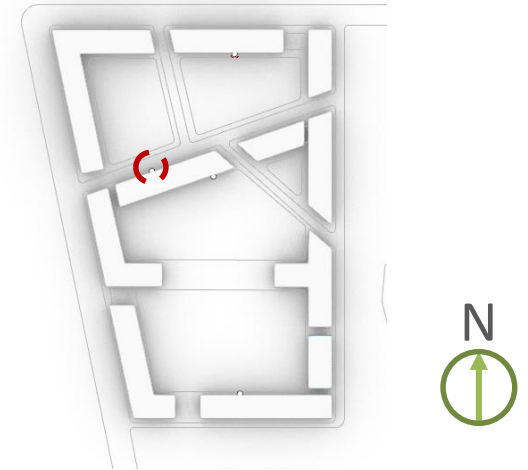
Project: IIPE
Architects: Architect Hafeez Contractor

A1 North West Semi Shade

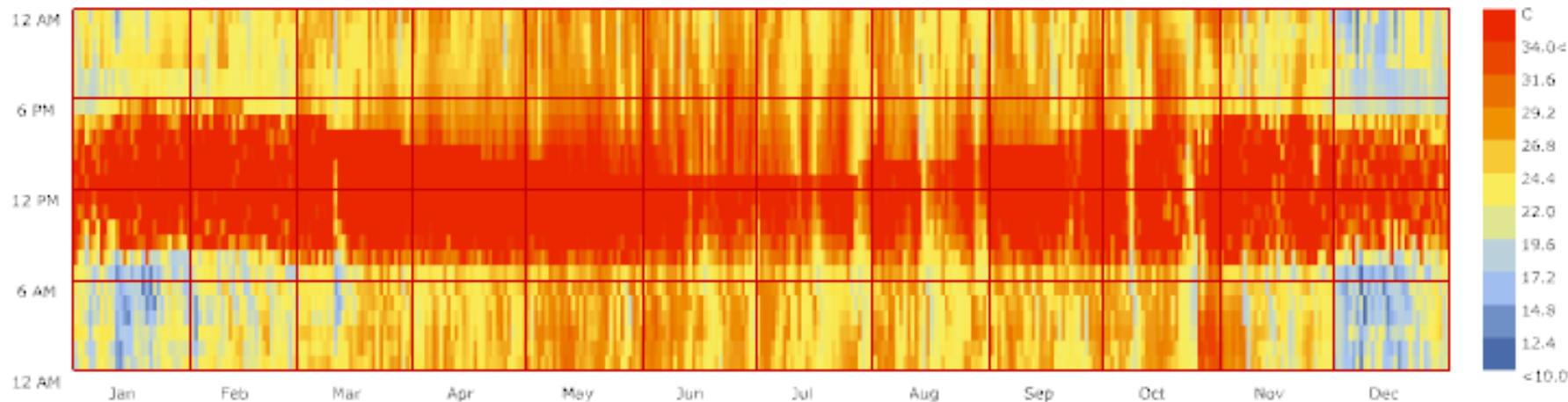


Physiologically Equivalent Temperature (for (sub)tropical humid climates) - values (C) - Hourly
VISHAKHAPATNAM_ANDHRA PRADESH_IND
1 JAN 1:00 - 31 DEC 24:00

PET 92 % of year comfortable (<math><34</math>)

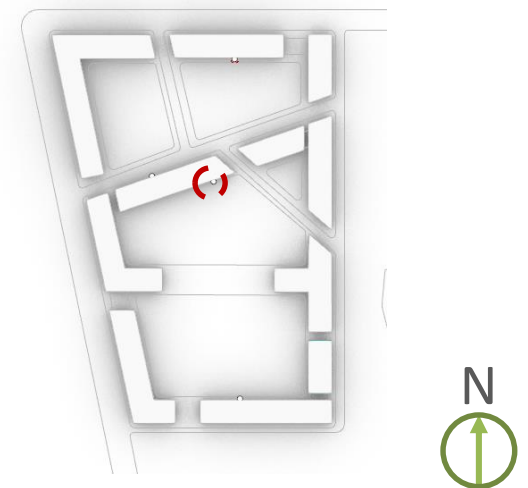


A1 South East Semi Shaded



Physiologically Equivalent Temperature (for (sub)tropical humid climates) - values (C) - Hourly
VISHAKHAPATNAM_ANDHRA PRADESH_IND
1 JAN 1:00 - 31 DEC 24:00

PET 80 % of year comfortable (<math><34</math>)



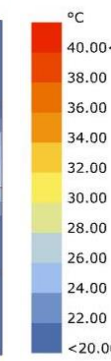
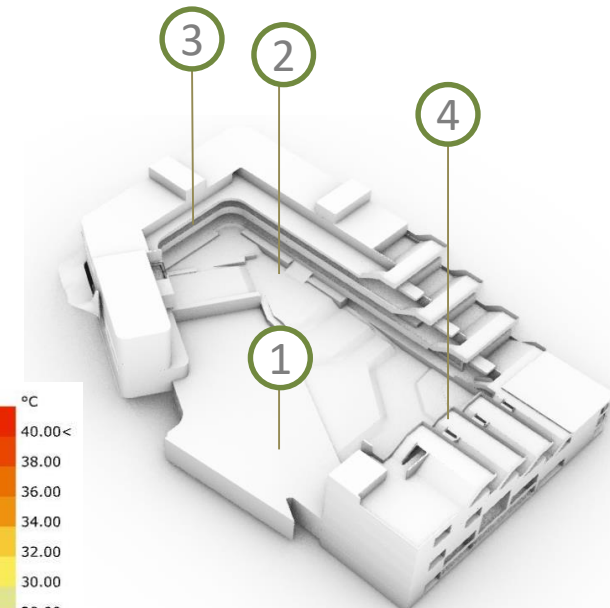
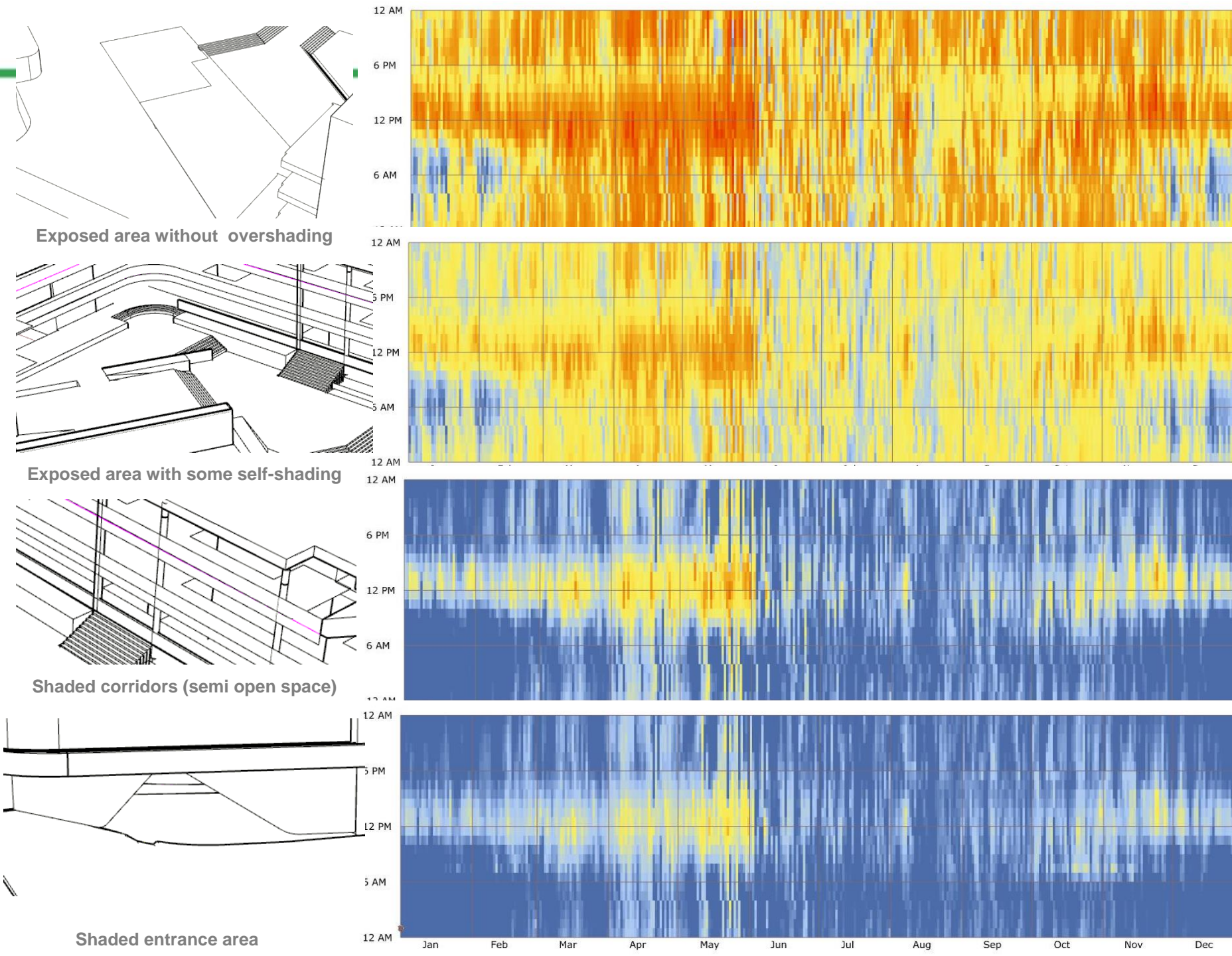
Project: IPE

