From principles to practice :-
Integrating natural ventilation in modern building design

Passive Cooling Working Group

Conducted By:-
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PRINCIPLES

Why Natural Ventilation

Thermal Comfort

- Physiological cooling:
  - Convective heat transfer from skin
  - Evaporative heat transfer from skin

- Convective cooling: air carrying/ taking away heat with it. Prevent overheating in summer

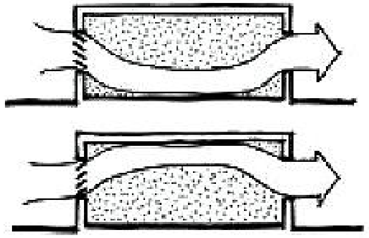
Why Natural Ventilation

Air Quality

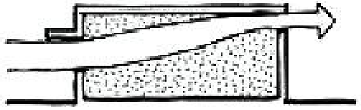
- Supply of fresh air to remove indoor pollutants
    - (CO,CO2,VOCS,microbes)

How Natural Ventilation works

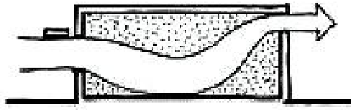
Wind driven Cross ventilation



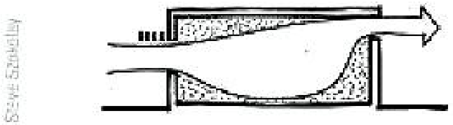
Louvres can direct airflow upward or downward.



A canopy over a window tends to direct air upward.

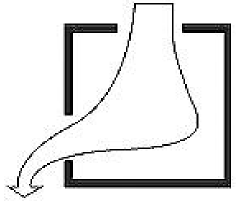


A gap between canopy and wall ensures a downward pressure.

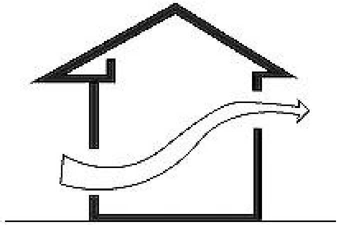


Downward pressure is improved further in the case of a louvered sunshade.

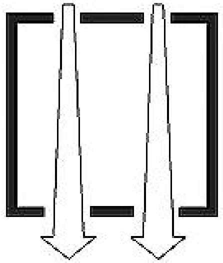
_cross-ventilation

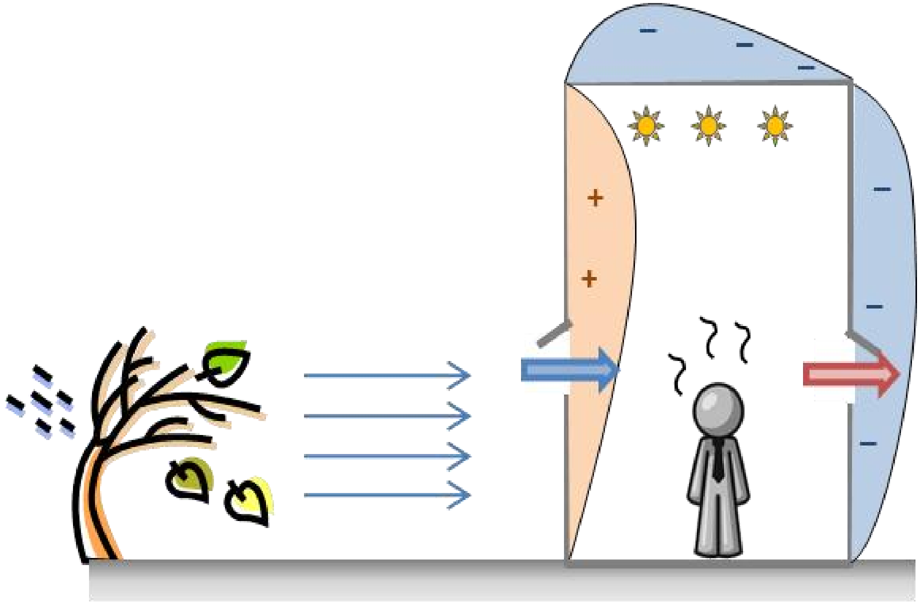


_higher up windows to allow hot air to escape



_smaller inlet windows facing prevailing winds and larger outlet windows on opposite side

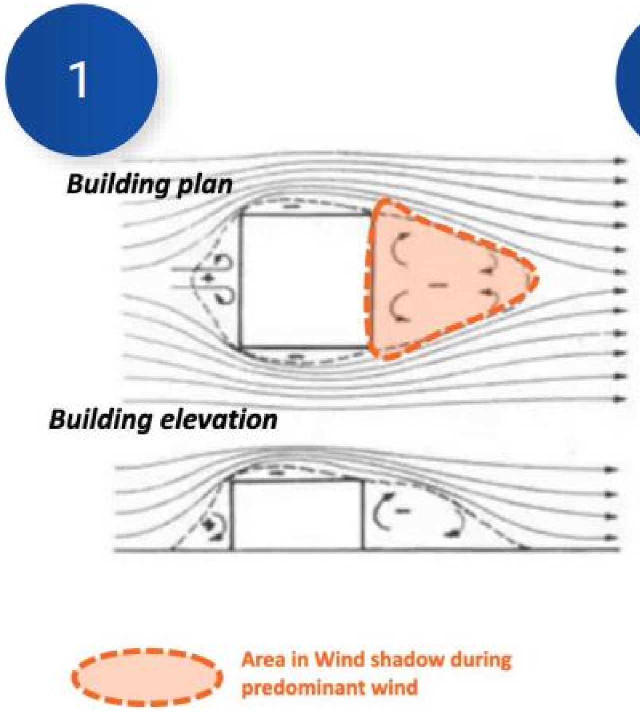


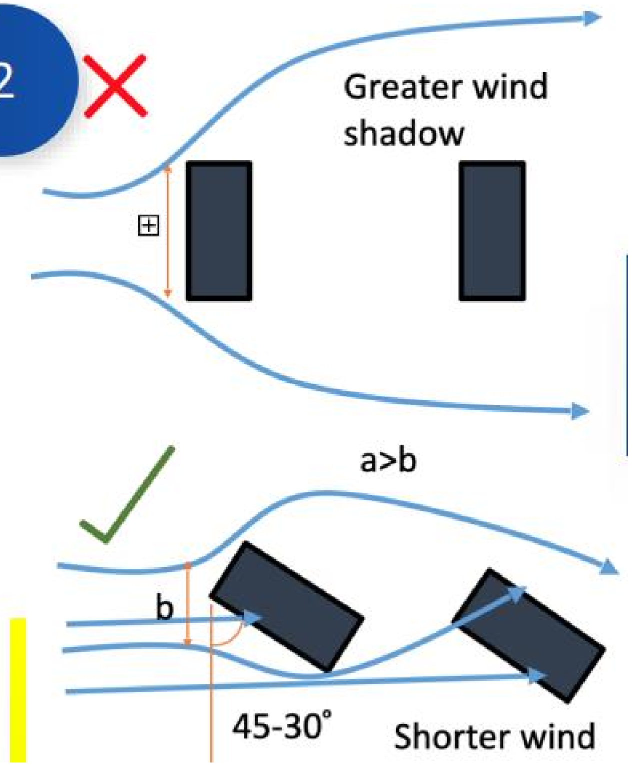


High pressure *Low pressure*

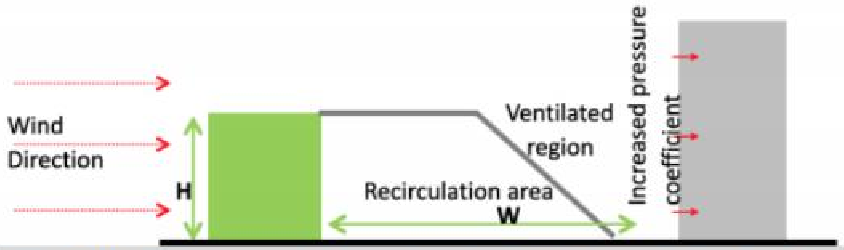
How Natural Ventilation works

Wind driven Cross ventilation



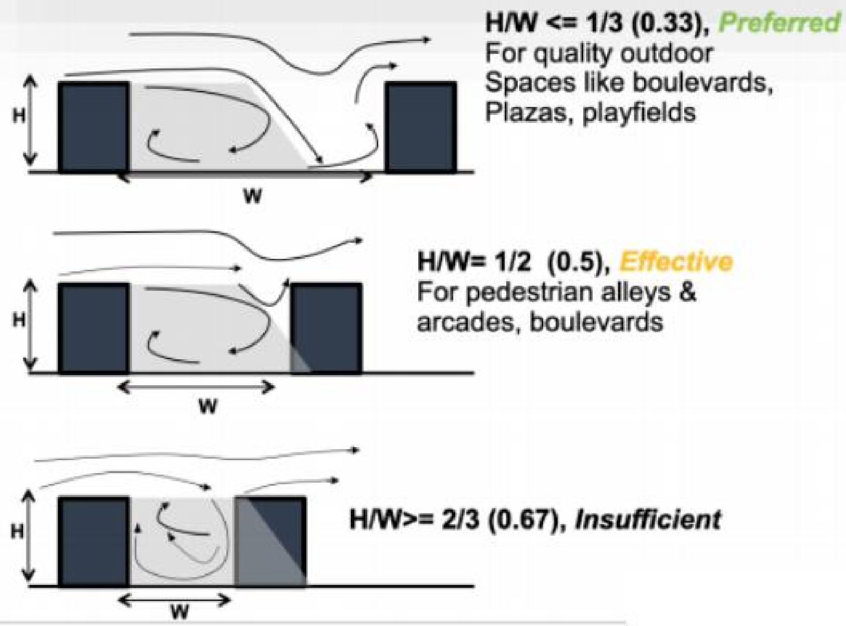


Lower building heights towards windward side



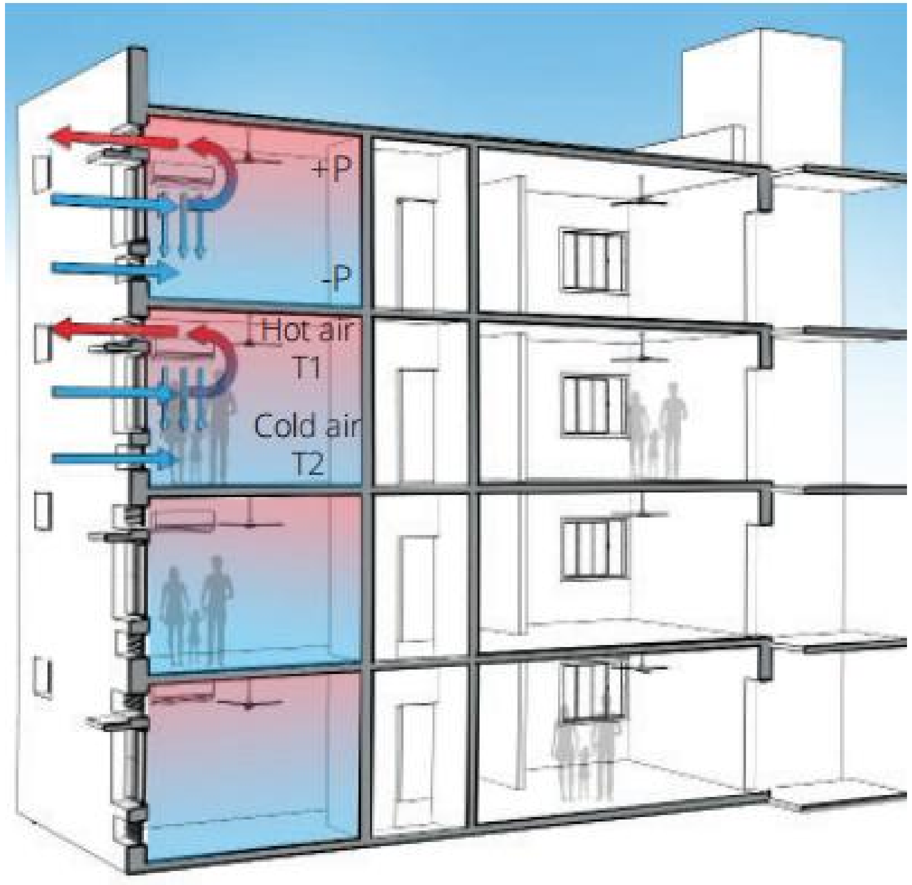
Width (W) – The average distance from the building facade edges to the shortest distance to the adjacent block.

Incase building heights cannot be varied, and buildings are placed one behind the other in the wind direction, following needs to be ensured.



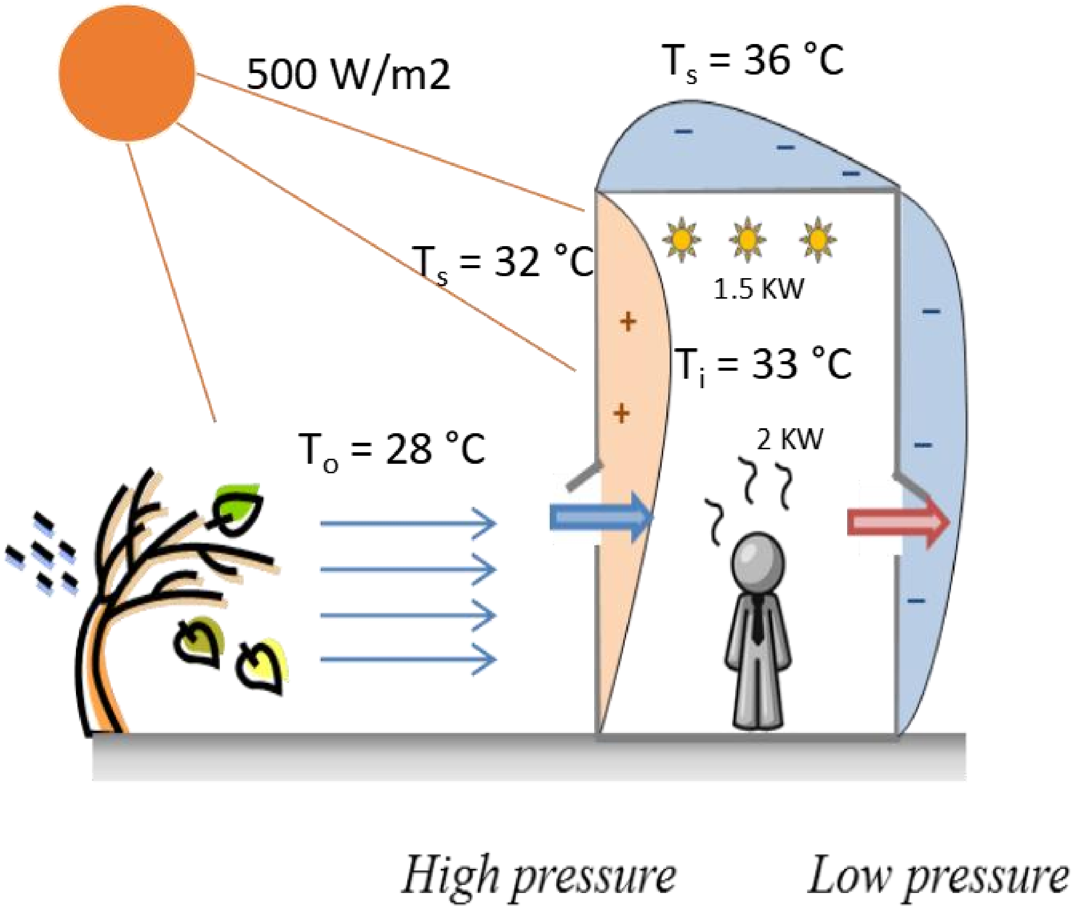
How Natural Ventilation works

Buyoancy driven / Stack ventilation



How Natural Ventilation works

Cooling effect of Ventilation



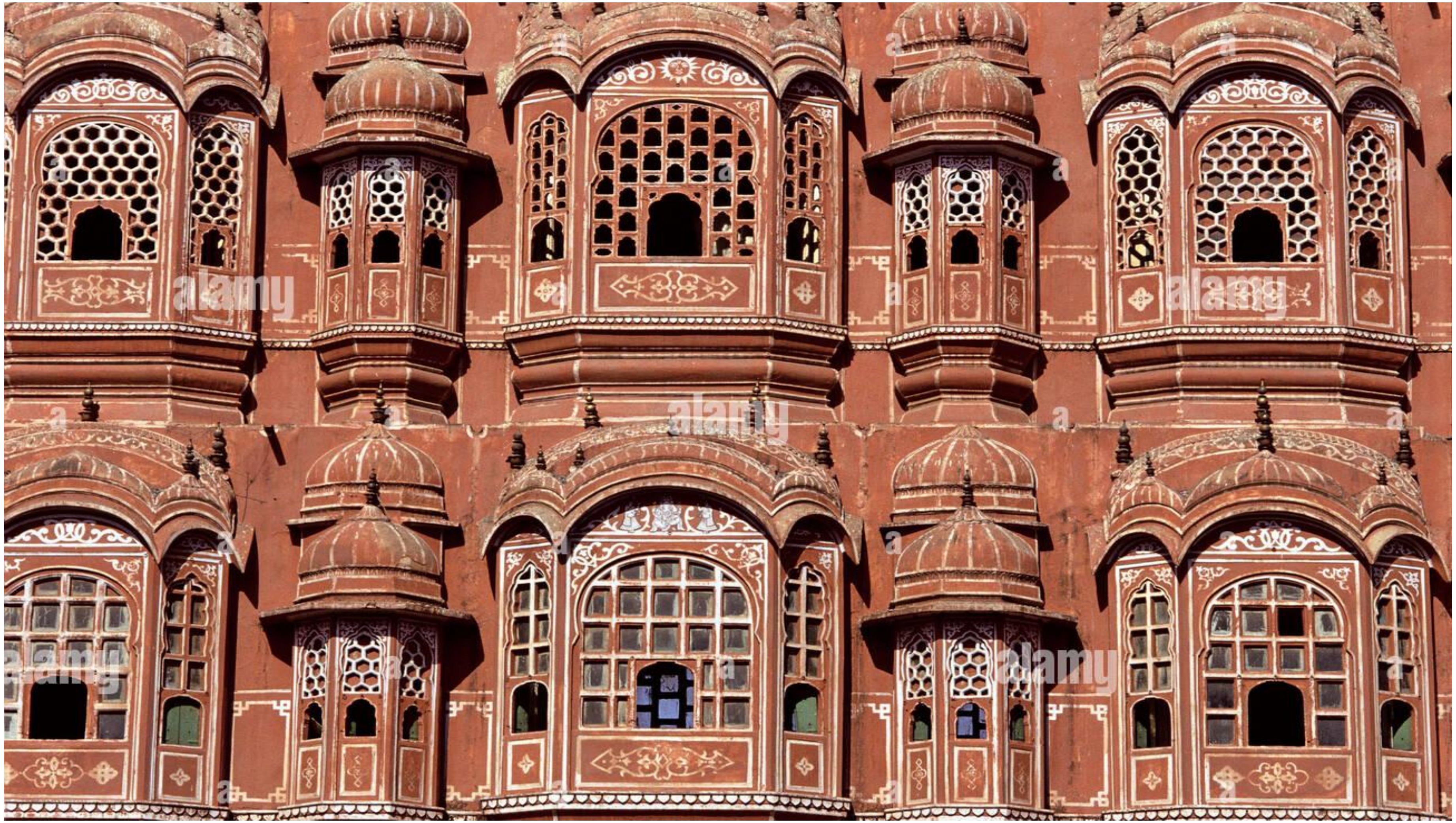
Indoors warmer than Outdoors

Enough quantity / flow rate to remove internal heat

Assisted with Passive Design elements

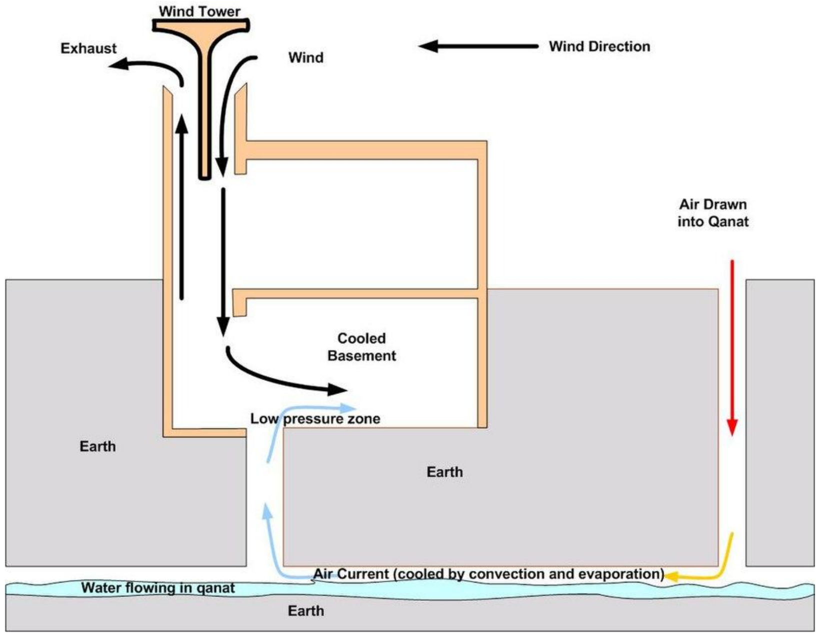
PRACTICE

Design for Natural Ventilation



Indespensible part of vernacular architecture

Design for Natural Ventilation



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Design for Natural Ventilation

