Evaluating Occupant Comfort in Naturally Ventilated Spaces in Singapore

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Learning Objectives

Objective 1:	To understand what occupant comfort is in Naturally Ventilated spaces
Objective 2:	Will moisture affect occupant comfort in Naturally Ventilated spaces
Objective 3:	Will airborne contaminants affect occupant comfort in Naturally Ventilated spaces
Objective 4:	Can moisture and contaminants be controlled in naturally Ventilated spaces?

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Get out of Jail Card

- The contents of this presentation are the authors point of view based upon 30 years of experience in designing naturally ventilated spaces around the world.

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Hypothesis

- A human being occupying a conditioned space or a naturally ventilated space will have the same sensations

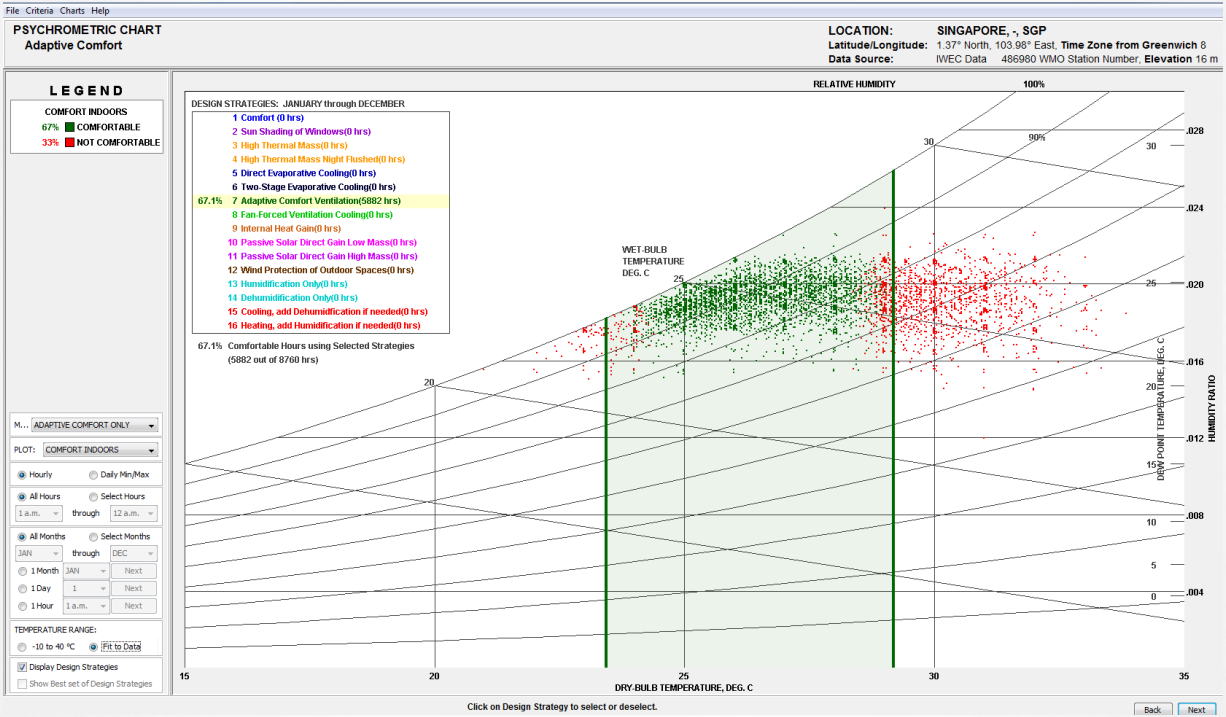
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Singapore



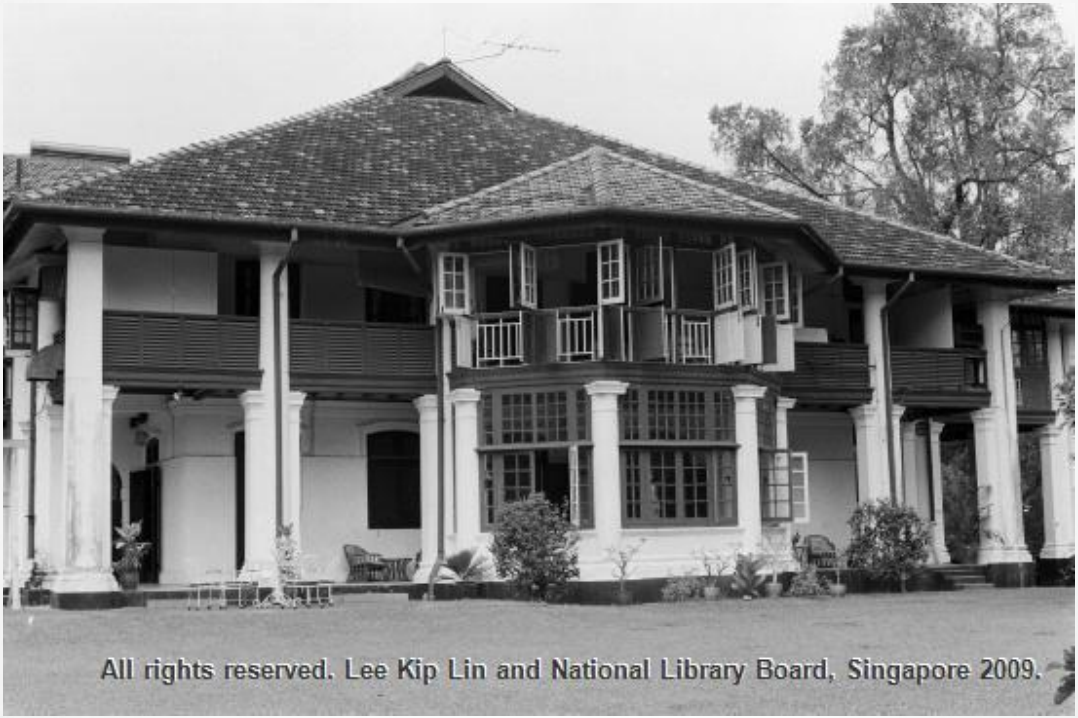
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Singapore weather



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Typical Historic Design



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Wisma Yeap Chor Ee at Pengkalan Weld



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Loke Thye Kee (Restaurant) at 2, Jalan Burma



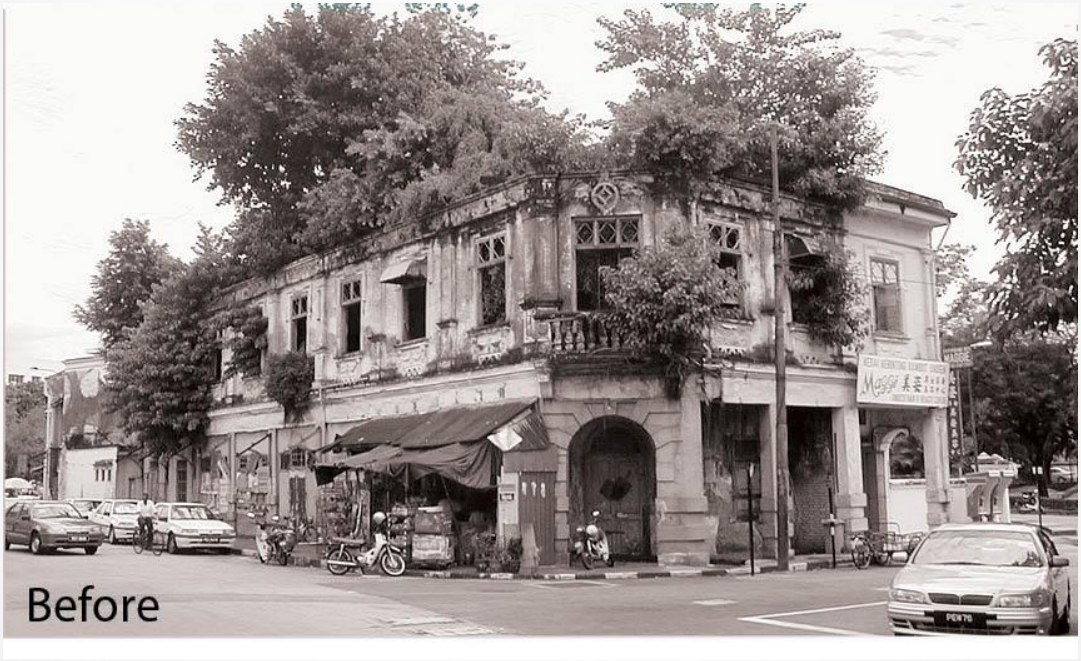
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Sweet Chili Hotel at Gat Lebuh Melayu



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George Town World Heritage Incorporated at 115 & 118, Lebuh Acheh



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Sinkeh Hotel at 105, Malay Street





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Naturally Ventilated Buildings in Singapore



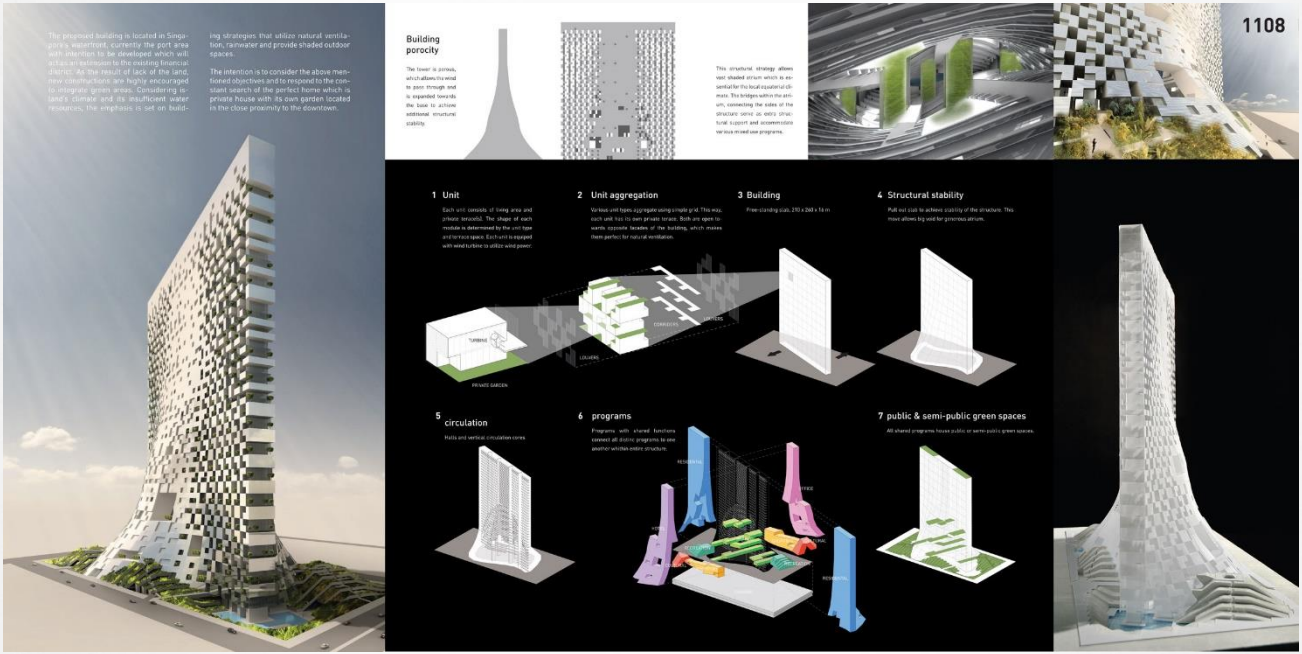
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Naturally Ventilated Buildings in Singapore



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Naturally Ventilated Buildings in Singapore