Architects: Architect Hafeez Contractor

UTCI of outdoor spaces

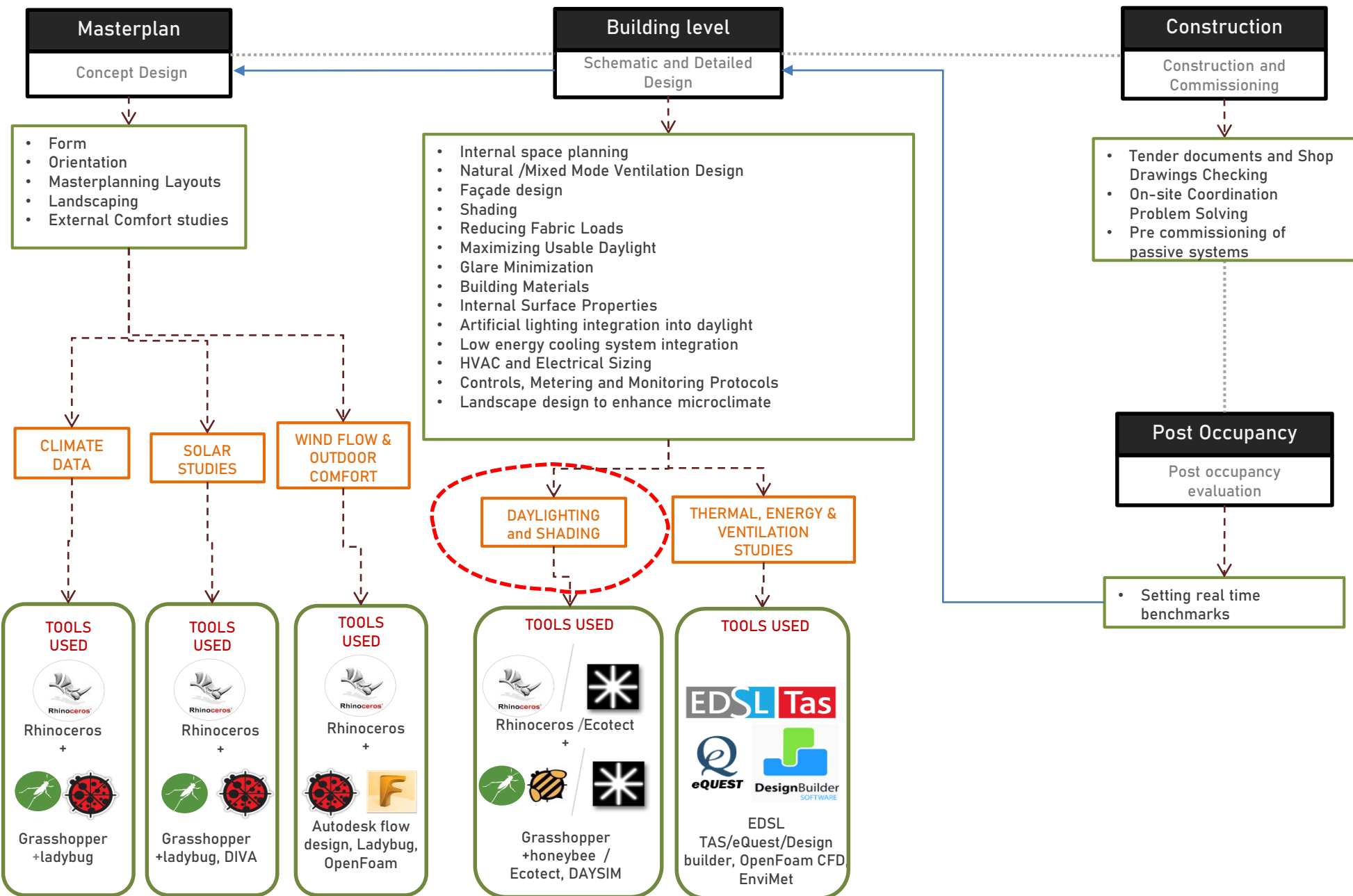
UTCI is an outdoor comfort metric that combines various factors like –dry bulb temp, wind speed, relative humidity and MRT, to arrive at a comfort index.

A UTCI between 26 and 28 degrees Celcius indicates slight heat stress (comfortable for short periods of time). Between 28 and 32 degrees, UTCI indicates moderate heat stress (hot but not dangerous). Between 32 and 38 degrees, UTCI indicates strong heat stress (dangerous beyond short periods of time). Above 38, UTCI indicates very strong to extreme heat stress (very dangerous).

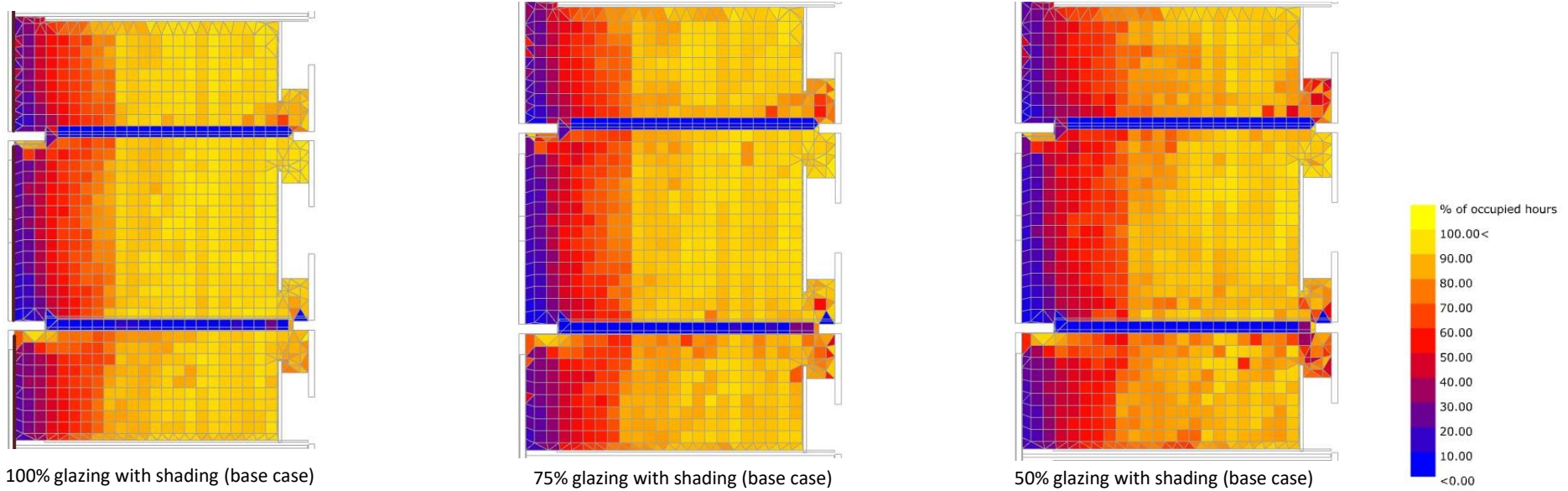


Project: MAHE Architecture School
Architects: Purple Ink Studio

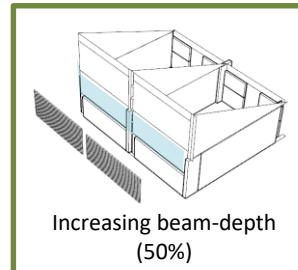
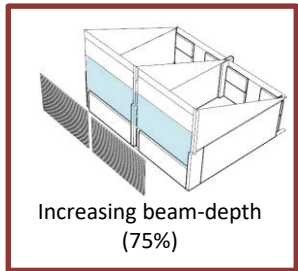
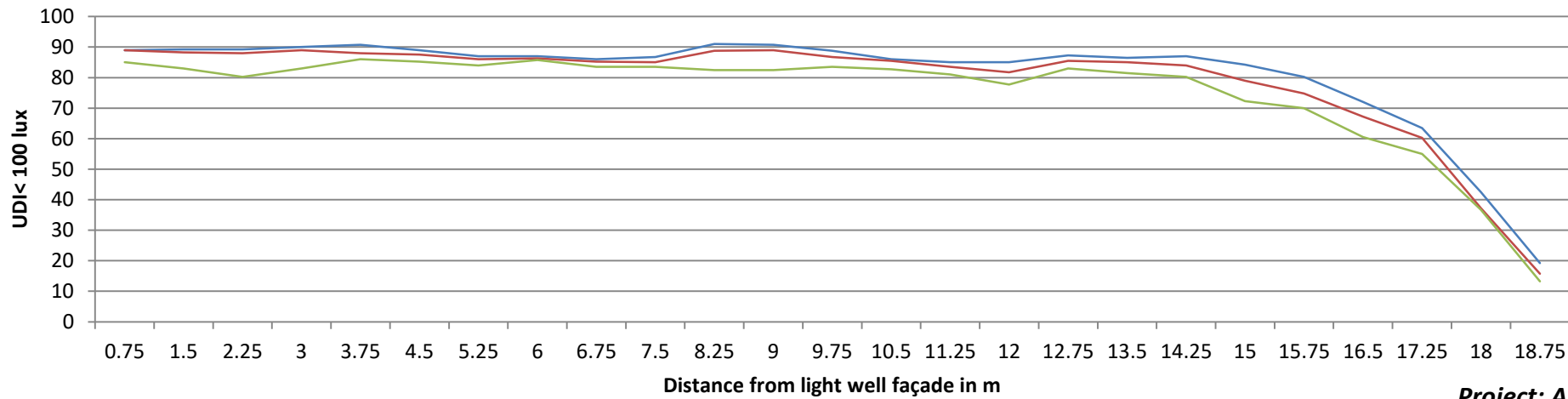
Detailed Design Stage



Chief Justice's Court hall 1_ UDI between 100 and 2000 lux

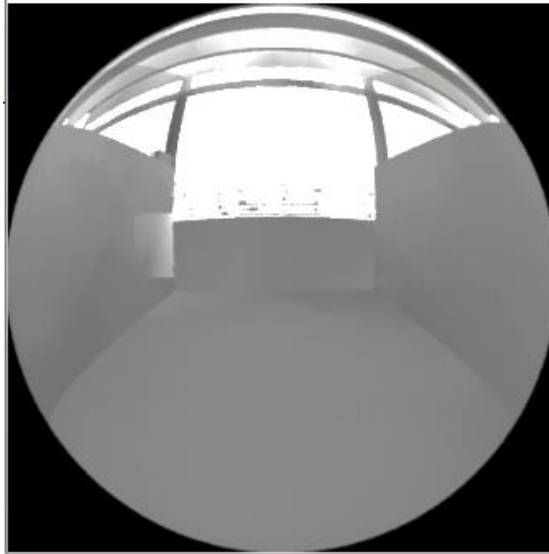


UDI between 100 and 2000 lux(Chief Justice court room)

