DDL753 Design of sustainable habitats

Dr Jay Dhariwal,
Assistant Professor,
Department of Design,
IIT Delhi

Topic 3: Health & Wellness in the Built Environment

29th September, 2023

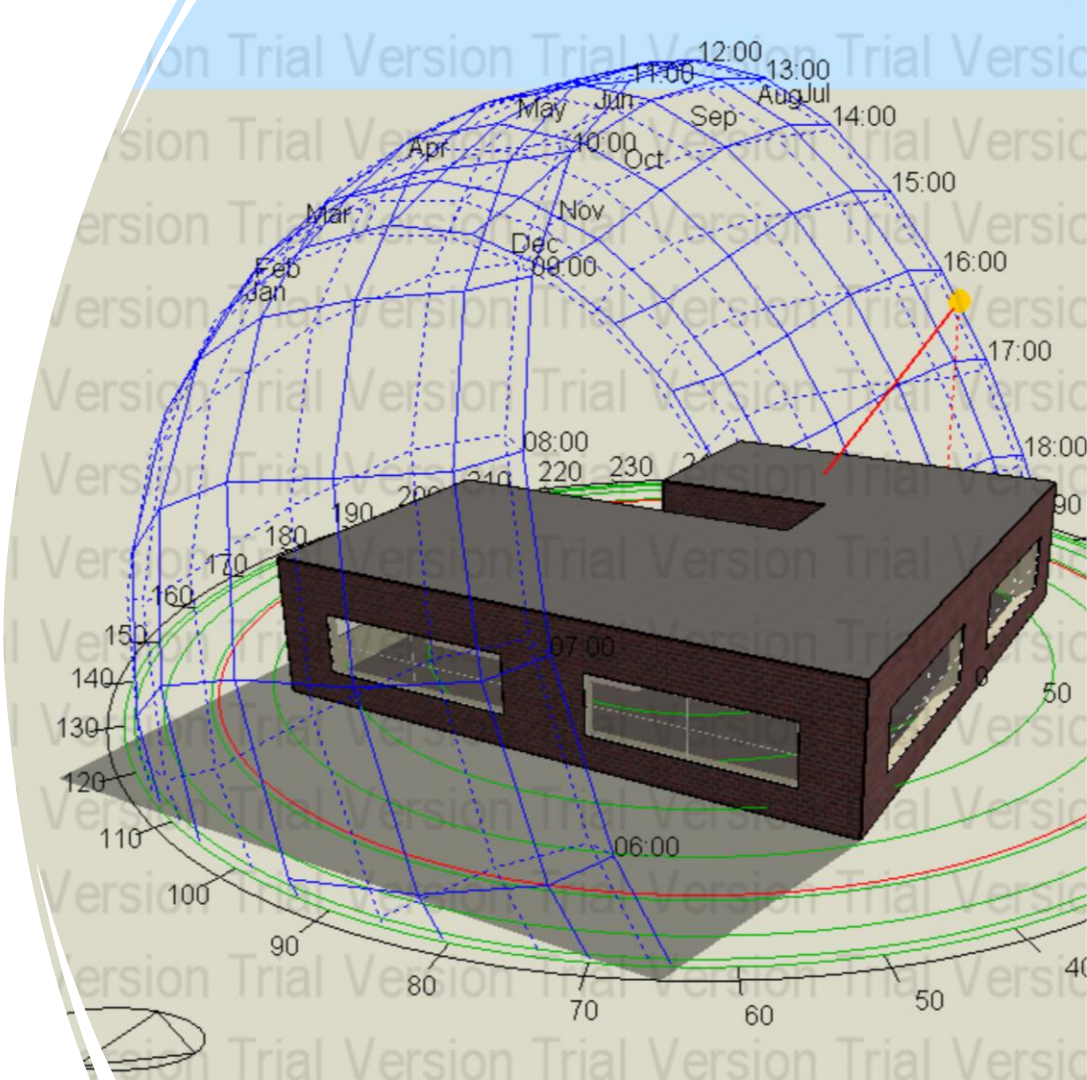
Source: https://www.savethechildren.net/blog/i-decided-take-role-climate-warrior#

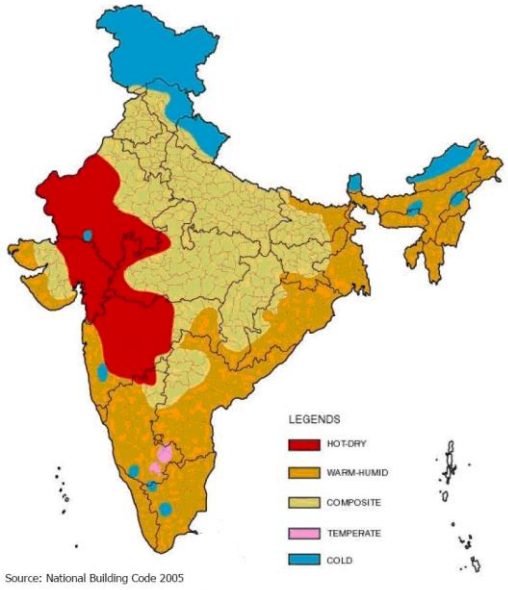
Climate Change affecting lives

- Race for Tomorrow – Bangladesh, Amazon rainforests, Greenland
- Finland's Climate Warriors | People and Power

Climate responsive design

- Climate analysis
- Shoe box modelling





Source: National Building Code 2005

Climate Zone

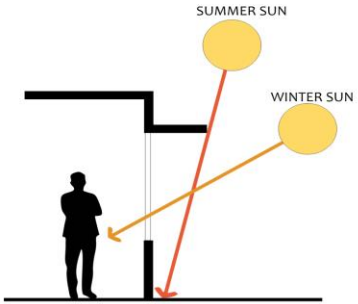
Click to generate report

Composite

REPORT

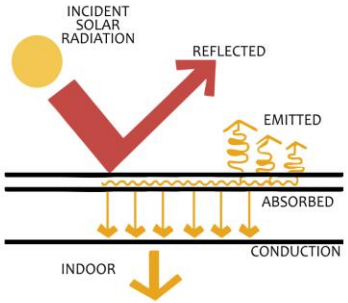
Composite

Shading



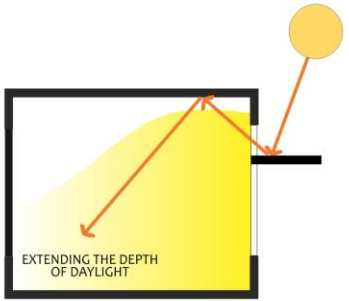
Extended roof, horizontal overhangs over the windows are effective in shading. These devices are designed to block the summer sun but allowing the winter sun.

Cool Roof



Cool roofs reflect most of the solar radiation and efficiently emit some of the absorbed radiation back into the atmosphere, instead of conducting it to the building below.

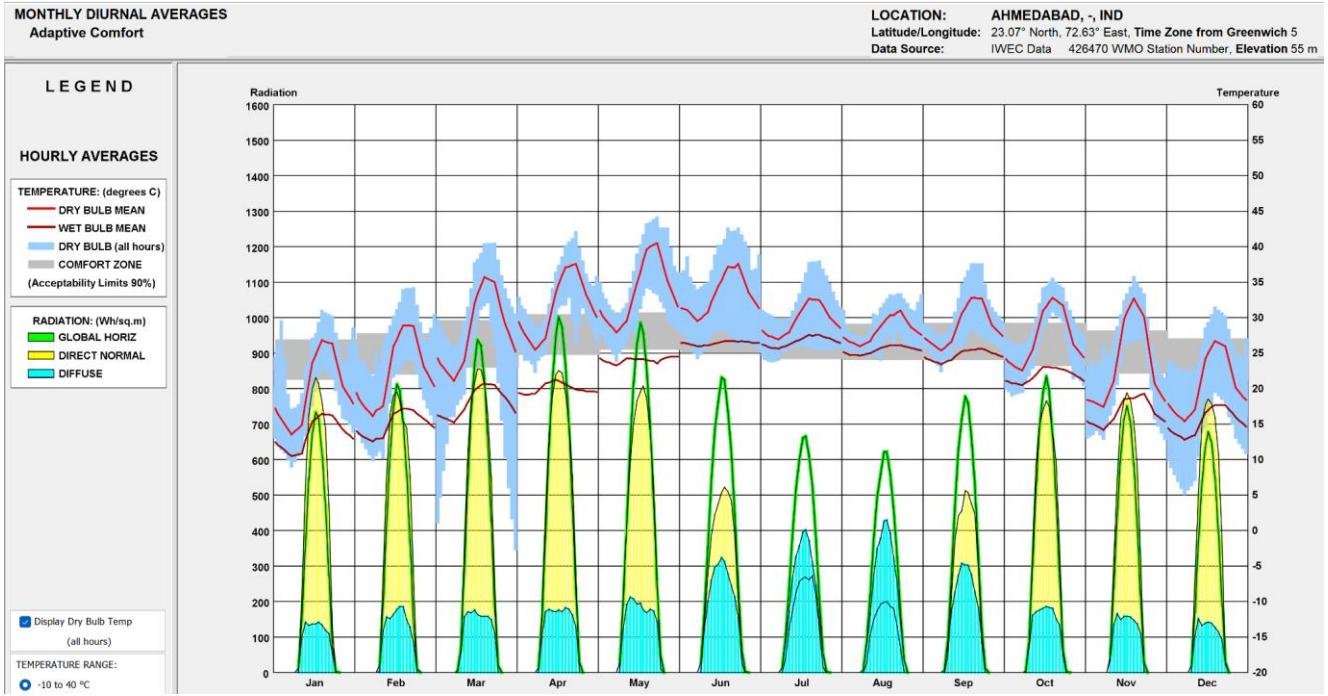
Light Shelf



The external light shelves to penetrate diffused light inside the space. They serve the dual purpose by acting as a shading device.

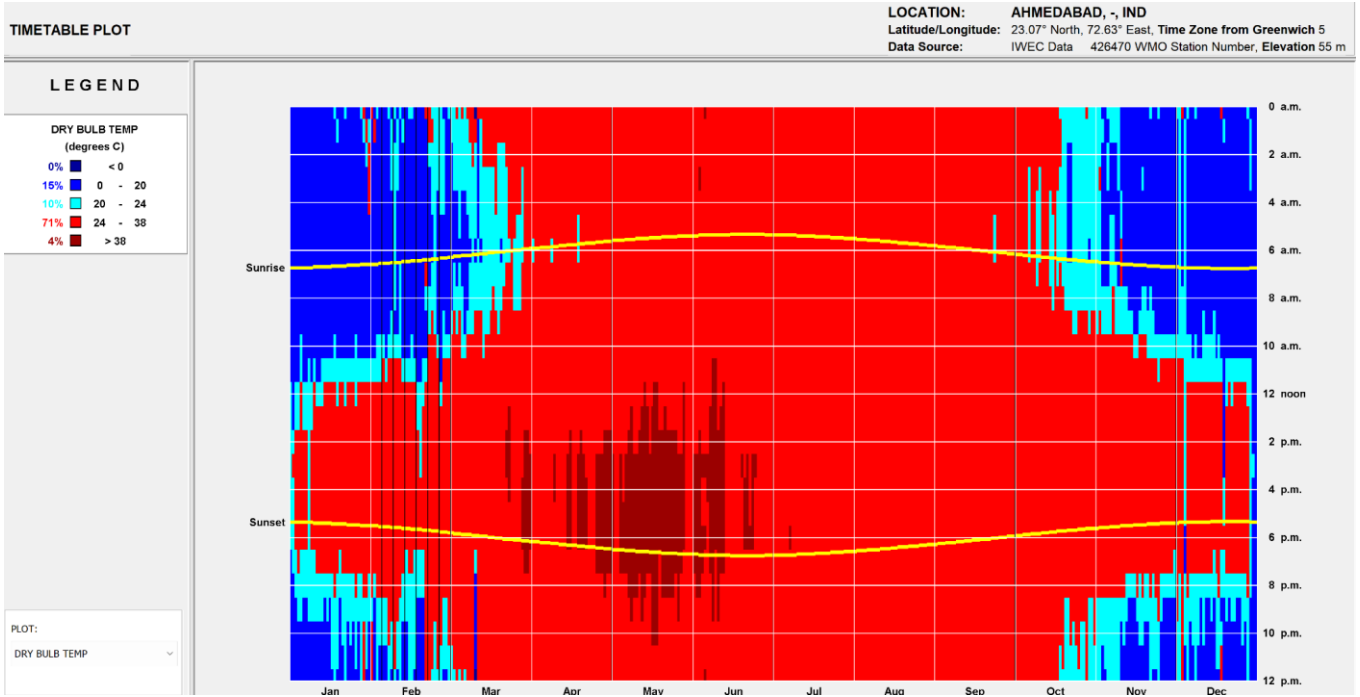
ECBC climate zone finder (example: Delhi)

Climate Consultant based analysis (example: Ahmedabad)

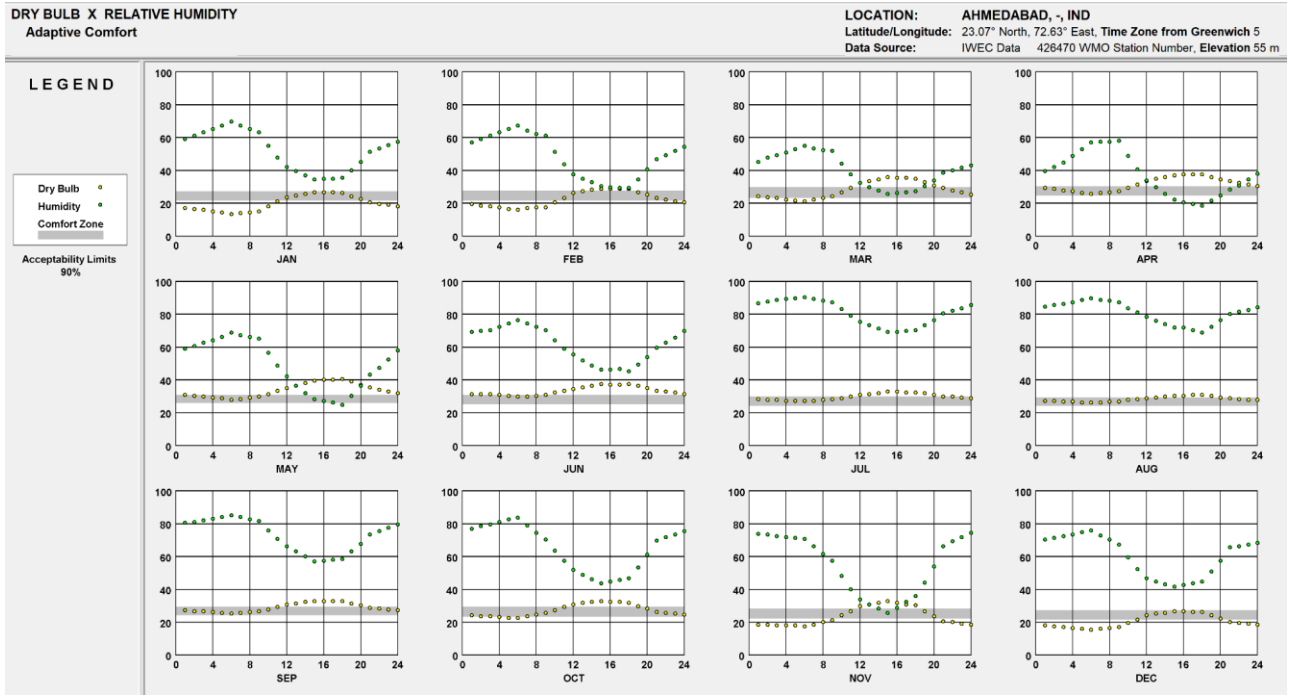


Climate vs. weather, TMY, current weather, predicted weather, urban vs rural, urban microclimate

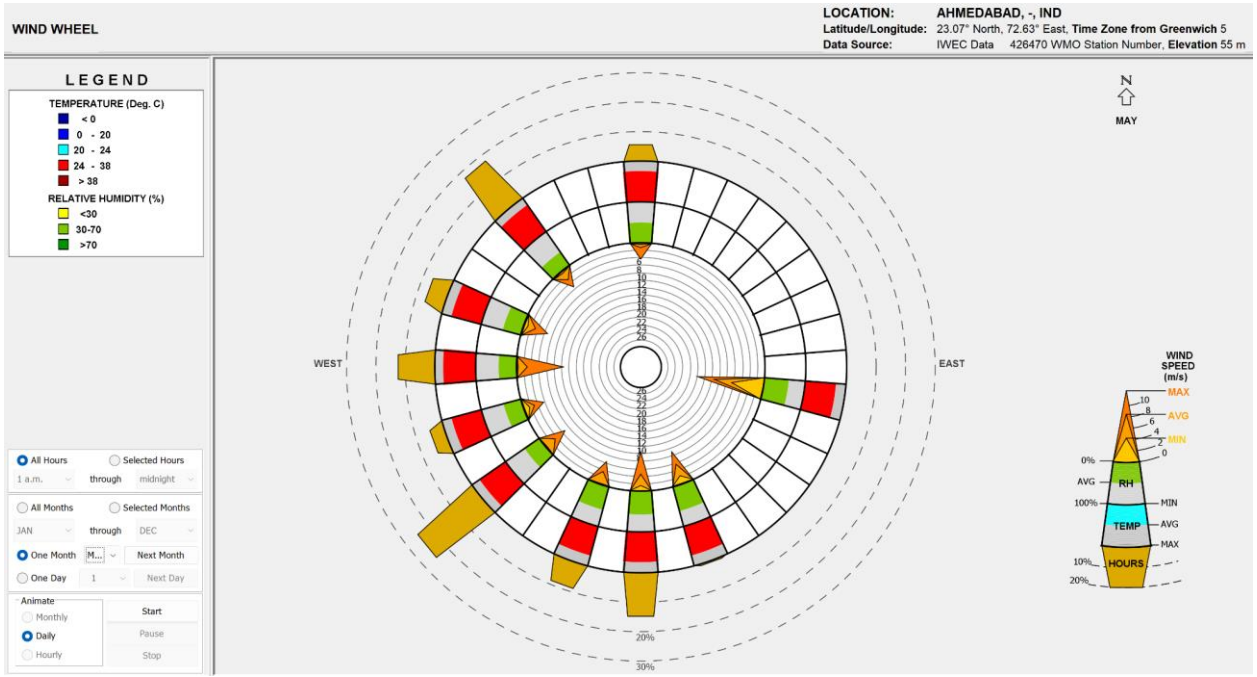
Air temperature variation



Effect of air temperature and humidity



Prevailing wind directions



PSYCHROMETRIC CHART
Adaptive Comfort

LOCATION: **AHMEDABAD, -, IND**
Latitude/Longitude: 23.07° North, 72.63° East, **Time Zone from Greenwich** 5
Data Source: IWEC Data 426470 WMO Station Number, **Elevation** 55 m

LEGEND

COMFORT INDOORS
100% COMFORTABLE
0% NOT COMFORTABLE

M... PLUS ASHRAE Standard 55

PLOT: COMFORT INDOORS

Hourly / Daily Min/Max

All Hours / Select Hours

1 a.m. through 12 a.m.

