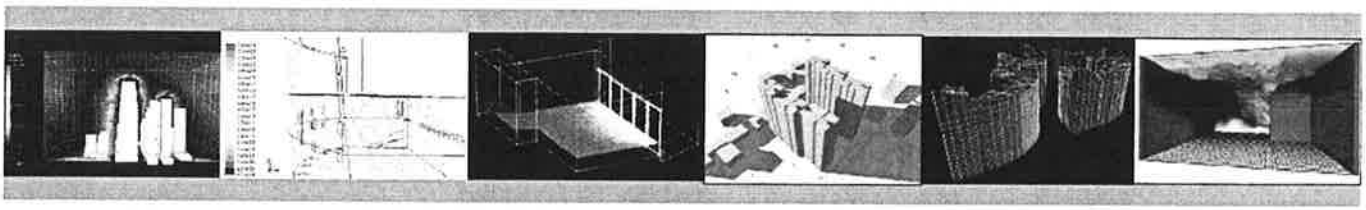
# BUILDING PERFORMANCE SIMULATION



*Mr Yong Peng Quen (GMP / LEED® AP)*

*Mr Po Woei Ken*

*Building System and Diagnostics Pte Ltd*

## Global Target

- **Buildings account for 48% of all energy consumption and greenhouse gas emissions**
- **Goals**
  - **Carbon neutral by 2030**
  - **Reduce building energy usage by 50%**
- **Building's performance must be ensured prior to construction.**
- **"Performance checklist" to measure design impacts**

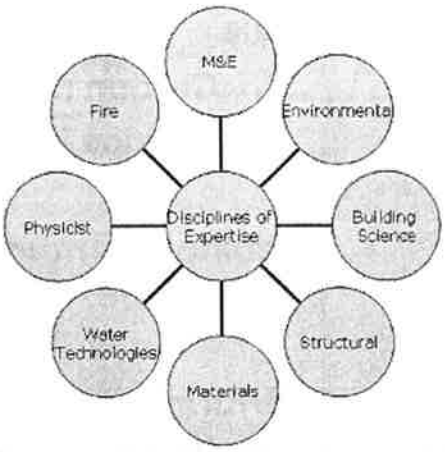
# Why Simulations

- Analyze impacts of changes
- Reduce time and expense
- Answers "What if…"
- Provides comprehensive data not easily obtainable from experimental tests
- Allows alternatives to be studied before optimum designs are confirmed



# Limitations

- Know-how… Garbage in, garbage out
- Hardware - high cost
- Software - built for tropics?
- Multi-disciplinary



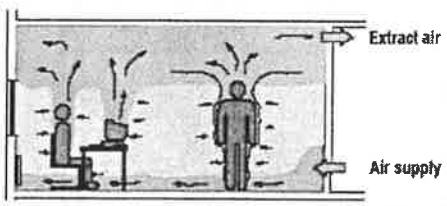
# Building Performance Simulations

- Ventilation
- Solar and daylighting
- Thermal analysis
- Embodied energy
- Energy



# Ventilation

- Thermal comfort- Interaction of wind and buildings.
- Blow away- apply natural ventilation where possible.
- Cooling potential of ventilation




| Climatic Factors | Physiological Factors |
|---|---|
| ▫Temperature<br>▫Relative Humidity<br>▫Wind Speed<br>▫MRT | ▫Metabolic Rate<br><br>▫Clothing Insulation (Clo Value) |

# The Beauty of Wind

A naturally ventilated building:

1. Reduces capital costs No need to expect high efficiency a/c
2. Reduces operating costs
3. Opportunity for occupant control
4. Reduced environmental impact



# Wind Speeds

| Type of Winds | Beaufort Number | Wind Speed (m/s) | Effects |
|---|---|---|---|
| Calm, light air | 1 | 0 - 1.5 | Calm, no noticeable wind |
| Light breeze | 2 | 1.6 - 3.3 | Wind felt on face |
| Gentle breeze | 3 | 3.4 - 5.4 | Hair is disturbed, Clothing flaps |
| Moderate breeze | 4 | 5.5 - 7.9 | Raises dust, dry soil and loose paper - Hair disarranged |
| Fresh breeze | 5 | 8.0 - 10.7 | Force of wind felt on body |
| Strong breeze | 6 | 10.8 - 13.8 | Umbrellas used with difficulty, Hair blown straight, Difficult to walk steadily, Wind noise on ears unpleasant. |
| Near gale | 7 | 13.9 - 17.1 | Inconvenience felt when walking. |
| Gale | 8 | 17.2 -20.7 | Generally impedes progress, Great difficulty with balance. |
| Strong gale | 9 | 20.8 - 24.4 | People blown over by ***gusts***. |

Source: BRE report

| Air Temp °C | Recommended wind velocity (m/s) |
|---|---|
| 28 | 0.33 |
| 29 | 0.50 |
| 30 | 0.81 |
| 31 | 1.15 |
| 32 | 1.50 |
| 33 | 1.84 |
| 34 | 2.19 |

**Source: NUS study by Prof Wong**

# Airflow simulations

- Assist to ensure factors such as building layout, orientation, spacing, openings, etc promote natural ventilation
- Optimizes the strategies for mechanical ventilation

- To determine the required air flow, cmH, air change

**Team-based approach beginning at design stages!**

**Important to do Simulation at start not at end of project!!!!**



# What is CFD ?

- A branch of fluid mechanics which studies how **fluids move** in motion.
- Computer based.
- It uses numerical methods and algorithms to solve and analyze problems involving fluid flows.
- Parameters to be solved include **velocity**, pressure and **temperature.**

# CFD – How?

- Three main Steps:

1. Pre-process
2. Solving Equations
3. Post-evaluation



**Pre-Process** | Solving equations | Post evaluation

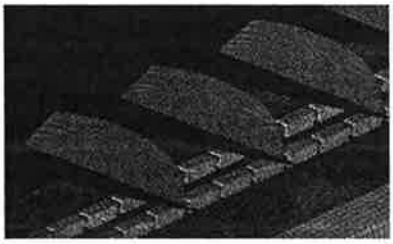
<u>Model creation</u>

- Elevations, plans
- Artist impressions
- Physical models
- Site survey



<u>Mesh generation</u>

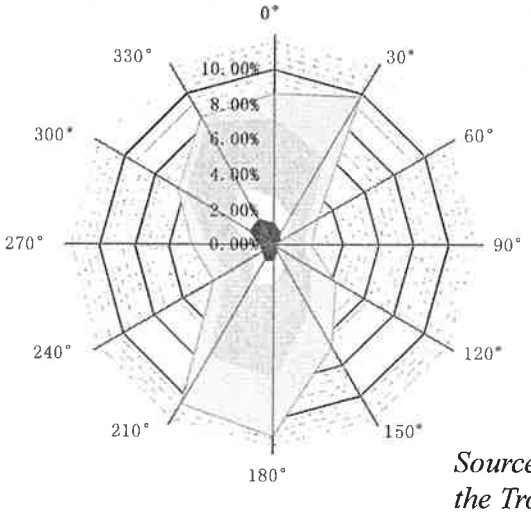
- The finer the mesh, the more details we can see
- ~ millions

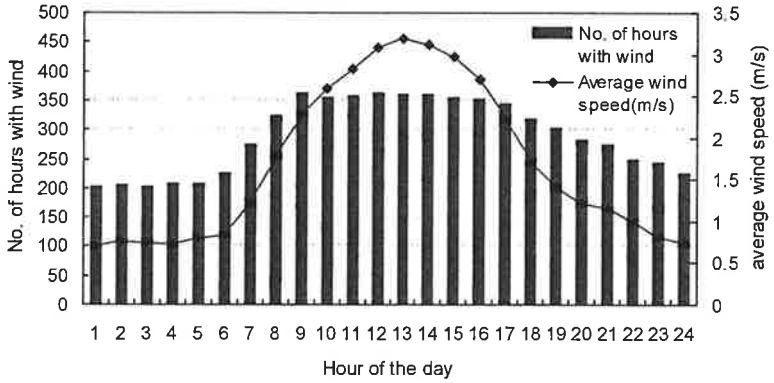


<u>Define boundary conditions</u>

- Speed of wind
- Distance from target
- Direction of wind, etc

- Steady state simulation.
- Prevailing North, South, North-East and South-East winds
- Wind velocity set as 2.0, 2.8, 2.9 & 3.2 m/s.




*Source: Thermal Comfort Issues in Naturally Ventilated Buildings in the Tropics and the impacts on Building Design,* ***A/P Wong N.Y.***





- Software should be well validated and approved by BCA.
- Surrounding buildings residing within the proximity of minimum ~3 times in radius the length of the development needs to be included
- Computation domain to be large enough to accommodate included surrounding buildings and not resulting in non-physical airflow solution
- Cell size should be 0.1 to 0.2m in the residential unit, 0.5 to 1m at all buildings and ground level and 10 m at the far field boundary with a minimum of 50 m away from the ground.
- All windows and doors “open” except main door to unit



- The equations include those for the conservation of momentum, which are sometimes referred to as the Navier-Stokes equations, and the conservation of mass.

