Indoor air quality (IAQ): Rural and urban perspectives

TERI

Background

Air is essential for life and we cannot survive more than 2 minutes without air…

…and the quality of air we breathe directly impacts our health & performance

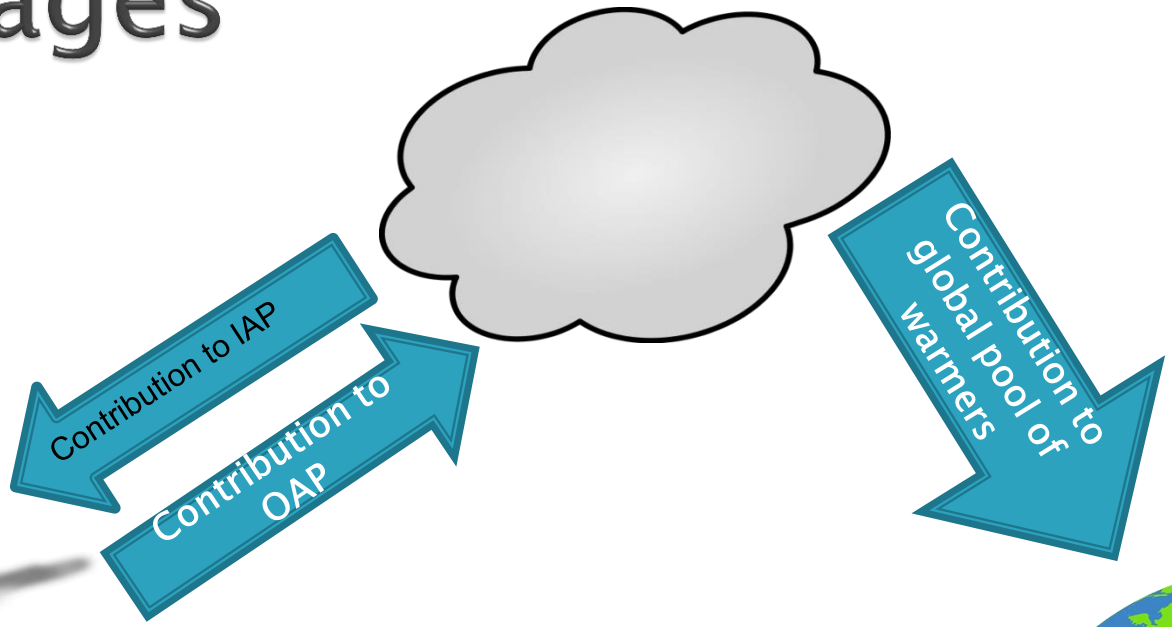
1. https://www.livescience.com/32320-how-long-can-a-person-survive-without-water.html
2. *http://blog.cashins.com/hs-fs/hub/137863/file-350390514-jpg/images/indoor-air-quality-resized-600.jpg?t=1499800795385*

Background

It is estimated that we spend about 80-90% of time indoors….

…and on an average an office employee spends >8 hours indoors

Linkages



In India, contribution of IAP to AAP is estimated to vary between 22 and 52 % (UNEP)

Indoor Air Quality (IAQ)

- "Air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants"- EPA

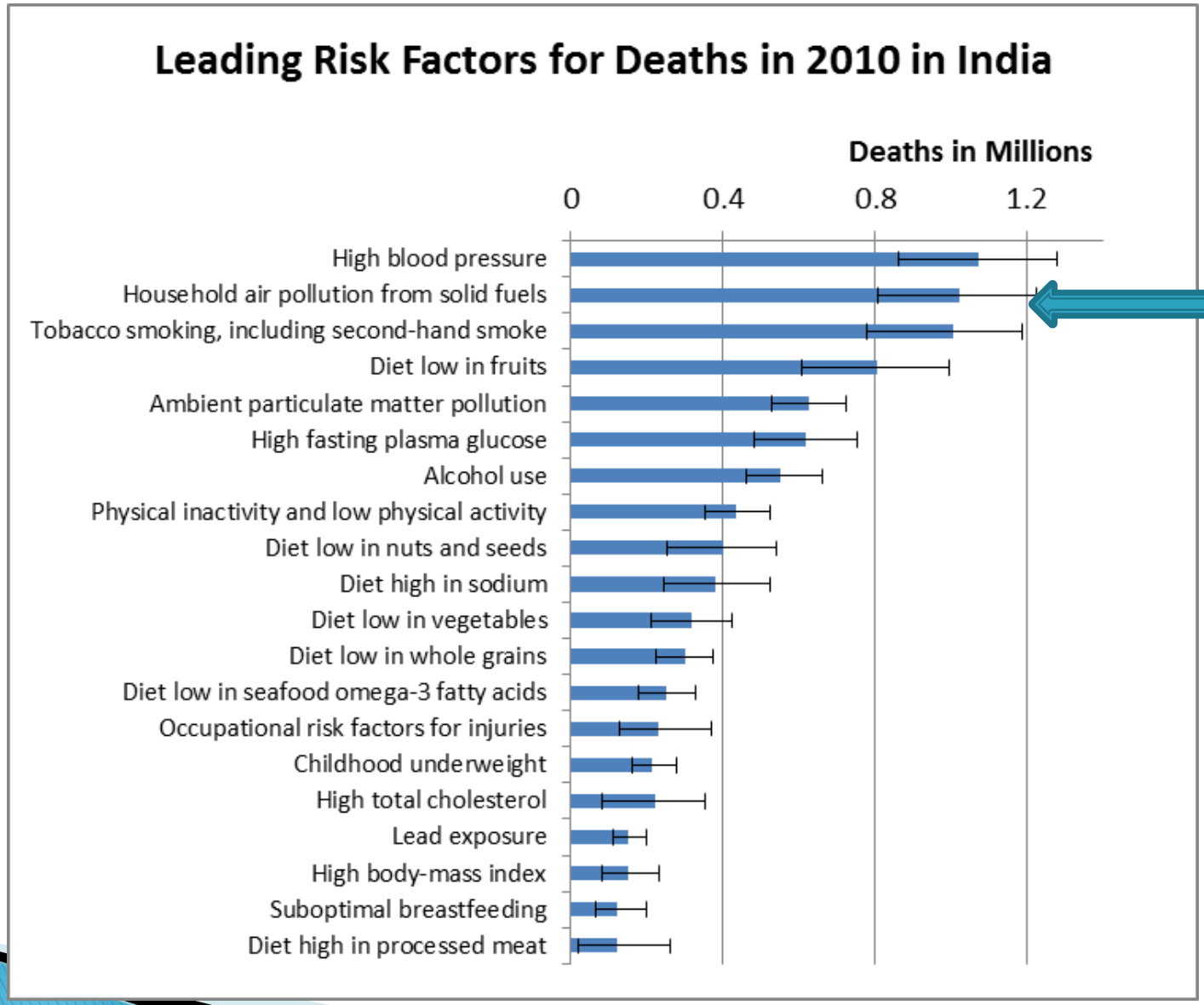
- IAQ can significantly impact the health, productivity and sense of wellbeing of employees at workplace.

- Prolonged exposure to the indoor air pollutants could also lead to Sick Building Syndrome which could result in decrease in productivity.

IAQ – an area of concern

- While ambient air quality is slowly attracting attention, Indoor air quality is still ignored.
- US EPA: indoor air pollution poses a greater risk than outdoor air pollution – people spend 80-90% of their time indoors (Yu and Browers, 2013)
- IAQ is directly linked to health of the occupants of a building
- IAQ is an important concern – both rural and urban
- VOCs indoors could be 2 to 5 times higher than outdoors
- IAP is a global issue due to adverse effects on human health (Tsakas, Siskos and Siskos, 2011)
- IAP ranked among the top five environmental health risks to the public by EPA.

GBD estimates :IAP is 2nd leading risk factor

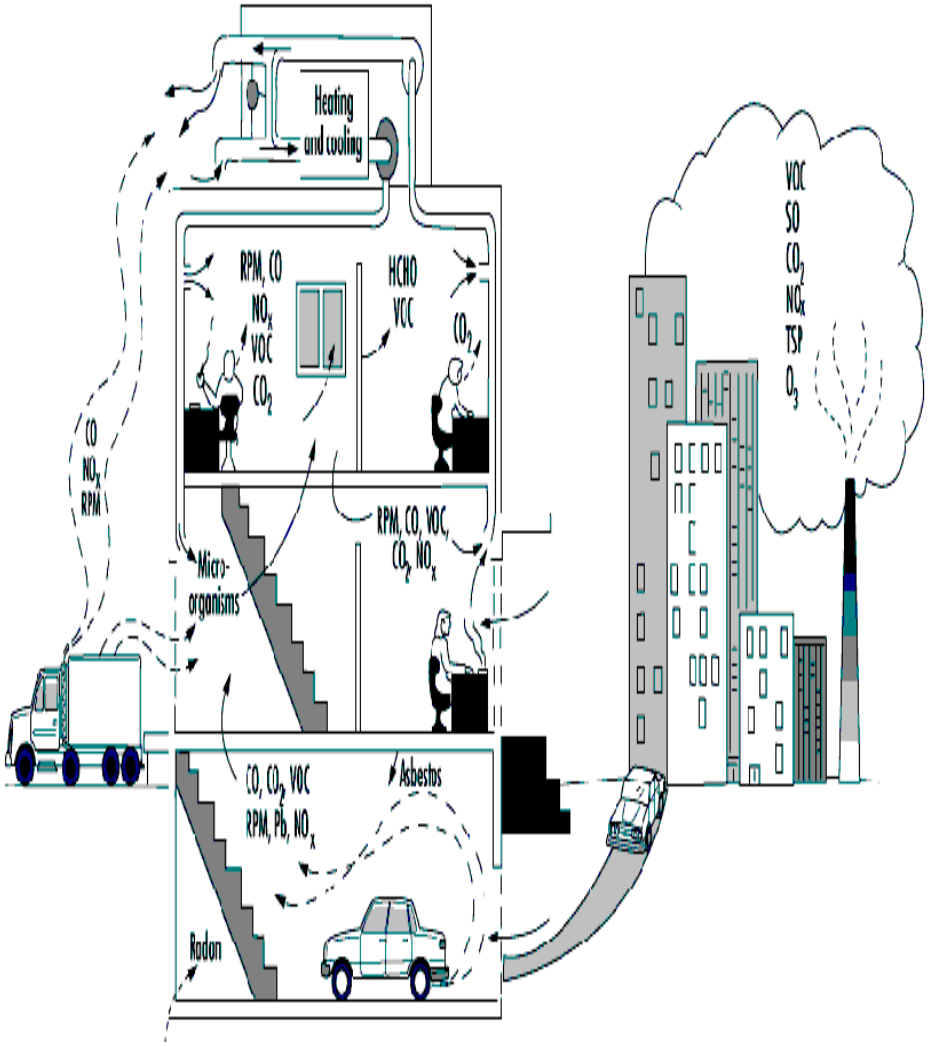


IAP cause estimated deaths in

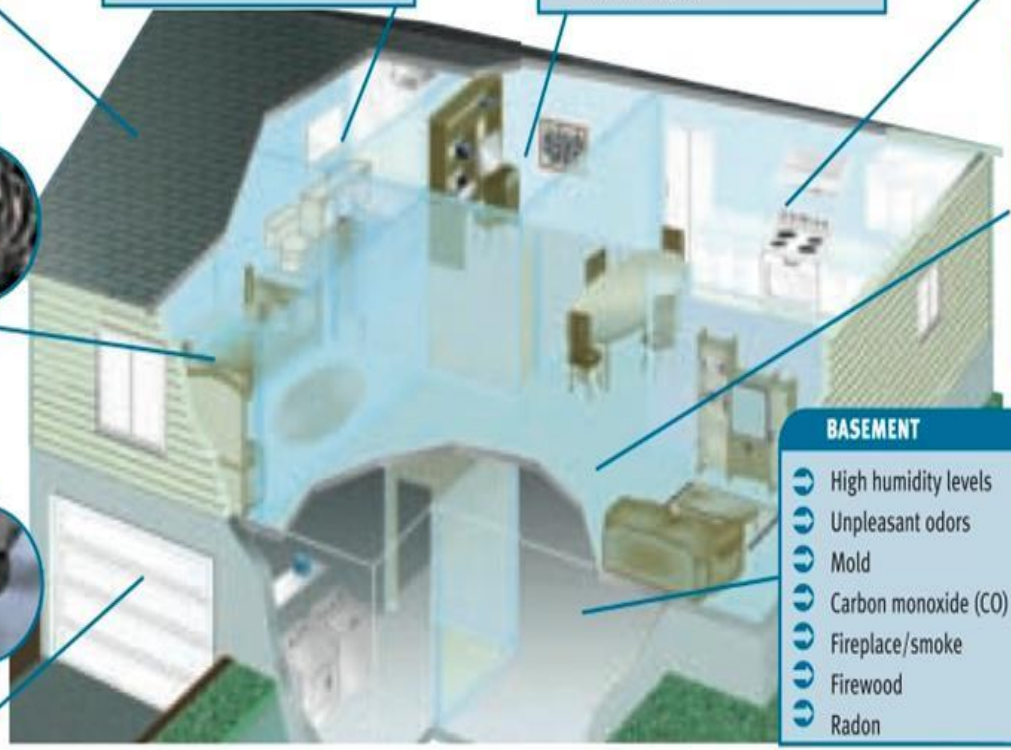
GBD-Lancet, 2012

Sources of Indoor Pollutants

- Base on Specific Building
- Combustion activity
- Furniture
- Chemical
- Building materials
- Food
- Water
- Smoking activity
- Outdoor air pollution