All Months / Select Months

JAN through DEC

1 Mo... JAN Next

1 Day 1 Next

1 Hour 1 a.m. Next

TEMPERATURE RANGE:

-10 to 40 °C / Fit to Data

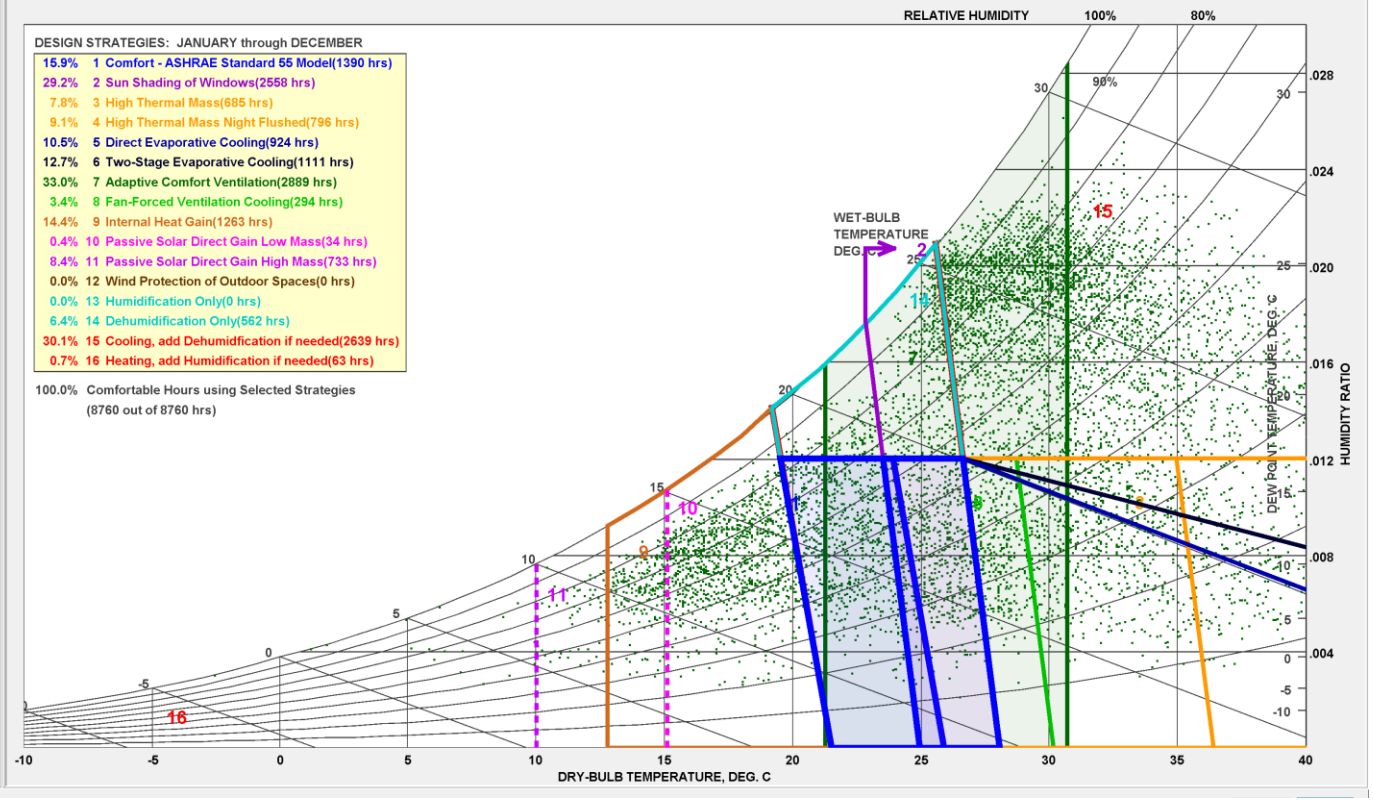
Display Design Strategies

Show Best set of Design Strateg...

DESIGN STRATEGIES: JANUARY through DECEMBER

15.9%	1	Comfort - ASHRAE Standard 55 Model(1390 hrs)
29.2%	2	Sun Shading of Windows(2558 hrs)
7.8%	3	High Thermal Mass(685 hrs)
9.1%	4	High Thermal Mass Night Flushed(796 hrs)
10.5%	5	Direct Evaporative Cooling(924 hrs)
12.7%	6	Two-Stage Evaporative Cooling(1111 hrs)
33.0%	7	Adaptive Comfort Ventilation(2889 hrs)
3.4%	8	Fan-Forced Ventilation Cooling(294 hrs)
14.4%	9	Internal Heat Gain(1263 hrs)
0.4%	10	Passive Solar Direct Gain Low Mass(34 hrs)
8.4%	11	Passive Solar Direct Gain High Mass(733 hrs)
0.0%	12	Wind Protection of Outdoor Spaces(0 hrs)
0.0%	13	Humidification Only(0 hrs)
6.4%	14	Dehumidification Only(562 hrs)
30.1%	15	Cooling, add Dehumidfication if needed(2639 hrs)
0.7%	16	Heating, add Humidification if needed(63 hrs)

100.0% Comfortable Hours using Selected Strategies
(8760 out of 8760 hrs)

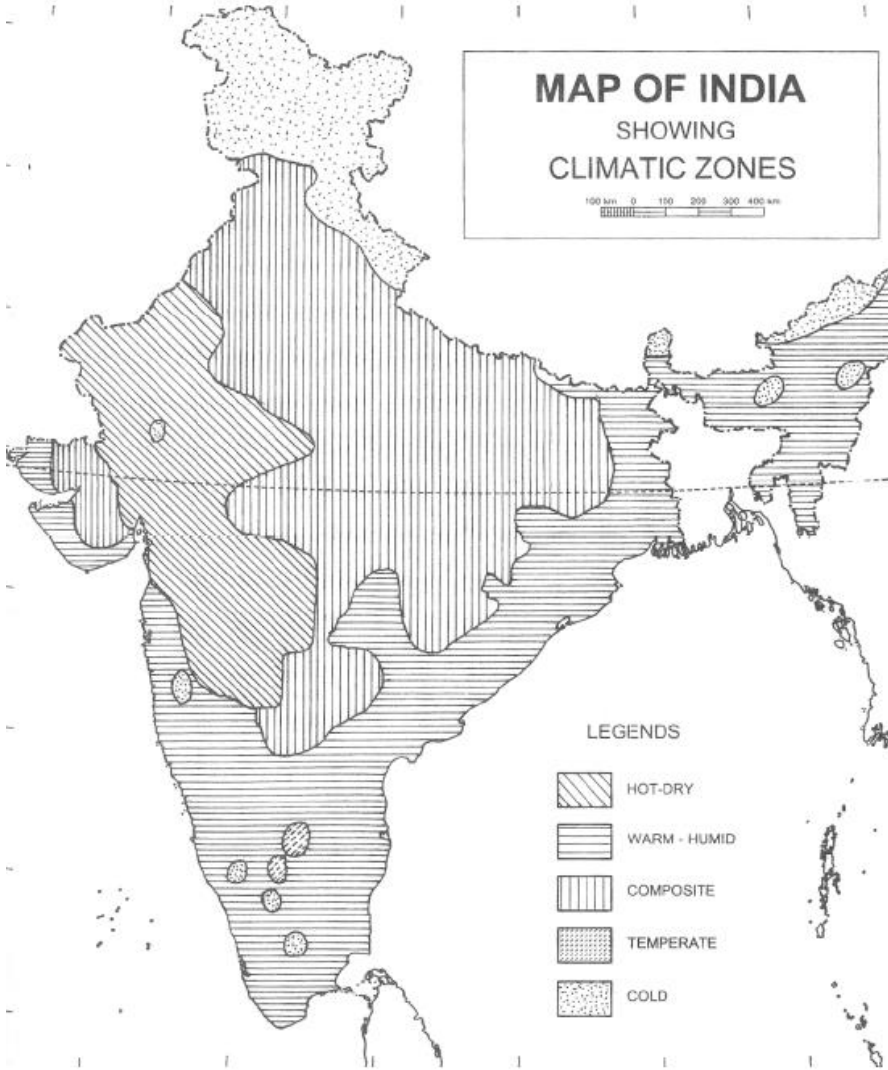


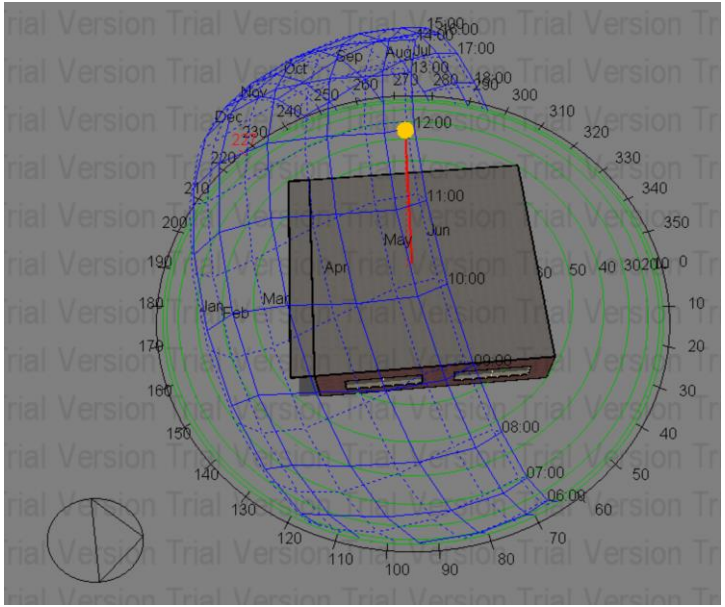
Climate zones of India

Source: Nayak, J.K., and J.A.Prajapati. 2006. *Handbook on Energy Conscious Buildings* IIT Bombay and Solar Energy Centre, Ministry of Non-conventional Energy Sources, Government of India: R & D project no. 3/4(03)/99-SEC.

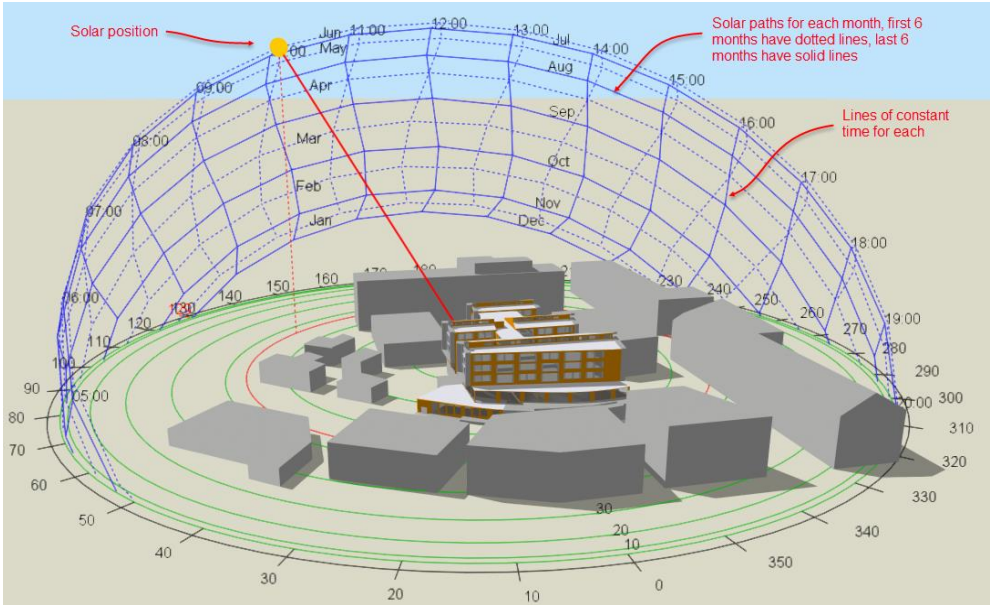
5)Composite Region

OBJECTIVES	PHYSICAL MANIFESTATION
1)Resist heat gain in summer and Resist heat loss in winter	
- Decrease exposed surface area	Orientation and shape of building. Use of trees as wind barriers
• Increase thermal resistance	Roof insulation and wall insulation
- Increase thermal capacity (Time lag)	Thicker walls
• Increase buffer spaces	Air locks/ Balconies
• Decrease air exchange rate	Weather stripping
• Increase shading	Walls, glass surfaces protected by overhangs, fins and trees
• Increase surface reflectivity	Pale colour, glazed china mosaic tiles, etc.
2)Promote heat loss in summer/ monsoon	
• Ventilation of appliances	Provide exhausts
• Increase air exchange rate (Ventilation)	Courtyards/ wind towers/ arrangement of openings
• Increase humidity levels in dry summer	Trees and water ponds for evaporative cooling
• Decrease humidity in monsoon	Dehumidifiers/ desiccant cooling



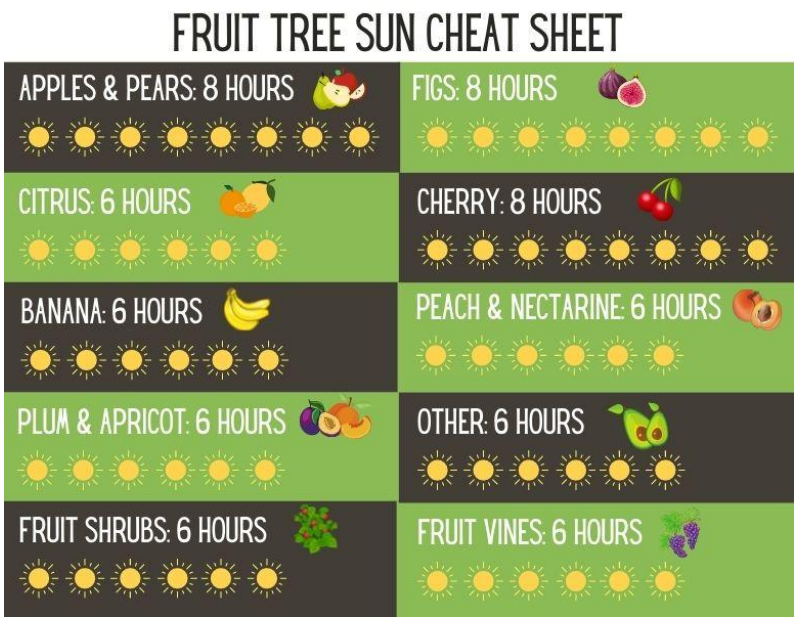


Location: Ahmedabad



Source: [DesignBuilder]

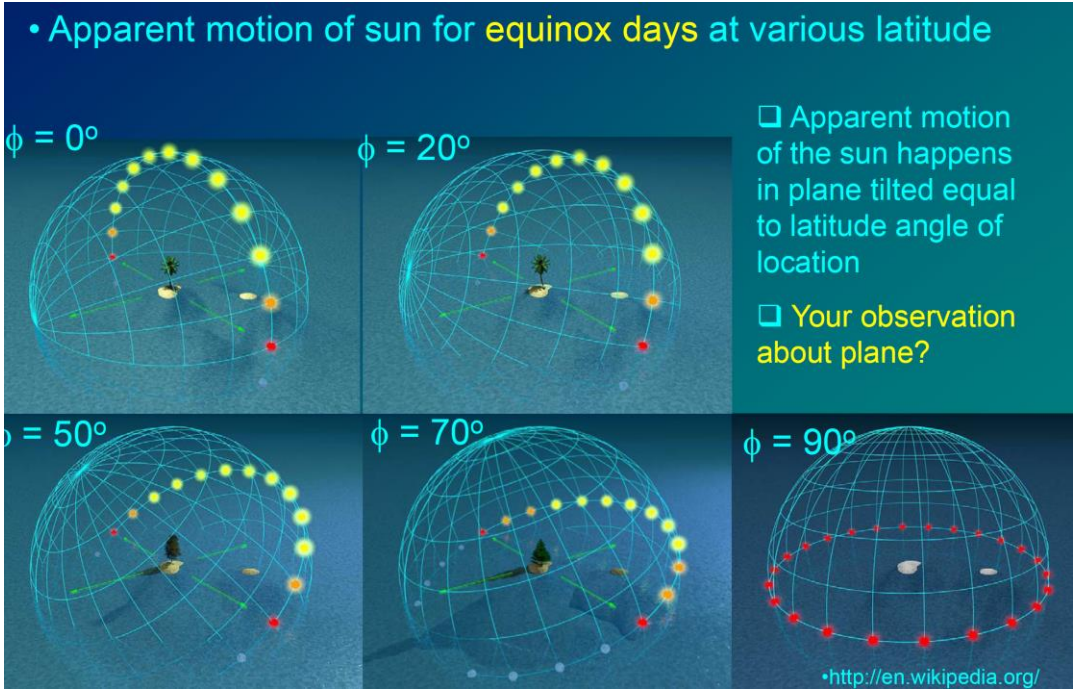
Sunpath



Sunlight needs of our fruits and veggies

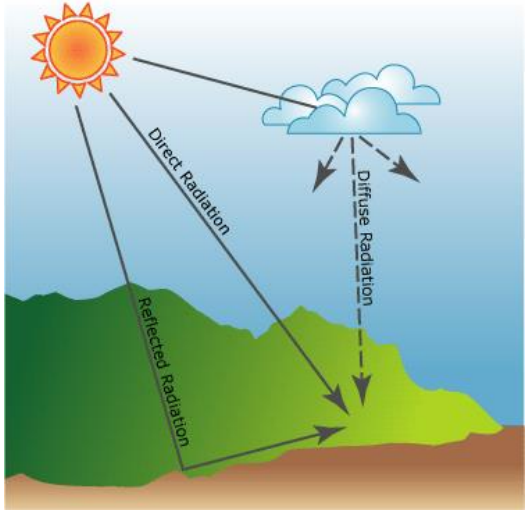
Source: https://www.pinterest.com/pin/376543218839357284/
https://www.naturehills.com/blog/post/how-much-sun-do-fruit-trees-need

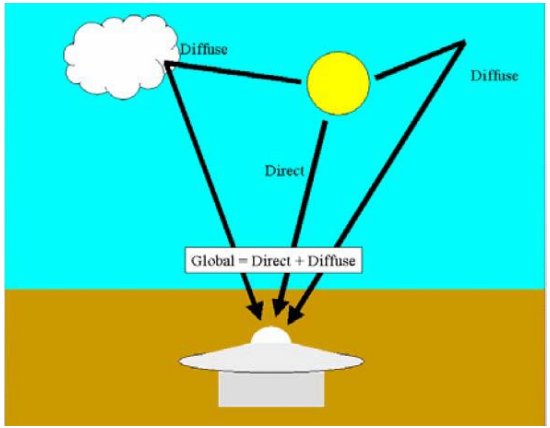
Apparent motion of the Sun

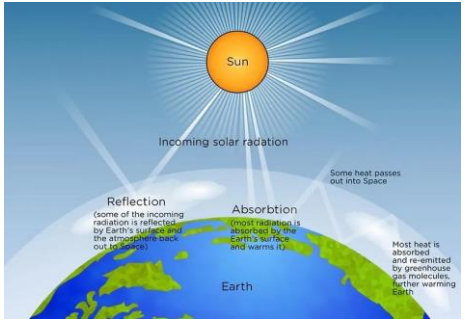


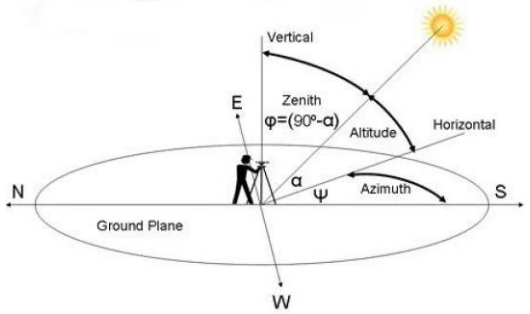
Source: Prof Chetan Singh Solanki's lecture notes from EN301, IIT Bombay