**Conservation of mass:**

$$\rho\cdot\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=k_x-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left[\mu\cdot\left(2\cdot\frac{\partial u}{\partial x}-\frac{2}{3}\cdot(\nabla\cdot\mathrm{v})\right)\right]+\frac{\partial}{\partial y}\left[\mu\cdot\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]+\frac{\partial}{\partial z}\left[\mu\cdot\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)\right]$$

$$\frac{\partial\rho}{\partial t}+\frac{\partial(\rho\cdot u)}{\partial x}+\frac{\partial(\rho\cdot v)}{\partial y}+\frac{\partial(\rho\cdot w)}{\partial z}=0$$

**Conservation of energy:**

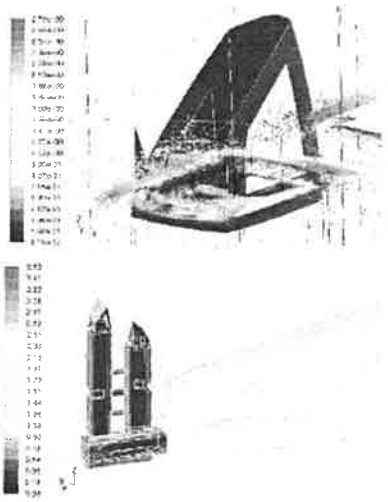
$$\rho\left(\frac{\partial e}{\partial t}+u\frac{\partial e}{\partial x}+v\frac{\partial e}{\partial y}+w\frac{\partial e}{\partial z}\right)=\left(\frac{\partial}{\partial x}\left(\lambda\cdot\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda\cdot\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\lambda\cdot\frac{\partial T}{\partial z}\right)\right)-p\cdot(\nabla\cdot\mathrm{v})+\mathbf{k}\cdot\mathrm{v}+\rho\cdot\dot{q}_s+\mu\cdot\Phi$$

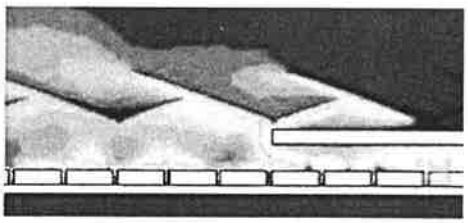




- Air velocity distribution
- Temperature distribution
- Pressure distribution
- Turbulence distribution
- Pollutant dispersal profile
- Fire and smoke movement

- Velocity vectors, contours and path lines.
- Temperature contours
- Static pressure plots.







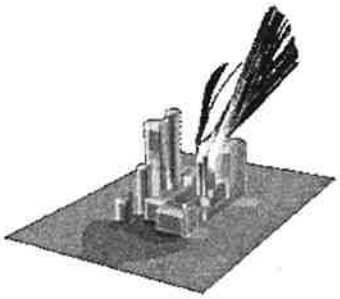
# Areas of Application

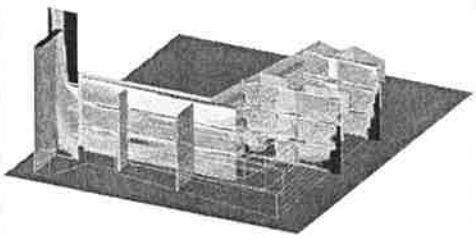
- Architectural design
- Thermal comfort
- Room layout for cross flows
- ACMV sizing for room comfort & locating diffusers
  (Passive displacement Ventilation)
- Locating diffusers
  - wind driven rain
  - Pollution dispersion simulation
- Locating of wind farms
- Designing towards BCA's Green Mark Scheme

# CFD codes

- STAR CCM +
- AIRPAK
- CFX
- NUMECA
- FLUIDYN
- PHOENICS
- VORTEX









# Objective of GMM

- Not to run simulations
- Understand how to make use of simulations to enhance building design and performance
- Recognize “alert red” conditions, ask for more information, order modifications, etc.

# Illustrations with Case Examples

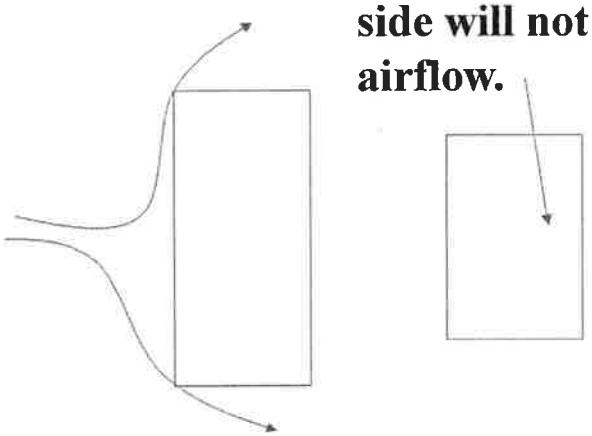


## Good practices

- Arrangement of blocks
  - Functional spaces oriented towards North and South.
  - ~~Parallel arrangement.~~
  - Staggered arrangement ~~promoted~~ since wind flow can ~~be evenly~~ distributed from windward to leeward sides.

# Parallel arrangement

**Block on the leeward side will not receive airflow.**

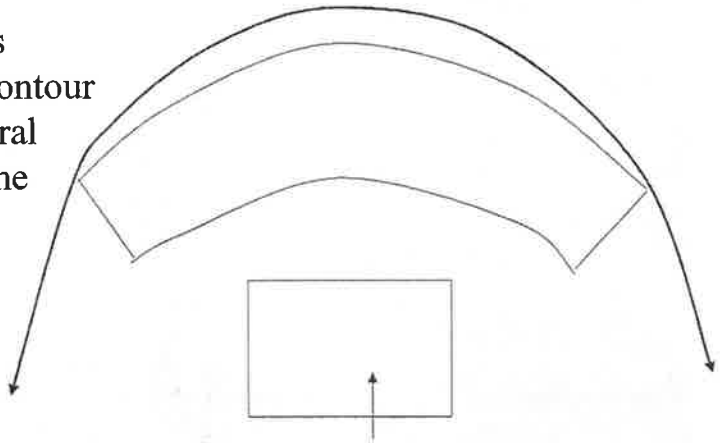


**Wind flow path is obstructed by the blocks. Wind not allowed to reach leeward areas**



# Parallel arrangement

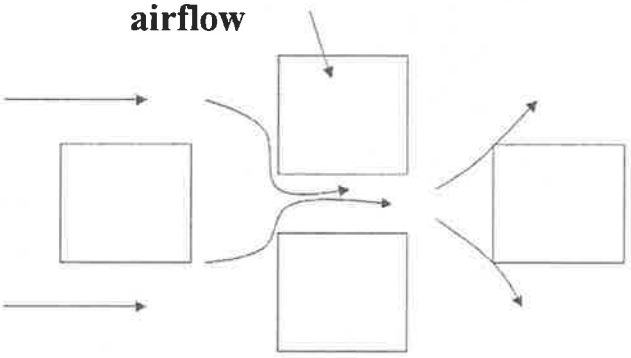
Wind flows along the contour of the general block outline



**Block on the leeward side will not receive airflow.**

# Staggered arrangement

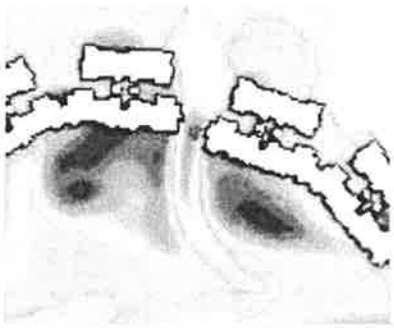
**All blocks can enjoy good airflow**



**Wind can be channeled around the blocks to reach downstream areas.**



# Block layout and design



- Permeability of blocks
  - Spacing between blocks
  - Corridor railings should be perforated
  - Void decks, sky gardens
  - Lift lobby within blocks with natural ventilation

