URBAN ENVIRONMENTAL MODELLING & SUSTAINABILITY: UNDERSTANDING THE URBAN MICROCLIMATE AND BUILDING ENERGY PERFORMANCE IN SUSTAINABLE TOWN DESIGN

Presenter: Dr. POH Hee Joo,
pohhj@ihpc.a-star.edu.sg
Principal Scientist & Domain Specialist (Built Environment), IHPC, A*STAR

Assoc. Prof, Department of the Built Environment, NUS
bdgphj@nus.edu.sg

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Contents

CREATING GROWTH, ENHANCING LIVES

Integrated Environmental Modeller (IEM)
Background

- Advanced modelling tool that is capable of simulating the interaction of urban micro-climatic conditions, , such as wind flow, temperature fluctuations, and solar irradiance with one another, as well as their combined effects on the surrounding urban landscape

2010 — TRL 2

Basic research
- CFD research for Greenmark building
- In-house urban environment modelling

2014 — TRL 3-4

Collaboration
- Between IHPC, I2R and HDB

2018 — TRL 6

IEM prototype
- Used by HDB
- Master planning and urban design tool

2020 — TRL 7

IEM implementation
- Deployed at HDB
- IEM-TreeFOAM, Incorporated with Virtual Singapore. New user: NParks

2021 — TRL 8

IEM commercialisation
- Licensable software package (**IEMSim**; Gap funded)

2021 → TRL 3

IEM Phase 2
- New Physics (rain, greenery, urban flow with radiation, building energy, climate)
- Advanced modeling algorithms (overset, surrogate modelling for optimization)

2024 — TRL 7

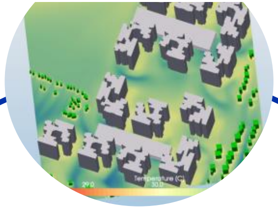
IEM-2
- IEM-2 Deployment
- User adoption

IEM was developed through the TRL process from basic research to prototype, implementation with public agencies and commercialisation.

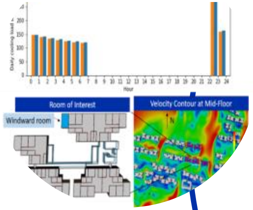
IEM Phase 2
Project Objective

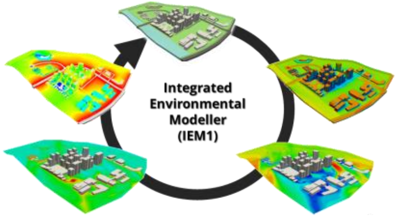
Integrated Environmental Modeller – Phase 2 (IEM2)

Urban Physics
Expand on the number of environmental factors



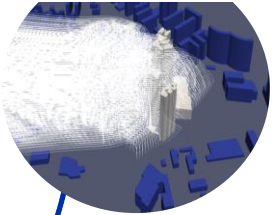
Building Energy Modelling
precinct and district level



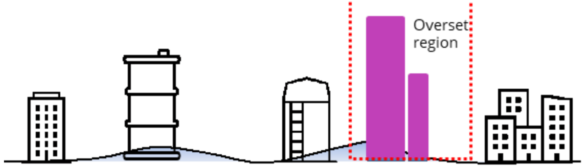


Model validation and integrated software development

Wind Driven Rain
Lagrangian and Eulerian methods



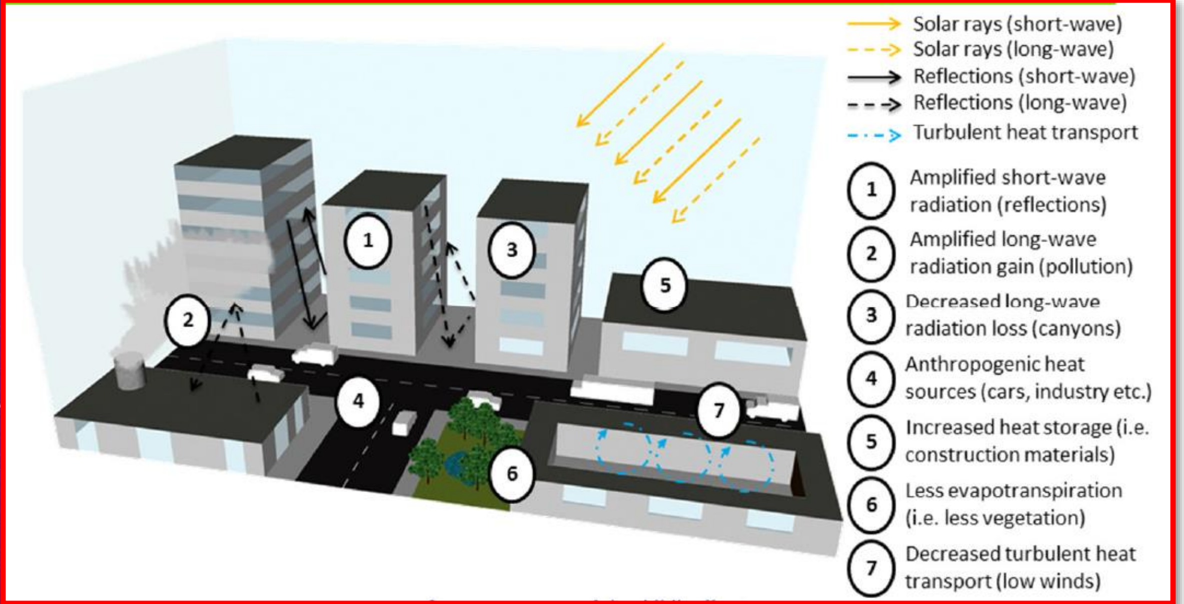
Overset & Optimization
Utility tools to speed up modelling process



Urban Environmental Modelling & Sustainability

Urban Heat Island – Multi-Disciplinary Research

- Scientists need to break down silos and work together to better understand the interrelationships between various factors, and design integrated countermeasures that are able to address UHI on a macro and holistic level



1. Canyon Radiative Geometry - multiple reflection of short-wave radiation between the canyon surfaces, decreasing the effective albedo of the system
2. Urban 'Greenhouse' - increased incoming long-wave radiation from the polluted and warmer urban atmosphere
3. Canyon Radiative Geometry - decreased long-wave radiation loss from within street canyons due to the complex exchange between buildings and the screening of the skyline
4. Anthropogenic Heat - heat released from combustion of fuels and animal metabolism
5. Thermal Properties - increased storage of sensible heat in the fabric of the city.
6. Evaporation - transpiration - reduction of evaporating surfaces in the city putting more energy into sensible, and less into latent, heat.
7. Shelter - reduced turbulent transfer of heat from within streets

Y. Toparlar et al, Building and Environment 83 (2015) 79-90
T. R. Oke, et al, Boundary-Layer Meteorology, 56, 4 (1991), 339-358

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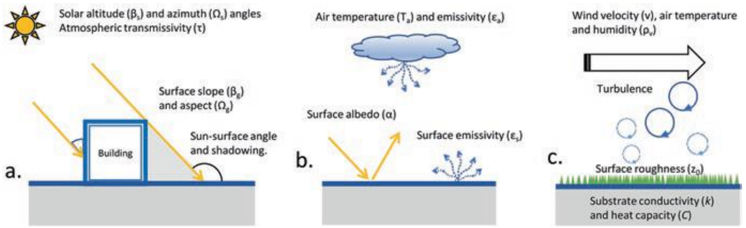
The Urban Heat Island: Energetic Basis and UBL

Surface Energy Budget @ Planetary Boundary Layer



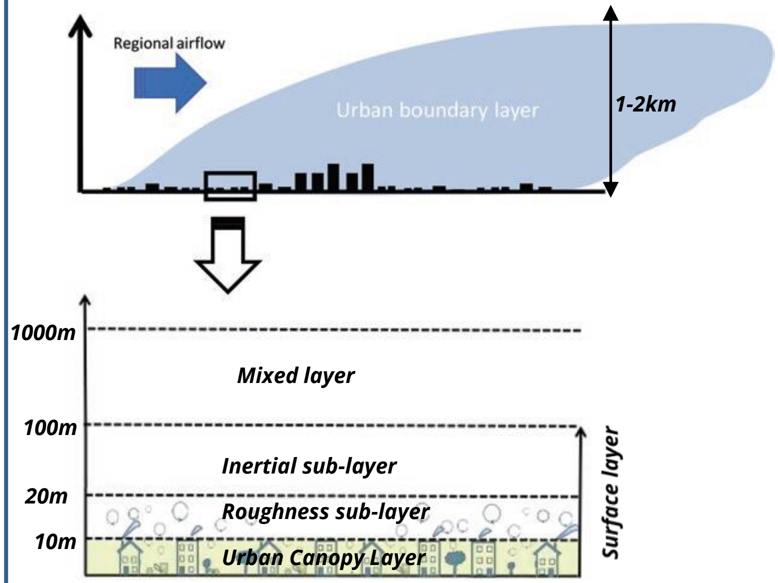
The controls on (a) short-wave and (b) long-wave radiation exchanges at the surface and (c) on the surface-air and substrate exchanges

$$Q^* = Q_H + Q_E + Q_G$$

Energy budget term	Controls
Received short-wave radiation ($K\downarrow$)	Solar geometry: azimuth (Ω) and altitude (Z)
	Atmospheric transmissivity (τ) and cloud (k)
	Surface geometry: slope (β_s) and aspect (Ω_s)
Reflected short-wave radiation ($K\uparrow$)	Surface reflectivity or albedo (α)
Received long-wave radiation ($L\downarrow$)	Atmospheric temperature (T_a)
	Atmospheric emissivity (ε_a)
Emitted long-wave radiation ($L\uparrow$)	Surface temperature (T_s)
	Surface emissivity (ε_s)
Turbulent sensible heat flux (Q_H)	Surface-air temperature difference (ΔT_a)
	Atmospheric stability (Φ)
	Wind (v) and surface roughness (z_o)
Turbulent latent heat flux (Q_E)	Surface-air humidity difference ($\Delta\rho_a$)
	Atmospheric stability (Φ)
	Wind (v) and surface roughness (z_o)
Conductive sensible heat flux (Q_G)	Surface-substrate temperature difference (ΔT_s)
	Thermal conductivity (k_s) and heat capacity (C_s)

Energy budget terms and controls on the magnitude of fluxes (W/m²)

Surface & Mixed Layer @ Urban Boundary Layer



The development of the urban boundary layer (UBL) as airflow crosses the upwind urban edge (top diagram). The UBL can be divided into a surface layer, which occupies the lower 10%, and a mixed layer. The surface layer is comprised of an inertial sublayer (ISL) where flux densities are nearly constant with height and a roughness sublayer (RSL) that is characterised by enhanced turbulence caused by underlying urban surface. The urban canopy layer (UCL) is immersed within the RSL and extends from the ground to mean building height

Gerald Mills, Julie Futcher, and Iain D. Stewart, Urban Microclimate Modelling for Comfort and Energy Studies, Chp. 3, , 2021

Urban Microclimate with Vegetation - Park Cool Island (PCI)

Classification of urban parks and characterization of PCI

	Daytime PCI	Night-time PCI
Type of park	Irrigated park with substantial tree cover	Dry parks with sparse tree cover
Mechanisms involved	Evaporation and shading: trees shade the surface, while grass is typically cooler than paved surfaces if it is well irrigated	Long-wave radiant cooling: sky view factor close to unity
Temporal pattern: time of maximum intensity	Afternoon (forest type) or early evening (garden, savannah and multi-use types)	Several hours after sunset
Comments		Warmer during the day than neighbouring urban areas

