Passive Cooling for Green Building Design in the Tropics

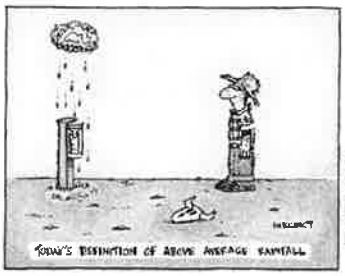
Presented by
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Vice President,
Sustainable Development Unit
Jurong Consultants Pte Ltd
Singapore

Mr Tan Szue Hann
Deputy Head

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Lush Beach Sands, abundant rainfall, rain forests, sun bathing, coconut trees and many more....









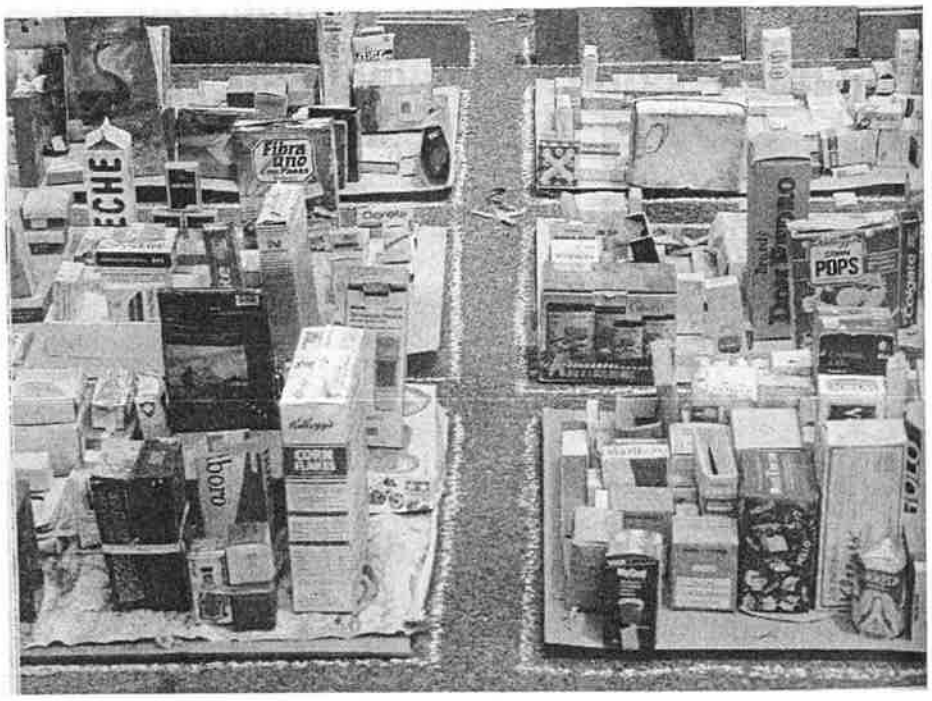




Tropical Climate – An Introduction

- ✓ Tropical zone is defined as the area of water between the 23.5° N and 23.5° S latitudes.
- ✓ This zone houses about 40% of the land surface of the earth and accommodates more than 50% of the total world population…
- ✓ Typically, a flat pitch kind of a HOT and HUMID climate…. With some minor 10% variations here and there..
- ✓ Very mild or tolerable seasonal changes… no huge variations.. .. Very minor extremities…. A rather reasonably stable climatic condition…
- ✓ Well, that sounds very good… as designers would very well know what they are handling and the complexity reduces when the number of inherent parameters to consider reduce as well..

What is a tropical context?



Some unique points on Singapore!



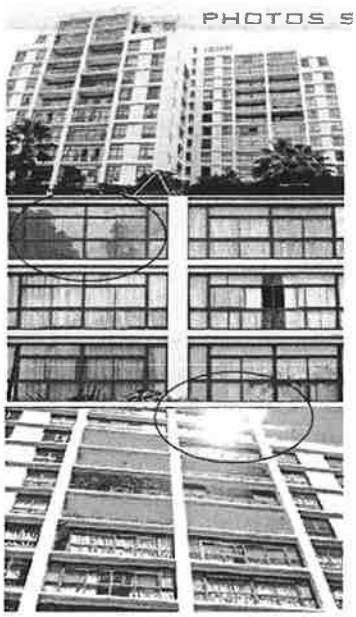
Do you see screened facades..



Can you guess what type of a building this is..