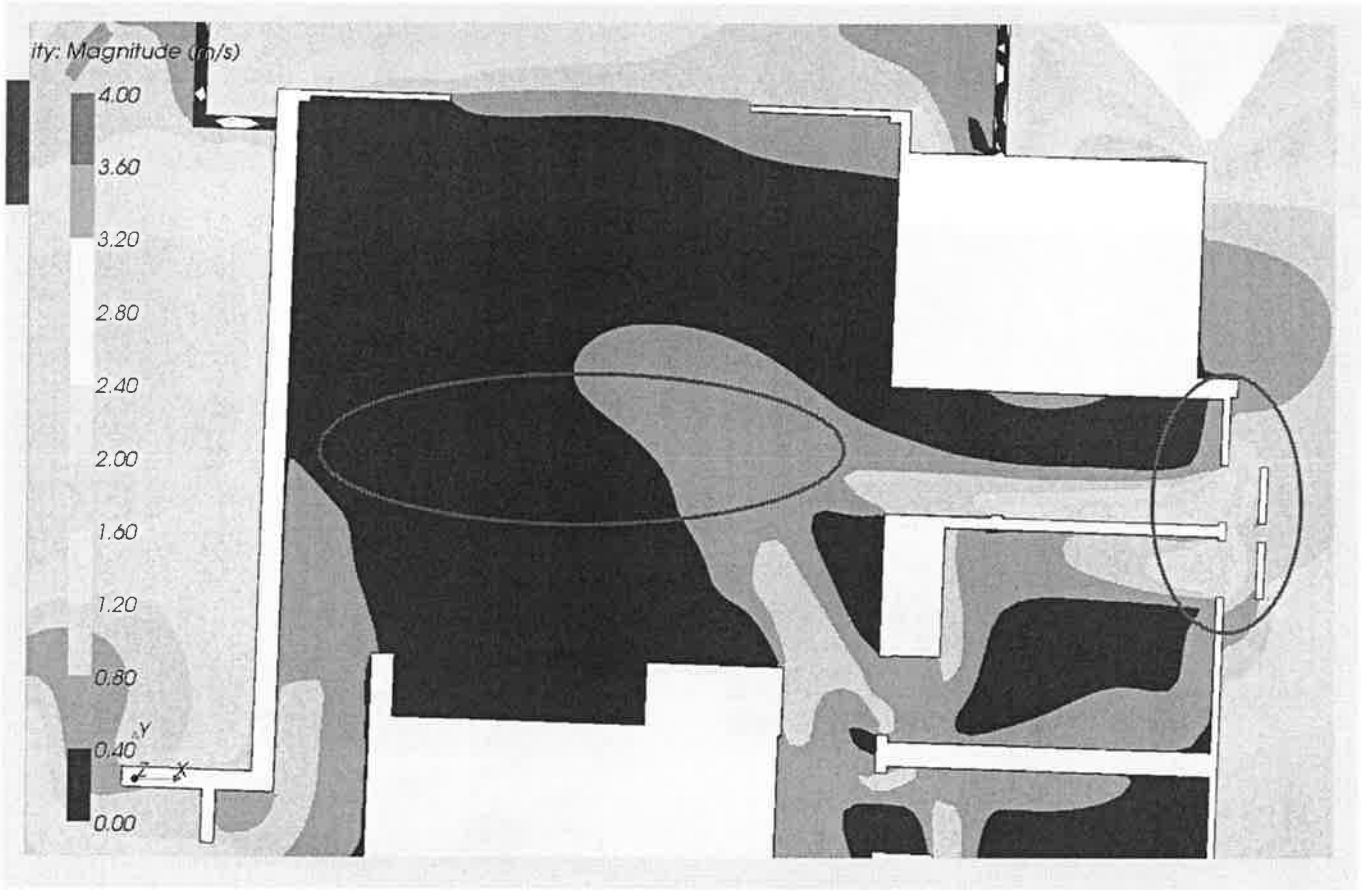
# Permeability

1. Block spacing allows cross flows
2. Link bridges, corridors to be permeable
3. Sky gardens and voids allow cross flows
4. Double volume void at 1st storey

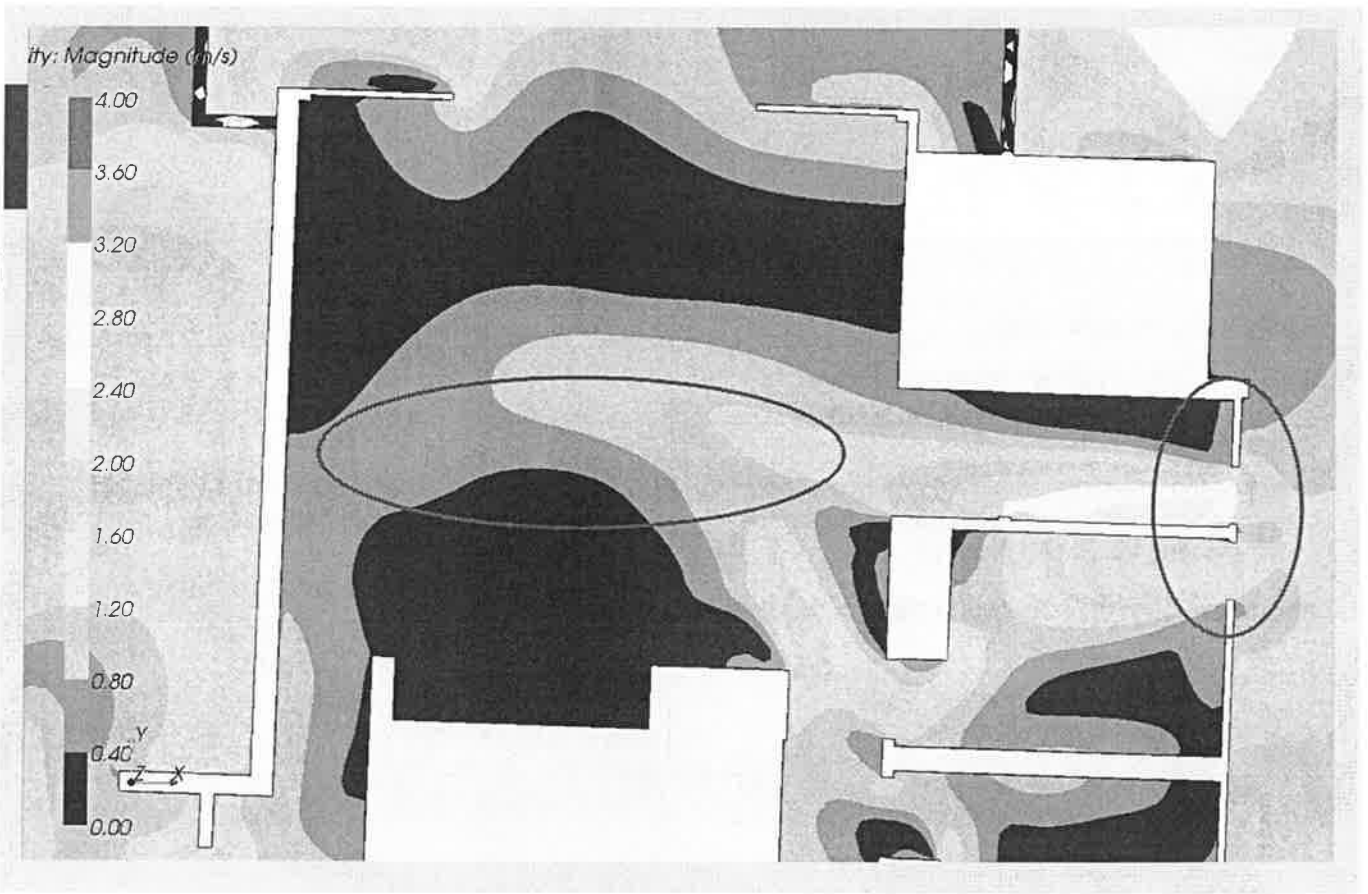


# Unit layout and design

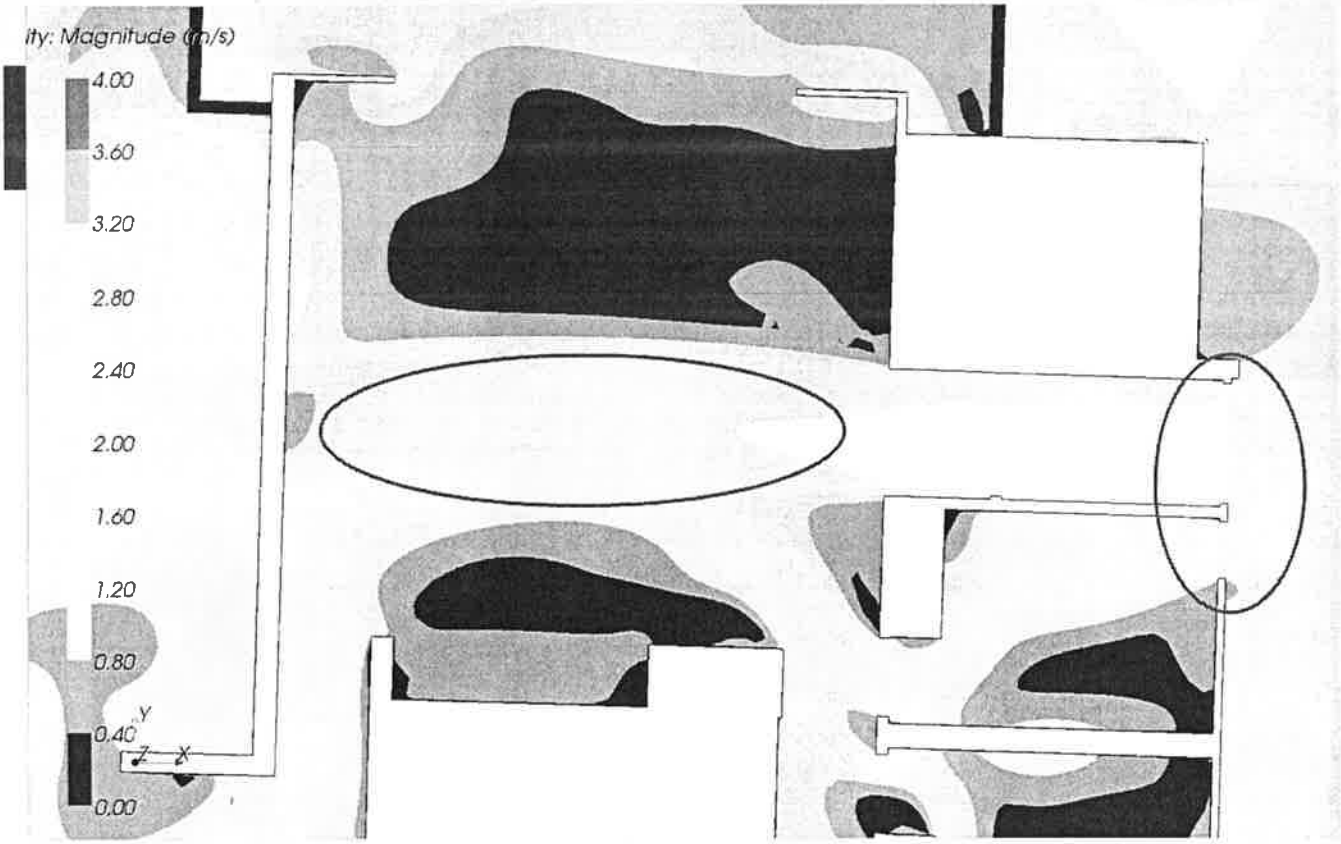
- Bedroom doors and windows to align each other and towards the general direction of cross ventilation
- Facade apertures to aligned with the corridor so that the corridor provides a channeling path to ventilate the entire unit.
- Window types such as casement, allows for bigger opening than sliding windows
- The number of openings that serves as outlets should number evenly as inlets.