Daytime PCI

1) *Irrigated park with dense tree cover*
2) *Combined effects of **soil moisture** and **shading***
3) *However, trees also inhibit nocturnal long-wave radiative cooling by blocking off part of the sky*
4) *Excess moisture increases the thermal capacity of the soil and slows down surface cooling*

Night-time PCI

1) *Relatively dry park with a sparse tree cover (daytime temperatures may sometimes be higher than in neighbouring urban areas)*
2) *Driven by **long-wave radiative cooling** (especially if the sky view factor is close to unity)*
3) *Distances of about 2.2 to 3.5 times the height of the park border - weaker radiative cooling where the sky view factor is reduced by obstructing features*

Greenery on ground** to counter urban heat - **study cases

- Size & shape of park,
- Cooling outside the park,
- Plant selection & placement
- Oasis effect - enhanced evaporation
- Thermostat effect – in the presence of wind
- Shading (solar permeability) – tree species transmissivity & foliation

Row of trees adjacent to buildings is too close to the facade, and when they are fully grown will cut off air-flow near the wall

How much cooling can trees be expected to generate? The magnitude of the cooling effect depends on several factors

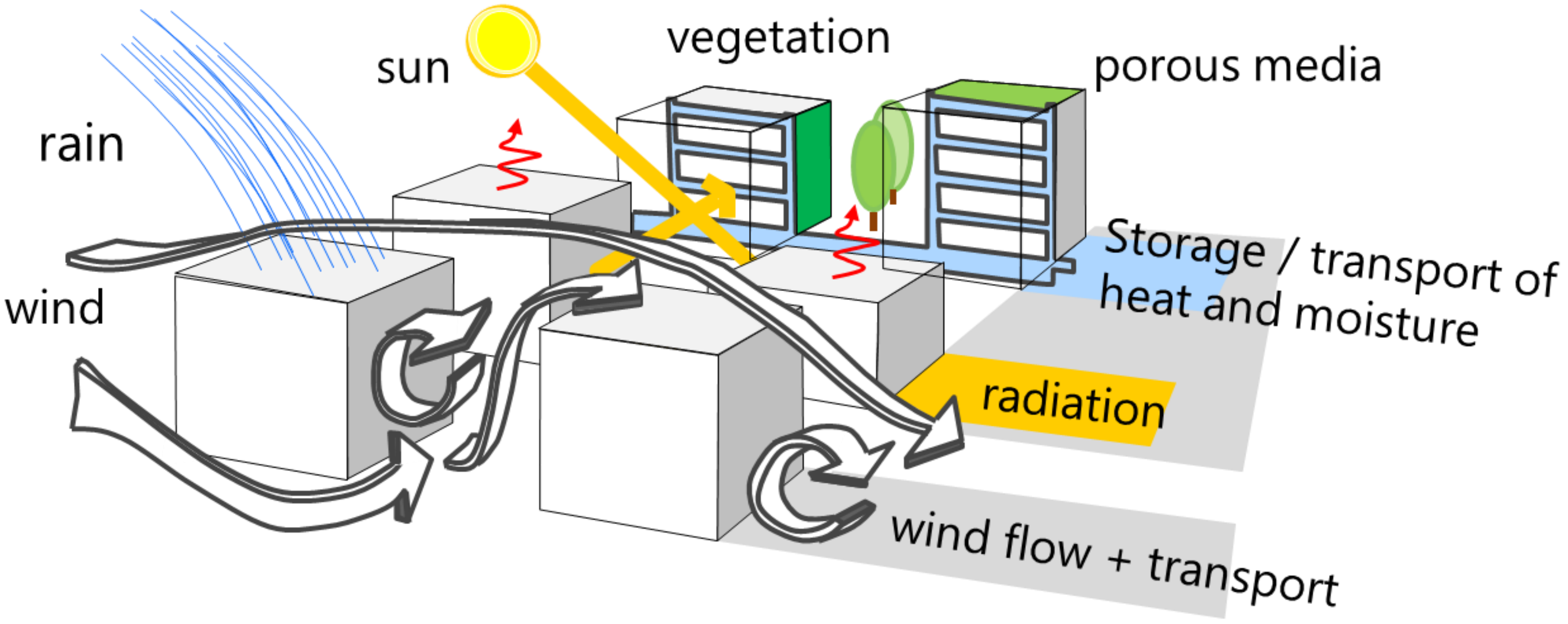
1) *the size and type of tree,*
2) *the extent of the area covered by trees,*
3) *water availability,*
4) *surface properties,*
5) *psychrometric factors,*
6) *counteracting effects of advection*

Erell, Evyatar; Pearlmutter, David; Williamson, Terence, Urban Microclimate : Designing the Spaces Between Buildings, Chp.9 , 2010
Nyuk Hien Wong, et al, Nature Reviews Earth & Environment, 2, pages 166–181 (2021)

The Physics and Tools

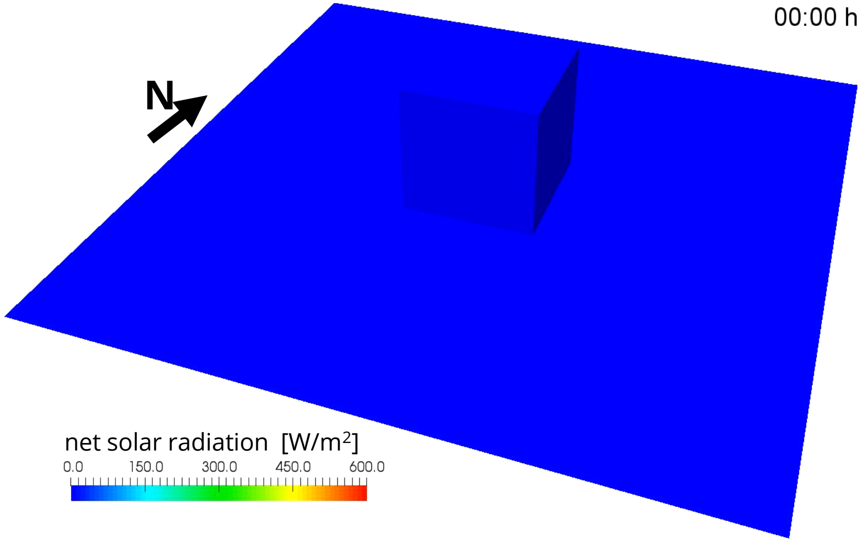
1. Urban Physics
2. Wind Driven Rain
3. Urban Ventilation & Optimization
4. Building Energy Modelling Coupled with Microclimate

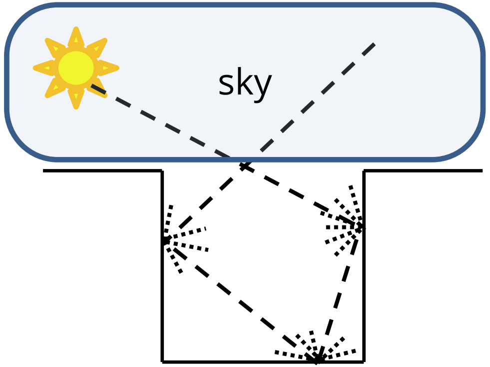
Urban physics - micro-climate model at the building scale



Courtesy from Carmeliet, Derome, Kubilay

Physics of Urban Micro-Climate - Modeling Radiative Heat Exchange





Shortwaves

$$I_{tot} = I_{dir} + I_{dif}$$

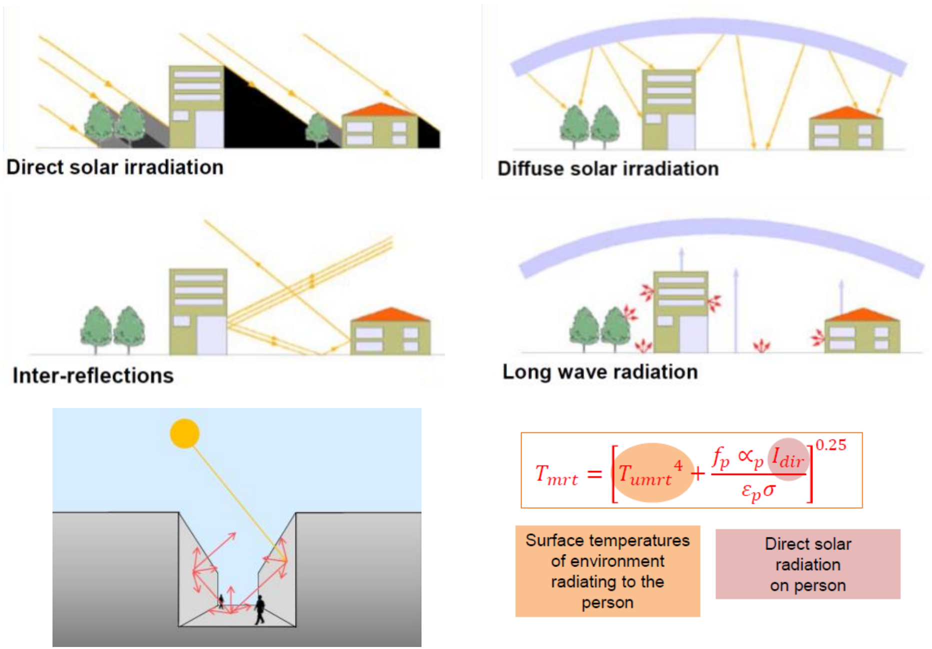
$$q^s_{out,k} = -(1 - a_k)\, I_{sol} + a_k \sum_{j=1}^{N} F_{kj} q^s_{out,j}$$

longwaves

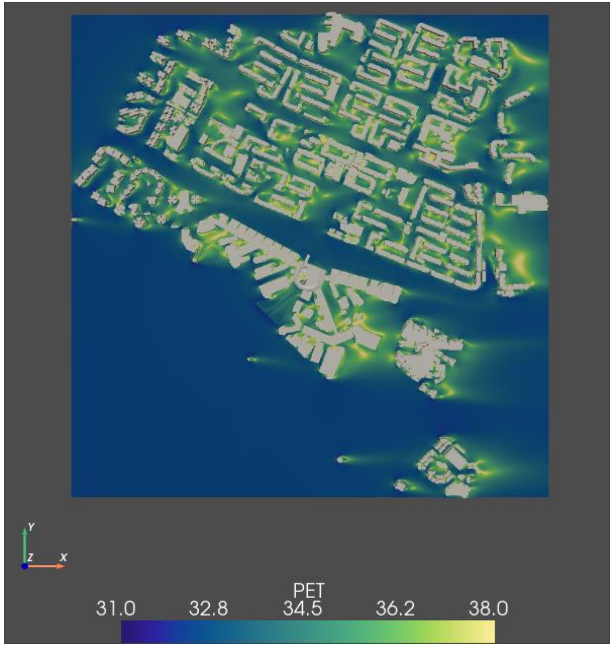
$$q^l_{out,k} = \epsilon_k \sigma T_k^4 + \rho_k \sum_{j=1}^{N} F_{kj} q^l_{out,j}$$

Courtesy from Carmeliet, Derome, Kubilay

Urban Physics
Outdoor Thermal Comfort (OTC)