PRIMARY SOURCES OF INDOOR AIR POLLUTION



ATTIC

- Asbestos
- Insulation
- Fibreglass
- Dust and dust mites

BATHROOM

- Excess humidity
- Personal hygiene products (aerosols, sprays, etc.)
- Mold spores

HOME OFFICE

- Printers, photocopiers: ozone, volatile organic compounds (VOC)
- Melamine furniture (harmful vapors, VOC, formaldehyde)

KITCHEN

- Lingering odors
- Bacteria
- Cooking pollutants

BEDROOM

- Allergens
- Dust and dust mites
- Pet hair and dander
- Carbon dioxide (CO_2)
- Carpet

LIVING ROOM

- Fireplace
- Dust and dust mites
- Allergens
- Second-hand smoke
- Humidifiers
- Pet hair and dander
- Carpet

GARAGE

- Carbon monoxide (CO)
- Gas
- Solvents
- Pesticides and herbicides
- Dust
- Paint and chemicals
- Cleaning agents

BASEMENT

- High humidity levels
- Unpleasant odors
- Mold
- Carbon monoxide (CO)
- Fireplace/smoke
- Firewood
- Radon
- Solvents
- Woodstove
- Dust and dust mites
- Combustion system
- Paint and chemicals
- Household cleaners

Source: ww.standardheating.com

Pollutants & Sources

Location	Sources	Pollutant
Offices, government buildings	HVAC systems, carpets, painting & polishing , household cleaners, aerosols, insecticides, pesticides and personal care products	Primary: PM, VOCs Additional : CO, NOx, SO2
Parking areas	Vehicular movement	Primary : PM, CO, NOx, HC Additional : SO2, PAHs,
Public places such as restaurants, hotels, libraries, shopping malls (misc. sources	HVAC systems, carpets, painting & polishing , insecticides, pesticides, smoking, constriction activities	Primary: PM, VOCs, Nicotine Additional : CO, NOx, SO2
Rural households using biomass	Biomass burning for cooking, heating, waste burning. Kerosene burning for lighting,	Primary: PM, CO, BC Additional : VOCs

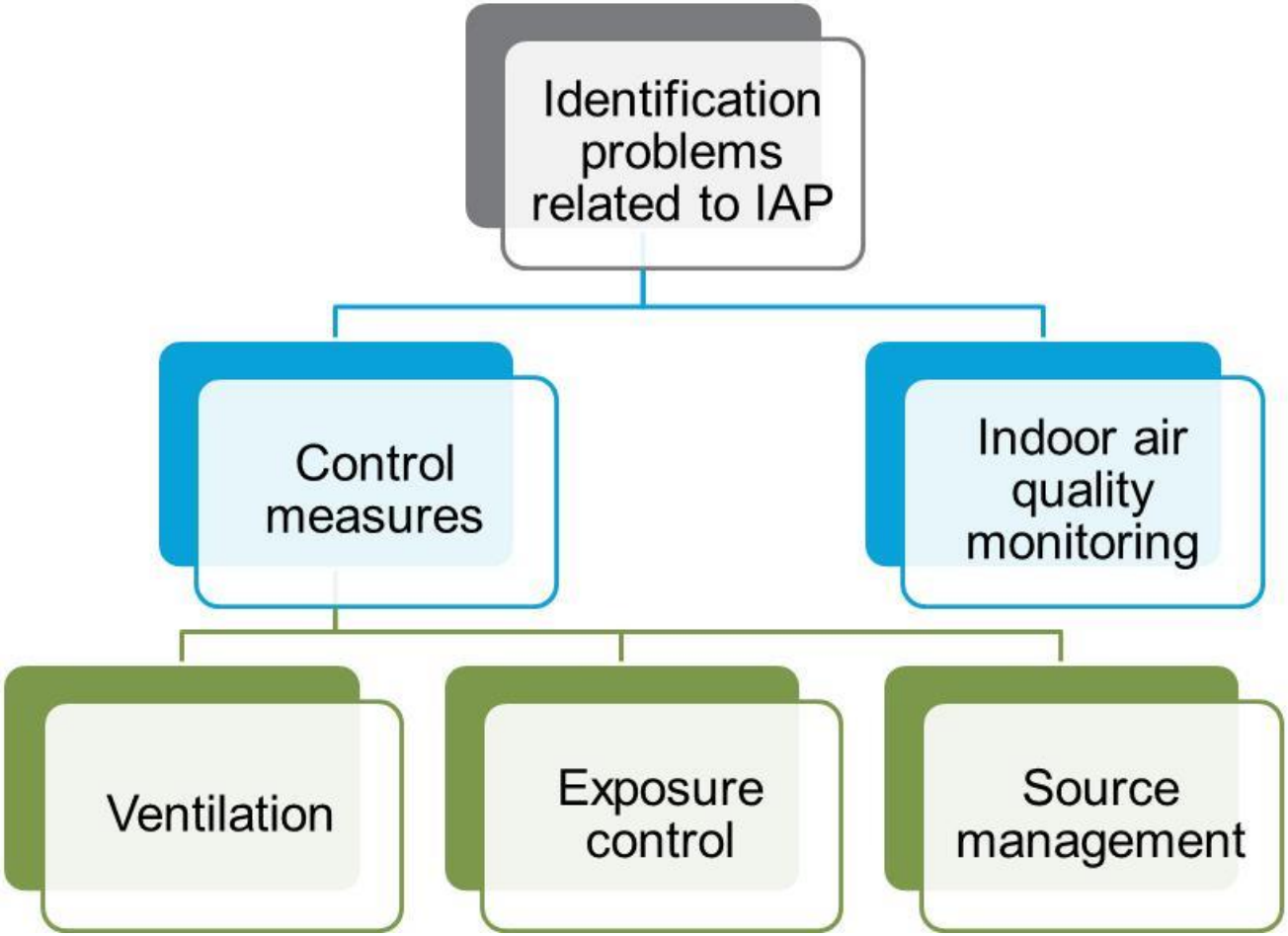
NOx + VOC + Sunlight = OZONE

Other problems of IAQ

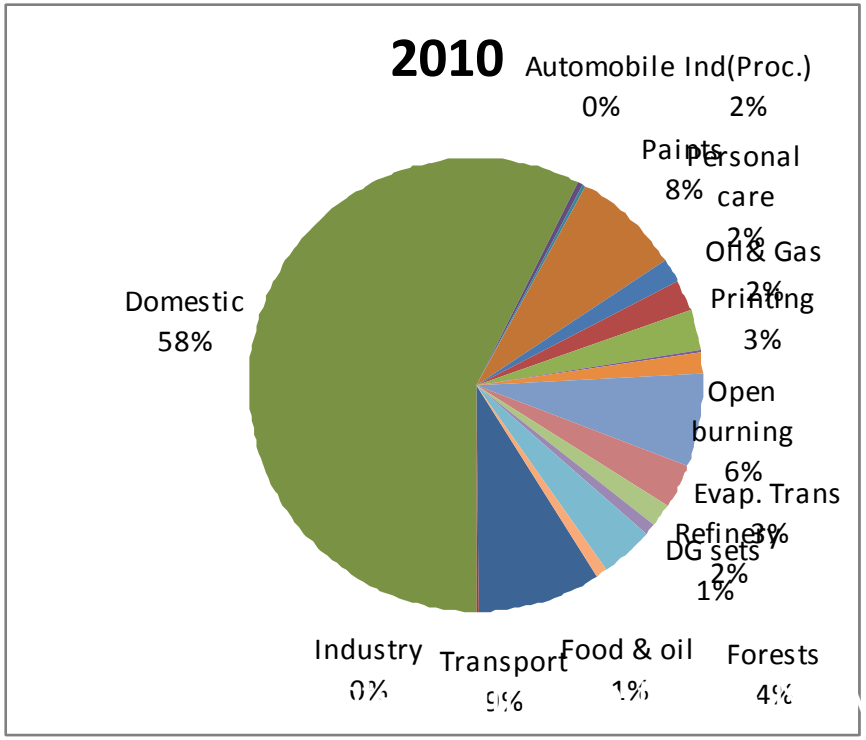
Enclosed space inhabited by humans produce the following effects

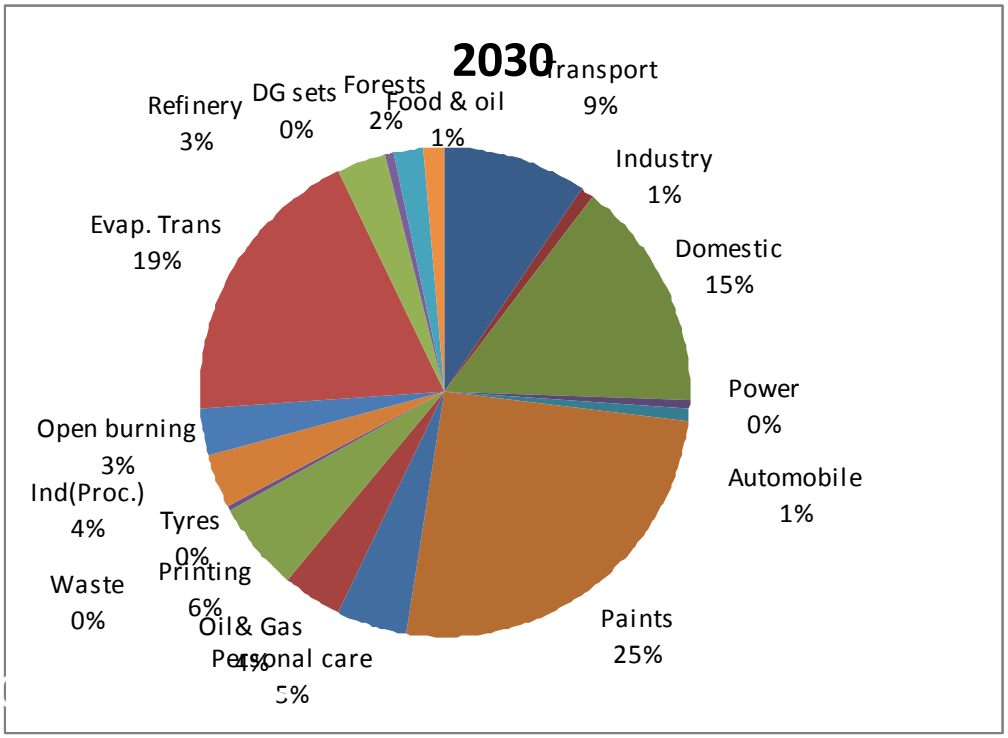
- ⇩ Oxygen level or ⇧ CO_2 level
- Increase in temperature and humidity
- Increase in bio-aerosol and odor
- Accumulation of air pollutants

