20.203
Architectural Energy Systems
Spring 2020

Instructor

Yehezkiel Wiliardy
Zheng Kai

Learning Objectives

By the end of this course, students will be able to:

- Explain the scope and performance requirements of energy systems in buildings.
- Define the fundamental laws that govern energy flows in buildings.
- Apply these fundamental laws to the thermal design and analysis of buildings.

Measurable Outcomes

- Perform building energy, daylighting, and natural ventilation simulations as well as explain and understand their results.
- Design a building in order to minimize energy use intensity and maximize comfort.

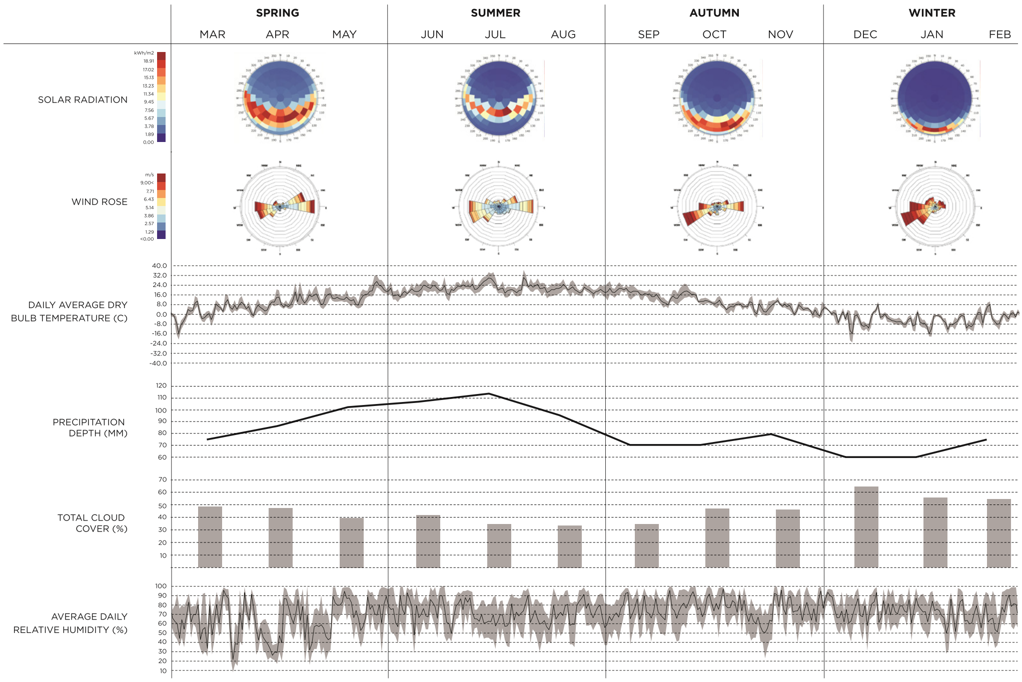
Course Description

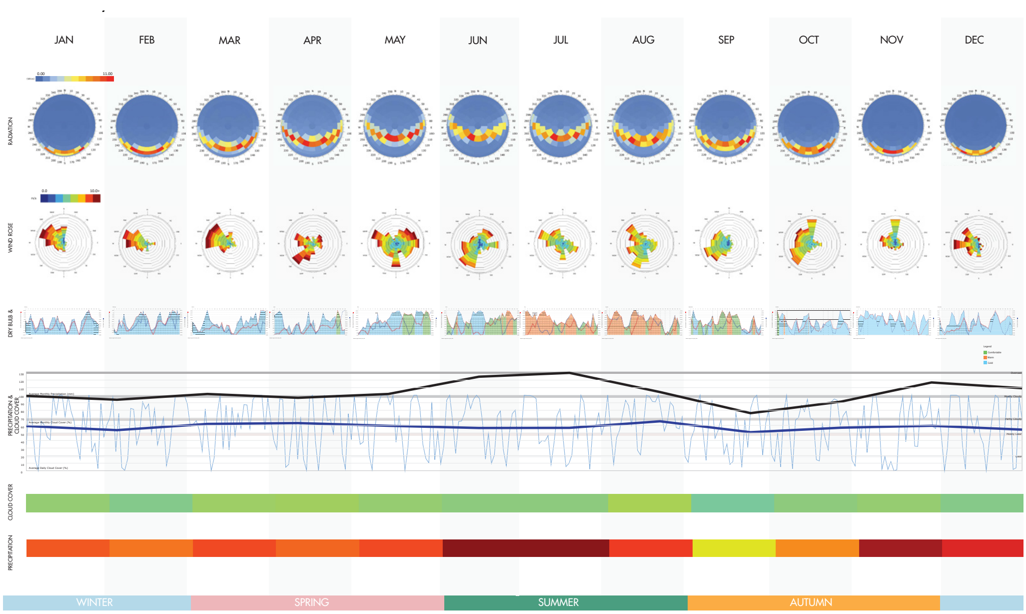
Energy poses one of the greatest challenges to a future sustainable built environment. The individual buildings that comprise our ever-expanding urban landscape retain the potential to contribute significant efficiency savings to an overall mix of strategies necessary for a sustainable future. This module addressed the needs of a variety of building types and the systems that distribute energy-based resources to their occupants.