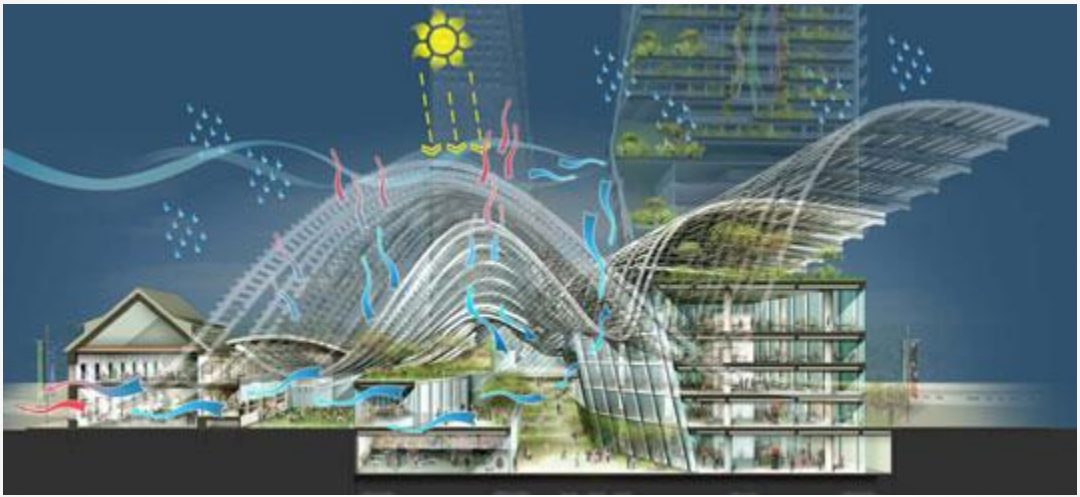
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Naturally Ventilated Buildings in Singapore



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Greenland Group Suzhou Center – Wujiang, China

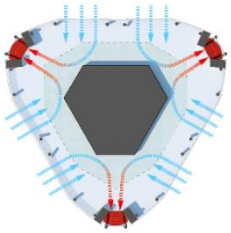


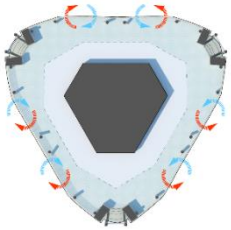


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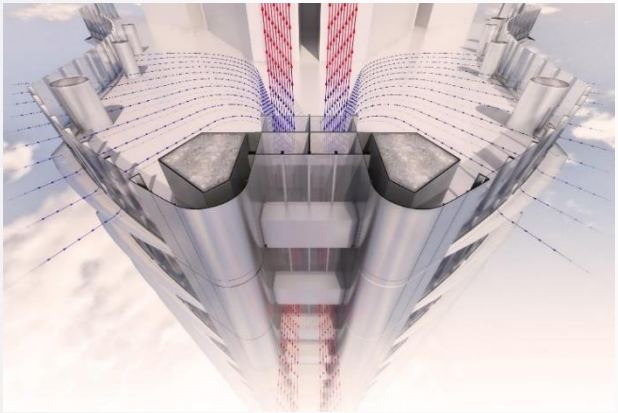


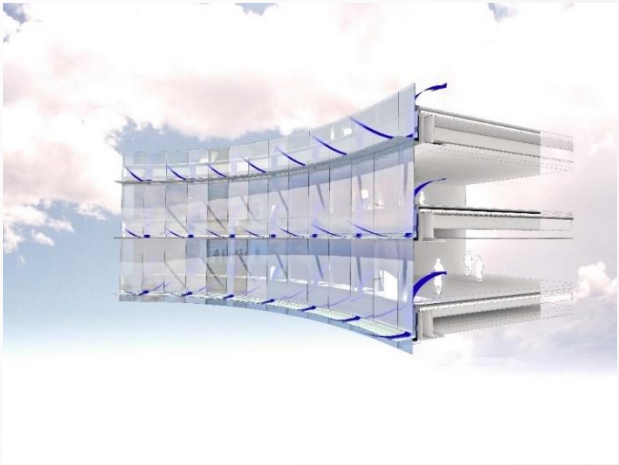




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Early work 1991

Title: **Experience with naturally ventilated atria**

Author: Peter Simmonds

ABSTRACT

The new teaching hospital in Groningen will be finished around the year 2000 and will have a 1000 beds. In total 9 atria will cover the pedestrian areas. These atria are neither heated of mechanically ventilated. Smoke extract openings in the roof are used to provide natural ventilation.
The first atrium was finished in 1988, eight temperature recorders were placed in this atrium.
Measurements were also continuously made of the outside air temperature, solar intensities, and the position of the openings (open of closed).
The measured results were then compared to the original calculations to see if it was necessary to make design, construction or operational changes for the future atria.

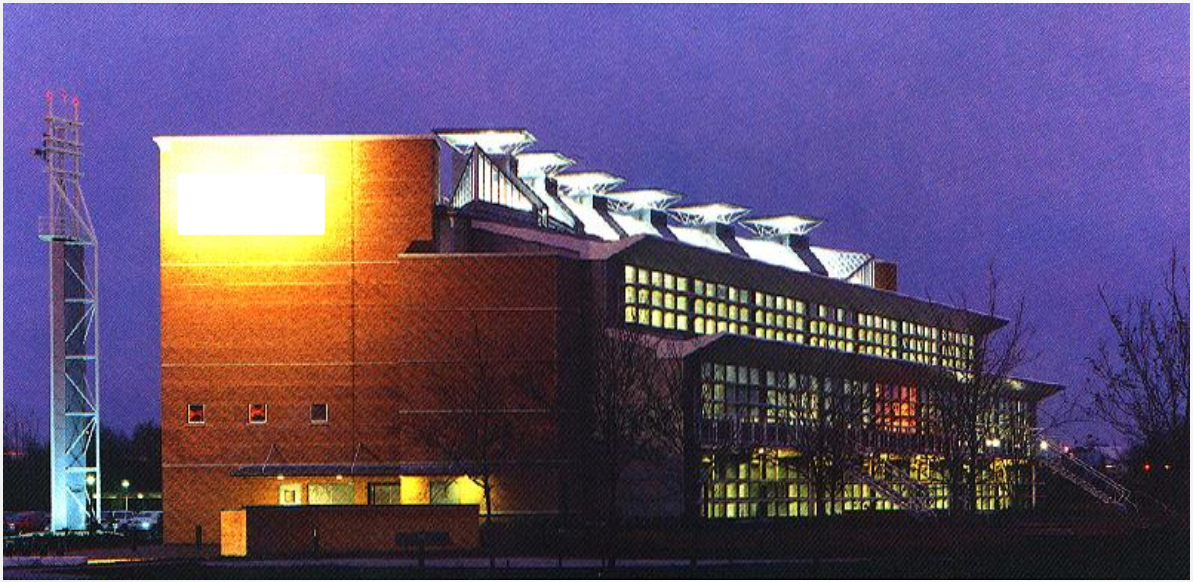
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Previous Projects

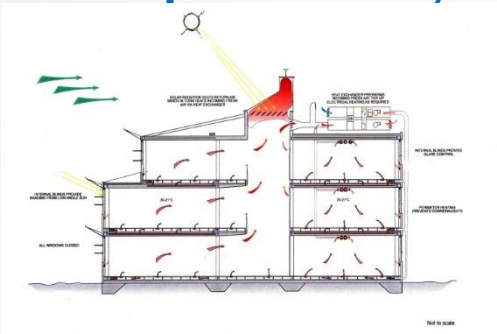
- AZG Atria
- Stichting 'De Nieuwe Weerdjes', Arnhem, Netherlands
- Achtse Barrier, Eindhoven, Netherlands
- Ionica Cambridge
- Century Towers, San Francisco, CA
- Ross School, Ross, CA
- Ana Head, Student accommodation
- UC Berkeley, Campbell Hall Replacement, Berkeley, CA
- Deneve, Student accommodation
- UC San Diego, Revelle Housing, La Jolla, CA (LEED Platinum)
- Beijing Financial Street
- San Joaquim Apartments
- Claremont McKenna College, Kravis Center, Claremont, CA, (LEED® Gold)
- Herb Alpert Educational Village, Santa Monica, CA
- LAUSD, East Valley High School Theater, Classrooms & Gymnasium, sun Valley, CA
- LAUSD, Net Zero School Prototype, Los Angeles, CA
- Westmont College, David K. Winter Hall for Science & Mathematics, (LEED® Gold)
- APC Melrose Place, Beverley Hills, CA
- Park Row, Residence and Studio, Elysian Heights, CA

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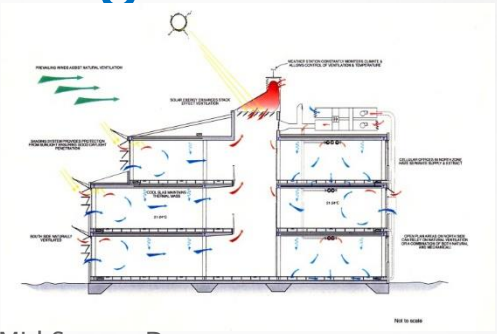
Previous Designs: Headquarters, Cambridge



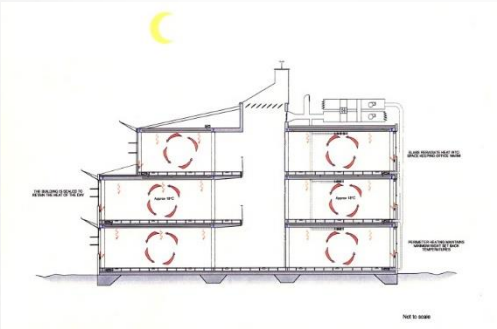
Previous Designs: Headquarters, Cambridge



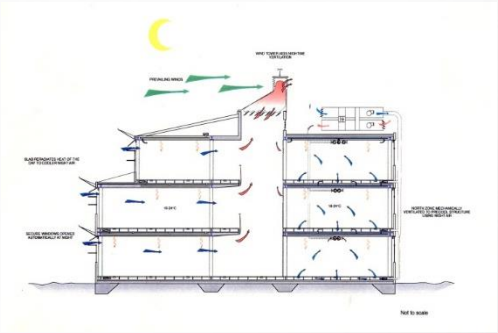
Winter Day



Mid-Season Day



Winter Night



Mid-Season Night

Naturally Conditioned Spaces

The standard requires the user to follow the requirements of Section 5.4, which applies to spaces that are naturally conditioned, including the provisions to extend the thermal comfort boundaries based on elevated air movement in Section 5.3.3, Note (b). Specifically, the standard requires that the following parameters are measured in the space being evaluated:

a) Indoor air temperature

b) Mean radiant temperature

c) Outdoor air temperature

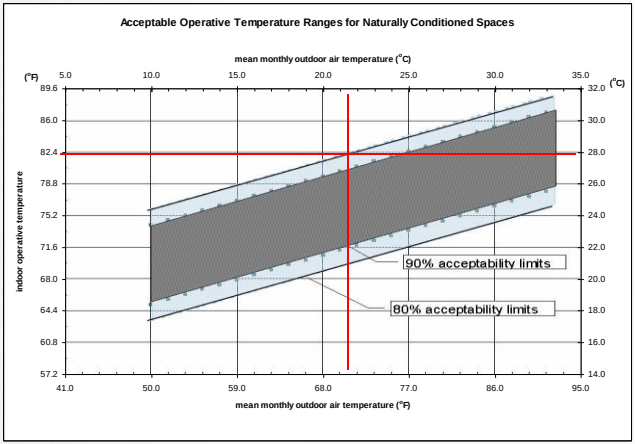
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Summary of weighted linear regression of bin-mean thermal sensation on operative temperature (after de Dear et al 1997)

	HVAC	NV	MM
Number of buildings	109 2 missing	44 1 missing	4 None missing
Number of buildings included in the analysis	63	36	3
Mean (+/- stdev) model gradient	0.52 +/-0.248	0.27 +/-0.134	0.39 +/-0.105

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NATURAL VENTILATION ADAPTIVE COMFORT



The mean monthly outdoor air temperature was calculated. The design month for the simulation was determined based on the month which contained the cooling design day temperature from ASHRAE fundamentals and the CEC – Title 24 Appendix.