Solar geometry

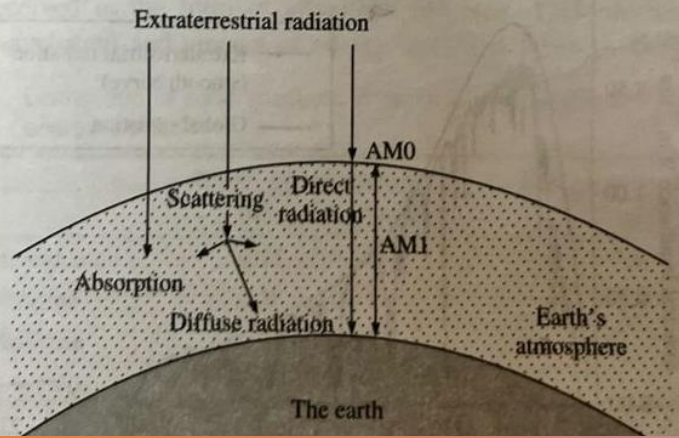


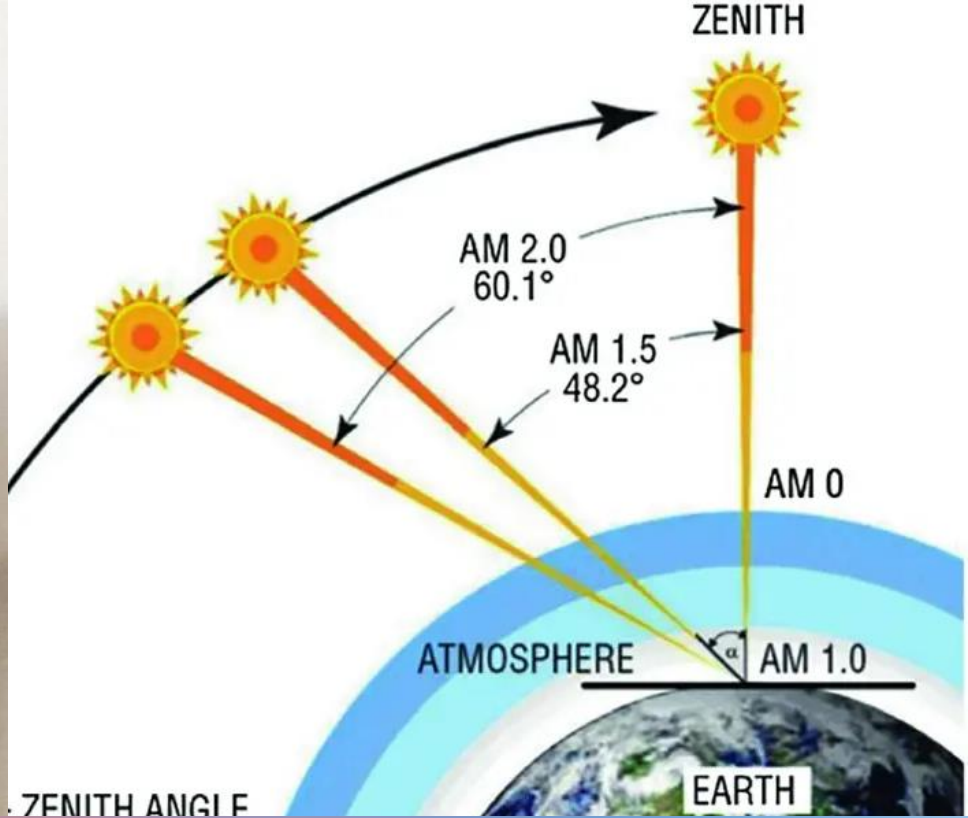






Distance travelled by sun rays to reach earth's surface, or Air Mass	*Solar radiation flux reaching the surface* (W/m^2)
AM0 (extraterrestrial)	1376
AM1 (sun at overhead position)	1105
AM1.5 (sun at about 48° from overhead position)	1000
AM 2 (sun at about 60° from overhead position)	894

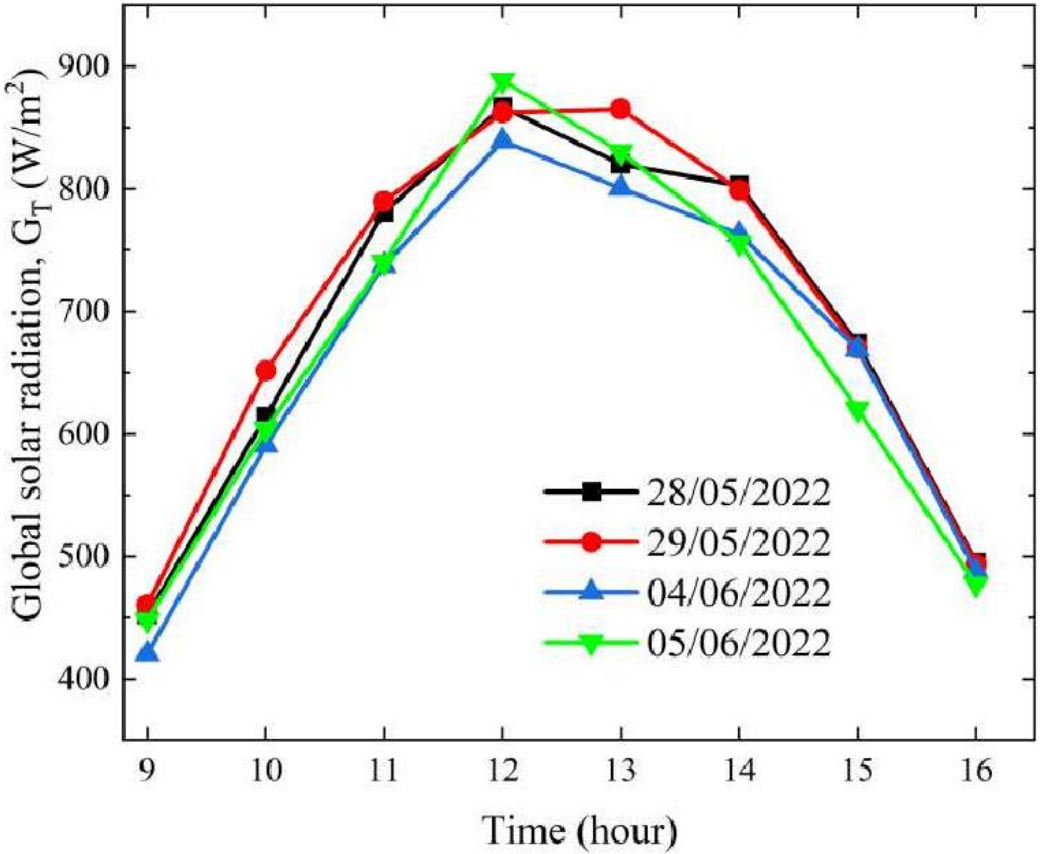




Solar radiation variation with air mass

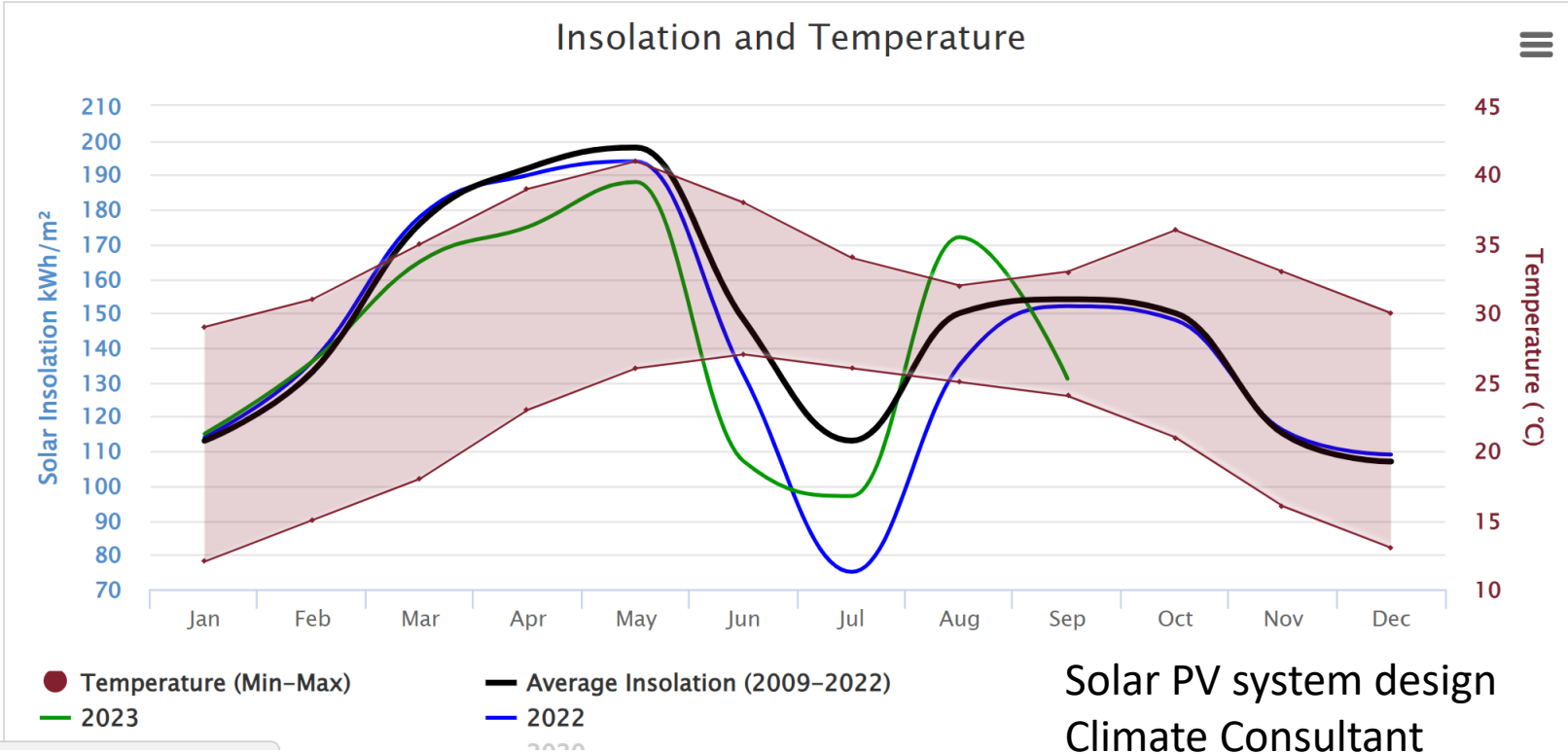
Source: "Renewable Energy Technologies" book by Prof Chetan Singh Solanki

Hourly variation in global solar radiation



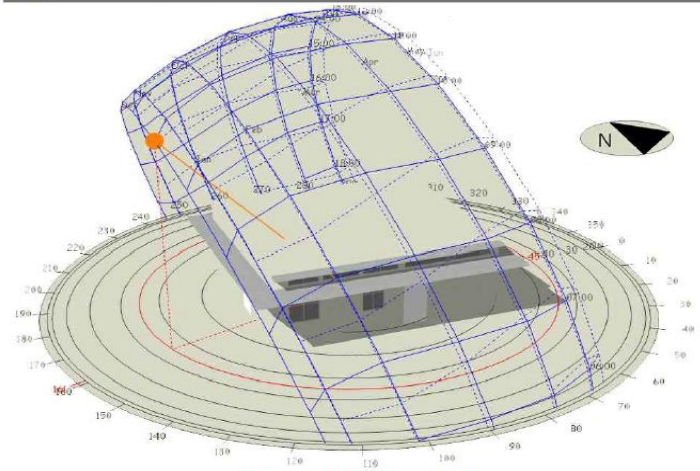
Source: https://www.researchgate.net/figure/Hourly-variation-in-global-solar-radiation-over-four-test-days_fig2_372036568

ISRO Solar Calculator

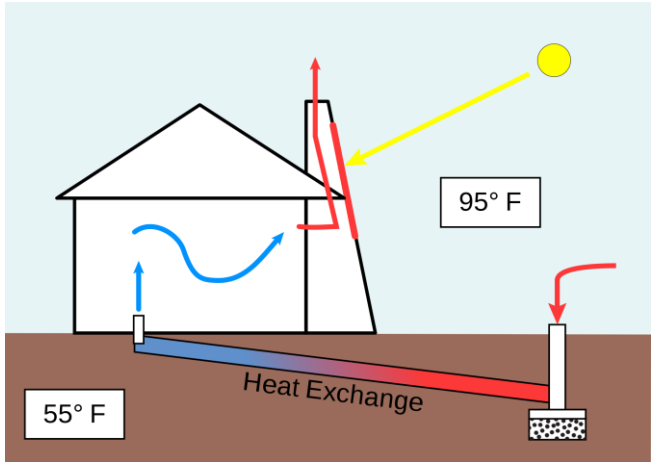


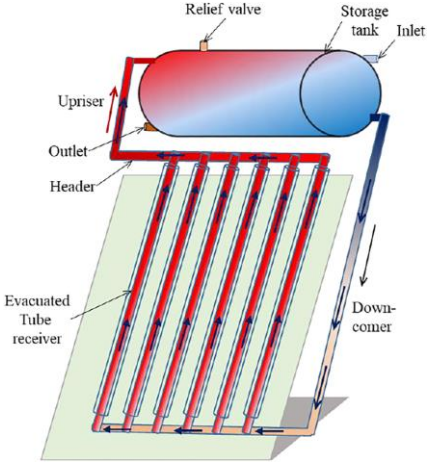
Solar PV system design
Climate Consultant