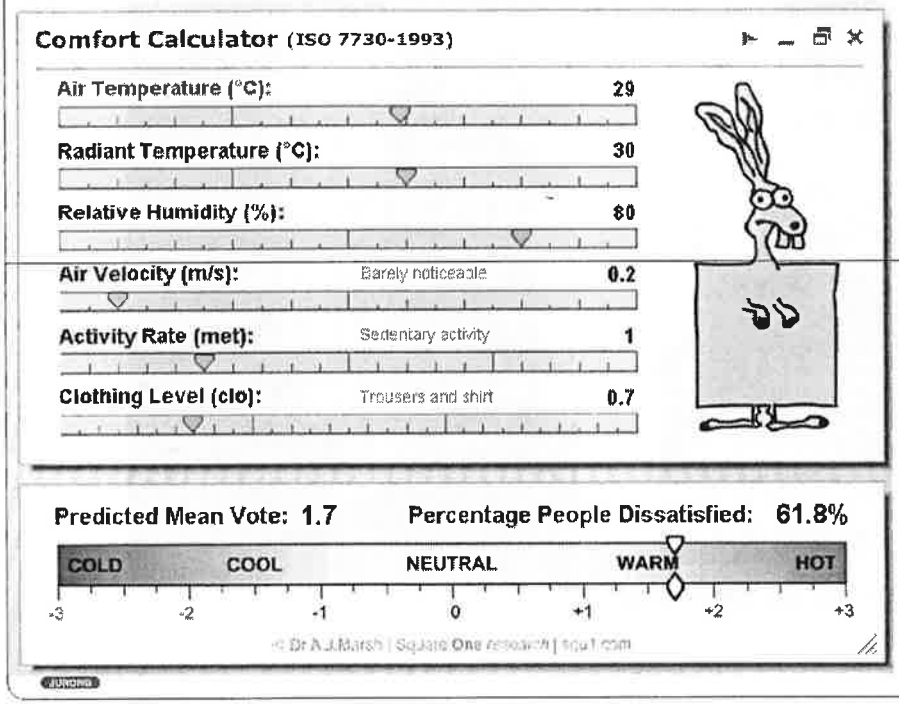




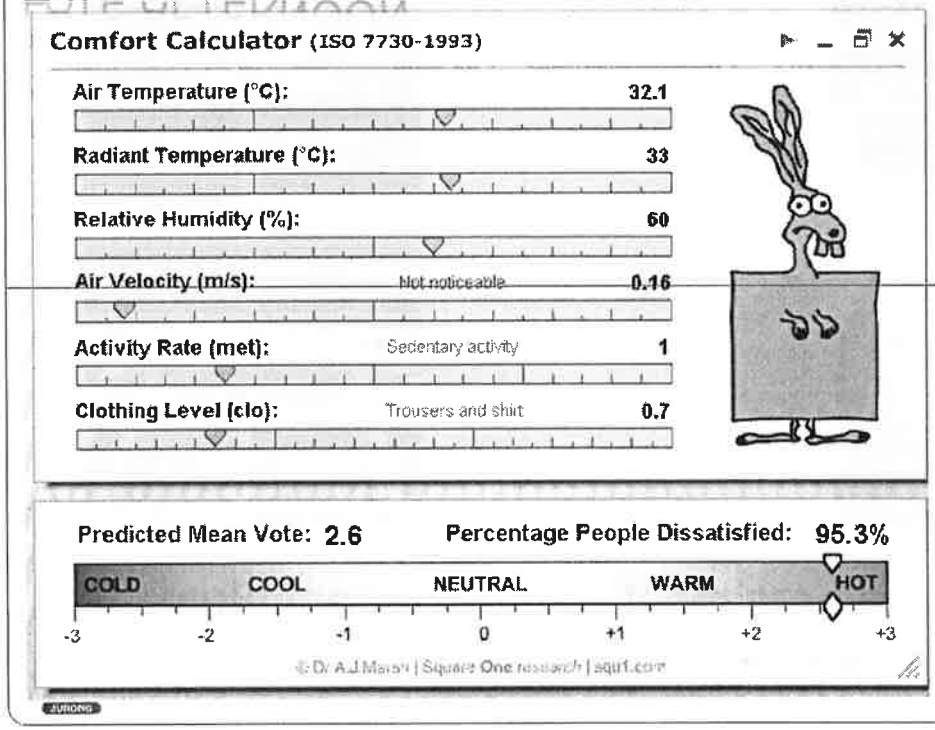


Situations where most of the condominium windows are curtained!

COMFORT CALCULATOR FOR A NATURALLY VENTILATED SPACE
EARLY MORNING



COMFORT CALCULATOR FOR A NATURALLY VENTILATED SPACE
LATE AFTERNOON



- Heat and humidity all around the year
- Torrential rainfall
- Very low diurnal variation change of temp and humidity.
- High soil temperatures (especially so in Singapore)
- Low wind speeds (an island average of 3 m/s)

What is unique about tropics?

- Very high humidity levels coupled with low wind speeds.. Evaporative cooling is ineffective provide pool of water for wind to flow through. Does not work as wind speed is low.
- Earth cooling does not work as the earth temperatures are higher than the average air temperatures.. 30 m below ground is still 28 – 30 deg C.
- Night Ventilation through spaces brings in heat as well as humidity along.. So natural ventilation / even purging as a method to respond to environment is not assuring effectiveness..
- We could not opt for a large thermal mass, as our diurnal variation is very small...
- As a result of this, almost 80% of our buildings succumb to air conditioning..

How far could we go passive?



- So… what am I trying to say here..
- Standard solutions universally applied to achieve climatologically responsive architecture might not work….
- China's green attempt…

http://www.iht.com/articles/2007/02/14/news/green.php

What am I doing right now.. What is my topic for discussion?

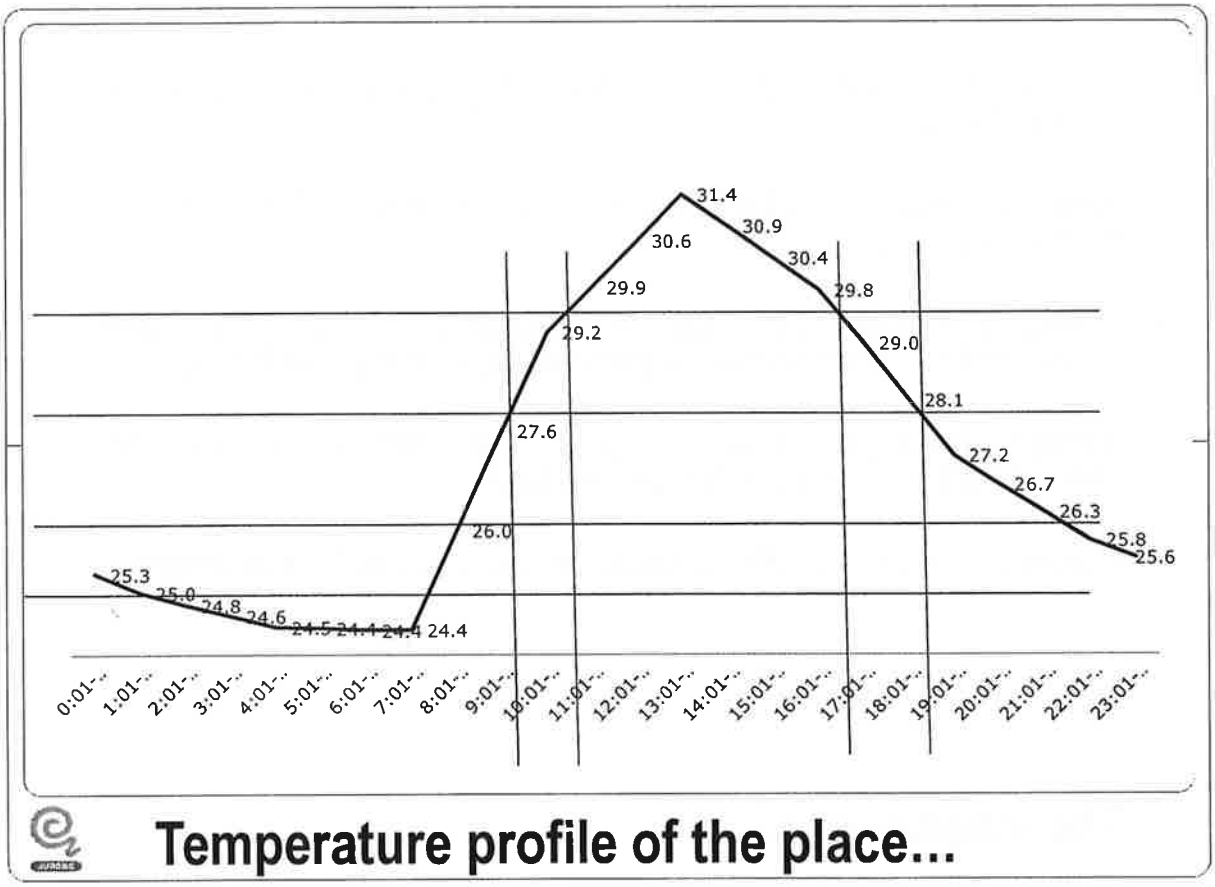
PASSIVE COOLING STRATEGIES

HOW TO ATTEMPT INCORPORATION OF PASSIVE STRAGEGIES IN A TROPICAL BUILDING?