Using the adaptive comfort graph and the calculated mean monthly outdoor temperature of 70.9° F (21.6° C), the upper operative comfort limit was determined to be 82.4° F (28° C). The lower limit is not critical for this simulation study since the building is located in Southern California.

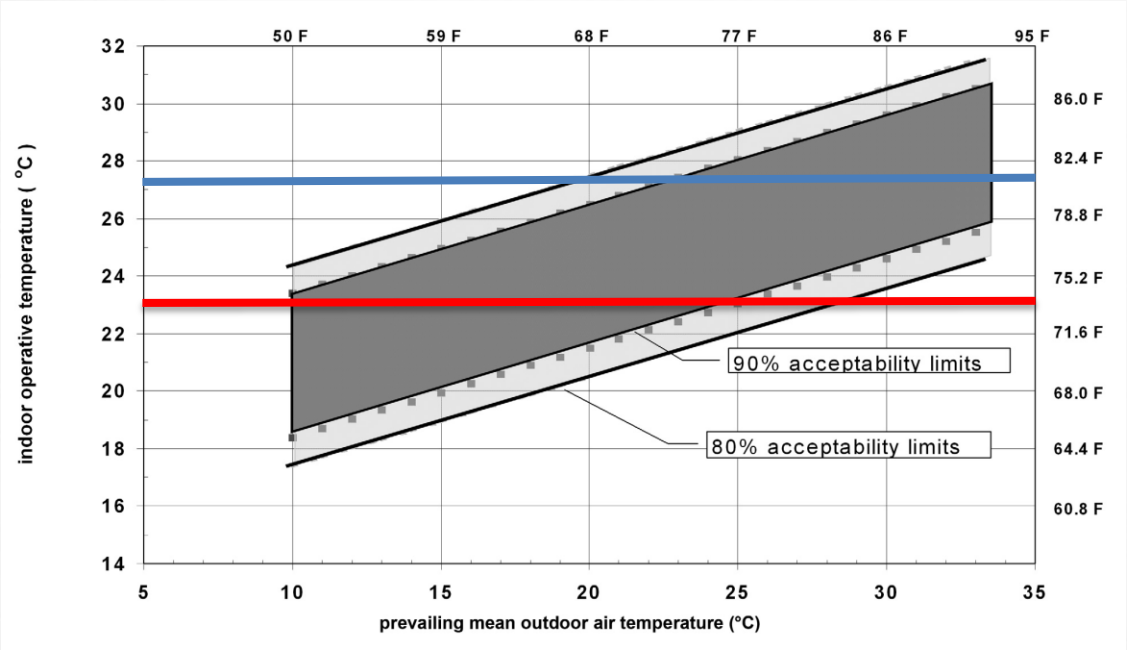
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The equations corresponding to the acceptable operative temperature ranges in Figure 5.4.2 are:

- Upper 80% acceptability limit (°C) = 0.31 (momat) + 21.3 = 28.43C
- Upper 90% acceptability limit (°C) = 0.31 (momat) + 20.3 = 27.43 C
- Lower 80% acceptability limit (°C) = 0.31 (momat) + 14.3 = 21.43 C
- Lower 90% acceptability limit (°C) = 0.31 (momat) + 15.3 = 22.43 C
- *momat = mean outdoor monthly air temperature*

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FIGURE 5.4.2 Acceptable operative temperature (t_o) ranges for naturally conditioned spaces.



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Why Investigate?

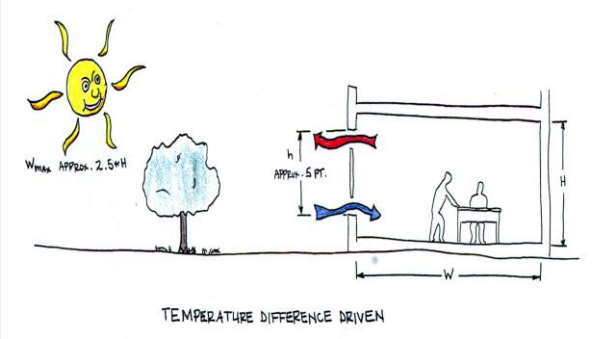
To understand whether or not occupants will comfortable ?

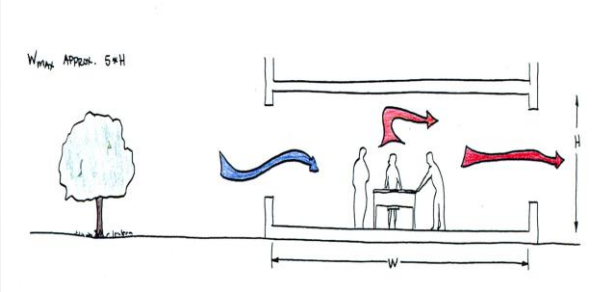
Or

Whether or not ASHRAE Standard 55, Adaptive Comfort is practical?

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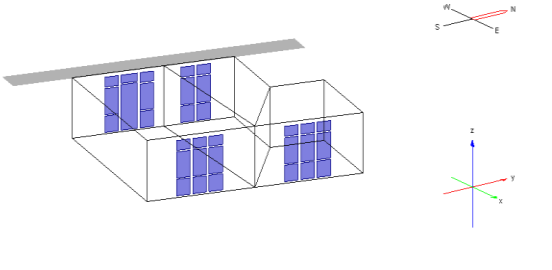
Natural Ventilation





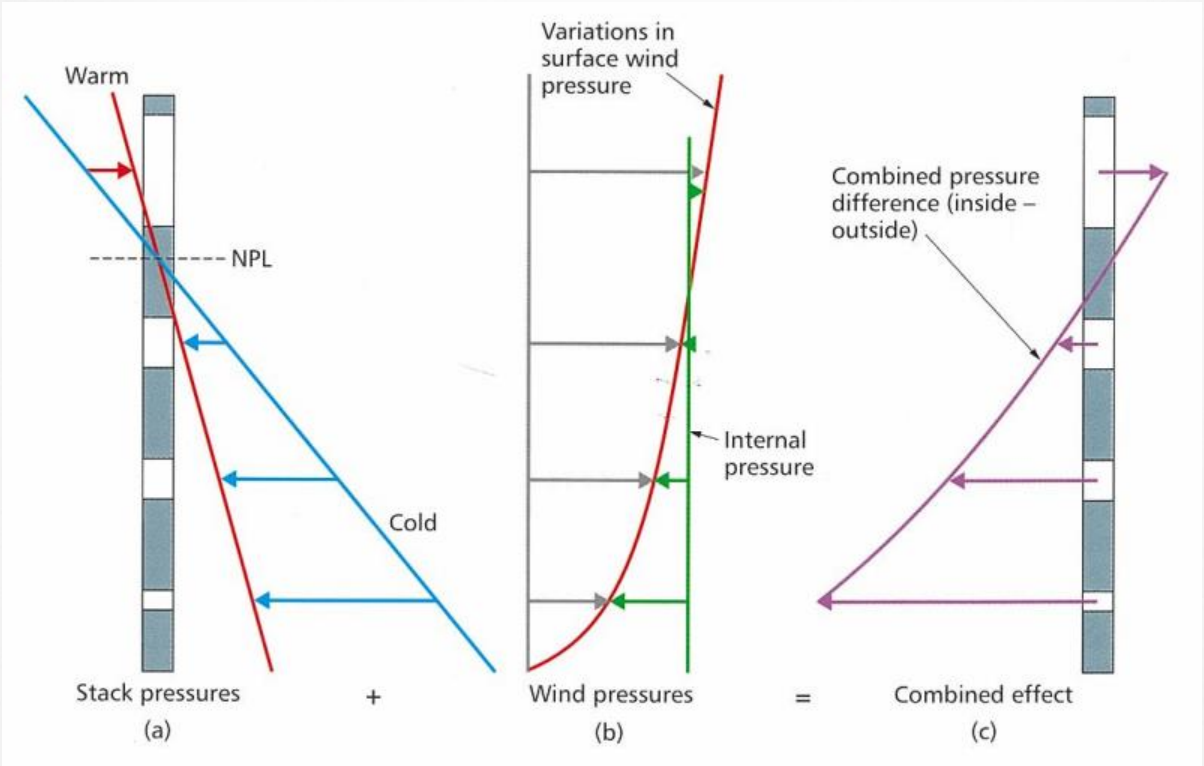
Buoyancy driven

Wind driven



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Wind +Buoyancy Driven



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Buoyancy Driven Formulas

For BUOYANCY induced ventilation		Numerical Technique - AIVC	Computational Technique - CONTAM
Volume air Flow	Q	$Q = C_d \times A \times [\, 2 \times g \times \Delta h \times (T_i - T_o / T_i)]^{1/2}$	$Q = C_d A \left\{ \frac{2 \Delta P}{p} \right\}^{1/2}$
Neutral plane level	NPL	$\frac{H_n}{H_s} = \frac{1}{1 + (T_o / T_i)^{1/3}}$	$\frac{H_n}{H_s} = \frac{1}{1 + (T_o / T_i)(A_b / A_o)^2}$
Pressure difference	DP	$P_s = - p_o g (H_2 - H_1) (1/T_o - 1/T_i)$	$\Delta P = \left\{ P_1 + \frac{p V_1^2}{2} \right\} - \left\{ P_2 + \frac{p V_2^2}{2} \right\} + pg (Z_1 - Z_2)$
Mass flow	M	$M_z = C_d A \, (2 \times p_o \times \Delta P)^{1/2}$	$M = C (\Delta P)^n$

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Wind Driven Formulas

For WIND induced ventilation		Numerical Technique - AIVC	Computational Technique - CONTAM
Voume air flow rate	Q	$Q = C_d A \left\{ \frac{2 \Delta P}{\rho} \right\}^{1/2}$	$Q = C_d A \left\{ \frac{2 \Delta P}{\rho} \right\}^{1/2}$
Wind velocity reduction	Vr	$V = V_m \times K_s \times Z^a$	$C_h = A_o^2 \left\{ \frac{H}{H_{ref}} \right\}^{2a}$
Pressure difference	DP	$P_w = 0.5\, C_p\, p\, V_r^2$	$P_w = 0.5\, C_p\, p\, V_r^2$

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Wind Pressure

- Wind creates a distribution of static pressure on the building envelope, which is dependent on wind direction and location on building envelope.

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Air density varies with temperature

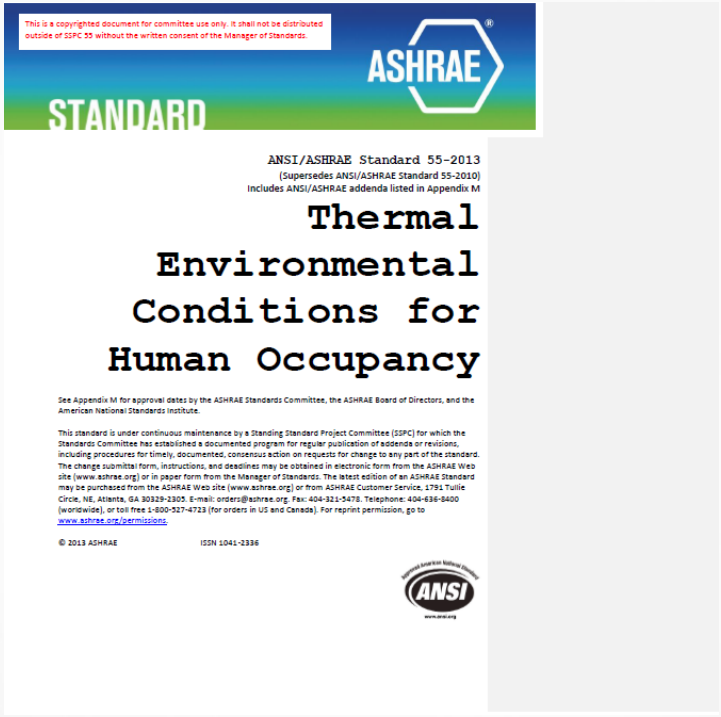
- In cold weather, low density air infiltrates the building, rises within the high rise bldg's vertical shafts as it warms & creates stack effect pressure. The basic stack effect theory is expressed as:

$$\Delta P_S = C_2 \rho_i g (h - h_{neutral})(T_i - T_0)/T_0$$

ΔP_S = stack pressure, in of water
T = temperature
i & o = inside & outside
h = height, feet
C_2, ρ, g = air density and gravity constant, 0.01444
$h_{neutral}$ = height of neutral pressure level

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Thermal Comfort Standards



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ASHRAE

STANDARD

ANSI/ASHRAE Standard 55-2013

(Supersedes ANSI/ASHRAE Standard 55-2010)

Includes ANSI/ASHRAE addenda listed in Appendix M

Thermal Environmental Conditions for Human Occupancy

See Appendix M for approval dates by the ASHRAE Standards Committee, the ASHRAE Board of Directors, and the American National Standards Institute.