House Design: Passive Solar Architecture



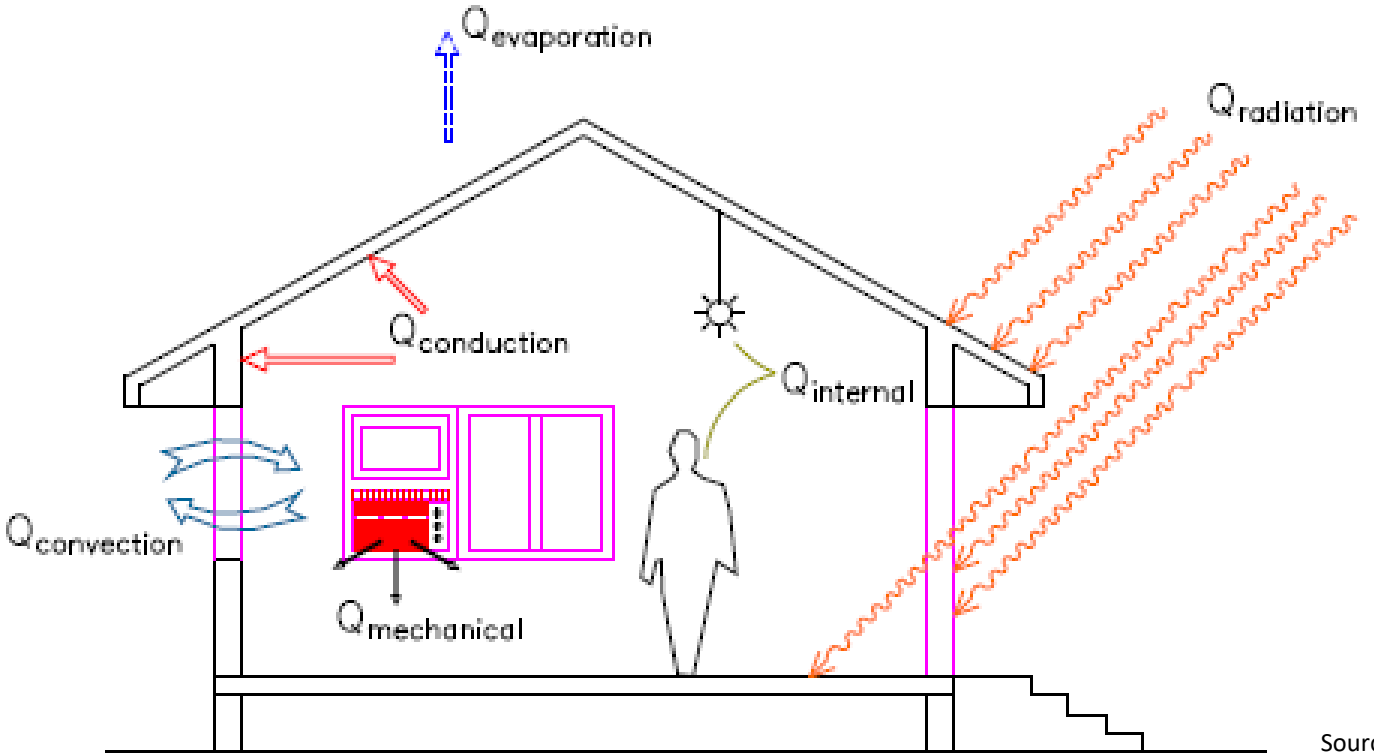
SUN PATH ANALYSIS FOR MUMBAI





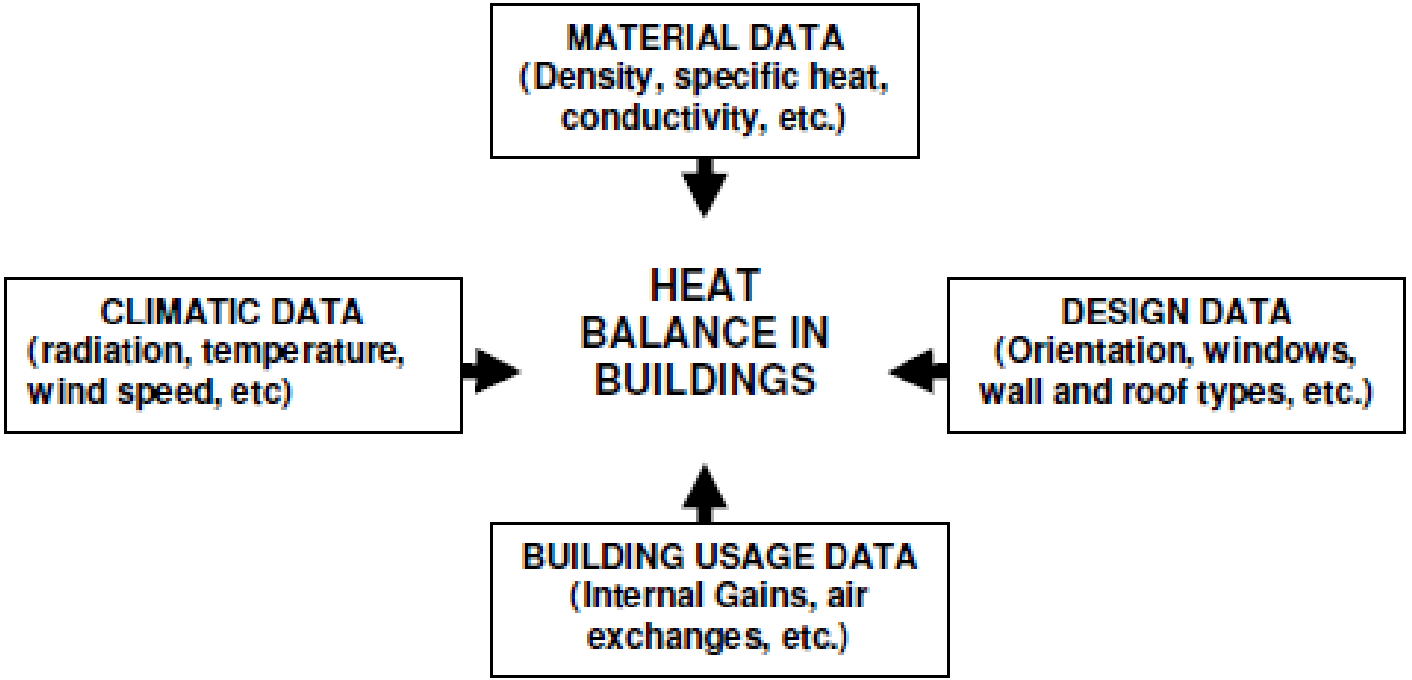
Applications of solar energy

Heat gains in a building

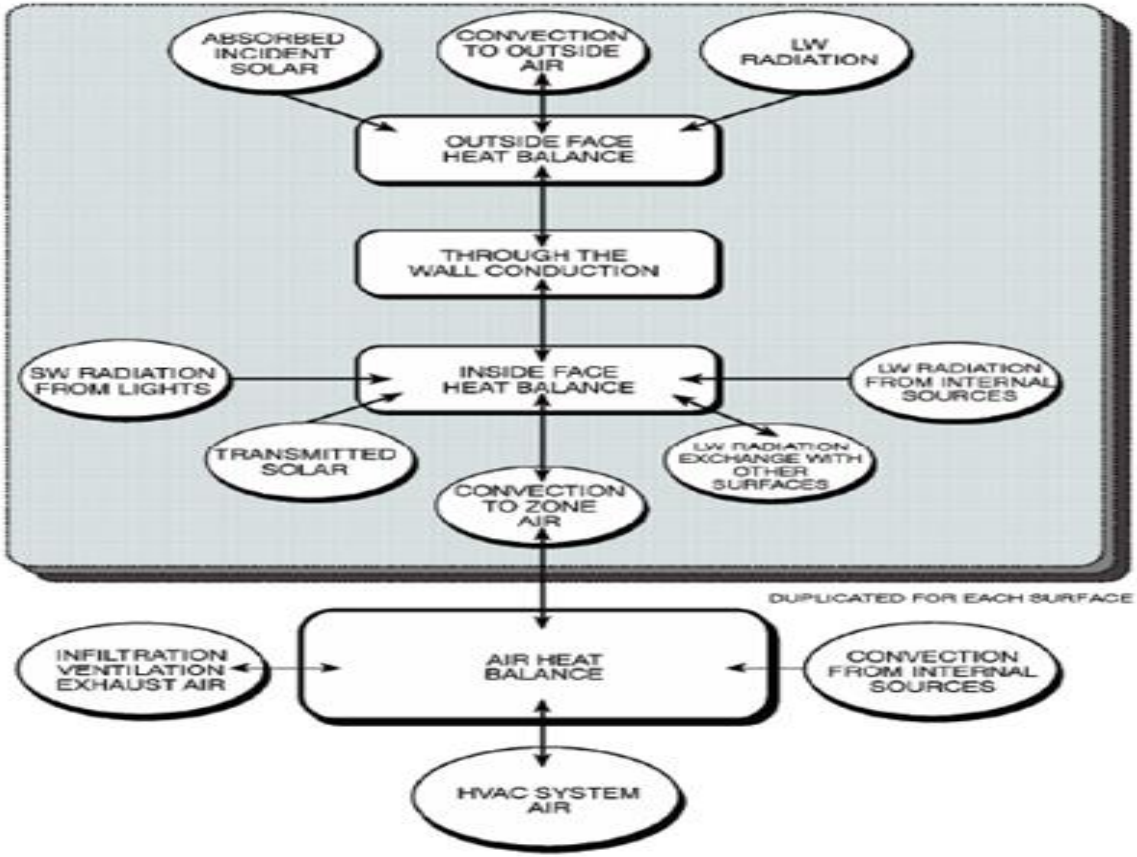


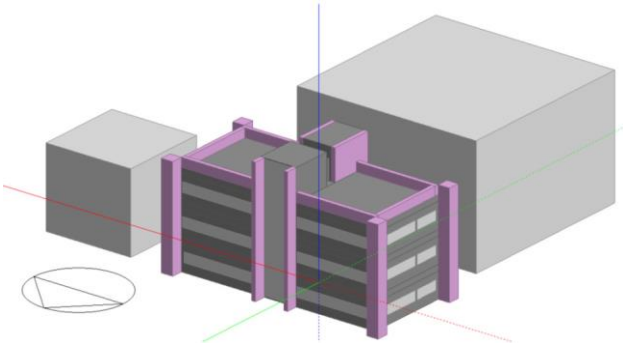
Source: Nayak, J.K., and J.A.Prajapati. 2006. *Handbook on Energy Conscious Buildings* IIT Bombay

Building Energy Simulation

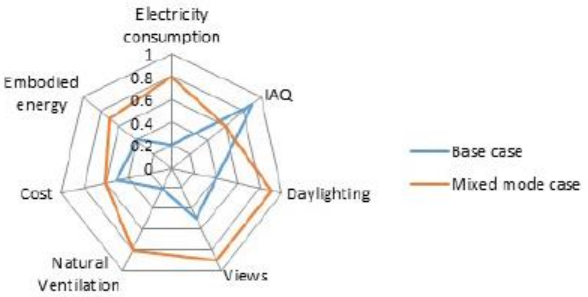


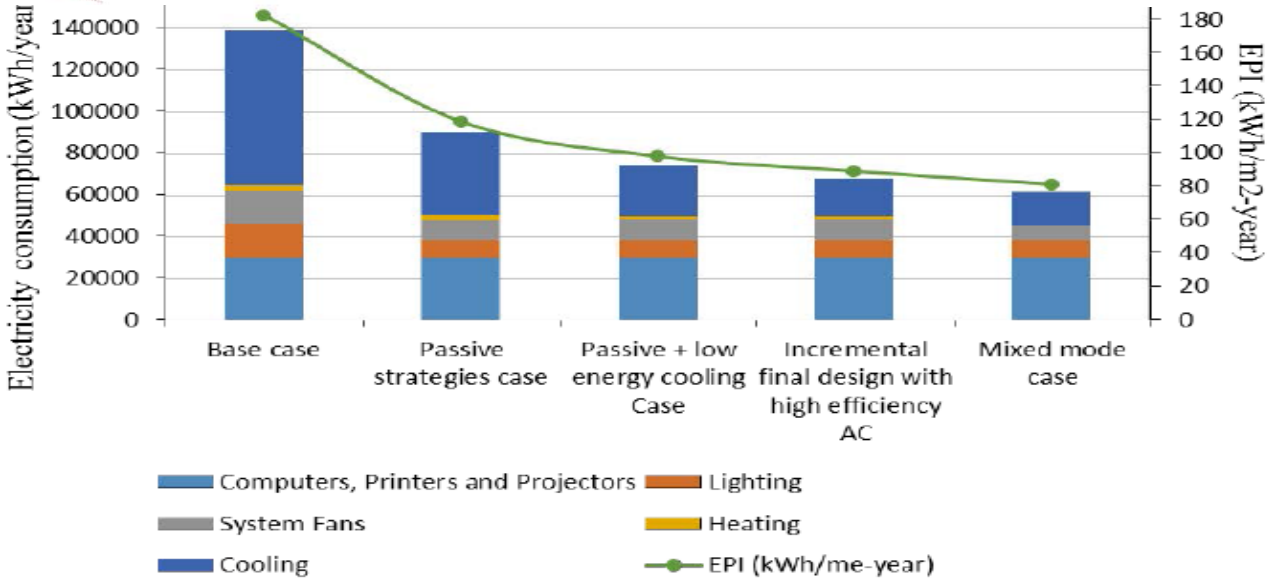
Heat balance processes in a zone (ASHRAE 2009)





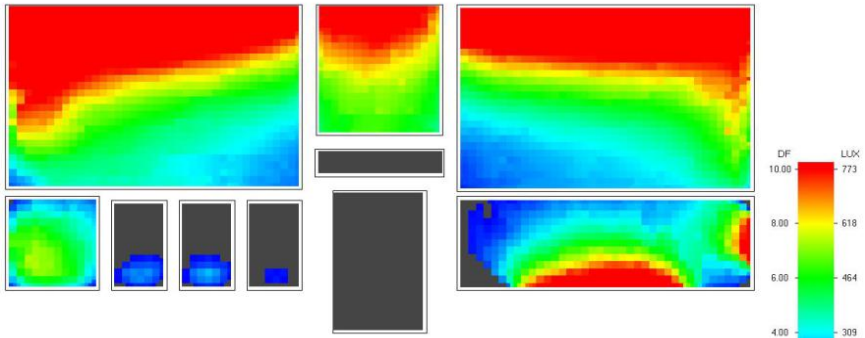
New Delhi climate



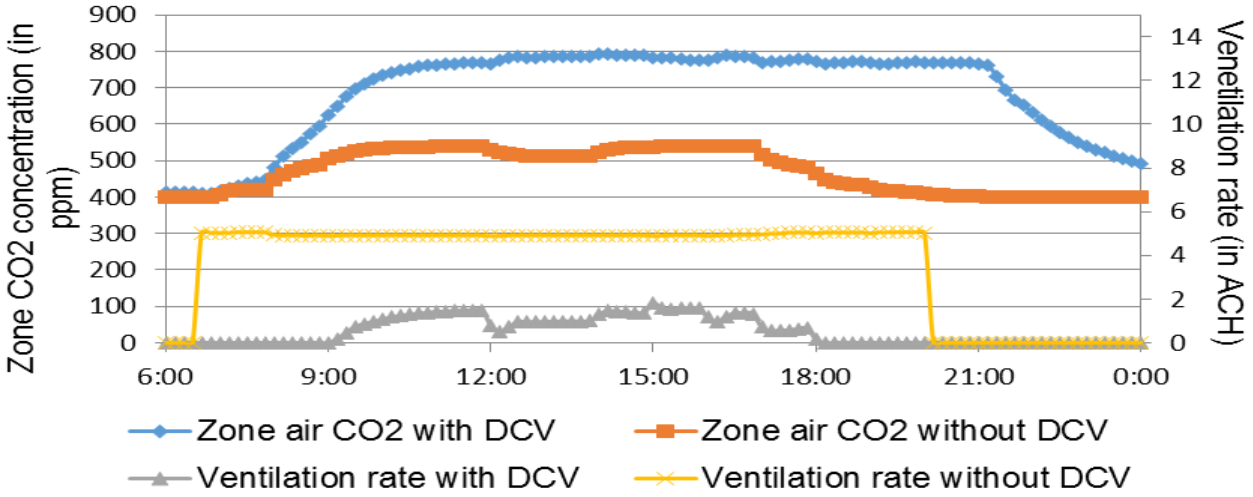


Dhariwal J., 'Design and simulation of a mixed-mode office building', *BS2015, 14th International Conference of International Building PerformanceSimulation Association (IBPSA),* Dec 2015. Winner of the student modelling competition for this entry.

Daylighting simulation



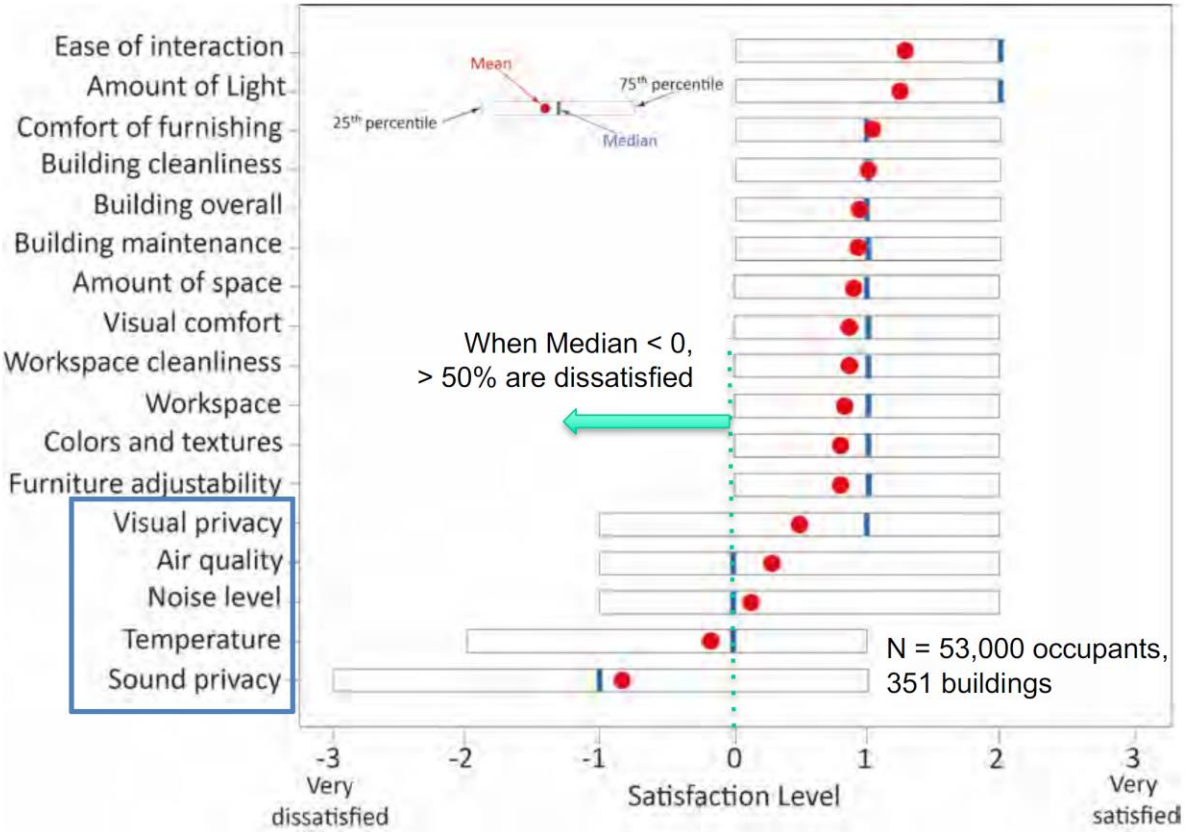
Demand controlled ventilation




Perceived Air Quality
Carbon Monoxide
Carbon Dioxide
Ozone
Nitrogen Oxides
Mould & Bacteria
Smoke
Volatile Organic Compounds
IAQ
Perceived Visual Comfort
Visual Ergonomics
Glare
Natural Light
Artificial Lighting
View
Privacy
Building Design
Visual Comfort
IEQ
Air Velocity
Humidity
Air/Surface Temperature
Clothing/Insulation
Activity Level
Thermal Comfort
Perceived Thermal Comfort
Acoustic Comfort
Sound Insulation
Noise Levels
Privacy
Perceived Acoustic Comfort

CBE occupant satisfaction survey, office buildings

– > 50% are dissatisfied with temperature



- Frontczak M, Schiavon S, et al. 2011. Indoor Air Journal

Lighting

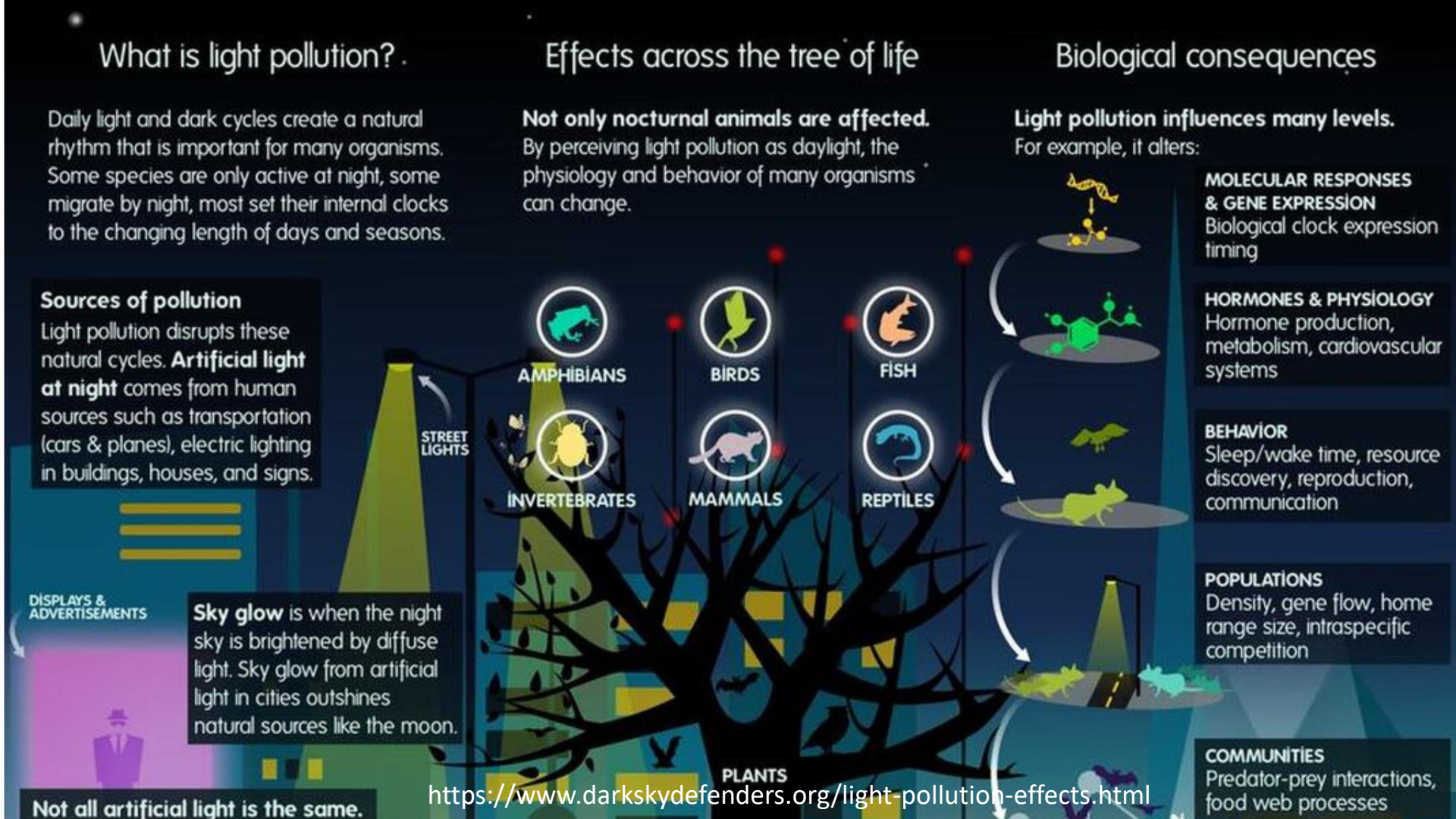
Table 4 Recommended Values of Illuminance
(*Clauses* 4.1.3.1, 4.1.4, 4.1.4.2, 4.3.2 *and* 4.3.2.1)