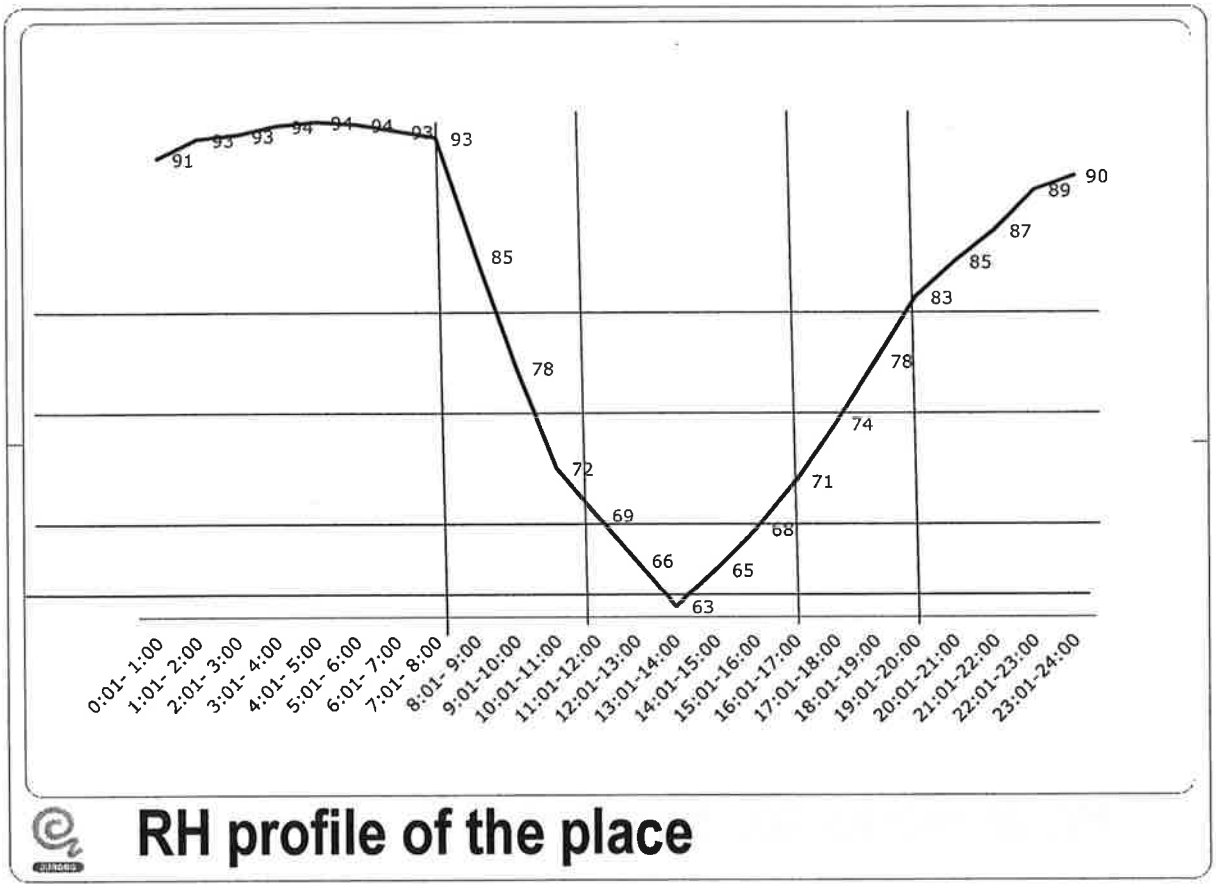
- Climate conscious design... is driven highly by the magical word, "CONTEXTUALITY"
- Appropriateness of solutions to the right context... That's the magic for the tropics...
- Multidimensionality of problems is evident in each of the above mentioned key environmental parameters under consideration...
- Today's discussion was to highlight the multi-dimensionality of climatic factors... in the tropical countries..
- However, serious climatic considerations seem to be still lacking

The magical word..

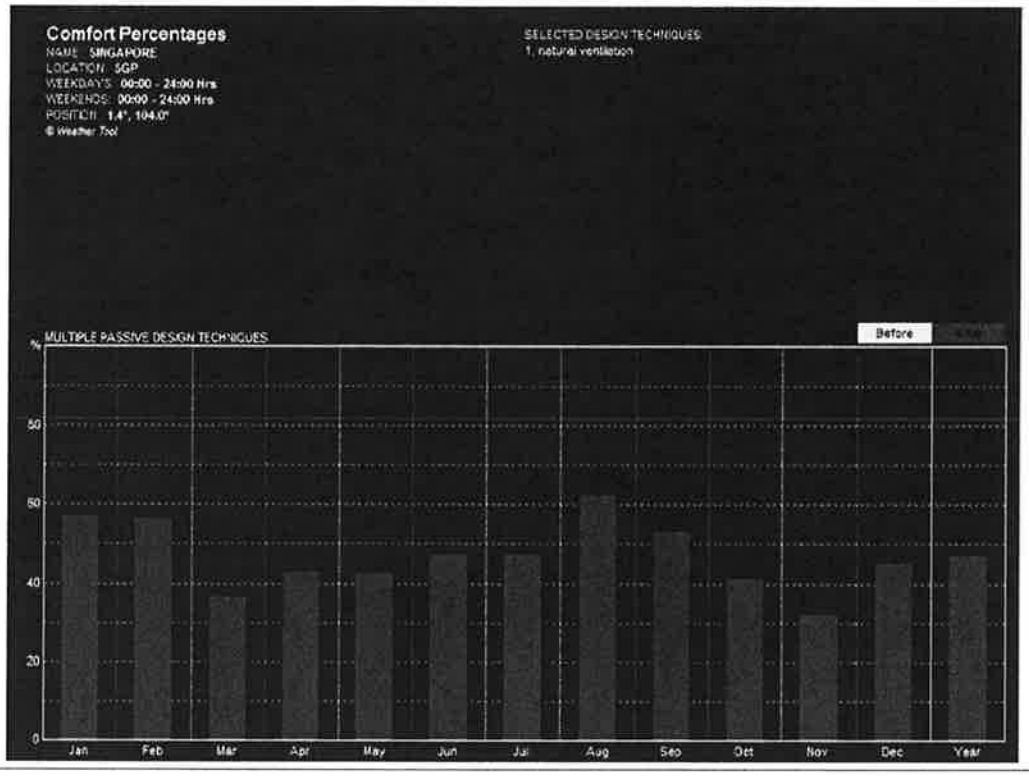
What works for Singapore?