There are different cities with each unique climatic challenges to specifically optimise the performance of the design. Using various simulations, the design journey starts from understanding the climate, how surrounding buildings affecting the site, discovering how changing forms affect the energy usage, and lastly unit design maximised for occupants comfort.

The first step is to understand the potentials and challenges of the climatic cycle of the site. Visualizing the annual data of temperature, wind, sunpath, and rain in comparative graphics allow us to strategize and set up goals for the building we design. E.g. in the summer prevailing wind comes from the North, hence the design should have cross-ventilation oriented North-South; allowing good natural airflow and reducing the cooling load. The next step is to see how the surrounding affect the site we are working with. For instance, shading, sunlight hours, and prevailing wind.

There are two main objective that each design should aim to achieve; optimise occupant comfort and minimizing energy use in the building. Occupant comfort comes in thermal comfort and visual comfort; e.g. designing outdoor that is shielded from Winter wind, bedrooms facing Winter sun, but covered from Summer sun. In terms of energy usage, minimizing cooling load during summer / tropical condition and reducing heating load during summer.





Understanding climatic challenges and opportunities of Toronto (Top) and Boston (Bottom)

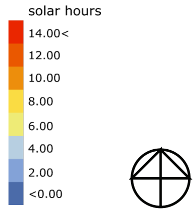
Credits: Audrey Chan, Chen Ran, Chin Kee Ting, Rachel Lau, Benjamin Chong, Naomi Wong,Grace Sim,Teo Shao Tian, Lucas Ngiam, Lester Lim