Sl No.	Type of Interior or Activity	Range of Service Illuminance (*See* Note) lux	Quality Class of Direct Glare Limitation (*See* Note)
(1)	(2)	(3)	(4)
21	**EDUCATION**		
21.1	Assembly Halls		
21.1.1	General	200-300-500	3
21.1.2	Platform and stage		
21.2	Teaching Spaces		
	General	200-300-500	1
21.3	Lecture Theatres		
21.3.1	General	200-300-500	1
21.3.2	Demonstration benches	300-500-750	1
21.4	Seminar Rooms	300-500-750	1
21.5	Art Rooms	300-500-750	1
21.6	Needlework Rooms	300-500-750	1
21.7	Laboratories	300-500-750	1
21.8	Libraries	200-300-500	1
21.9	Music Rooms	200-300-500	1
21.10	Sports Halls	200-300-500	1
21.11	Workshops	200-300-500	1

Source: Page 97 NBC 2016 Volume 2

Light and health

https://www.sleepfoundation.org/bedroom-environment/light-and-sleep



https://www.darkskydefenders.org/light-pollution-effects.html

Sound levels

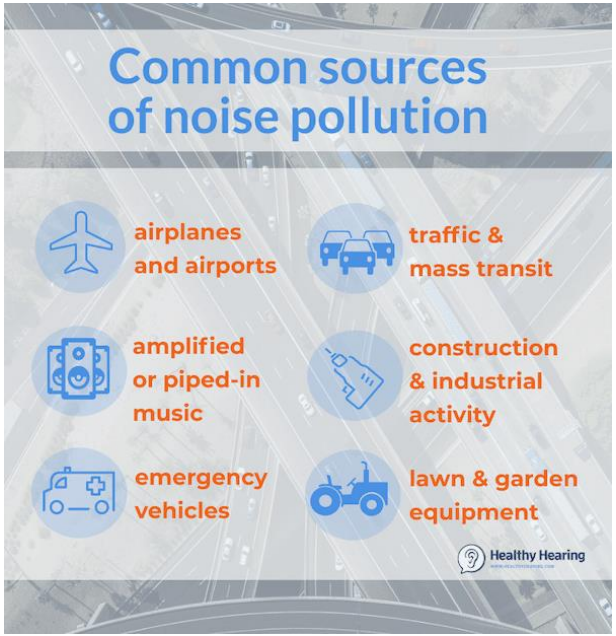
Table 4 Acceptable Indoor Noise Levels for Various Buildings

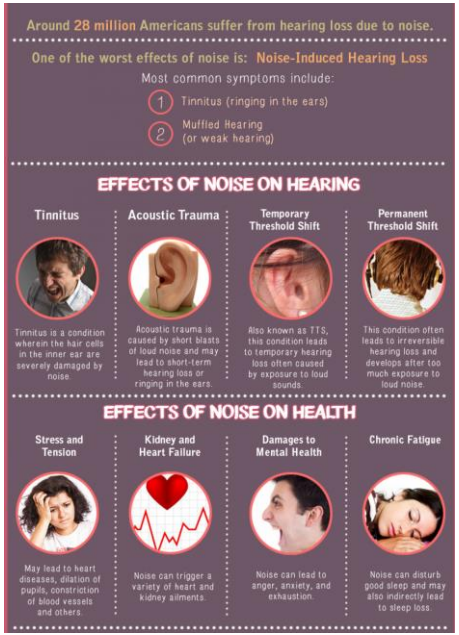
(*Clause* 4.1)

Sl No. (1)	Location (2)	Noise Level dBA (3)
i)	Auditoria and concert halls	20-25
ii)	Radio and TV studios	20-25
iii)	Cinemas	25-30
iv)	Music rooms	25-30
v)	Hospitals	35-40
vi)	Apartments, hotels and homes	35-40
vii)	Conference rooms, small offices and libraries	35-40
viii)	Court rooms and class rooms	40-45
ix)	Large public offices, banks and stores	45-50
x)	Restaurants	50-55

Source: Part 8, Section 4, Page 402, NBC 2016 Volume 2

Noise pollution sources and health effects





https://visual.ly/community/Infographics/health/effects-noise-health-and-hearing

Thermal Comfort

a) *For naturally ventilated* (NV) *buildings*:

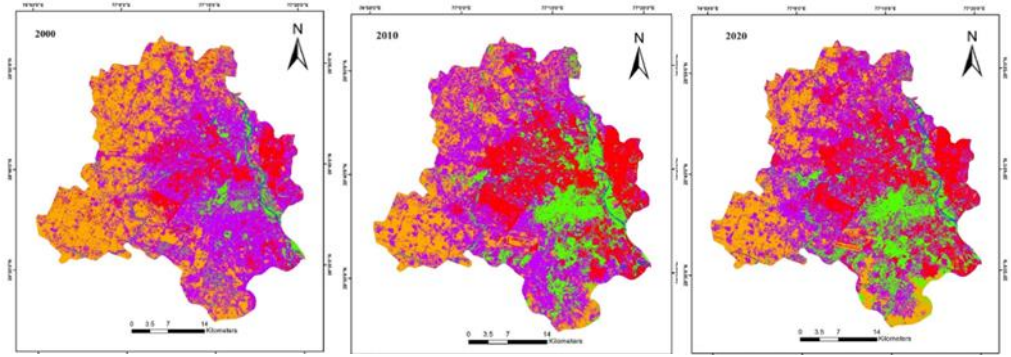
The following equation should be used for design and operation of naturally ventilated (NV) buildings. It indicates that occupants in NV buildings thermally adapt to the outdoor temperature of their location. It is based on the 30 day outdoor running mean temperature (in °C).

Indoor operative temperature = (0.54 × outdoor temperature) + 12.83

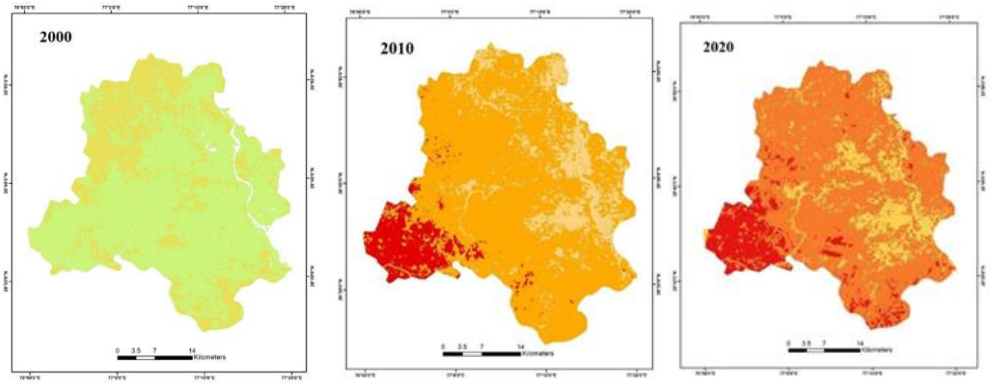
Where, indoor operative temperature (in °C) is neutral temperature, and outdoor temperature is the 30 day outdoor running mean air temperature (in °C).

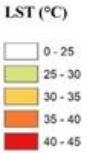
Source: Section 3 HVAC, Page 330 of NBC 2016 Volume 2

Heat stress assessment & mitigation



LULC map of Delhi – 2000, 2010 and 2020



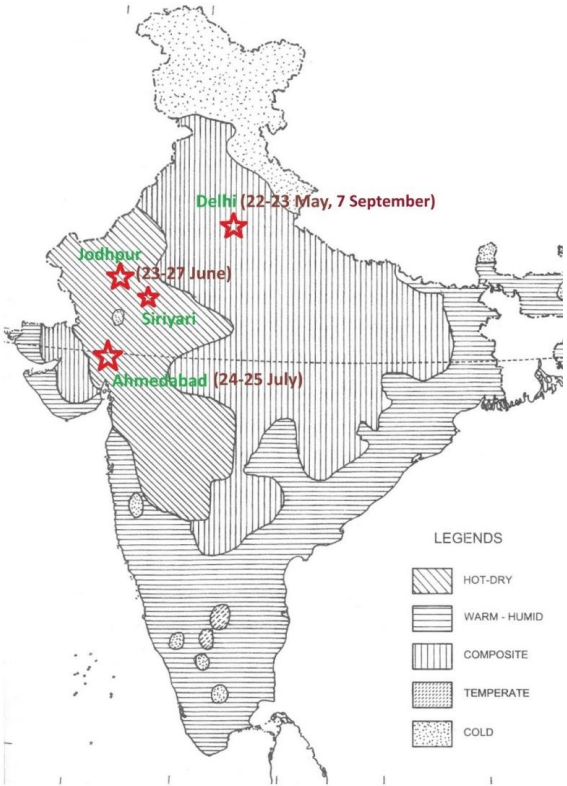


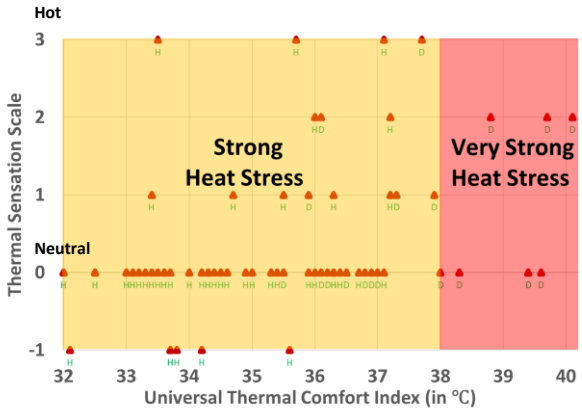
Land Surface Temperature (LST) Distribution Delhi 2000, 2010, and 2020.

On **28th June 2022** , the outdoor temperatures in Delhi was **40°C**, but because of high humidity, it felt like **58°C** & we had to use AC.

UTCI calculator

Urban heat island effect and vulnerable populations





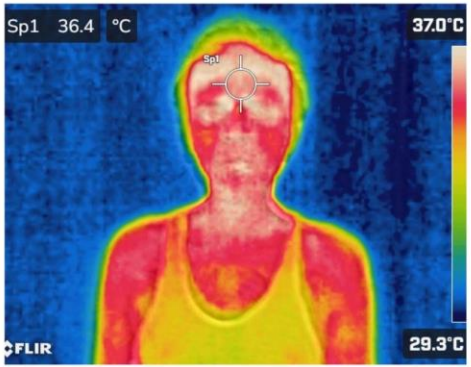
Research gaps: Human limits of thermal comfort, Behavioural adaptation of normal householders to reduce energy consumption, adaptation of IIT hostellers

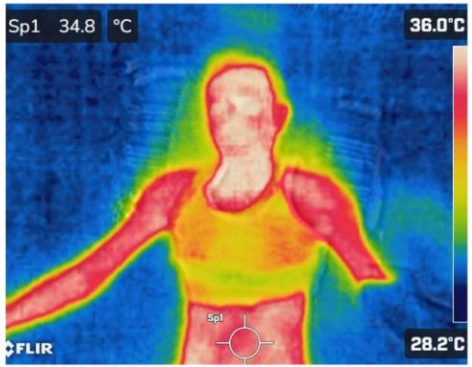
Communities living a low carbon lifestyle

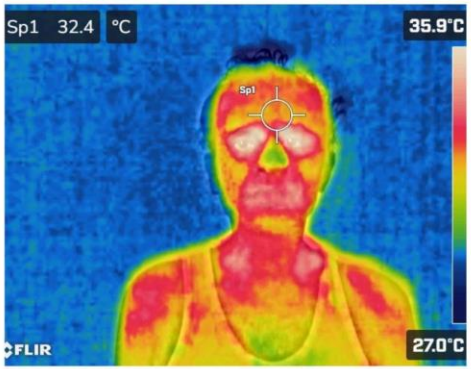
Areas: Design for Sustainability, Behavioural Design, Environmental Ergonomics

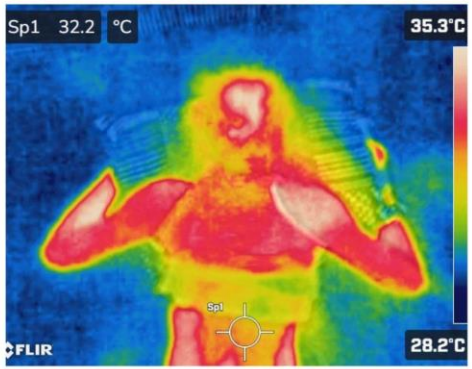
Collaboration with Prof Pramod Khadilkar, Dept. of Design, IIT Delhi

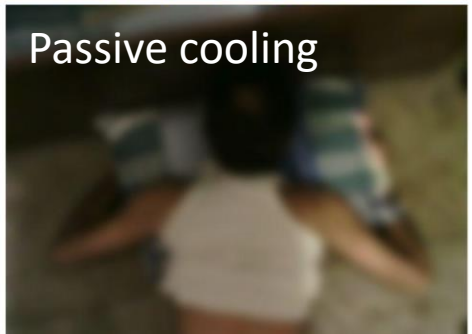
Dhariwal, J. & Gangrade, S. (2023). Learnings from the extreme thermal comfort adaptation of Jain ascetics during the summer and the monsoon months in India. Accepted for publication at CATE2023, 13 - 15 December 2023 | CEPT University, Ahmedabad, India.











Thermal imaging for identifying target behaviours for low energy cooling

Ventilation

Sl No. (1)	*Application* (2)	*Air Change per Hour* (3)
18.	Dairies	8-12
19.	Dance halls	12, *Min*
20.	Dye works	20-30
21.	Electroplating shops	10-12
22.	Engine rooms/DG Rooms/GG Rooms	*see* Note 2
23.	Entrance halls	3-5
24.	Factories and work shops	8-10
25.	Foundries	15-30
26.	Garages	6-8
27.	Glass houses	25-60
28.	Gymnasium	6, *Min*
29.	Hair dressing saloon	10-15
30.	Hospitals sterilising	15-25
31.	Hospital wards	6-8
32.	Hospital domestic	15-20
33.	Laboratories	6-15
34.	Launderettes	10-15
35.	Laundries	10-30
36.	Lavatories	6-15
37.	Lecture theatres	5-8
38.	Libraries	3-5

Source: Part 8 Building Services, Section 1, Page 118 of National Building Code Volume 2

Table 3 Minimum Ventilation Rates in Breathing Zone (*See* Notes 1 to 5)

[*Clause* 6.2(c)(3)]

(This table is not valid in isolation; it shall be used in conjunction with the accompanying notes.)

Sl No.	Occupancy Category	People Outdoor Air Rate, R_p		Area Outdoor Air Rate, R_a		Notes	Default Values			Air[1] Class
							Occupant Density (*see* Note 4)	Combined Outdoor Air Rate (*see* Note 4)		
		cfm/ person	l/s. person	cfm/ ft^2	l/s.m^2		Persons per 1 000 ft^2 or per 100 m^2	cfm/person	l/s.person	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
i)	Correctional facilities:									
	a) Cell	5	2.5	0.12	0.6		25	10	4.9	2
	b) Dayroom	5	2.5	0.06	0.3		30	7	3.5	1
	c) Guard Stations	5	2.5	0.06	0.3		15	9	4.5	1
	d) Booking/waiting	7.5	3.8	0.06	0.3		50	9	4.4	2
ii)	Educational facilities:									
	a) Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6	2
	b) Daycare sickroom	10	5	0.18	0.9		25	17	8.6	3
	c) Classrooms (ages 5-8)	10	5	0.12	0.6		25	15	7.4	1
	d) Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7	1
	e) Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3	1
	f) Lecture hall (fixed seats)	7.5	3.8	0.06	0.3		150	8	4.0	1

Source: Section 3 HVAC, Page 333 of NBC 2016 Volume 2

Need for adequate ventilation (high CO_2 levels)

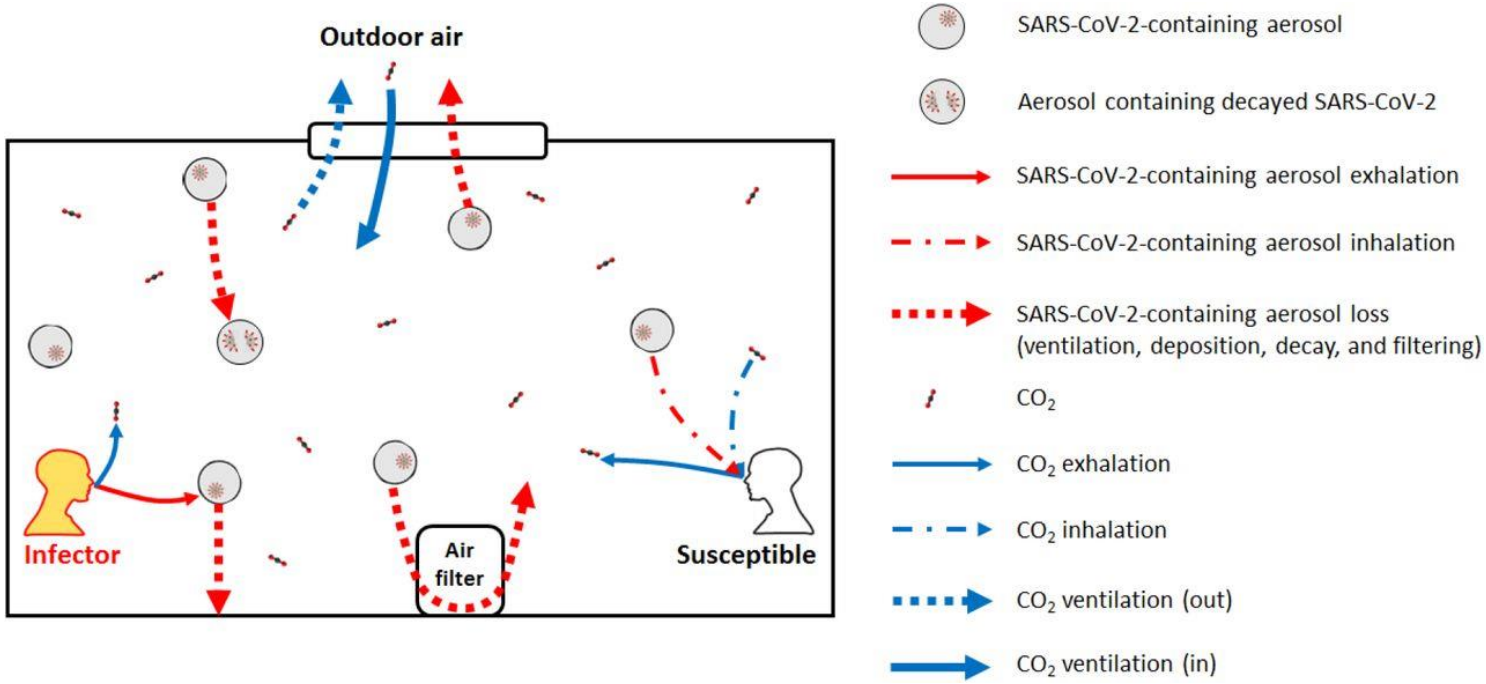
Table 1 | Overview of potential health effects

	CO_2 concentration (ppm)	Duration	Selected key references
Adverse health outcomes associated with acute CO_2 exposure			
CO_2 retention	1,000–5,000	<4 h	Zhang et al.[75]; Zhang et al.[73]; Vehvilainen et al.[77]; Shiraram et al.[76]
Inflammation	2,000–4,000	2 h	Thom et al.[80,81]; Schneberger et al.[82]
Cognitive effects	1,000–2,700	1–6 h	Kajtar and Herczeg[85]; Satish et al.[86]; Allen et al.[87,88]; Zhang et al.[75]; Zhang et al.[73,74]; Rodeheffer et al.[91]; Snow et al.[90]
Adverse health outcomes associated with chronic CO_2 exposure			
Chronic, low-grade systemic inflammation	~3,000	13 d	Zappulla[2,69]; Beheshti et al.[101]
Bone demineralization and kidney calcification	~2,000–3,000	60–90 d	Schaefer et al.[102,103]
Chronic, low-grade (sub-clinical) respiratory acidosis	Unknown	Decades	Carnauba et al.[109]; Robertson[61,106]
Behavioural changes and physiological stress	700–3,000	13–15 d	Beheshti et al.[101]; Wade et al.[104]; Martrette et al.[111]; Kiray et al.[112]
Hedonic feeding behaviours	Unknown	Ecological	Hersoug et al.[113]; Zheutlin et al.[1]
Oxidative stress and endothelial dysfunction	3,000–5,000	13 d to 6 months	Beheshti et al.[101]; Thom et al.[80,81]; Zwart et al.[119]

Exposure levels, including magnitude and duration, for which health effects may manifest. The selected key references are most relevant to the health end-point.