Radiation modelling and Mean Radiant Temperature (MRT) calculation



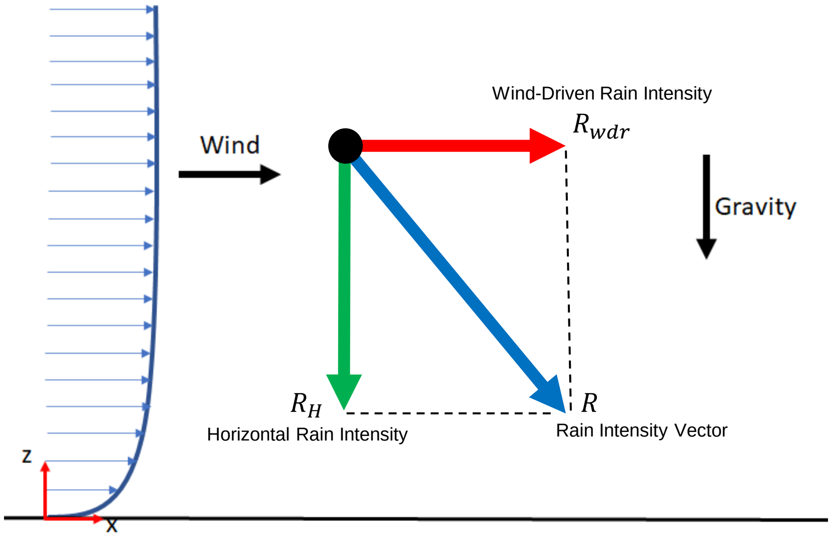
Incorporating OTC indices in IEM2 post-processing

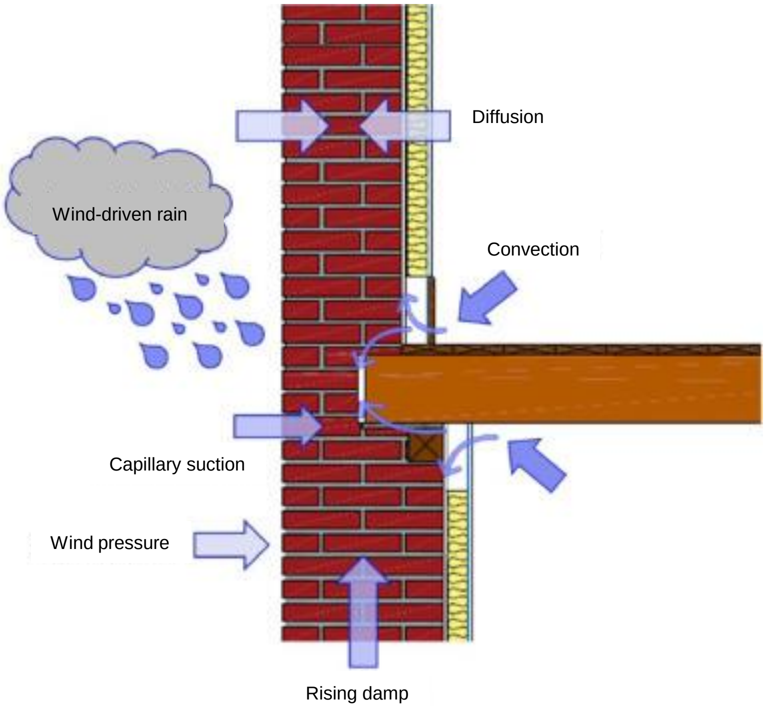
- Discrete Ordinates model - solves the full 3D radiative transfer equation for a finite number of discrete angles
- OTC indices (PET, UTCI) can be incorporated in IEM2 GUI

CREATING GROWTH, ENHANCING LIVES

What is wind-driven rain

Rain that falls obliquely due to the influence of the wind





Why wind-driven rain

- Damages to building and facades
- Health risks
- Hazards and safety

(a) Erosion of building surfaces

(b) Mold growth on building structures

(c) Flooding and slipping hazard

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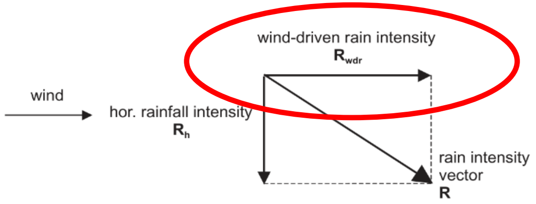
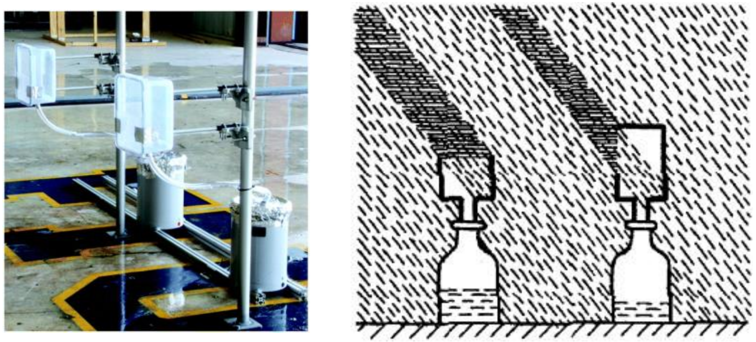
Calculation of WDR Intensity, R_{wdr}



Ways to calculate WDR intensity:

1. On-site measurements
2. Semi-empirical models
   - ISO Standard (ISO (2009))
   - Straube and Burnett model
3. Numerical simulations (CFD model)
   - Eulerian-Eulerian method
   - Eulerian-Lagrangian method



On-site measurements.

- ISO-Standard (ISO (2009)) – Method 1
  - ✓ Airfield indices (annual and spell)

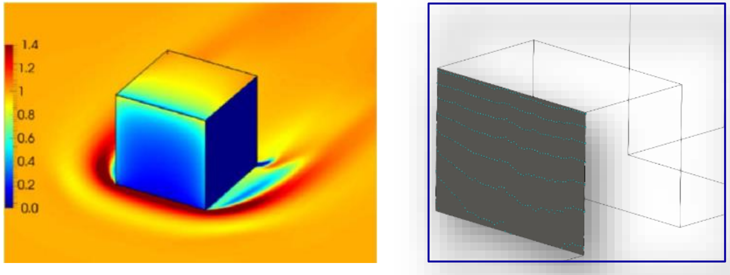
$$I_A = \frac{2}{9} \frac{\sum U_{10} \cdot R_h^{8/9} \cdot \cos\theta}{N} \qquad I_S' = \frac{2}{9} \sum U_{10} \cdot R_h^{8/9} \cdot \cos\theta$$

  - ✓ Wall indices

$$I_{WA} = I_A \cdot C_R \cdot C_T \cdot O \cdot W \; ; \qquad I_{WS} = I_S \cdot C_R \cdot C_T \cdot O \cdot W$$

$$R_{wdr} = \frac{2}{9} C_R \, C_T \, O \, W \, U_{10} \, R_h^{0.88} \cos\theta \qquad (2)$$

Semi-empirical model (ISO 2009).



CFD-based simulations.

Urban Ventilation Assessment Metric from CFD

- 3 Ventilation metrics

Mean velocity ratio*

$$V_r = \frac{U_p}{U_{ref}}$$

U_{ref} Freestream wind speed †

U_p *Averaged* wind speed at 2 m height

Air change rate in canyon*

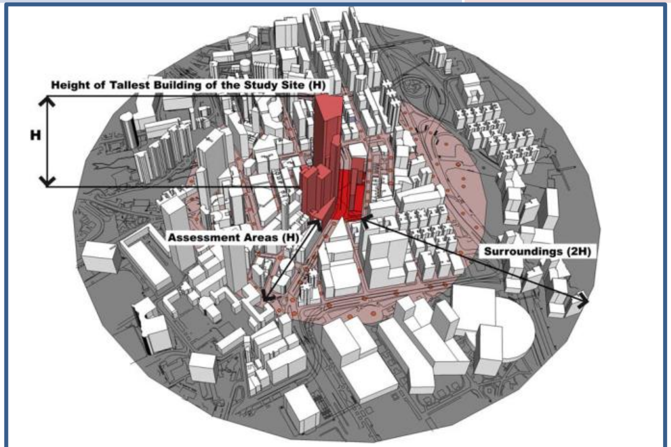
$$ACH_{vol} = 3600 \times \frac{Q_T}{vol}$$

Q_T Total flow entering the 'target' control volume

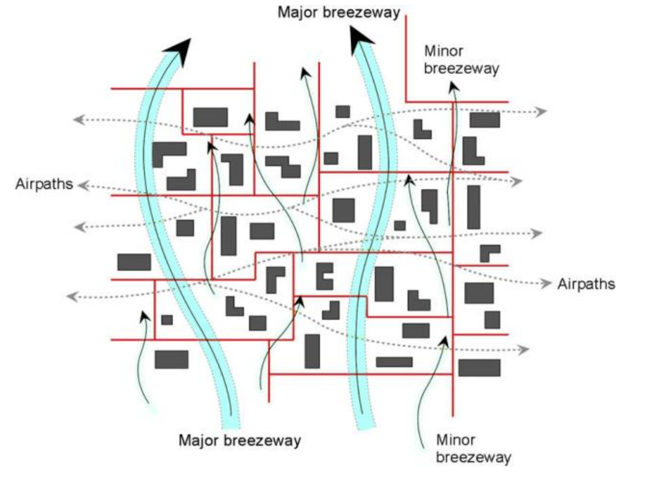
vol Volume of the unoccupied canopy

Air removal from roof*

$$ACH_{roof} = \int \left(w_+ + \frac{1}{2}\sqrt{\frac{2k}{3}} \right) dA_{roof}$$



The assessment area and the surrounding area defined by the height of buildings on site



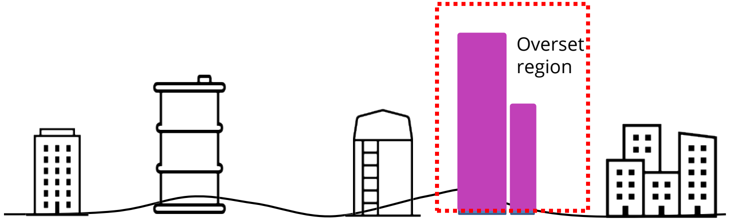
Breezeway/air path

Chen, G., *Building and Environment,* December, Volume 206, p. 108344.
Ng, E., 2009. Building and Environment, July, Volume 44, p. 1478–1488.

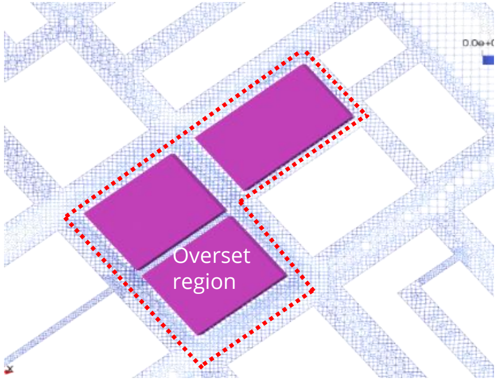
Urban Ventilation & Optimization
Physics & Numerics

- Innovation:
  - Application of in-house overset mesh library that can handle:
    - overlapping mesh and interpolation between meshes.
    - overlapping building design and close-proximity of buildings.
  - Development of **fast surrogate CFD model** for urban flows.

- Two examples:
  - Handling of **terrain and close-proximity buildings**
  - **Guideline** for **overset grid simulations**



Complex terrain shapes can be meshed in overset regions with ease.