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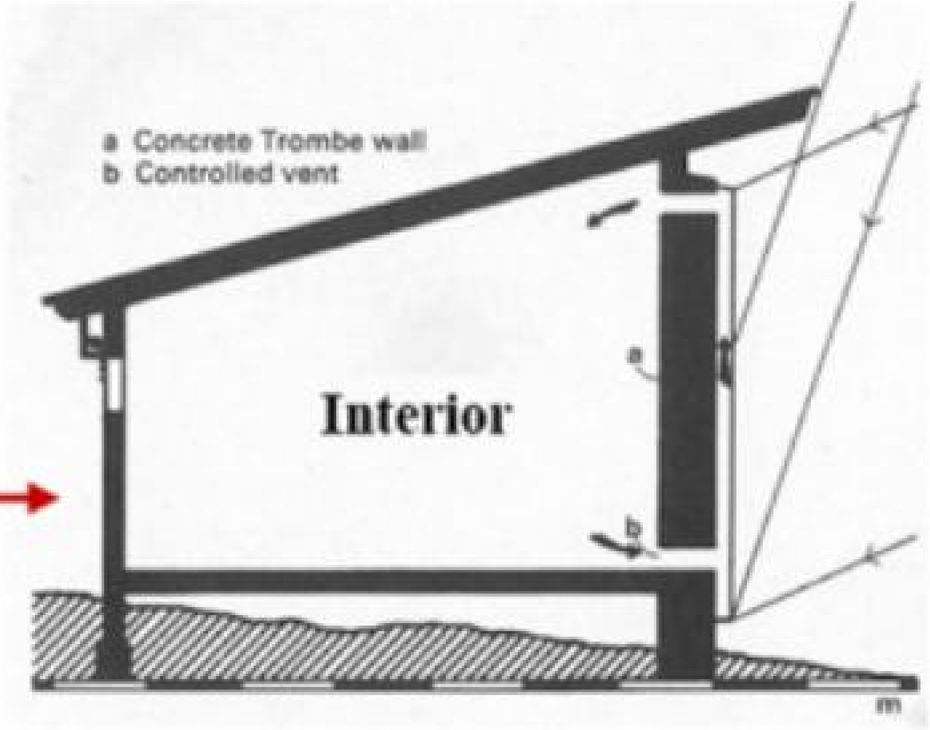
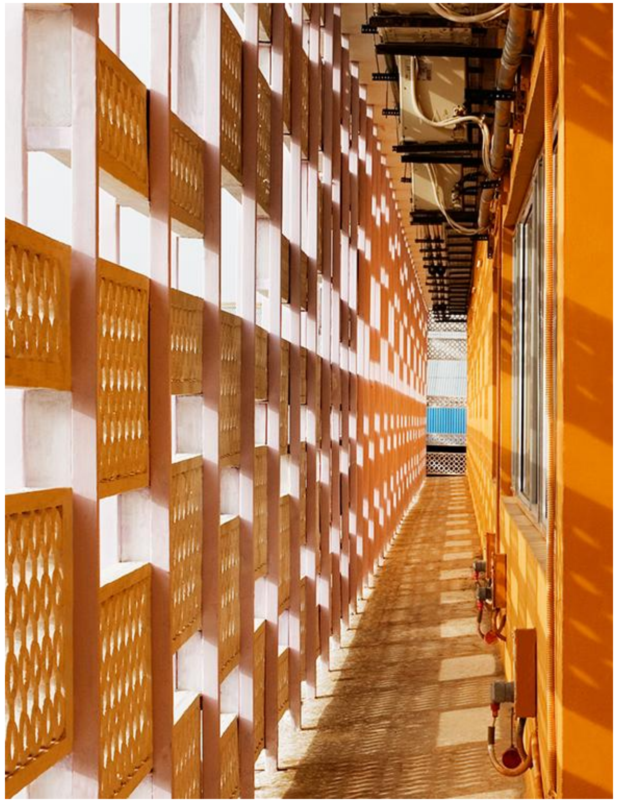
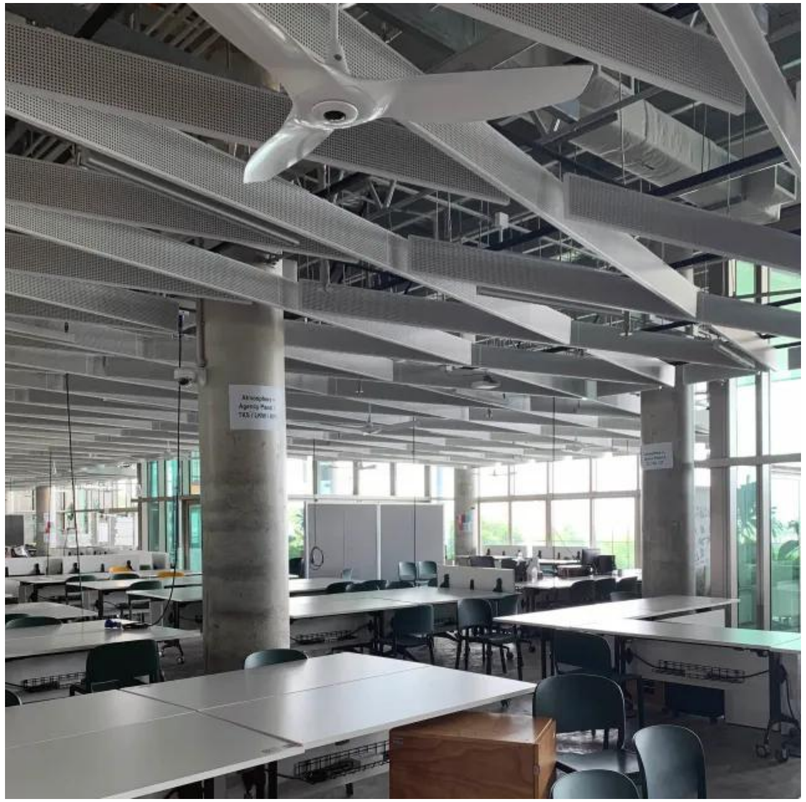
Design for Natural Ventilation



Indespensible part of vernacular architecture

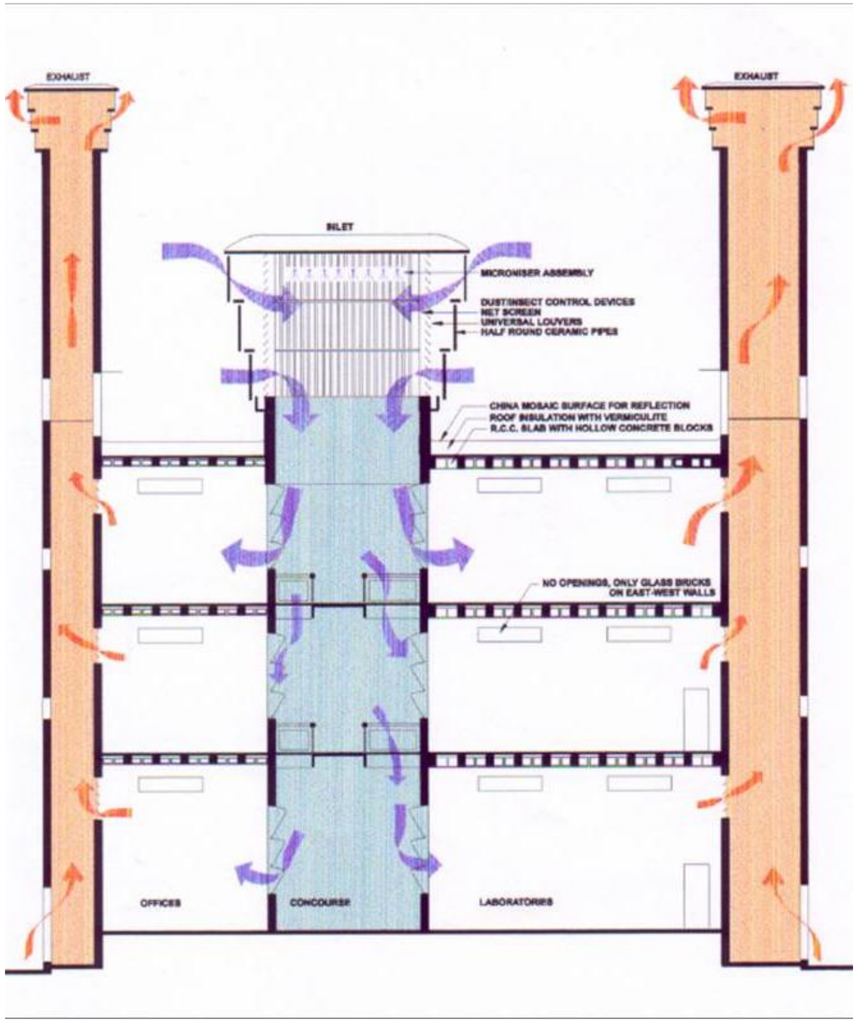
Modern Adaptation - Levaraging Mechnaical asistance with NV





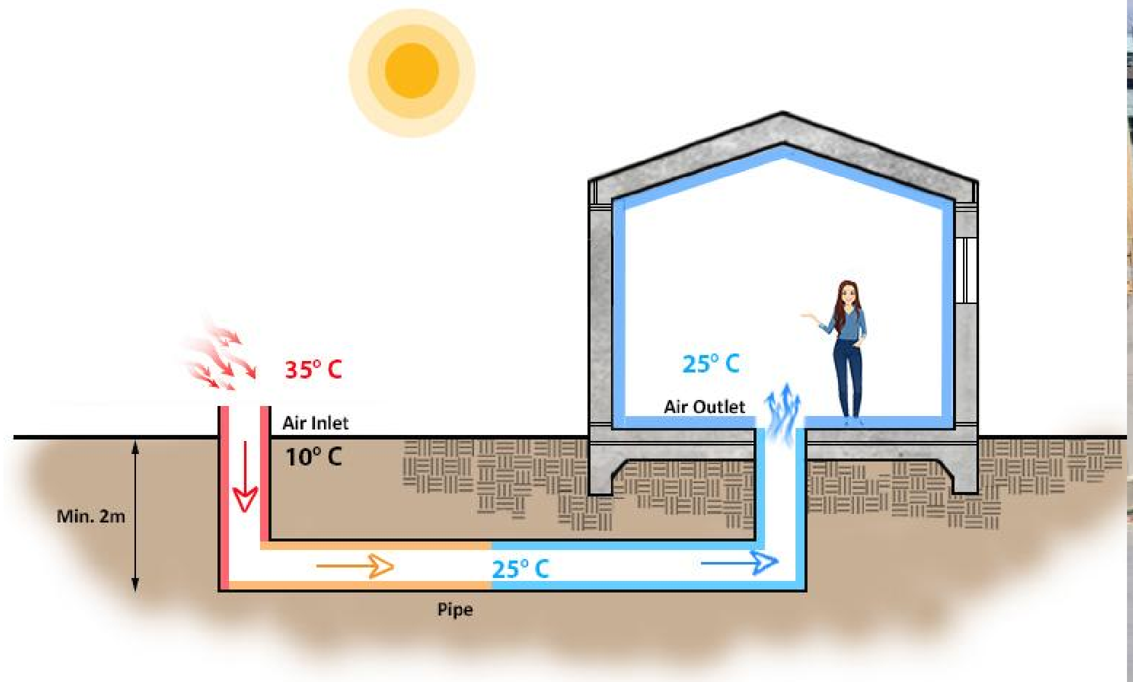
Double skin - ventilated facades and Ceiling Fans

Modern Adaptation - Levaraging Mechnaical asistance with NV



Solar chimneys and Passive Downdraft Evaporative Coolers

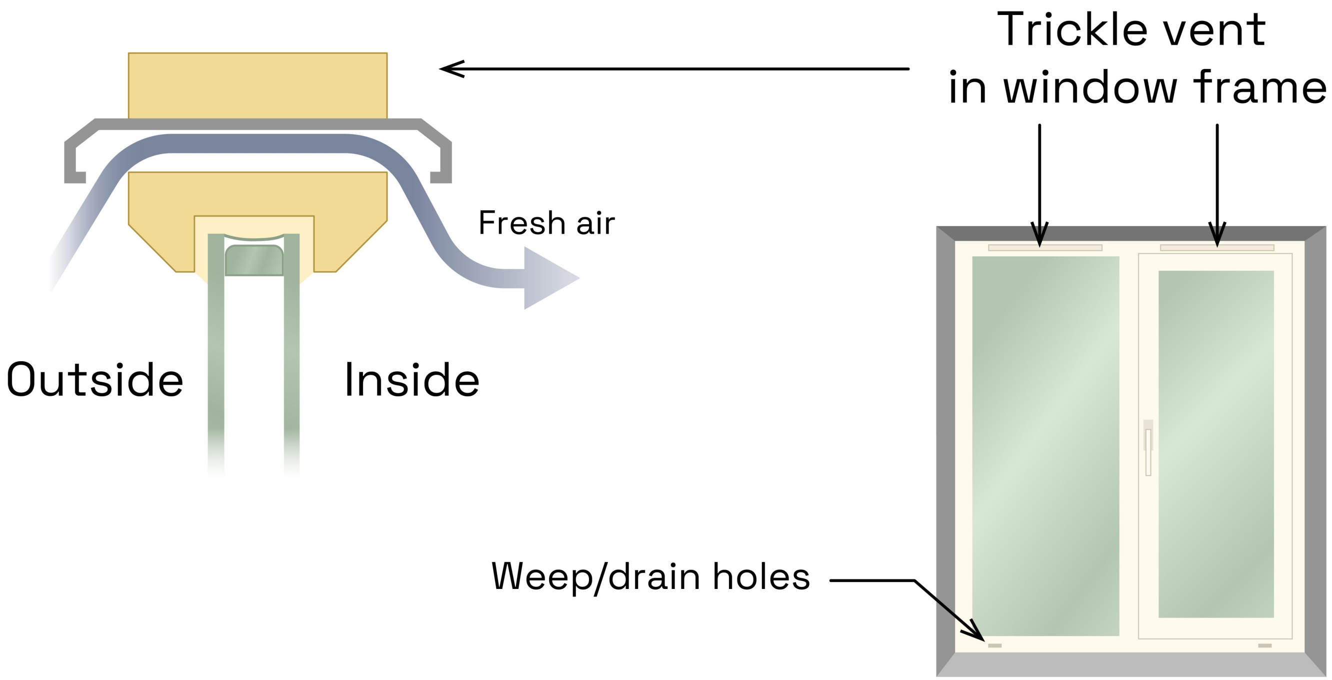
Modern Adaptation - Levaraging Mechnaical asistance with NV



Earth Air tunnels

Modern Adaptation - Levaraging Mechnaical asistance with NV

Trickle vents in windows

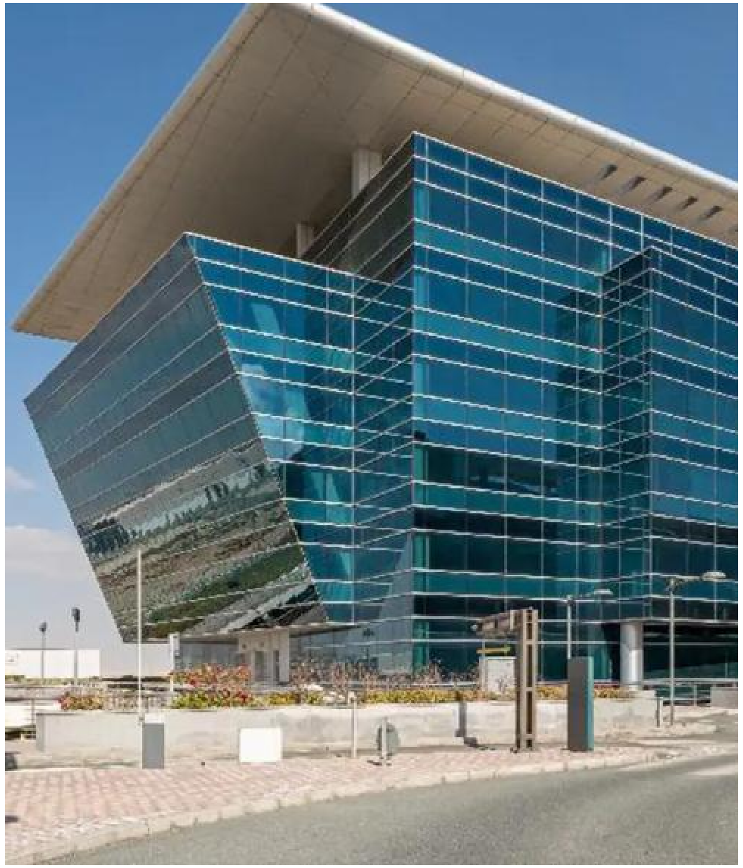


Trickle windows and Swirl Ventilator for Fresh Air

BUT THESE FEATURES ARE BECOMING LESS COMMON

Dissappearing Design for Ventilation - UNIVERSALIZATION OF ARCHITECTURE

India



Dubai

London

AIR CONDITIONING

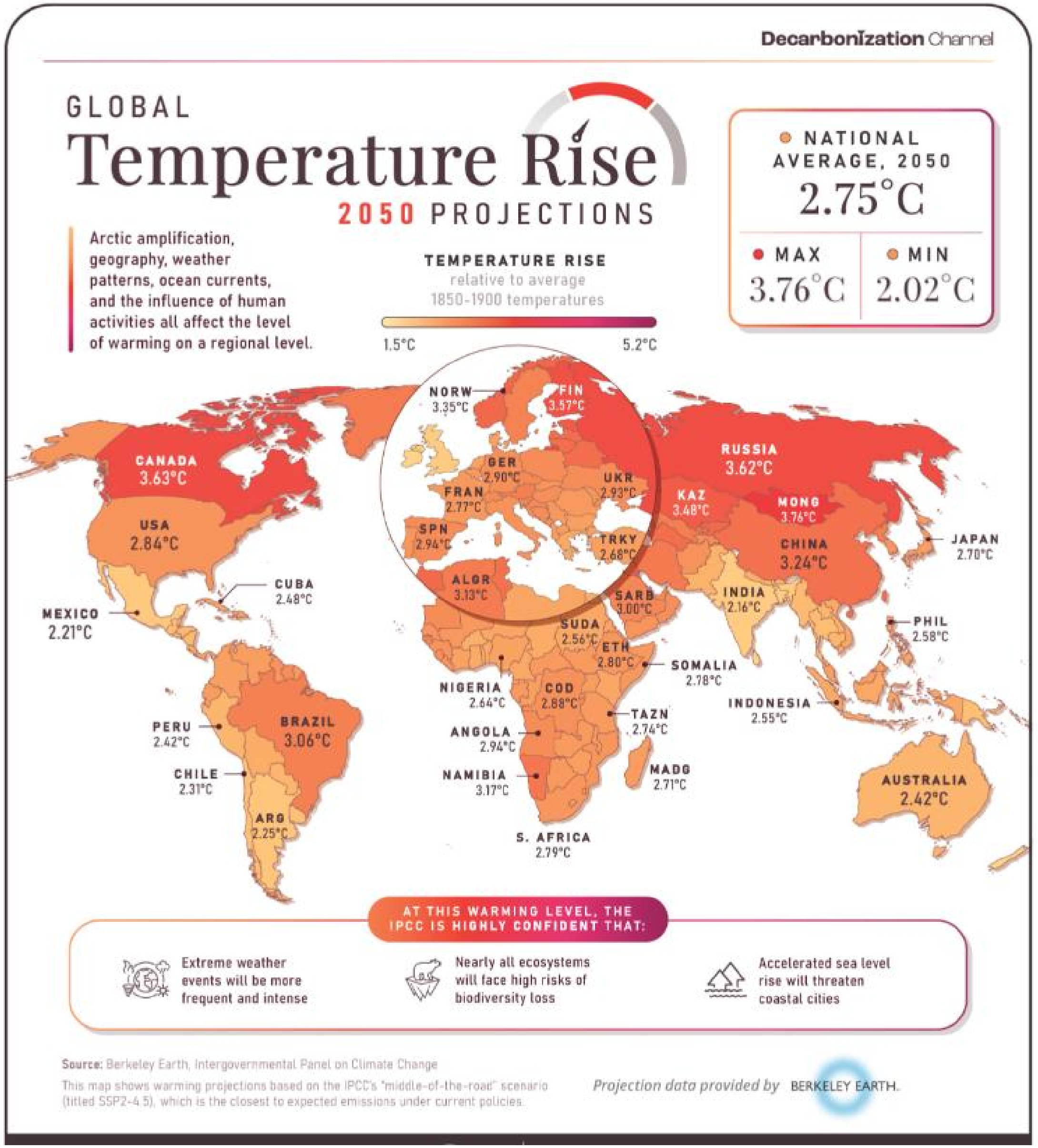
=

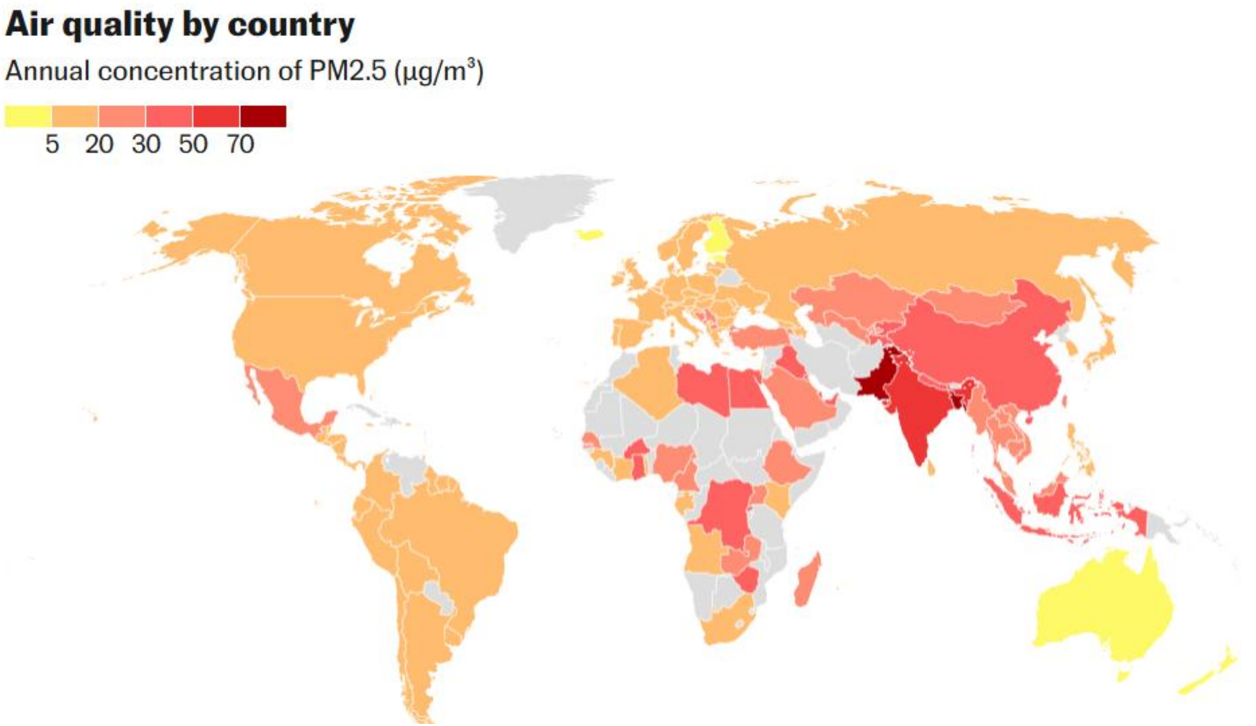
AIR TIGHTNESS

=

SUPER INSULATED

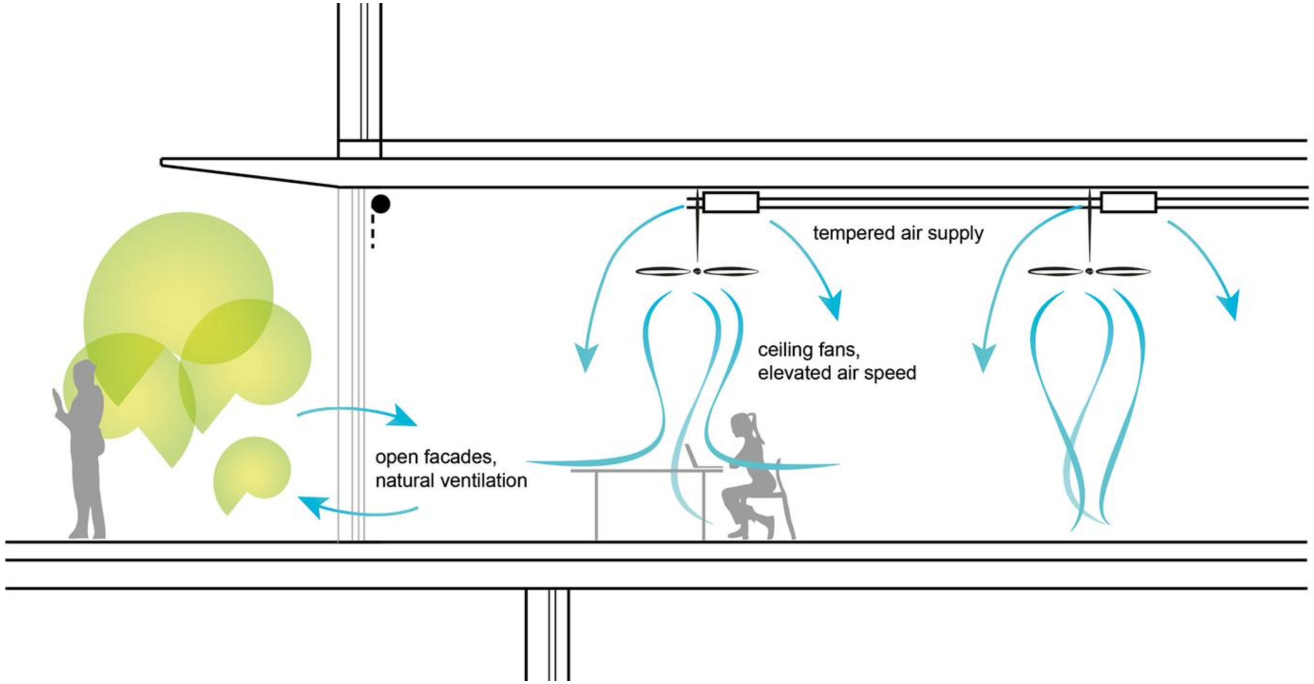
Dissappearing Design for Ventilation - Global warming and rising Pollution