Jacobson, Tyler A, Jasdeep S Kler, Michael T Hernke, Rudolf K Braun, Keith C Meyer, and William E Funk. 2019. "Direct Human Health Risks of Increased Atmospheric Carbon Dioxide." *Nature Sustainability* 2 (8): 691–701. https://doi.org/10.1038/s41893-019-0323-1.

CO_2 levels as a proxy for Covid-19 transmission



Peng, Zhe, and Jose L. Jimenez. 2021. "Exhaled CO2as a COVID-19 Infection Risk Proxy for Different Indoor Environments and Activities." *Environmental Science and Technology Letters* 8 (5): 392–97. https://doi.org/10.1021/acs.estlett.1c00183.

Impacts of Sick Building Syndrome on well-being

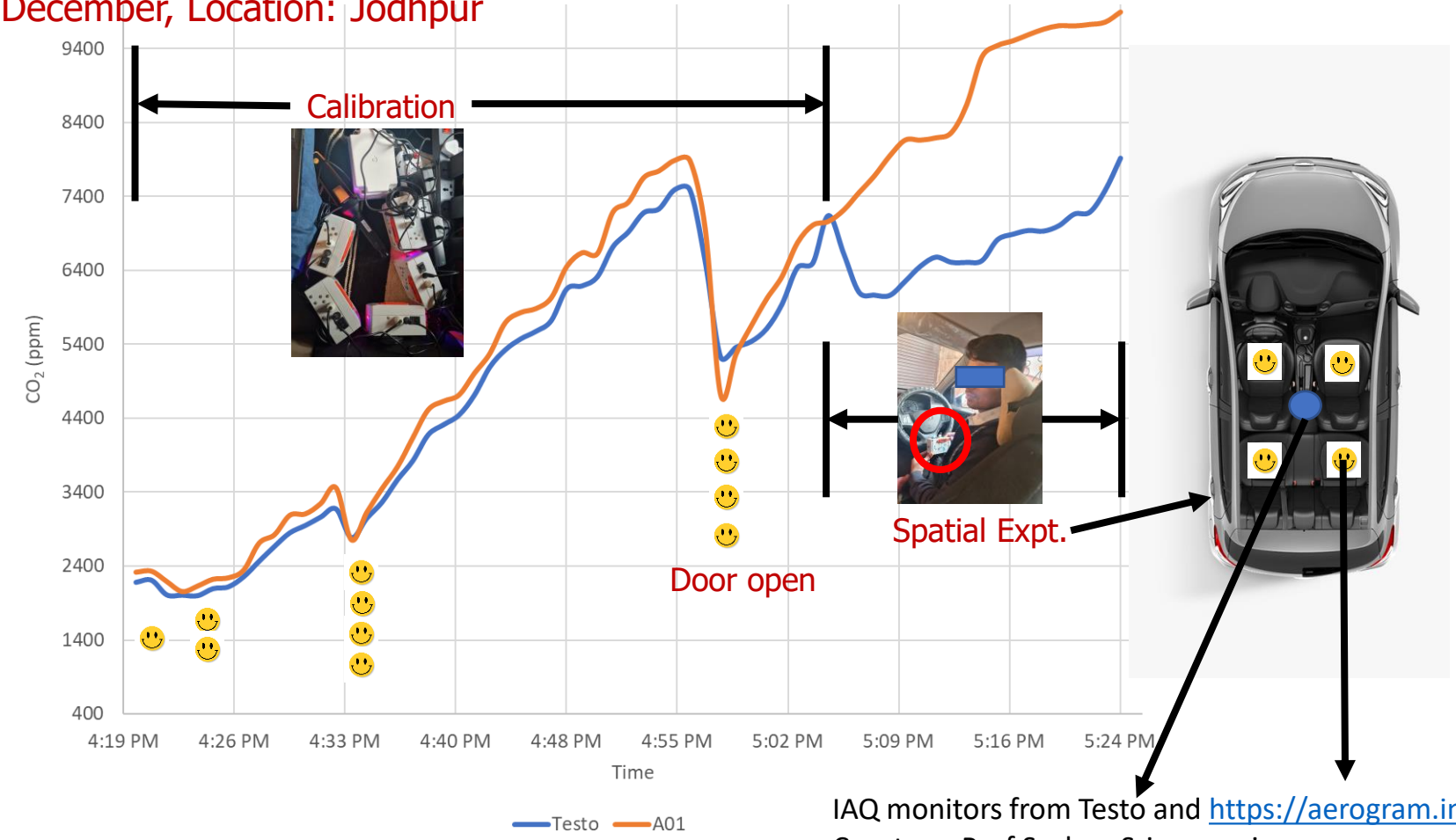
Author(s)	Country	Type of building	Identified symptoms associated with SBS
Magnavita (2015)	Italy	Companies	Anxiety, depression, environmental discomfort and job strain
Jafari et al. (2015)	Iran	Office buildings	Malaise, headache, throat dryness, cough, sputum, wheezing, skin dryness and eye pain
Zhang et al. (2014)	China	Schools	Skin symptoms, mucosal symptoms
Shan et al. (2016)	Singapore	Schools	Head and eye related issues
Norbäck et al. (2016a)	Malaysia	Schools	Ocular, rhinitis, throat symptoms, headache and tiredness, dermal symptoms
Lim et al. (2015)	Malaysia	University	Dermal, mucosal and general symptoms
Amin, Akasah, and Razzaly (2015)	Malaysia	University	Dry skin, runny nose, dry eyes, blocked/stuffy nose, tiredness and flu-like symptoms
Sun et al. (2013)	China	Dormitory	General symptoms of sick building, mucosal or skin problems and nose irritation
Sahlberg et al. (2013)	Sweden/Estonia/ Iceland	Residential Building	General signs of sick building (i.e. mucosal symptoms)
Takigawa et al. (2010)	Japan	Residential Building	Optical, nasal, and gular symptoms
Tsai, Lin, and Chan (2012)	Taiwan	Office building	Eye irritation and upper respiratory symptoms
Lukcso et al. (2016)	U.S.A.	Office building	Asthma and allergic disease
Gomzi et al. (2007)	Croatia	Office buildings	Fatigue, sore and dry eyes, and headache
Runeson-Broberg and Norbäck (2013)	Sweden	Office buildings	Headache, tiredness, nausea, and sensation of a cold

Ghaffarianhoseini, Amirhosein, Husam AlWaer, Hossein Omrany, Ali Ghaffarianhoseini, Chaham Alalouch, Derek Clements-Croome and John Tookey. 2018. “Sick Building Syndrome: Are We Doing Enough?” *Architectural Science Review* 61 (3): 99–121. https://doi.org/10.1080/00038628.2018.1461060.

Experiment 1: understanding CO_2 build up with occupancy in a closed car
Date: 17th December, Location: Jodhpur

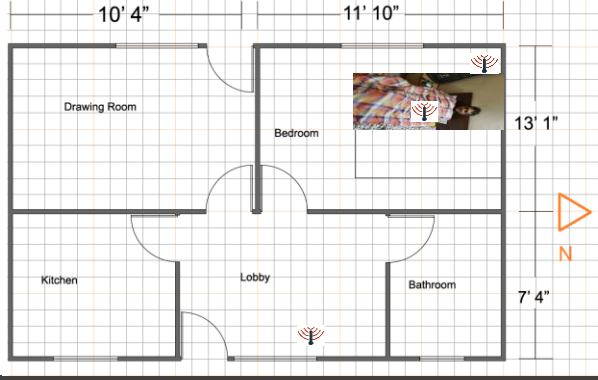
Insights:

1. CO2 levels can build up to unhealthy levels in less than an hour with just 4 people.
2. CO2 levels higher close to the people exhaling CO2 than in other parts of the car.
3. Have any of you been in such a situation in classes, offices, trains, etc.?



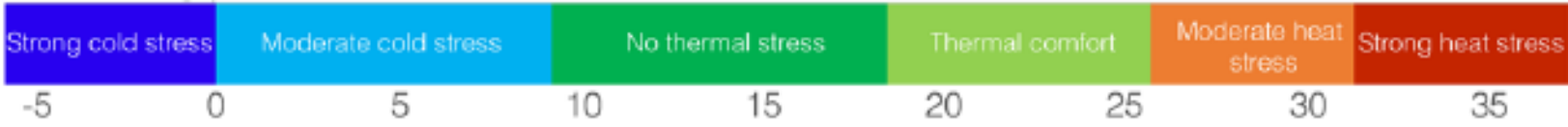
IAQ monitors from Testo and https://aerogram.in/
Courtesy: Prof Seshan Srirangarajan

Experiment 2: CO_2 levels in a bedroom (no heater)
Date: 25th December, Location: New Delhi

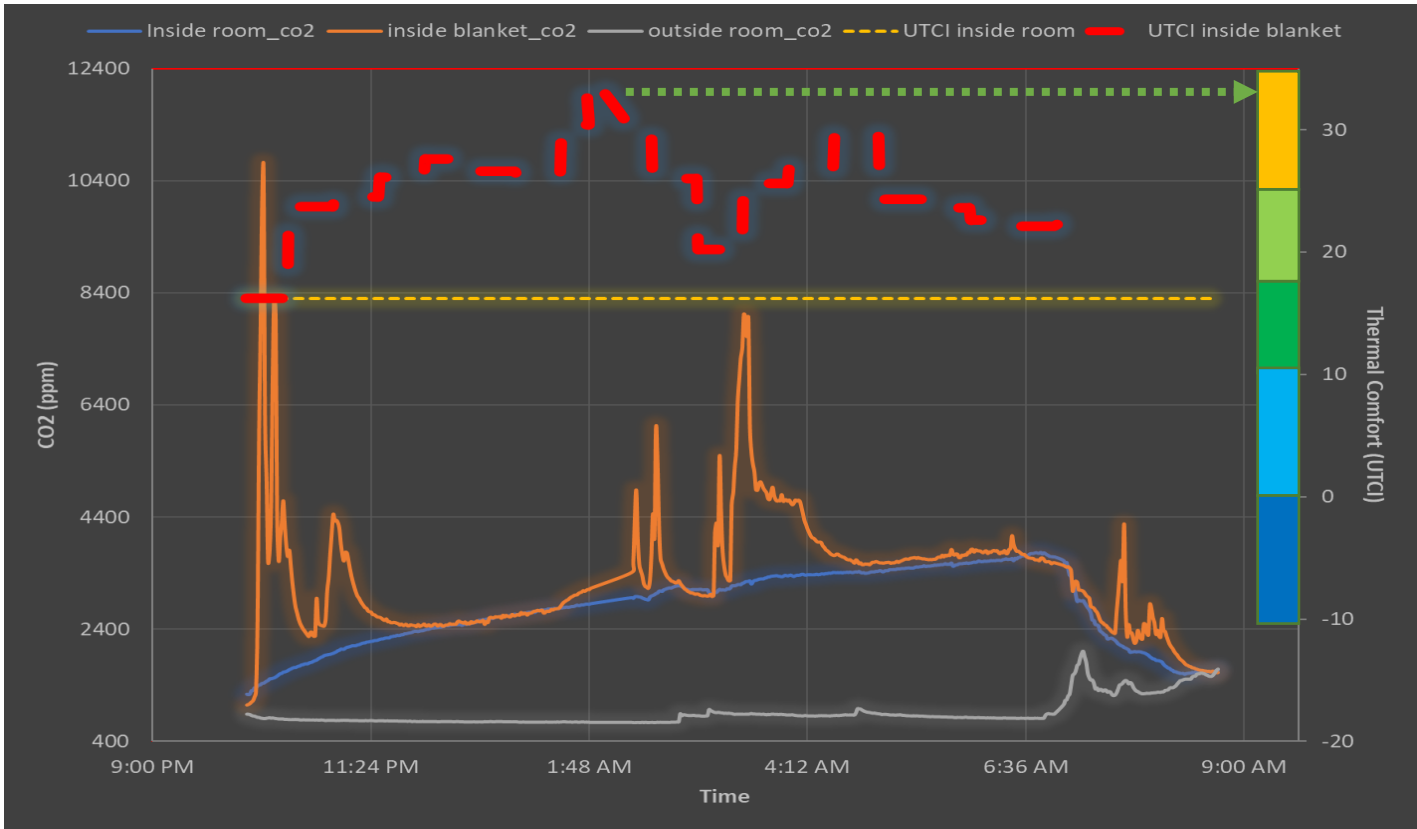


Insights:

1. Outside room CO_2 levels were around 800 ppm
2. Indoor room CO_2 levels reached 3500+ for two occupants. It's a fact as pointed out by the Nature paper.
3. CO_2 levels inside the blanket spiked to 10000+ ppm also. Its better to keep the face outside the blanket as we spend 1/3rd of our life sleeping. How many of you would want to put your face into the blanket as it is cold?
4. Door opening led to mixing of CO_2 levels for inside and outside of room.



Experiment 2: CO_2 levels vs. thermal comfort in a bedroom (no heater)
Date: 25th December, Location: New Delhi



Insights:

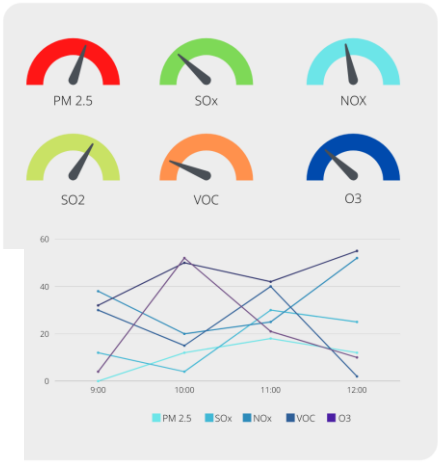
1. Outside and inside room UTCI was around 16 C
2. Inside blanket UTCI reached even 34 C
3. With no heater, it is better if the door can be kept open to have low CO_2 levels.

Data cloud

Calibration and Network Deployment of Low Cost Pollution Sensors

Network of low-cost sensors and network calibration

Sensor calibration

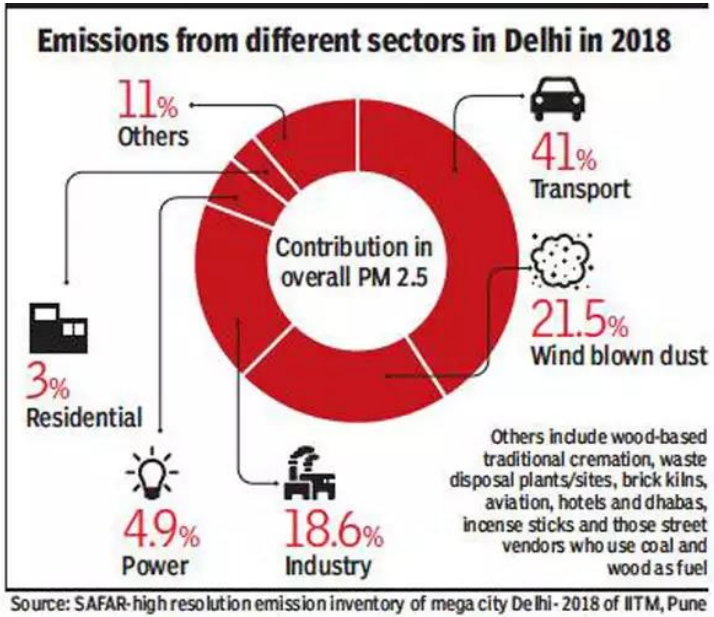


Pollution data analytics and dashboard

PIs: Prof. Seshan Srirangarajan & Prof. Jay Dhariwal, IIT Delhi

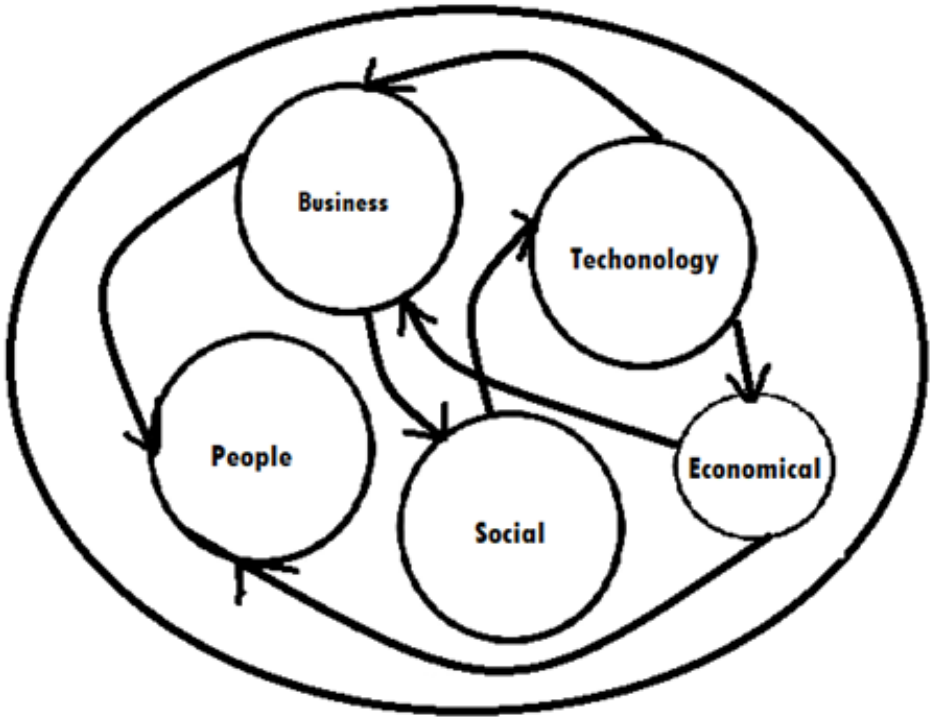
Air pollution mitigation

- Electric Vehicles
- Crop residue as insulation, eco-friendly plates, packaging
- Air purifiers
- Renewables



Source: [Delhi air pollution: Smaller sources add up to 11% of PM2.5 emission | Delhi News - Times of India (indiatimes.com)]