Velocity Magnitude Contour
Top hung window + non full width window




Velocity Magnitude Contour
Casement window + non full width window




Velocity Magnitude Contour
Casement window + full width window

# Green Mark V4.1- Residential

| Part 1 – Energy Efficiency | Green Mark Points |
|---|---|
| **RB 1-1 Thermal Performance of Building Envelope – Residential Envelope Transmittance Value (RETV)**<br><br>Enhance the overall thermal performance of building envelope to minimise heat gain thus reducing the overall cooling load when required.<br><br>Baseline : Maximum Permissible RETV = 25 W/m$^2$<br><br>*Prerequisite Requirement :*<br>*Green Mark Gold$^{Plus}$ – RETV of 22 W/m$^2$ or less*<br>*Green Mark Platinum – RETV of 20 W/m$^2$ or less* | 3 points for every reduction of 1 W/m$^2$ in RETV from the baseline<br><br>Points scored = 75 – [3 x (RETV)]<br>where RETV ≤ 25 W/m$^2$<br>(Up to 15 points) |

# Green Mark V4.1- Residential

| | |
|---|---|
| **RB 1-2 Naturally Ventilated Design and Air-Conditioning System**<br>(a) Dwelling Unit Indoor Comfort<br>Enhance dwelling unit indoor comfort through the provision of good natural ventilation design and energy efficient air-conditioners<br><br>Option 1 – Ventilation Simulation Modeling<br>Use of ventilation simulation modeling and analysis or wind tunnel testing to identify the most effective building design and layout to achieve good natural ventilation for all unit types.<br><br>*Prerequisite Requirement :*<br>*Green Mark Platinum –Minimum 70% of selected typical dwelling units with good natural ventilation. Common areas are to be designed as naturally ventilated spaces.*<br><br>OR | 0.2 point for every percentage of typical units with good natural ventilation<br><br>Points scored = 0.2 x (% of typical units with good natural ventilation)<br><br>(up to 20 points)<br><br>OR |



# Green Mark V4.1- Residential

| | |
|---|---|
| Option 2 – Ventilation Design (without the use of simulation modeling) and Efficient Use of Air-Conditioning System<br>(i) Air flow within dwelling units<br>• Building layout design: Proper design of building layout that utilizes prevailing wind conditions to achieve adequate cross ventilation.<br>• Dwelling unit design: Good ventilation in indoor units through sufficient openings. | 0.5 point for every 10 % of units with window openings facing north and south directions<br>Points scored = 0.5 x (% of units /10)<br><br>0.5 point for every 10% of living rooms and bedrooms designed with true cross ventilation<br>Points scored = 0.5 x (% rooms/10)<br><br>(Up to 8 points) |

# GM V4.1- Residential

1. Four wind directions are included for both estate and residential simulation. To select N or NE and S or SE (2 out of 4)

Table 1: Tabulation of Prevailing Wind Direction & Speed obtained from NEA over a Period of 18 Years.

| Wind Direction | Mean Speed (m/s) |
|---|---|
| North | 2.0 |
| North-East | 2.9 |
| South | 2.8 |
| South-East | 3.2 |

select only 2.



# GM V4.1- Residential

2. The percentage units achieving good ventilations is given as:

$$\frac{\Sigma(\text{No. of Selected Units for Each Layout} \times \text{Area-Weighted Average Wind Velocity})}{\text{Total Number of Selected Units} \times 0.60\ \text{m/s}} \times 100\%$$

3. Top 5 typical layouts with most units should be included in the simulation (One unit representing each unit type)

# GM V4.1- Residential

## Calculation of the Average Unit Pressure Differential, $\Delta P_{ave}$, under all Analyzed Wind Directions

Example unit has 7 window openings

| | | NORTH | SOUTH | NORTH-EAST | SOUTH-EAST |
|---|---|---|---|---|---|
| Unit: | 1-01 4RM | P [Pa] | P [Pa] | P [Pa] | P [Pa] |
| 1 | Living-Balcony | -0.50 | -2.50 | -1.00 | -2.50 |
| 2 | Dining-Balcony | | | | |
| 3 | Kitchen | | | | |
| 4 | Mbed | 1.50 | -2.50 | -5.00 | -2.50 |
| 5 | Mbed(2) | -1.50 | -2.50 | -3.00 | -1.50 |
| 6 | Mbath | -0.50 | -2.50 | -3.00 | -2.50 |
| 7 | Bed2 | -1.50 | -2.50 | -3.00 | -2.50 |
| 8 | Bed3 | -0.50 | -2.50 | -1.00 | -2.50 |
| 9 | Bed4 | | | | |
| 10 | Bath2 | | | | |
| 11 | WC | | | | |
| 12 | Yard | -0.50 | -2.50 | -3.00 | -2.50 |
| 13 | | | | | |
| 14 | | | | | |
| 15 | | | | | |
| 16 | | | | | |
| +1.5 Pa – (-1.5 Pa) = | | ΔP [Pa] 3.0 | ΔP [Pa] 0.0 | ΔP [Pa] 4.0 | ΔP [Pa] 1.0 |



# GM V4.1- Residential

## Calculation of the Global Pressure Differential, $\Delta P_{ave\ global}$, under all Analyzed Wind Directions

Proposed development has 3 unit types (3RM, 4RM and 5RM) separated out in 7 tower blocks, and the unit pressure differential of all units at the mid building height is shown

This is the $\Delta P_{ave}$

| UNIT | Type | N ΔP [Pa] | S ΔP [Pa] | NE ΔP [Pa] | SE ΔP [Pa] | N+S+NE+SE ΔP [Pa] | N+S+NE+SE ΔP - AVE ΔP [Pa] | Note |
|---|---|---|---|---|---|---|---|---|
| 1-01 | 4RM | 3.00 | 0.00 | 4.00 | 1.00 | 2.00 | -0.69 | |
| 1-02 | 4RM | 1.00 | 1.00 | 8.00 | 0.00 | 2.50 | -0.19 | |
| 1-03 | 5RM | 0.00 | 3.00 | 8.00 | 1.00 | 3.00 | 0.31 | |
| 1-04 | 5RM | 5.00 | 2.00 | 0.00 | 4.00 | 2.75 | 0.06 | Eligible |
| 1-05 | 5RM | 0.00 | 2.00 | 0.00 | 6.00 | 2.00 | -0.69 | |
| 1-06 | 4RM | 4.00 | 1.00 | 0.00 | 1.00 | 1.50 | -1.19 | |
| 1-07 | 4RM | 5.00 | 0.00 | 0.00 | 0.00 | 1.25 | -1.44 | |
| 2-01 | 4RM | 6.00 | 0.00 | 8.00 | 0.20 | 3.55 | 0.86 | |
| 2-02 | 4RM | 4.00 | 3.00 | 10.00 | 0.60 | 4.40 | 1.71 | |
| 2-03 | 5RM | 0.00 | 3.00 | 0.00 | 0.60 | 0.90 | -1.79 | |
| 2-04 | 5RM | 2.00 | 2.00 | 4.00 | 0.40 | 2.10 | -0.59 | |
| 2-05 | 4RM | 0.00 | 5.00 | 0.00 | 0.20 | 1.30 | -1.39 | |
| 2-06 | 5RM | 1.00 | 0.00 | 6.00 | 1.00 | 2.00 | -0.69 | |
| 2-07 | 5RM | 2.00 | 0.00 | 6.00 | 0.40 | 2.10 | -0.59 | |
| 3-01 | 4RM | 4.00 | 0.00 | 2.00 | 0.00 | 1.50 | -1.19 | |
| 3-02 | 4RM | 1.00 | 0.00 | 4.00 | 0.00 | 1.25 | -1.44 | |
| 3-03 | 5RM | 0.00 | 7.00 | 10.00 | 6.00 | 5.75 | 3.06 | |
| 3-04 | 5RM | 4.00 | 6.00 | 2.00 | 6.00 | 4.50 | 1.81 | |
| 3-05 | 5RM | 0.00 | 9.00 | 0.00 | 10.00 | 4.75 | 2.06 | |
| 3-06 | 5RM | 5.00 | 0.00 | 8.00 | 0.00 | 3.25 | 0.56 | |
| 3-07 | 5RM | 3.00 | 1.00 | 4.00 | 0.00 | 2.00 | -0.69 | |
| 4-01 | 4RM | 2.00 | 0.00 | 6.00 | 0.00 | 2.00 | -0.69 | |
| 4-02 | 4RM | 1.50 | 1.00 | 2.00 | 2.00 | 1.63 | -1.06 | |
| 4-03 | 5RM | 0.50 | 7.00 | 2.00 | 16.00 | 6.38 | 3.69 | |
| 4-04 | 5RM | 0.50 | 7.00 | 2.00 | 12.00 | 5.38 | 2.69 | |
| 4-05 | 5RM | 1.00 | 7.00 | 2.00 | 0.00 | 2.50 | -0.19 | Eligible |
| 4-06 | 4RM | 0.00 | 7.00 | 2.00 | 4.00 | 3.25 | 0.56 | |
| 4-07 | 4RM | 0.50 | 5.00 | 6.00 | 4.00 | 3.88 | 1.19 | |