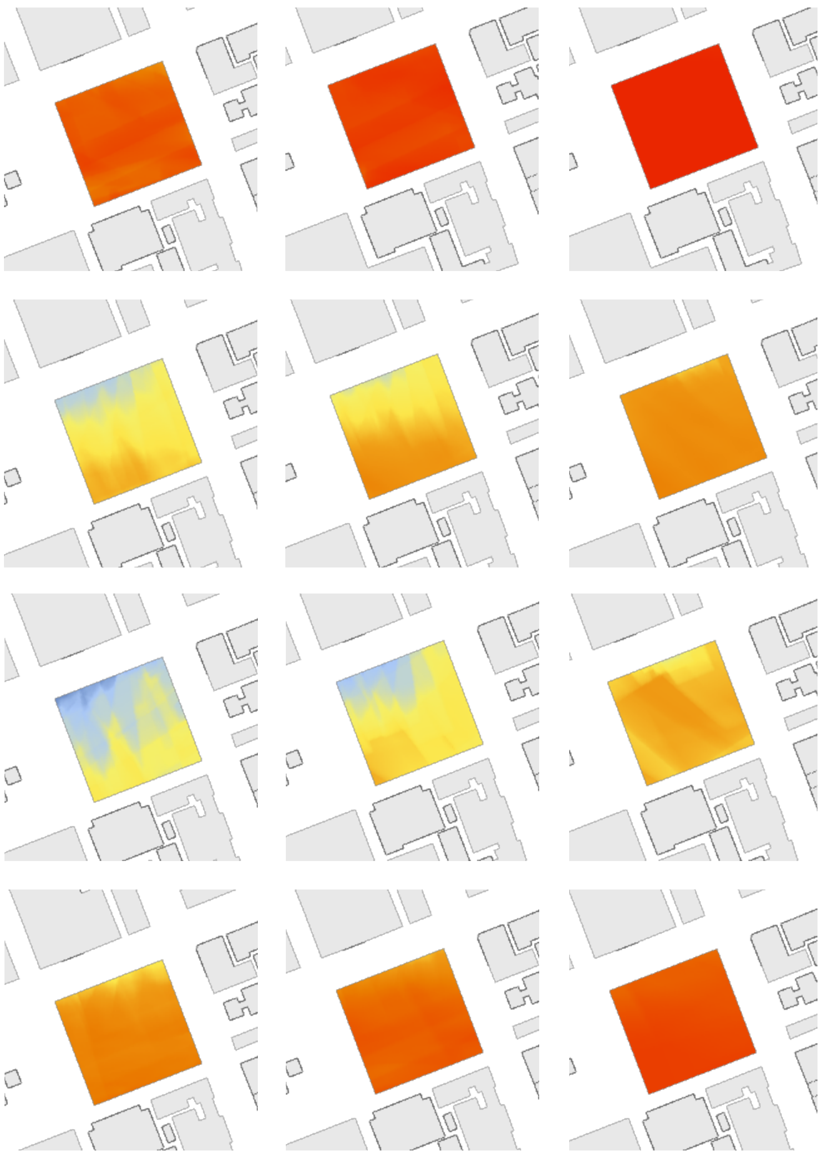
DESIGN STRATEGY:
SOLAR GAIN AND HEAT RETENTION STRATEGY

With reference to the previous analysis on dry bulb temperature of Melbourne, temperature is too low (less than 17°C) for most time of the year. There is a need to maximise sunlight hours and heat gain.

1. Public space voids can be placed at higher elevation in order to get more sunlight hours.

2. Outdoor green spaces for residents can be placed at the South side to maximise sunlight hours and thus usage during the Autumn and Winter time.



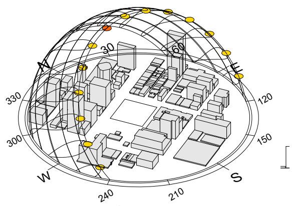


Summer
(Dec - Feb)

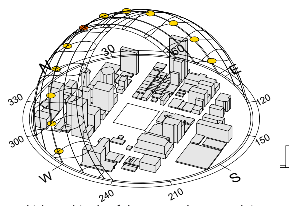
Autumn
(Mar - May)

Winter
(June - Aug)

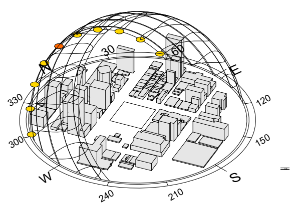
Spring
(Sept - Nov)



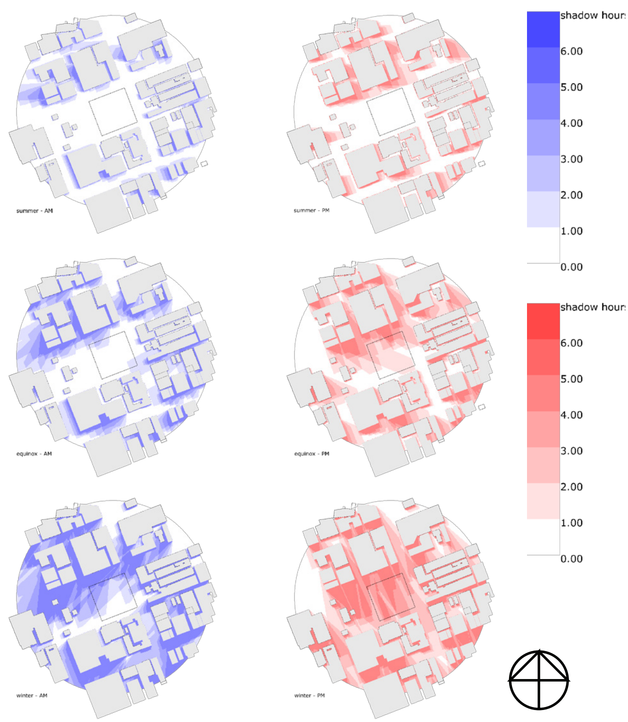
highest altitude of the sun on the sun path is 75.22°



highest altitude of the sun on the sun path is 52.00°



highest altitude of the sun on the sun path is 28.66°



ANALYSIS

Solstice is the point during the Earth's orbit around the sun at which the sun is at its greatest distance from the equator, while during an equinox, it's at the closest distance from the equator.