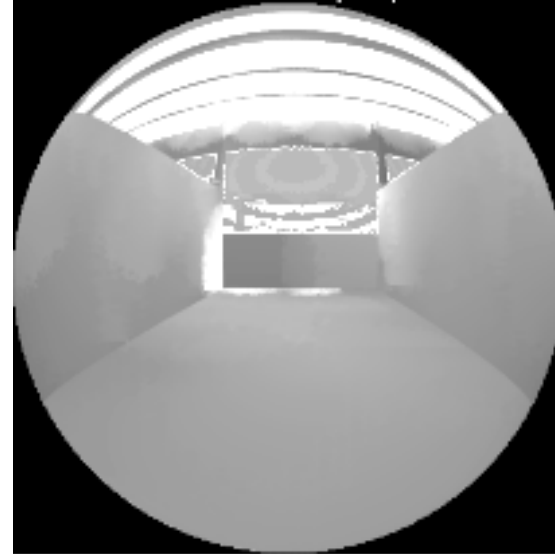


Project: Amaravati High Court
Architects: Foster + Partners, AHC

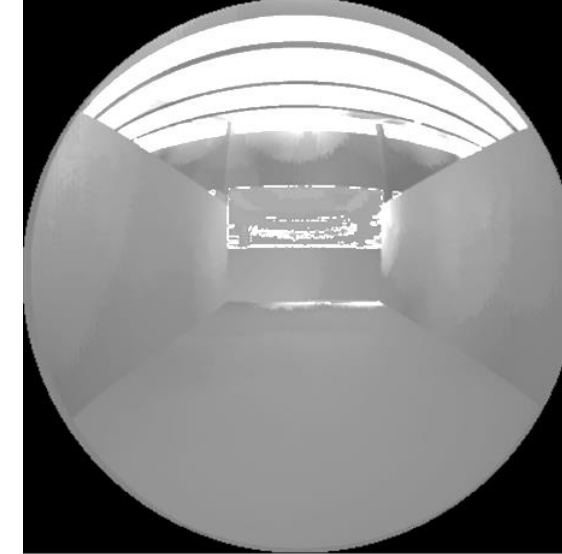
Fish eye images for Daylight glare possibility



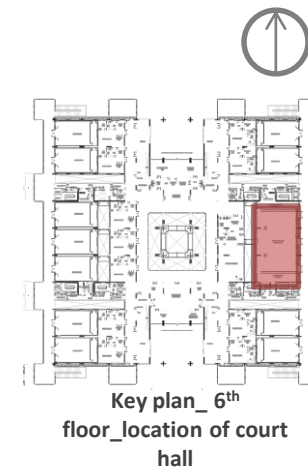
100% glazing case- Chief justice's court-(sixth floor)
Daylight glare probability – 0.27 (DGP<0.34 is imperceptible glare)



75% glazing case- chief justice's court (sixth floor)
Daylight glare probability – 0.24 (DGP<0.34 is imperceptible glare)

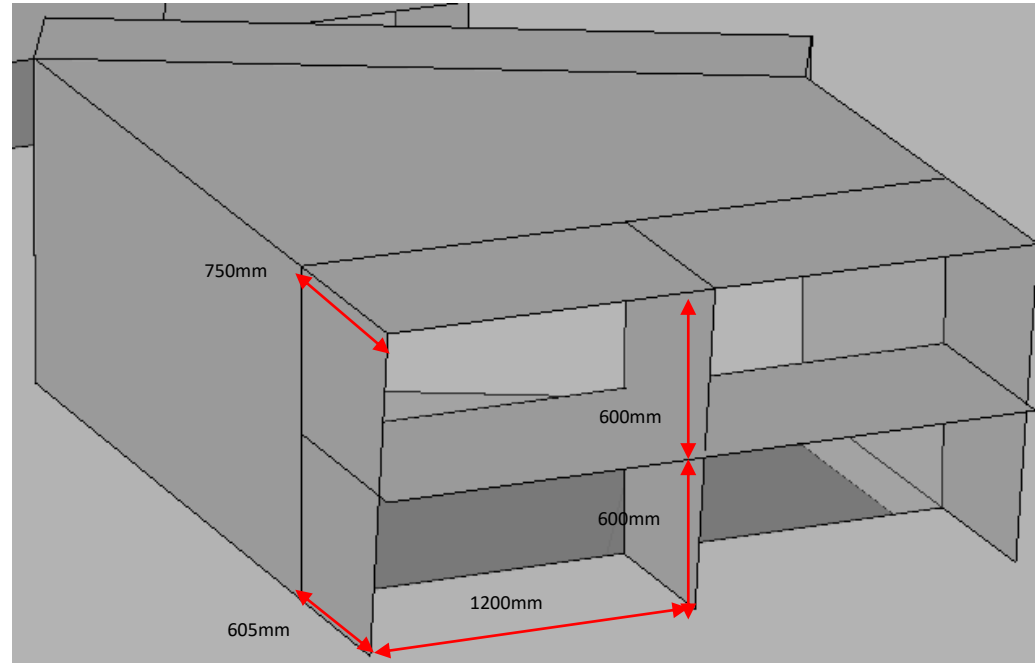
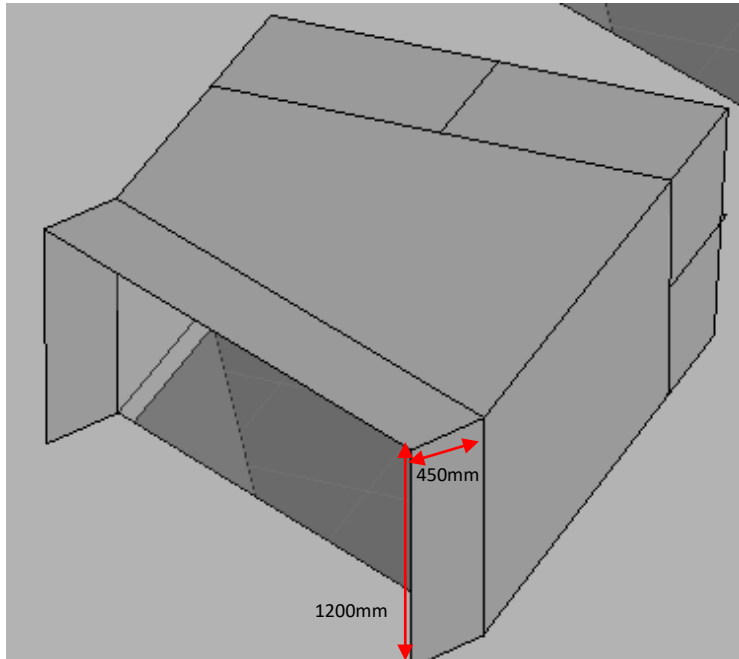


50% glazing case-Chief justice's court (sixth floor)
Daylight glare probability – 0.202 (DGP<0.34 is imperceptible glare)



Project: Amaravati High Court
Architects: Foster + Partners, AHC

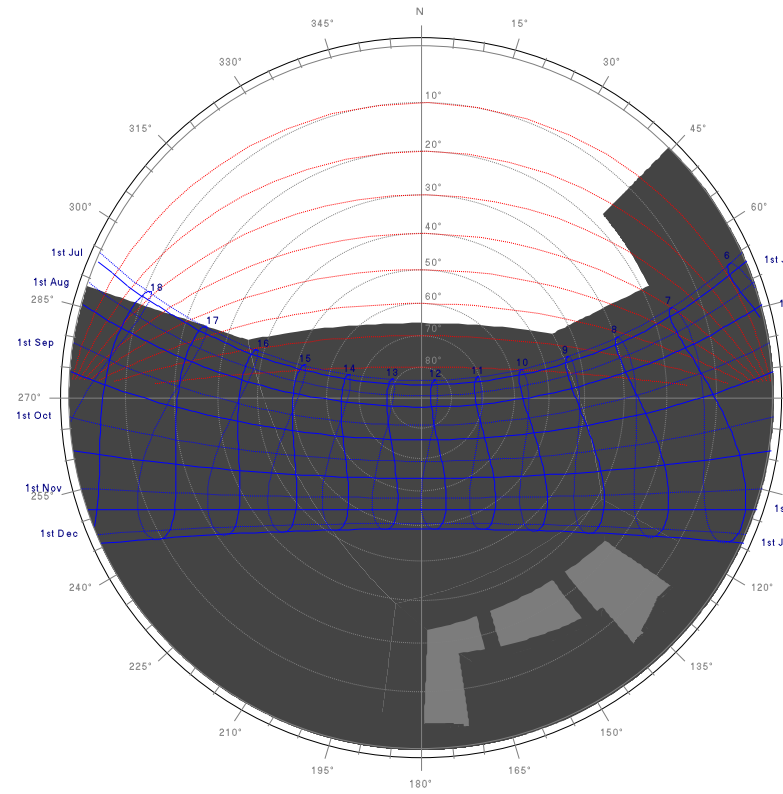
SKYLIGHT GEOMETRY



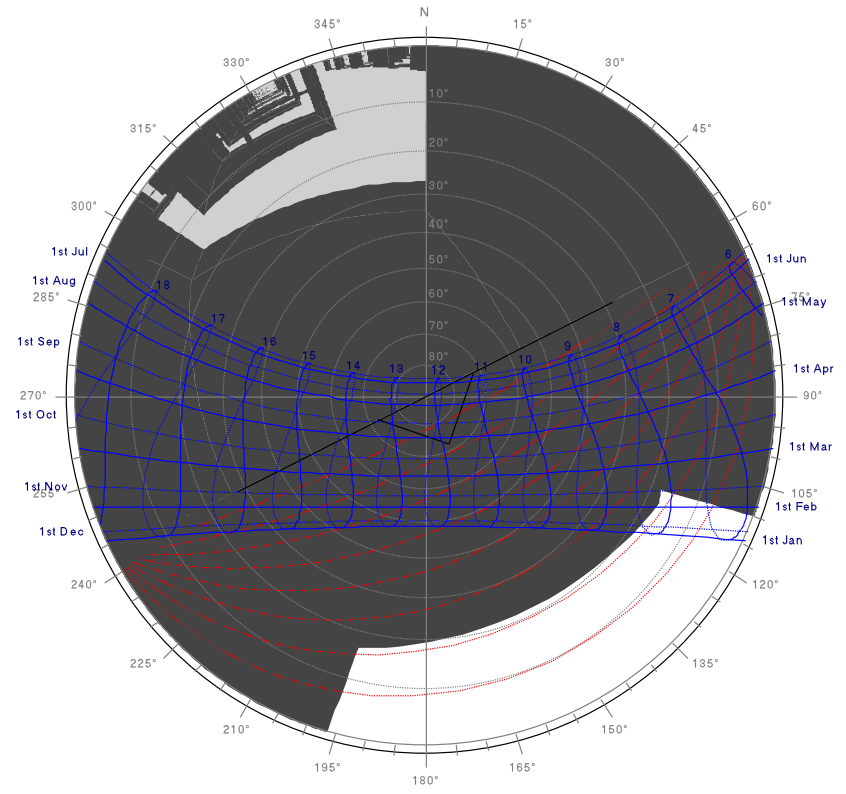
North Shading is ideal when taken perpendicular to the surface, incase it is extended in line of skylight, dimension of shading increases to 610mm.

