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Urban Canyon Modelling: A Need for the Design of Future Indian Cities

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Abstract

India has experienced a high rate of Urbanization, higher density of population in cities has more of it. The higher population Density with cities like Mumbai having population densities of 20680 person/km^2 has led to crowded space in a urban setting decreased Natural Ventilation of Air Pollutants. Using the advanced Computational and Mathematical models pollutant concentrations are estimated. Street Canyon models, which may include simplified photochemistry and particle deposition-suspension algorithms. These models when used in a knowledgeable way principles that govern the dispersion and transformation of atmospheric pollutants. A study of vehicle exhaust dispersion within different street canyons models in urban ventilated by cross-wind is conducted at this work to investigate how air pollutant dispersion is exaggerated by wind speed, building height to width ratios, street and building geometries and canyon street number.

Keywords: Urban canyon modelling, urban heat island, net radiation flux.

Introduction

The Future planned Indian Cities of Durgapur, West Bengal, Greater Noida, Uttar Pradesh, Lavasa, Maharashtra, Mohali, Punjab, GIFT, Gujarat, New Town, Kolkata, Sri Gangbanger, Rajasthan, Sricity, Andhra Pradesh and so forth are spreading at a fast pace in its width there are to take into consideration the effect of the congregation of the air pollutants due to peculiar geometry of the design of the buildings urban canopy.

The World Bank has given status of Indian Urban Area as it is going to be 50% by 2050 from 2013. So we need to build these future areas in such a way that it mitigates the effect of Urban Heat Island and have natural ventilation in the cities.

The Cities have experienced rapid urbanisation which has brought more clusters of tall buildings, compact urban space and the smaller street geometry in the metro cities; it influences the urban climate in quite large manner. It is very necessary to study the urban canyon at a micro-scale and how it does affect the overall climatic condition on an urban scale also the concept associated with it urban canopy, urban heat island Roughness subsurface and boundary layers.

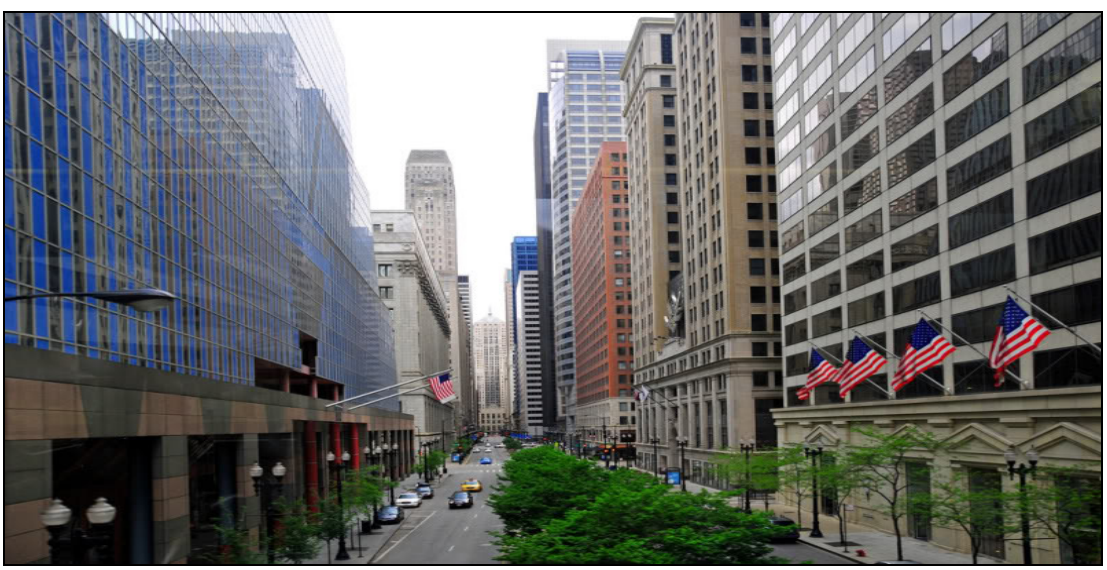

Figure-1
Typical Urban Street Canyon

As the Vehicles Need Fossil Fuel to operate like diesel, petrol, natural gas they contribute to air pollution significantly[1].

Particulate Matter, Hydrocarbon, Carbon Monoxide, Nitrogen Oxide, Ozone which are most important Traffic-related air pollutants in modern urban agglomerations. Air quality limit values, whose objective is to safeguard public health, are frequently exceeded, particularly in busy streets and urban areas. The dilution and removal of vehicular traffic exhausts in urban street canyons is of great importance for the public health and quality of life of people living or working in city centres.