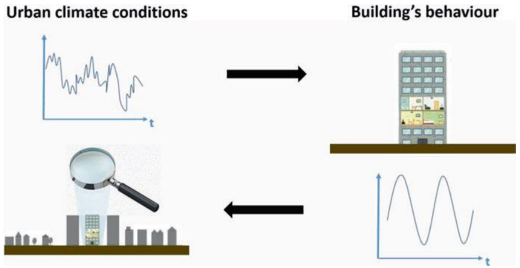


Overset library can handle close-proximity buildings

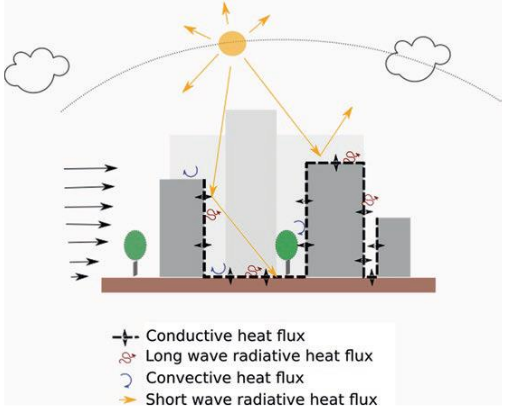
Urban Microclimate and Building Energy Modelling

Co-simulation Strategies: Coupling or Chaining

Running UCM simulation and providing the results into weather files used in BEM tool

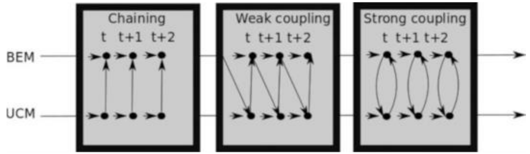


Interaction between UCM and BEM



Heat exchanges around the building - Radiation, convection and ventilation heat fluxes in BEM

Three different Strategies



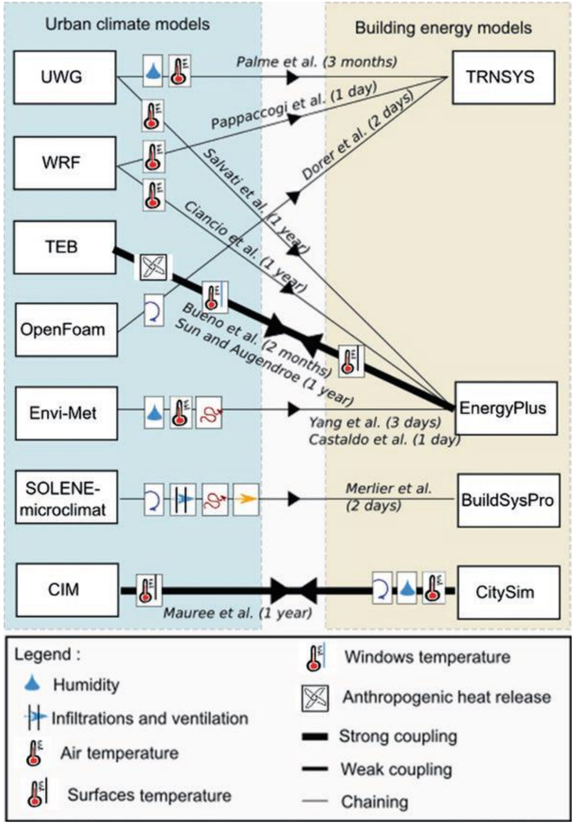
Chaining, weak coupling or strong coupling between BEM and UCM

1) ***Chaining methods***: *The first model is solved and then the outputs are used directly as input to the second model to be solved for the same time step: it is a* ***one-way communication***

2) ***Weak coupling***: *The models are run in sequence, and each model uses as boundary condition the known output values (of the previous time step) of the other model. This method is also named the* ***ping-pong coupling***

3) ***Strong coupling strategy*** *or full dynamic coupling is defined as the combination of two models that iterate at the same time within each time step until the error estimate falls within a predefined tolerance. This method is also named as* ***onion coupling*** *in building performance simulation field*

Co-simulation projects between BEM and UCM



Auline Rodler et. al., Urban Microclimate Modelling for Comfort and Energy Studies, Chp. 15, , 2021

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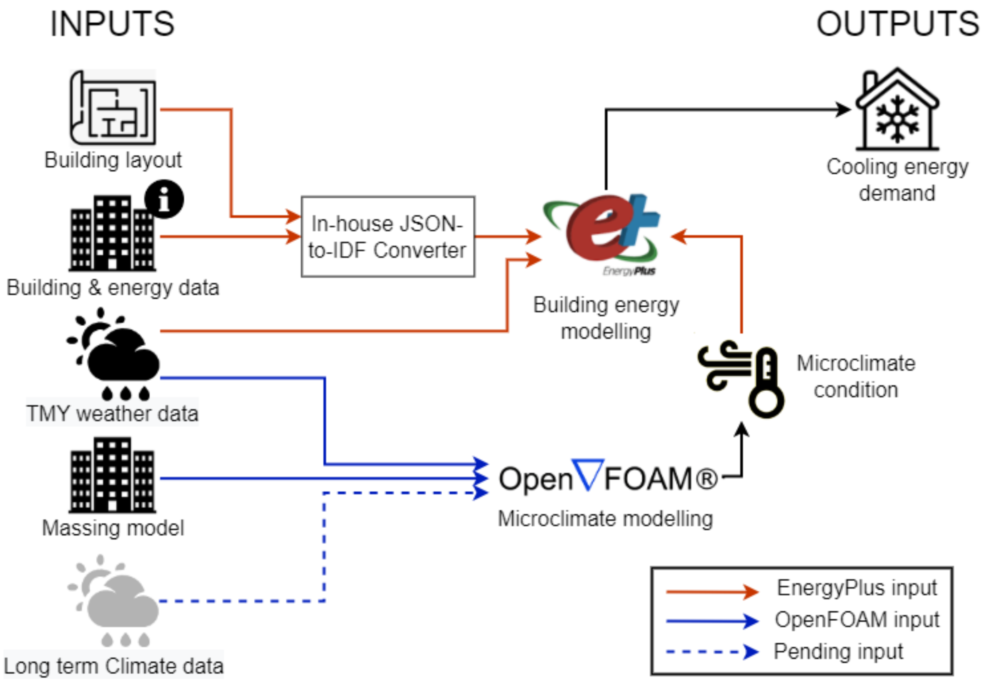
Microclimate-Coupled Building Energy Modeling Framework in IHPC



One-way coupling between CFD and BEM with time- and spatial-varying microclimate data

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Applying UEM in Planning and Design: Case Studies

Typical Practical Example to Mitigate Urban Heat & Reduce Building Energy Consumption

Green Infrastructure & Cool Material

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Green Infrastructure to Mitigate Extreme Temperatures in Cities

	Tree cover	Urban parks	Green roofs	Vertical greenery systems
Mechanisms of air temperature regulation				
Reduction of reflected solar radiation	+	++	+	
Provision of shade	++	+		+
Cooling by evapotranspiration	++	++	+	+
Regulation of wind speed	+	++		+
Spatial scale of influence				
Urban	++	++		
Local	++	++	+	
Building	+		++	++

contribution of green infrastructure to mitigate urban heat at different spatial scales

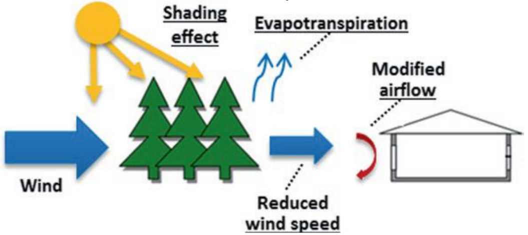
Cooling mechanism

1) ***To increase land surface albedo**: Lower albedo implies increased solar radiation absorption by surface areas, which in turn increases surface and air temperature.*
2) *Providing Shade*
3) *Cooling by Evapotranspiration*
4) *Regulating Wind Speed*

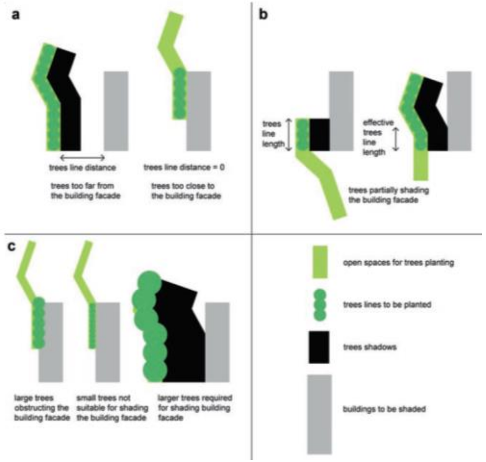
Green Infrastructure to Mitigate Heat

1) *Urban Parks.*
2) *Tree Cover*
3) *Green Roofs*
4) *Vertical Greenery Systems*

Green Infrastructure to Reduce the Energy Demand of Cities

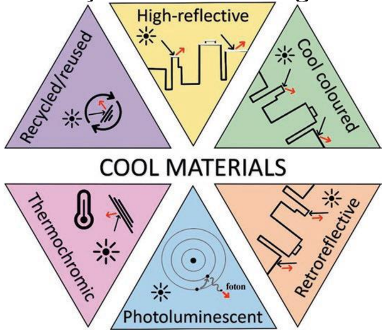


The effects of trees on a building energy balance

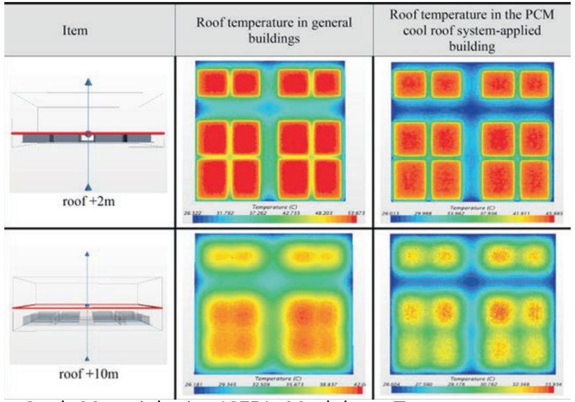


Three parameters as morphological key constraints: (a) Tree line distance, (b) tree line length, (c) tree species.