Project: Aga Khan Academy
Architects: DCOOP

STEREOGRAPHIC SUN PATH PROJECTION



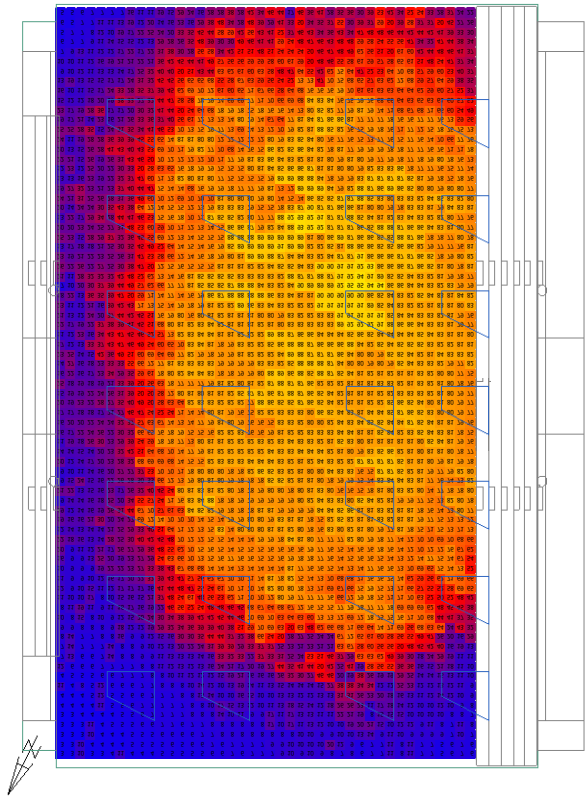
North skylight is well shaded and sunlight infiltration is observed only after 5pm during summer months



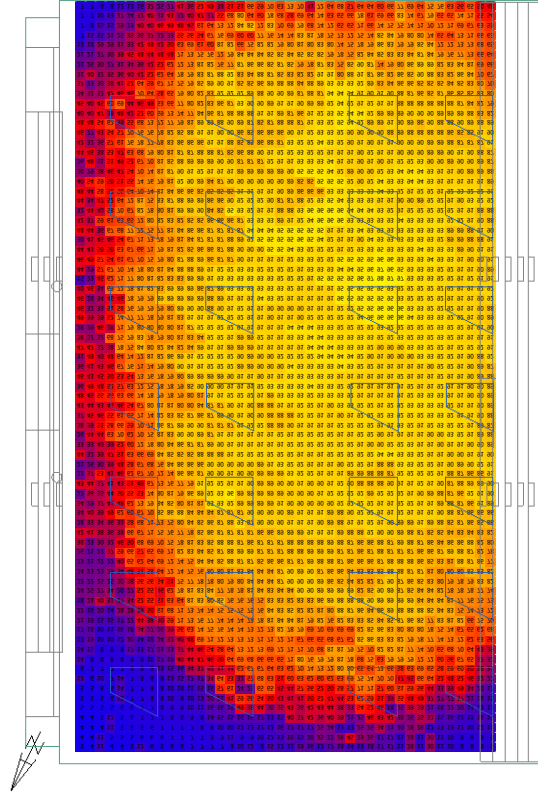
South East skylight is well shaded and sunlight infiltration is observed only till 8.15 am during winter months

Project: Aga Khan Academy
Architects: DCOOP

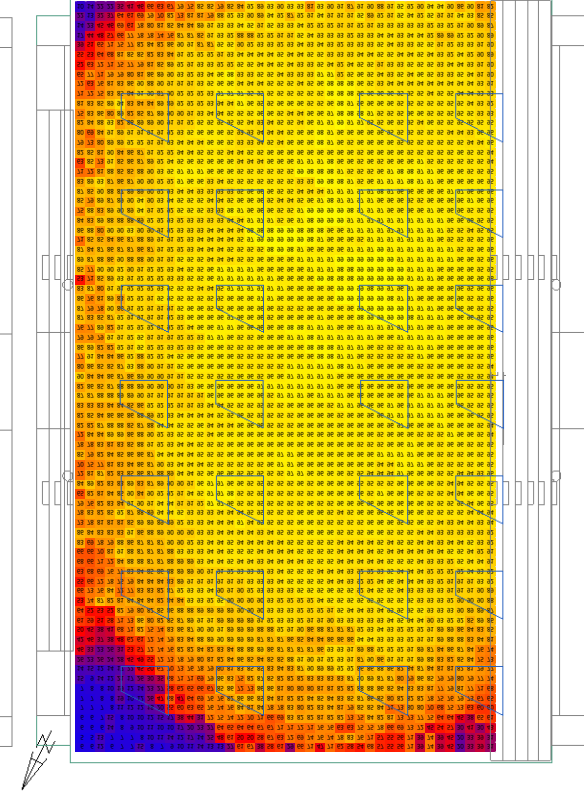
DAYLIGHT AUTONOMY



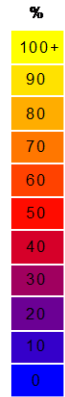
DA@250: Average- 54.2%



DA@200: Average- 71.7%

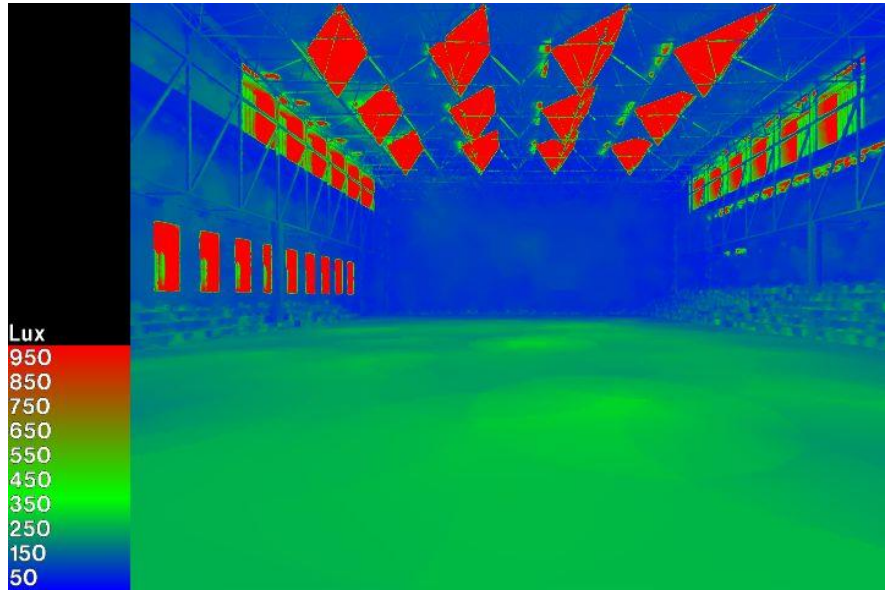


DA@150: Average- 87.1%



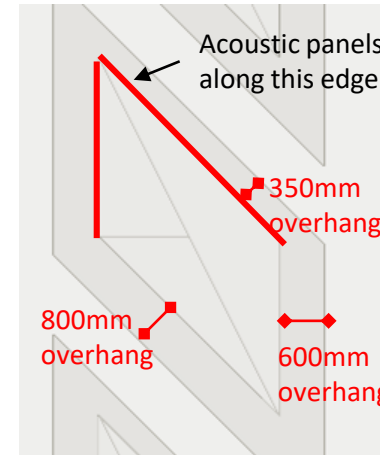
Project: Aga Khan Academy
Architects: DCOOP

600MM SKYLIGHT OPENING- Acute Angle Panel options

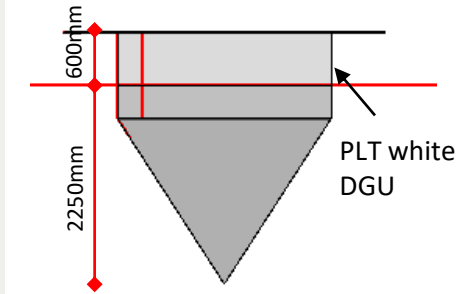


CASE 1A

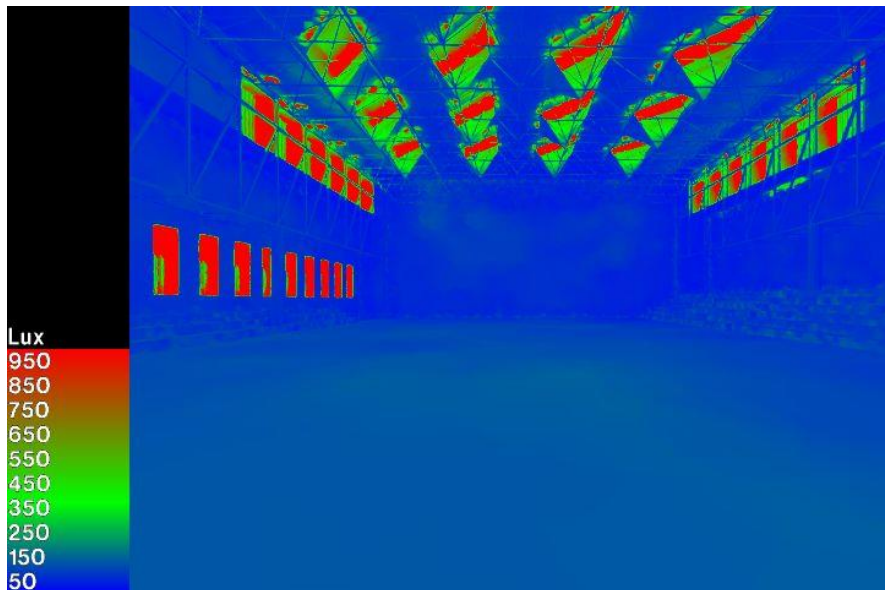
- This configuration of acoustic panels does not provide sufficient shading from direct sun. It also results in high visual contrast in the line of sight (as seen as red patches) that results in glare.
- Daylight levels are adequate