Temperature profile of the place...



RH profile of the place



Which passive strategy contributes the most to Singapore!

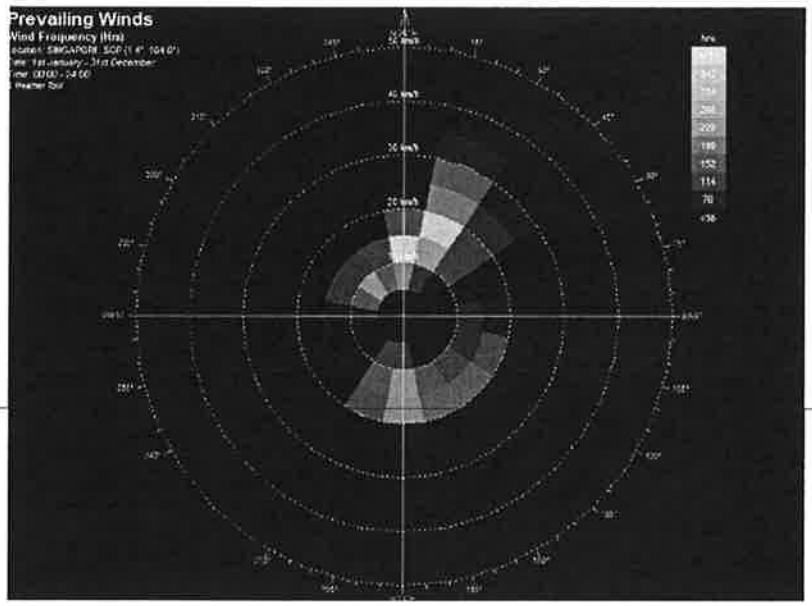
What makes Natural Ventilation work?

Natural ventilation is dependent on three parameters

- Wind velocity
  - Wind ventilation is not effective unless wind speed is in excess of 2.5 m/s
- Wind direction
  - Wind direction changes on a daily basis or seasonal basis, so you design for the majority of the year.
- Temperature difference
  - As the temperature difference increases, the density of air decreases, air rises.
  - Temp. difference between inside and outside of the building, and between different areas of the building, create pressure differences and in turn air movement. (STACK EFFECT)

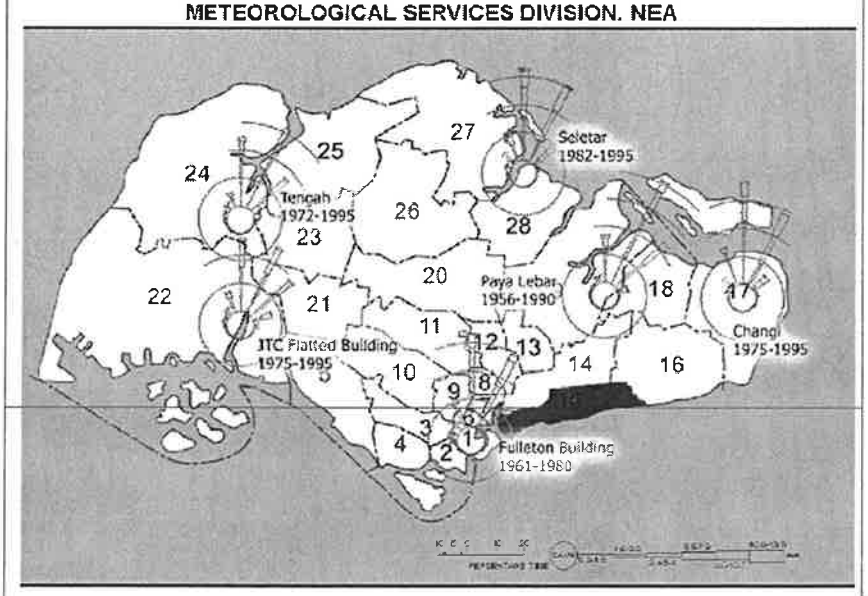
Parameters that affect natural ventilation

What information you need to assess natural ventilation potential in a space...



Wind rose of a place

The above one is from Singapore suggesting that the wind is predominantly from NE and S SW



Wind rose for Singapore

Wind statistics for KL			
Month	Predominant wind direction	Secondary wind direction	Wind speed
January	North	NW/SW	3.12
February	Noth	NW/W	3.5
March	North	NW	2.2
April	North	NW/S	2.2
May	North	South	3.12
June	Noth	South/NW	3.12
July	North	South	3.5
August	North	NW/S	3.5
September	North	S/NW	3.12
October	Noth	NW	2.7
November	North	NW	2.7
December	North	NW	2.2

Monthly wind statistics of the place...

How do we assess An internal space for natural ventilation

Table C3.4: 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

The prescribed wind directions and relevant wind speeds for Green mark version 4.1

1. BCA Green Mark Platinum Criteria for Naturally ventilated Spaces: Pre requisite for Residential Buildings (Version 4.1)

To be eligible for Green Mark Platinum rating, it is a requirement to use ventilation simulation software to identify the most effective building design and layout.

The simulation results and the recommendations derived are to be implemented to ensure good natural ventilation. A minimum 70% of the typical units should have an area weighted average wind velocity of 0.6m/s.

Other than dwelling units, common areas like staircases and lobbies (excluding those that are located in basement areas) should also be designed to be naturally ventilated (i.e. to provide operable windows or other openings with aggregate area of not less than 5% of the floor areas or space required to be ventilated (Only for residential buildings)

Methodology to Assess Thermal Comfort

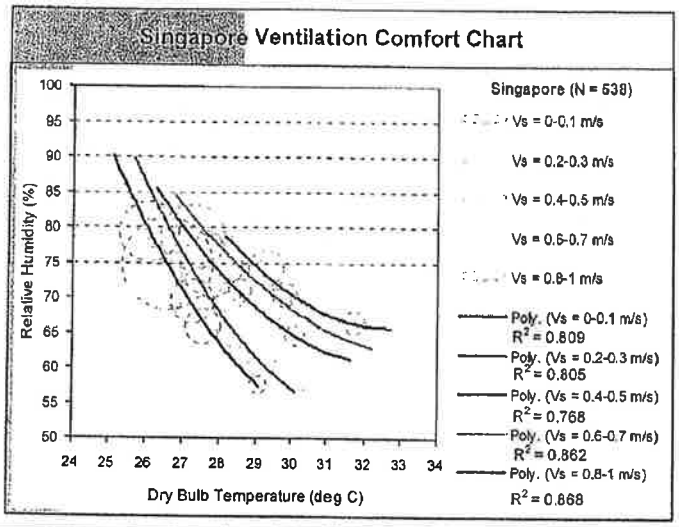
BCA green mark platinum criteria for naturally ventilated spaces
Residential Buildings in the absence of simulations