Cool Materials for Passive Cooling in Buildings



Classification of cool materials



Cool Materials in (CFD) Models - Temperature distribution of commercial area

Massimo Palme & Agnese Salvati, Urban Microclimate Modelling for Comfort and Energy Studies, Chp. 19, 23,24, 2021

Typical Practical Example to Mitigate Wind Driven Rain (WDR)

Classification, Massing & Façade Typologies

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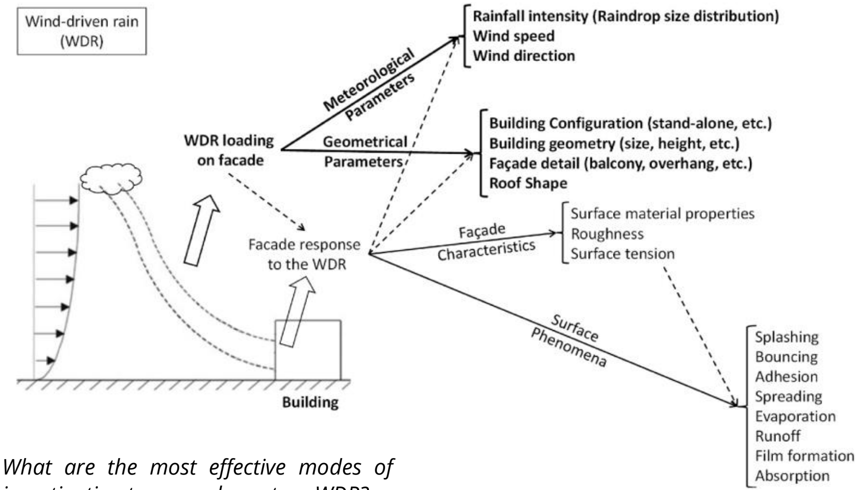
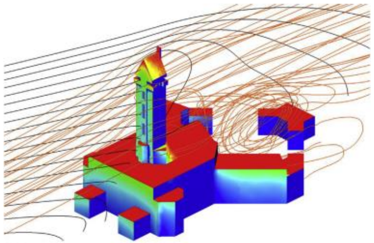
Classification of Wind-driven rain (WDR) and influential parameters

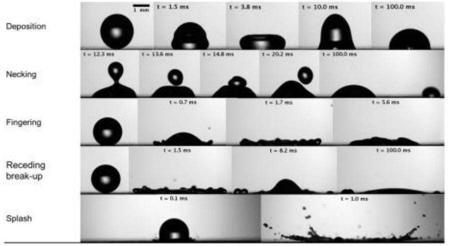


What are the most effective modes of investigation to properly capture WDR?



Catch ratio on all the surfaces of a complex geometry together with streamlines of wind (orange) and rain (black) phases

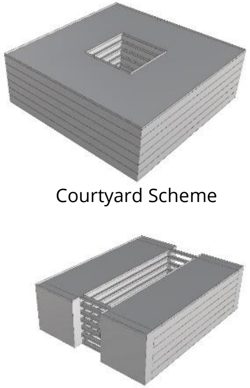
How do rain droplets interact with impervious surfaces?



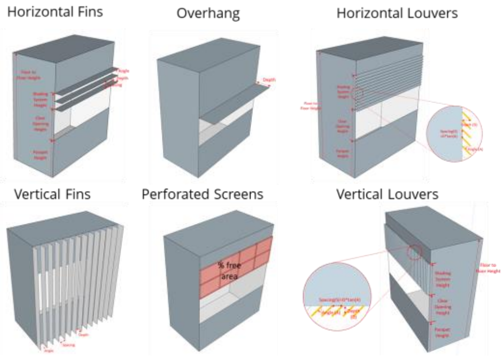
Building and Environment 221 (2022) 109314

Building and Environment 114 (2017) 495-506

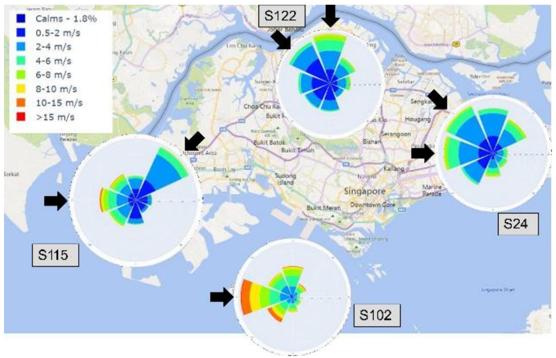
Massing Typologies



Façade Types



Regional Variation of wind speed and direction (during rain event)



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Applying UEM in Planning and Design: Case Studies

1. **Nparks Cluny Park Road Urban Microclimate simulation** – wind, building temperature and solar flux with different albedo values
2. **Trees as a mitigation strategy** countering urban heat island : Case Study in Montreal
3. **WDR Use Case -** Neighbourhood buildings in Singapore
4. **BEM Use Case** - CHTC derivation for low-rise porous buildings in the tropics – BEM, CFD & Experimental

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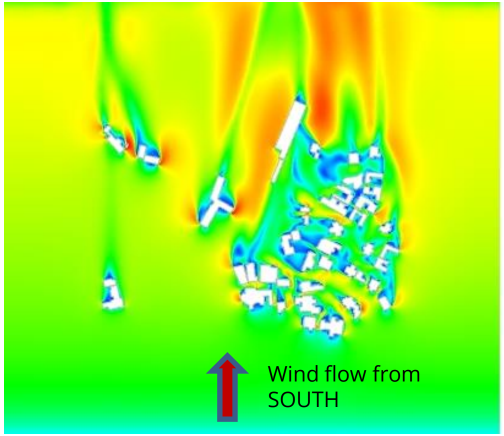
Cluny Park Road Urban Microclimate CFD simulation

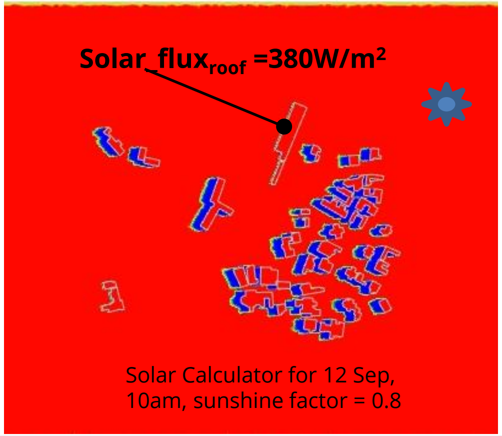
Wind, solar heat flux, temperature & T_{MRT} with DO radiative heat transfer, building albedo 0.3 – without tree

Geometry extraction from Open Street Map

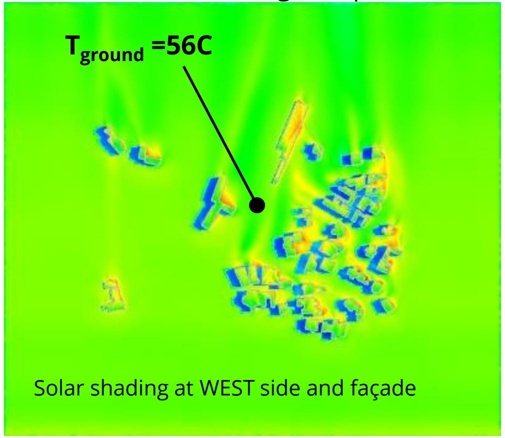
Wind Flow



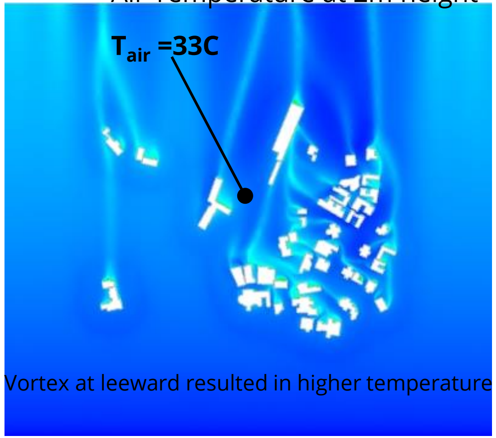
Solar Heat Flux on Ground and Building



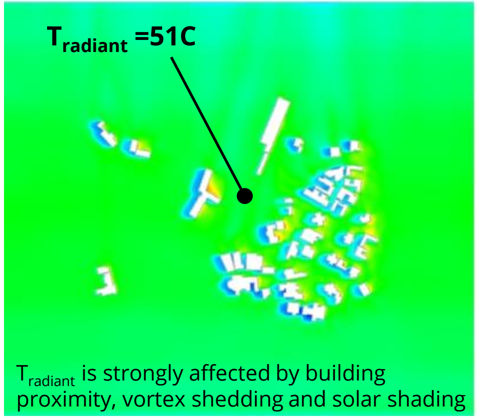
Ground and Building Temperature



Air Temperature at 2m height



$T_{radiant}$ at 2m height



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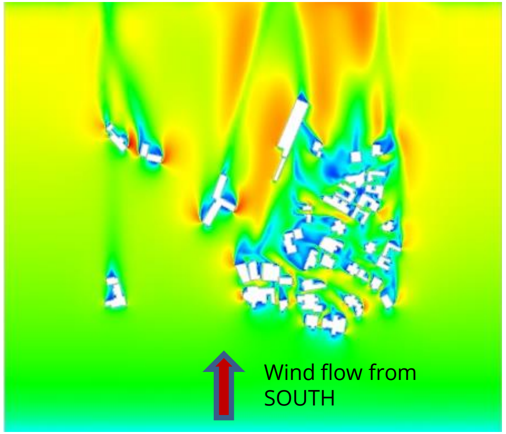
Cluny Park Road Urban Microclimate CFD simulation

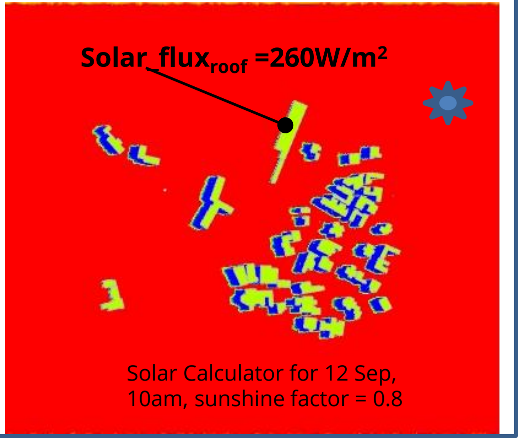
Wind, solar heat flux, temperature & T_{MRT} with DO radiative heat transfer, building albedo 0.55 – without tree

Geometry extraction from Open Street Map

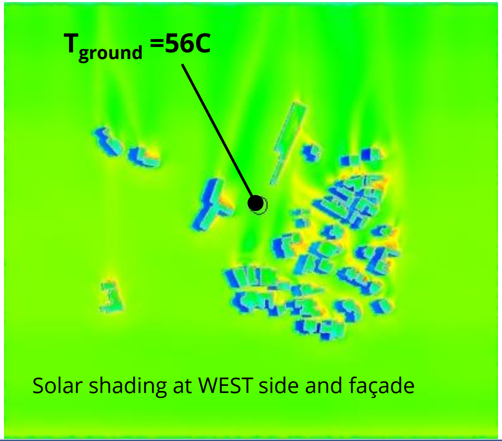
Wind Flow



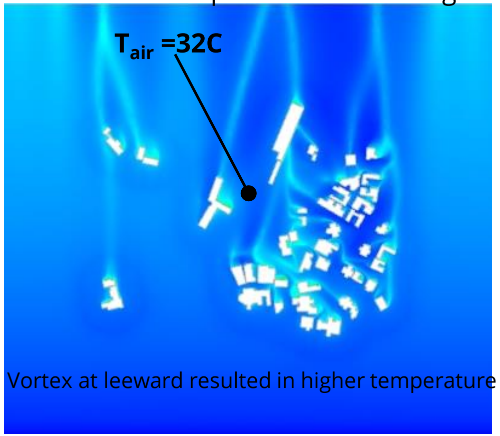
Solar Heat Flux on Ground and Building



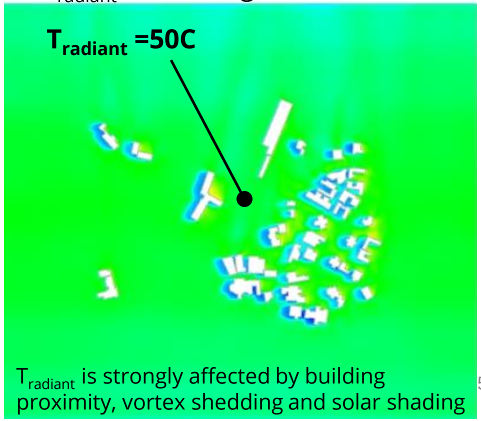
Ground and Building Temperature



Air Temperature at 2m height



$T_{radiant}$ at 2m height

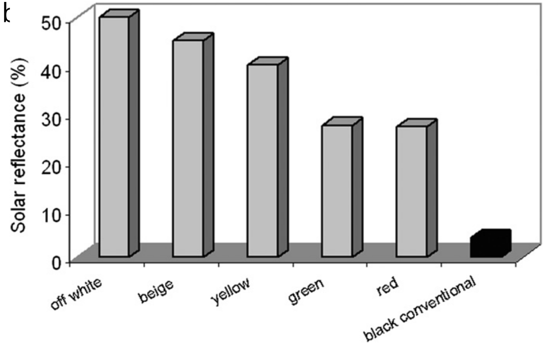


Cluny Park Road Urban Microclimate CFD simulation

Solar heat flux & temperature at building with different albedo value 0.30 vs. 0.55