- **Clear DGU with 0.75 VLT is used**
- Position of Acoustic panel as per architect's drawing

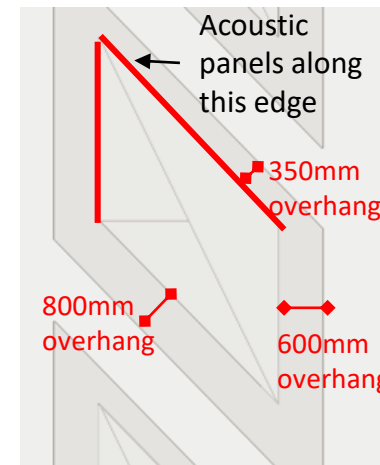


CASE 1A

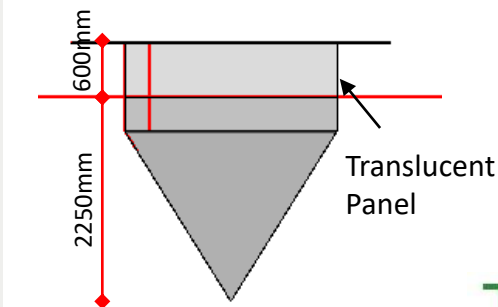


CASE 1B

- With translucent panels, daylight levels drop by more than 40% to around 150 lux as compared to the above case.
- Glare is also high due to the brightness of the translucent panels.



- **Translucent panel with 0.7 VLT is used**
- Position of Acoustic panel as per architect's drawing



CASE 1B

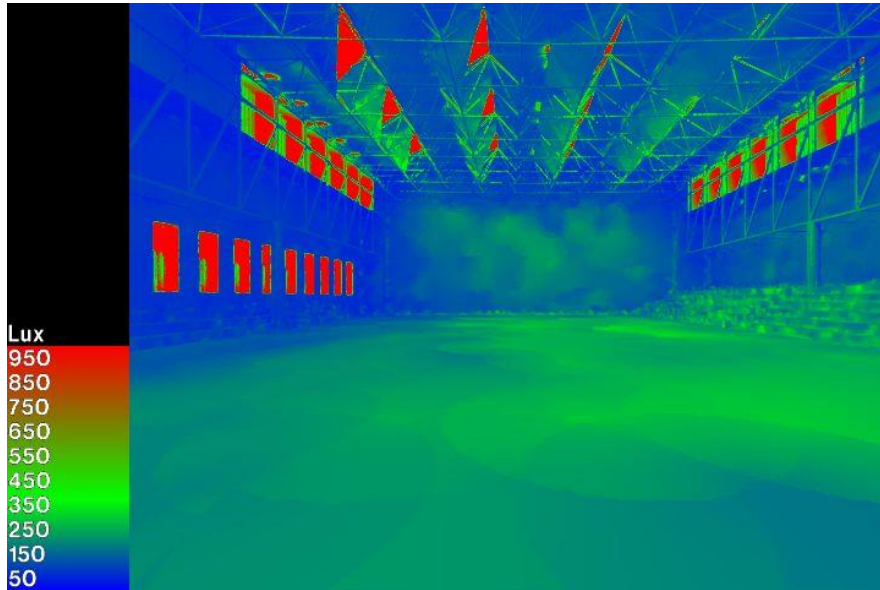
Project: Aga Khan Academy
Architects: DCOOP

600MM SKYLIGHT OPENING- Obtuse Angle Panel option

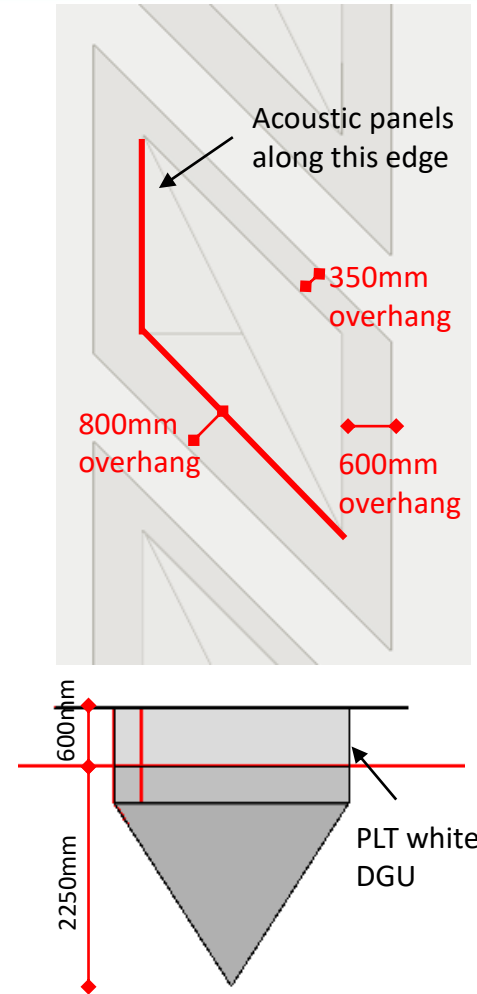
- This configuration of acoustic panels with clear DGU provides adequate daylight as well as good glare control.

Recommendation

- Increase the spacing between the roof monitors by reducing the number.