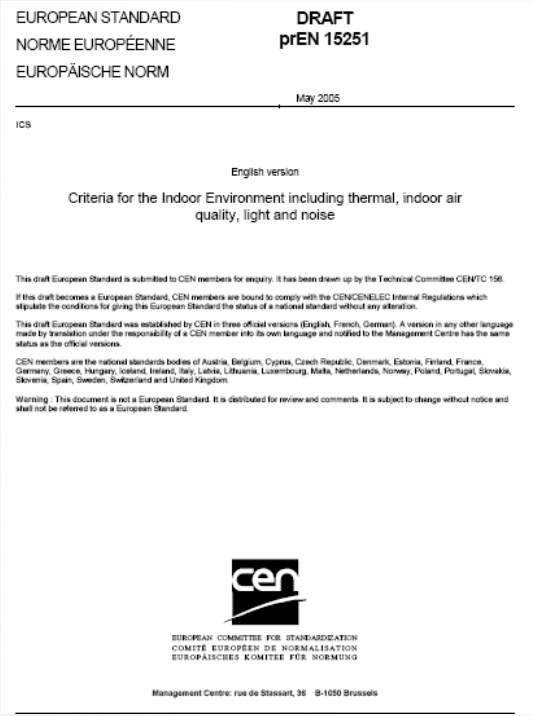
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ANSI

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Thermal Comfort Standards



EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

DRAFT
prEN 15251

May 2005

ICS

English version

Criteria for the Indoor Environment including thermal, indoor air quality, light and noise

This draft European Standard is submitted to CEN members for enquiry. It has been drawn up by the Technical Committee CEN/TC 156.

If this draft becomes a European Standard, CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

This draft European Standard was established by CEN in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Management Centre has the same status as the official versions.

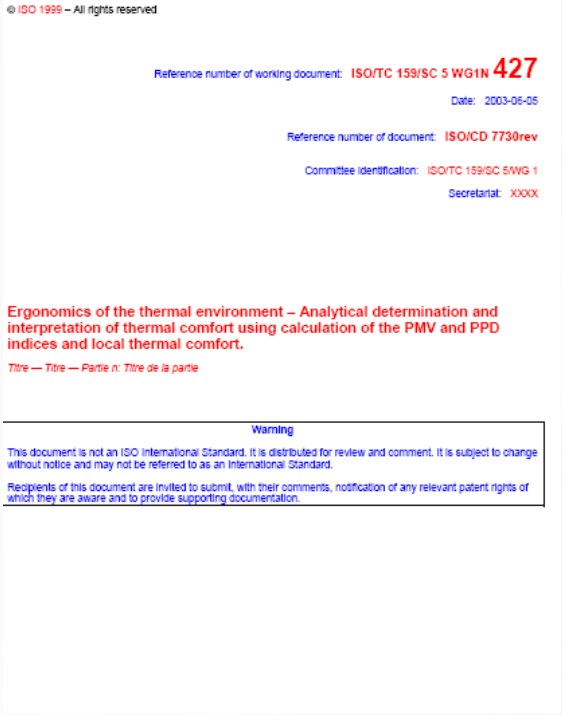
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Reference number of working document: ISO/TC 159/SC 5 WG1N 427

Date: 2003-06-05

Reference number of document: ISO/CD 7730rev

Committee identification: ISO/TC 159/SC 5/WG 1

Secretariat: XXXX

Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort.

Titre — Titre — Partie n: Titre de la partie

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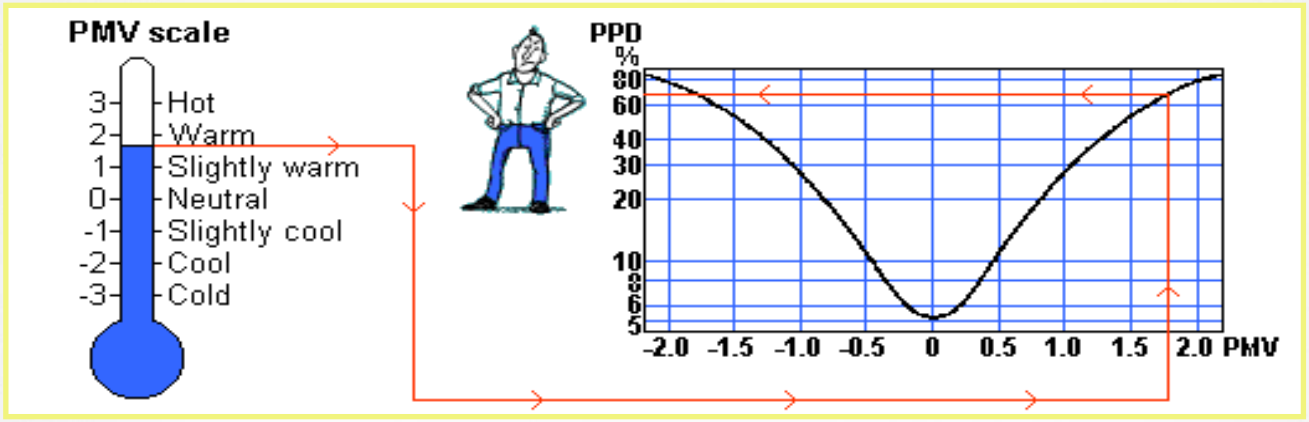
Definitions

- ***predicted mean vote (PMV):*** an index that predicts the mean value of the votes of a large group of persons on the seven-point thermal sensation scale.

- ***predicted percentage of dissatisfied (PPD):*** an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people determined from PMV.

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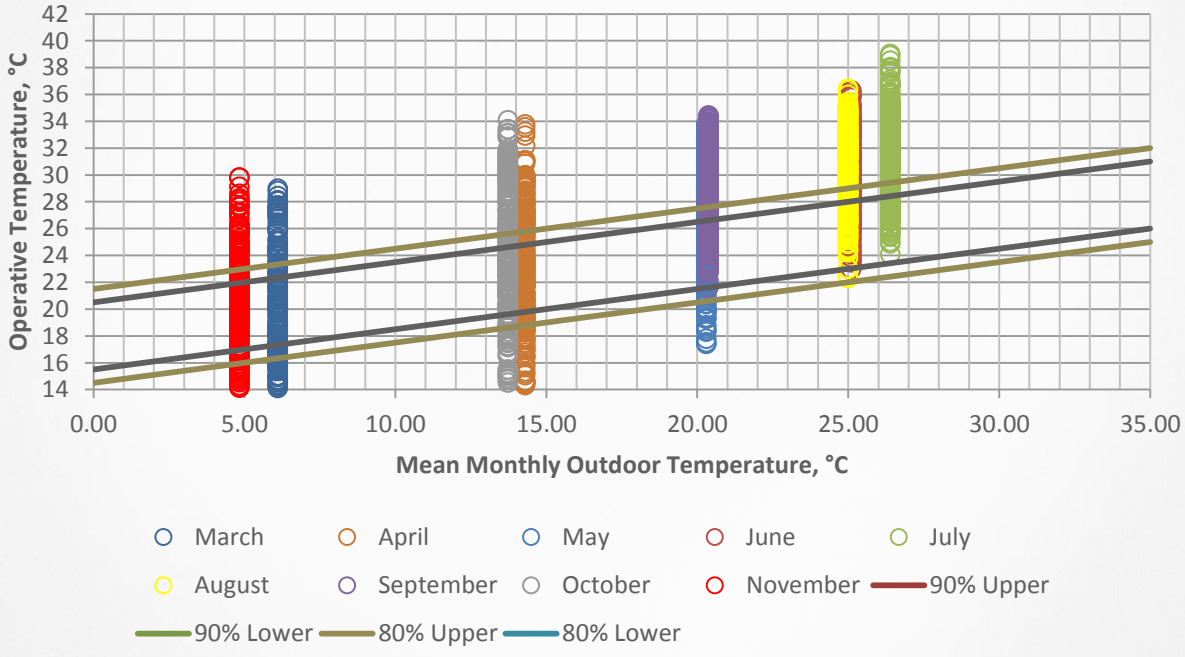
THERMAL COMFORT



- 1) Metabolic rate.
- 2) Clothing insulation.
- 3) Air temperature.
- 4) Radiant temperature
- 5) Air speed
- 6) Humidity

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ASHRAE 55- Mean monthly



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Exponentially weighted running mean temperature

$$T_{rm} = (1-\alpha).\{T_{od-1} + \alpha.T_{od-2} + \alpha^2 T_{od-3} \ldots..\}$$