| UNIT | Type | N ΔP [Pa] | S ΔP [Pa] | NE ΔP [Pa] | SE ΔP [Pa] | N+S+NE+SE ΔP [Pa] | N+S+NE+SE ΔP - AVE ΔP [Pa] | Note |
|---|---|---|---|---|---|---|---|---|
| 5-01 | 4RM | 5.00 | 1.00 | 10.00 | 4.00 | 5.00 | 2.31 | |
| 5-02 | 4RM | 0.00 | 2.00 | 4.00 | 10.00 | 4.13 | 1.44 | |
| 5-03 | 4RM | 0.00 | 3.00 | 4.00 | 6.00 | 3.25 | 0.56 | |
| 5-04 | 3RM | 3.00 | 0.50 | 2.00 | 0.00 | 1.38 | -1.31 | |
| 5-05 | 3RM | 3.00 | 0.00 | 10.00 | 2.00 | 3.75 | 1.06 | |
| 5-06 | 3RM | 4.00 | 0.50 | 5.00 | 2.00 | 3.13 | 0.44 | Eligible |
| 6-01 | 4RM | 5.00 | 0.00 | 8.00 | 0.00 | 3.25 | 0.56 | |
| 6-02 | 4RM | 2.00 | 1.00 | 8.00 | 1.00 | 3.00 | 0.31 | |
| 6-03 | 4RM | 0.00 | 1.00 | 2.00 | 6.00 | 2.25 | -0.44 | |
| 6-04 | 4RM | 1.00 | 0.50 | 2.00 | 1.00 | 1.13 | -1.56 | |
| 6-05 | 4RM | 0.00 | 0.50 | 2.00 | 2.00 | 1.13 | -1.56 | |
| 6-06 | 3RM | 4.00 | 0.50 | 0.00 | 2.00 | 1.63 | -1.06 | |
| 6-07 | 3RM | 4.00 | 0.50 | 8.00 | 0.00 | 3.13 | 0.44 | Eligible |
| 6-08 | 3RM | 2.00 | 0.00 | 6.00 | 0.00 | 2.00 | -0.69 | |
| 7-01 | 4RM | 5.00 | 0.00 | 10.00 | 0.50 | 3.88 | 1.19 | |
| 7-02 | 4RM | 3.00 | 0.20 | 8.00 | 2.50 | 3.43 | 0.74 | |
| 7-03 | 4RM | 0.00 | 1.20 | 4.00 | 1.00 | 1.55 | -1.14 | |
| 7-04 | 4RM | 1.00 | 0.40 | 0.00 | 0.50 | 0.48 | -2.21 | |
| 7-05 | 4RM | 0.00 | 0.40 | 2.00 | 0.50 | 0.73 | -1.96 | |
| 7-06 | 3RM | 3.00 | 0.00 | 0.00 | 0.50 | 0.88 | -1.81 | |
| 7-07 | 3RM | 4.00 | 0.20 | 10.00 | 0.00 | 3.55 | 0.86 | |
| 7-08 | 3RM | 3.00 | 0.00 | 8.00 | 0.50 | 2.38 | -0.31 | |
| | | 2.16 | 1.86 | 4.36 | 2.37 | | | |

| N+S+NE+SE 0.9 * AVE ΔP [Pa] | N+S+NE+SE AVE ΔP [Pa] | N+S+NE+SE 1.10 * AVE ΔP [Pa] |
|---|---|---|
| 2.42 | 2.69 | 2.96 |

This is the $\Delta P_{ave\ global}$

# GM V4.1- Residential

| Dwelling Unit Layouts /Types | | No. of Units | Area Weighted Average Wind Velocity |
|---|---|---|---|
| 1 | Typical Layout A | 80 | 0.60 |
| 2 | Typical Layout B | 30 | 0.60 |
| 3 | Typical Layout C | 20 | 0.70 |
| 4 | Typical Layout D | 20 | 0.50 |
| 5 | Typical Layout E | 20 | 0.40 |
| **Total Number of Selected Units :** | | **170** | |
| 6 | Typical Layout F* | 15 | Not included |
| 7 | Typical Layout G* | 15 | Not included |

** Dwelling Unit Layout not selected for simulation*



# GM V4.1- Residential

Percentage of units achieving good natural ventilation is given by:

$$\frac{\Sigma(\text{No. of Selected Units for Each Layout} \times \text{Area-Weighted Average Wind Velocity})}{\text{Total Number of Selected Units} \times 0.60\ \text{m/s}} \times 100\%$$

$$= \frac{80\times0.60+30\times0.60+20\times0.70+20\times 0.5 +20\times0.40}{170\times0.60} \times 100\%$$

$$= 96\%$$

Points scored for 1-2(a) Option 1 = 0.2 x 96% = 19.2 points

# Sequence of simulation

1. 3D CAD generation + Boundary Condition Specification + Meshing

2. Macro Level CFD Simulation

3. Obtain pressure and velocity plots at macro level to select units to study

4. Add in units into the overall 3D CAD model in (1)

6. Micro Level CFD simulation

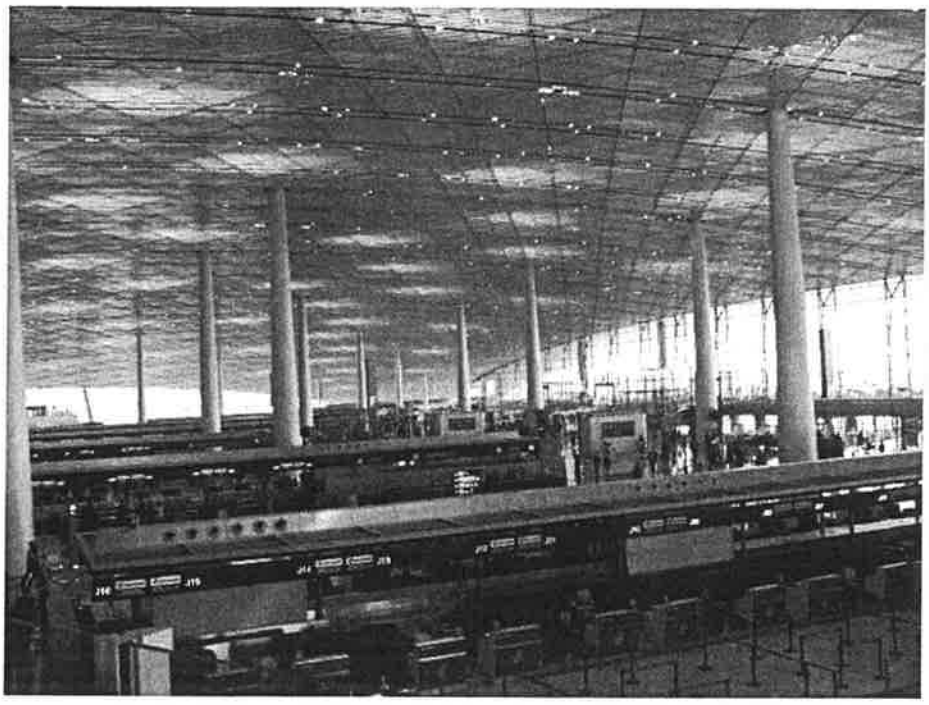
7. Determine average area weighted velocity for units

8. If CFD requirement (70% of selected units with good NV performance) is achieved, end study. If not, make changes to design and re-run. Restart from either (2) or (6)

9. Present result to BCA



# Solar and Daylighting



# Solar and Daylighting

Daylight penetration is usually accompanied with solar heat gain. A balance between excessive heat gain and sufficient daylighting has to be achieved. "Cool daylighting" reduces the need for electric lighting and space cooling, through:

- Exterior shading devices;
- Carefully placed windows;
- Low-transmittance glass;
- Window blinds;
- Paint and fabric colors



# Solar Simulation- Why?

<u>Externally</u>

- Identifies facades that receive excessive radiation
- Design of shading devices, planters, balconies, fins, etc in reducing radiation.

# Solar Simulation- Why?

Internally

- Adequate indoor daylighting
- Efficiency of lighting system/lighting design.
- Predict if there are glare problems



# Simulation Inputs

- Building data- Plans and elevation, façade materials, shading details, orientation, location, etc.
- Material/lighting properties - Eg. U values, ETTV, IES specifications, etc.
- Site survey - determine if surrounding buildings or objects will have shading effect on development, etc.

# Simulation Inputs

- Domain should be ~2 times in radius the length of the development.
- Walls and partitions must be modeled.
- Simulations carried out for 22nd of Dec, Mar, Jun and Sept at 10am and 4pm.
- For daylighting analysis: Simulations under Overcast sky condition at 1pm with working pane at 0.7m from ground.

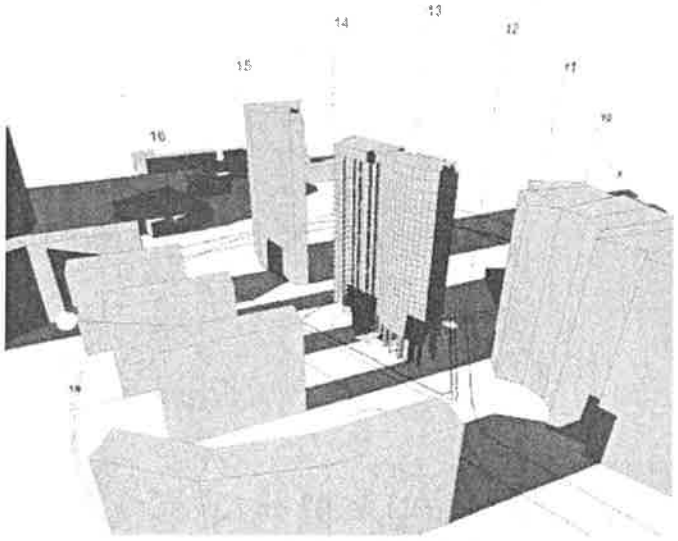


# Simulation Inputs

- For glare analysis: simulate under Sunny sky
- Results to consist at least 2 viewpoints (1.25m from ground) for each façade orientation and decided from Sunpath analysis to capture worst case condition.
- The viewpoints at least 120 degrees measured from the centre of each viewpoint.