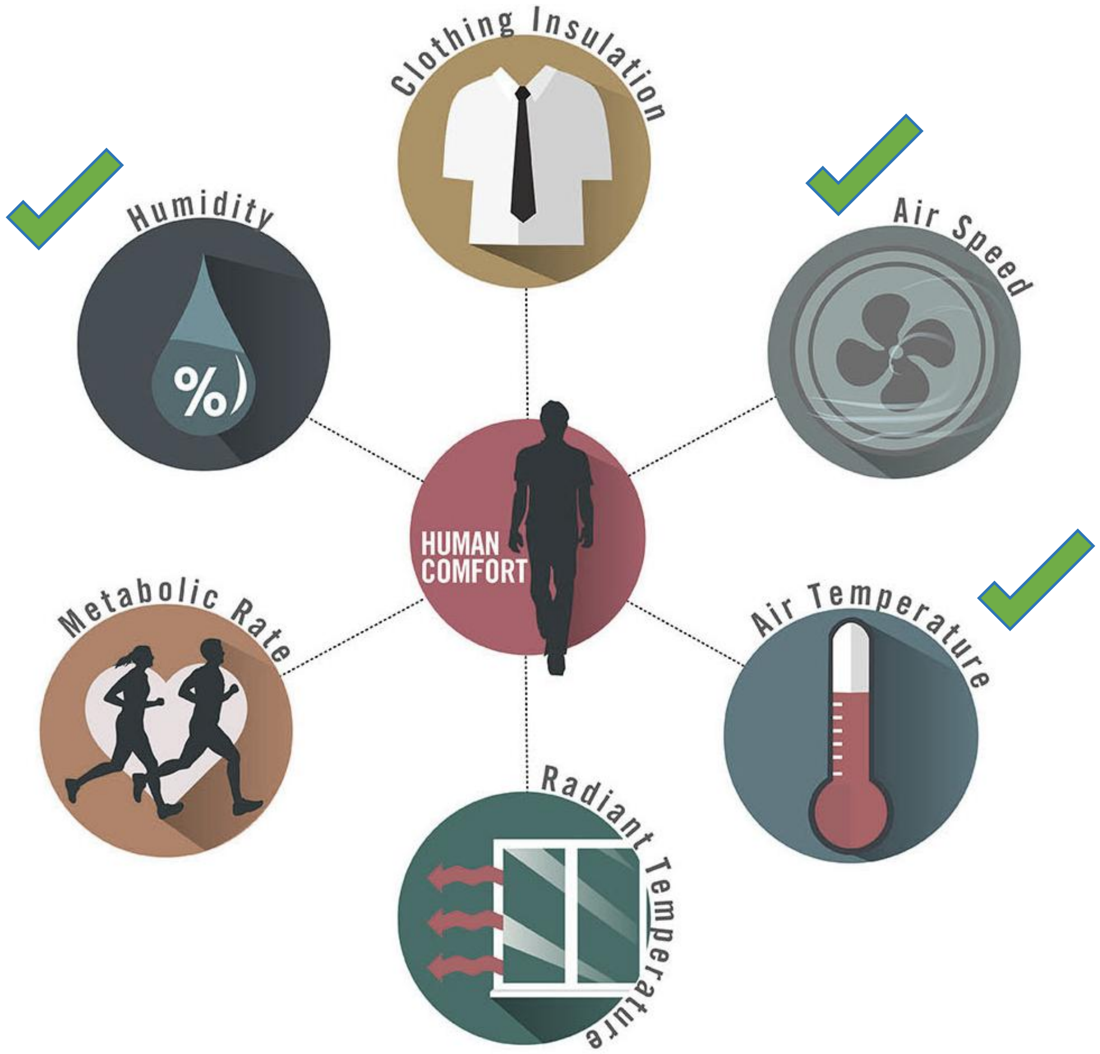




Natural Ventilation opportunity based on Climate Classification

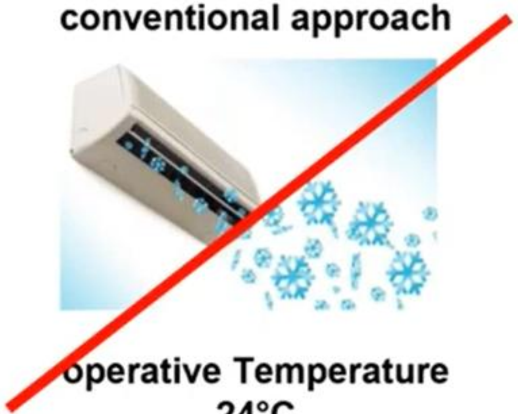
Thermal comfort and Ventilation





Adaptive THERMAL COMFORT

conventional approach



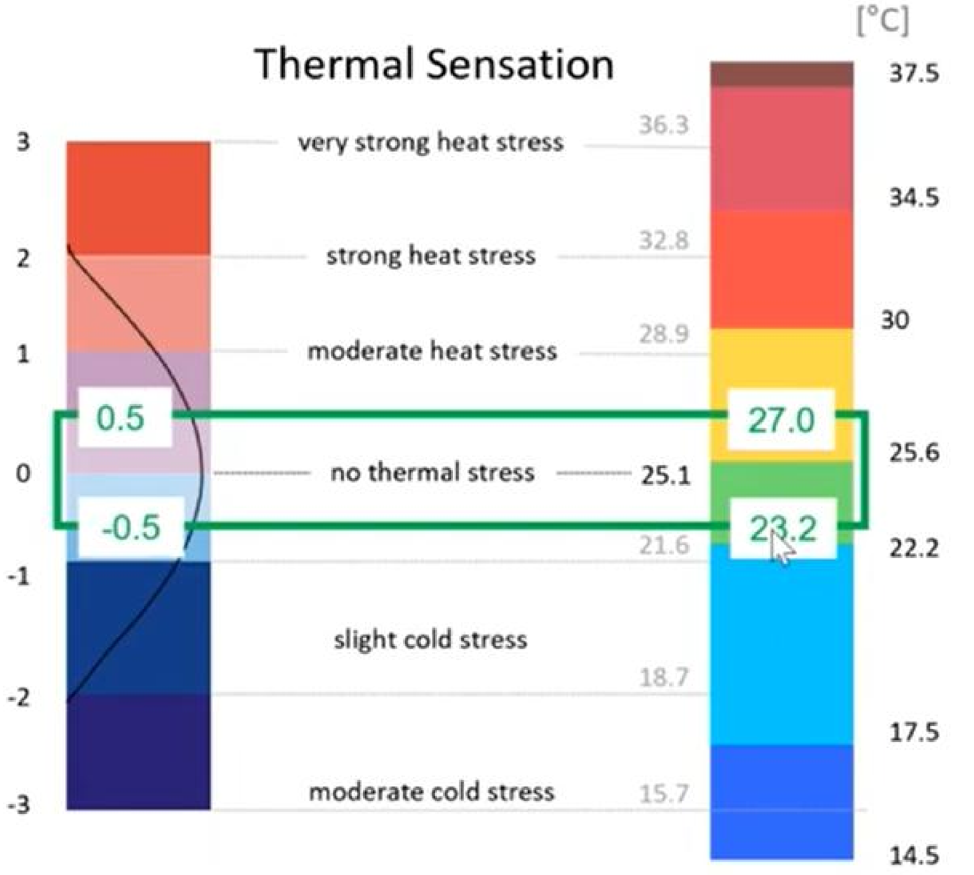
operative Temperature 24°C

adaptive comfort approach

operative Temperature 29°C
tempered air + elevated air speed

Model Predicted Mean Vote (PMV)

Model Standard Effective Temperature (SET)



Adaptive THERMAL COMFORT

Thermal comfort and Ventilation

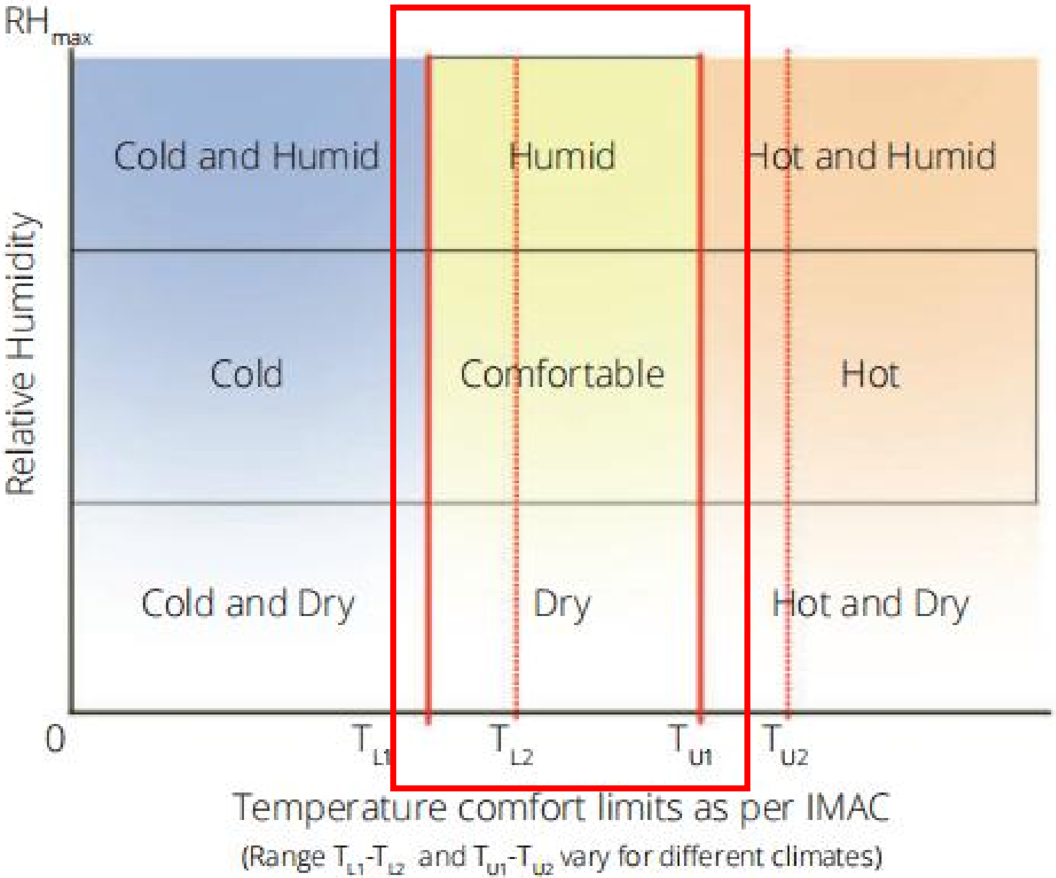
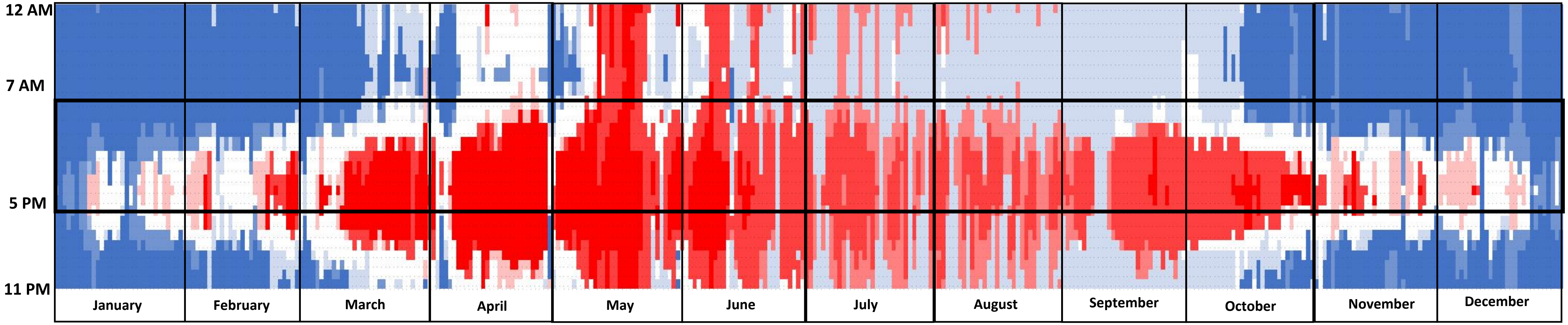


Figure 2: The logic for categorization of annual hours based on temperature and humidity thresholds. Source: Manu et. al. (2016).

Operation mode	Temperature thresholds	RH thresholds
Natural Ventilation	Within the 80% acceptability band	30% -70%
Heating	< Lower limit of 80% acceptability	30% -70%
Heating and Dehumidification	< Lower limit of 80% acceptability	>70%
Cooling	> Upper limit of 80% acceptability	30% -70%
Cooling and Dehumidification	> Upper limit of 80% acceptability	>70%
Dehumidification	Within the 80% acceptability band	>70%
Humidification	Within the 80% acceptability band	<30%
Heating and Humidification	< Lower limit of 80% acceptability	<30%
Cooling and Humidification	> Upper limit of 80% acceptability	<30%

Source:-
LeCAVIR CARBSE CEPT

Thermal comfort and Ventilation



No.	Condition	% OF HOURS (TOTAL IN THE YEAR)	
1	Cold & Humid	24.9%	2182.0
2	Cold	4.7%	410.0
3	Cold & Dry	0.0%	2.0
4	Humid	19.4%	1703.0
5	Comfortable	15.2%	1333.0
6	Dry	3.2%	277.0
7	Hot & Humid	5.6%	493.0
8	Hot	16.3%	1430.0
9	Hot & Dry	10.6%	930.0
		100.0%	8760.0

Thermal comfort and Ventilation - Different Climates in India

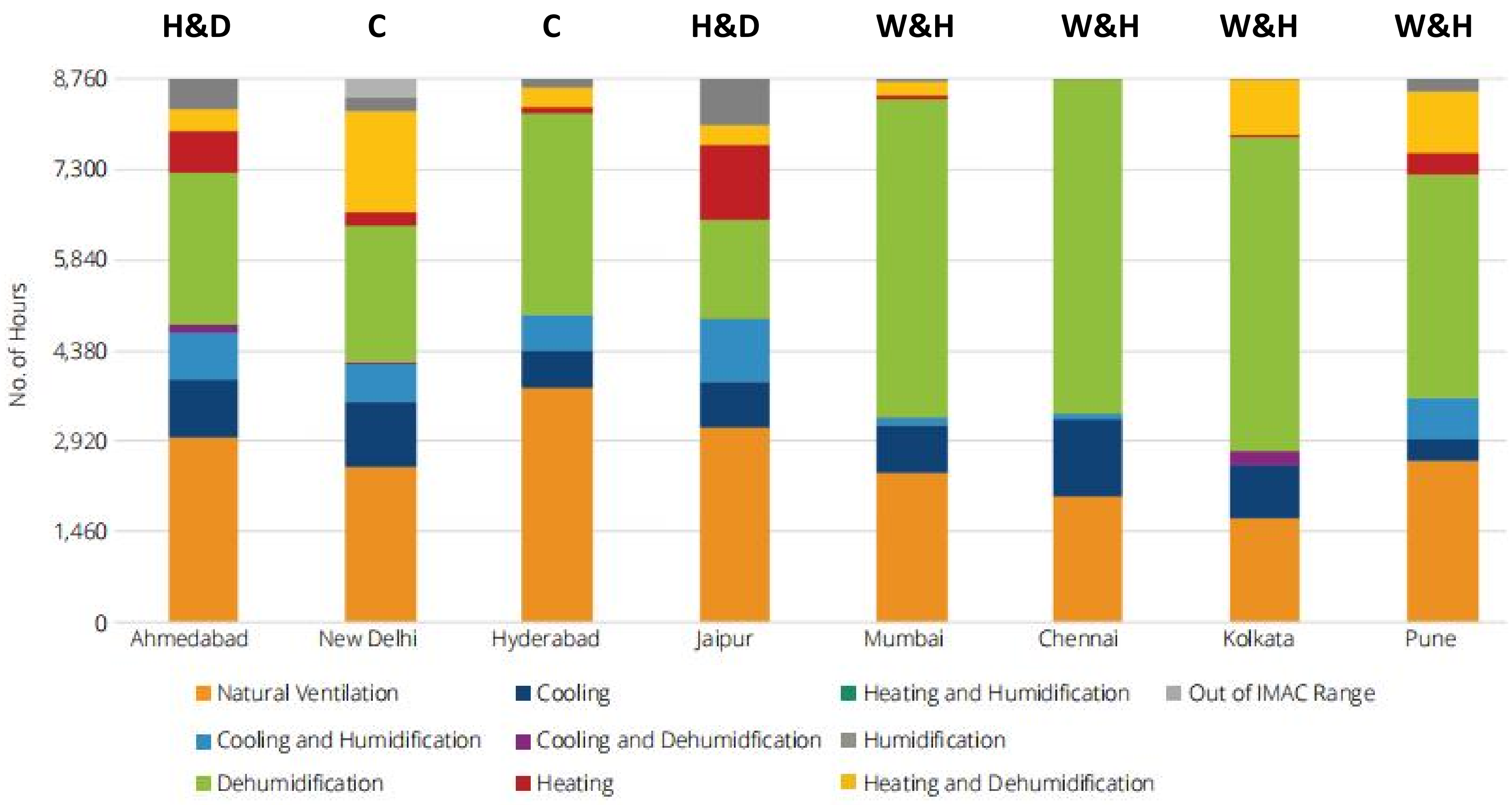
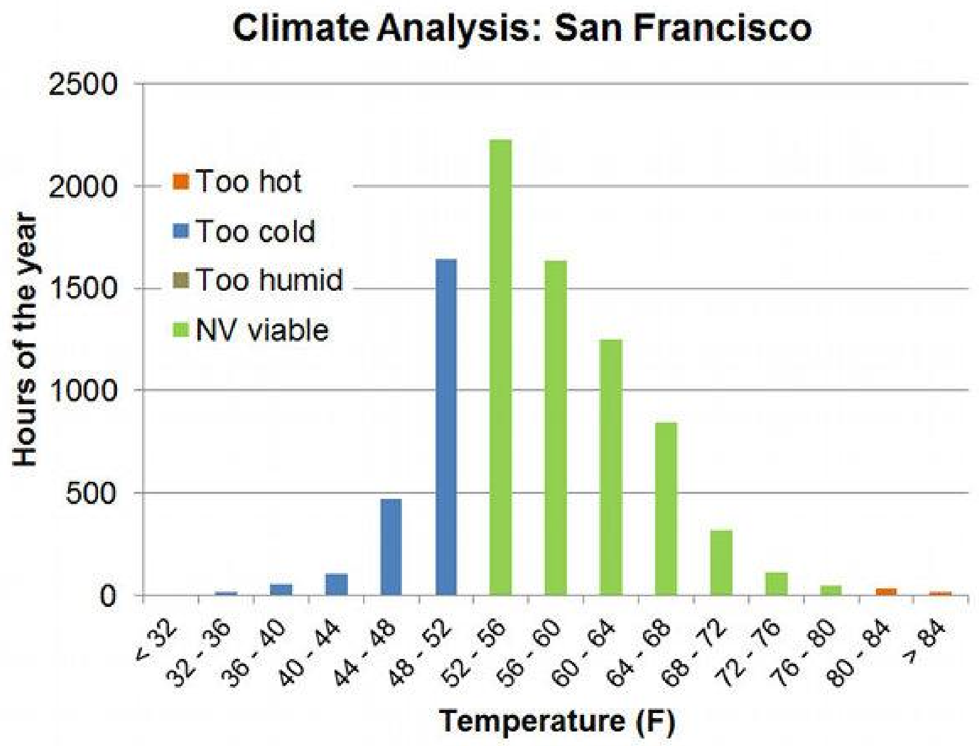
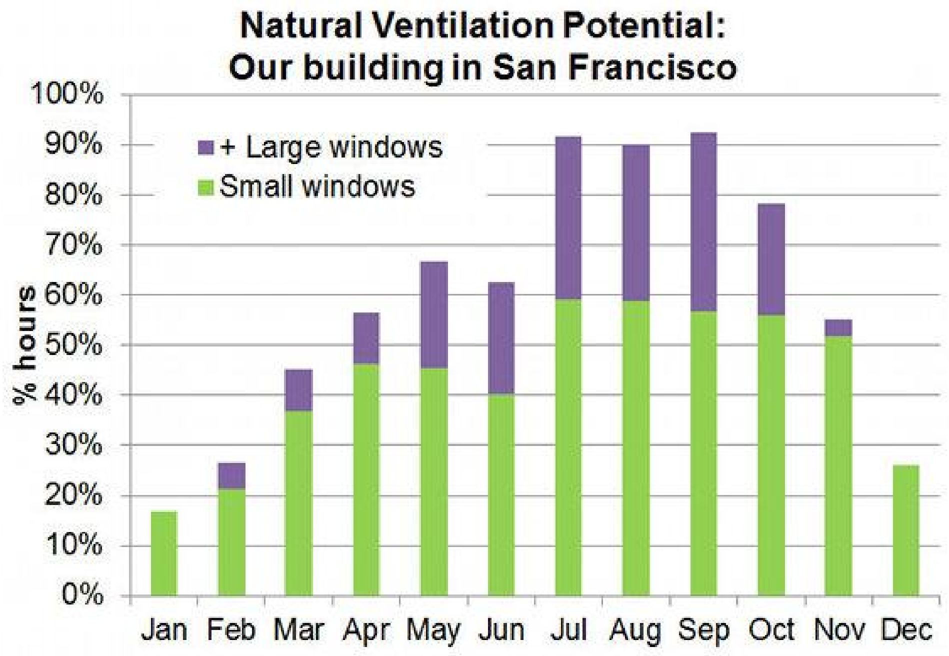


Figure 3: Number of comfort hours in a year for different operating modes as per IMAC-MM for eight Indian cities.