Urban Canyon Modelling Definition

Air dispersion characteristic modelling in a typical urban space where there is a restriction of the vehicular pollution emission dispersion. The modelling can be done in different scales from micro-scale (street level) to Meso-scale (whole city) which is given in the below figure. The nature of our research influences the selection of the size of area which is to be considered.

The buildings change air flow field, influencing pair exchanges and dispersion of pollutants in urban areas where population and traffic density are relatively high human exposure to dangerous substances is significant. Due to this distress, the street canyons are considered as hot spots for air pollution problems.

Irregular shaped buildings increase turbulence and vertical mixing in atmosphere; W/H ratios of urban canyons affect street air dispersion.

Urban Heat Island (UHI): Atmospheric temperature rise experienced due to heat island phenomenon has been commonly linked with cities. These types of surfaces are dark, dry which are characterized by low albinos, high impermeability and favourable thermal properties which are capable of heat energy storage and subsequent heat release. The lesser is the sky view factor the greater is the absorbance and the remittance from their surface in the urban canyon. Due to these factors urban areas have greater temperature in relation to their rural counterparts which have more vegetation, and thus their temperatures are maintained through the evapotranspiration progression, shades of trees and interception of sun's radiation.

Components of urban Canyon Modeling

Emissivity of the material[2]: The relative ability of its building surface to its emit energy by radiation, important related to the UHI phenomenon is called as Emissivity. As the Urban Agglomerate is built up usually by Bricks, Concrete and Asphalt there is enormous amount of heat emitted which is 0.93, 0.88, and 0.93. High Emissive Materials emit radiation at night making the temperature of the Surface Urban Heat Island is comparatively higher at nights than the rural counterparts.

Albedos of the Different Material: Commonly used materials like concrete, brickwork and bitumen heats up rapidly in the day time in contrast to water bodies. Due to nature of the surface its albedo is lower. More Heat is enthralled and conducted through the Material. Warmth is added into the atmosphere as the heat is emitted slowly. This phenomenon keeps urban climates relatively high and the contrast between the urban environment and the rural fringe is highest at night.

Sky View Factor (SVF): It is one of the most vital factors in Urban Heat Island required as a parameter in its modelling using Arc View GIS and the possibilities of the 3DSkyView Tool.SVF is the ratio of the radiation received by a planar surface to the radiation by the entire hemispheric environment.

Urban Sub-surface Roughness: The roughness sub layer is usually termed as the region where the flow is influenced by the individual roughness elements as reflected by the spatial in homogeneity of the mean flow, for example[3], in the atmospheric context states that in the Urban Scenario it is affected by the High-rise Buildings thus giving in homogeneity to the mean flow.

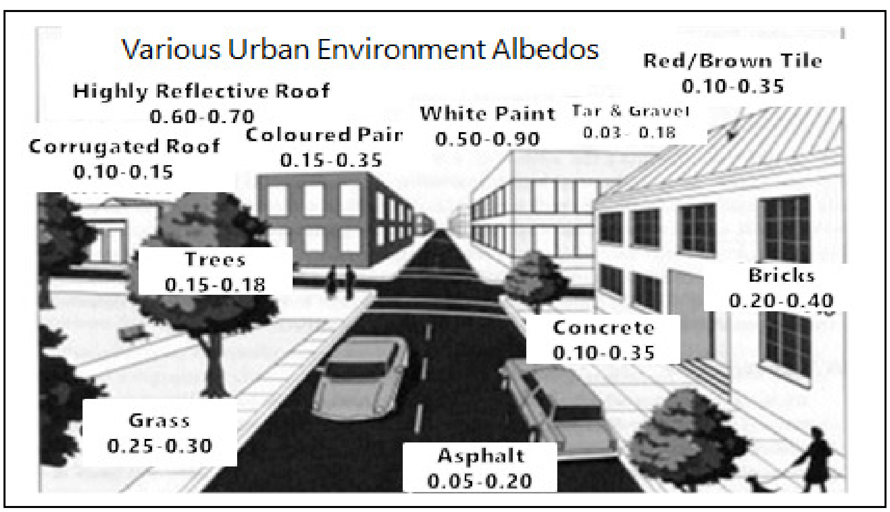

Figure-2
Albedos of different material in Urban City

Net Radiation Flux: Net Radiative Flux of the underlying surface is difference between the absorbed radiant energy and that emitted by the underlying surface, the atmosphere or by the earth-atmosphere system. Greatest variations of meteorological parameters in urban areas are caused due to short wavelengths. Long-wave radiations are as a result of reemitting from the urban surface downward to where it is retained by the ground. Representation of Heat Flow in Urban setting in figure-3.