Indoor air quality management



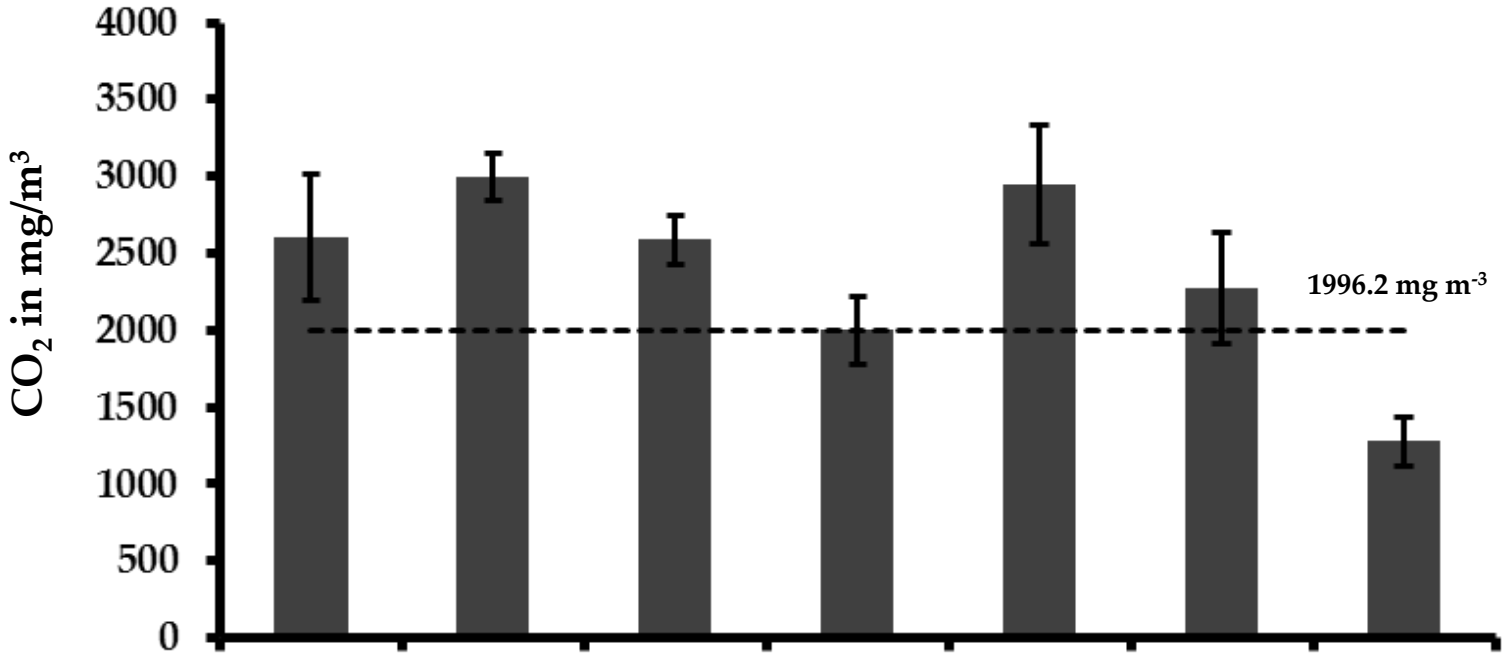
NMVOC emissions in India



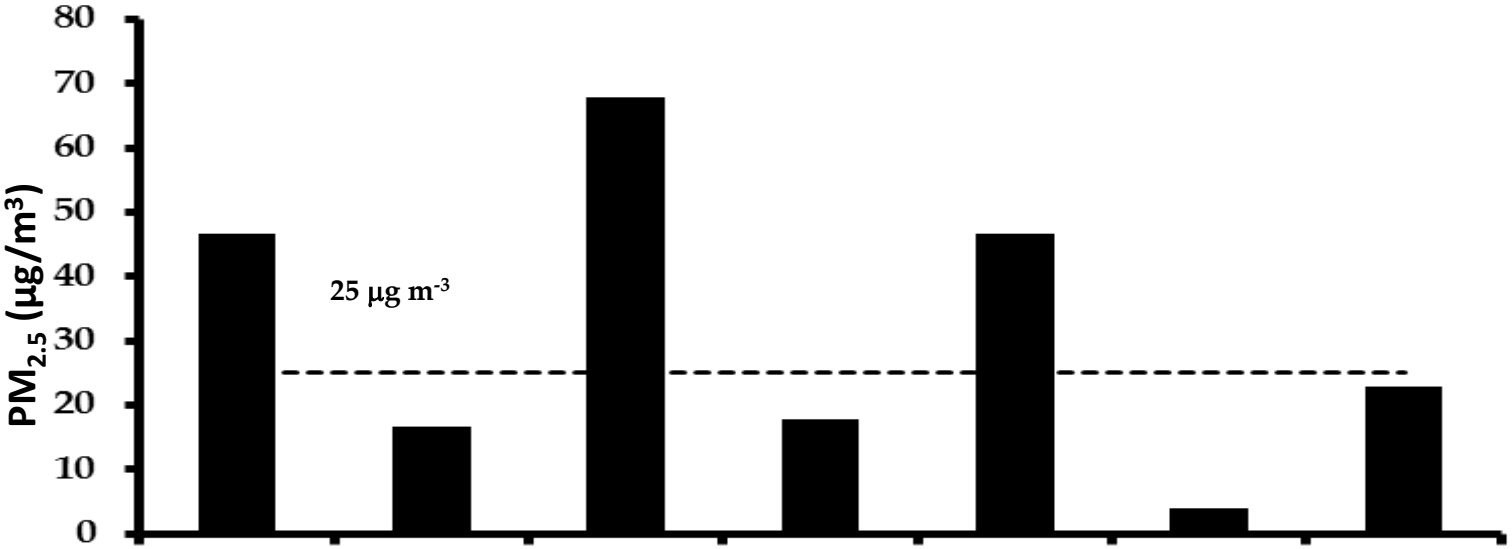


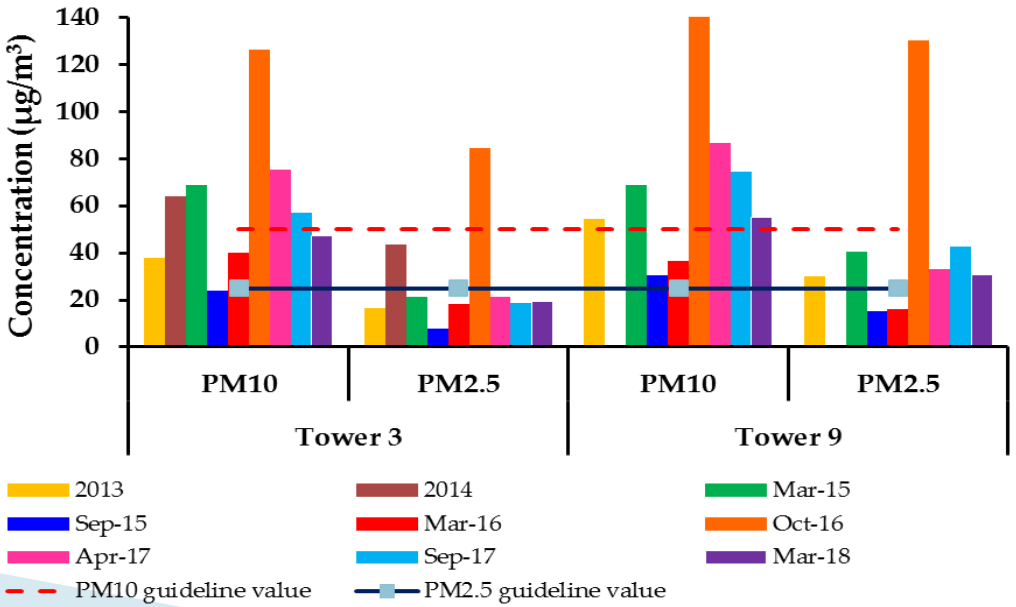
- In next 20 years, the share is about to grow to 25%.
- This has implications over outdoor and indoor air quality.