- 0.5 point for every 10 % of units with window openings facing north and south directions
- 0.5 point for every 10% of living rooms and bedrooms designed with true cross ventilation
- Points scored = 0.5 x (% rooms/10) (Up to 8 points)

BCA green mark platinum criteria for naturally ventilated spaces
Pre-requisites for Non – residential buildings

- To be eligible for Green Mark Platinum rating, it is a requirement to use ventilation simulation modeling and analysis to identify the most effective building design and layout, subject to a minimum area of naturally ventilated spaces
- The simulation results and the recommendations derived are to be implemented to ensure good natural ventilation

1. Prof. Wong's study results



Degrees C	25	26	27	28	29	30	31	32	33	34	35
Recommended Wind Speed m/s	0	0	0-0.31	0-0.65	0-1	0.26-1.35	0.61-1.69	0.96-2.04	1.30-2.38	1.65-2.73	1.99-3.08

Methodology to Assess Thermal Comfort due to natural ventilation

2. Tropical Summer Index:

Tropical Summer Index is a comfort index derived especially for hot humid and hot dry tropical and sub-tropical climates around this region.

Tropical Summer Index is defined by the equation:

$$TSI = 0.745t_a + 0.308t_w - 2v + 0.841$$

Ta = Dry Bulb Temperature , Tw = Wet bulb temperature and v= wind velocity

Methodology to Assess Thermal Comfort

3. Singapore Index

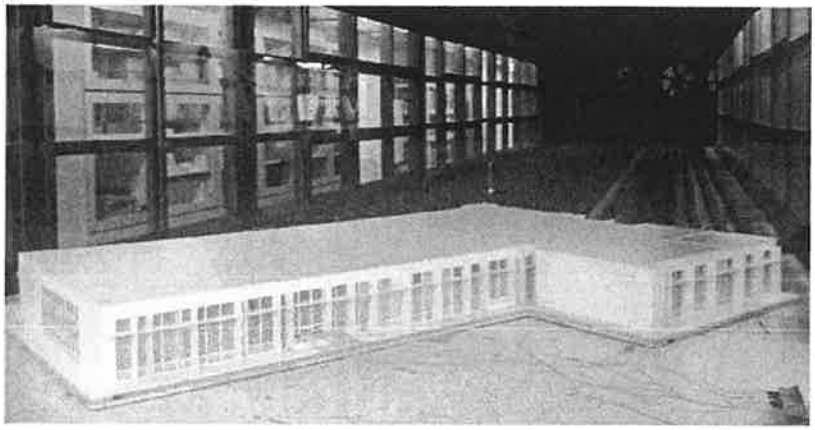
The warm and humid Singapore climate has been described in relation to the overall thermal sensations of fully acclimatized subjects through Singapore index.

$$SingaporeI\ ndex = 0.447t + 0.553tw - 0.231v^{1/2}$$

t = Dry Bulb Temperature , tw = Wet bulb temperature and v= wind velocity in feet per min

Methodology to Assess Thermal Comfort

HOW TO STUDY/ASSESS NATURAL VENTILATION POTENTIAL FOR A PROJECT



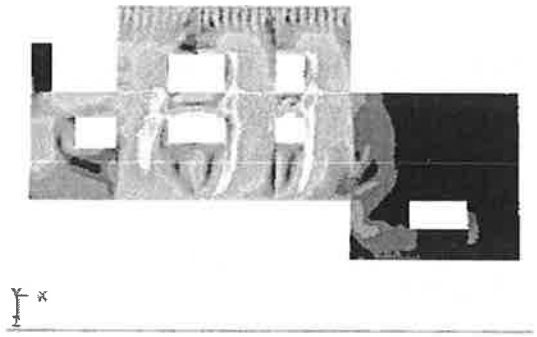
WIND TUNNEL STUDIES

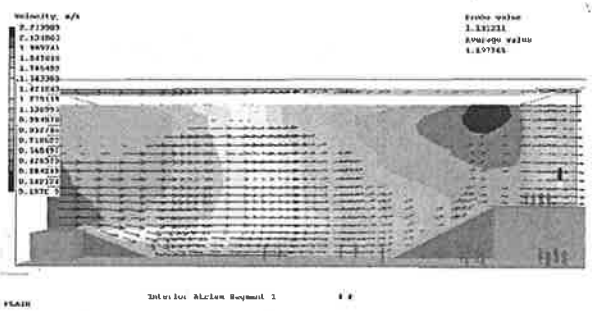
Software
- Vasari
- Phoenix
- Numeca
- Ansys

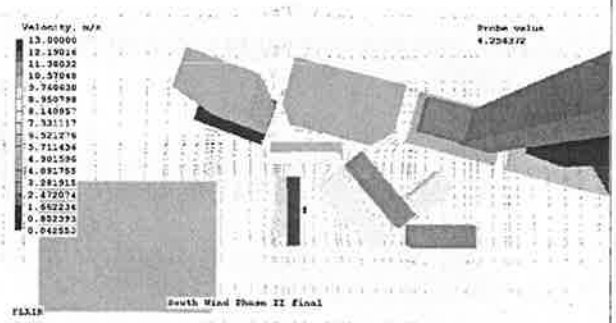
} wind simulation

Ecotect - solar modelling and daylighting

IES - solar modeling, daylighting and energy modeling







CFD STUDIES (BOTH EXTERNAL AND INTERNAL)

PASSIVE COOLING STRATEGIES

EVAPORATIVE COOLING POTENTIAL FOR TROPICAL CLIMATES

- ROOF SPRINKLING SYSTEMS
  - FOR FLAT ROOF SURFACES COOLED BY MISTING SPRAY HEADS THAT COVER THE ROOF OF THE BUILDING.
  - WHEN THE MIST EVAPORATES, IT ABSORBS LARGE AMOUNTS OF HEAT.
  - MORE SUITABLE FOR HOT AND ARID AREAS
- ROOF PONDS – ONLY SUITABLE WHEN WET BULB LOWER THAN 20 DEG C
- MOVING WATER FILM – FLOW OF A WATER FILM OVER THE ROOF SURFACE
  - EVAPORATION PROCESS ENHANCES WITH THE INCREASE IN THE RELATIVE VELOCITY BETWEEN THE AIR AND THE WATER SURFACE
  - THE COOLER WATER IS STORED AND THEN CIRCULATED INSIDE THE BUILDING SPACE, COOLING IT.
  - THE CONDITION IS THAT THE ROOF TEMPERATURE SHOULD BE MUCH HIGHER THAN THE WET-BULB TEMPERATURE OF THE AMBIENT AIR.