# 1. Output- Sun Path Diagram

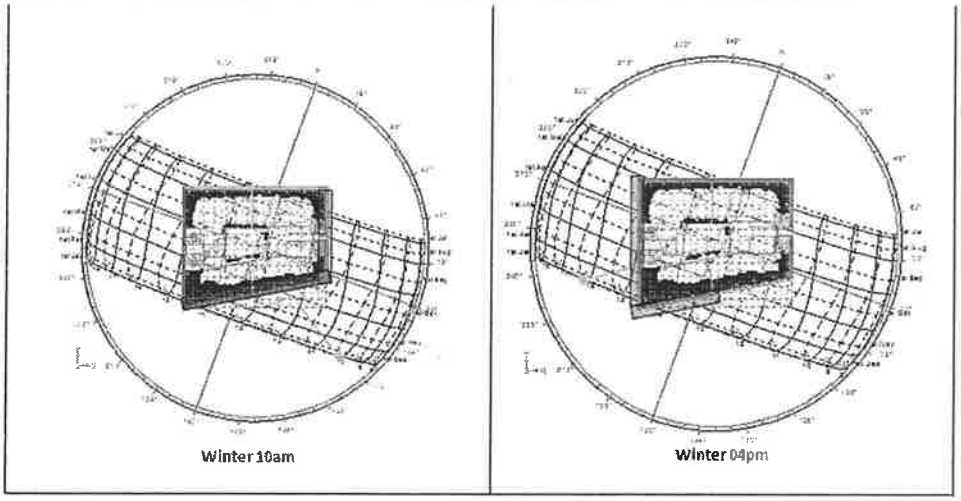
- Determine the extent of self-shading and overshadowing.
- Evaluate if exposure to sun is suitable for defined space usage.



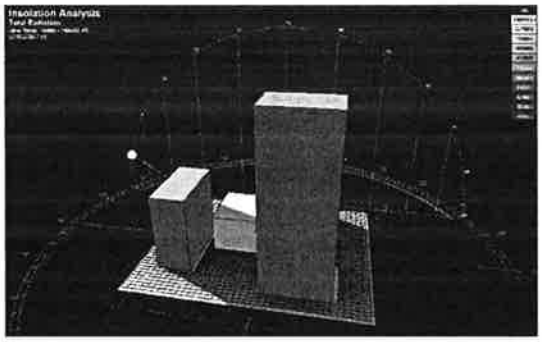


# 1. Output- Sun Path Diagram

- Determine the viewpoint locations for the façade affected with glare.



# 2. Output- Solar radiation




Solar radiation results helps in:

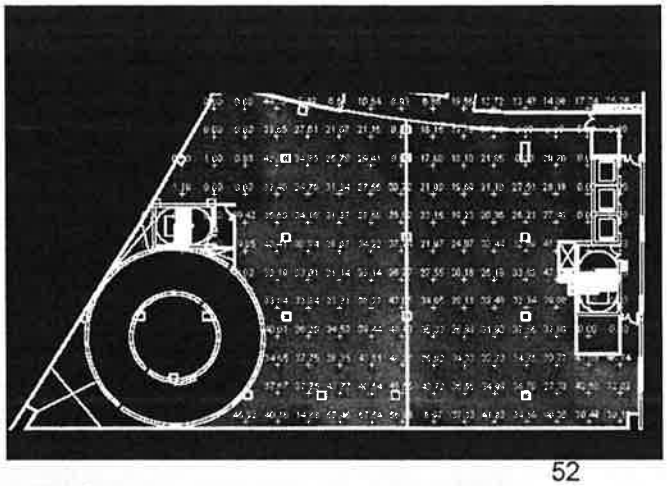
- Selection of facades to protect against heat transfer so that there will not be over/ under protection (eg. Thermal paints, Low-E glass)
- Placement of solar panels
- Locating sun decks/ pools





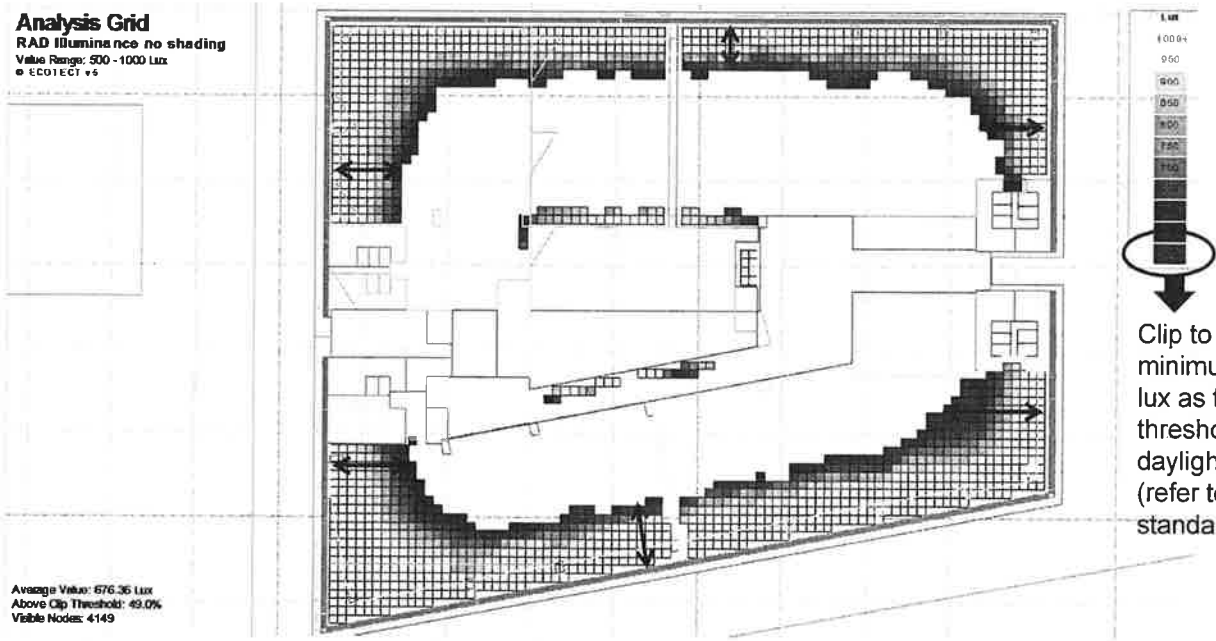
# 3. Output- Daylight illuminance

- Available light levels in lux or daylight factor in a space.
- Determine if luminance is sufficient for task and if artificial lighting is required
- Assist in tenancy planning.



# 3. Output- Daylight illuminance

- For GM V4 has to measure depth of the daylight penetration




Clip to minimum 500 lux as the threshold for daylight level. (refer to the standard)



# 3. Output- Daylight illuminance

| Average DF | Appearance | Energy implications |
|---|---|---|
| < 2% | Room looks gloomy | Electric lighting needed most of the day |
| 2% to 5% | Predominantly daylit appearance, but supplementary artificial lighting is needed. | Good balance between lighting and thermal aspects |
| > 5% | Room appears stongly daylit | Daytime electric lightin rarely needed, but potential for thermal problems due to overheating |

Ratio of the illuminance at a particular point within an enclosure to the simultaneous unobstructed outdoor illuminance under the same sky conditions

# 3. Range of illuminances

To achieve visual comfort, certain illuminance level should be achieved:

| Type of Activity | Illuminance Category | Lux | Foot-candles | Reference Work Plane |
|---|---|---|---|---|
| Public spaces with dark surroundings | A | 20 - 30 - 50 | 2 - 3 - 5 | |
| Simple orientation for short temporary visits | B | 50 - 75 - 100 | 5 - 7.5 - 10 | General Lighting throughout spaces |
| Working spaces where visual tasks are only occasionally performed | C | 100 - 150 - 200 | 10 - 15 - 20 | |
| Performance of visual task of high contrast or large size | D | 200 - 300 - 500 | 20 - 35 - 50 | |
| Performance of visual task of medium contrast or small size | E | 500 - 750 - 1000 | 50 - 75 - 100 | Illuminance on task |
| Performance of visual task of low contrast or very small size over | F | 1000 - 1500 - 2000 | 100 - 150 - 200 | |
| Performance of visual task of low contrast or very small size over a prolonged period | G | 2000 - 3000 - 5000 | 200 - 300 - 500 | Illuminance on task obtained by a combination of general and task lighting |

**Illuminance** is the total luminous flux incident on a surface, per unit area. (Unit: LUX)

IES standard

# 3. Range of illuminances

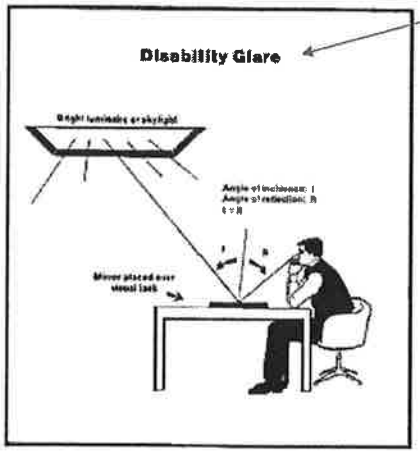
## Residential

| Performance Mandates | Sub-parameters | Recommended Range/Limits | Source of Information |
|---|---|---|---|
| Visual | Illuminance Level | 75 lux – 150 lux (general living room) | CP 38 |