Source:-
LeCAVIR CARBSE CEPT

Thermal comfort and Ventilation - San Francisco *Climate Zone 3C (Warm Marine)*





NV viability 73% of year

NV potential:

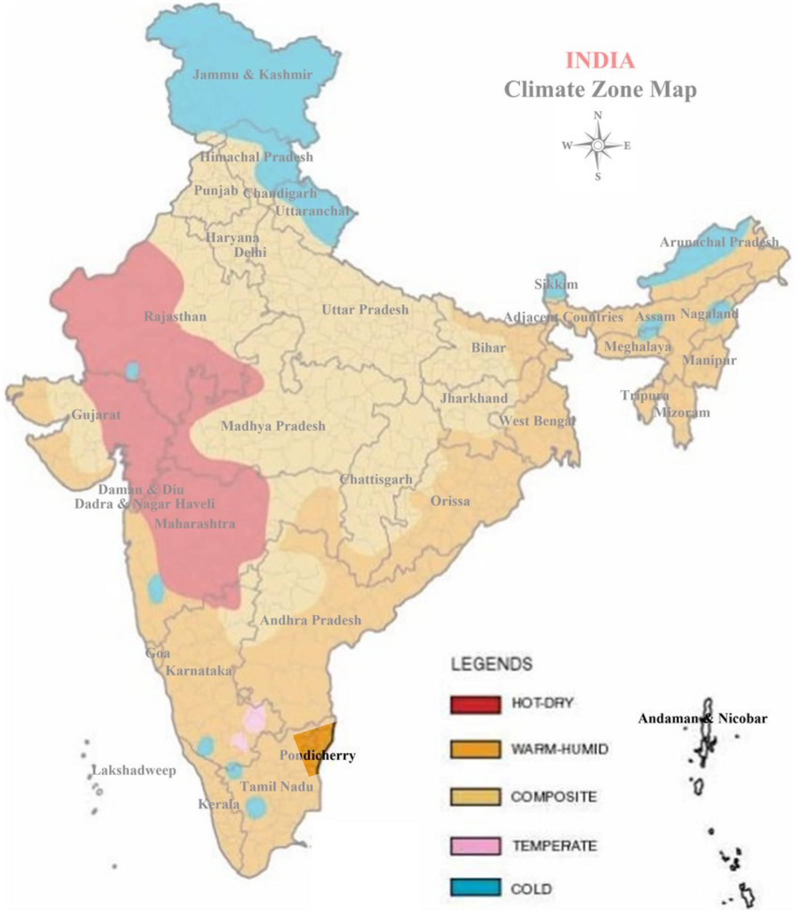
- 43% of year (small windows)
- 59% of year (large windows)

Source:- BuildingGreen.com

Natural ventilation for thermal comfort

- Wind driven Cross ventilation

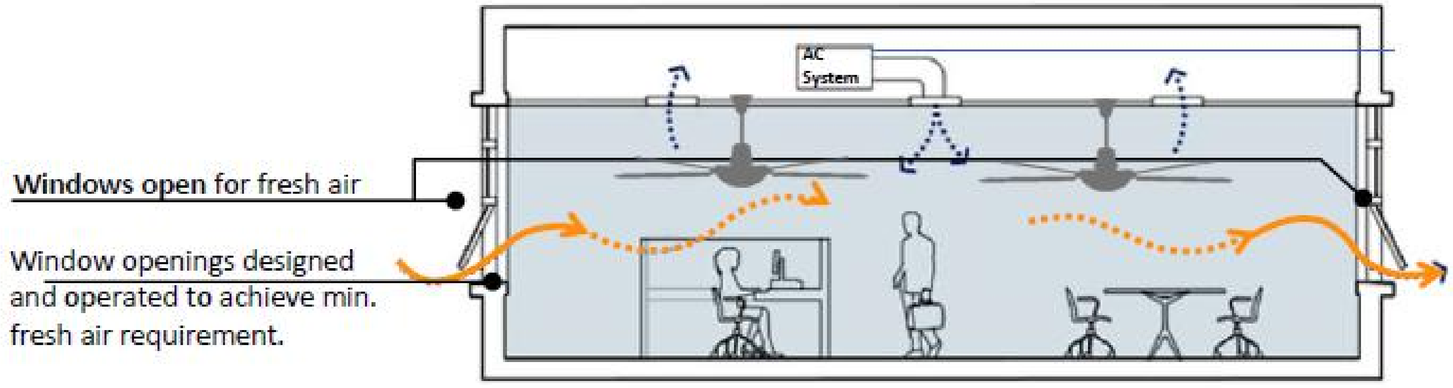
Wind driven Cross ventilation



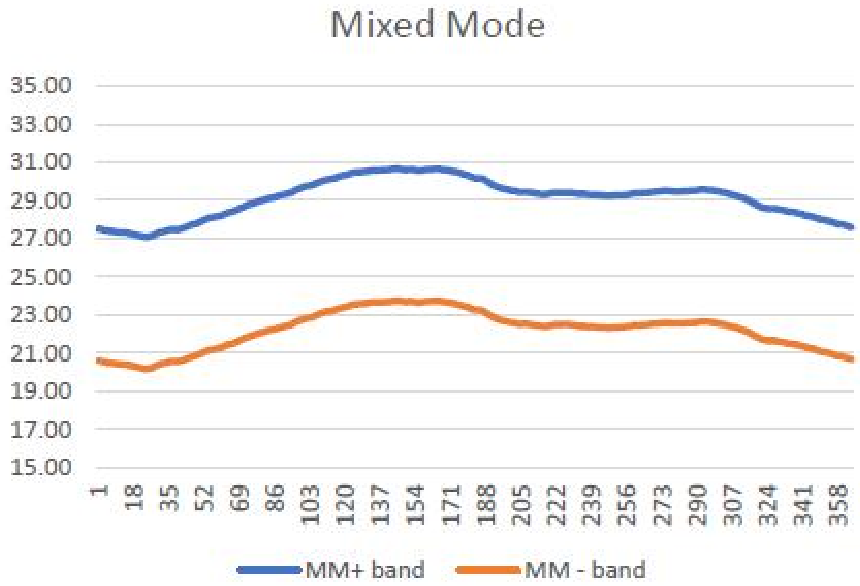
Warm Humid Climate

Mode of Operation - Mixed Mode

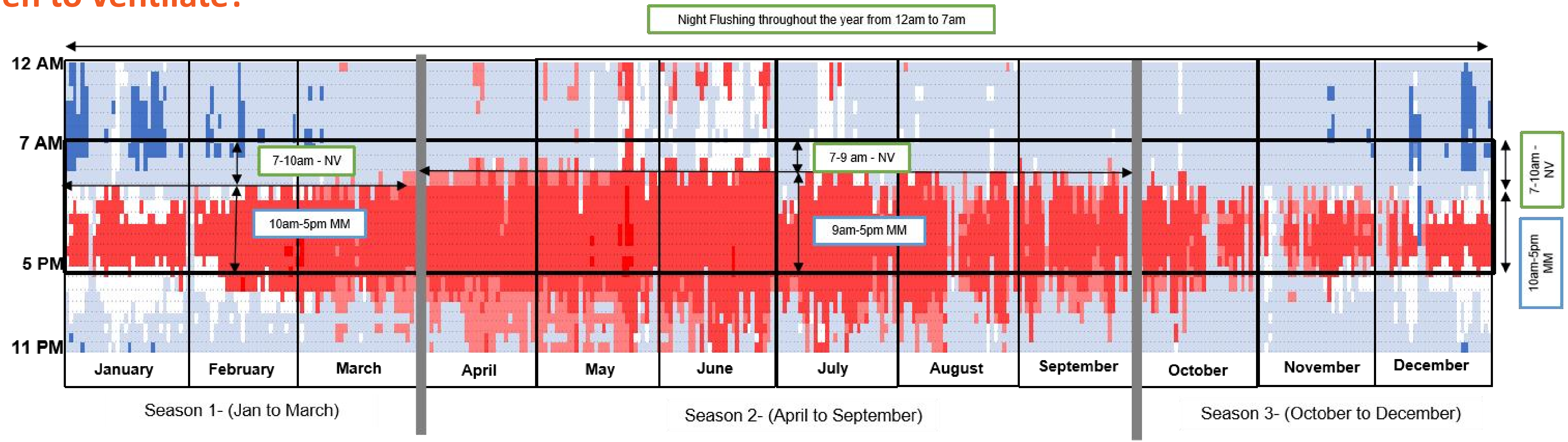
Ventilation for Air quality
Ventilation for thermal comfort $T_o < T_i$



Concurrent mixed- mode MM - (AC+NV)



When to ventilate?



Thermal comfort map - IMAC Mixed mode

No.	Condition	% OF OCCUPIED HOURS	Hrs.
1	Cold & Humid	1.3%	51.0
2	Cold	0.0%	1.0
3	Cold & Dry	0.0%	0.0
4	Humid	27.3%	1097.0
5	Comfortable	7.3%	292.0
6	Dry	0.0%	0.0
7	Hot & Humid	5.4%	216.0
8	Hot	58.0%	2329.0
9	Hot & Dry	0.7%	29.0

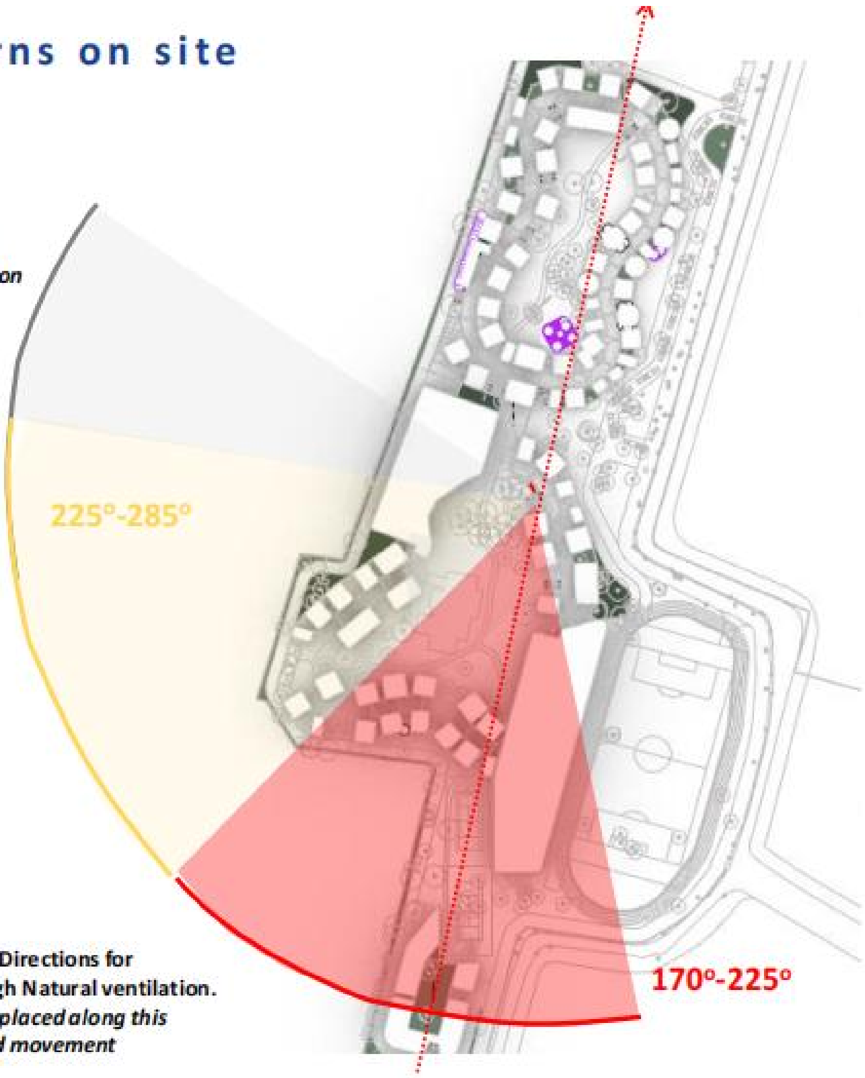
Natural ventilation only with Fans. AC will be off.
Maximum flow rate will be derived from maximum internal load of the buildings

Limited NV:
Maximum flow rate for only meeting minimum fresh air requirements.

Wind driven Cross ventilation

4. Wind Patterns on site

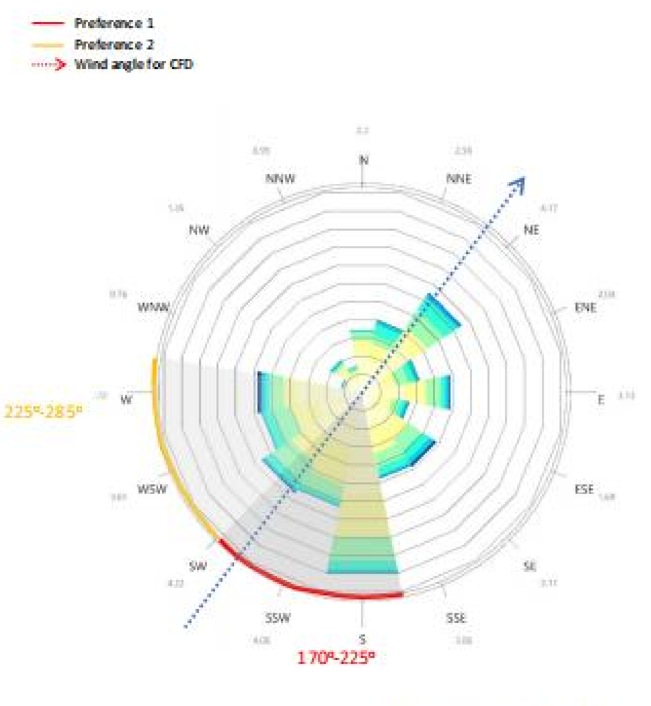
Warm winds – Preferably have a tree buffer and avoid openings to reduce heat gains from this direction



- Preference 1
- Preference 2

Favorable and Predominant Wind Directions for increasing Thermal comfort through Natural ventilation.
Windows and Openings should be placed along this direction to facilitate unobstructed movement

Predominant Wind Direction for Building blocks



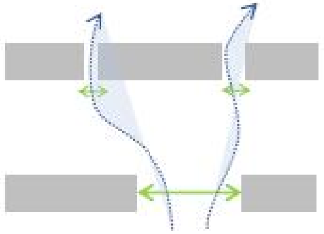
Annual wind rose
Wind speed > 1ms-1
DBT<35°C

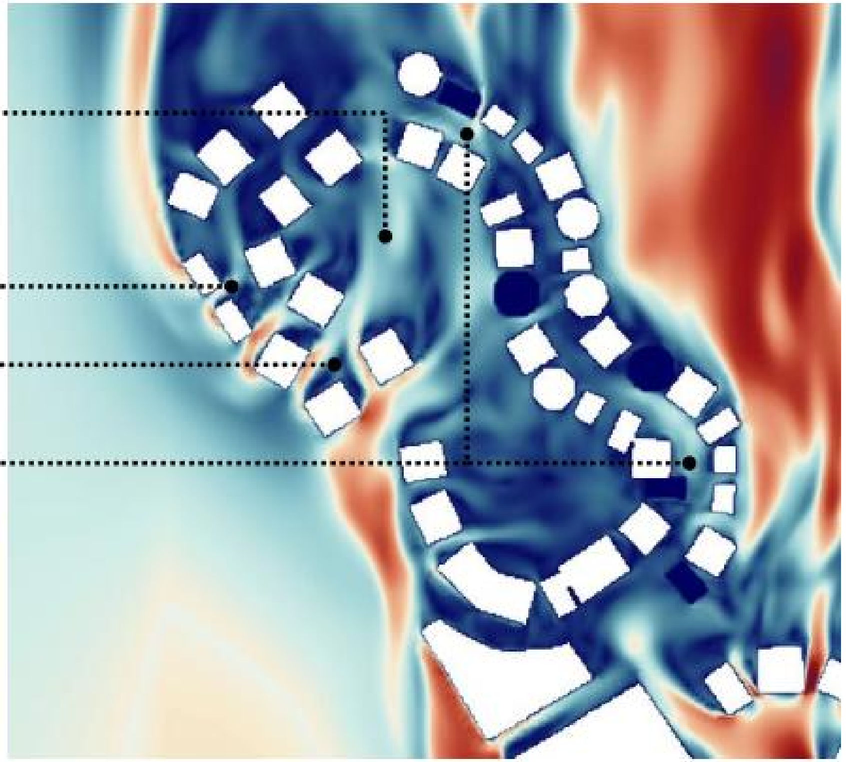
Inputs for CFD
Wind direction: **210°**
Wind speed : **3ms^{-1}**

Wind driven Cross ventilation

CFD Analysis | Primary block

Analysis & Recommendations



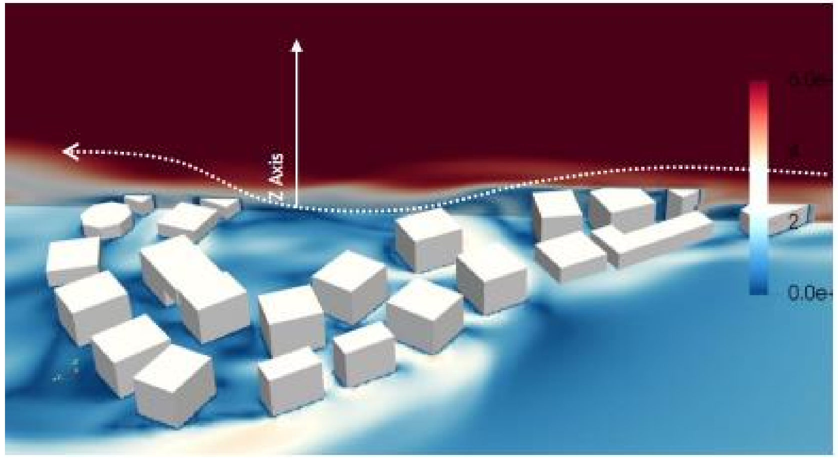


High wind zone area: *Outdoor play area can be placed*

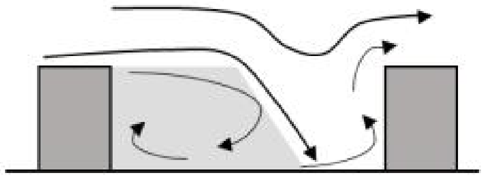
High potential of cross flow due to breaks and voids in the form.

Enhanced airflow in corridors due to staggered breaks in the built-form.

Air movement observed even in the corridors facing leeward side due to pressure difference induce by irregular & tapered voids.



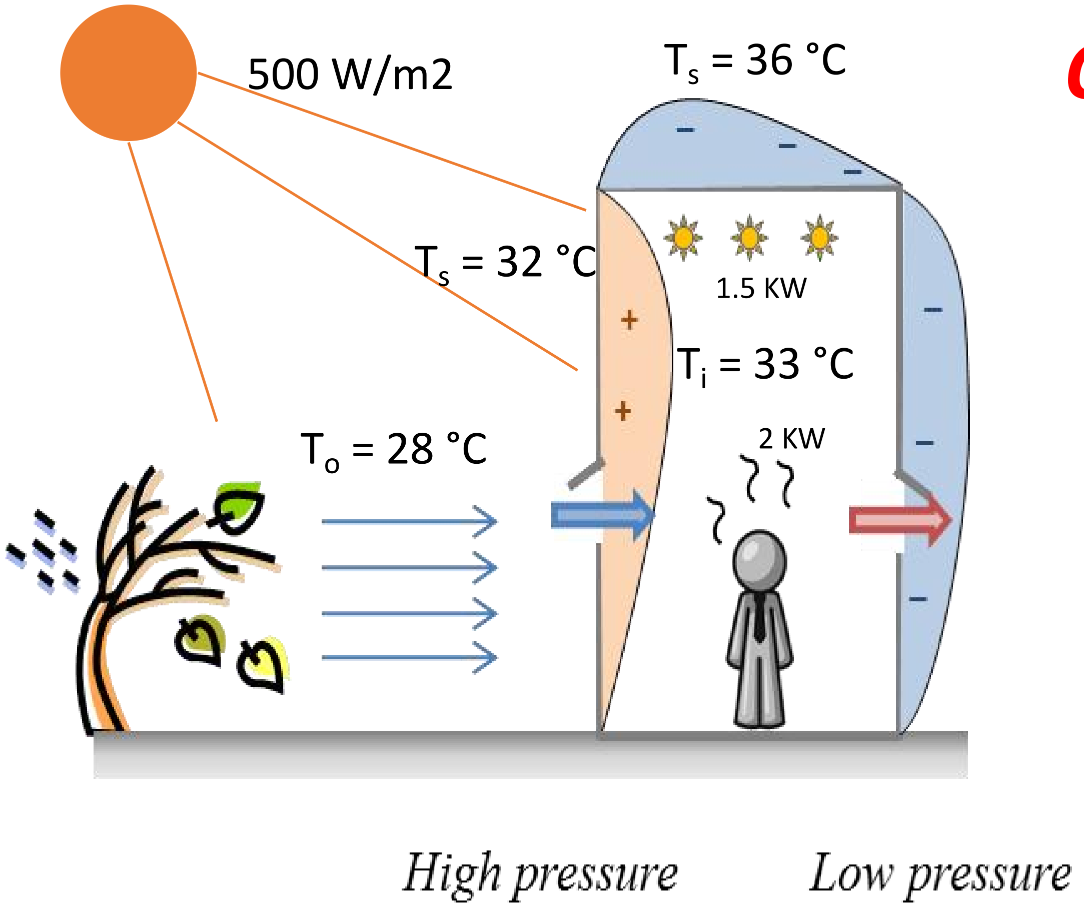
The aspect of the courtyards allow for the winds to regain its momentum towards the ground hence, air movement can be observed in these spaces even when in the leeward wind direction. (Canyon effect)



H/W>2, *Preferred*
For quality outdoor
Spaces like boulevards,
Plazas, playfields

How to size Windows?