CASE 2

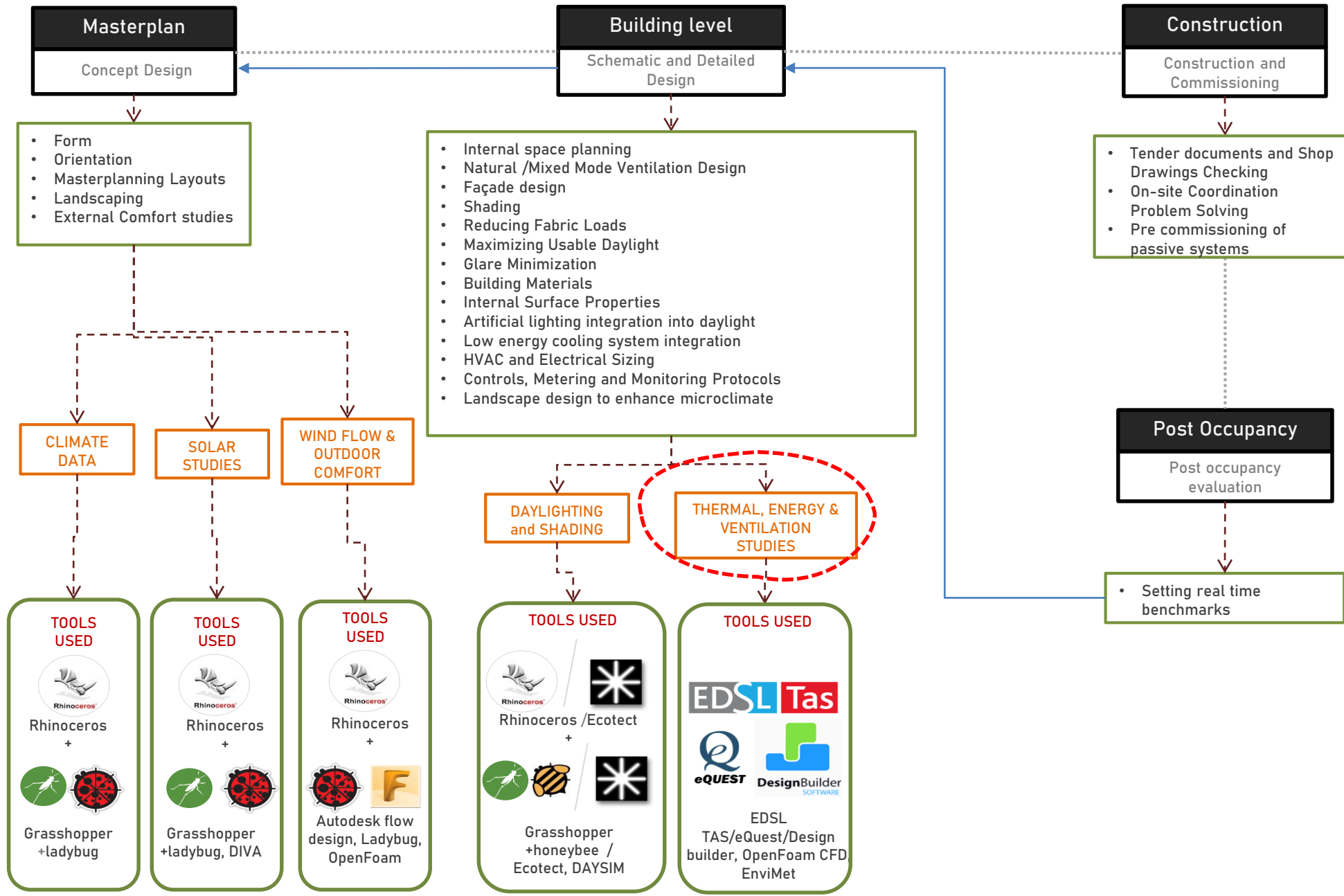


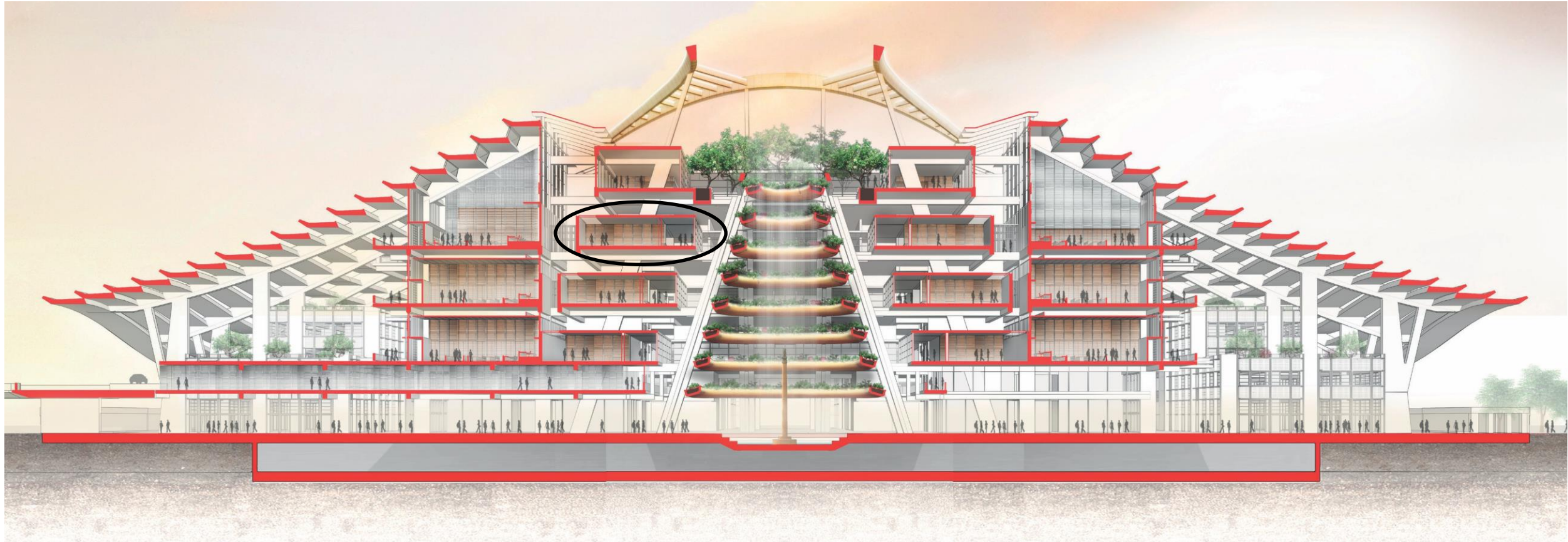
CASE 2

- Position of Acoustic panel as per report 9
- Clear DGU with 0.75 VLT is used

Project: Aga Khan Academy
Architects: DCOOP

Detailed Design Stage

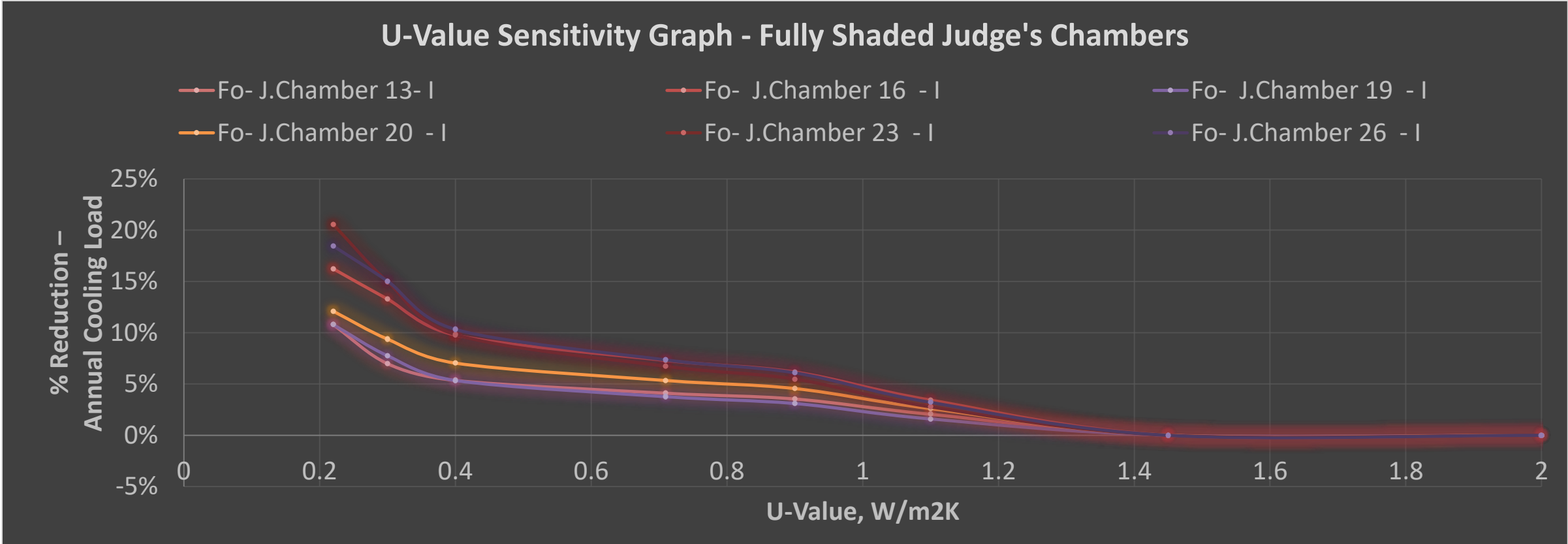




Project: Amaravati High Court
Architects: Foster + Partners, AHC

TerraViridis
Environmental Design Consultancy

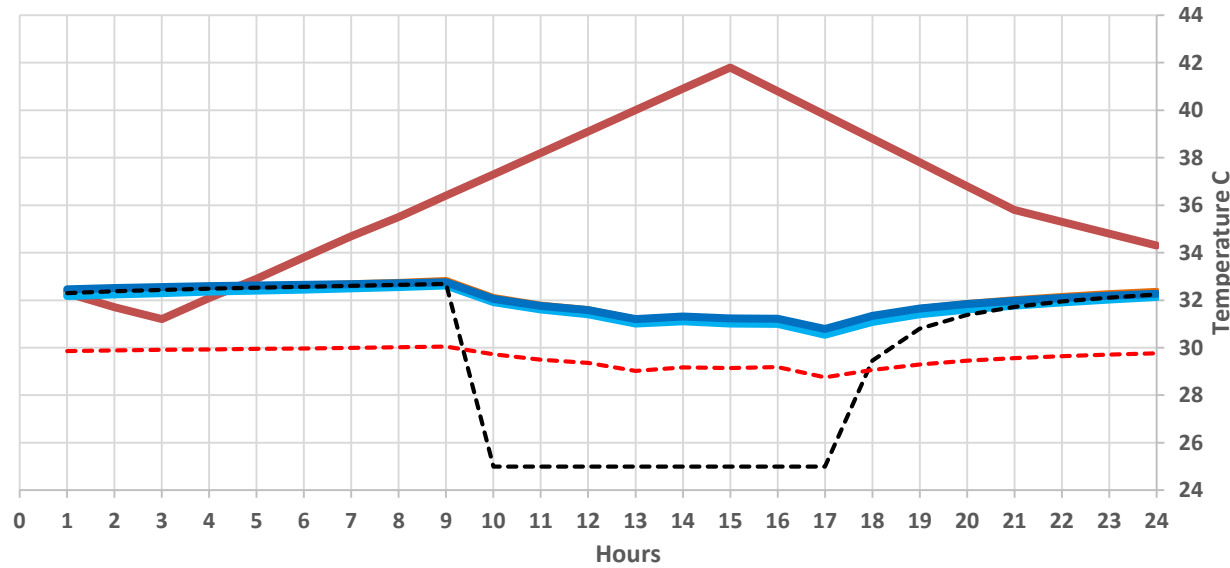
Such as understanding the impact of U-Value on cooling loads as well as comfort in a fully shaded space.....



Project: Amaravati High Court
Architects: Foster + Partners, AHC

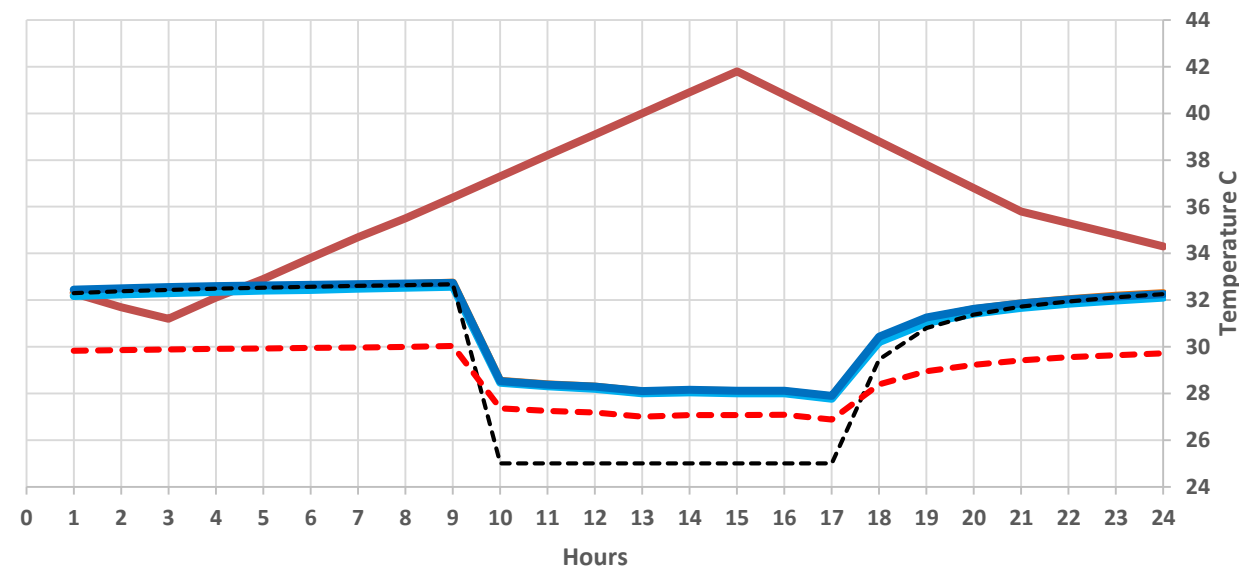
Such as understanding the impact of U-Value on comfort in a fully shaded space.....