$$T_{rm}^{n} = (1-\alpha).T_{od}^{n-1} + \alpha.T_{rm}^{n-1}$$

α is a constant ($\alpha < 1$),

T_{rm} Running mean temperature

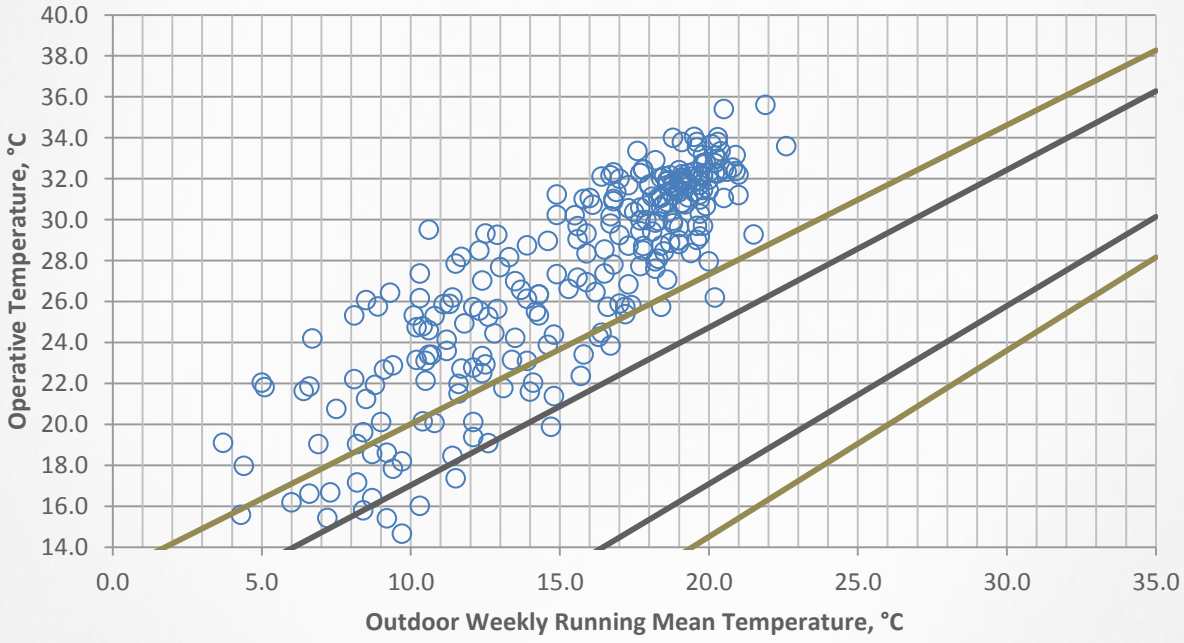
Trm^{n} is Trm on day n

In this database TrmX = Trm for α = X/100

T_{od} Daily mean temperature

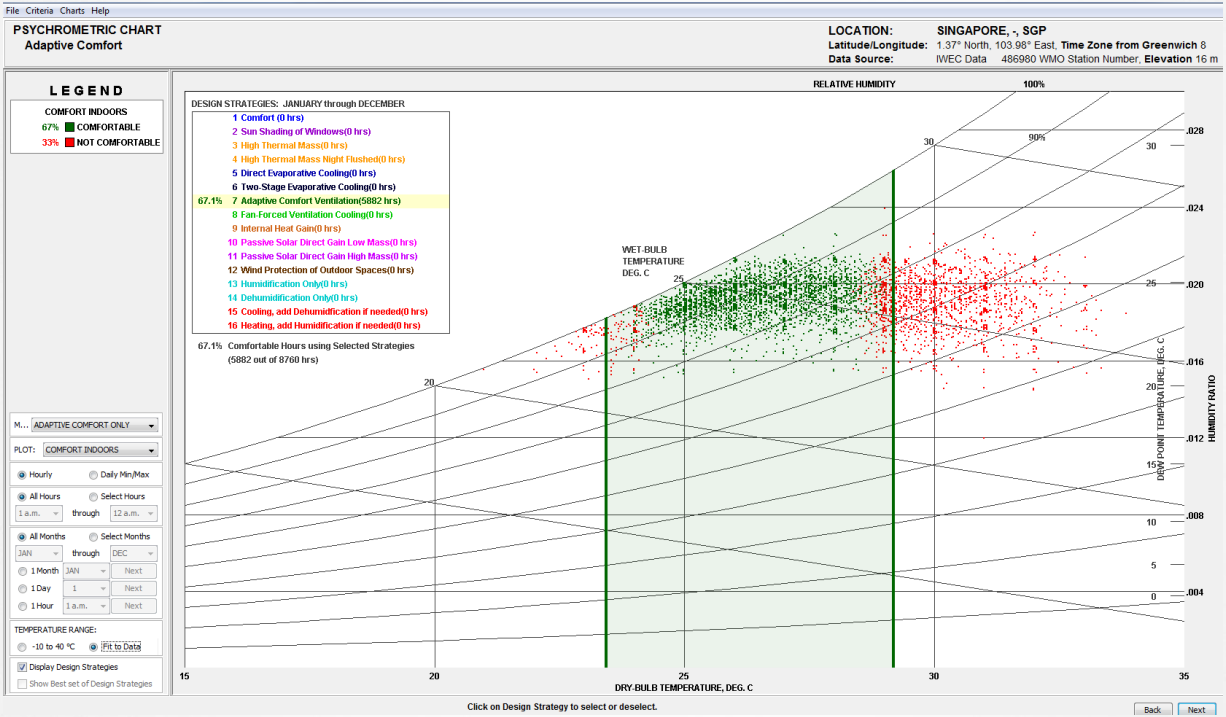
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Weekly Running Mean Temperature



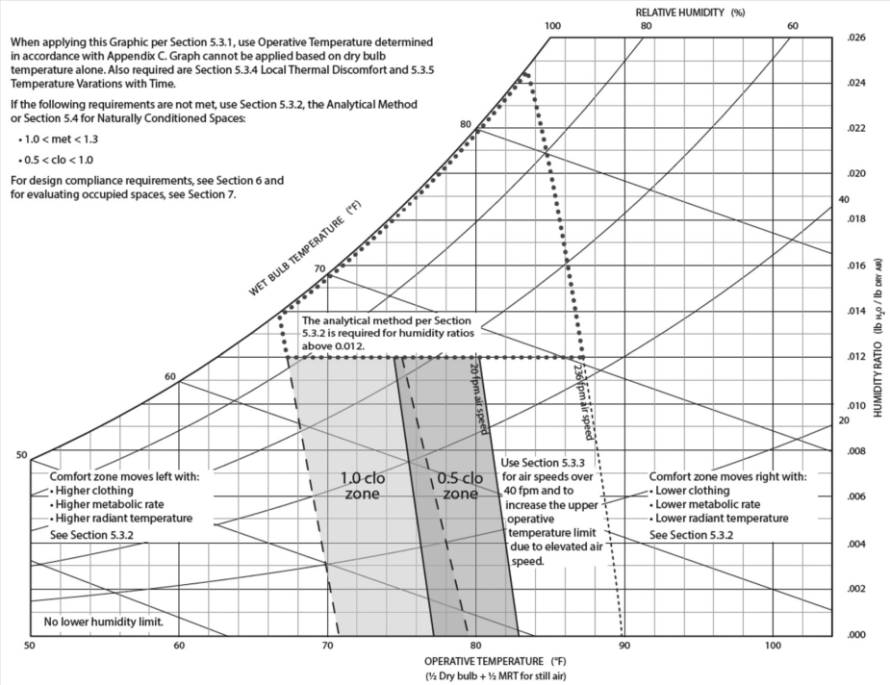
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Singapore weather



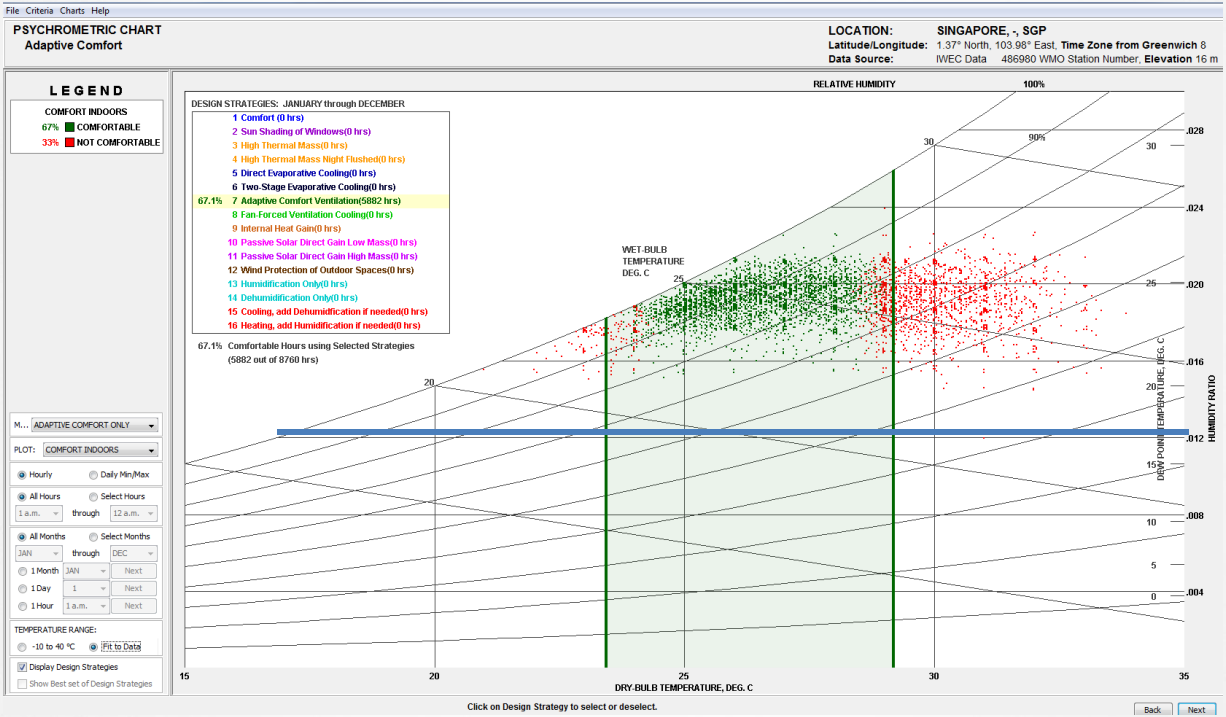
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The Dreaded Chart



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Adaptive Comfort for Singapore



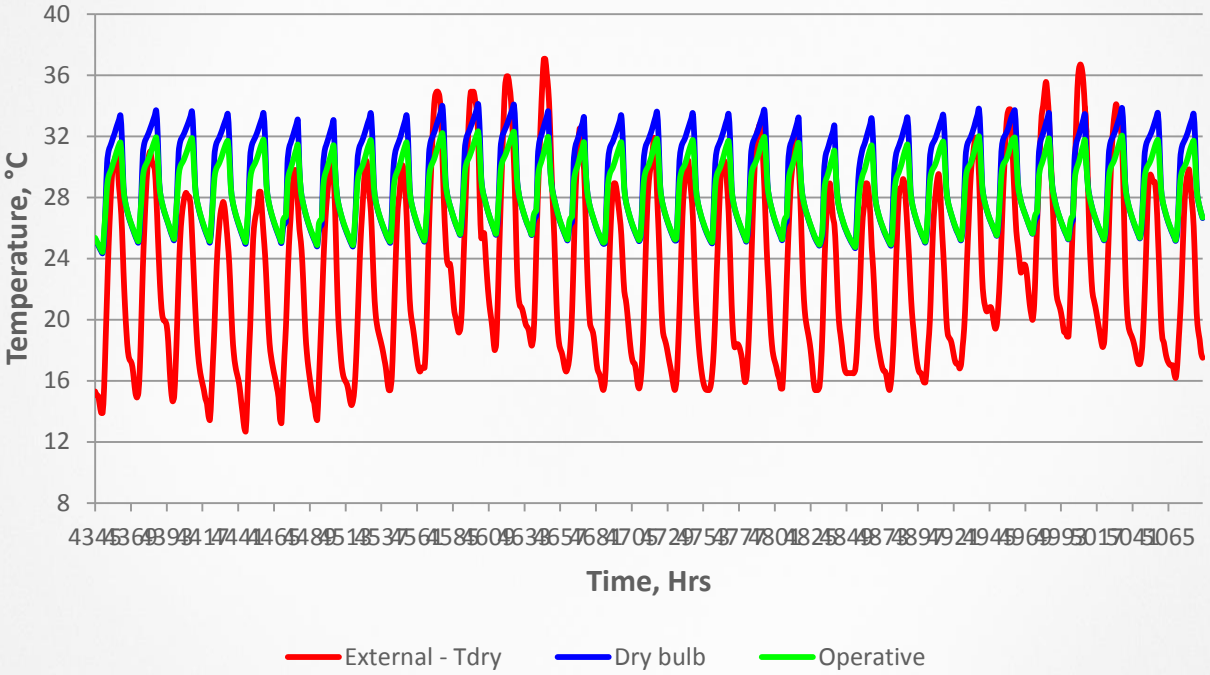
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openings

- There are drawings showing the façade details or natural ventilation openings. For this study we have assumed the following:
- Openings. We have assumed 5m2 of opening at high level, 3m above the floor level and 5m2 of low level openings just above floor level on each of the four sides of the tower. The discharge coefficient of each opening is 0.61
- Profile. The openings are assumed to be open from 8 am to 6 pm
- Infiltration is zero