Calculate Heat Load



$$Q_{vent} = \dot{m}\, C_{pa}\, \Delta T = \rho_a \cdot V_r \cdot C_{pa} \cdot \Delta T$$

Heat from :-

1. Envlope - Glass, Walls, Roof, floors
2. Occupants
3. Equipment
4. Lights

THIS HEAT NEEDS TO BE REMOVED

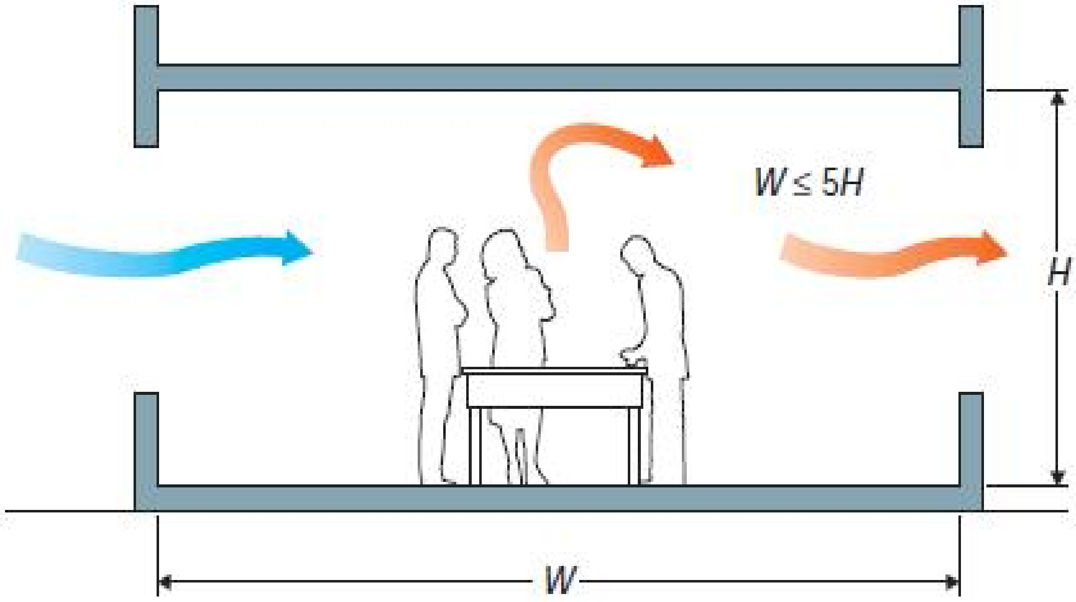
Calculate Flow rate

$$Q_{vent} = \dot{m}\, C_{pa}\, \Delta T = \rho_a \cdot V_r \cdot C_{pa} \cdot \Delta T$$

Space (type and Location)	Typical Week (October) 8-9am		Typical Week (October) 10-12pm		Hot Week (May) 8-9am	Hot Week (May) 10-12pm
	Avg. Heat gains (W)	**Air changes required**	Avg. Heat gains (W)	**Air changes required**	Avg. Heat gains (W)	Avg. Heat gains (W)
Activity room 1 (circle West facing)	1410	**15**	1640	**10**	1420	1880
Activity room 2 (Square West facing)	1800	**19**	2690	**27**	1950	2900
Activity room 3 (Octagon East facing)	1440	**12**	1605	**15**	1550	1790
Activity room 5 (Square East facing)	1500	**13**	1544	**12**	1600	1790
Activity room 5 (Circle East facing)	1370	**4**	1500	**6**	1470	1600

Calculate Window Size

Reference : CIBSE AM10 - Natural Ventilation Design



$$A = q\left(C_d U \sqrt{\frac{\Delta C_p}{2}}\right)^{-1}$$

A = Total opening area m2
q = Flow rate m3/s
Cd = Discharge Coefficient
U = Wind speed adjusted for height m/s
ΔCp = Pressure difference between windward and leeward side

Calculate Window Size

***ΔCp* = Pressure difference between windward and leeward side**

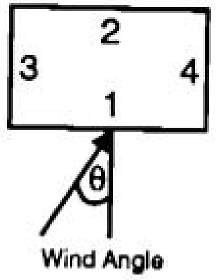
Table 3.5 (iv) Wind Pressure Coefficient Data

Low-rise buildings (up to 3 storeys)

Length to width ratio: 2:1

Shielding condition: Exposed

Wind speed reference level: Building height



Location	Wind Angle							
	0°	45°	90°	135°	180°	225°	270°	315°
Face 1	0.5	0.25	–0.5	–0.8	–0.7	–0.8	–0.5	0.25
Face 2	–0.7	–0.8	–0.5	0.25	0.5	0.25	–0.5	–0.8
Face 3	–0.9	0.2	0.6	0.2	–0.9	–0.6	–0.35	–0.6
Face 4	–0.9	–0.6	–0.35	–0.6	–0.9	0.2	0.6	0.2

Calculate Window Size

U = Wind speed adjusted for height m/s

$U = U_{mean}\, k\, z^{a}$

Umean: wind speed at weather station at 10m height

z is the building height

k and a are constants

Terrain Coefficient	k	a
open, flat country	0.68	0.17
country with scattered wind breaks	0.52	0.20
urban	0.35	0.25
city	0.21	0.33

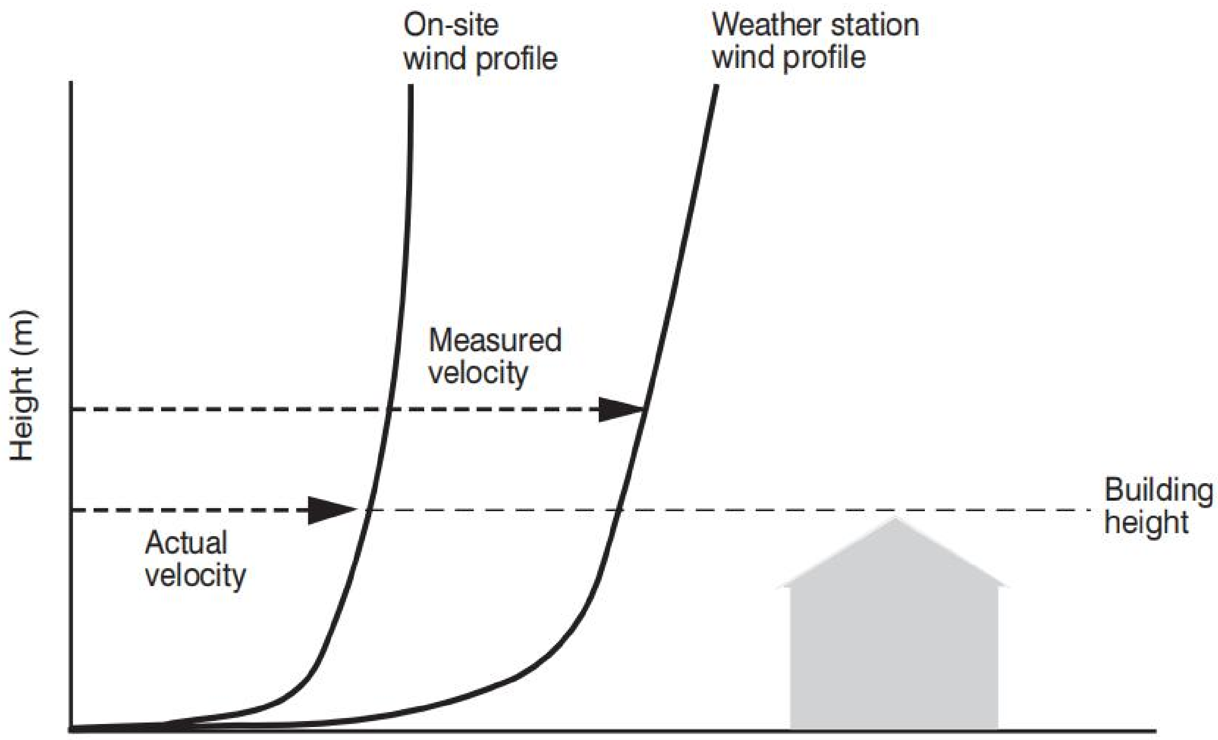


Figure 12.7 Influence of Wind Profile and Terrain Characteristics on Local Wind Speed

Calculate Window Size

Cd = Discharge Coefficient

$$\Delta p_i = P_{E0} - P_{I0} - \Delta \rho_0 \, g \, z_i \qquad (4.2)$$

where P_{E0} and P_{I0} are the external and internal hydrostatic pressures respectively at ground level (Pa), $\Delta \rho_0$ is the density difference at ground level ($kg{\cdot}m^{-3}$), g is the gravitational force per unit mass ($m{\cdot}s^{-2}$) and z_i is the height of opening i above ground level (m).

The density difference is defined by:

$$\Delta \rho_0 = \rho_E - \rho_I \qquad (4.3)$$

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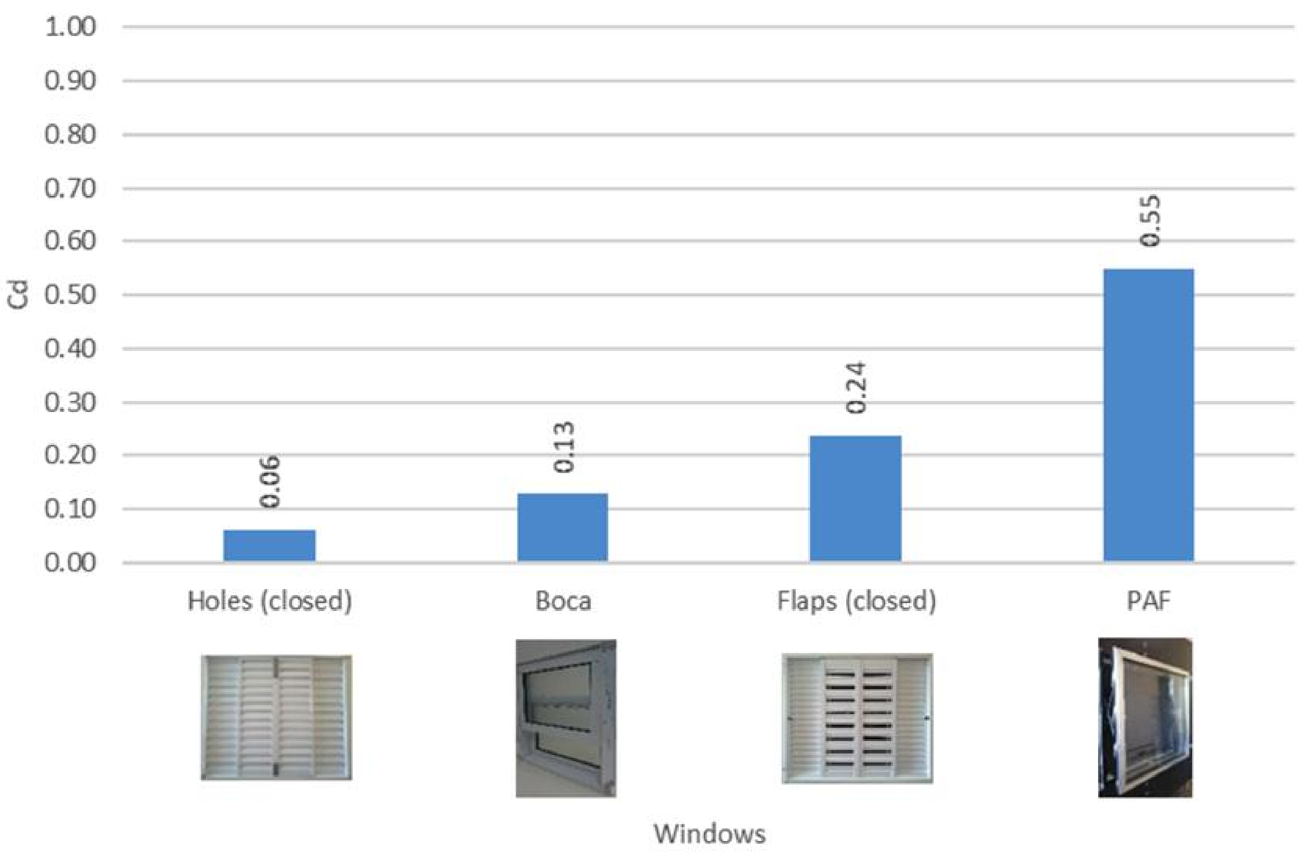
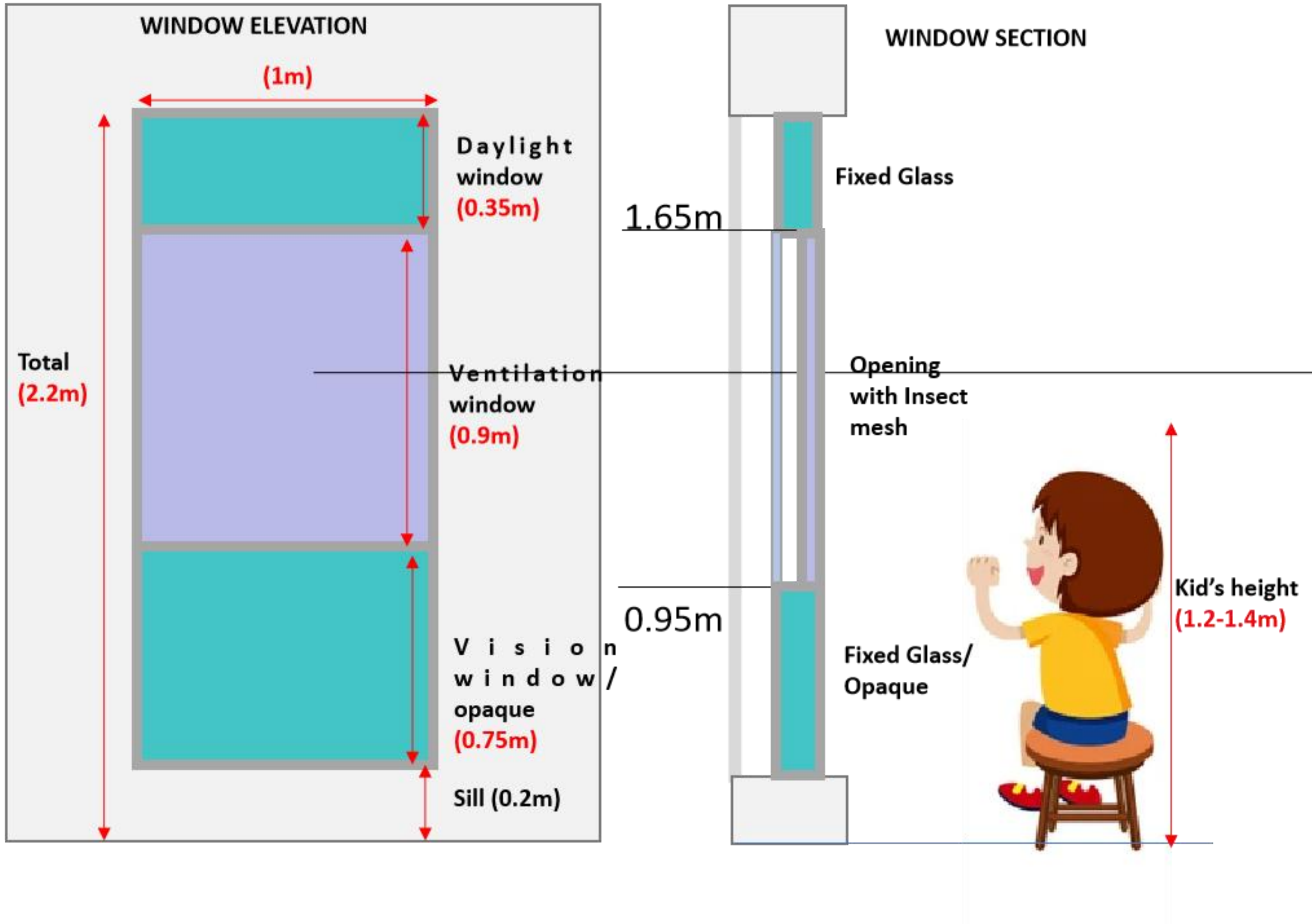


Planning Window design

Based on the inferences from the Daylight and Shading mask analysis and the requirements for Natural ventilation, a window design scheme is worked out following a series of optimization studies. This window design scheme adequately serves all the purposes and allows for optimum Visual and thermal comfort.



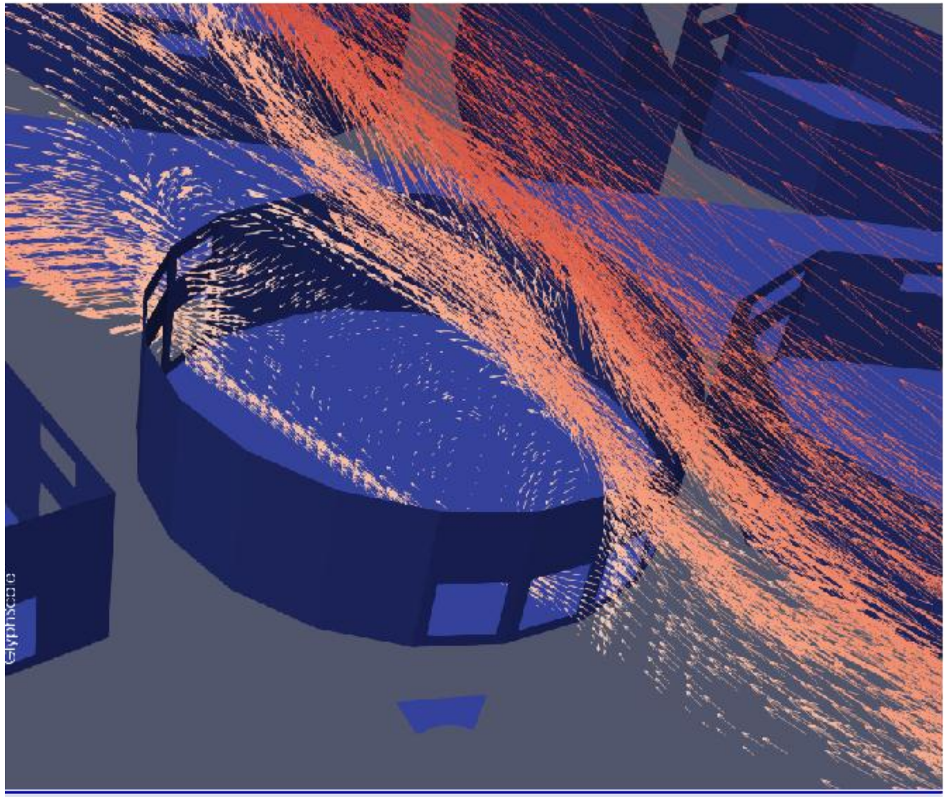
As per the Calculations for Natural ventilation, a minimum of **8m2 of window area must be operable** to create air changes of 10-15 per hour.

Option 1 – Casement windows with Stays

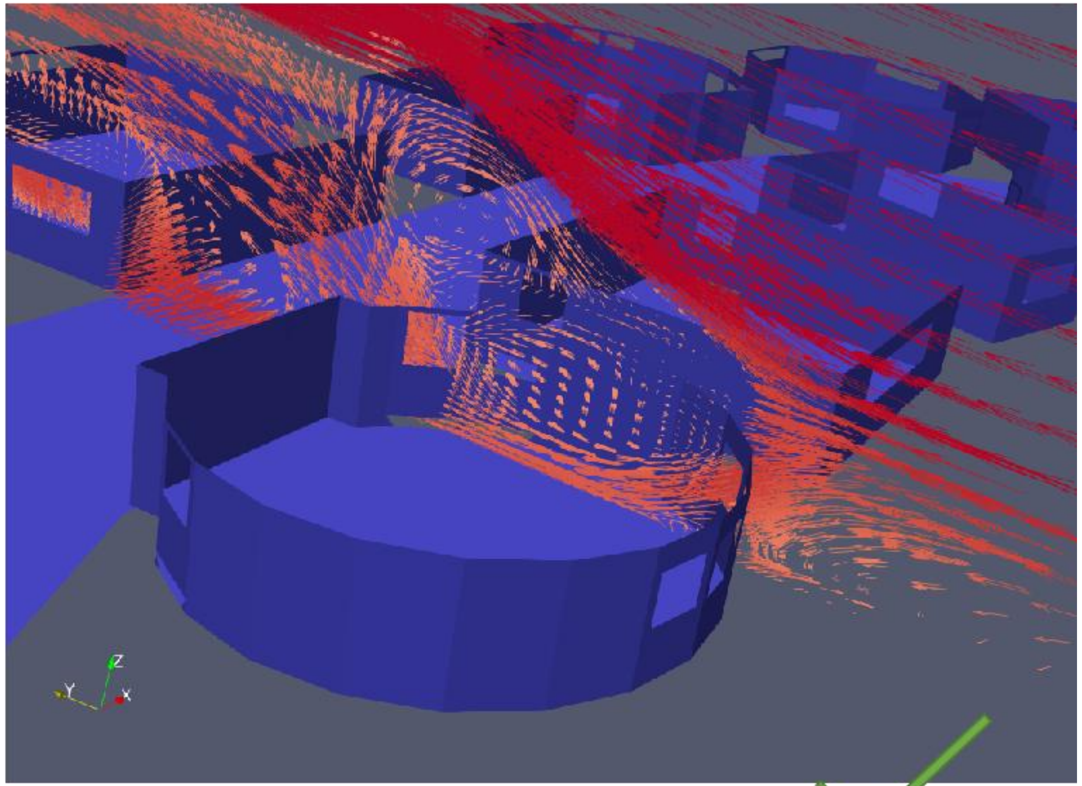
Option 2 – Double sliding window

Testing Window design

Inlet and outlet at low height.



Inlet at moderate height and outlet at higher level

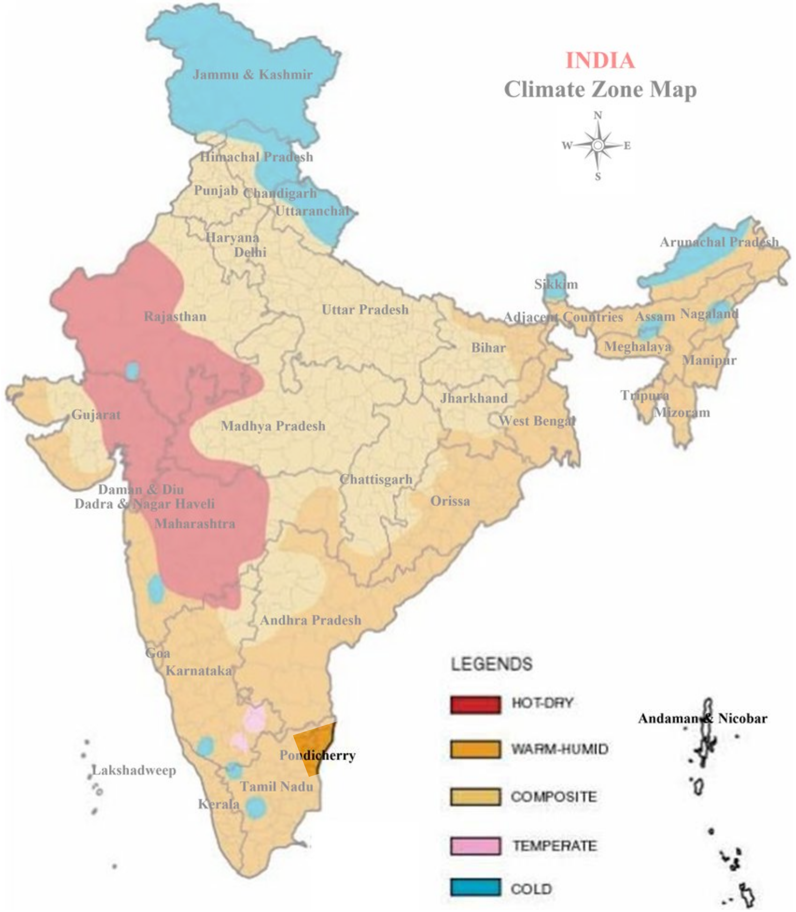


Windows opening at 0.75m from the ground allow a better air distribution compared to lower level. The air in case of lower windows sinks further and can only be felt till 300mm from the flooring level.