The Summer solstice observes the highest altitude of the sun on the sun path at 75.22°. While the Winter solstice highest altitude is significantly lower at 28.66°.

DESIGN STRATEGY:
SOLAR GAIN AND HEAT RETENTION STRATEGY

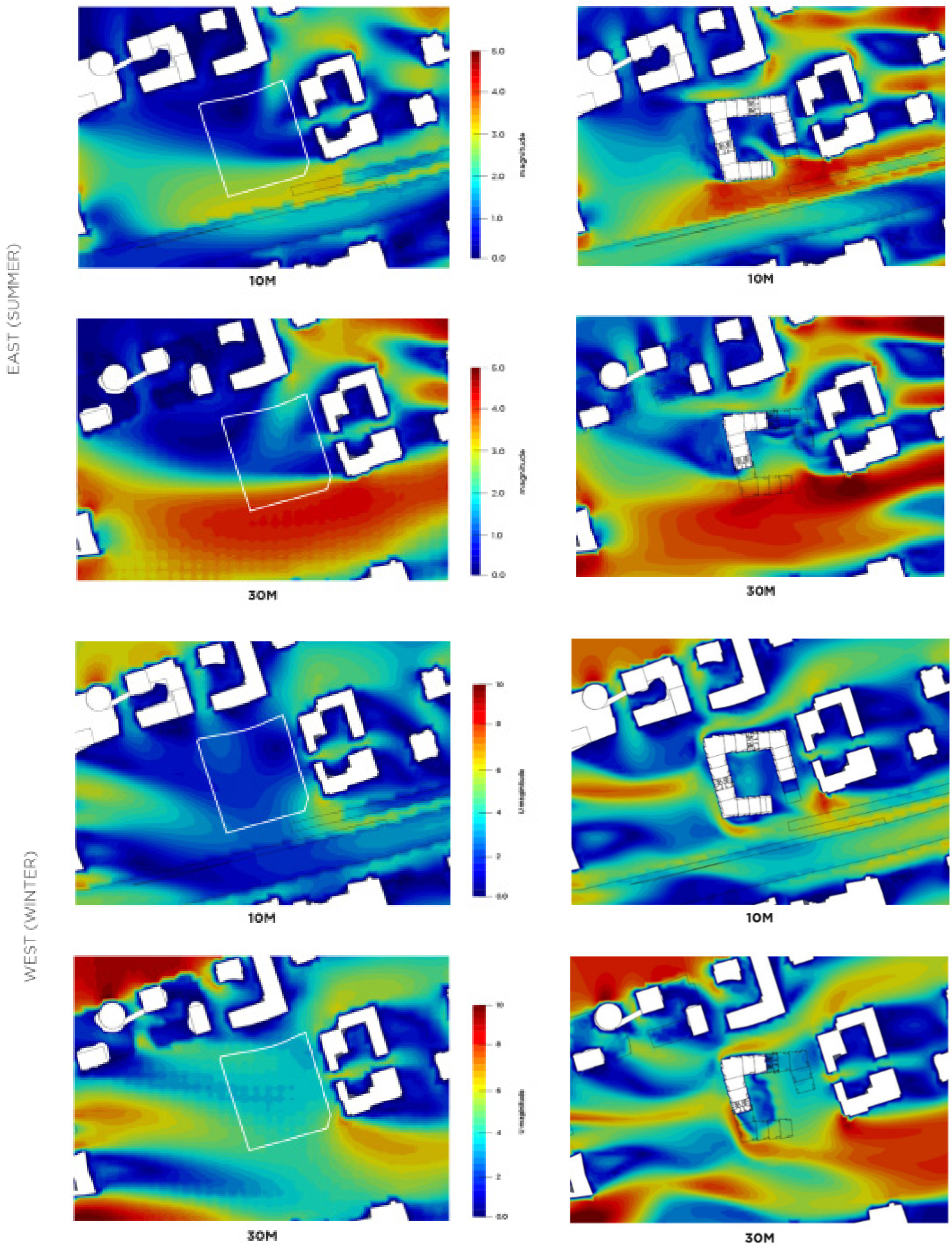
With reference to the diagrams on the right, winter sun is lower than summer sun.

1. Placement of windows on the lower floors to allow winter sun to shine in but not summer sun.

2. Presence of heat-retaining interior walls that absorbs heat in the day and releases heat at night to keep a more constant temperature indoors.