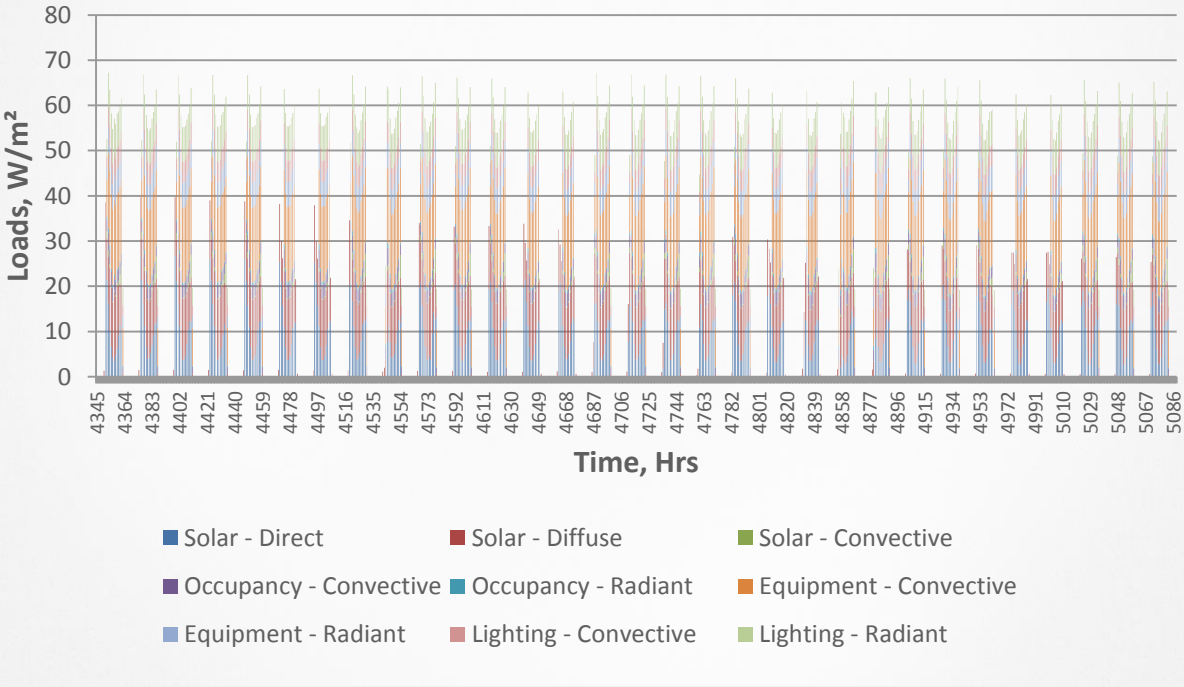
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Fully Mixed Conditions for 1st to the 31st JULY - Natural Ventilation



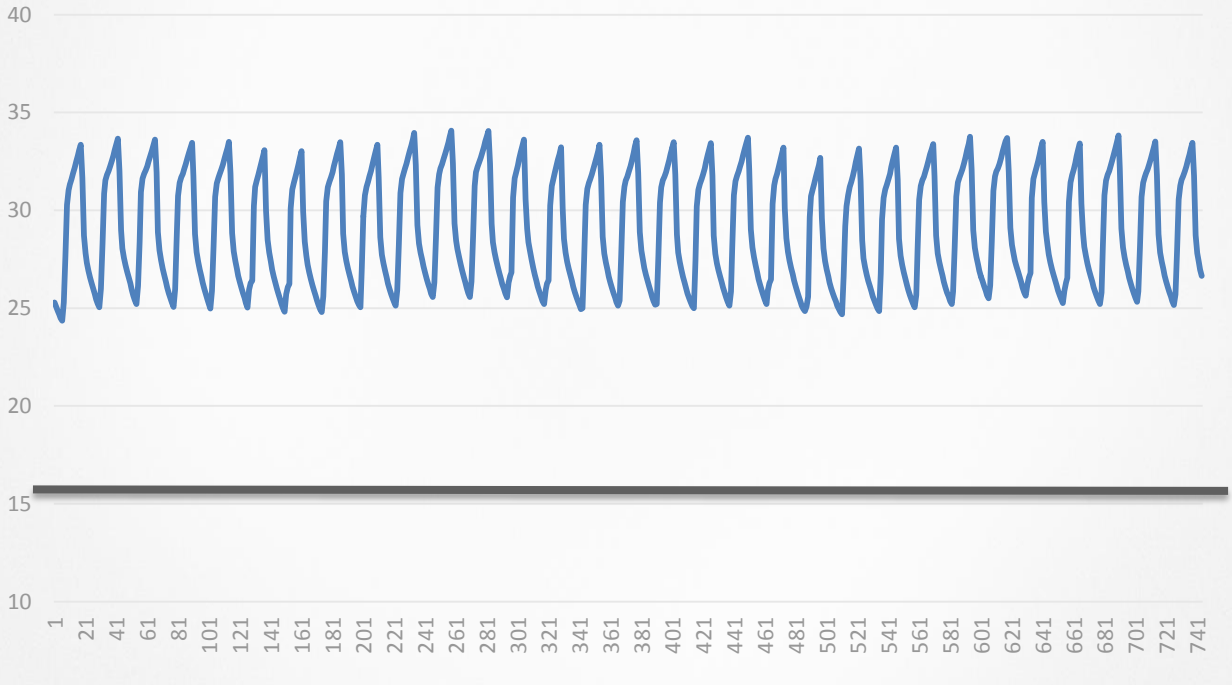
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Internal Sensible Gains for 1st to the 31st JULY



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Dewpoint Temperatures- Natural Ventilation



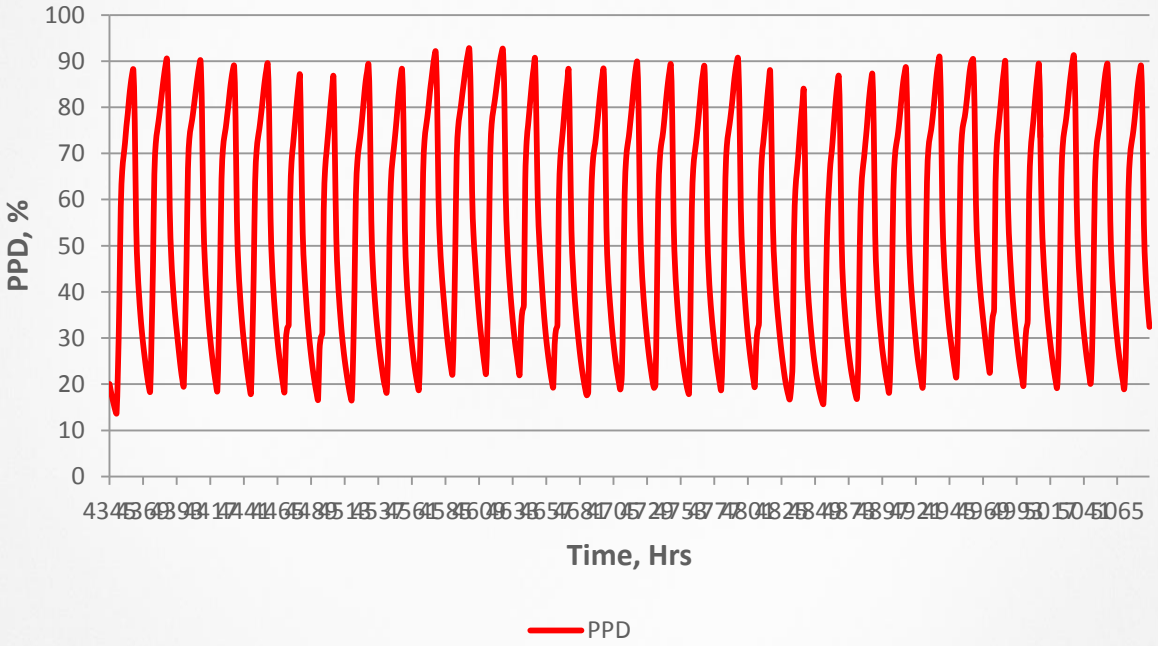
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Hypothesis

- A human being occupying a conditioned space or a naturally ventilated space will have the same sensations

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PPD for 1st to the 31st JULY - Natural Ventilation



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Natural Ventilation Top 10 Feasibility Questions

1. Building Envelope
2. Internal Heat Loads
3. Weather Normals: Mean Maximum/ Mean Minimum
4. Frequency of Occurrence Psychrometric Chart
5. Ambient Environment, Possible Locations of Openings
6. Window Locations and Sizes, Accessibility
7. Wind Rose, Feasible Flow Paths: Inlet to Outlet Under All Wind Conditions
8. High Afternoon Temperatures
9. Diurnal Range on Hot Days
10. Dew-Point Temperatures Throughout Year

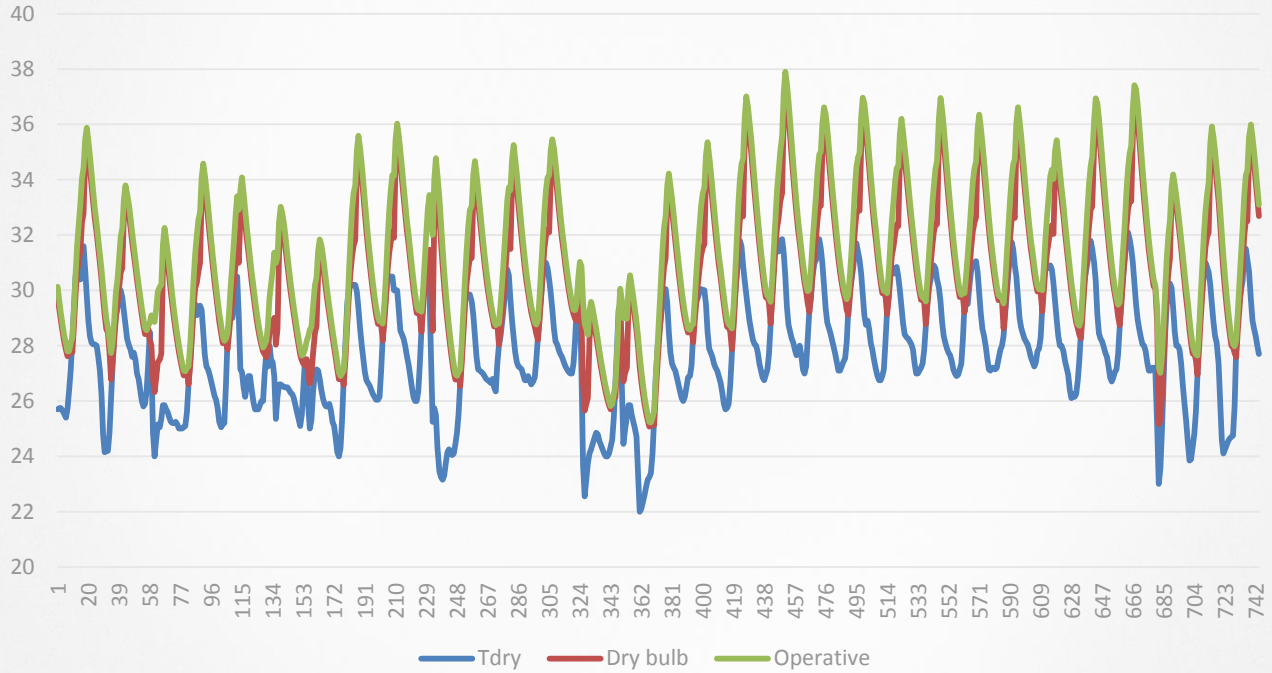
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The equations corresponding to the acceptable operative temperature ranges in Figure 5.4.2 are:

- Upper 80% acceptability limit (°C) = 0.31 (momat) + 21.3 = **29.88C**
- Upper 90% acceptability limit (°C) = 0.31 (momat) + 20.3 = **28.88 C**
- Lower 80% acceptability limit (°C) = 0.31 (momat) + 14.3 = **22.88 C**
- Lower 90% acceptability limit (°C) = 0.31 (momat) + 15.3 = **23.88 C**
- *momat = mean outdoor monthly air temperature = 27.7 C*