Natural ventilation for thermal comfort

Buoyancy driven ventilation

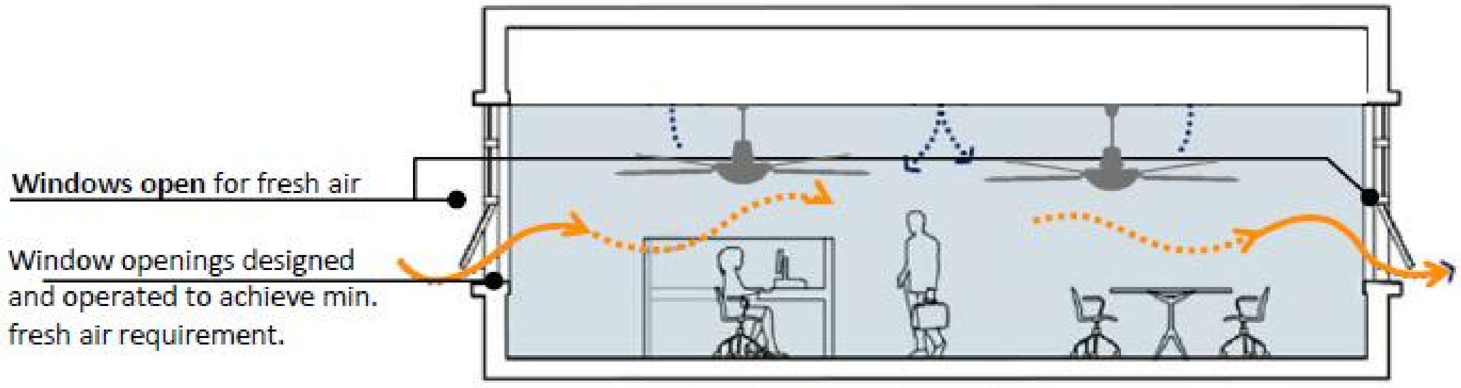
Buoyancy driven Ventilation



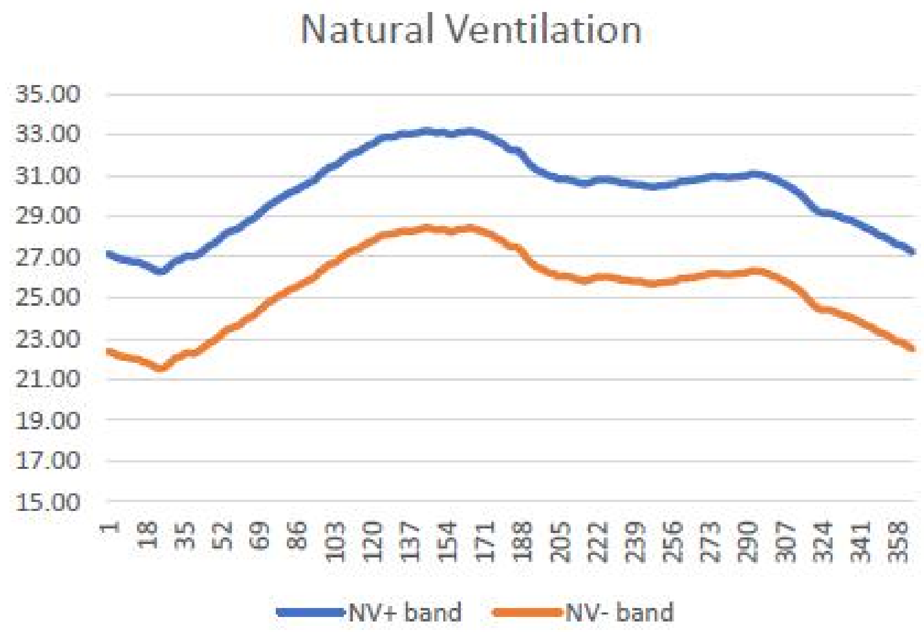
Warm Humid Climate

Modes of Operation - NV

Ventilation for thermal comfort $T_o<T_i$

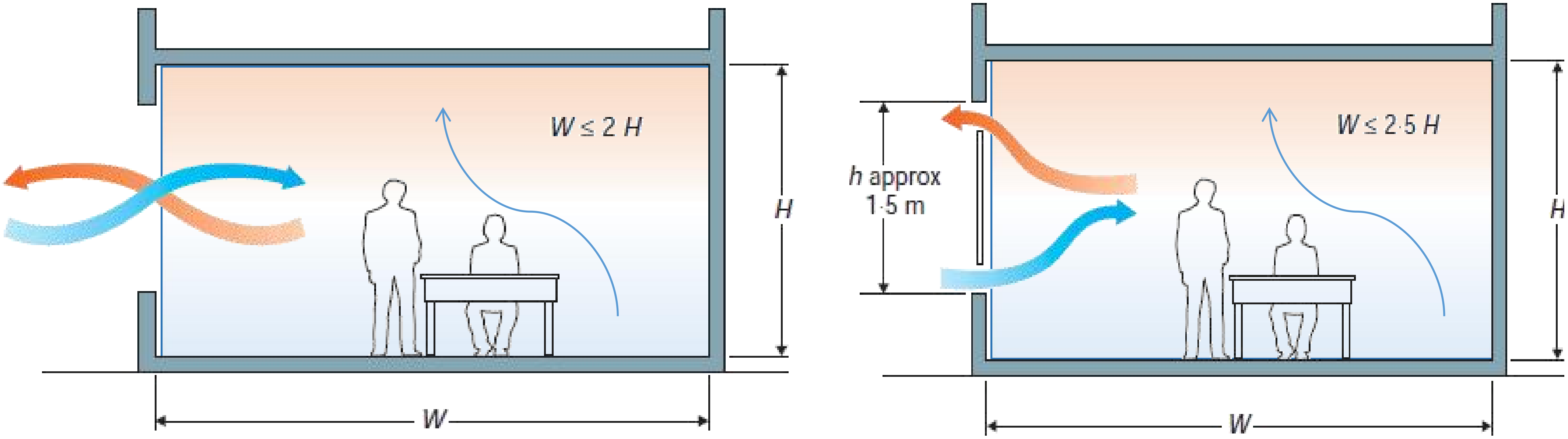


Natural Ventilation (NV)



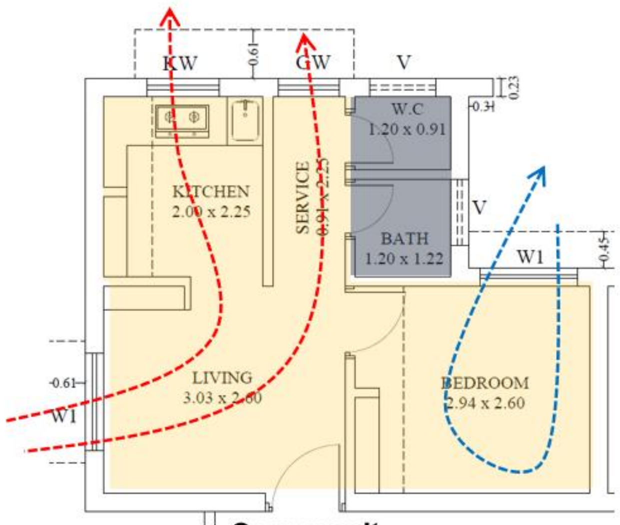
Buoyancy driven Ventilation

High temperature - Low density

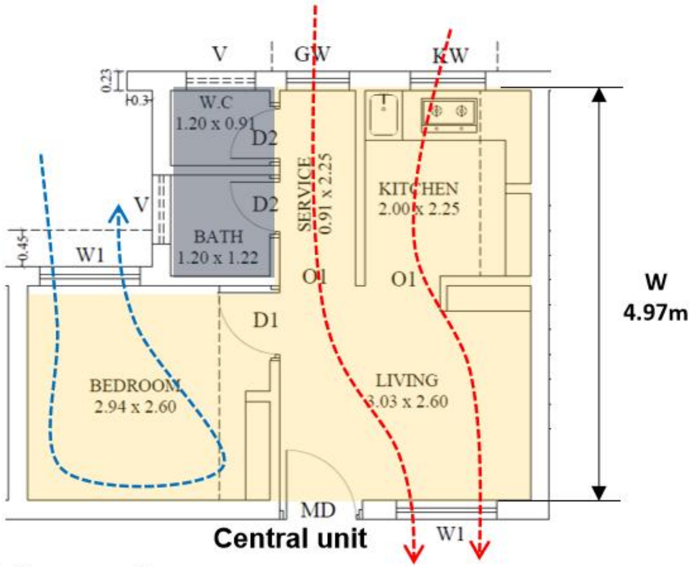


Low temperature - High density

Buoyancy driven Ventilation



Corner unit



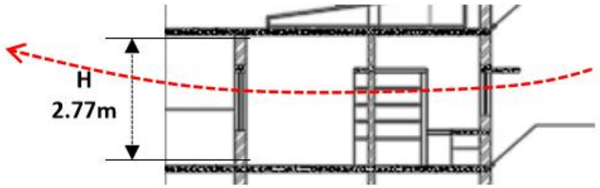
Central unit

Cross ventilation

Single side ventilation

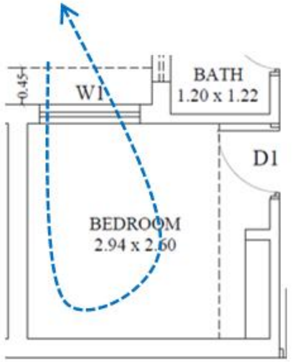
Regularly occupied spaces

Non Regularly occupied spaces

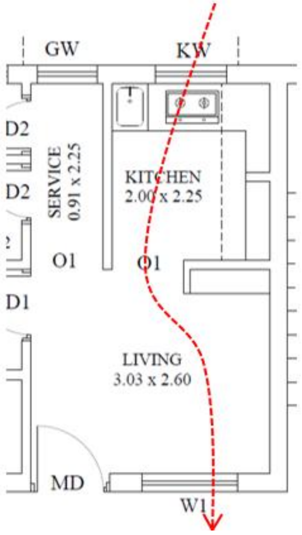


Section showing cross ventilated spaces – living room and kitchen

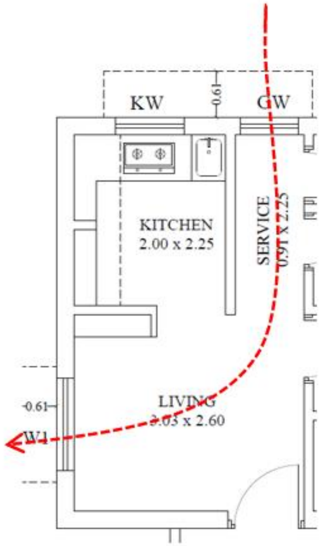
Single side ventilated



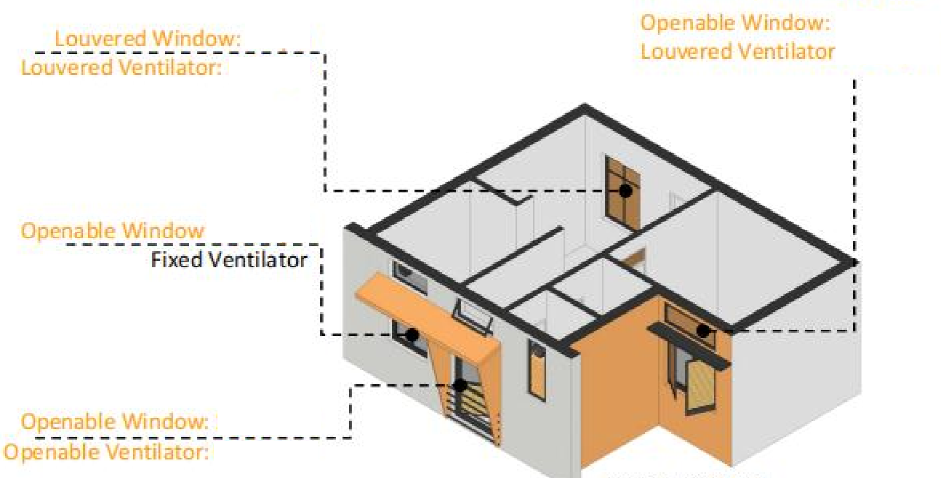
Cross ventilated – central unit



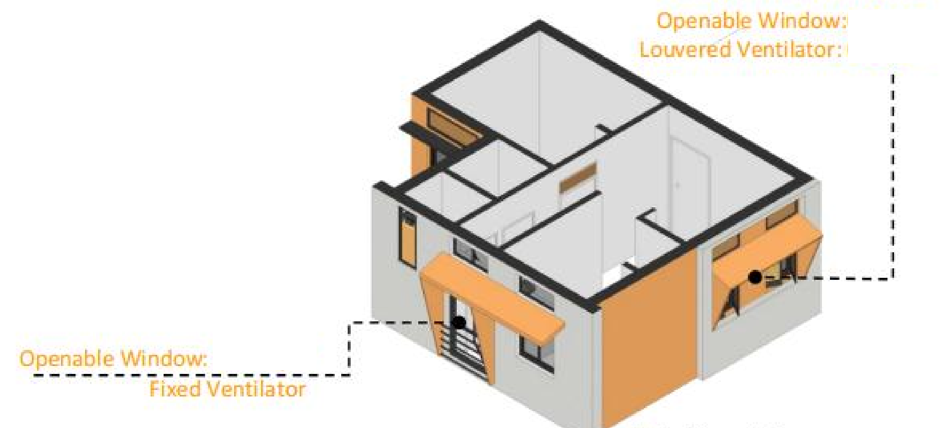
Cross ventilated – corner unit



Buoyancy driven Ventilation

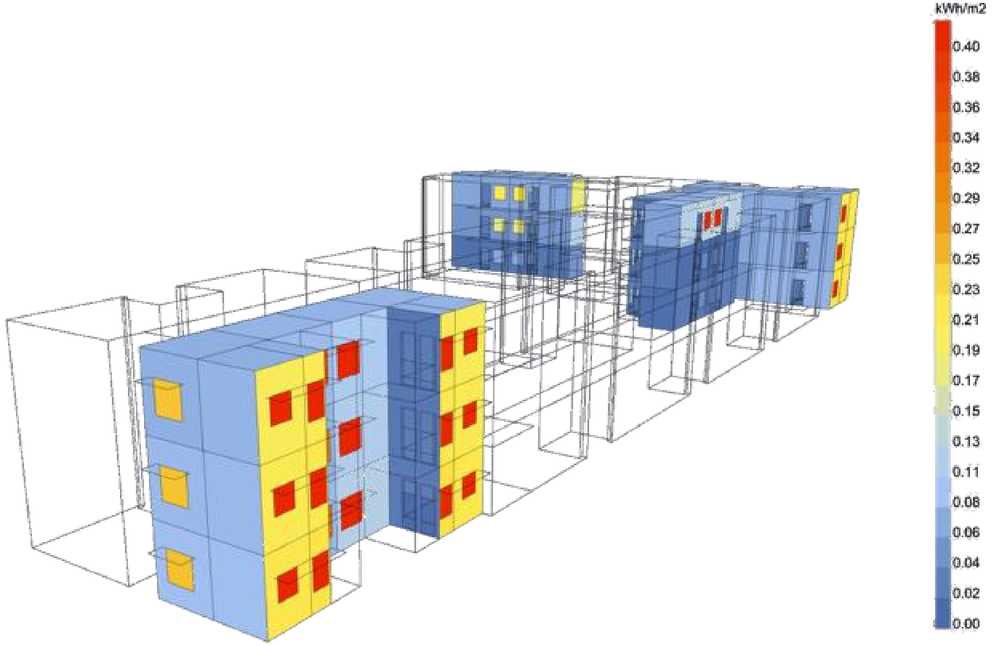


Typical Dwelling Unit



Typical Corner Unit

$$Q_{vent} = \dot{m}\, C_{pa}\, \Delta T = \rho_a \cdot V_r \cdot C_{pa} \cdot \Delta T$$



Buoyancy driven Ventilation

Reference : CIBSE AM10 - Natural Ventilation Design

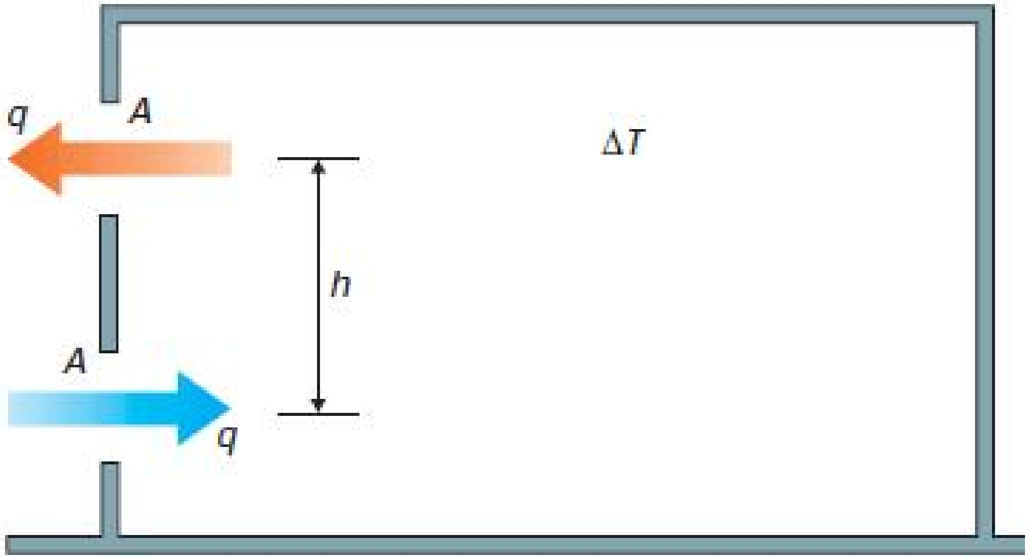


Figure 4.9 Case 1: single-sided ventilation, two identical openings, driven by buoyancy alone

Figure 4.11 Case 3: single-sided ventilation, single opening, driven by wind alone

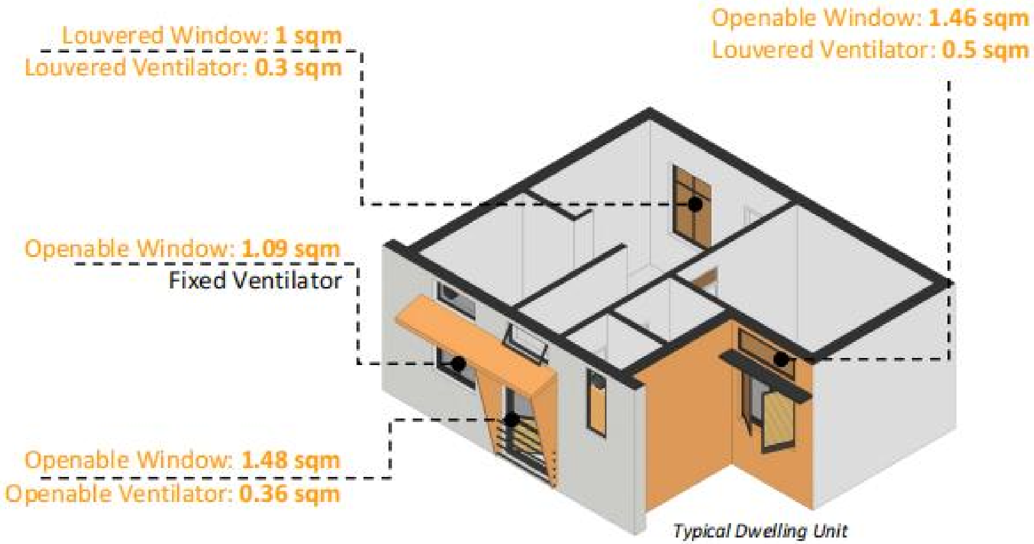
$$A = \frac{q}{C_d}\sqrt{\frac{(T_I + 273)}{\Delta T\, g\, h}}$$

T_I= internal temperature (°C)
ΔT = difference between the internal and external air temperatures (K)
g= gravitational force per unit mass (m/s^2)
h = height between the openings (m)

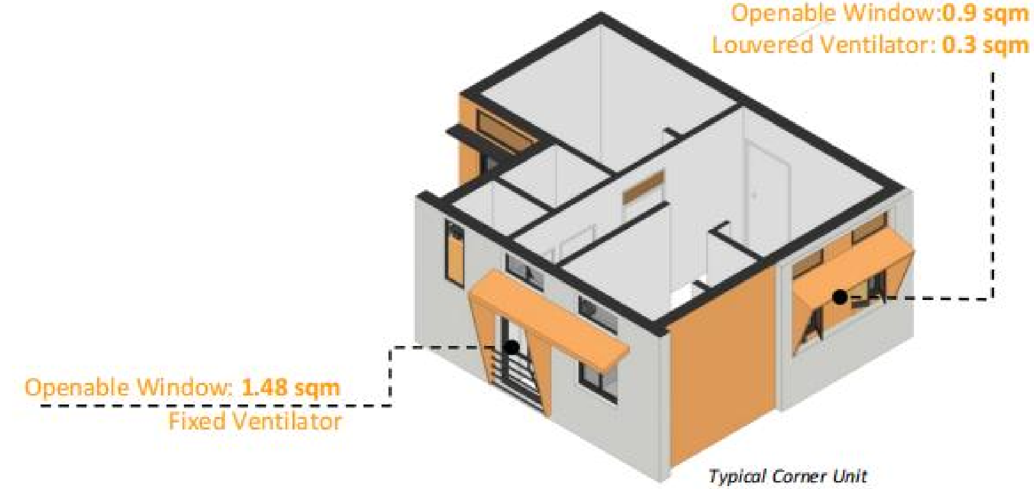
Buoyancy driven Ventilation

Central Dwelling Unit	Single Sides SINGLE Vent by Buoyancy Alone								
Space	Req. Area of Opening	Flow Rate	Discharge Coeff	Temp Diff	ACH	Optimized window	Window Dimension		Present window area vs Required window area
	m2	m3/s		K	ACH	m2	m	m	
	A	q	Cd	DeltaT	ACH	A	l	h	
Living Room	0.48	0.09	0.65	2	15	1.21	0.9	1.35	Satisfied
Service	0.10	0.02	0.65	2	15	2.07	0.9	2.3	Satisfied
Bedroom	0.43	0.09	0.65	2	15	1.46	1.22	1.2	Satisfied
Kitchen	0.29	0.05	0.65	2	15	1.09	0.91	1.2	Satisfied

Corner Dwelling Unit	Single Sides SINGLE Vent by Buoyancy Alone								
Space	Req. Area of Opening	Flow Rate	Discharge Coeff	Temp Diff	ACH	Optimized window	Window Dimension		Present window area vs Required window area
	m2	m3/s		K	ACH	m2	m	m	
	A	q	Cd	DeltaT	ACH	A	l	h	
Bedroom	0.40	0.09	0.65	2	15	2.18	1.22	1.79	Satisfied
Living Room	0.44	0.09	0.65	2	15	1.2	0.75	1.6	Satisfied
Kitchen	0.29	0.05	0.65	2	15	1.09	0.91	1.2	Satisfied
Service	0.10	0.02	0.65	2	15	2.07	0.9	2.3	Satisfied