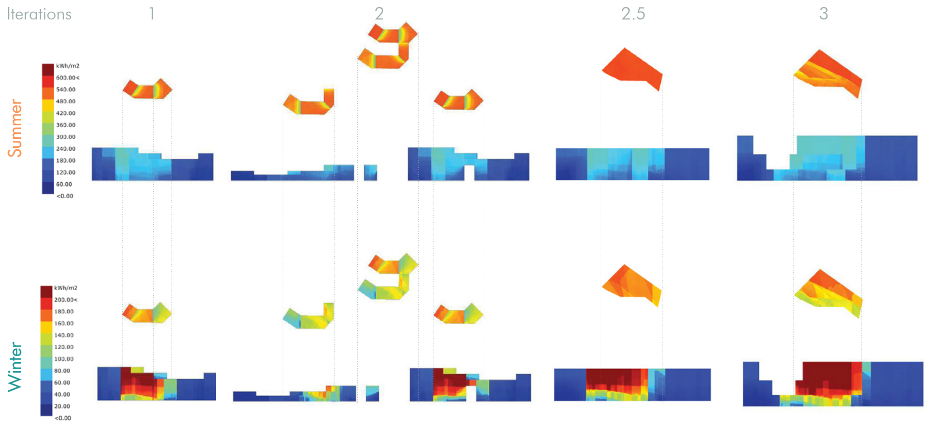
Site Analysis in Melbourne (Solar Study - Shadow, Sunlight, and Solar Angle)

Credits: Song Tingxuan, Naomi Bachtiar, Nurul Nabilah Izzati, Paris Lau, Wang Meng Cheng



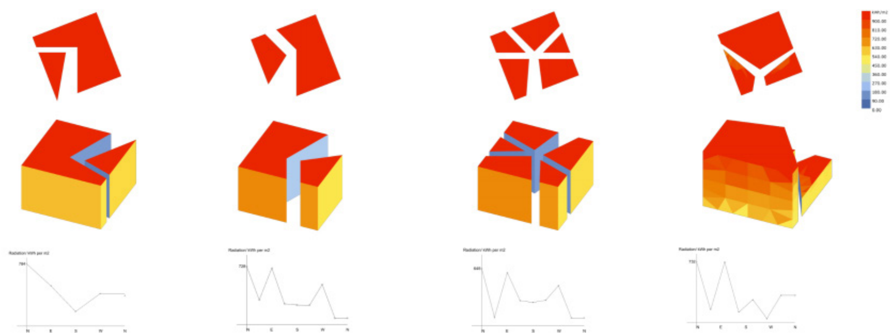
Prevailing wind during Summer and Winter in Toronto

Credits: Audrey Chan, Chen Ran, Chin Kee Ting, Rachel Lau, Benjamin Chong



Percentage of facade area receiving high solar radiation with according to their respective scales per season (%):

	1	2	2.5	3
Summer	36.5	25.0	36.5	39.1
Winter	63.5	75.0	63.5	60.9
		Deprovement from initial massing	No improvement from initial massing	Iteration used for further analysis

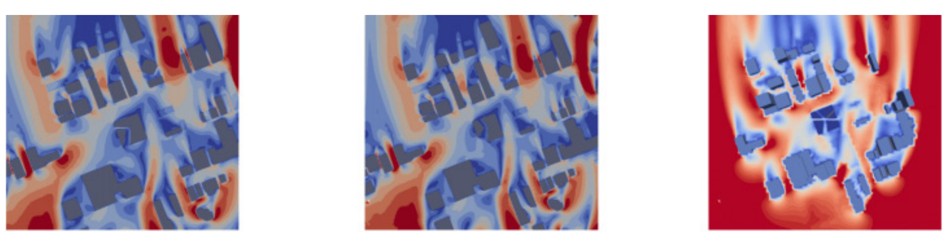


WIND CORRIDOR TOWARDS WEST
most solar radiation: North
highest solar radiation: 728 kWh/m^2
building to site area ratio: 36.6%

WIND CORRIDOR TOWARDS NORTH-WEST
most solar radiation: North
highest solar radiation: 784 kWh/m^2
building to site area ratio: 33.0%

WIND CORRIDOR IN ALL DIRECTIONS EXCEPT NORTH
most solar radiation: North, East
highest solar radiation: 645 kWh/m^2 at the North
building to site area ratio: 32.6%