PASSIVE INDIRECT EVAPORATIVE SYSTEMS

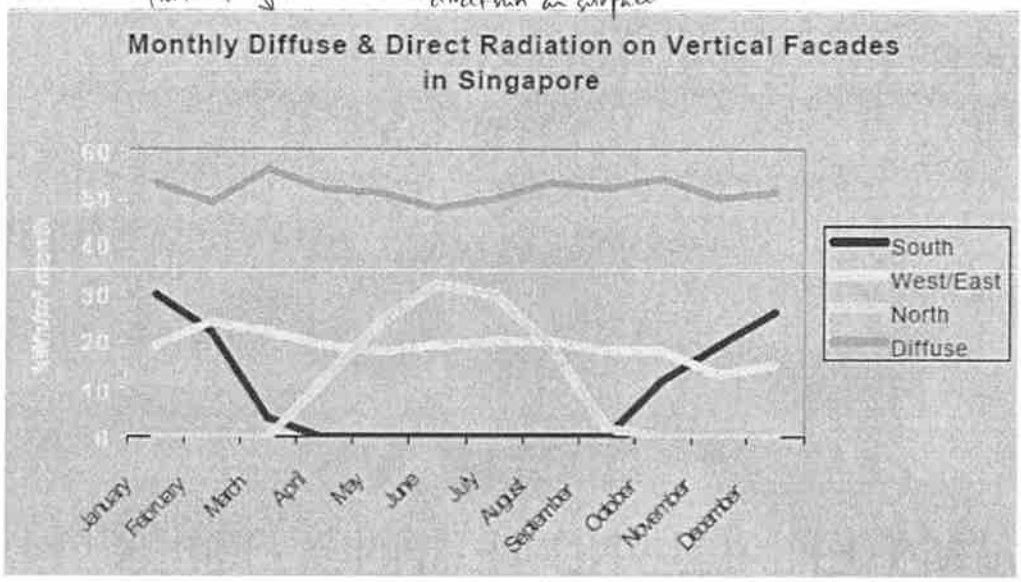
PASSIVE COOLING STRATEGIES

EFECTIVE HEAT ATTENUATION FROM THE FACADES

Radiation profile in Singapore...

Heat reflected from surface

direct sun on surface



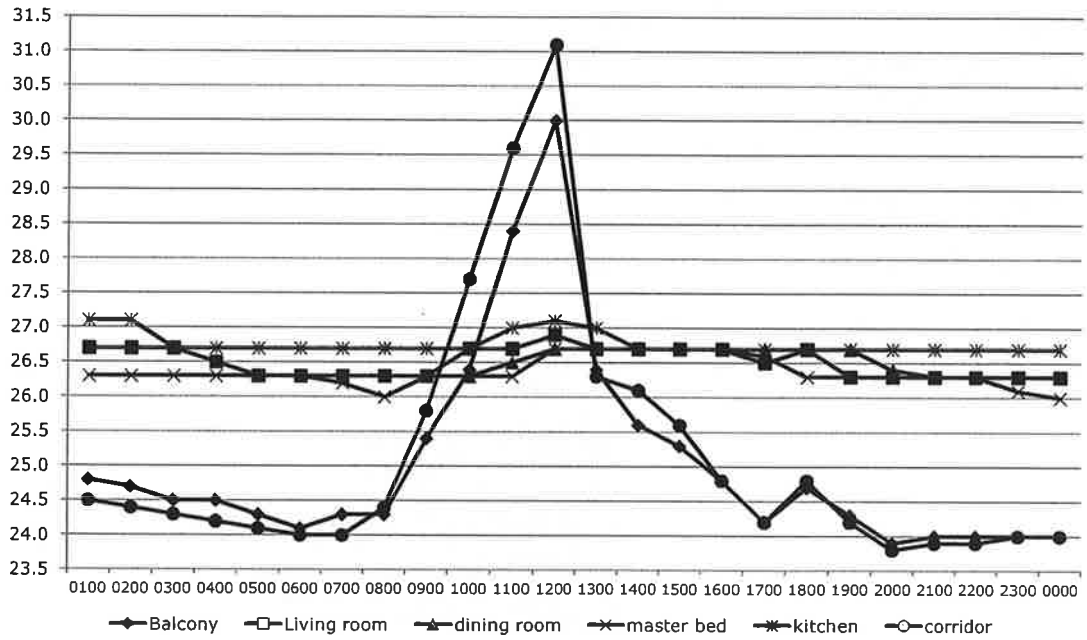
"Should be able to tune itself to provide the ideal thermal response to any given set of external climatic conditions, occupancy requirements, orientation and building type..."

Battle and McCarthy..

CONCEPT OF AN "Intelligent Skin"

NEW MATERIALS AND TECHNOLOGIES

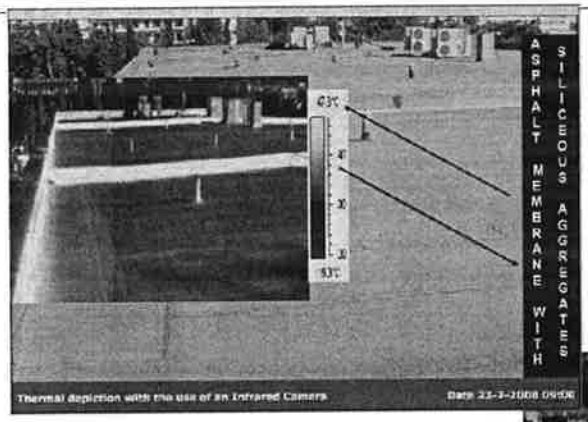
COOL PAINTS AND COOL FINISHES

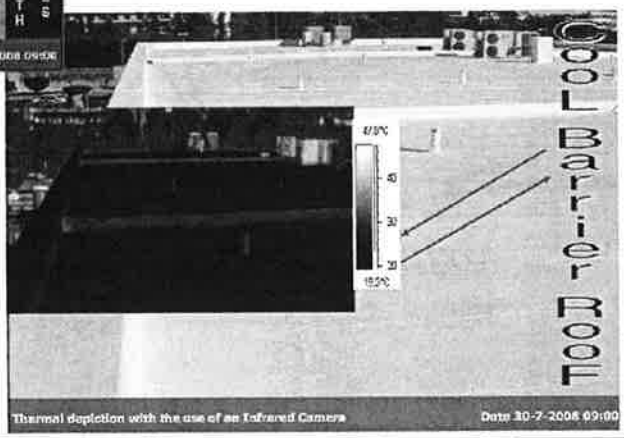


LACK OF PERIODIC HEAT FLOW
NEED FOR HIGH SOLAR REFLECTIVE FINISHES

- The term solar reflectance (SR) designates the total reflectance of a surface, considering the hemispherical reflectance of radiation, integrated over the solar spectrum, including specular and diffuse reflection.
- The infrared emittance (e) specifies how well a surface radiates energy away from itself as compared with a black body operating at the same temperature.
- The Solar Reflectance Index (SRI.) is a measure of a surfaces' (roof) ability to reject solar heat, as shown by a small temperature rise. It is defined so that a standard black (reflectance 0.05, emittance 0.90) is 0 and a standard white (reflectance 0.80, emittance 0.90) is 100. (LBNL Cool Roofing Materials Database). For matt surface.