Court Complex 13 -Radiant Temperatures -Day 158



External Temperatures
 Planitherm Pristine White
 SKN 165+U-0.4(walls and roof)
 Single Glazing
 SKN 165
 Double Glazing
 Dry Bulb Temperatures

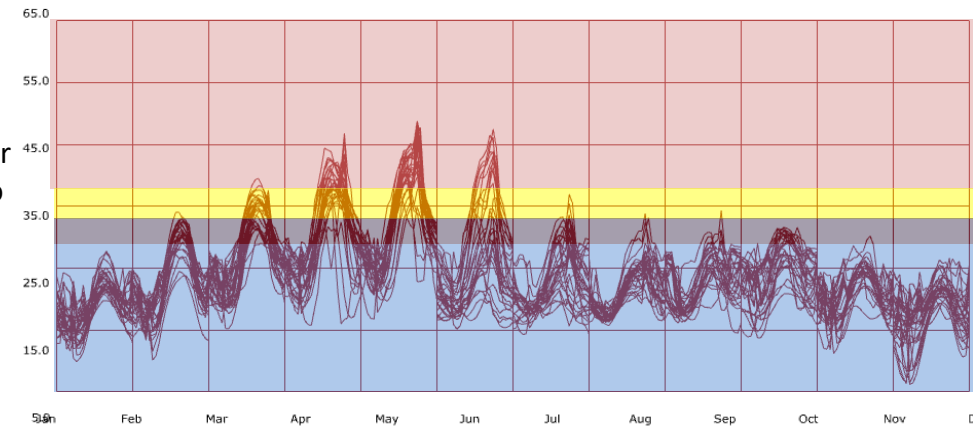
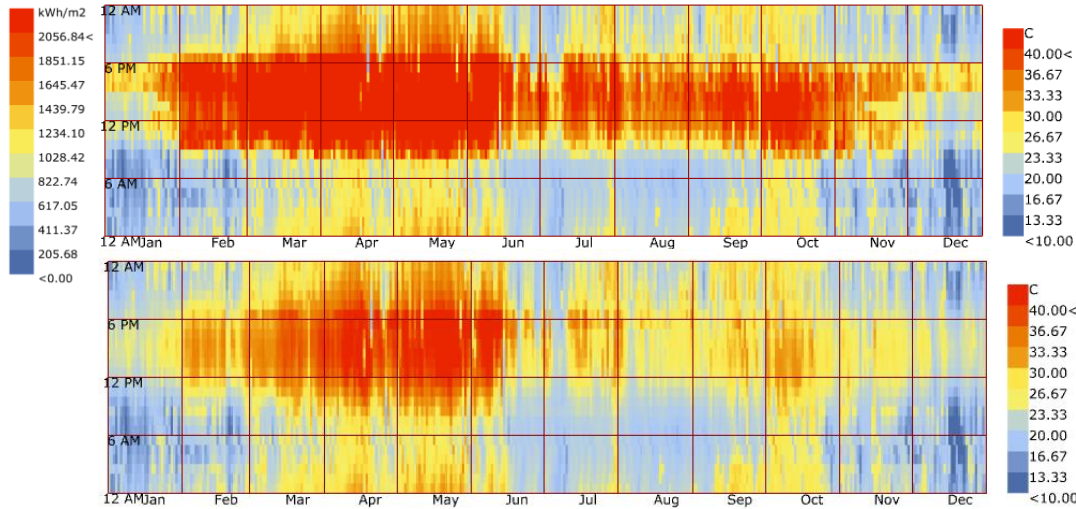
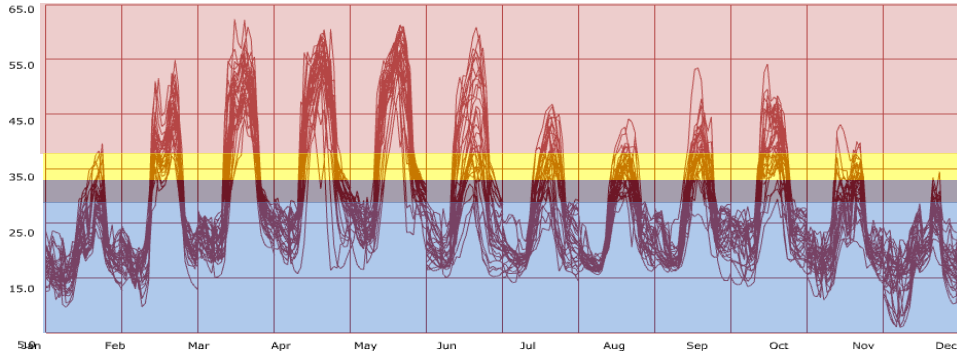
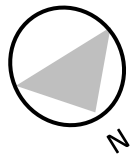
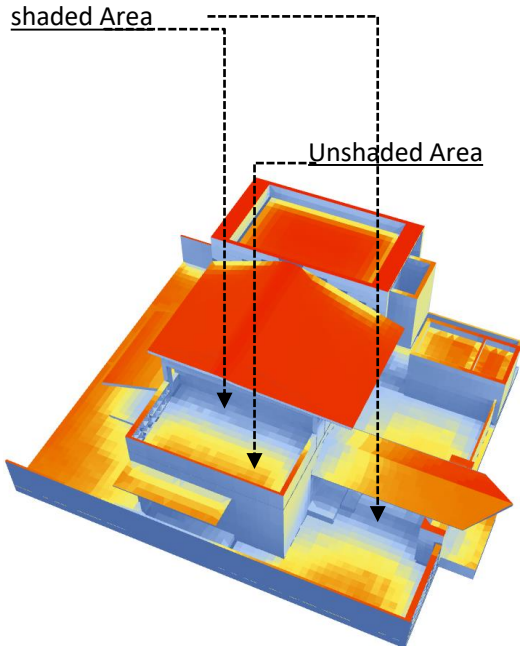
Court Complex 13 -Resultant Temperatures -Day 158



External Temperatures
 Planitherm Pristine White
 SKN 165+U-0.4(walls and roof)
 Single Glazing
 SKN 165
 Double Glazing
 Dry Bulb Temperatures

Project: Amaravati High Court
 Architects: Foster + Partners, AHC

Irradiation studies-North Facing Balcony for all east and west facing Villa

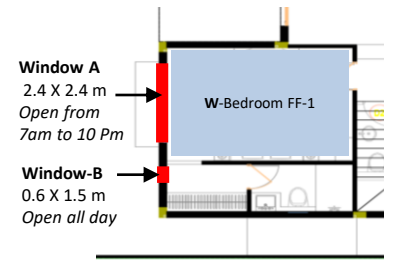
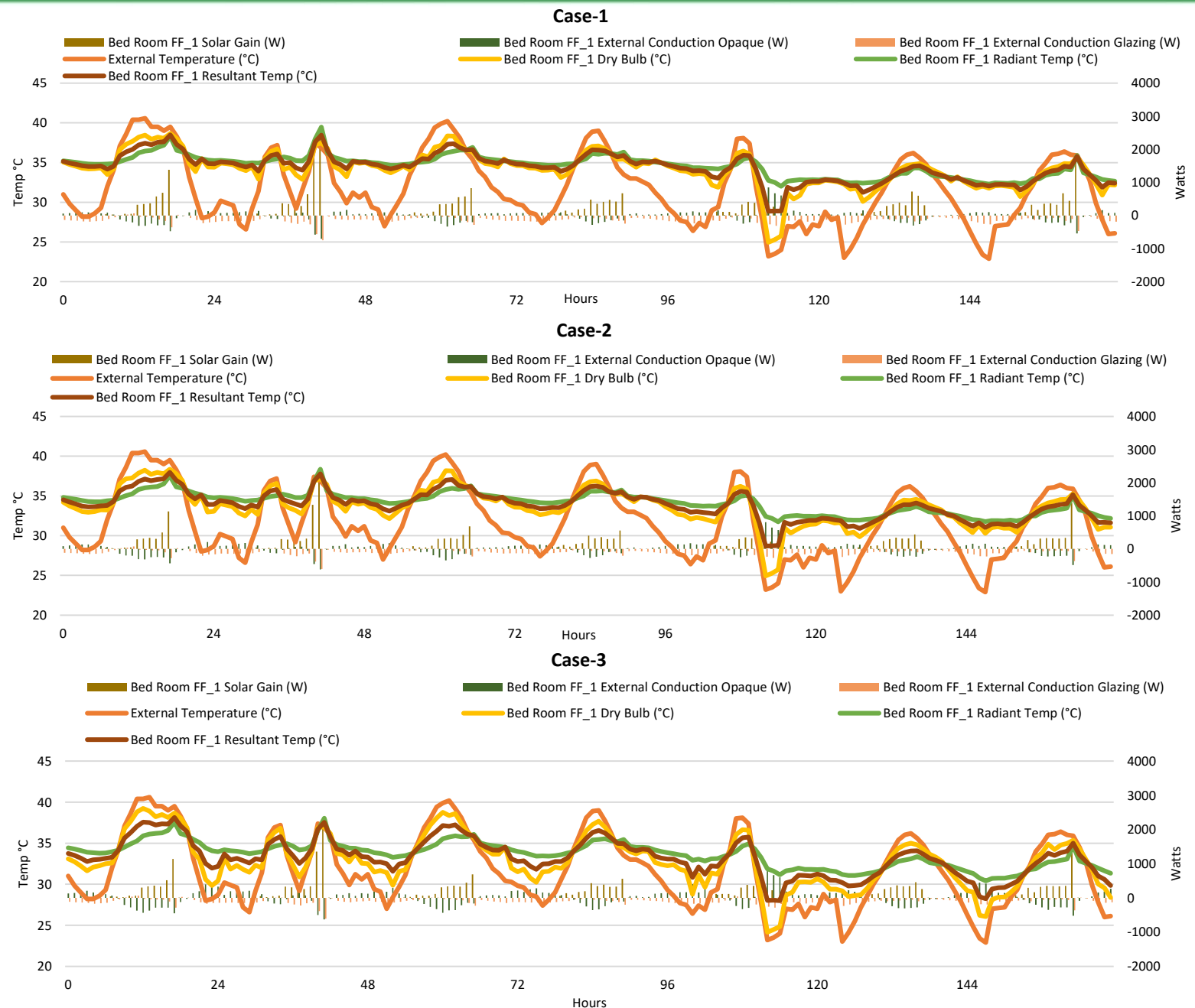


	Un-Shaded (% of Time Annually)	Shaded (% of Time Annually)
Hot to Very Hot (>38°C)	17%	4%
Warm (34-38°C)	6%	4%
Slight Warm (30-34°C)	8%	7%
Cool to Comfortable (<30°C)	65%	85%

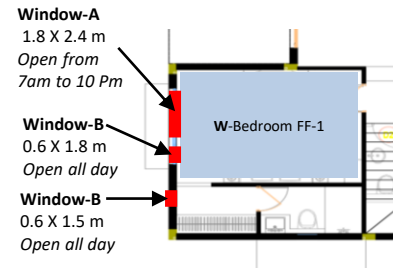
- Based on the irradiation studies it is recommended to shade the open terrace on the North since the irradiation is higher than 2064kwh/m2 throughout the year to allow the occupants to use the space.