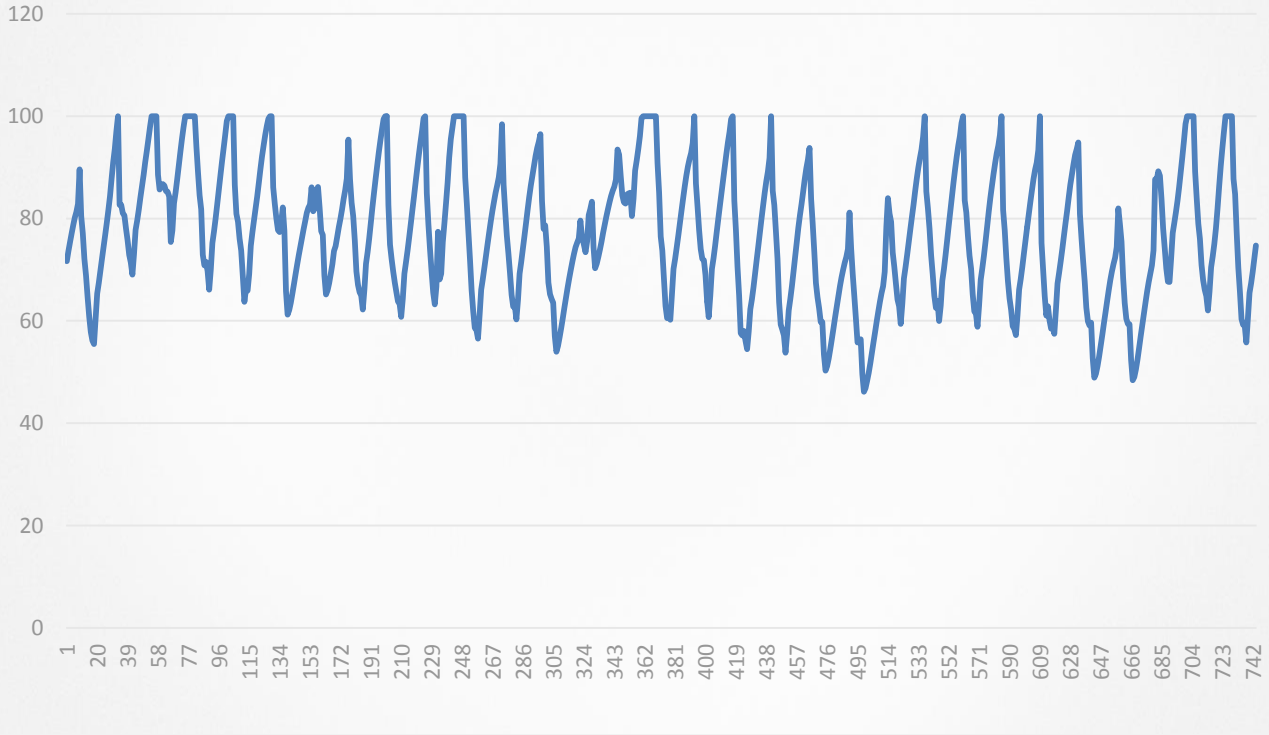
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Temperatures Singapore (July)



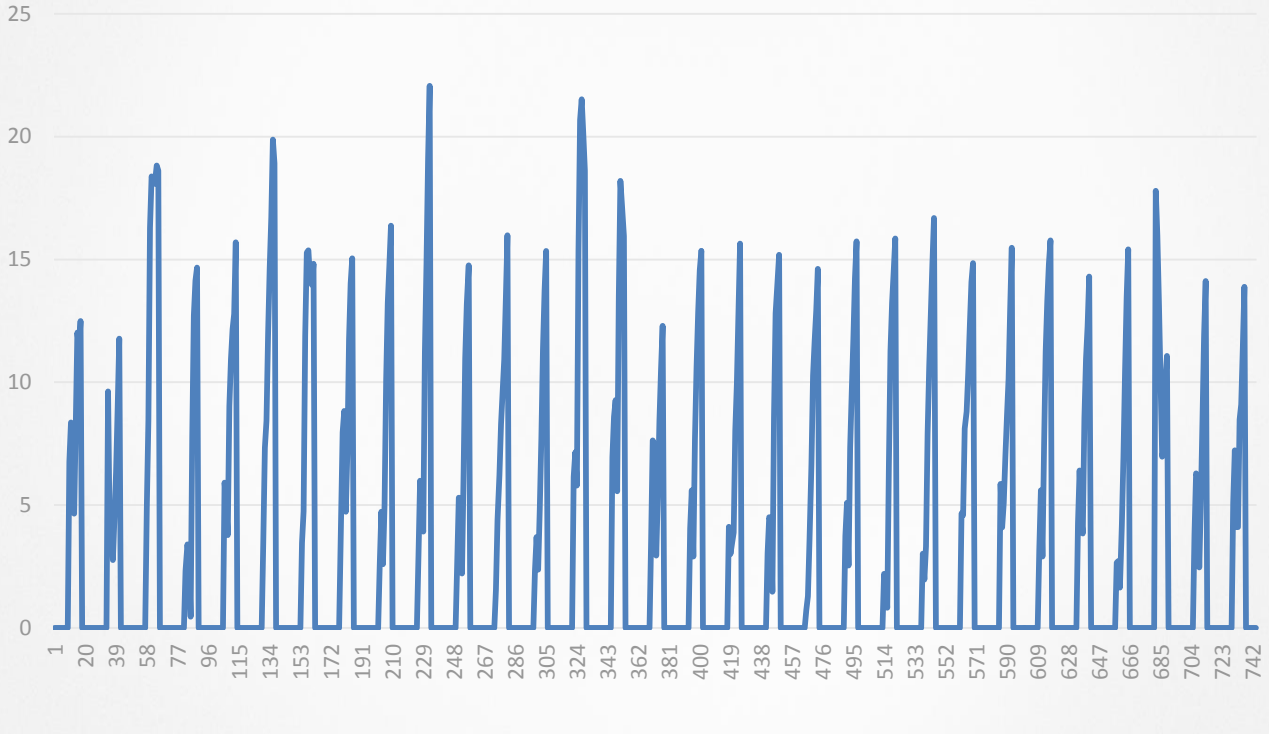
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Humidity, Singapore, (July)



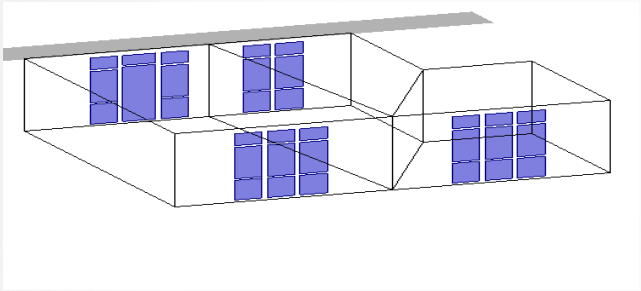
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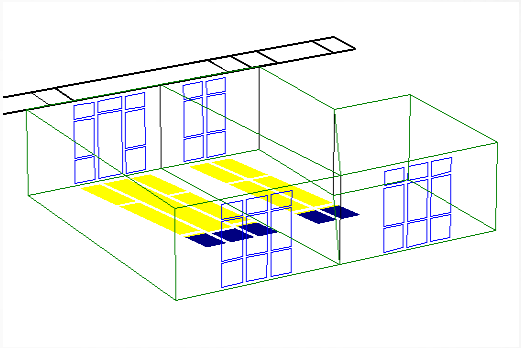
ACH, Singapore, (July)

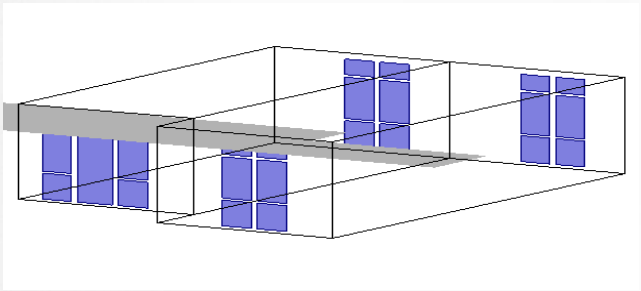


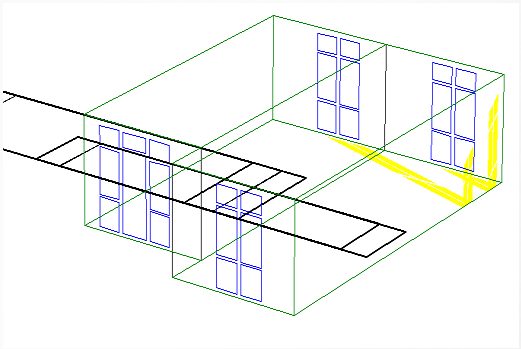
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High Rise Apartments

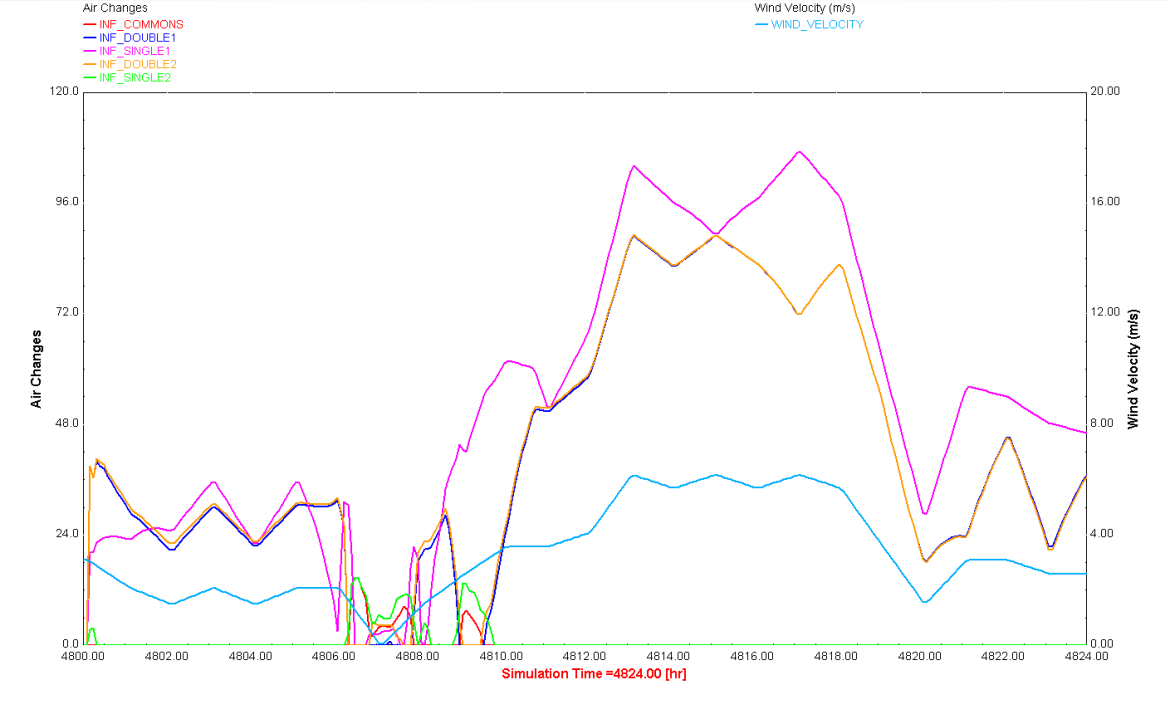








Infiltration air changes for each room. A zero infiltration means air is supplied to the room from connecting zones (doorways)