Concept of Cool Paints - SRI

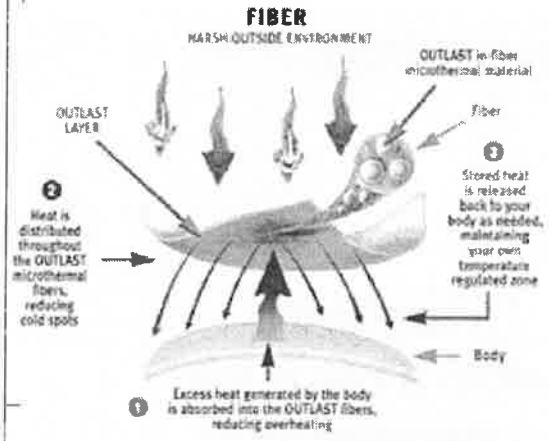




IMPACT OF USING COOL PAINTS...

NEW MATERIALS AND TECHNOLOGIES

PHASE CHANGE MATERIALS IN CONSTRUCTION



Phase change materials are solid materials at room temperature.

They can smooth temperature fluctuations in room temperature by lowering the peak temperatures.

When the temperature become warmer, they liquefy, absorb and store heat, thus cooling the space.



When the temperature drops, the material will solidify and give off heat, warming the space at night.

PHASE CHANGE MATERIALS FOR PASSIVE COOLING

material change state - eg. solid to liquid etc.



Concluding remarks.. Once upon a time..

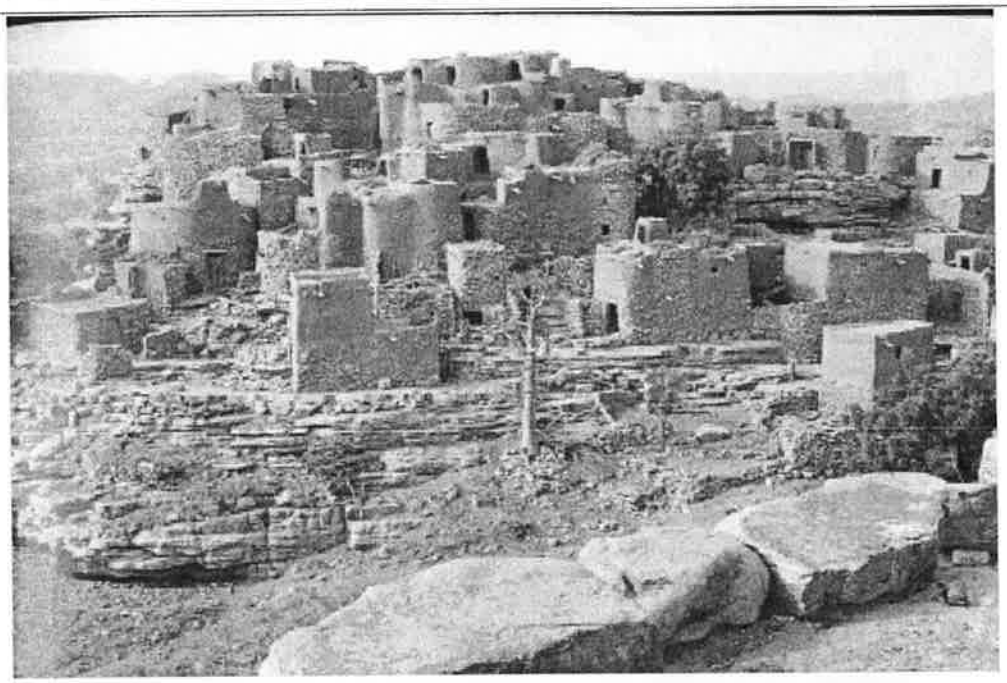
Examples of such communities…



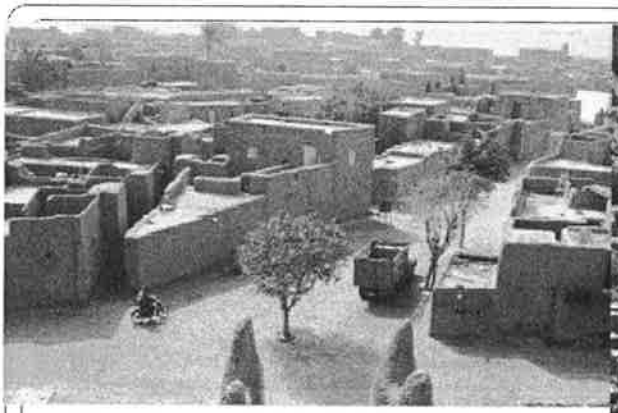
Figure 1.21
Termite hill in Kenya, Africa. © Oxford Scientific Films

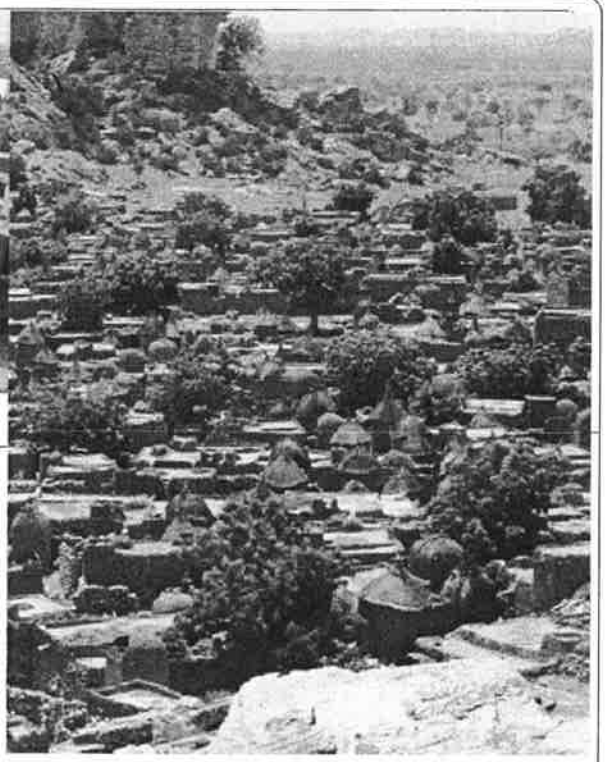
A termite hill, which is one of the most ecological designs..