TERI measurements in office buildings

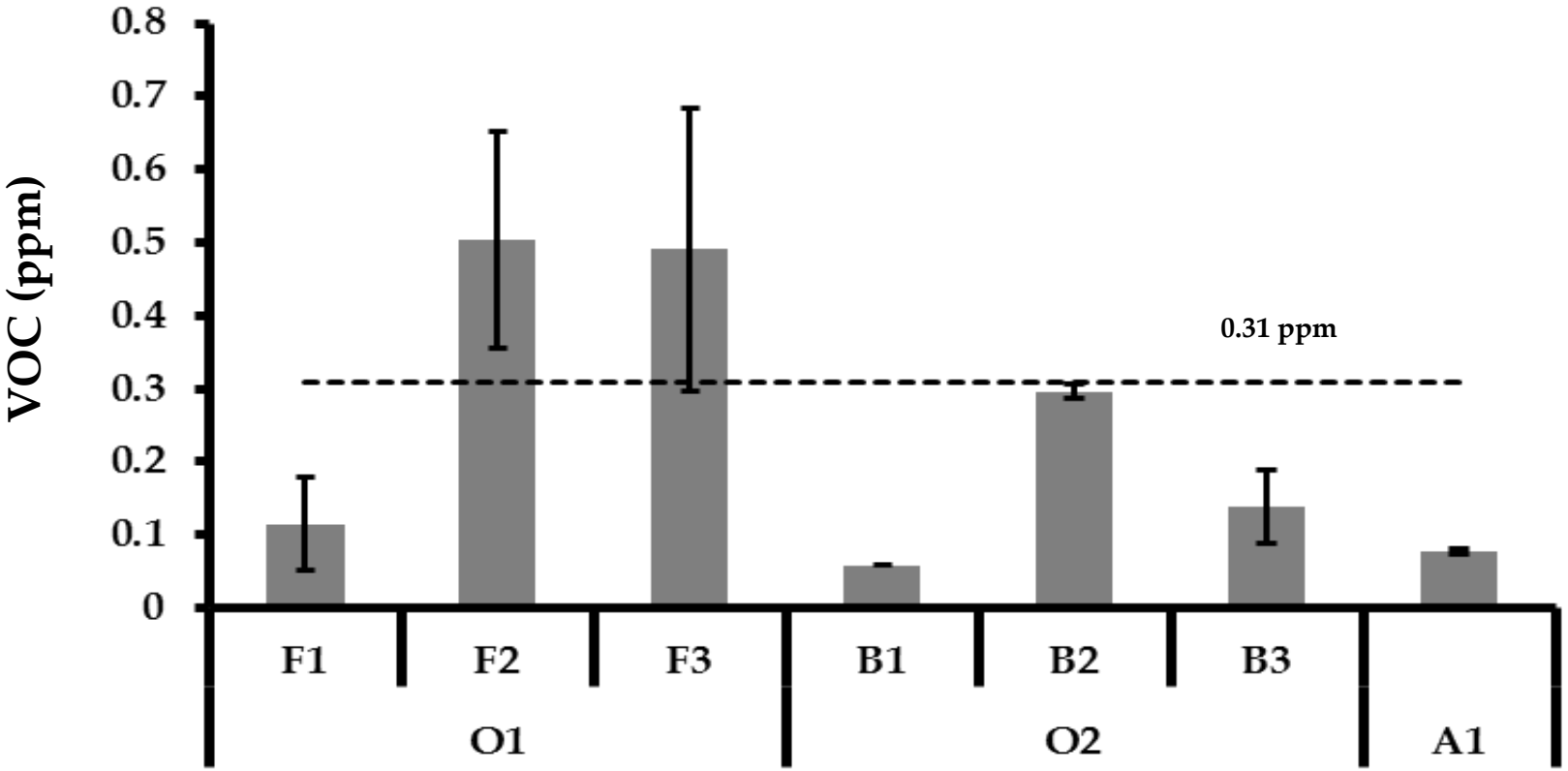


Office building



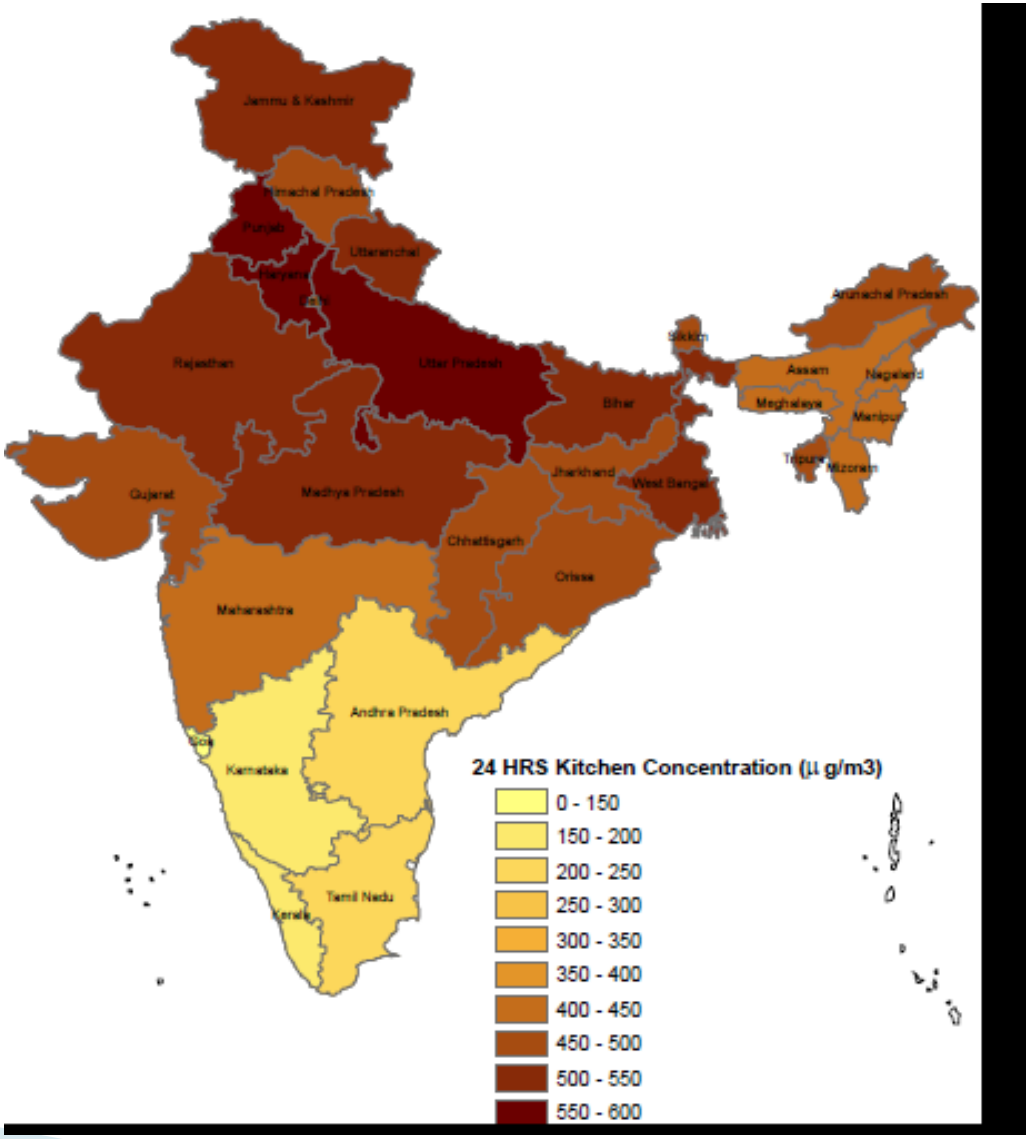


Office building



IAQ – Rural measurements

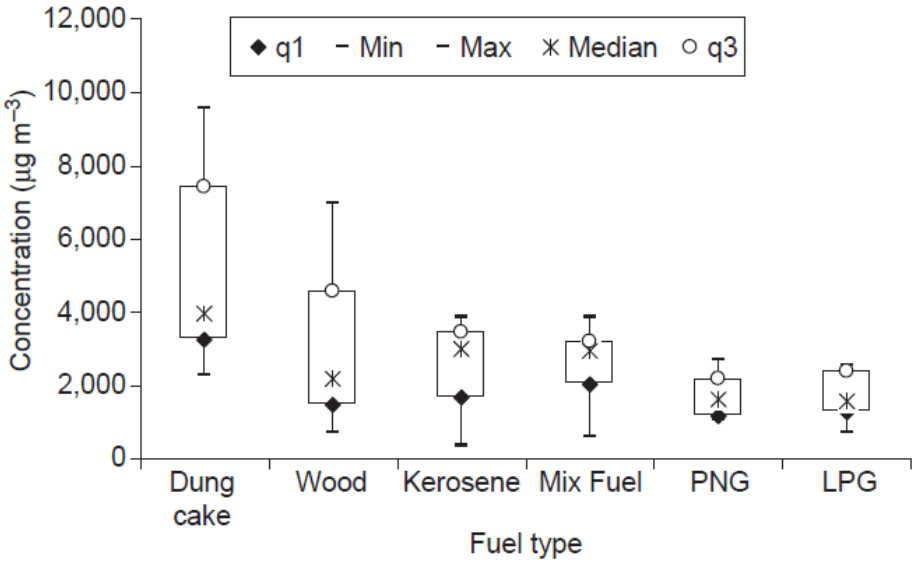
State-wise estimates of 24-h kitchen concentrations of PM2.5 in India



Solid-fuel using households Balakrishnan et al. 2013 (SRU group)

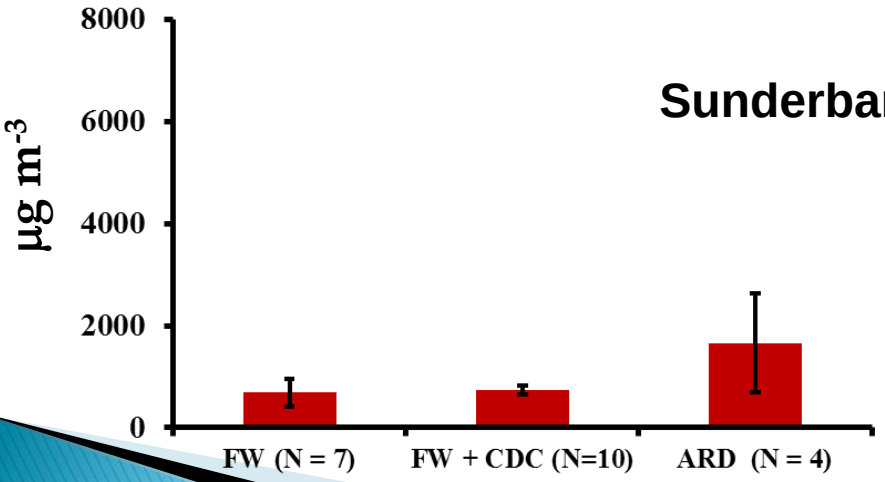
Fuel wise $PM_{2.5}$ measurement in rural households

Bhallabgarh



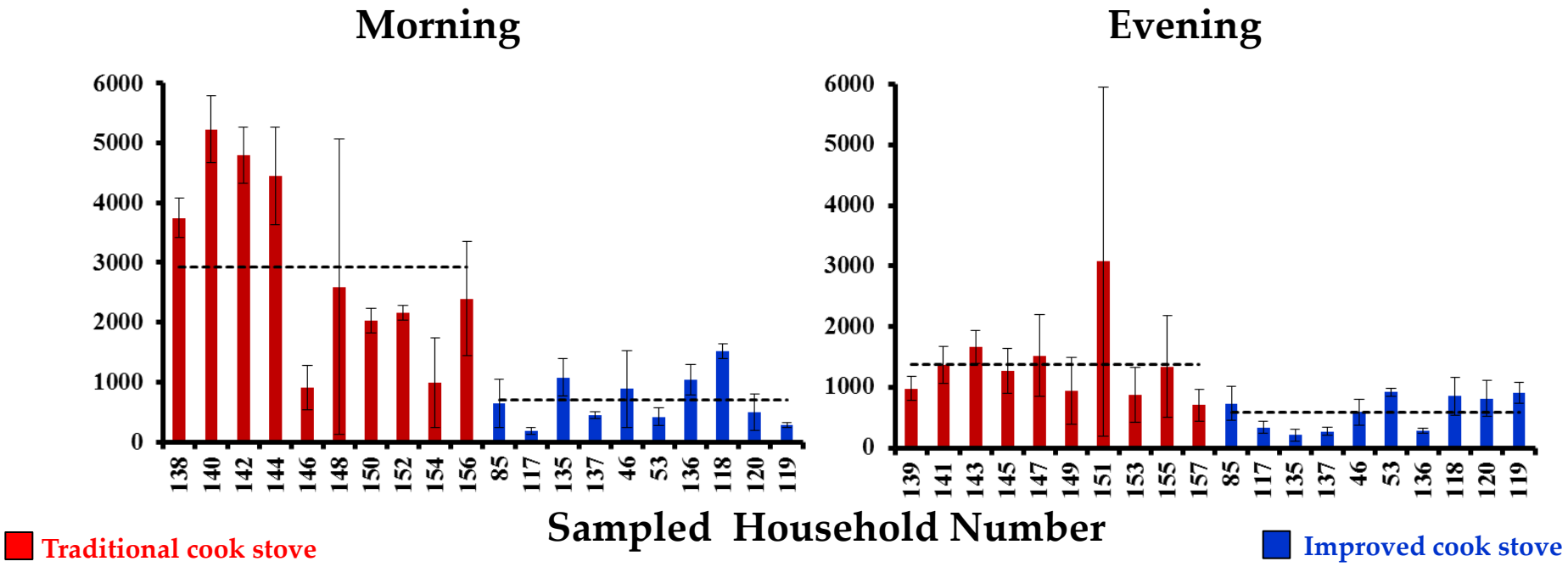
M Sehgal et.al

Sunderban



A Datta et.al

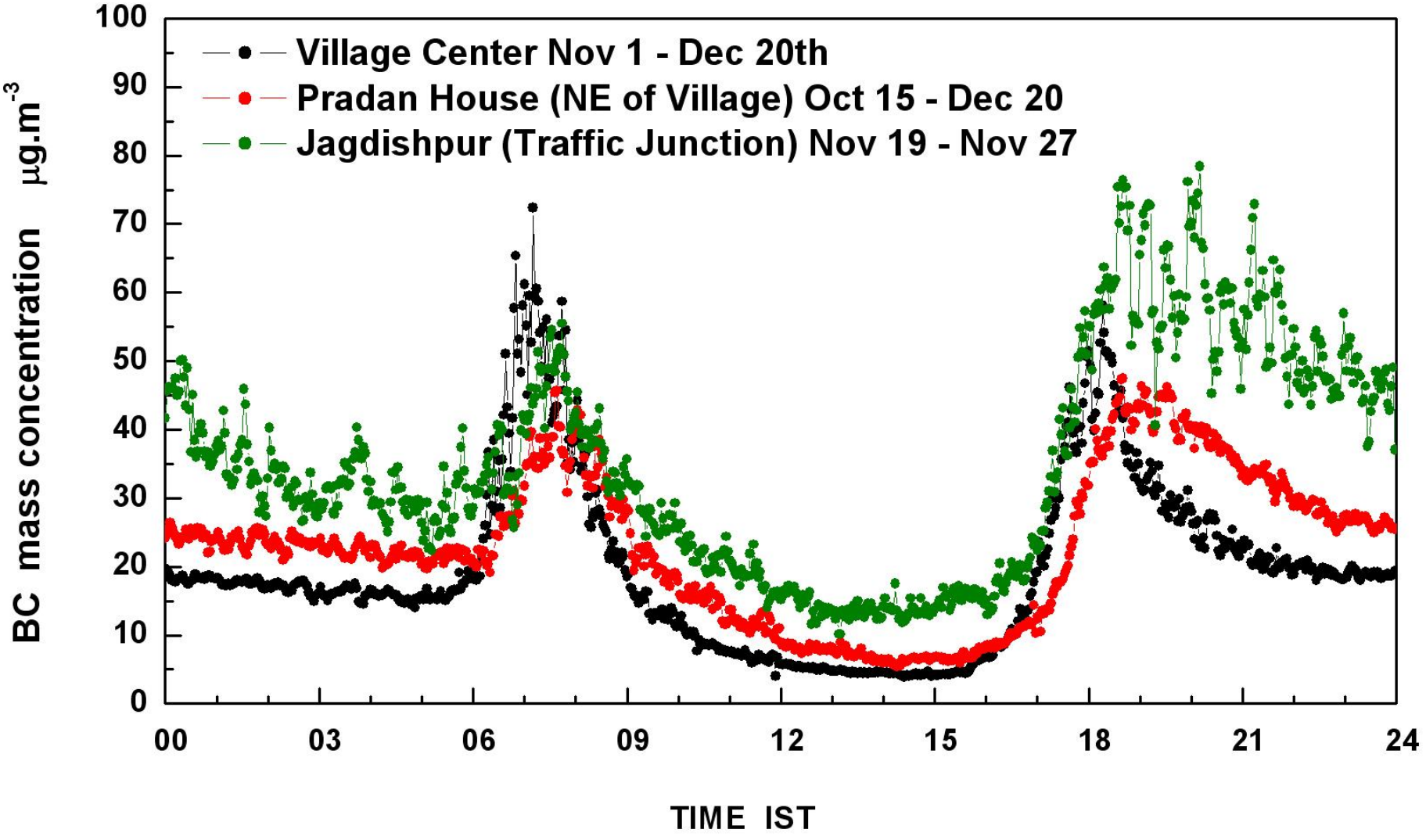
$PM_{2.5}$ Level in different Kitchen during the Cooking Time (Winter, 2014), Sunderban