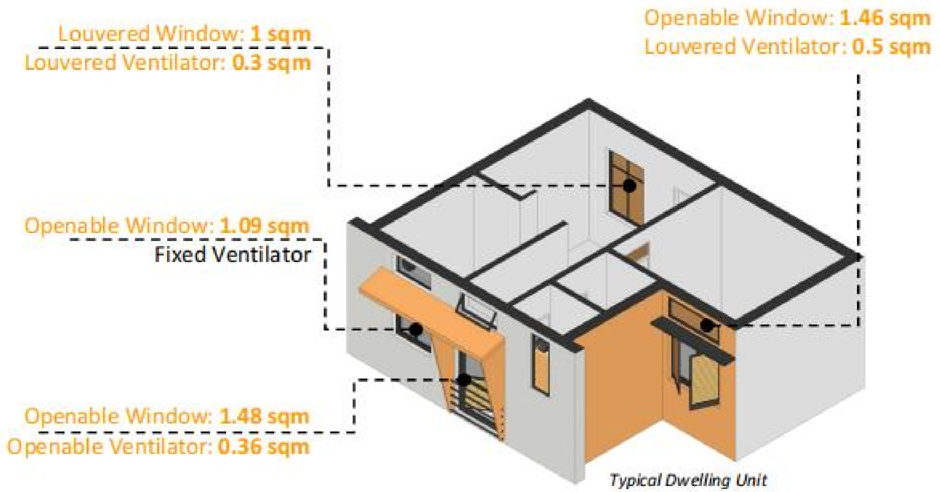


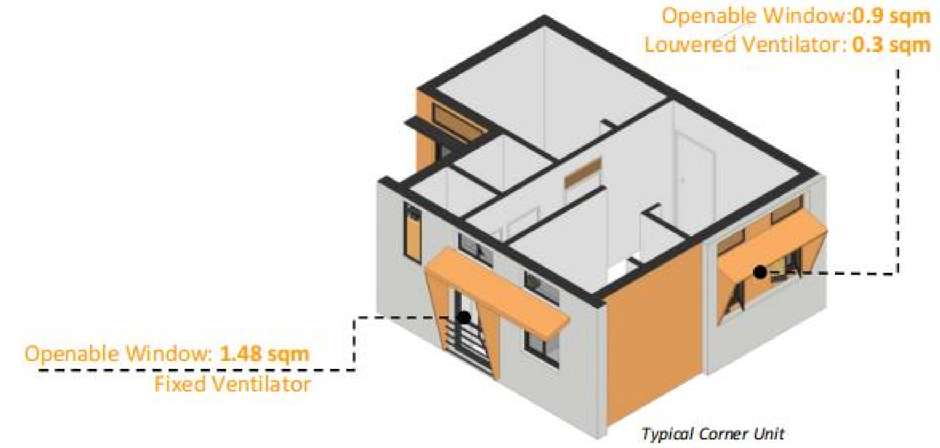
Typical Dwelling Unit



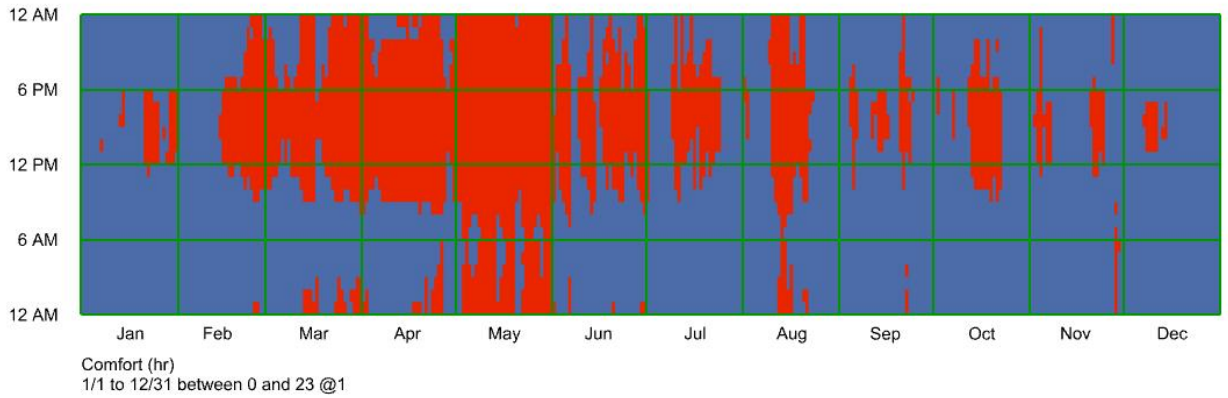
Typical Corner Unit

Buoyancy driven Ventilation



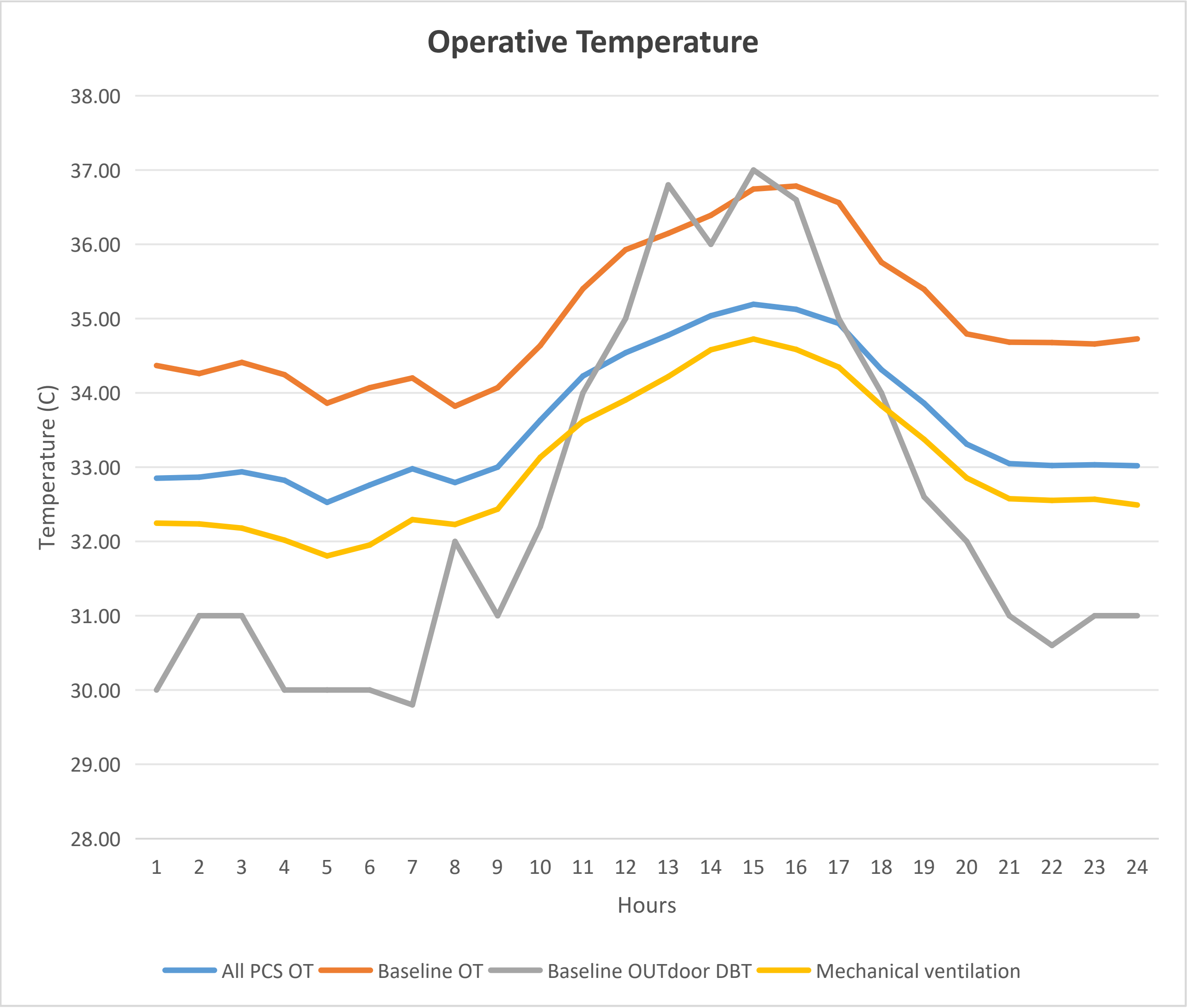


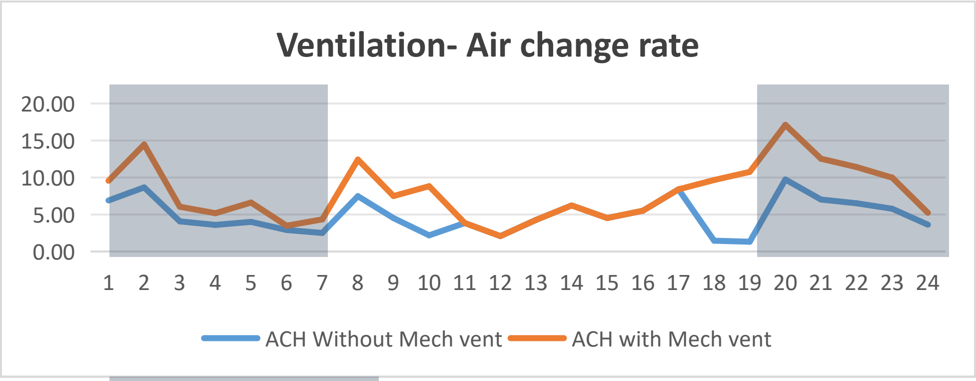
Assesment for Thermal comfort



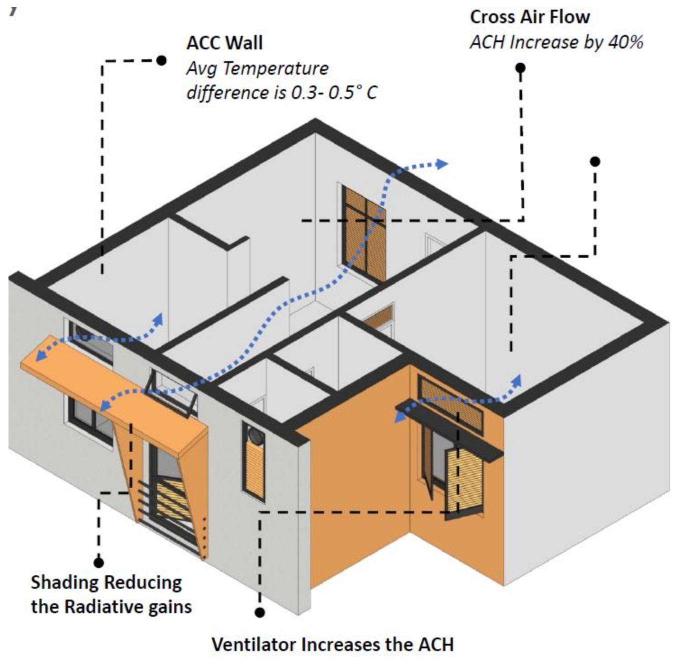
Comfortable hours - 6187 Hrs

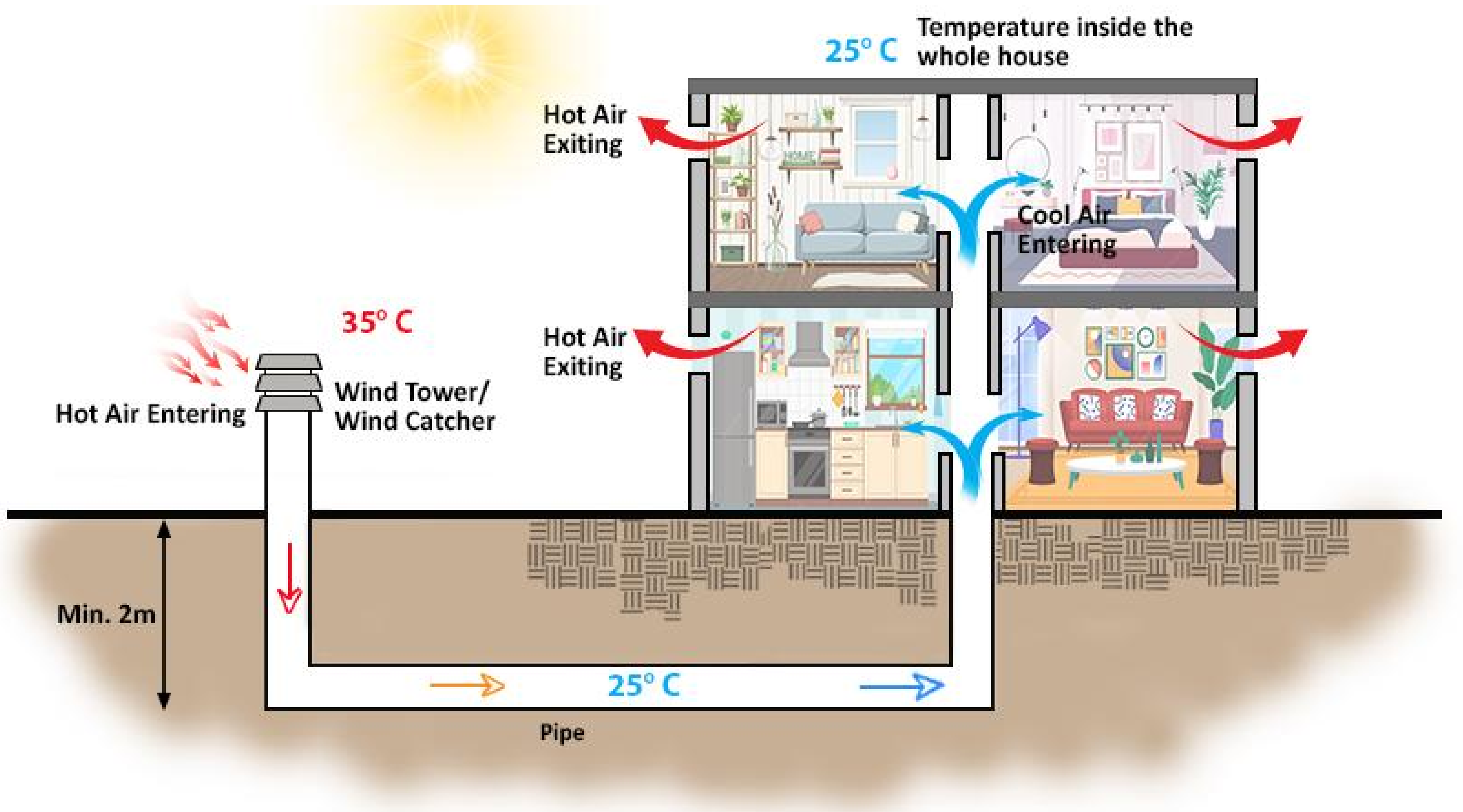
Buoyancy driven Ventilation with Mechanical assistance





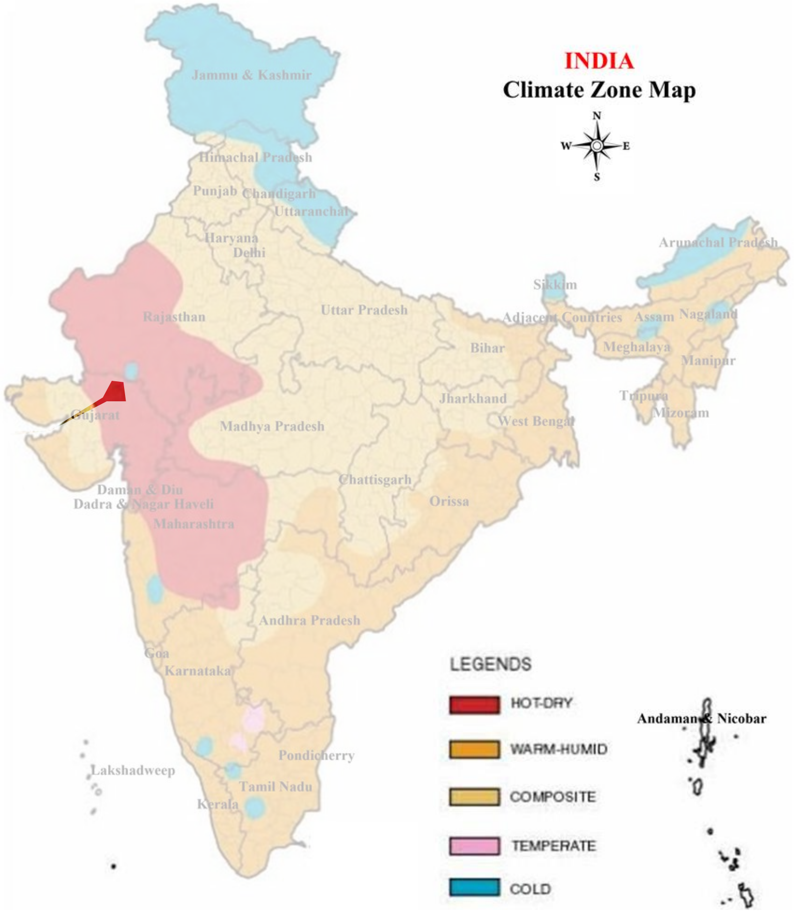
Vent on - 7pm to 7am





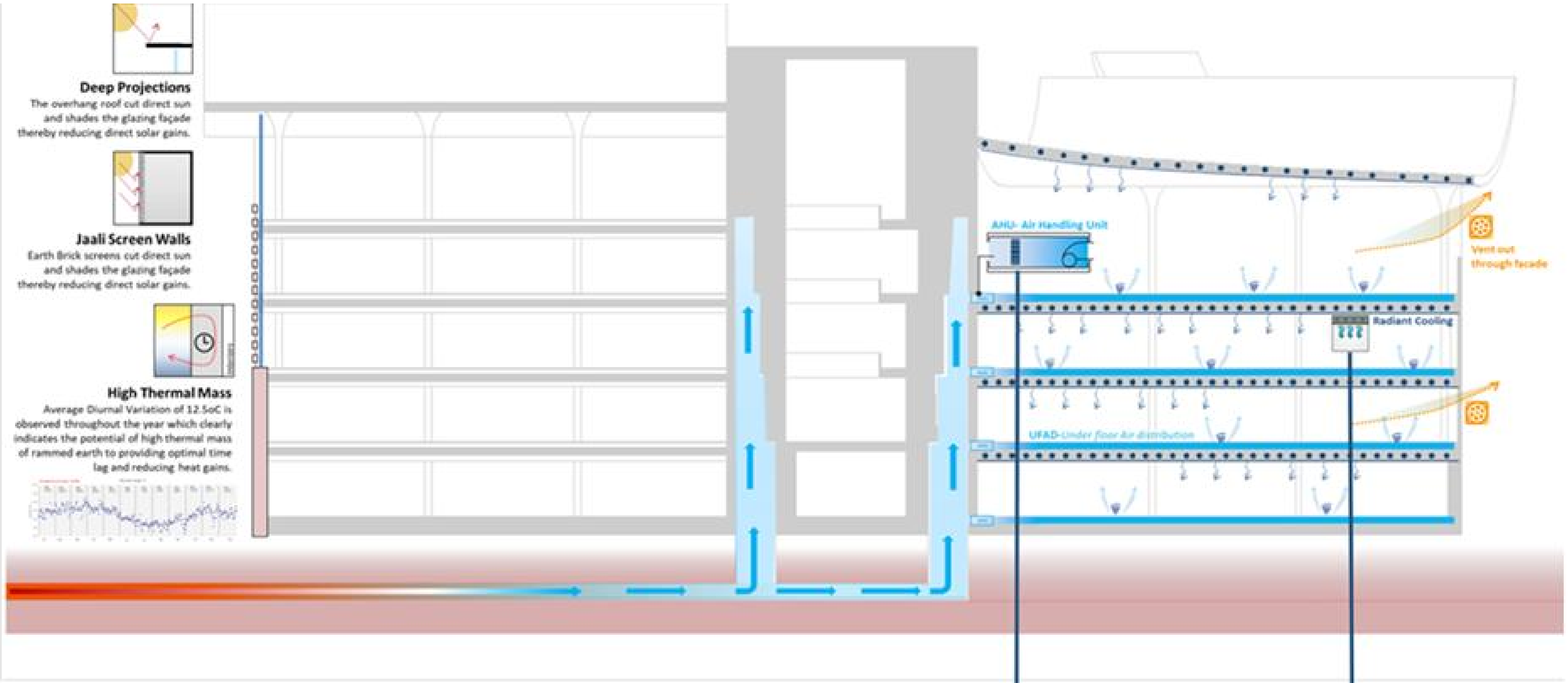
Stack effect

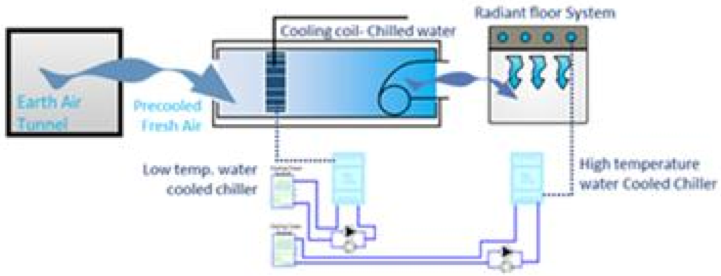
Solar Chimeny and Earth Air Tunnels

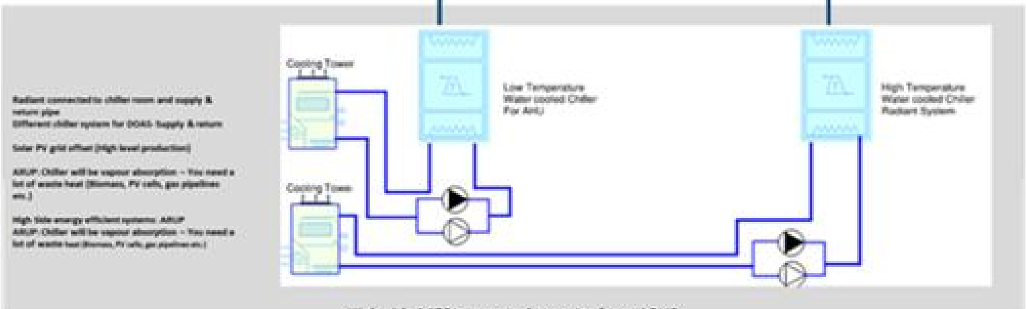


Hot and Dry Climate

Stack effect - Earth Air Tunnels



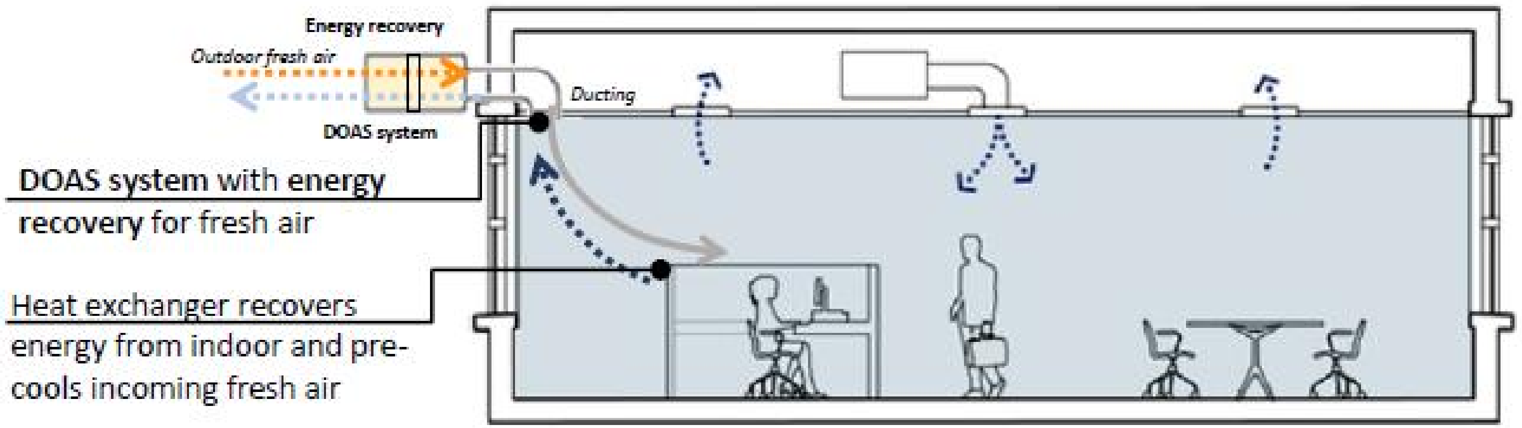




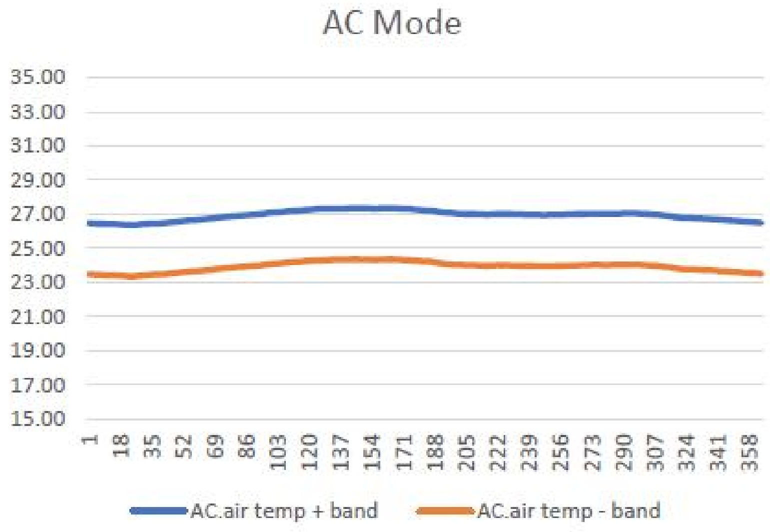
High side MEP system schematics from ARUP