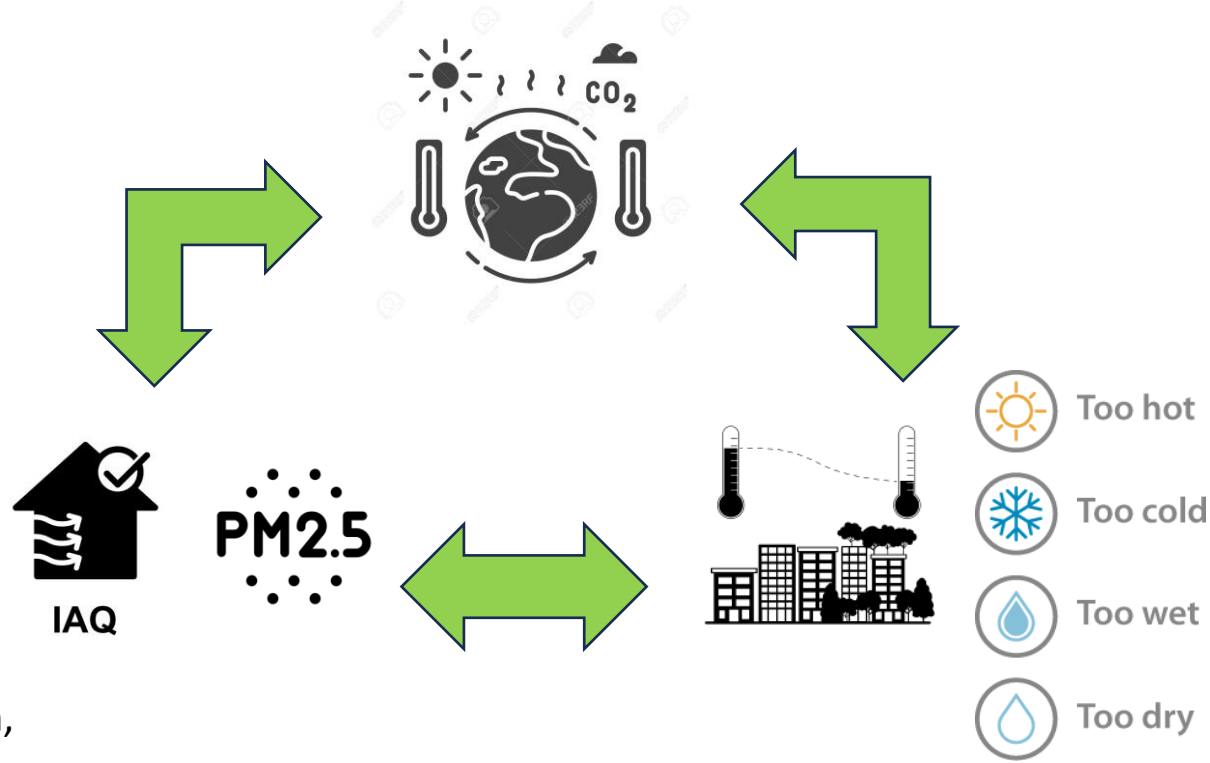
Systems Thinking



- What happens if we don’t use systems thinking?
- Was the invention of electricity, cars, plastics good from systems thinking point of view?

Source: Origin of System Dynamics - System Dynamics Society

Design for Health and Wellness in a Delhi Classroom



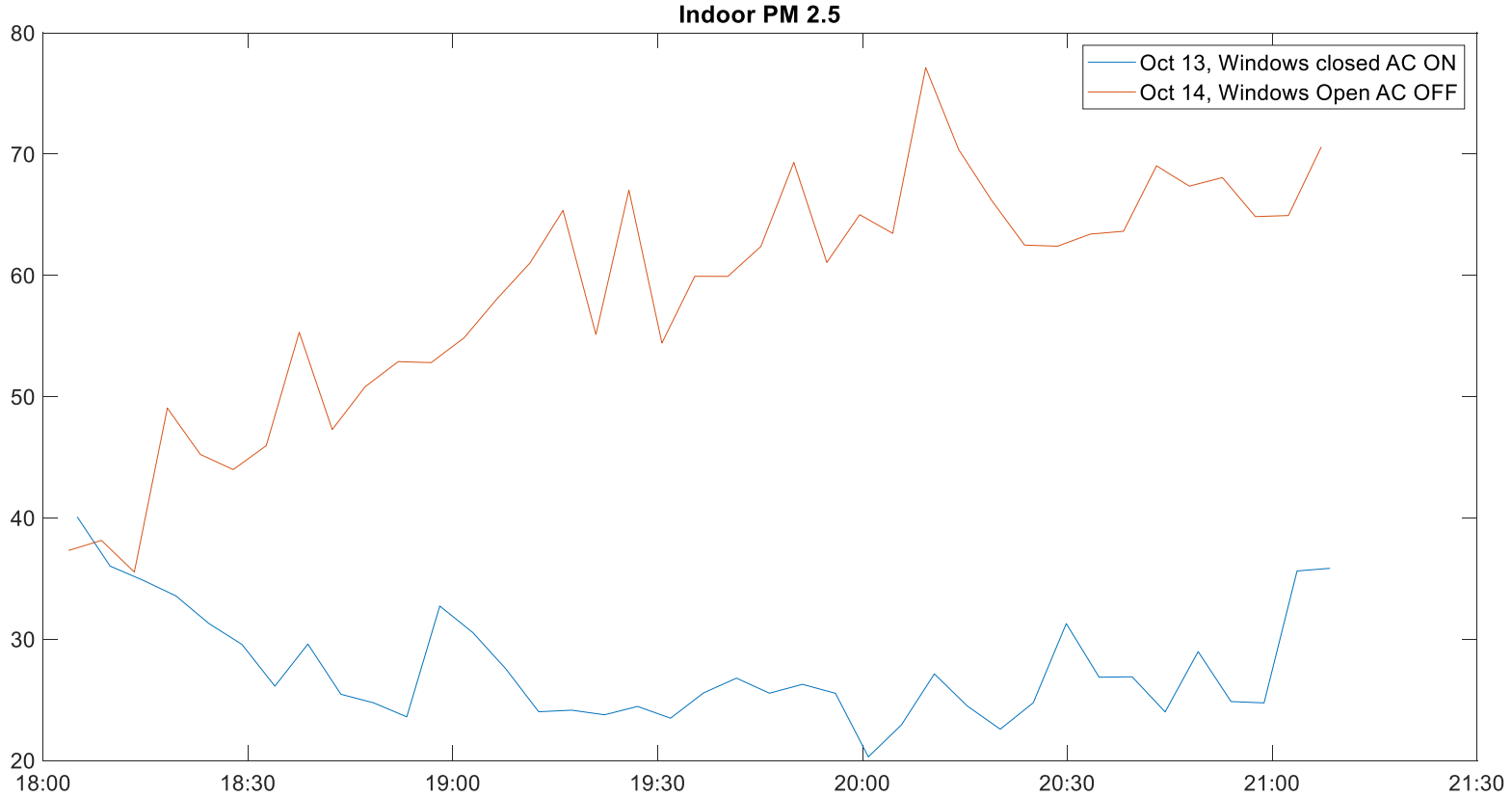
Maximize Health and Wellness for Class Occupants:

1) Keep Thermal Comfort: < 32℃
2) Keep Air Quality: CO_2 < 1000 ppm, PM2.5 < 50 µg/m3
3) Minimize Energy Consumption

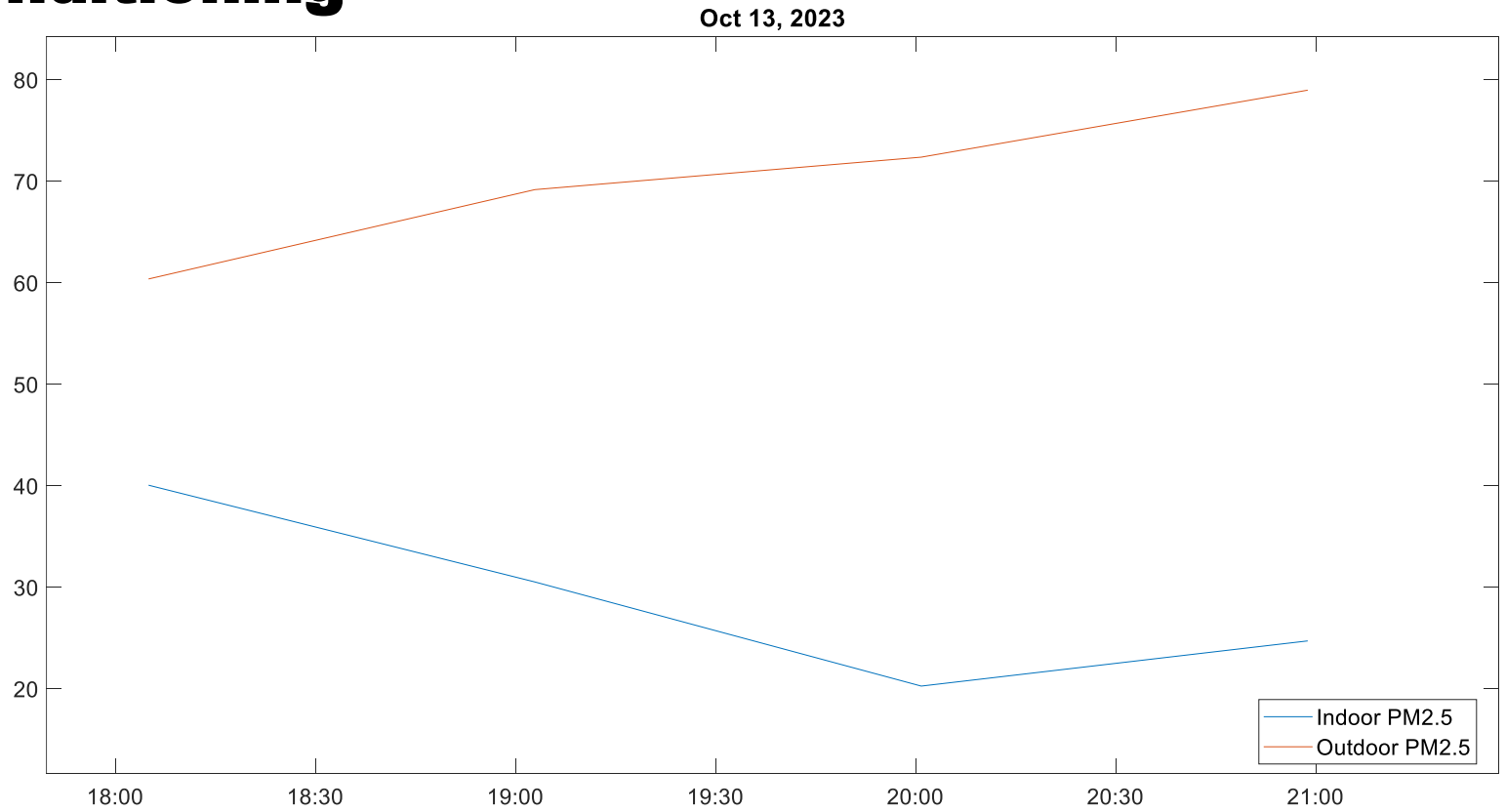
Experiments in the class on IAQ, PM2.5, thermal comfort and energy usage

VARIATION OF PM 2.5

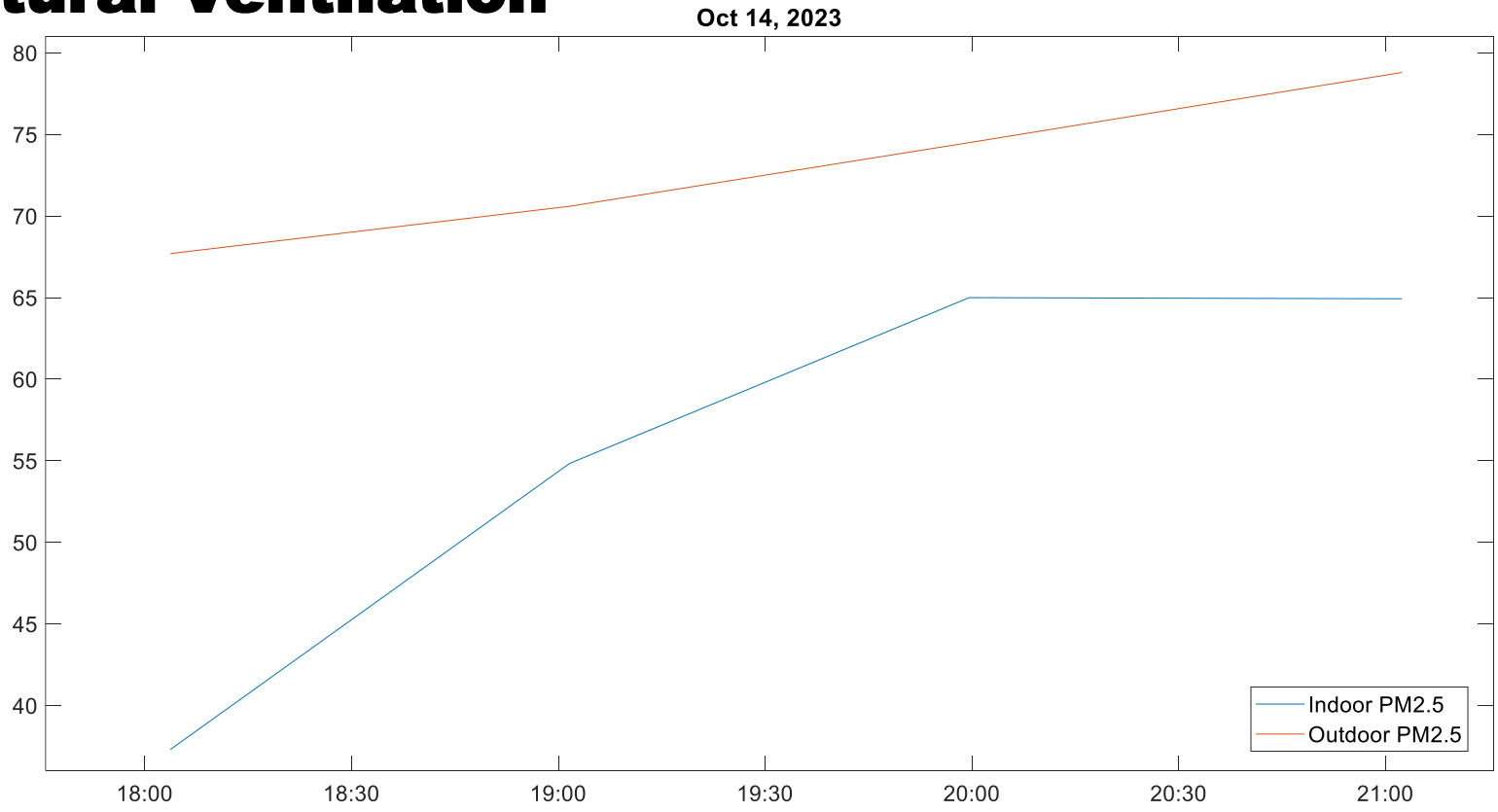
Variation in concentration of PM2.5 in Air Conditioning and Natural Ventilation conditions