MAXIMISE AREA EXPOSED TO THE NORTH
most solar radiation: North, East
highest solar radiation: 732 kWh/m^2 in the North
building to site area ratio: 38.4%



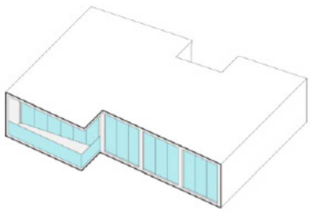
WIND CORRIDOR TOWARDS WEST
run-end time: 3000
cell size: 30
building to site area ratio: 36.6%

WIND CORRIDOR TOWARDS NORTH-WEST
run-end time: 3000
cell size: 30
building to site area ratio: 33.0%

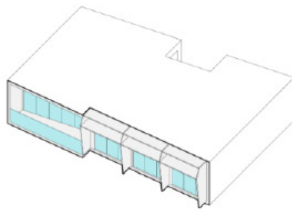
WIND CORRIDOR IN ALL DIRECTIONS EXCEPT NORTH
run-end time: 3000
cell size: 30
building to site area ratio: 32.6%

Evaluation of performance for different massing options in Boston (Top) and Melbourne (Bottom)

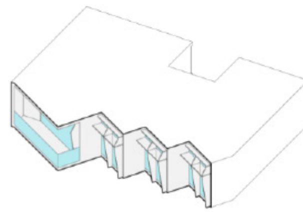
Credits: Naomi Wong, Grace Sim, Teo Shao Tian, Lucas Ngiam, Lester Lim, Song Tingxuan, Naomi Bachtiar, Nurul Nabilah Izzati, Paris Lau, Wang Meng Cheng



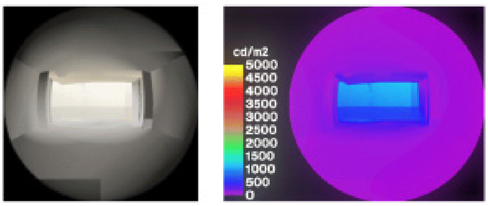
DESIGN A
Increase WWR ratio by having more glass to allow more light in



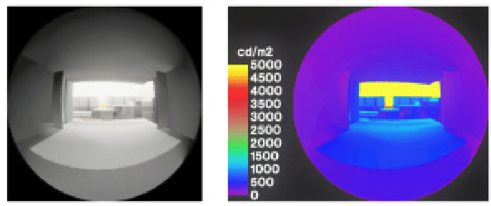
DESIGN B
Vertical fins and overhangs are designed in addition to design A



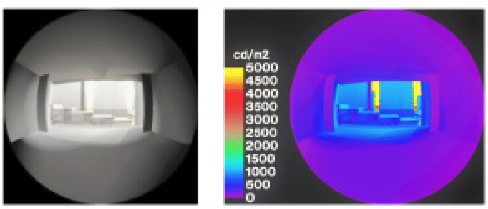
DESIGN C
More angled glass with same placement of fins and overhang as design B



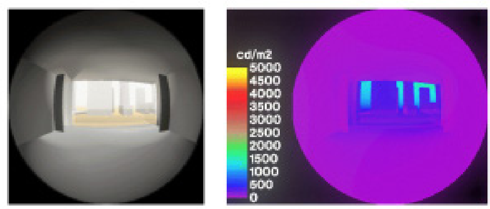
NORTH FACING (JUN 12PM)
DGP = 0.232



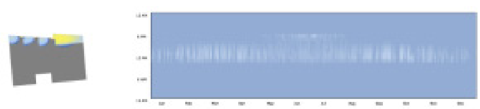
SOUTH FACING (JAN 12PM)
DGP = 0.382



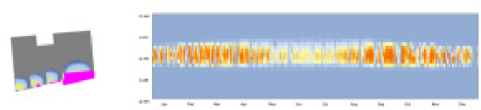
EAST FACING (MAY 9AM)
DGP = 0.269



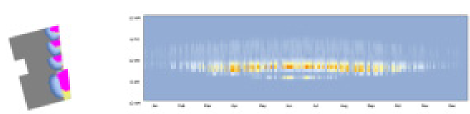
WEST FACING (AUG 6PM)
DGP = 0.199



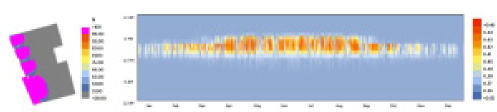
NORTH FACING
$UD_{200lx,80\%}$ = 32.57%
$UDI_{3000lx,10\%}$ = 10.12%
$DA_{300lx,50\%}$ = 22.45%