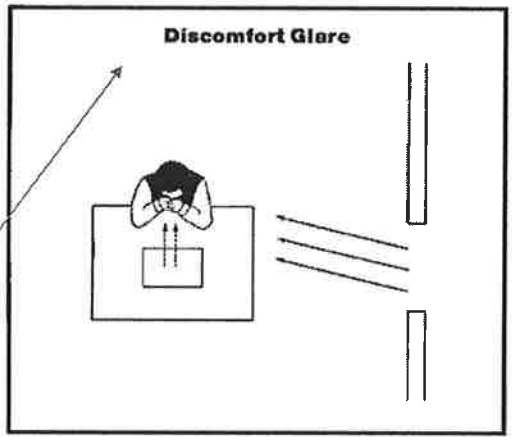
## Non- Residential

| Performance Mandates | Sub-parameters | Recommended Range/Limits | Source of Information |
|---|---|---|---|
| Visual | Illuminance Level | 100 lux – 200 lux (common areas)<br>300 lux – 750 lux (offices, workstations) | SS531 – Code of Practices for Lighting of Work Places |

# 4. Glare




reduced visibility of a target due to the presence of a light source elsewhere in the field



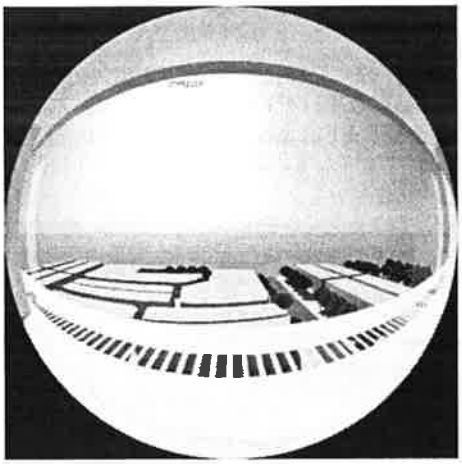

sensation one experiences when the overall illumination is too bright

# 4. Outputs- Glare

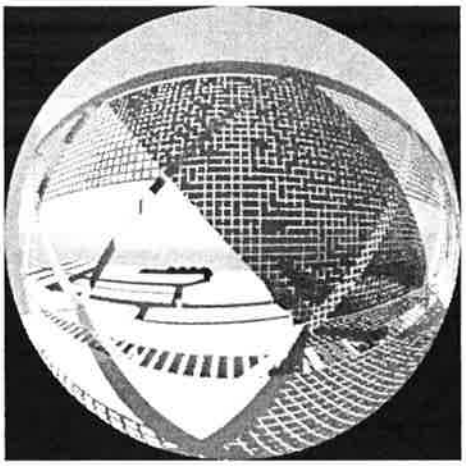
- Assess the level of acceptability of glare as a result of daylight through facade.
- Benchmark against reference guides to determine if sun shades are required.

| Zone | Region | DGI |
|---|---|---|
| Discomfort Zone | intolerable | >28 |
| | just intolerable | 28 |
| | uncomfortable | 26 |
| | just uncomfortable | 24 |
| Comfort Zone | acceptable | 22 |
| | just acceptable | 20 |
| | noticeable | 18 |
| | just perceptible | 16 |

# 4. Outputs- Glare



No shading devices
UGR = 48.15
(discomfort glare)



With shading devices
UGR = 0
(not affected with glare)

| File Name | Winter_04pm_cam02 | | |
|---|---|---|---|
| Glare Threshold = 5523.13 cd/m² | | | |
| View Angle (deg.) | Guth Visual Comfort Probability | CIE Glare Index (Einhorn) | Unified Glare Rating |
| 60 | 100 | 0 | 0 |
| 50 | 100 | 0 | 0 |
| 40 | 100 | 0 | 0 |
| 30 | 100 | 0 | 0 |
| 20 | 100 | 0 | 0 |
| 10 | 100 | 0 | 0 |
| 0 | 100 | 0 | 0 |
| -10 | 100 | 0 | 0 |
| -20 | 100 | 0 | 0 |
| -30 | 100 | 0 | 0 |
| -40 | 100 | 0 | 0 |
| -50 | 100 | 0 | 0 |
| -60 | 100 | 0 | 0 |
| aver | 100.00 | 0.00 | 0.00 |
| min | 100.00 | 0 | 0 |
| max | 100 | 0 | 0 |

**Guth Visual Comfort Probability (GVP)**
→ Percentage of people who will be satisfied with the condition.
If the area is not affected with glare : GVP 100%
**CIE Glare Index and Unified Glare Rating (UGR)**
→ Standard index for discomfort glare



# 4. Glare Index

## Residential

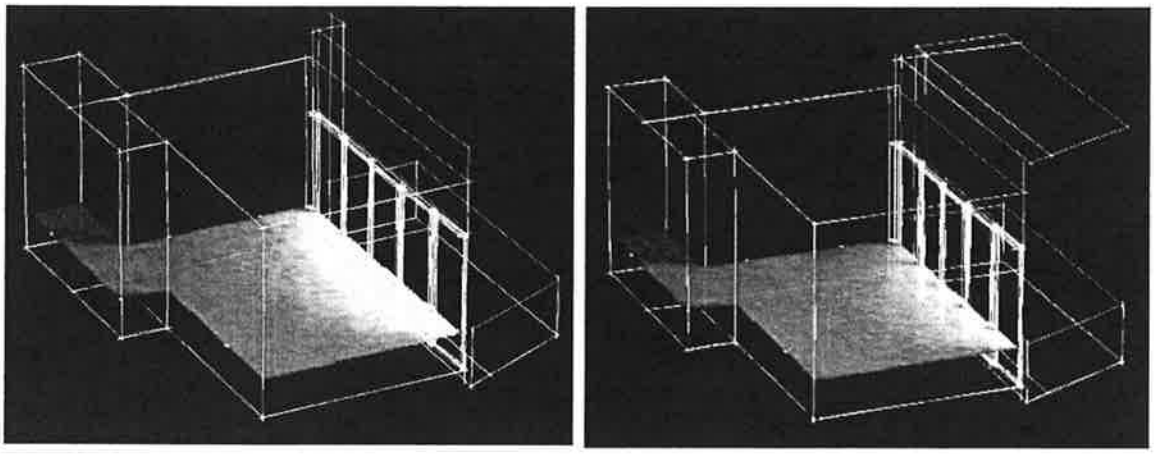
| Performance Mandates | Sub-parameters | Recommended Range/Limits | Source of Information |
|---|---|---|---|
| Visual | UGR (Unified Glare Rating) | 22 (dining room)<br>22-28<br>(Common areas) | SS531 – Code of Practices for Lighting of Work Places |

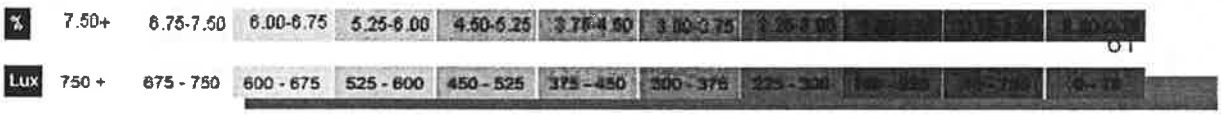
## Non- Residential

| Performance Mandates | Sub-parameters | Recommended Range/Limits | Source of Information |
|---|---|---|---|
| Visual | UGR (Unified Glare Rating) | 16 – 25<br>(Offices, workstations)<br>22-28<br>(Common areas) | SS531 – Code of Practices for Lighting of Work Places |

# 5. Sun shade effectiveness

By comparing illuminance with and without the sunshade to determine the improvements made by the sunshades






# Green Mark V4

## Residential Building

**RB 1-3 Daylighting**

Encourage design that optimises the use of effective daylighting to reduce energy use for artificial lighting.

(a) Use of daylight and glare simulation analysis to verify the adequacy of ambient lighting levels in all dwelling unit's living and dining areas. The ambient lighting levels should meet the illuminance level and Unified Glare Rating (UGR) stated in SS CP 38 – Code of Practice for Artificial lighting in Buildings and SS 531:Part 1:2006 – Code of Practice for Lighting of Work Places.

(b) Daylighting in the following areas :

(i) Lift lobbies and corridors
(ii) Staircases
(iii) Car parks

Extent of coverage: At least 80% of the units with daylighting provisions meet the minimum illuminance level and are within the acceptable glare exposure.

Points scored based on the extent of perimeter daylight zones

| Distance from the Façade Perimeters (m) | Points Allocation |
|---|---|
| ≥ 3.0 | 1 |
| 4.0 – 5.0 | 2 |
| > 5.0 | 3 |

(Up to 3 points)

Extent of Coverage : At least 80% of the applicable areas

1 point
1 point
1 point

# Green Mark V4

## Non-Residential Building

**NRB 1-5 Daylighting**

Encourage design that optimises the use of effective daylighting to reduce energy use for artificial lighting.

(a) Use of daylighting and glare simulation analysis to verify the adequacy of ambient lighting levels in meeting the illuminance level and Unified Glare Rating (UGR) stated in SS 531:Part 1:2006 – Code of Practice for Lighting of Work Places.

Extent of coverage: At least 75% of the units with daylighting provisions meet the minimum illuminance level and are within the acceptable glare exposure.

Points scored based on the extent of perimeter daylight zones

| Distance from the Façade Perimeters (m) | Points Allocation |
|---|---|
| ≥ 3.0 | 1 |
| 5.0 – 5.0 | 2 |
| > 5.0 | 3 |

(Up to 3 points)

(b) Daylighting for the following common areas:

(i) Toilets
(ii) Staircases
(iii) Corridors
(iv) Lift Lobbies
(v) Atriums
(vi) Carparks

Extent of Coverage : At least 80 % of each applicable area

0.5 point each

(Up to 3 points)

Note (5) : All daylit areas must be integrated with automatic electric lighting control system.