Are we not talking about humans..



An existing development in Africa





A few more existing developments in Africa Climatically driven – rather forced..

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Traditional clay Architecture..

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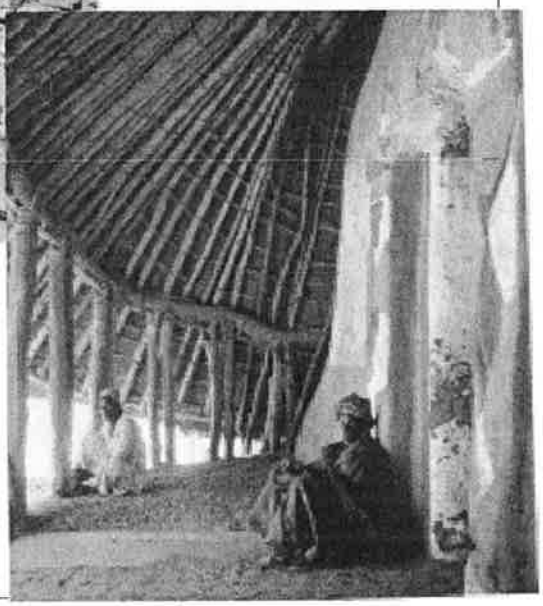




Narrow lanes and shaded courtyards



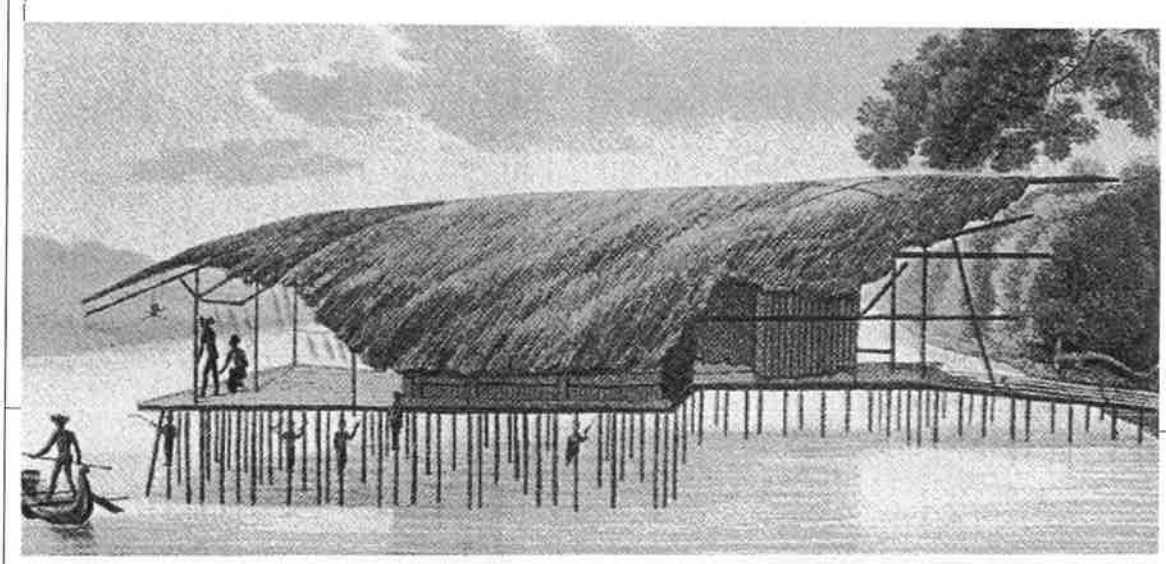
User requirement driven



A linear market square in a narrow lane

&

Comfortable verandahs..



Fishermen's villages in Sumatra...

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Enclosed verandah over the porte cochere.



Timber joists that support the upper storey.



Second floor hallway leading to the enclosed verandah.

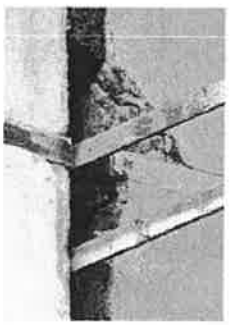




Louvered doors and windows are a standard feature.



Timber Stairs and a thoughfully placed window.



Close-up view of brick in-fill paneling into timber frames.



McAlister & Co. Mess, 14 Cable Road, Swan & Maclaren (1920)

Black and White bungalows in Singapore

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Questions!

Key Points for Passive Design & Natural Ventilation

GMM Course on Natural Ventilation – Summary

1. **Climatic properties of the Tropics**
   - Temperature
   - Rainfall & effect on Relative Humidity
   - Relationship between Temperature & Relative Humidity
   - Tropical Buildings that are **appropriate** for the Climate
   - Wind **Velocity** & **Direction**
   - Local appropriateness
2. **Identifying Human Comfort**
   - Tropical Summer Index & Singapore Index
   - Relationship between Temperature, RH & Human Comfort
   - Designing for Human Comfort
3. **Passive Design**
   - Design for Natural Ventilation – **appropriate** Orientation w.r.t. Prevailing Wind Directions
   - Design for Cooling – **appropriate** Orientation w.r.t Sun direction
   - North-South orientation
   - Proper material selection. Glass is not all bad – it's the **appropriate ratio** for the glass! Only after talking about **WWR** (Window to Wall Ratio) do we talk about the **performance** of the glass.
   - Evaporative cooling – does it work in Singapore?
4. **Green Mark aspects**
   - Green Mark Platinum for NRB (New Residential Buildings) (v4.1) – CFD simulation required
   - Percentage requirements for naturally-ventilated rooms
   - Common areas & bathrooms for residential buildings need to be NV (naturally ventilated)
   - What constitutes NV? 5% of floor area is opening / fenestration area
   - CFD simulations must be translated into built design!
5. **New Technologies**
   - Adaptive facades & principles behind them
   - Solar Reflectance Index (SRI) – what it measures
   - Principle behind cooling paints
   - Principle behind PCM (Phase Change Materials)
6. **Back to Basics**
   - What makes vernacular / indigenous architecture work?
   - What are the passive strategies?
   - How do we tie this back to Green Mark?

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