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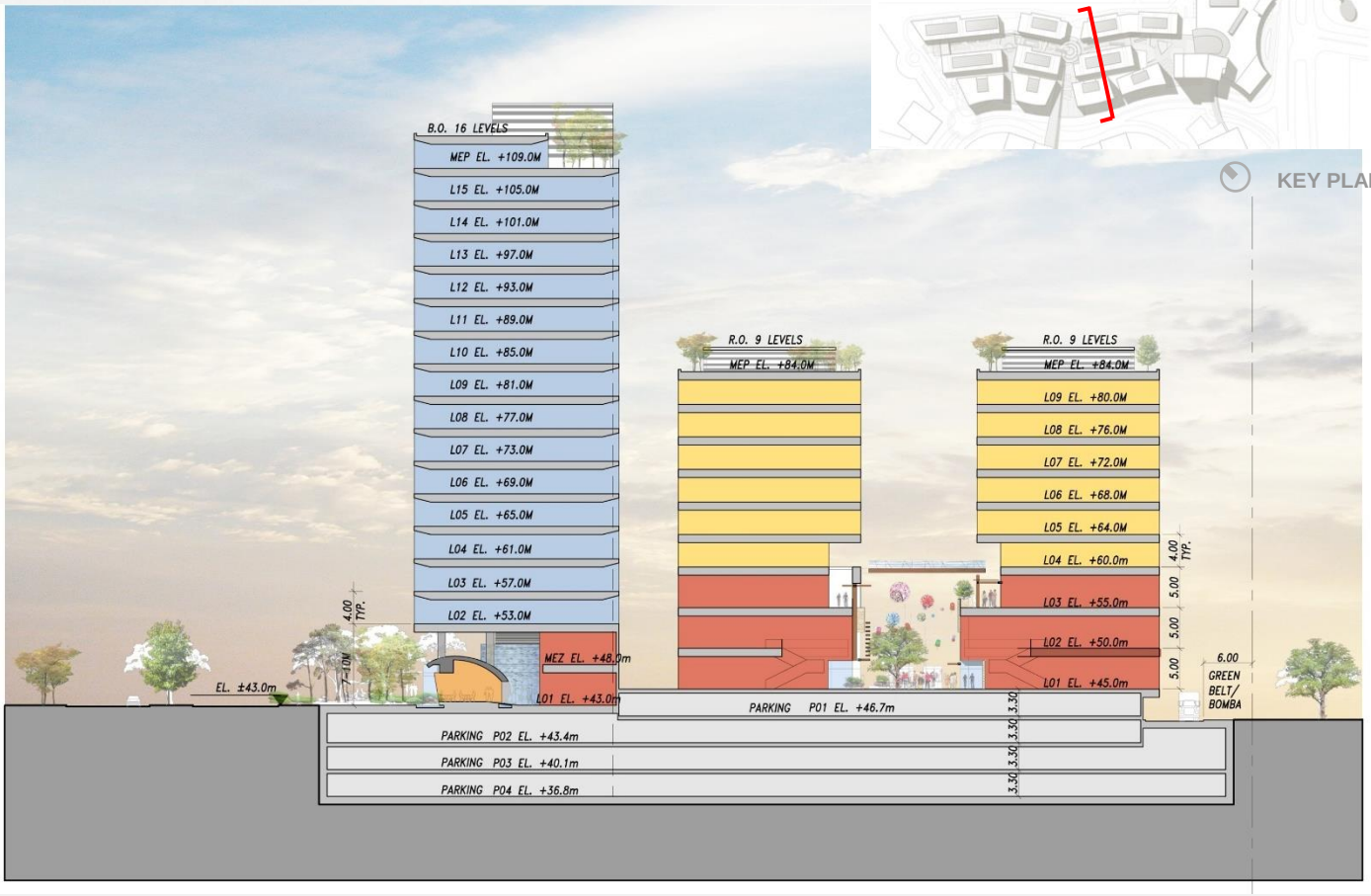


KEY PLAN



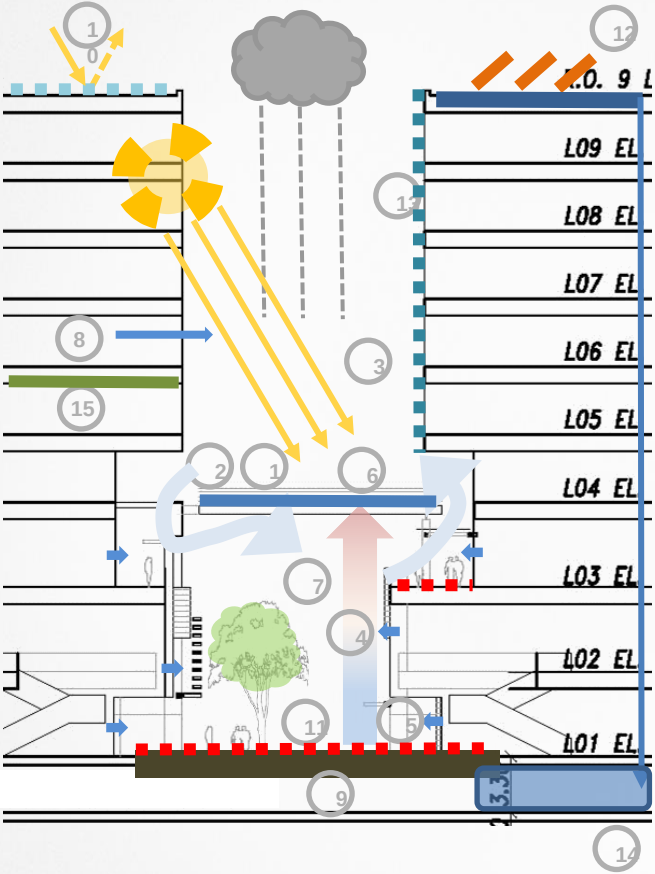
Long Section Through Festival Walk Canopy

RETAIL STREET SECTION VIEW



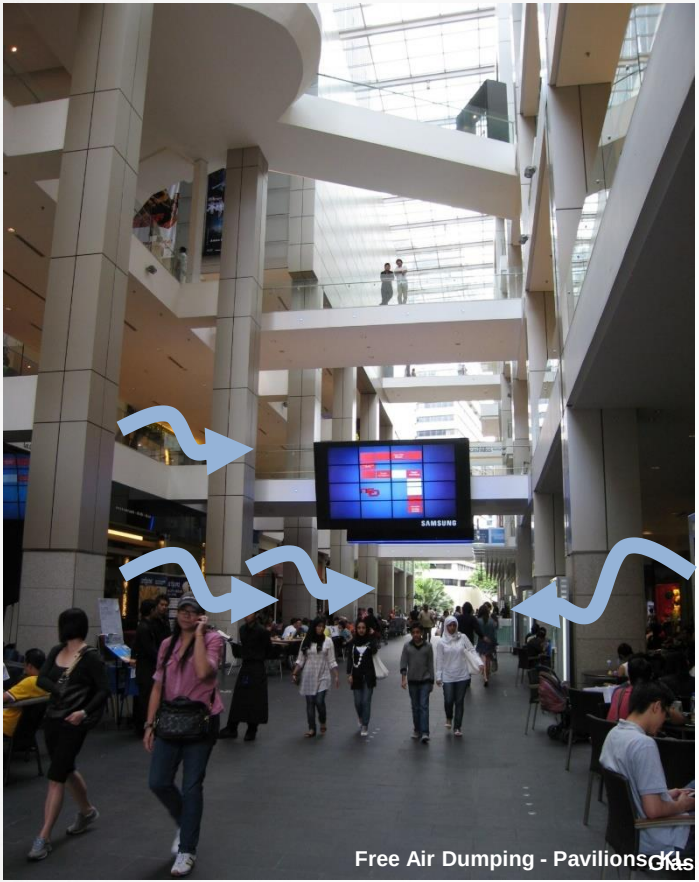
KEY PLAN

SECTION 2



SUSTAINABLE STRATEGIES – INTEGRATED DESIGN

1. Shading to reduce glare and solar heat gain
2. Operable roof to induce natural ventilation
3. Canopy to protect from rain
4. Natural stack effect to exhaust warm air
5. Cool air dumping from tenant A/C
6. High performance glass /ETFE to reduce solar gain
7. Trees to provide shade and 'outdoor' feel
8. Day lighting, views & indoor air quality
9. High thermal mass to reduce thermal flywheel effect
10. High albedo roof to reflect solar gain
11. Radiant cooling to floors
12. On site renewable energy – PV or solar hot water
13. High performance facade
14. Water Harvesting/ Grey water recycling
15. Recycled/locally sourced Materials



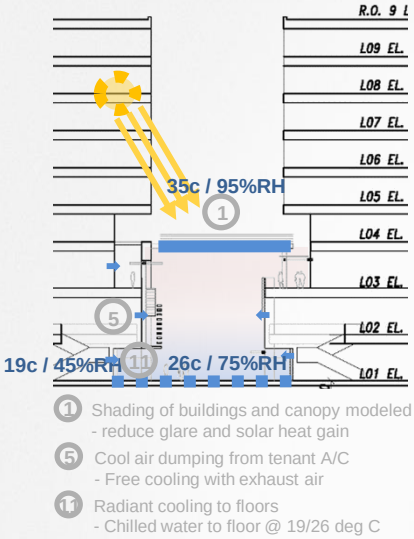
Free Air Dumping - Pavilions KL

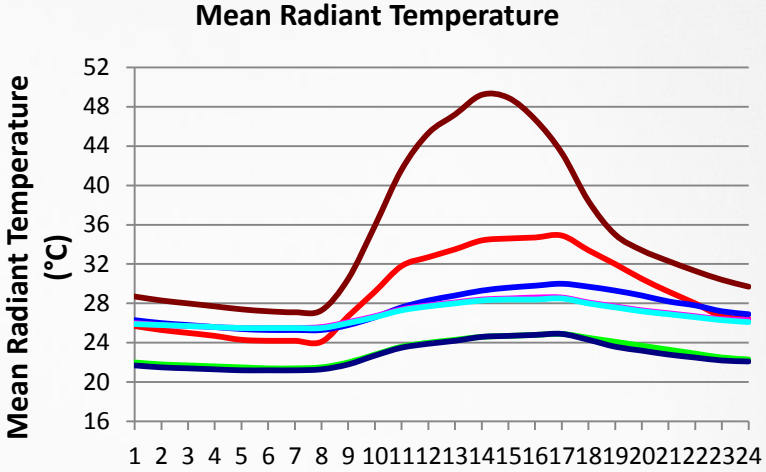


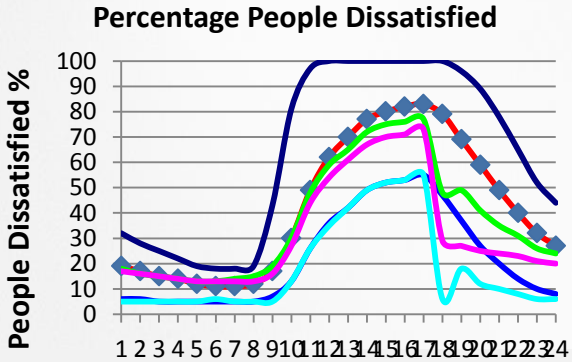
Mechanical Fans - Sunway Giza, Kota

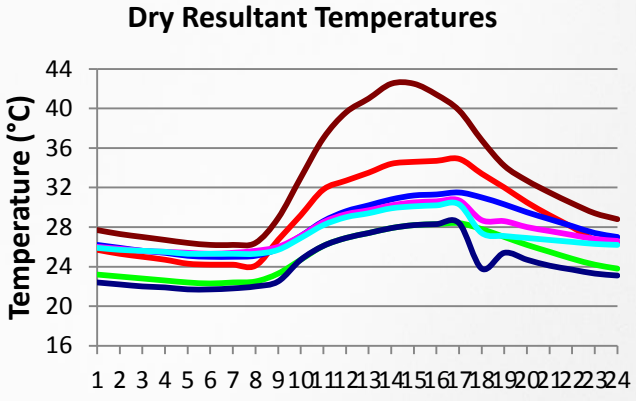


Glass canopy & AC diffusers - 101 Boulevard, Puchong


R.O. 9 L
L09 EL.
L08 EL.
L07 EL.
L06 EL.
L05 EL.
L04 EL.
L03 EL.
L02 EL.
L01 EL.
35c / 95%RH
19c / 45%RH
26c / 75%RH
1
5
11
1 Shading of buildings and canopy modeled
- reduce glare and solar heat gain
5 Cool air dumping from tenant A/C
- Free cooling with exhaust air
11 Radiant cooling to floors
- Chilled water to floor @ 19/26 deg C


Mean Radiant Temperature
Mean Radiant Temperature (°C)
52
48
44
40
36
32
28
24
20
16
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


Percentage People Dissatisfied
People Dissatisfied %
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


Dry Resultant Temperatures
Temperature (°C)
44
40
36
32
28
24
20
16
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Conclusions

The designer must-

- Understand the climate where the building is located
- Understand the use of the building
- Provide clear simple diagrams users can understand
- If there are conditions under which Natural Ventilation will not suffice, then fully describe those conditions.
- Having designed the system, be sure to check the architects specifications regarding windows and all other openings.

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THANK YOU SLIDE

For More Details

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