Comparison of Indoor-Outdoor PM2.5 in Air Conditioning

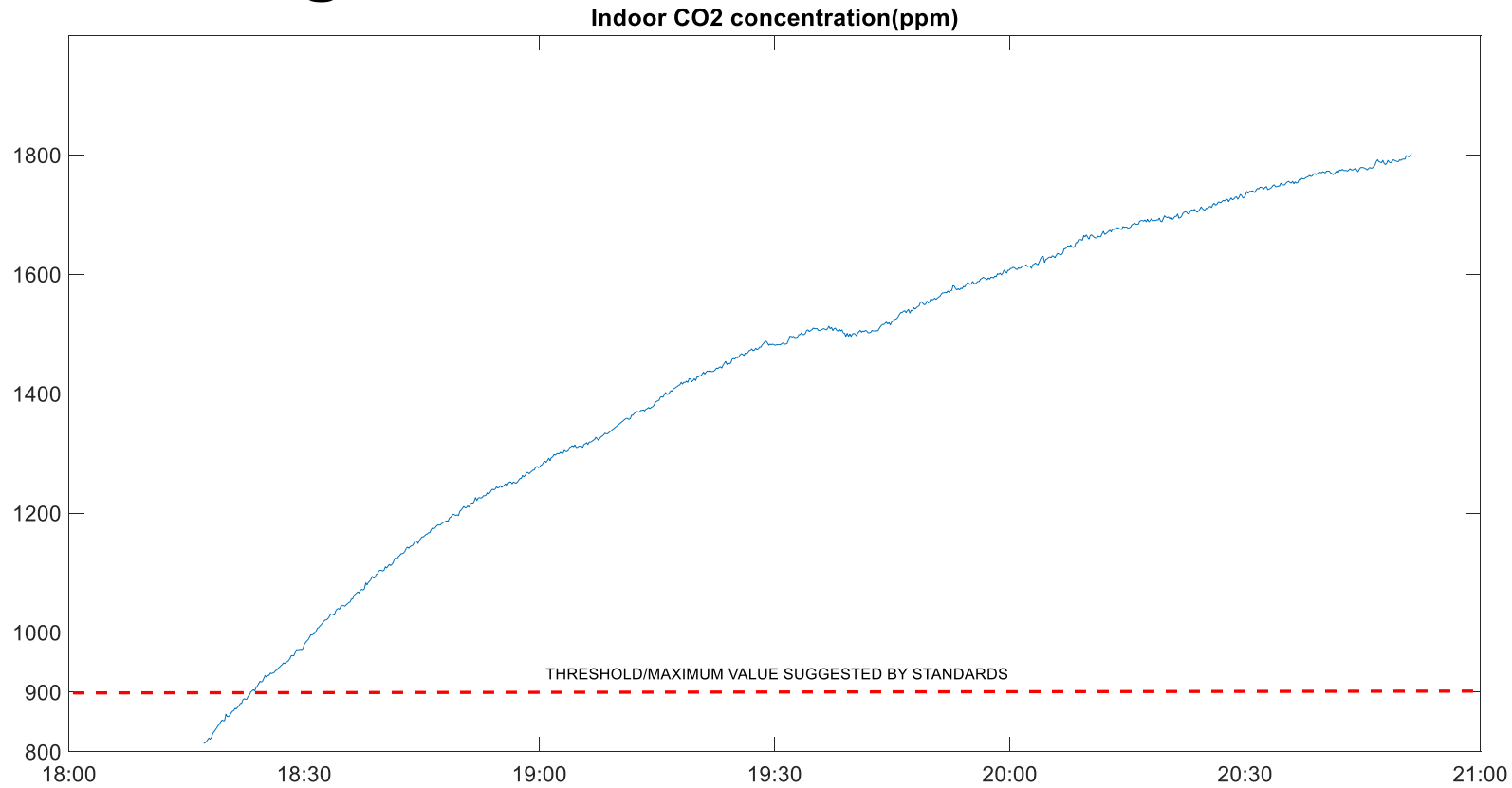


Comparison of Indoor-Outdoor PM2.5 conditions in Natural Ventilation

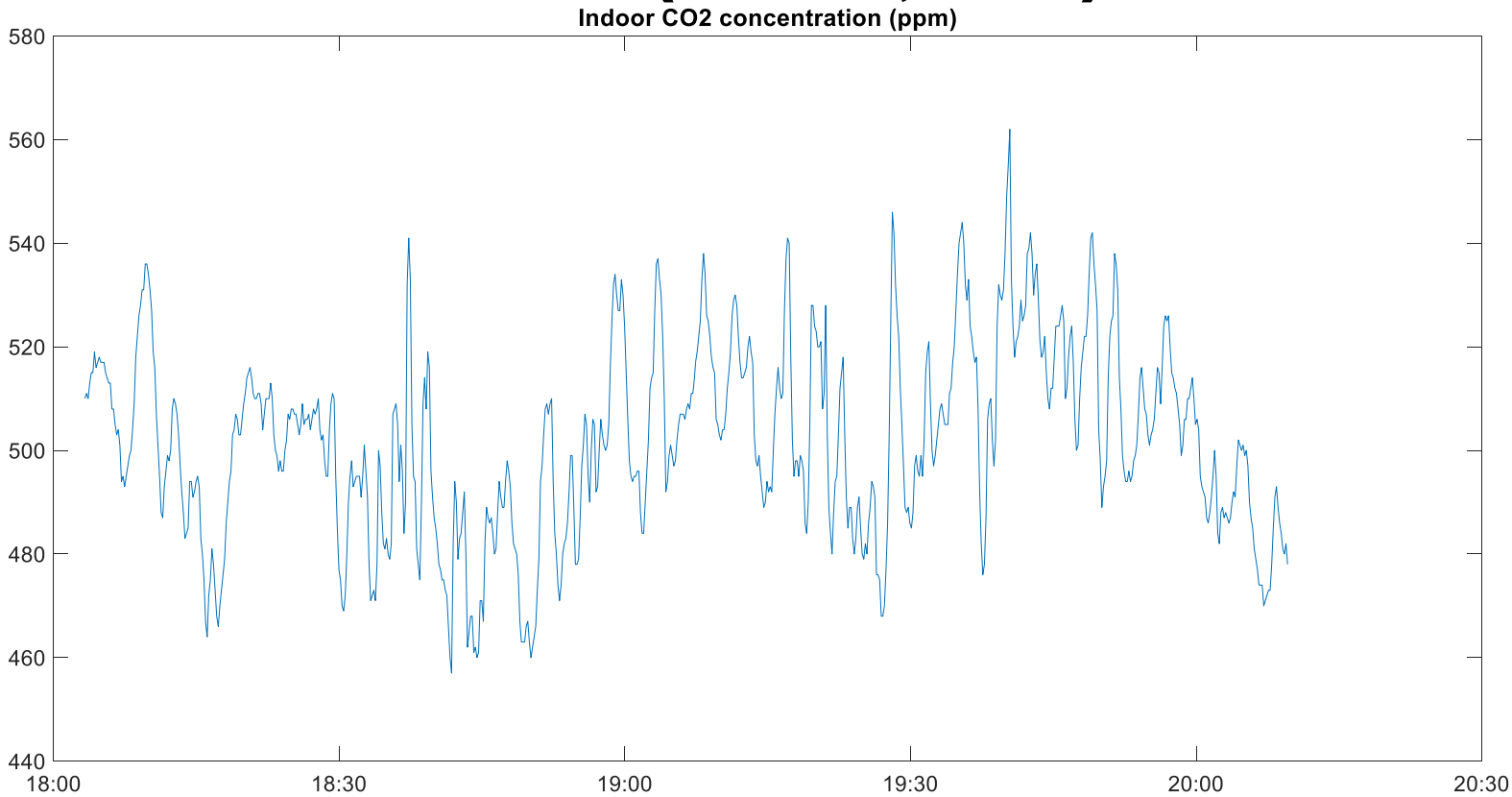


VARIATION OF CO2

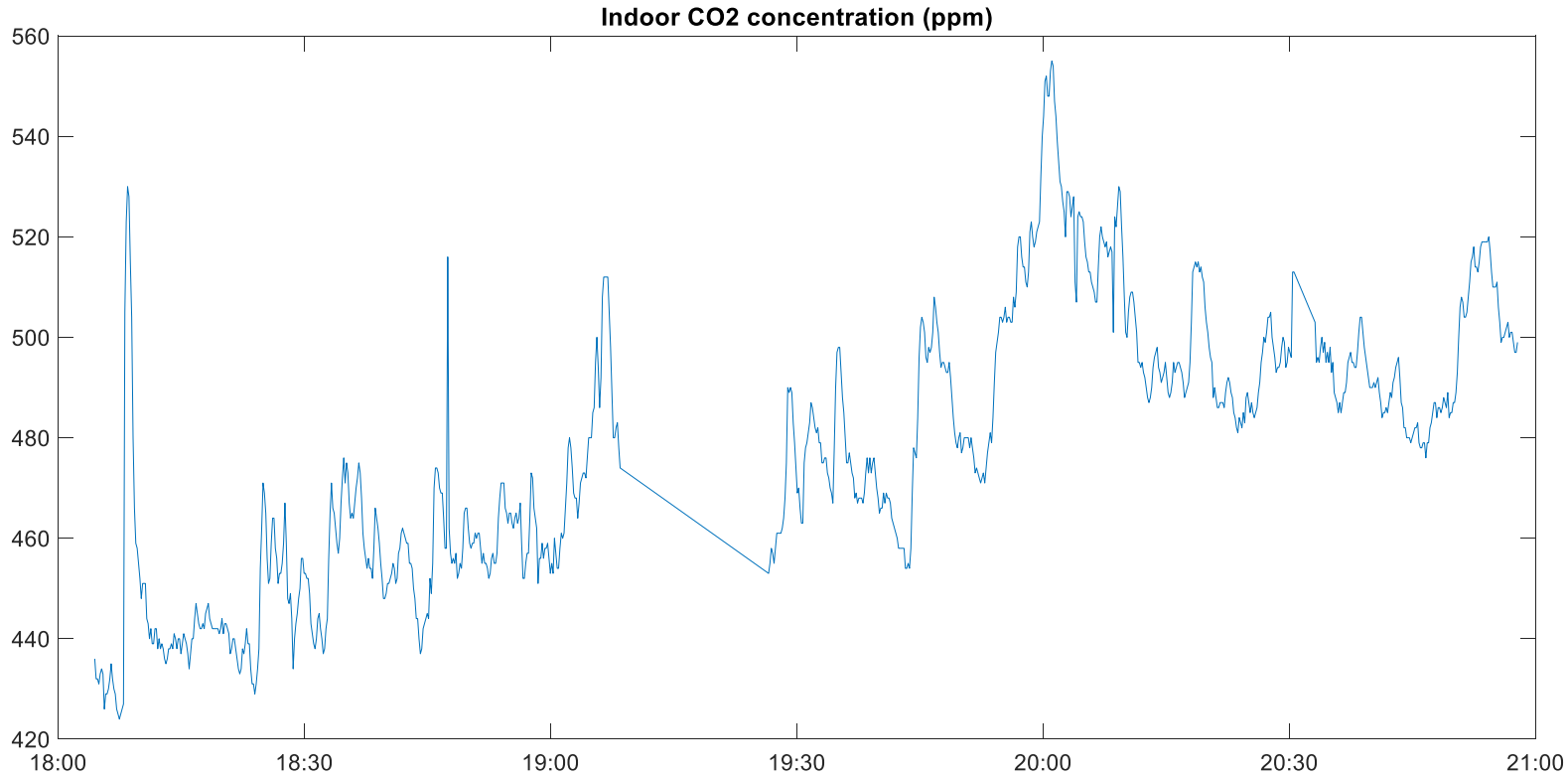
Variation in concentration of CO2 in Air Conditioning conditions



Variation in concentration of CO2 in Natural Ventilation conditions (Oct 13,2023) FANS ON

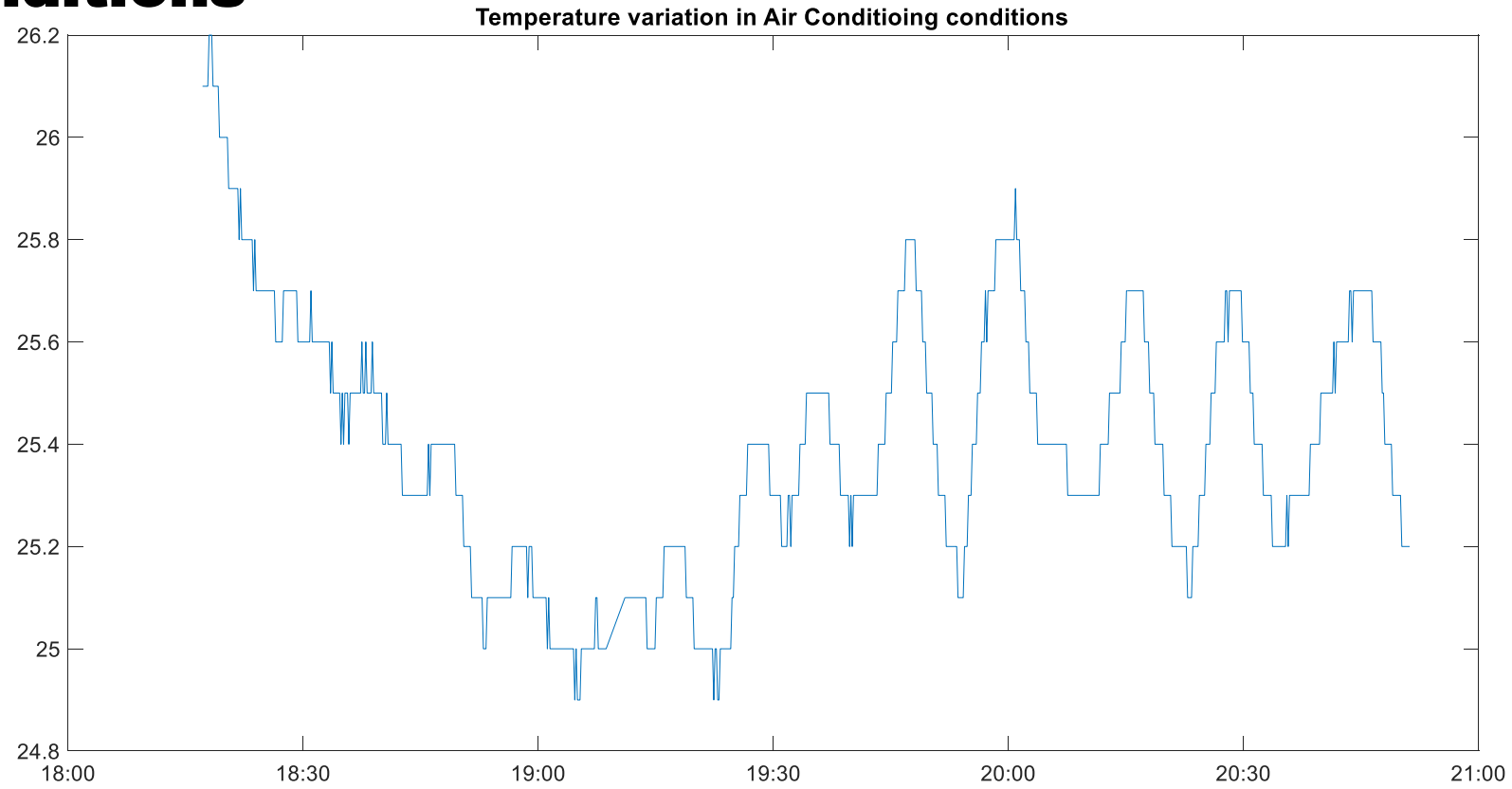


Variation in concentration of CO2 in Natural Ventilation conditions (Oct 20,2023) FANS OFF

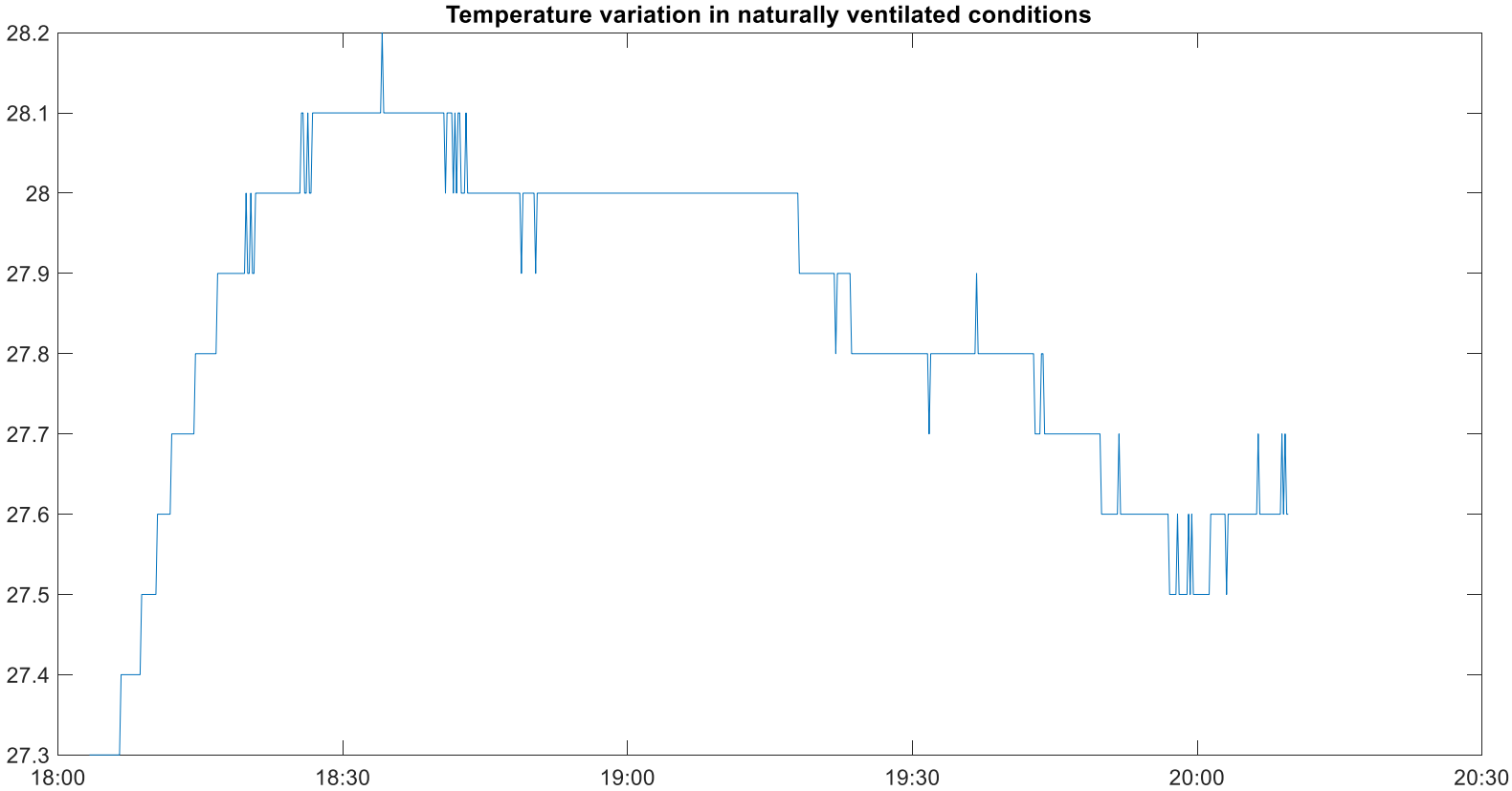


VARIATION OF TEMPERATURE

Temperature variation in Air Conditioning conditions



Temperature variation in Natural Ventilation conditions

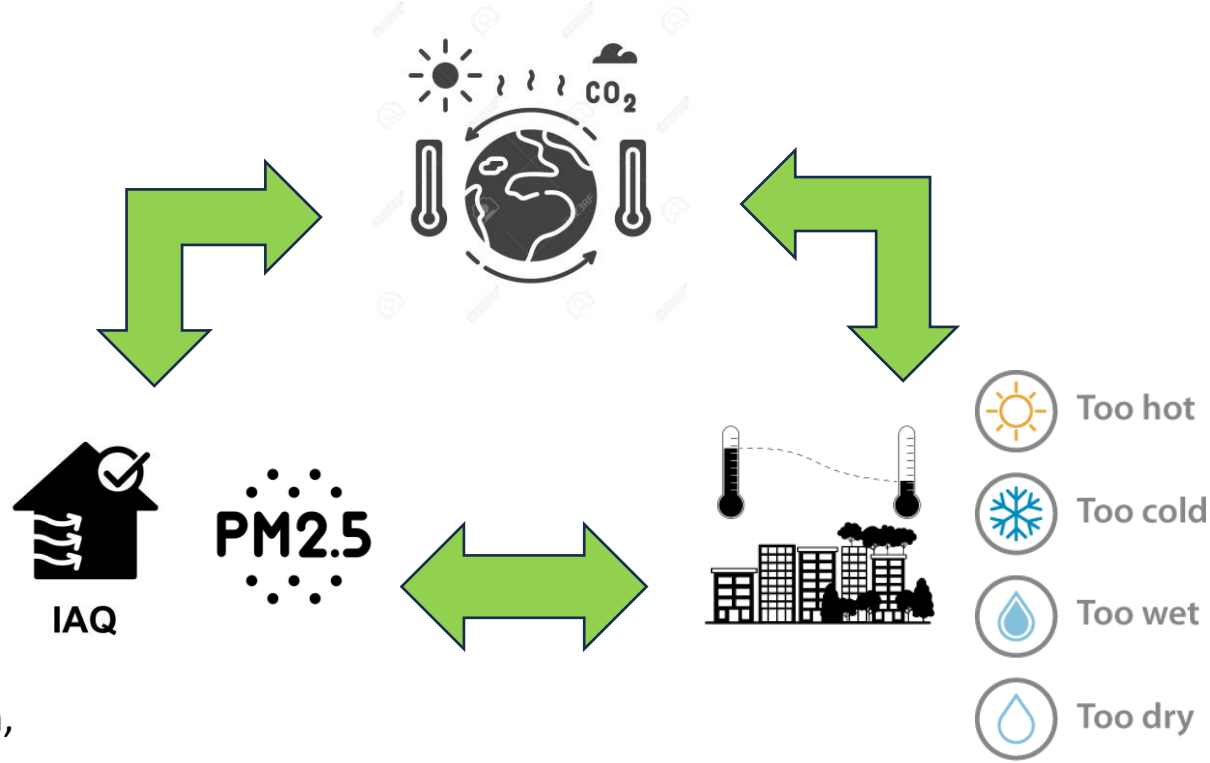


Lessons from experiments

Date	Status	Indoor PM2.5 ($\mu g/m^3$)	Outdoor PM2.5 ($\mu g/m^3$)	CO_2 (ppm)	Air temperature (℃)
October 13	AC and fans ON, Windows closed	30	80	1800	25
October 14	AC and fans OFF, Windows open	70	80	500	28

There is a trade-off between keeping CO_2 low or PM2.5 low.

Design for Health and Wellness in a Delhi Classroom



Maximize Health and Wellness for Class Occupants:

1) Keep Thermal Comfort: < 32℃
2) Keep Air Quality: CO_2 < 1000 ppm, PM2.5 < 50 µg/m3
3) Minimize Energy Consumption

Thank you!