Modes of Operation - AC

Ventilation for Air quality



AC + DOAS + Energy recovery

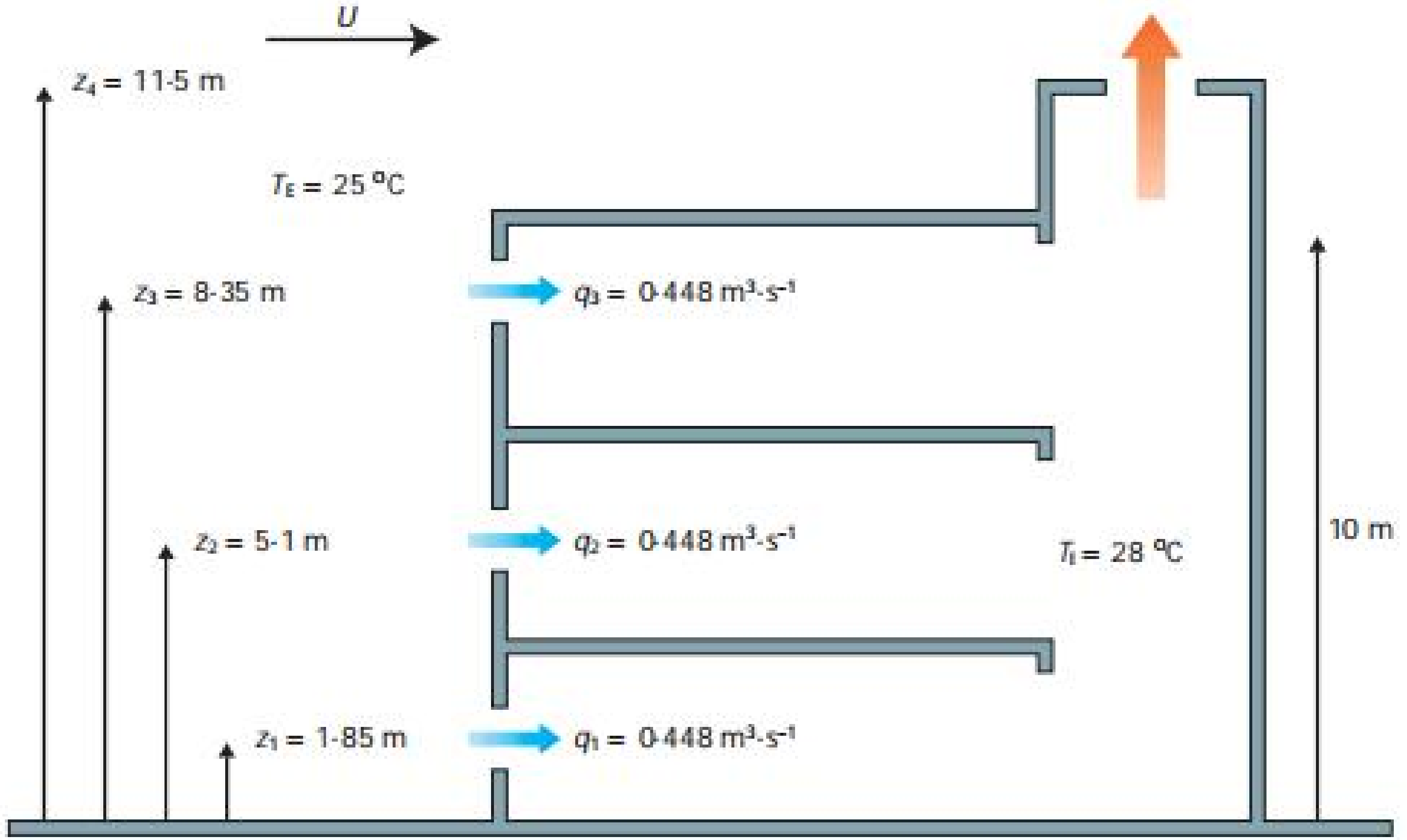


Modes of Operation - AC

Minimum ventilation rates of ASHRAE 62.1

Occupancy Category	People Outdoor Air Rate R_P		Area Outdoor Air Rate R_A		Notes	Default Values		
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)	
	cfm/person	L/s•person	cfm/ft^2	L/s•m^2		#/1000 ft^2 (#/100 m^2)	cfm/person	L/s•person
Educational Facilities								
Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6
Classrooms (ages 5-8)	10	5	0.12	0.6		25	15	7.4
Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7
Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3

Stack effect



— external temperature: $T_E = 25$ °C
— internal temperature: $T_I = 28$ °C
— temperature difference: $\Delta T_0 = 3$ K
— wind speed: U = 0 m/s
— dynamic pressure: $0.5\, \rho\, U^2 = 0$ Pa
— reference density: $\rho_0 = 1.2$ kg/m³
— density difference $\Delta\rho_0 = 0.01208$ kg/m³

$$q_i = CdiAi\sqrt{\frac{2|\Delta pi|}{\rho_0}}$$

$$A_i = \frac{q_i}{C_{di}}\sqrt{\frac{\rho_0}{2|\Delta pi|}}$$

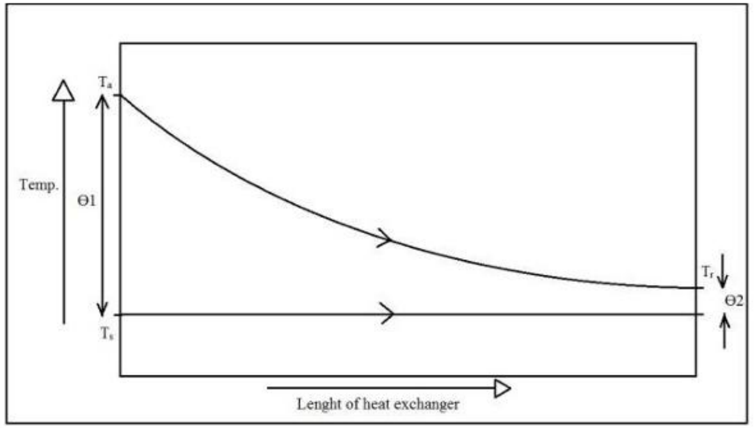
$$\Delta p_i = \Delta\rho_0\, g\, z_n - \Delta\rho_0\, g\, z_i$$

Earth Air Tunnel sizing

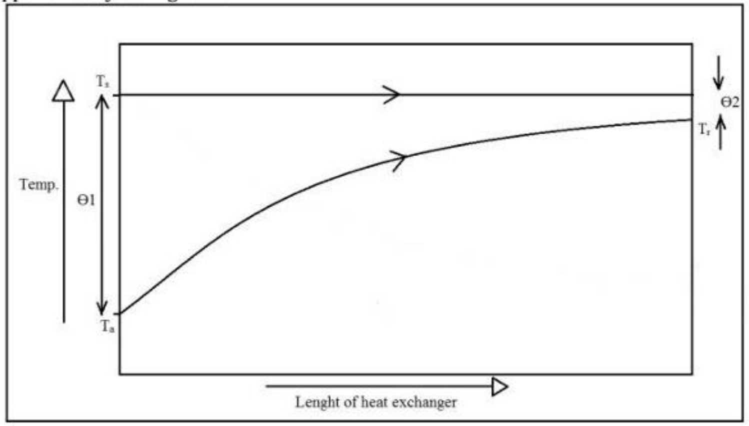
$$Q = h_a \times A \times T_{lm}$$

Where,

- Q= is the cooling load.
- h_a = is the heat transfer coefficient.
- A = surface area of heat exchanger from where heat will be exchanged between the pipe and the soil.
- T_{lm} = logarithmic mean temperature difference.



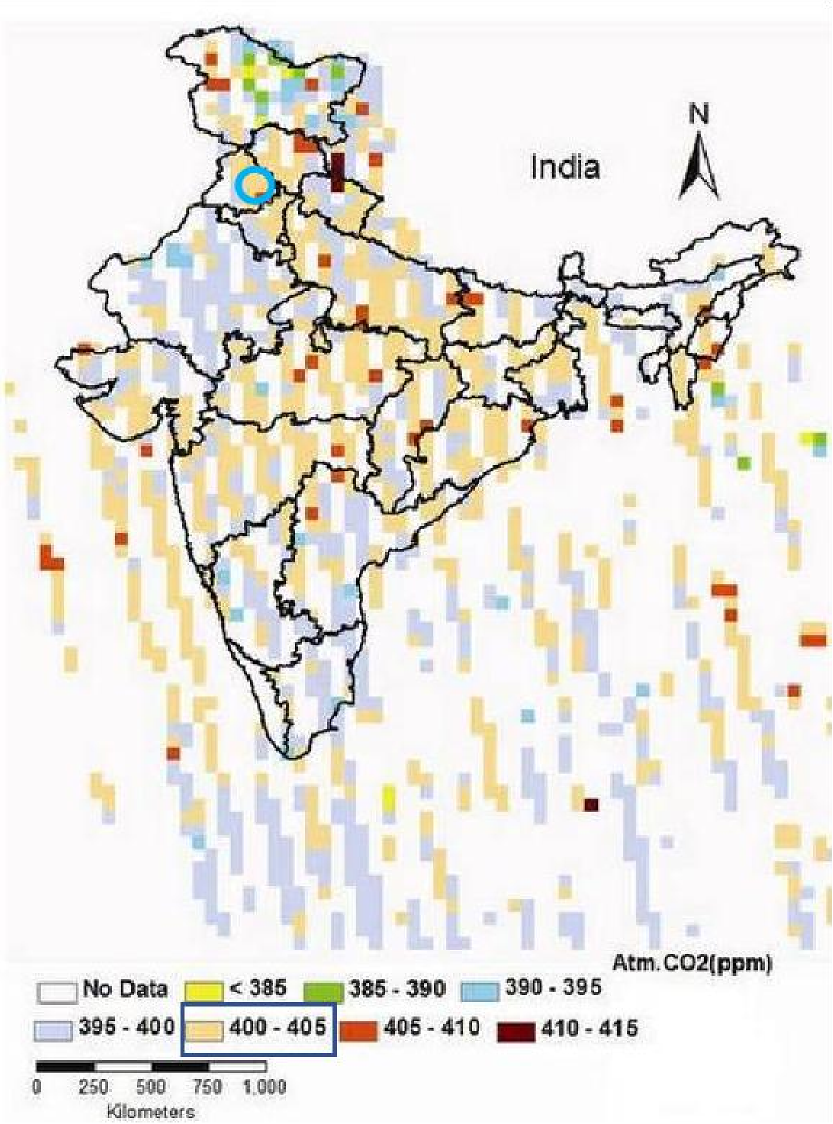
- $T_r \le T_s$, this happens mostly during winter



Ventilation for Air Quality

Ventilation for Air Quality

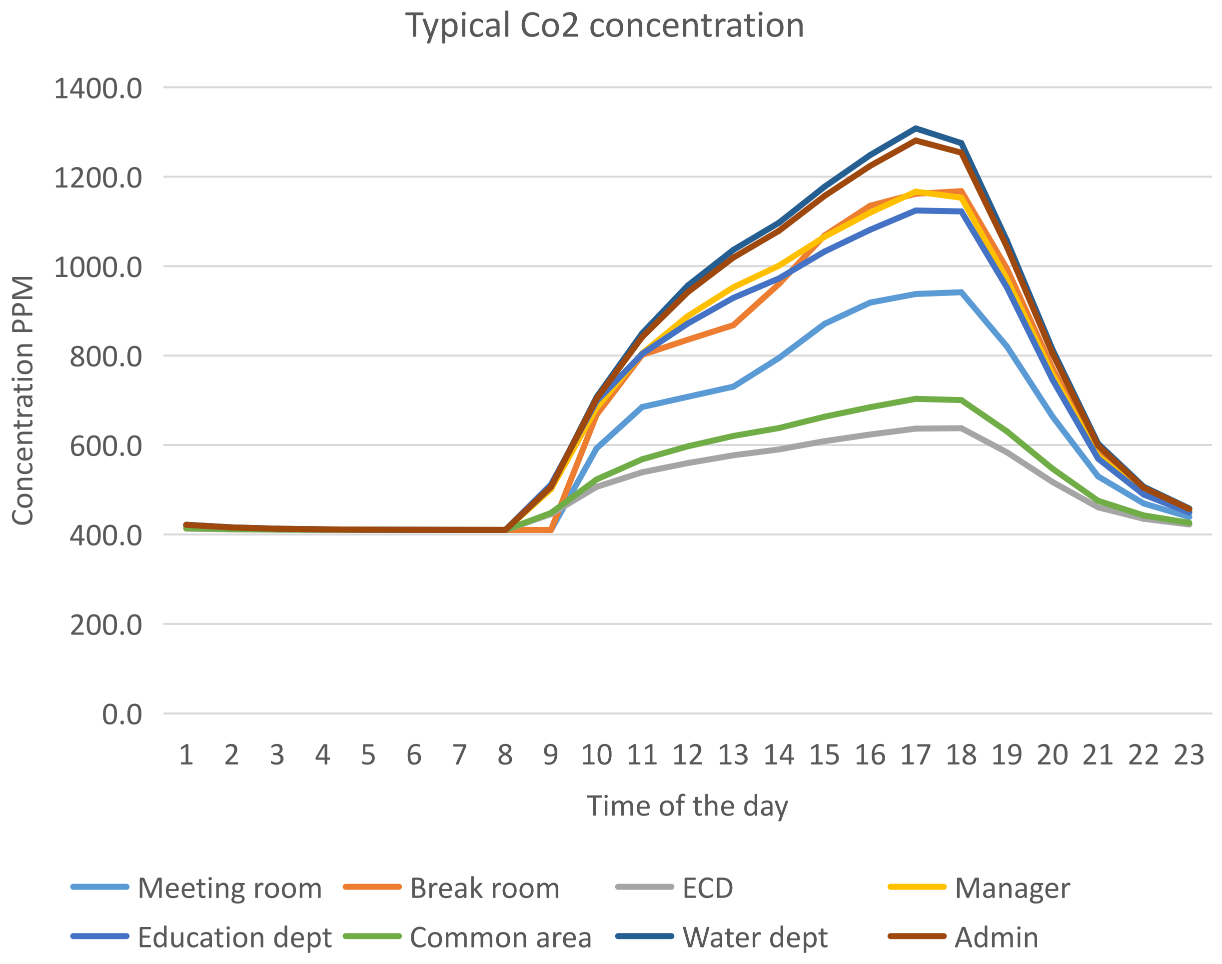
Outdoor CO2 levels



- Concentration of CO_2 in earth's atmosphere is measured at certain locations globally.
- The average maximum CO_2 concentration recorded lies between 400-418 ppm recorded in March 2021.
- The graph extrapolates data using scientific calculations to estimate the CO_2 ppm levels in different locations in India.
- For Delhi, the outdoor CO_2 level can be assumed to lie in the range of 400-405 ppm

Ventilation and Air Quality

Measured and simulated data



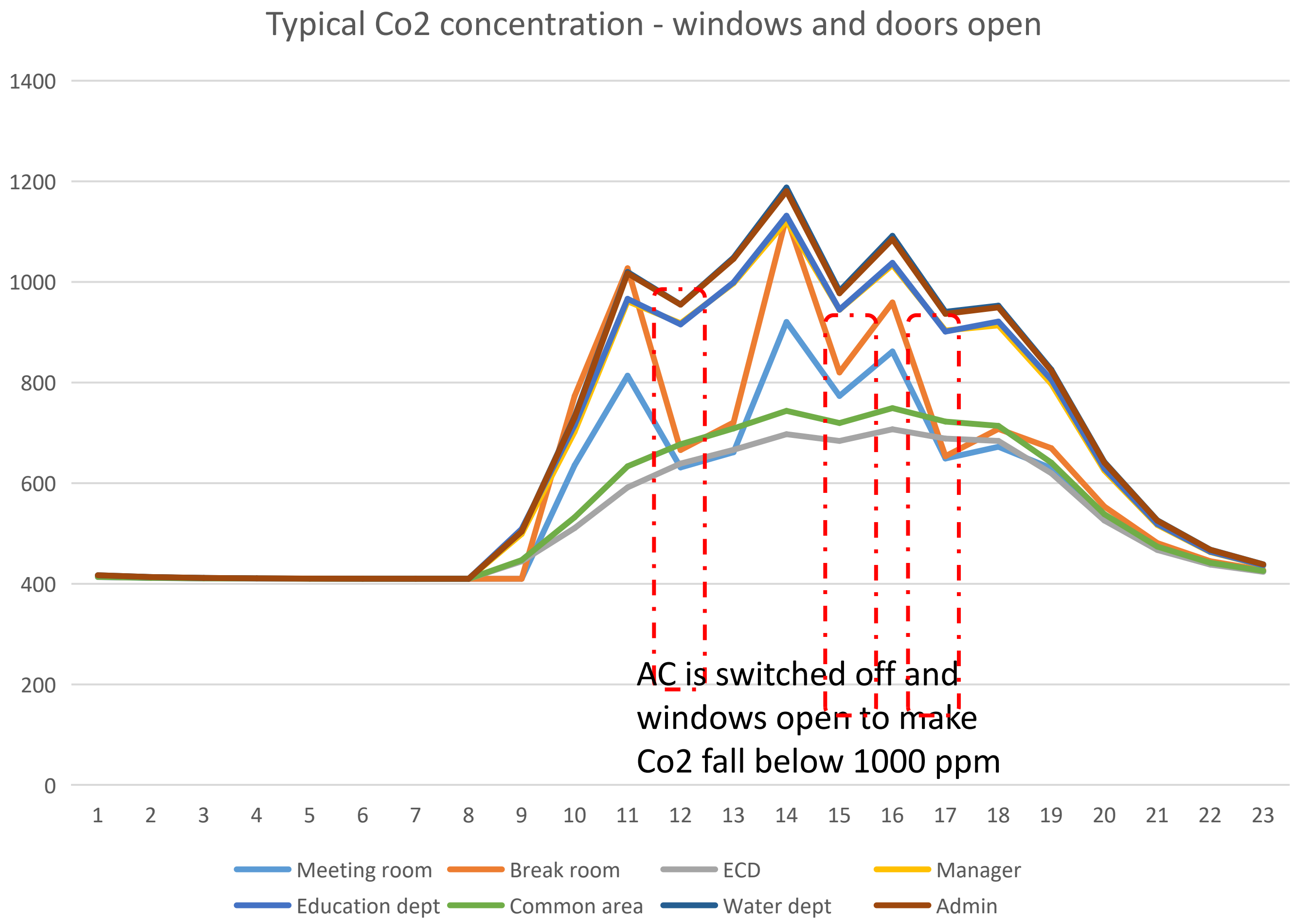
	On-site measurement with AC (windows and doors closed)				
Room	**Time of measurement**	**No. of Occupants**	**Temperature**	**TVoC ppb**	**CO2**
Meeting room	13:37 pm	4	27°C	1569	952 ppm
ECD room	13:37 pm	1	30°C	59%	759 ppm
Manager's room		2	26°C	63%	920 ppm
Education room		3	27°C	51%	680 ppm
Water & sanitation dept		2	NA – AC off		1207 ppm
Admin dept		2	NA – AC off		1081 ppm
Common area	14:30 pm	3	28°C	65%	1257 ppm

Ventilation and Air Quality
Measured and simulated data

Average Outdoor Air During Occupied Hours	Fresh Air /person (m3/s)	0.0025	As per ASHRAE 62.1 Minimum ventilation standards		
	Fresh Air /space (m3/s)	0.0003			
	Nominal Number of Occupants	Zone Volume [m3]	Area [m2]	Fresh air [m3/h]	**ACH**
ECDROOM	1	45.32	15.11	25.8588	0.6
MEETINGROOM	14	141.8	47.27	178.6716	1.3
BREAKROOM	4	27.34	13.02	49.2516	1.8
ADMIN	3	46.94	15.65	43.632	0.9
WATER DEPT	3	46.84	15.61	43.5888	0.9
COMMON AREA	2	79.21	26.4	46.332	0.6
EDUCATION DEPT	4	59.26	19.75	56.88	1.0
MANAGERS CABIN	2	33.74	11.25	30.33	0.9

CO2 sensors to raise an alarm for opening windows

https://tinyurl.com/uzh59myd



Thankyou