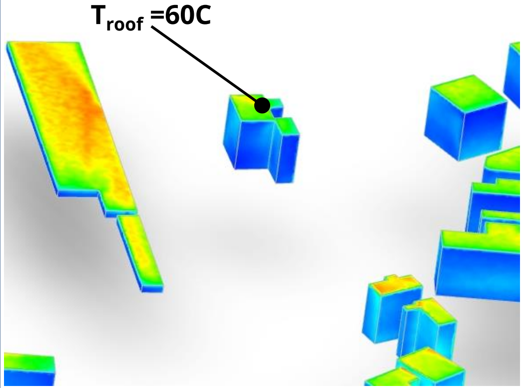
The five (1. beige, 2. off-white, 3. green, 4. red, 5. yellow) tested color thin layer

The solar reflectance of five tested color thin layer samples and the conventional b

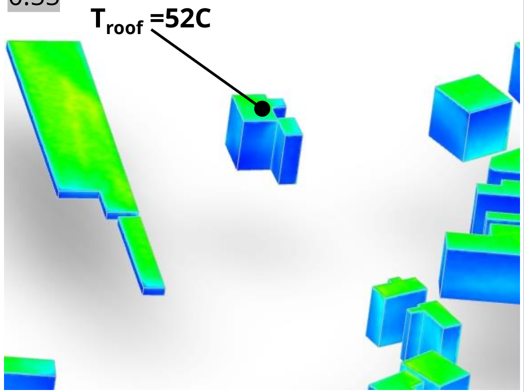


Santamouris, et al, Building and Environment 46 (2011) 38-44

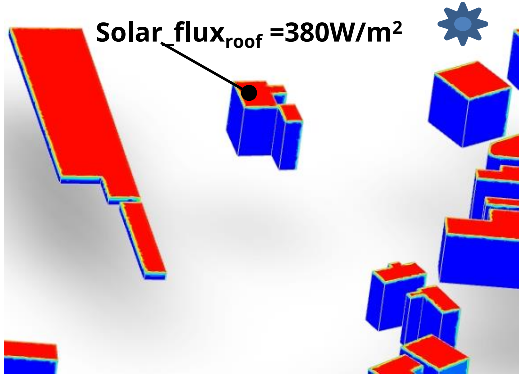
Building wall temperature, albedo = 0.30



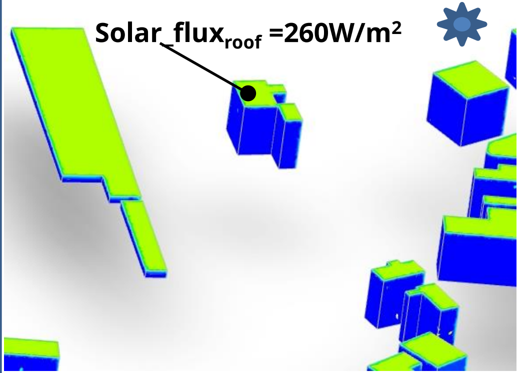
Building wall temperature, albedo = 0.55



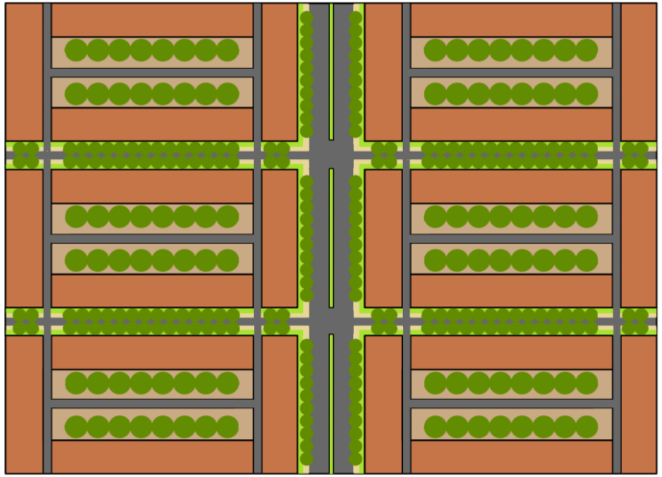
Solar Heat Flux on Building, albedo = 0.30



Solar Heat Flux on Building, albedo = 0.55



Montreal study case - Trees as a mitigation strategy Countering Urban Heat Island



Conditions :

- $Z_{ref} = 10\ m$
- Assuming 6 identical islands (urban lots)

Blvd Saint-Joseph :

- Length : 240 m
- Width : 30 m

Other streets :

- Length : 150 m
- Width : 15 m

Island size :

- Length : 150 m
- Width : 70 m
- Height : 10 m
- Depth : 20 m

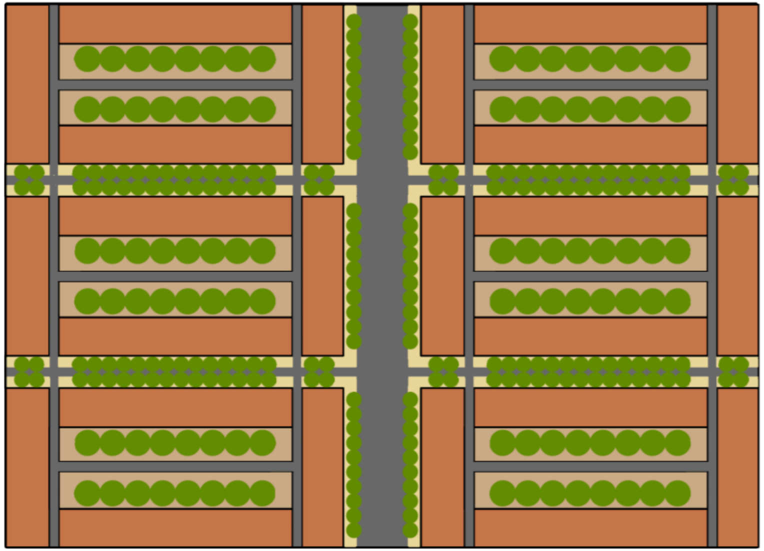
Blvd Saint Joseph, Montréal QC https://www.google.com/maps/

Table: Albedos for urban surfaces

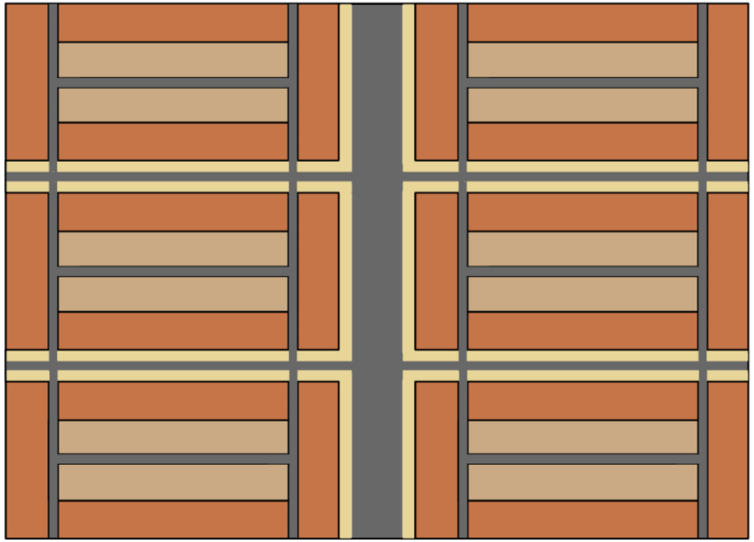
Brick	Grass	Trees	Street	Pavement	Soil
0.25	0.3	0.15	0.3	0.4	0.2

Courtesy from Derome, Nevers, Kubilay, Carmeliet

Study scenarios



Full – 320 trees

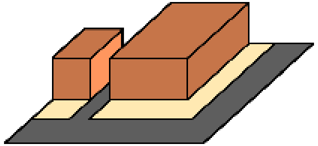


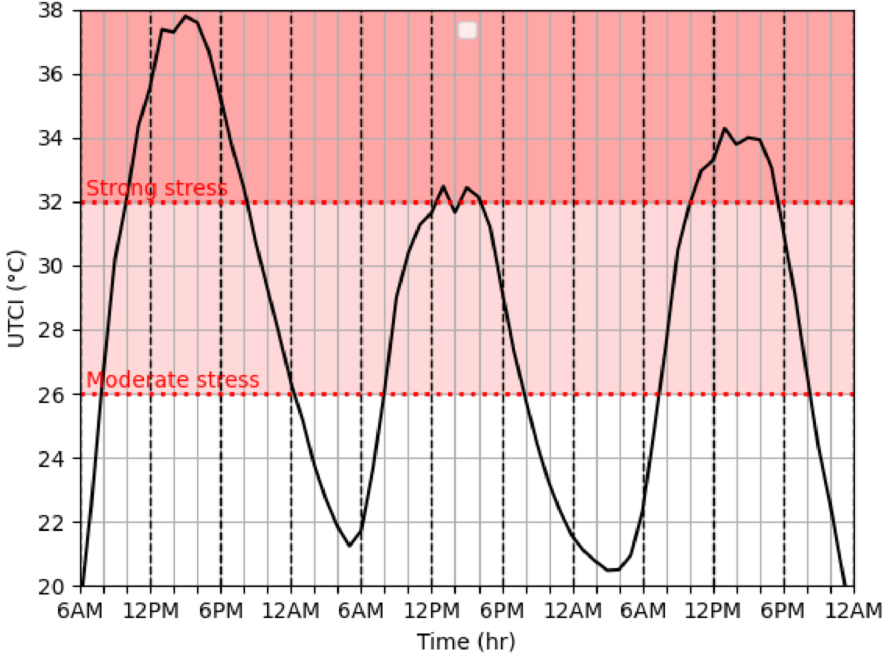
Reference

Courtesy from Derome, Nevers, Kubilay, Carmeliet

UTCI (Universal Thermal Climate Index)