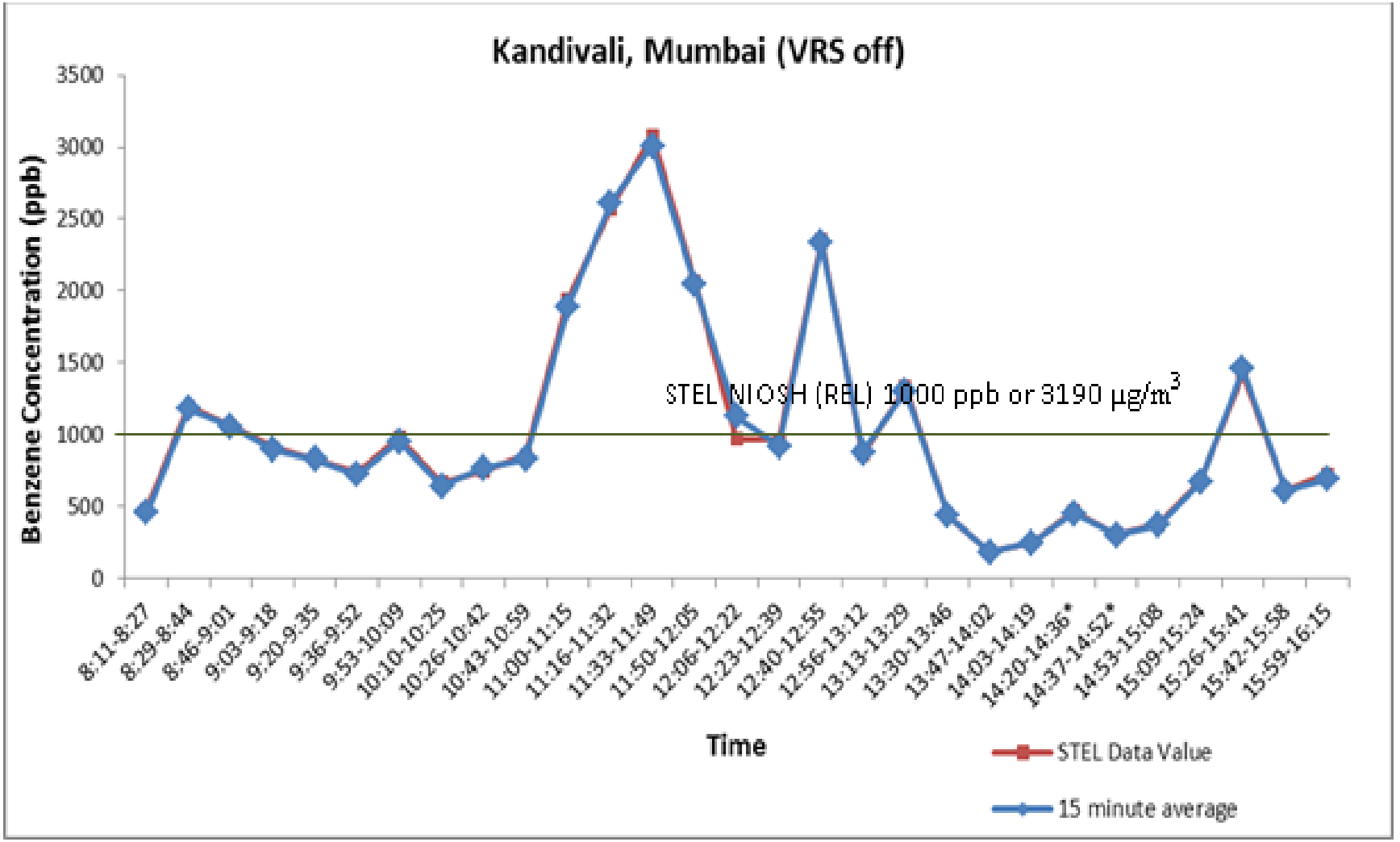
A Datta et.al

Indoor cooking affecting outdoor air

BC: Outdoor Measurements

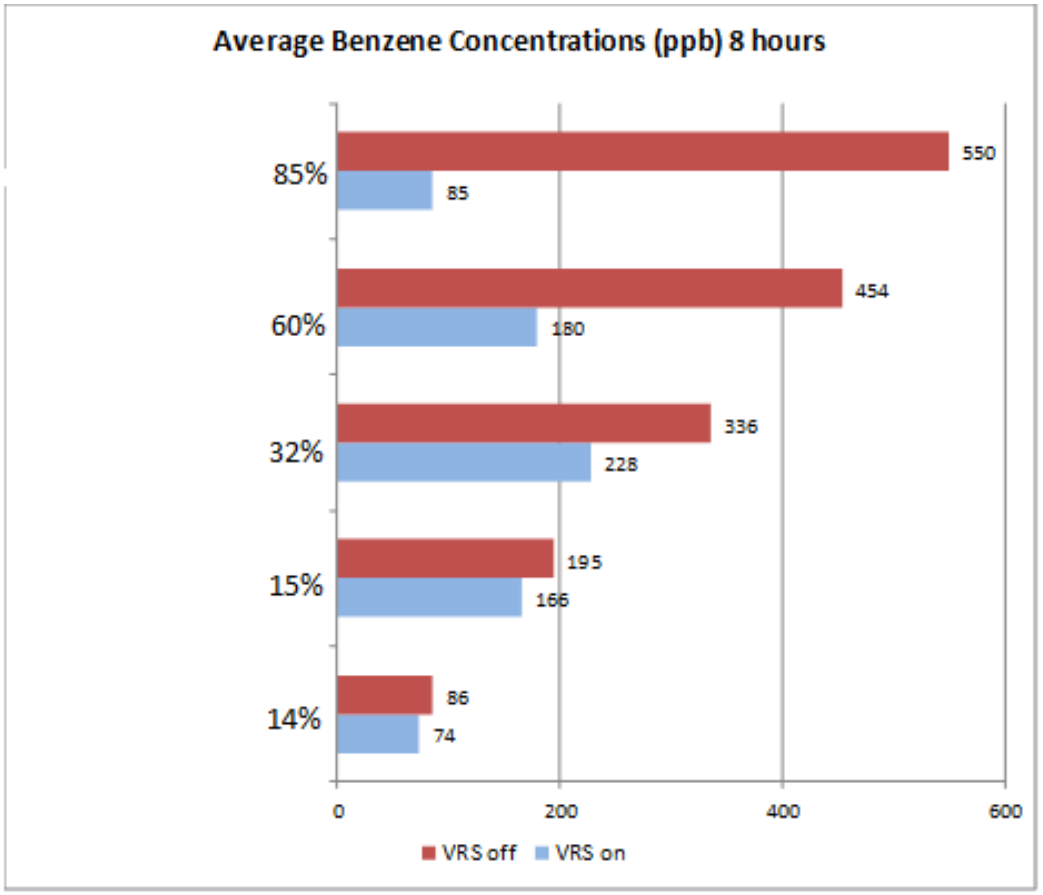


Workplace exposure, Petrol Pumps



Sehgal, M., Suresh, R., Sharma, V. P., and Gautam S. K. 2011. **Variation in air quality at Filling Stations, Delhi**, India, International Journal of Environmental Studies, DOI:10.1080/00207233.2012.

Workplace exposure, Petrol Pumps



Install vapour recovery systems in fuel refueling outlets to reduce benzene emissions in NCR.
CPCB has issued direction for installation of stage I and Stage II vapor recovery system in all retail outlets with capacity 3000 klm and more in 46 million plus cities by December 2017.
In Delhi and NCR all retail outlets should comply with this.

The final “Comprehensive Action Plan” by Environment Pollution Control Authority (EPCA), lists Action for reducing Vehicular Emissions.

(source: http://www.epca.org.in/EPCA-Reports1999-1917/Final-EPCA-Report-71-CAP-for-Delhi-NCR.pdf)

Workplace exposure, Toll booths

Assessment of outdoor workers' exposure to air pollution in Delhi (India)

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Air quality monitoring ($PM_{2.5}$, CO, NOx, SO_2 and EC/OC) was carried out at highway toll plazas, municipality toll plazas and control sites ($n = 23$) in the National Capital Region of Delhi, to determine the exposure of toll plaza workers to air pollution and its effect on lung function. Lung function indices ($n = 45$) were also measured for these workers. The results reveal the high level of air pollution at almost all locations with $PM_{2.5}$ values exceeding the national permissible limit except at a few control sites. Observed reduction in lung function indices was significant over years of occupational exposure even after adjusting for age, amongst non-smoking outdoor workers. This study found pollutant concentrations were highest at municipality toll plazas with minimum protective work area. The paper suggests measures to reduce the exposure of outdoor workers.

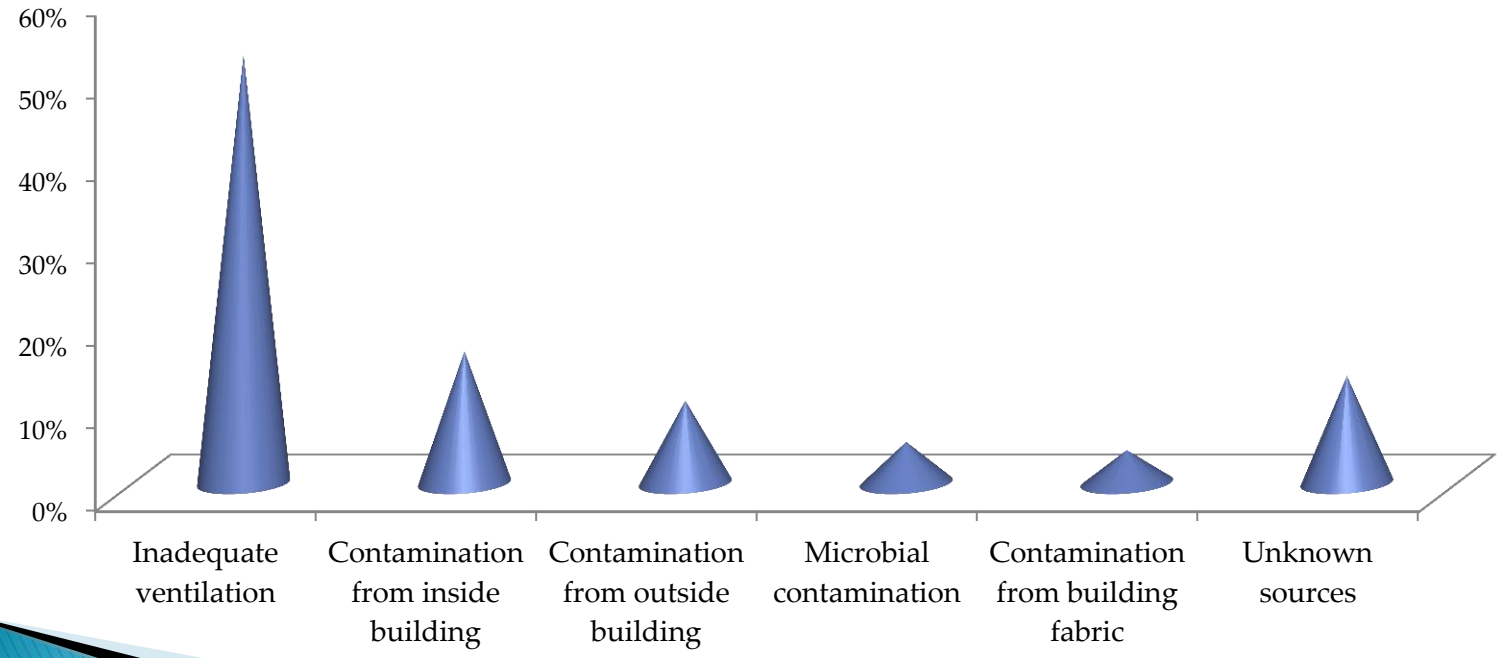
Keywords: Exposure; Occupation; $PM_{2.5}$; Pollution; Risk; Traffic