SOUTH FACING
$UD_{200lx,80\%}$ = 34.65%
$UDI_{3000lx,10\%}$ = 28.33%
$DA_{300lx,50\%}$ = 6.32%



EAST FACING
$UD_{200lx,80\%}$ = 19.86%
$UDI_{3000lx,10\%}$ = 0%
$DA_{300lx,50\%}$ = 19.86%



WEST FACING
$UD_{200lx,80\%}$ = 29.55%
$UDI_{3000lx,10\%}$ = 11.60%
$DA_{300lx,50\%}$ = 17.95%

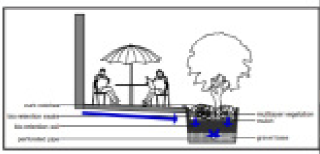
Study of different facade designs with visual comfort inside the apartment

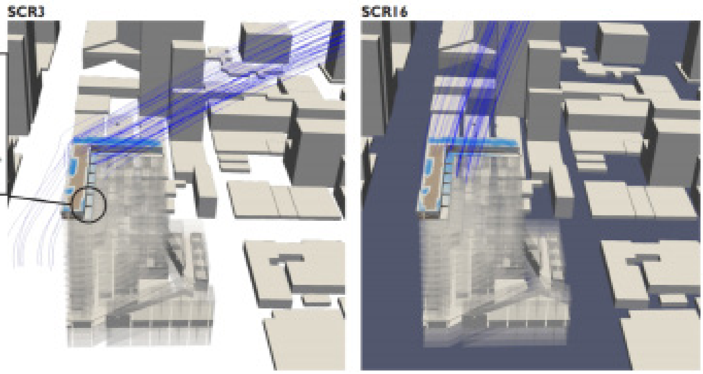
Credits: Audrey Chan, Chen Ran, Chin Kee Ting, Rachel Lau, Benjamin Chong

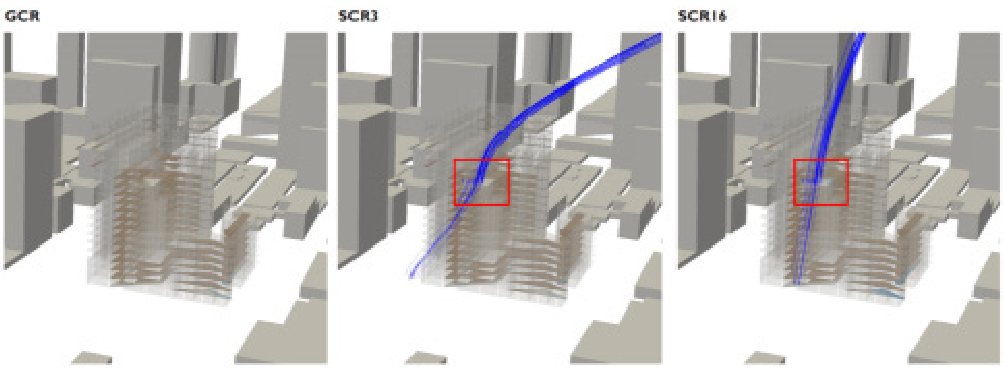
WIND DRIVEN RAIN ANALYSIS

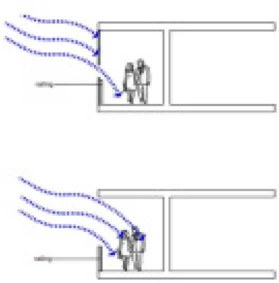
As the terrace / balcony receives a huge amount of water, toprevent flooding in that area, we will introduce a bioswale system that can filter the rain water while doubling as a drainage system.

On top of that, trees are also helpful in minimising the drafty wind coming in from the South.









WIND DRIVEN RAIN ANALYSIS

Most of the corridors are internal corridors and thus are not susceptible to water ingress. In parts of te corridors which are exposed, we implement an overhang system that blocks most of the rain from entering even during strong wind.

As a result, it can be seen that other than a small part of the top balcony (marked in red box), the other parts of the corridors are dry.

Rain mitigation strategy with Wind Driven Rain analysis during prevailing wind of the wettest month.

Credits: Song Tingxuan, Naomi Bachtiar, Nurul Nabilah Izzati, Paris Lau, Wang Meng Cheng