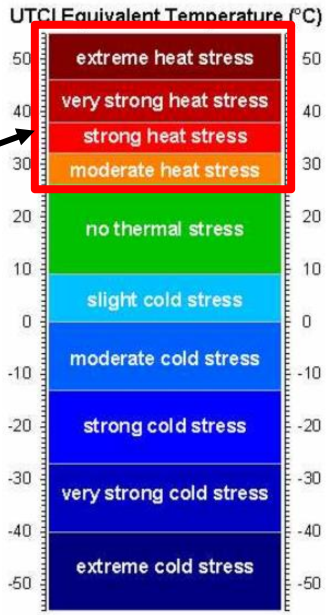
Reference case





UTCI on the reference case with stress zones

Mitigation strategies to avoid this zone



Courtesy from Derome, Nevers, Kubilay, Carmeliet

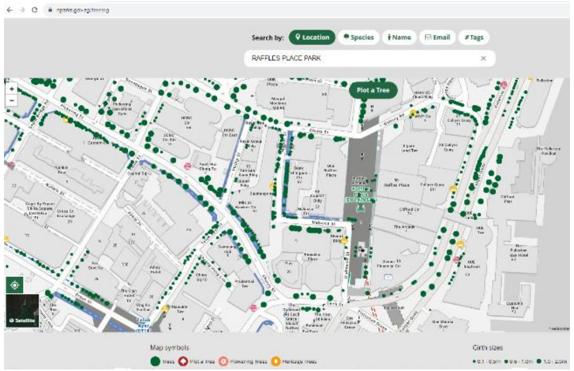
Possible Study Zone in Singapore – Future Work

SN	LCZ number	LCZ Name	Park Name
1	1	Compact High Rise	Raffles Place Park
2	2	Compact Mid Rise	Duxton Plain Park (A)
3	3	Compact Low Rise	Duxton Plain Park (B)
4	4	Open High Rise	Thomson Road Playground
5	5	Open Mid Rise	Botanic Gardens
6	6	Open Low Rise	Mimosa Road Playground
7	8	Dispersed Mid Rise	Bishan AMK park
8	9	Dispersed Low Rise	Bishan AMK park
9	11	Dense Trees	Sun Plaza Park
10	14	Low Plants	Bishan AMK park

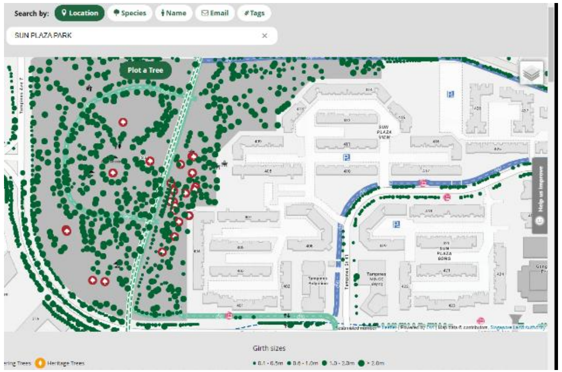
Example of Parks within different Local Climate Zone (LCZ) classification

- Park ~ 200m/100m
- Alignment with infrastructure, e.g. road, MRT and neighbouring buildings
- Mixed building typology
- Different greenery type
- Impact of waterbody in canal to PCI
- Possibility of a parametric study

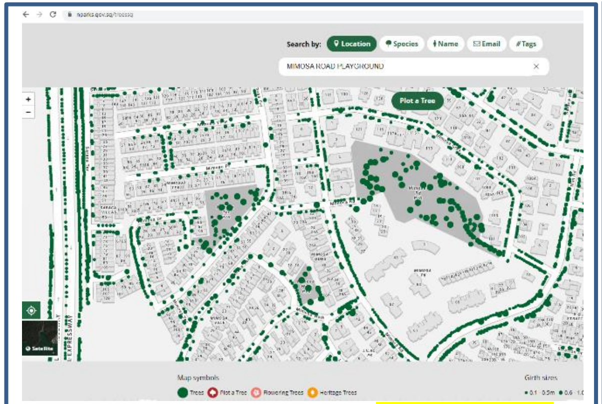
Urban Microclimate Modelling consideration



Raffles Place Park (compact high rise), located in CBD



Sun Plaza Park (dense trees)



Mimosa road playground (**open low rise**)

Chao Chu Kang Park

Sharing with permission from NParks, images are obtained from https://www.nparks.gov.sg/treessg#

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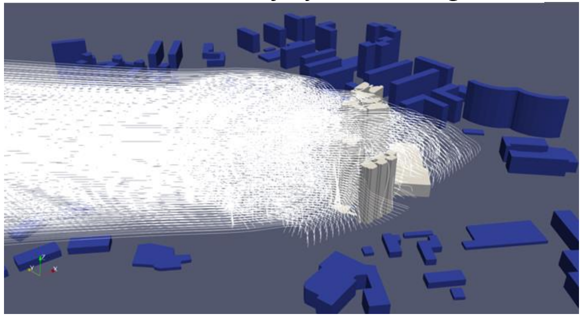
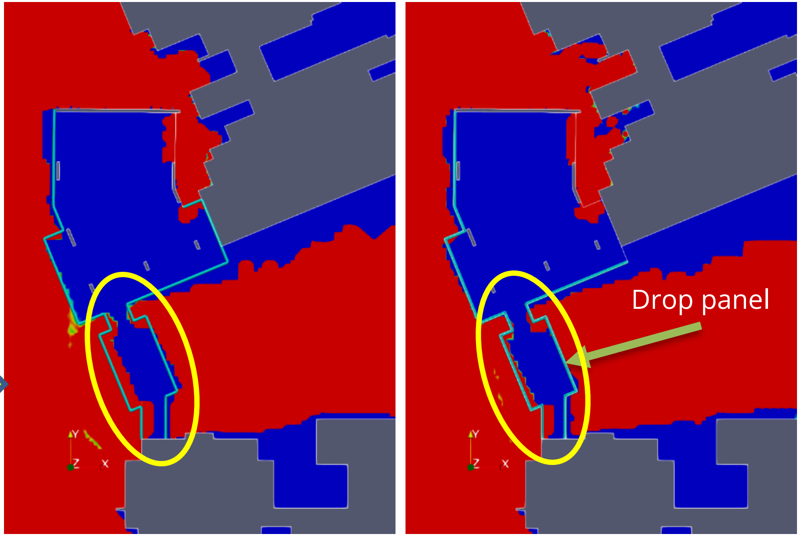
WDR Use Case :
Neighbourhood buildings

- Solutions from LPT approach
  - Effectiveness of the drop panel for keeping the pick-up/ drop-off area dry from WDR
  - 6.6m/s wind @15m, 2mm raindrops, SF = 5.0

(a) Geometry of the buildings.

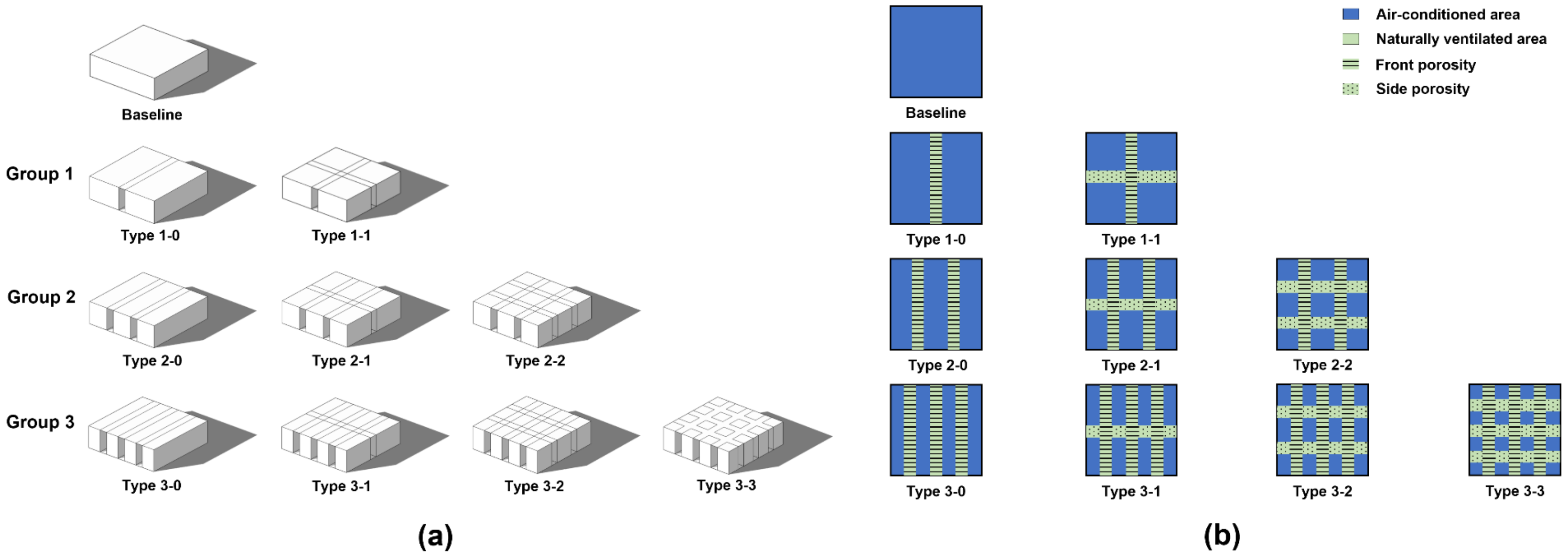


(b) Trajectory of raindrops.



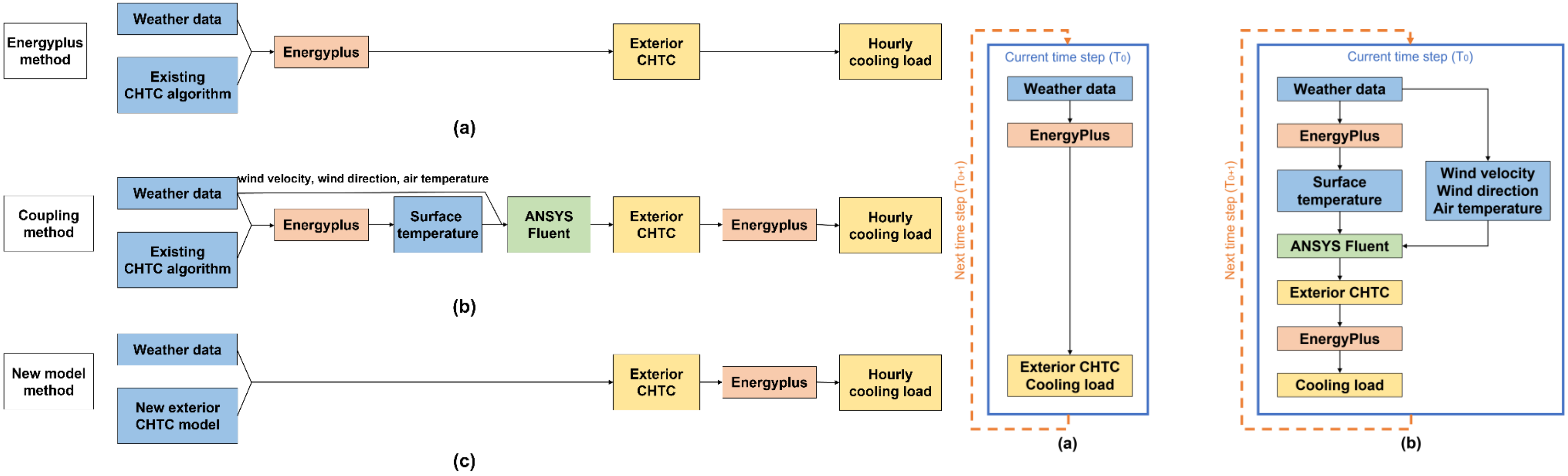
(c) Wetted (red) and dry (blue) areas indicated in the contour plots for the case without (left) and with (right) drop panels.