IAP and health

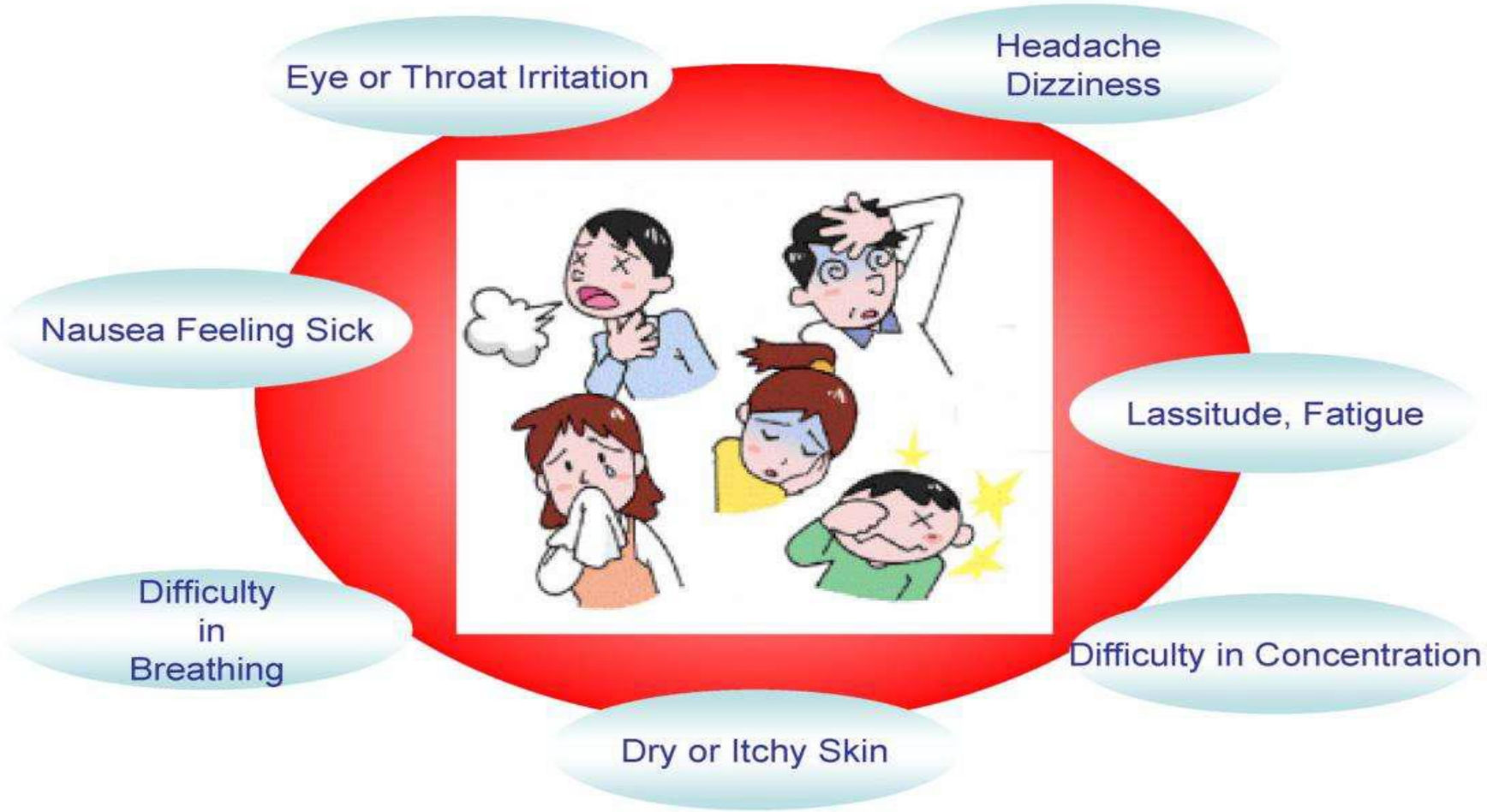
Pollutant	Health effects
NO_2	Type: Immediate: Causes: irritation to the skin, eyes and throat, cough etc
CO	Type: : Immediate; Causes: headache, shortness of breath, higher conc. May cause sudden deaths.
VOCs	Type: : Immediate; Causes: Liver, kidney disorders, irritation to the eyes, nose and throat, skin rashes and respiratory problems.
RSPM	Type: : Cumulative, Causes: Respiratory Illness (upper and lower), Acute (Asthma) and chronic (COPD), Lung cancer,
Pesticides	Type: : Immediate; Causes: Skin diseases
SO_2	Type: : Immediate; Causes: lung disorders and shortness of breath
Asbestos	Type: : Cumulative; Causes: Lung cancer
O_3	Type: : Immediate; Causes: eyes itch, burn, respiratory disorders, lowers our resistance to colds and pneumonia.

Sick building syndrome (SBS)

Building occupants experience acute health and comfort effects which is linked to time spent in the building, but no specific illness or cause identified.



Symptoms of SBS



Effect of temperature, RH and CO2

Temperature

- direct impact on **perceived comfort** and, **concentration** and **productivity**
- As per **ASHRAE Standard 55**, recommended temperature ranges termed "**comfortable**" are 22.8 to 26.1°C in the summer and 20.0 to 23.6°C in the winter.

Relative humidity

- Too high RH can contribute to the growth and spread of biological contaminants
- RH below 25% – increased discomfort and drying of skin and mucous membrane
- As per **ASHRAE Standard 55**, indoor humidity levels to be maintained between **30 –65 percent** for **optimum comfort**.

CO_2

- **Provides good indication of ventilation rates**
- **Generated in indoor primarily through human metabolism**
- **CO_2 build up in indoor is attributed to in-efficient or non-functioning of ventilation system**
- **As per ASHRAE, above 1000ppm CO_2 – requires adjustment of building's ventilation system**
- **Building shows SBS symptoms if CO_2 concentration > 1000 ppm**

IAQ standards and guidelines

1. Canada
2. Singapore
3. UK
4. Germany
5. USA
6. China
7. India??

Summary of guidelines

Parameter	WHO guideline value*	ASHRAE**	OSHA***	NAAQS/EPA (2000)****
PM_{10}	50µg/m³ (24-hr mean)	--	15mg/m³ (total)	150µg/m³ (24-hr)
$PM_{2.5}$	25µg/m³ (24-hr mean)	--	5mg/m³(resp.)	65µg/m³ (24-hr)
SO_2	20µg/m³ (24-hr mean)	--	5ppm (8-hr)	140ppb (24-hr) 75ppb (1-yr)
NO_2	200µg/m³ (1-hr) 40µg/m³(annual mean)	--	5ppm (8-hr)	53ppb (annual) 100ppb (1-hr)
CO	10ppm (8-hr)	9ppm (8-hr)	50ppm (8-hr)	9ppm (8-hr)
CO_2	--	1000ppm (8-hr)	5000ppm	
Humidity	--	30% - 65%	--	
Temperature	--	68°F - 74.5°F (20-23.6°C)(winter) 73°F - 79F° 22.8-26.1°C)(summer)	--	

*** Occupational Safety and Health Administration Permissible Exposure Limit — this level is a time-weighted average and is an enforceable standard that must not be exceeded during any eight-hour work shift of a 40-hour work week

** ASHRAE (American Society of Heating, Refrigerating and Air-conditioning Engineers Inc.) Standard 55

* WHO air quality guidelines global update 2005 and WHO guideline value for the "classical" air pollutants (WHO 1999a

**** The National Ambient Air Quality Standards (NAAQS) were developed by the U.S.

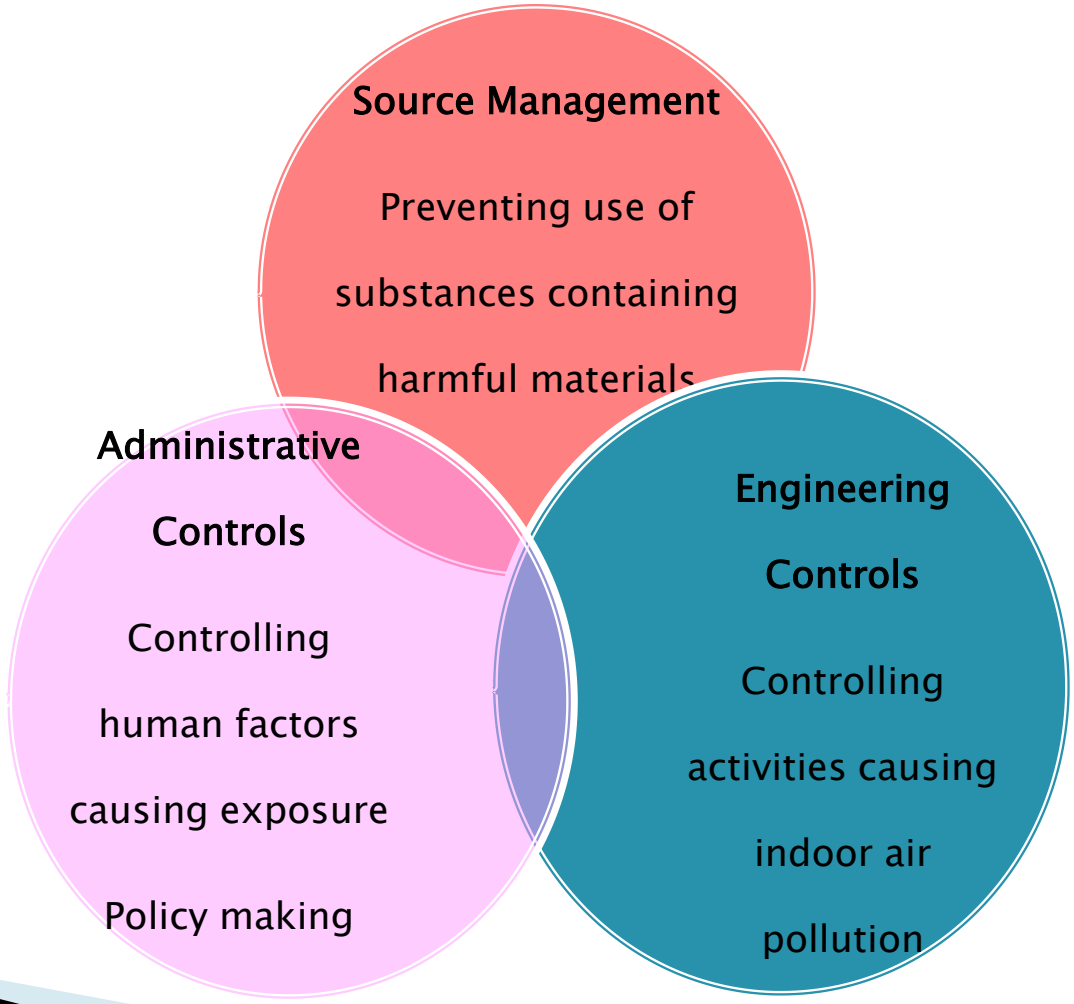
Environmental Protection Agency (EPA) under the Clean Air Act (last amended in 1990). These enforceable standards were developed for outdoor air quality, but they are also applicable to indoor air contaminant levels. The concentrations are set conservatively in order to protect the most sensitive individuals, such children, the elderly, and those with asthma.

Comparison of Regulations & Guidelines Pertinent to Indoor Environments

	Enforceable and/or Regulatory Levels			Non-Enforced Guidelines and Reference Levels			
	NAAQS/EPA (Ref. B-4)	OSHA (Ref. B-5)	MAK (Ref. B-2)	Canadian (Ref. B-8)	WHO/Europe (Ref. B-11)	NIOSH (Ref. B-13)	ACGIH (Ref. B-1)
Carbon dioxide		5,000 ppm	5,000 ppm 10,000 ppm [1 h]	3,500 ppm [L]		5,000 ppm 30,000 ppm [15 min]	5,000 ppm 30,000 ppm [15 min]
Carbon monoxide [c]	9 ppm [g] 35 ppm [1 h] [g]	50 ppm	30 ppm 60 ppm [30 min]	11 ppm [8 h] 25 ppm [1 h]	90 ppm [15 min] 50 ppm [30 min] 25 ppm [1 h] 10 ppm [8 h]	35 ppm 200 ppm [C]	25 ppm
Formaldehyde[h]		0.75 ppm 2 ppm [15 min]	0.3 ppm 1 ppm[i]	0.1 ppm [L] 0.05 ppm [L] [b]	0.1 mg/m^3 (0.081 ppm) [30 min][p]	0.016 ppm 0.1 ppm [15 min]	0.3 ppm [C]
Lead	1.5 µg/m^3 [3 months]	0.05 mg/m^3	0.1 mg/m^3 1 mg/m^3 [30 min]	Minimize exposure	0.5 µg/m^3 [1 yr]	0.1 mg/m^3 [10 h]	0.05 mg/m^3
Nitrogen dioxide	0.05 ppm [1 yr]	5 ppm [C]	5 ppm 10 ppm [5 min]	0.05 ppm 0.25 ppm [1 h]	0.1 ppm[1 h] 0.004 ppm [1 yr]	1 ppm [15 min]	3 ppm 5 ppm [15 min]
Ozone	0.12 ppm [1 h][g] 0.08 ppm	0.1 ppm	j	0.12 ppm [1 h]	0.064 ppm (120 µg/m^3) [8 h]	0.1 ppm [C]	0.05 ppm[k] 0.08 ppm[l] 0.1 ppm[m] 0.2 ppm[n]
Particles[e] <2.5 µm MMAD[d]	15 µg/m^3[1 yr][o] 65 µg/m^3 [24 h][o]	5 mg/m^3	1.5 mg/m^3 for <4 µm	0.1 mg/m^3 [1 h] 0.040 mg/m^3 [L]			3 mg/m^3
Particles[e]<10 µm MMAD[d]	50 µg/m^3[1 yr][o] 150 µg/m^3 [24 h][o]		4 mg/m^3				10 mg/m^3
Radon	See Table B-2[f]				2.7 pCi/L [1yr]		
Sulfur dioxide	0.03 ppm [1 yr] 0.14 ppm [24 h] [g]	5 ppm	0.5 ppm 1 ppm [i]	0.38 ppm [5 min] 0.019 ppm	0.048 ppm [24 h] 0.012 ppm [1 yr]	2 ppm 5 ppm [15 min]	2 ppm 5 ppm [15 min]
Total Particles[e]		15mg/m^3					

*Unless otherwise specified, va[illegible]given in parts per million (ppm)
*Where no time is specified, the averagi[illegible]eight hours.