Project: Organo Antaram
Architects: FHD Studios

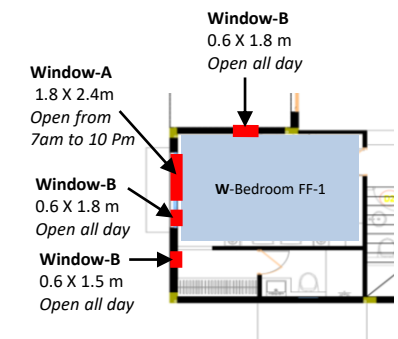
West Facing-First Floor Bedroom Typical Summer Week Results



Case-1



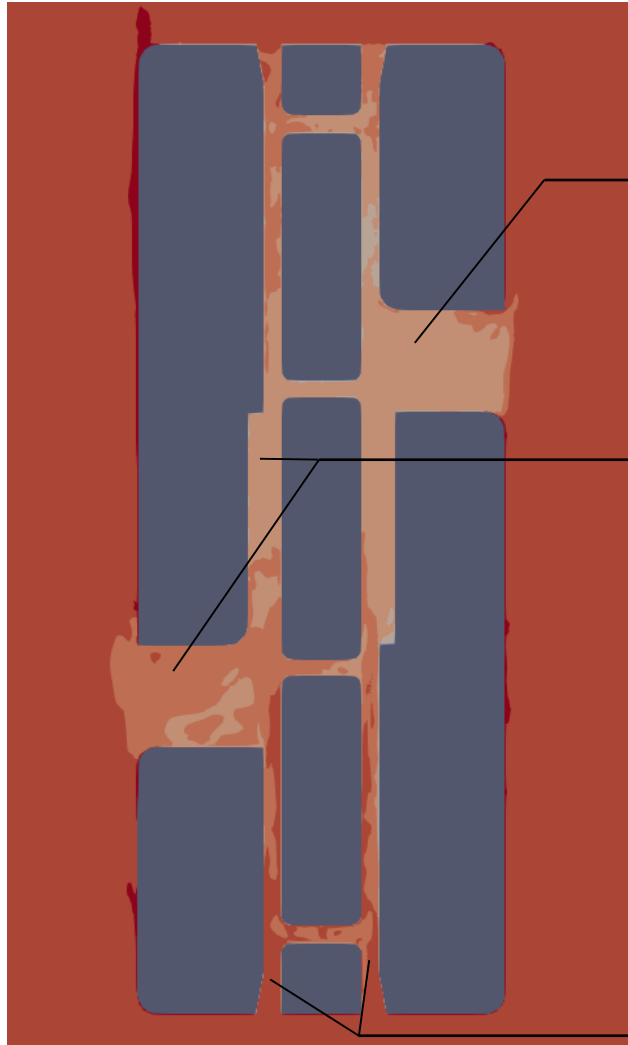
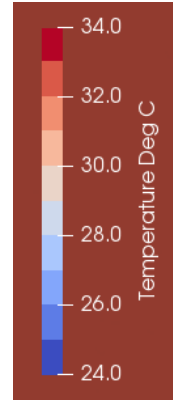
Case-2



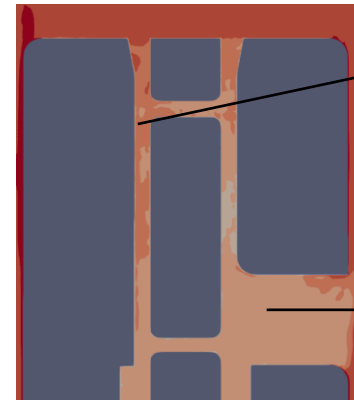
Case-3

Project: Organo Antaram
Architects: FHD Studios

Option 1– Temperature in C

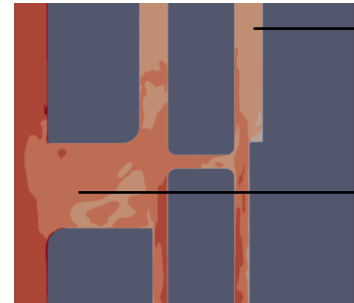


At 1.5mt from floor level



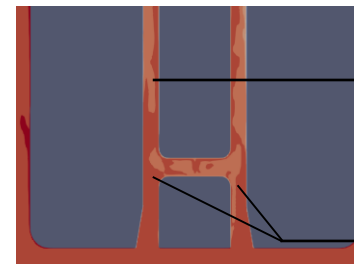
Due to low wind speed and weak eddies only 1c drop in temperature is observed.

The corridor though having less windspeed manages to have 2c temperature drop.



The corridor though having less windspeed manages to have 2c temperature drop.

1c temperature drop is observed.



1c temperature drop is observed.

The inlet regions can feel too hot .

Project: TCS Pune

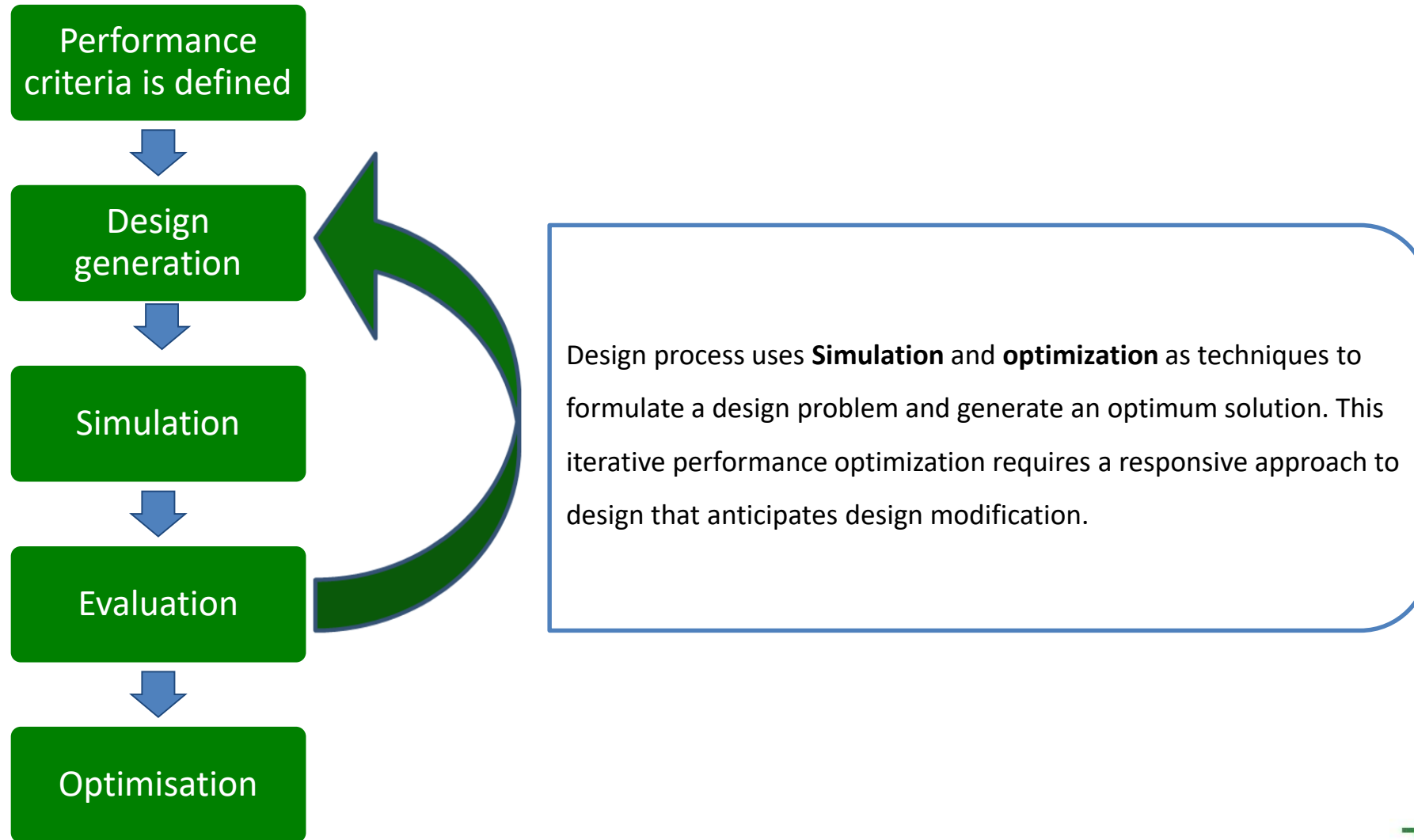
Architects: Edifice Architects

It is also important to understand what simulations can't help with in relation to Comfort

- *Privacy*
- *Security*
- *Dust*
- *Noise pollution*
- *Mosquitoes and flies*
- *Spiders and spider webs*
- *Pigeons*
- *Rain (water tightness)*
- *Accessibility of openings*

An Iterative Design Process

*Every building is unique
'Cookie Cutter' solutions seldom work well*



Comfort is

- Very subjective
- Unpredictable sometimes

However, if not considered, it has the potential to ruin any design