Case Study : CHTC derivation for low-rise porous buildings in the tropics – BEM, CFD & Experimental



Building Geometry

Case Study : CHTC derivation for low-rise porous buildings in the tropics – BEM, CFD & Experimental



Methods of deriving exterior CHTCs: (a) Energyplus, (b) Coupling, and (c) new model

Quantifying model uncertainty of convective heat transfer coefficient (CHTC) models in building energy simulation by onsite measurement

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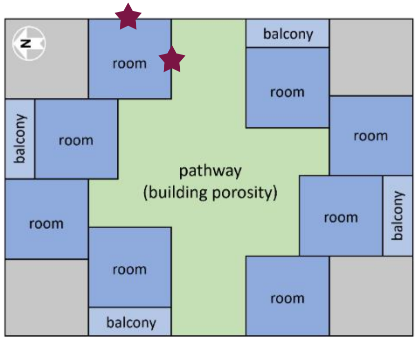
Onsite measurement – site

- A low-rise porous building
- A through corridor and four rooms
- Open flat grassland surrounded by tree belts and high-rise buildings
- Two measurement points

satellite view

oblique view

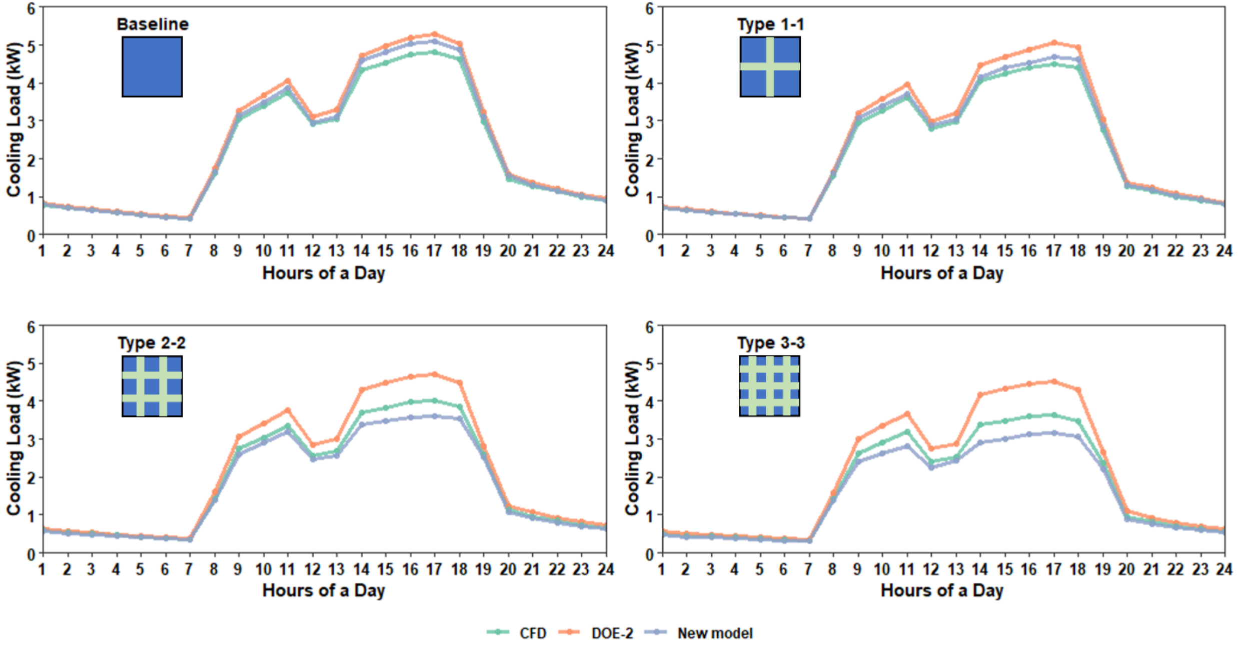
front view



floor plan

Case Study : CHTC modelling for low-rise porous buildings in the tropics – BEM, CFD & Experimental

Results



Hourly facade cooling load based on exterior CHTCs derived from different methods for different porous buildings: (a) Baseline, (b) Type 1-1, (c) Type 2-2, and (d) Type 3-3

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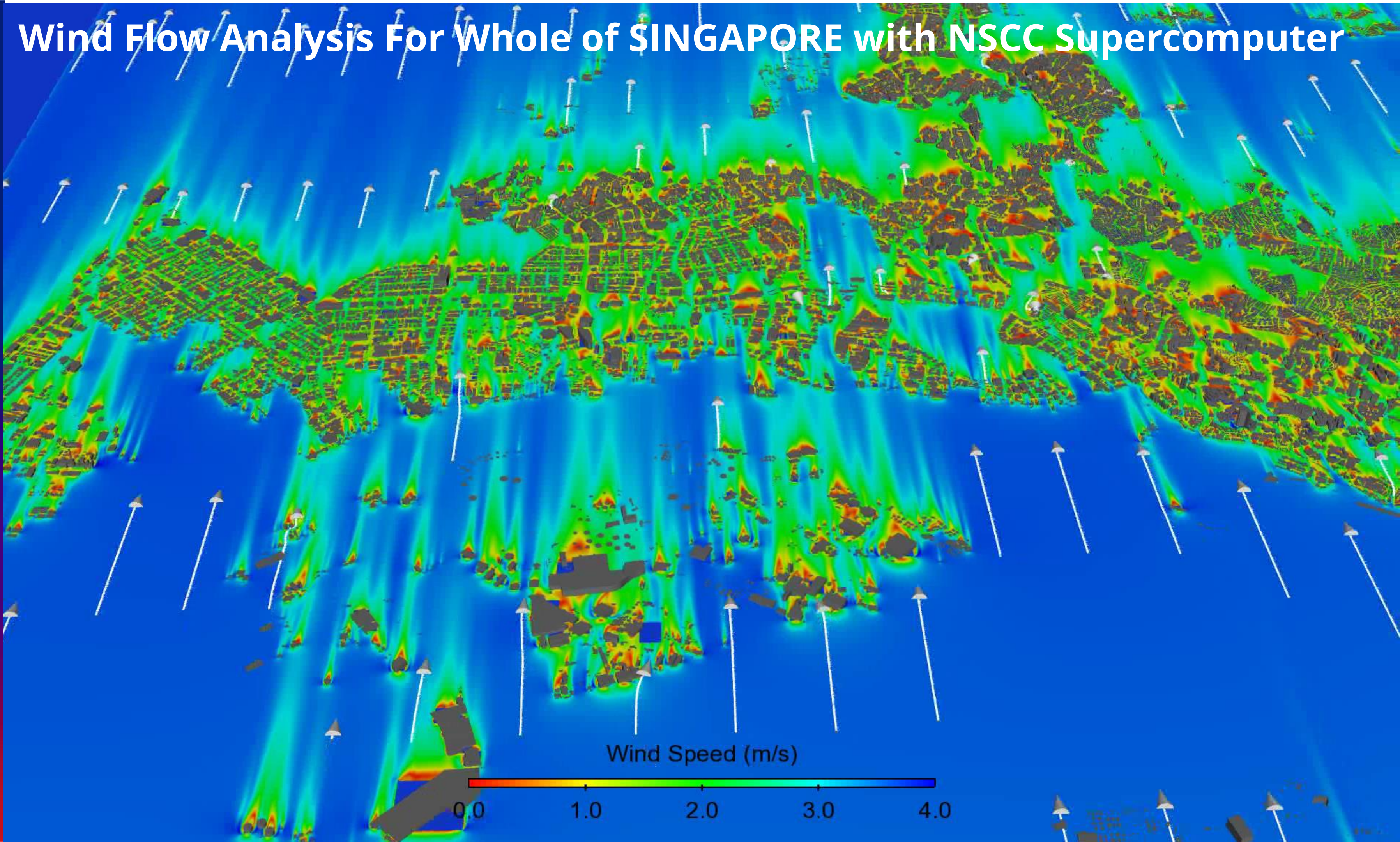
Wind Flow Analysis For Whole of SINGAPORE with NSCC Supercomputer



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NSCC - A National Research Infrastructure of NRF

NATIONAL RESEARCH FOUNDATION
PRIME MINISTER'S OFFICE SINGAPORE

A **National Research Infrastructure** funded by Singapore's **National Research Foundation (NRF)** providing supercomputing resources to Singapore's Research, Innovation and Enterprise (RIE) ecosystem.

National-level resource open to **all national research initiatives at** Institutes of Higher Learning, Research Institutes and the industry.

ASPIRE 2A – Singapore's New National Petascale Supercomputer

105,984 Cores	1,024 Cores	352 GPUs	476TB	25 PBytes	10 PBytes
CPU (AMD EPYC™ 7713) **800 Nodes**	High Frequency Nodes (AMD EPYC™ 75F3) **16 Nodes**	Accelerated Nodes GPU (NVIDIA A100) **82 Nodes**	Total System Memory	Storage (Spinning + Nearline)	Scratch Disk

Interested users: please contact bizdev@nscc.sg for more information

Conclusions & Future Work

Conclusions - IEM as WOG Environmental Modelling Tool

Wind – CFD, natural ventilation, building massing

Solar – shading, solar irradiance, absorbed solar energy

Wind + Thermal – buoyancy, horizontal homogeneity for stratified ABL flow, MSS input

Traffic Noise – sound dB at building façade, road categories, CRTN

Building Energy Modelling with microclimate effects – couple BEM with CFD for improved CHTC values, scaling up BEM to town level

IEM2 – environmental modelling tool by urban planners for sustainable town design

Advanced Greenery modelling – tree drag aerodynamics, thermal interaction, humidity and evapotranspiration model

Radiation – long wave + short wave, Mean Radiant Temperature, UHI & OTC evaluation

Aircraft noise – military aircraft noise prediction, model construction with limited source data and unknown flying path, noise mitigation

WDR modelling – Lagrangian & Eulerian approaches, rain droplet size spectrum, wetted area

Overset meshing – hole-cutting algorithm, improve simulation productivity with multiple building massing design cycle

Terrain modelling – topological treatment techniques, buffer area to model complex terrain

Integrating meso scale climate model – CCRS SINGV's output, 1-way downscaling, reconstruct weather scenarios

Thermal storage – 1D heat conduction, material properties, anthropogenic heat, diurnal cycle

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What are the new areas Singapore should embark on? (New Potential Use Cases in Environmental Modelling)

CREATING GROWTH, ENHANCING LIVES

- Advancement Work of IEM for **City Design & Urban Planning**
  - Extension of IEM2 for Integration with Compatible Digital Platform – to adopt Decision Support System (DSS)
  - Extension of Wind Driven Rain Studies – validation, rain splash-off, Eulerian mitigation feature modelling
  - Extension of Coupling CFD to Building Energy Modeling – enhanced model fidelity in district level BEM
- Extension of Wind Load Prediction on Urban Trees – **City in Nature**
  - Field test & simulation for single tree on open landscape – improved understanding on modelling tree scalability and flexibility
- Wind tree modelling in Plant-Air-Soil framework – **City in Nature**
  - Enhanced capability in Evapotranspiration Modelling & Geo-Hydrological Modelling
  - It is also appliable for Controlled Agricultural Environment (CAE)
- Mesoscale and microscale numerical modeling - **Healthy Cities**
  - Machine learning for climate model;
  - Pollution & Odor dispersion modelling
- Modelling transportation noise for traffic, aircraft and rail - **Healthy Cities**

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