Mitigation strategies



1. Source management

- Lot of indoor air pollutants directly linked to items of daily use
  - Cleaning items (low VOC products)
  - Fuels and cook-stoves (Clean fuels)
  - Building materials and furnishings (low VOC products)

- Building occupants may be the source of pollutants - perfumes or colognes, cigarette smoke (OSHA, 2011)

2. Administrative controls

Work schedules	• Eliminate or reduce the amount of time a worker is exposed to a pollutant • Reduce the amount of chemicals being used by or near workers • Control the location of chemical use
Education and Awareness	• Inform about the sources and effects of pollutants • Inform about proper operation of ventilation system • Awareness about clean alternatives, mitigation solutions
Housekeeping	• Prevent dirt from entering the environment • Dispose garbage timely • Store food properly • Choose cleaning products, methods that minimize introduction of pollutants into the building

3. Engineering controls

- HVAC (heating, ventilation, and air conditioning systems) control and management
- IAQ improving plants
- Air purifiers

Indoor plants

Pollutants	µg/h of pollutants removed
Benzene	579 (English ivy) – 4486 (Barberton daisy)
Formaldehyde	183 (Chinese evergreen) – 3196 (Bamboo palm)
Trichloro ethylene	298 (English Ivy) – 1622 (Barberton Daisy)

Plants are

- **effective in removing VOCs**
- **Reduce microbes and molds**
- **Increase humidity**
- **PM ????**

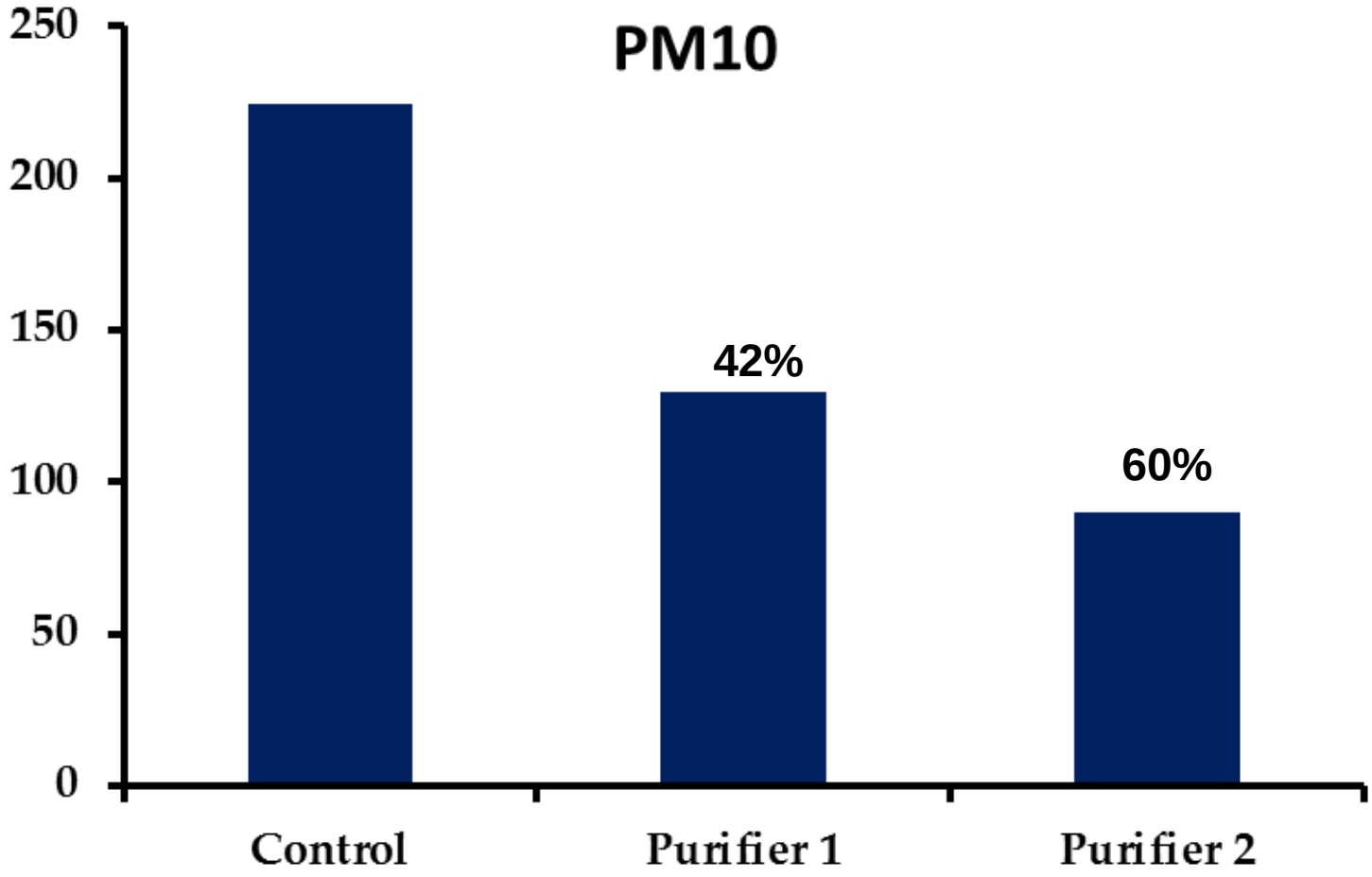
Recommended indoor plants

Sr No.	Common Name	Scientific name	↓ Pollutant	Watering	Shade	Planting Practice
1	Snake Plant	*Sansevieria trifasciata*	• CO_2 • Formaldehyde • Nitrogen dioxide	Do not water them too much, especially during the winter	Minimal light	6 days indoors 1 Day in bright sunlight
2	Areca palm	*Dypsis lutescens*	• CO_2	Water until the soil is evenly moist	Partial shade (low-light conditions)	4 days indoor 1 Day in bright sunlight
3	Aloe vera	*Aloe vera*	• CO_2 • Formaldehyde • Benzene	Water until the soil is evenly moist	Bright light	2 days indoor 1 Day in bright sunlight
4	Money plant	*Epipremnum aureum*	• Volatile Organic Compounds (VOC)	Once in 4-5 days	Partial sunlight	4 days indoor 1 Day in bright sunlight
5	Dragon Tree	*Dracaena marginata*	• Benzene, Formaldehyde, Toluene • Xylene	Allow the plants to dry between watering	Bright light	2 days indoor 1 Day in bright sunlight
6	Peace lily	*Spathiphyllum wallisii*	• Benzene, Formaldehyde, Toluene • Xylene	Water until the soil is evenly moist	Part shade to full shade	4 days indoor 1 Day in bright sunlight

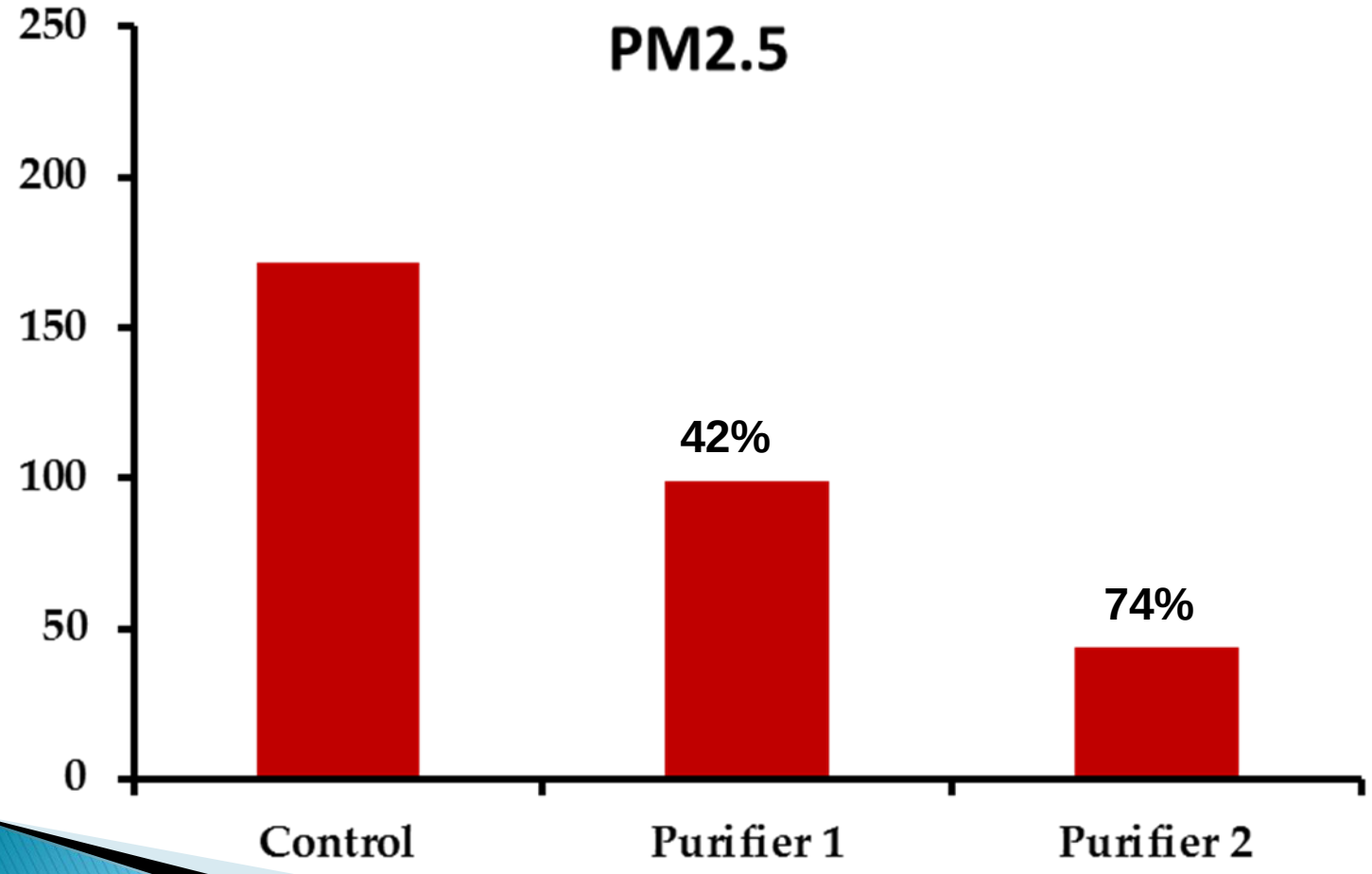
Recommended indoor plants

Sr No.	Common Name	Scientific name	↓ Pollutant	Watering	Shade	Planting Practice
7	Flamingo flower	Anthurium andraeanum	• Benzene • Formaldehyde • Toluene • Xylene	Should not be kept continuously moist.	Partial Sun	4 days indoor 1 Day in bright sunlight
8	Common ivy	Hedera helix	• Benzene • Formaldehyde • Toluene • Xylene	Water until the soil is evenly moist	Full Sun to partial shade	4 days indoor 1 Day in bright sunlight
9	Red ivy	Hemigraphis alternata	• Benzene • Formaldehyde • Toluene • Xylene	Water until the soil is evenly moist	Bright indirect sun to Part shade	2 days indoor 1 Day in bright sunlight
10	Rubber plant	Ficus robusta	• CO2 • Eliminates bacteria and mold spores • formaldehyde	Once the soil becomes slightly dry to touch	Bright indirect sunlight	2 days indoor 1 Day in bright sunlight