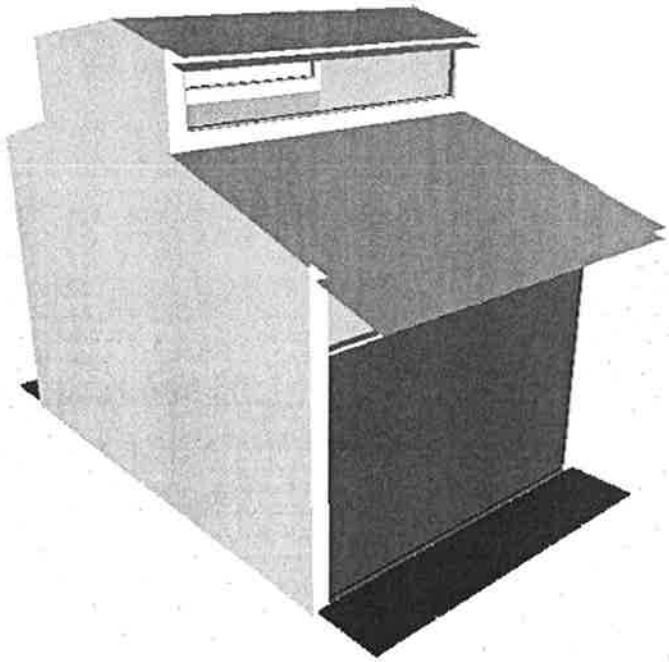
# Green Mark V4

Computation on qualifying units:

The percentage of units achieving effective daylighting is given by:

$$\frac{\text{Units achieving minimum required illuminance level}}{\text{Total number of units}} \times 100\%$$

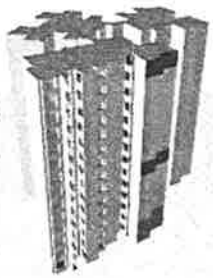
# Thermal Simulations





# Outputs

- Room temperatures
- Surface temperatures
- Humidity
- Condensation risk
- High heat transfer materials
- Thermal comfort



# Case Study

- Determine thermal comfort of penthouse unit

Building geometry

Input U-value of materials, location of building, solar heat flux, cooling load, etc

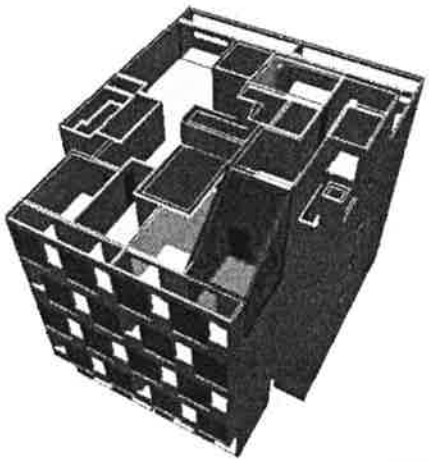


Table 1: Conductance values for 150mm RC wall.

| Element | Thickness (mm) | Conductance (W/m²C) |
|---|---|---|
| Plaster | 5 | 0.42 |
| Concrete | 150 | 0.30 |
| Plaster | 5 | 0.42 |
| Overall conductance (W/m²C) | | 1.909 |

Table 2: Conductance values for 300mm RC wall

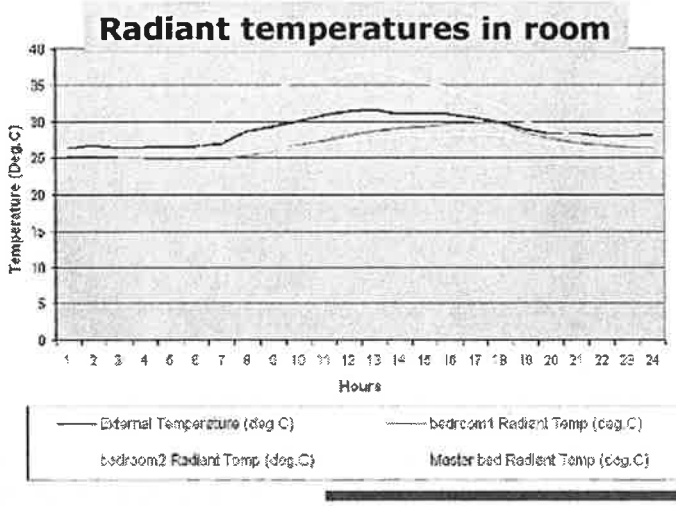
| Element | Thickness (mm) | Conductance (W/m²C) |
|---|---|---|
| Plaster | 5 | 0.42 |
| Concrete | 300 | 0.30 |
| Plaster | 5 | 0.42 |
| Overall conductance (W/m²C) | | 0.977 |

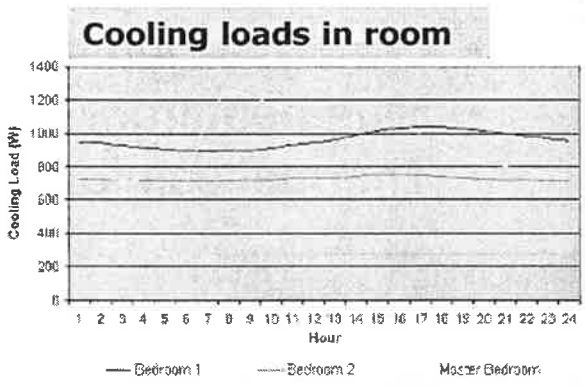
Table 3: Conductance values for Aluminum windowframe

| Element | Thickness (mm) | Conductance (W/m²C) |
|---|---|---|
| Aluminum | 6 | 204 |
| Overall conductance (W/m²C) | | 999.999 |

# Case Study

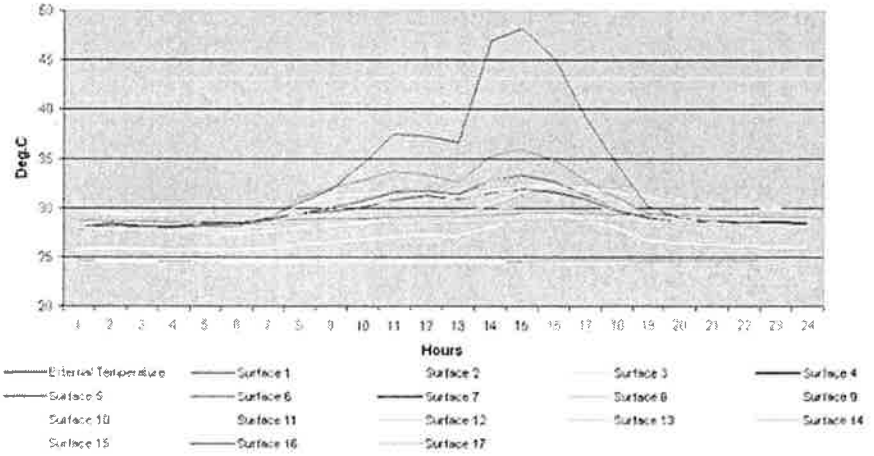
- Internal room temperatures, cooling loads



# Case Study

- Surface temperatures of materials

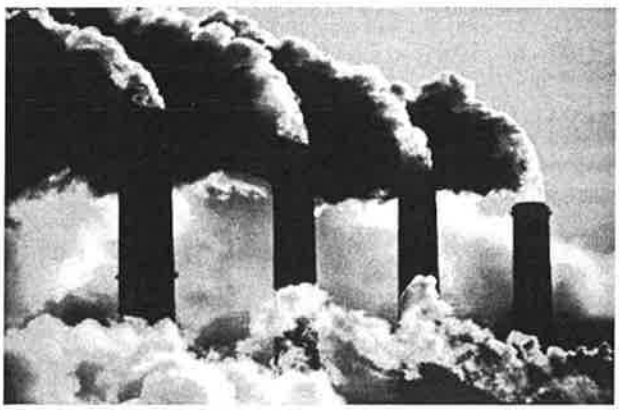



| | | | | |
|---|---|---|---|---|
| Surface 1: 150 RC ext wall | Surface 2: 150 RC ext wall | Surface 3: 150 RC ext wall | Surface 4: 150 RC ext wall | Surface 5: Metal roof |
| Surface 6: Concrete roof | Surface 7: 150 RC ext wall | Surface 8: 150RC wall | Surface 9: Low E glass sliding door | Surface 10: Alum frame |
| Surface 11: Plasterboard int wall | Surface 12: Plasterboard int wall | Surface 13: Plasterboard int wall | Surface 14:Wood Window frame | Surface 15: Wood Window panel |
| Surface 16: 150 RC ext wall | Surface 17: 150 RC ext wall | | | |

➡ **Allows high heat materials to be substituted or protected**



# Embodied Carbon





# Embodied Carbon

- A measure of the carbon ($CO_2$) released when a product is manufactured, shipped to a site and installed.
- 20:80 rule
- 20% from manufacture, transportation and assembly of construction materials
- 80% from Operation and Maintenance
- Some LCA softwares incorporates carbon calculations

http://buildcarbonneutral.org/



# Conclusions

- A building's in-use performance may be predicted even before it is built.
- Predicting its performance then allows us to decide if changes are needed and what should be changed.
- Simulations are better used as a design tool than as a verification tool.

# Its cheaper to simulate than to build the wrong building

**The future** http://usa.autodesk.com/adsk/servlet/item?id=10262483&siteID=123112