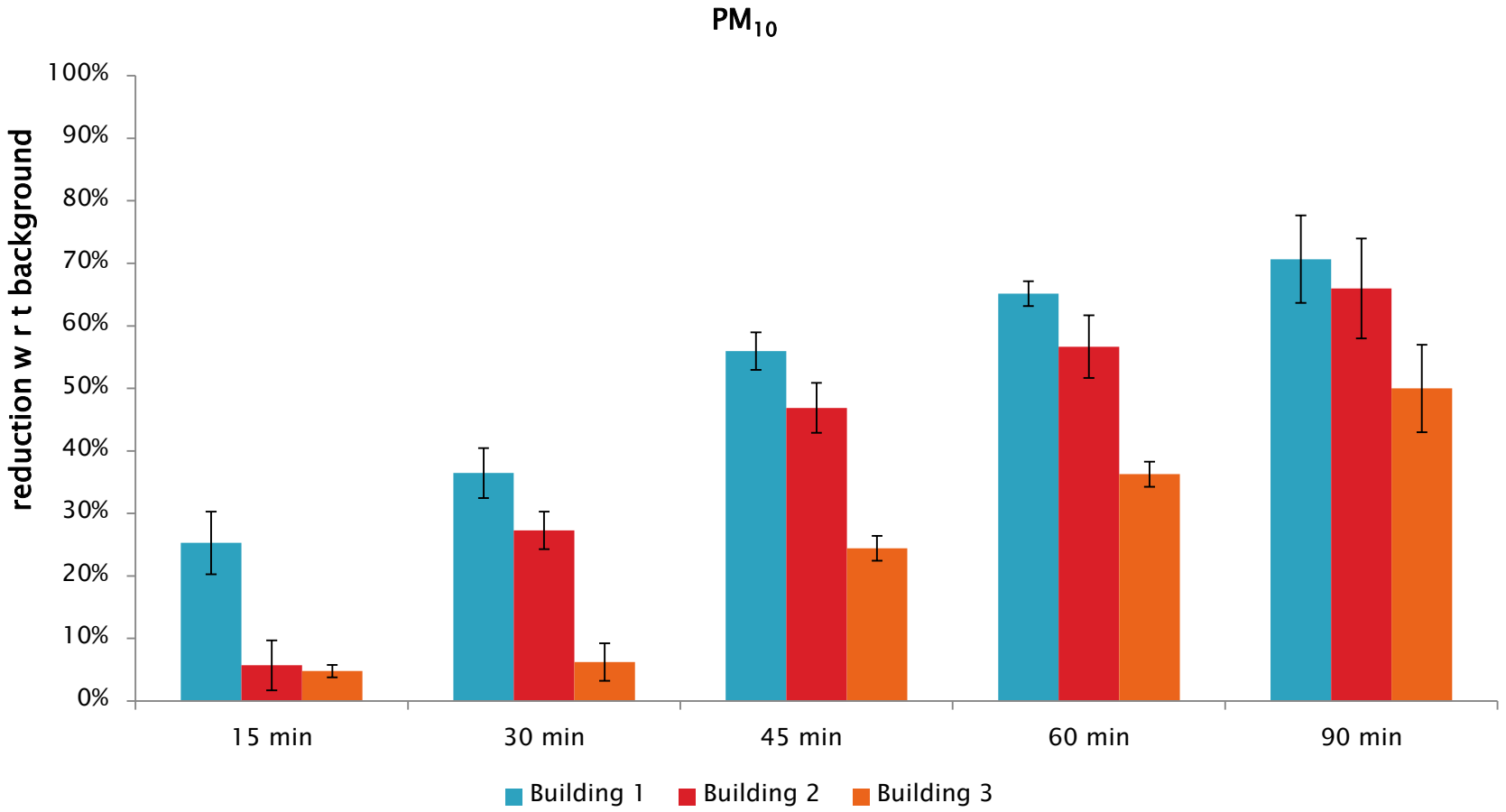
Air purifiers performance



Air purifiers performance

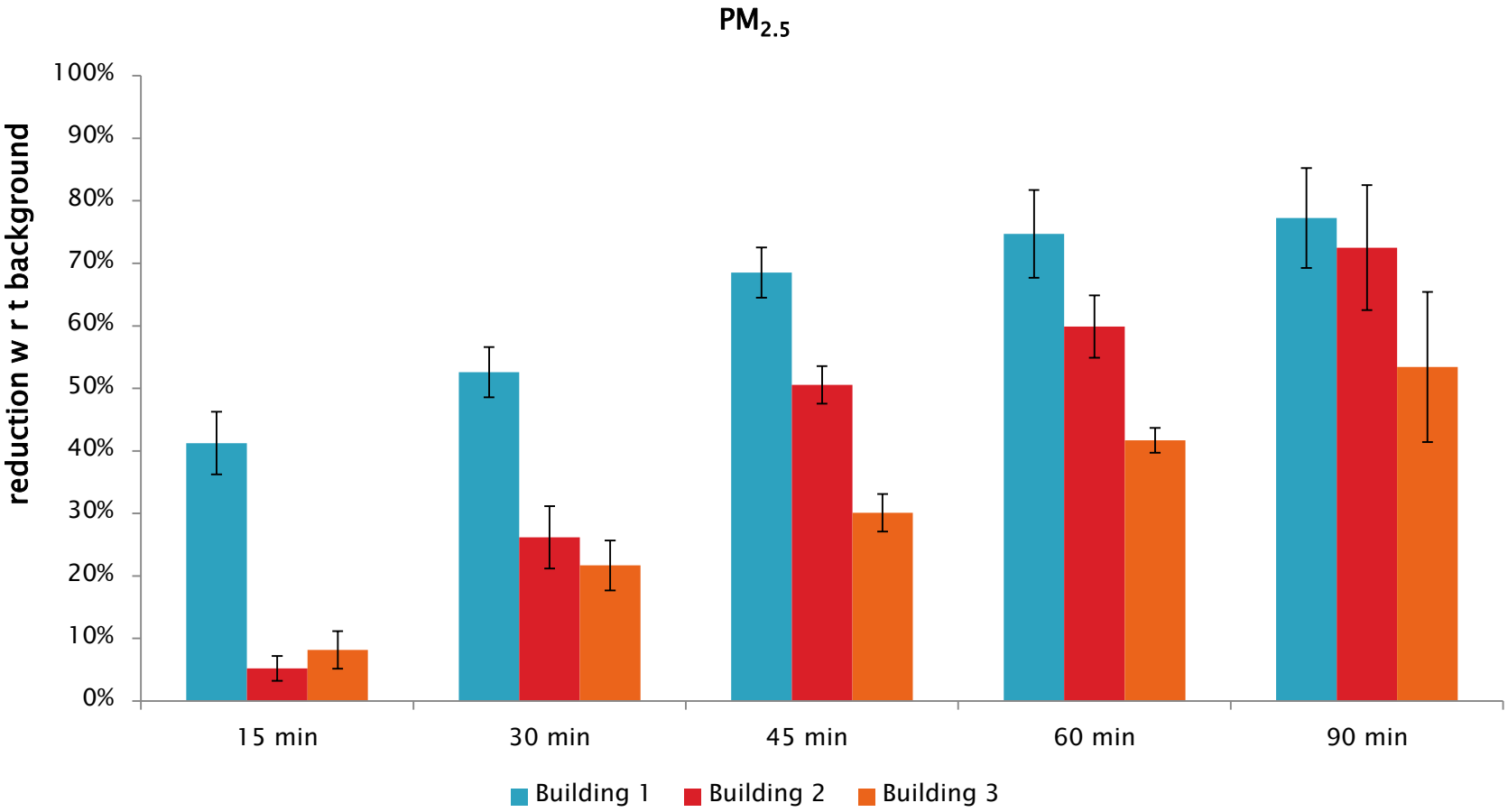


Air purifier performance



24-51%

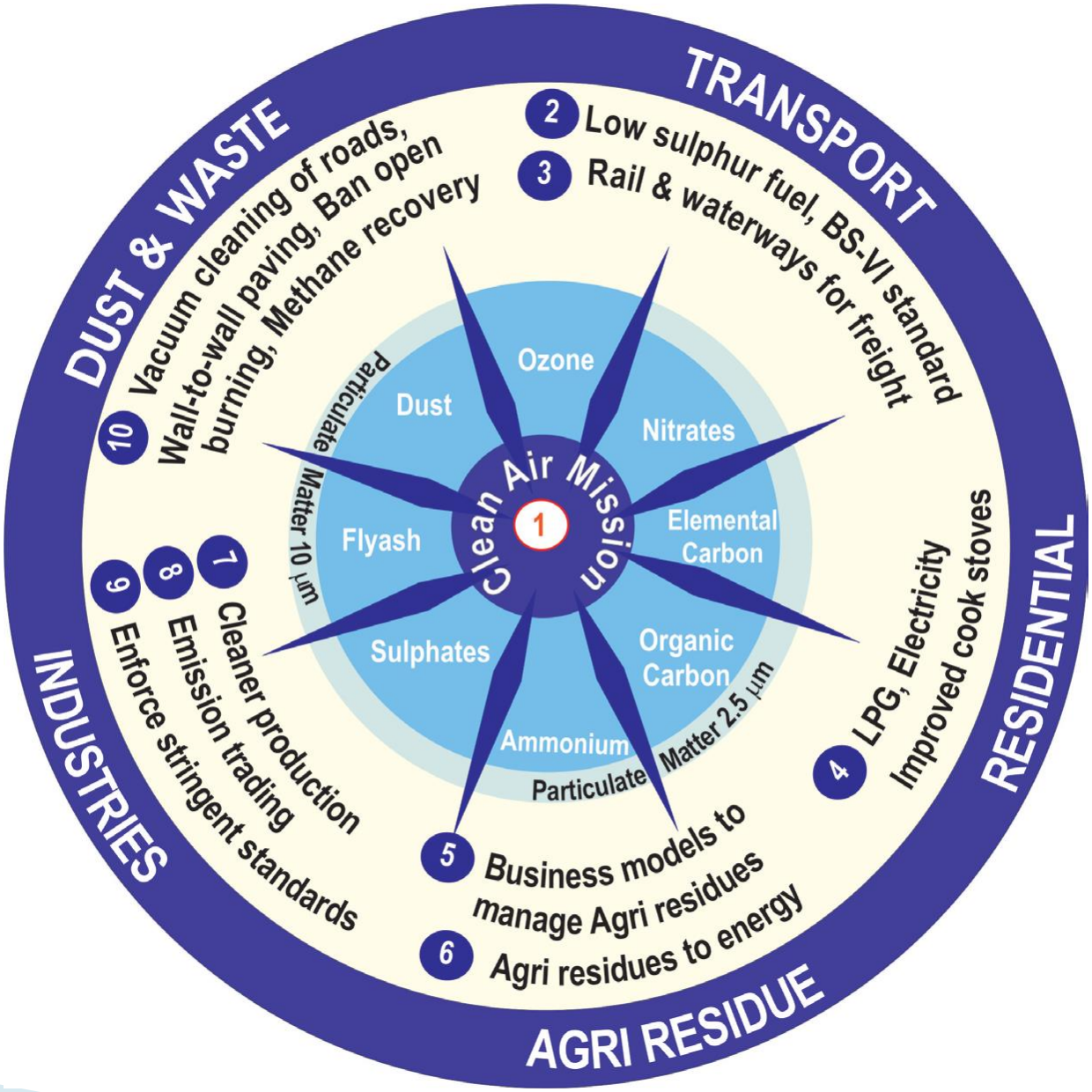
Air purifier performance



31-63%

Interventions required

- National standards and/or guidelines on indoor air quality
- Verifying claims of products – certifications
- Evaluation of important existing buildings
- GRIHA Rating evaluation to be included in building projects
- Improving outdoor air quality will help in improving IAQ also and vice versa.


TRANSPORT
RESIDENTIAL
AGRI RESIDUE
INDUSTRIES
DUST & WASTE
Clean Air Mission
1
Ozone
Nitrates
Elemental Carbon
Organic Carbon
Ammonium
Sulphates
Flyash
Dust
Particulate Matter 2.5 µm
Particulate Matter 10 µm
2 Low sulphur fuel, BS-VI standard
3 Rail & waterways for freight
4 LPG, Electricity Improved cook stoves
5 Business models to manage Agri residues
6 Agri residues to energy
7 Cleaner production
8 Emission trading
9 Enforce stringent standards
10 Vacuum cleaning of roads, Wall-to-wall paving, Ban open burning, Methane recovery

Thank you