Gartland[4] stated that although anthropogenic heat, low wind speeds, and air pollution in urban areas can contribute to UHI creation, there may be two main explanations for formation of UHI

Due to impermeable material used in the new-age construction the moisture is been trapped this does not allow heat to dissipate in the atmosphere; In a canyon set-up dry, dark surfaces can reach upto 88°C and the vegetated surface with moist soil can reach only upto 18°C building and pavements trap more heat of the sun's energy

Faces of the building in a Urban Setting: In the transverse, vertical plane at mid-canyon show that the pollutant concentrations has higher concentrations at leeward face than that at windward faces, and has higher concentrations above downwind buildings than that above upwind buildings, Longitudinal distributions of pollutant concentrations at leeward and windward faces show decreasing of the concentration with increasing building height. While calculating the impacts of the pollutant it's important to specify which direction of walls and if these are unequal in dimension that the whole models changes as the dispersion characteristics will change.

Distinction between Urban Surface Energy Balance and Rural Energy Surface Balance: Sensible heat flux is greater due to the man-made materials like more use bricks, cements, paving and intensification of surface area, Latent heat flux is lower due to a lower fraction of vegetative land-use cover, Urban surfaces have higher thermal inertia due to high heat capacity of the man-made surfaces, leading to a non-negligible storage flux, Complex processes of shadowing and multiple reflections affect short-wave radiation fluxes, and the wide range of materials affect the emissivity and thus long-wave fluxes, resulting (surprisingly) in little difference in net radiation flux, and Anthropogenic heat sources act in addition to the solar-driven energy balance, effectively increasing the sensible heat flux. The urban surface energy balance drives not only the temporal advancement of the urban heat island (UHI), but also the evolution and vertical structure of the UBL.

Roughness elements are large, and exert significant drag on the flow. An urban roughness sub layer (RSL) can be defined of depth between 2–5H, where H is the mean building height. Within this layer, flow is highly spatially dependent (figure-4); turbulence can dominate the mean flow; and turbulence has different characteristics from the flow in the inertial sub-layer (ISL) above, where the turbulence is homogeneous and fluxes vary little with height. The urban canopy layer is defined as the layer up to mean roof height.

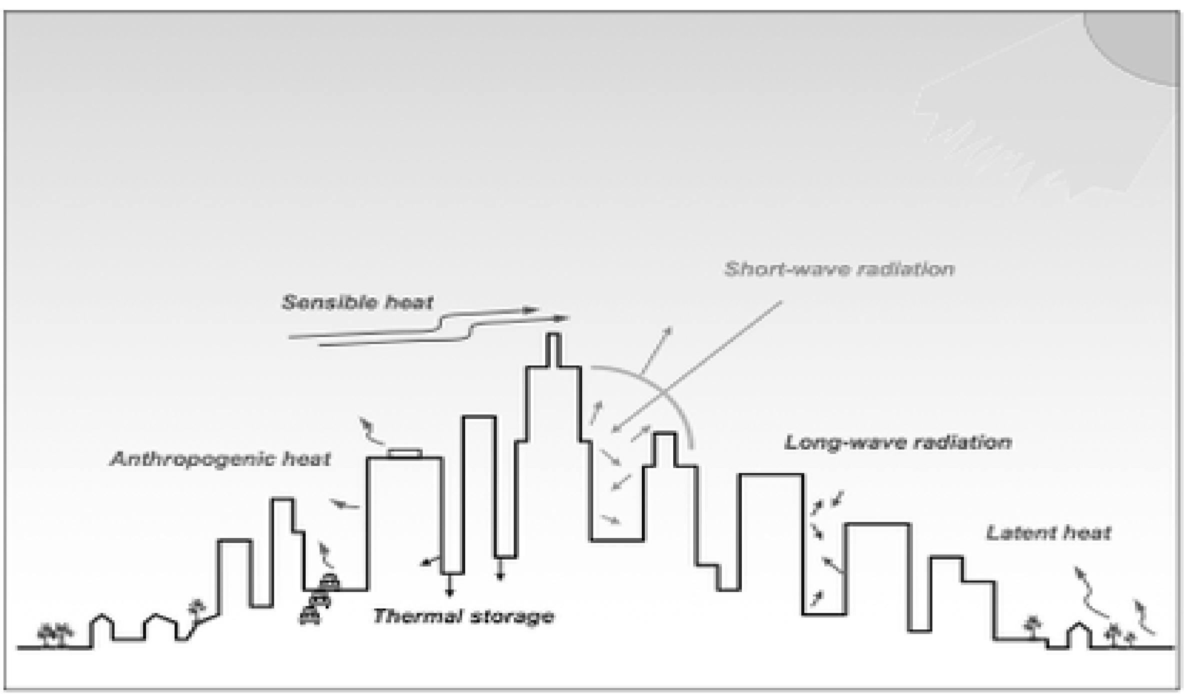

Figure-3
Typical Radiation Energy flow in a Urban Setting

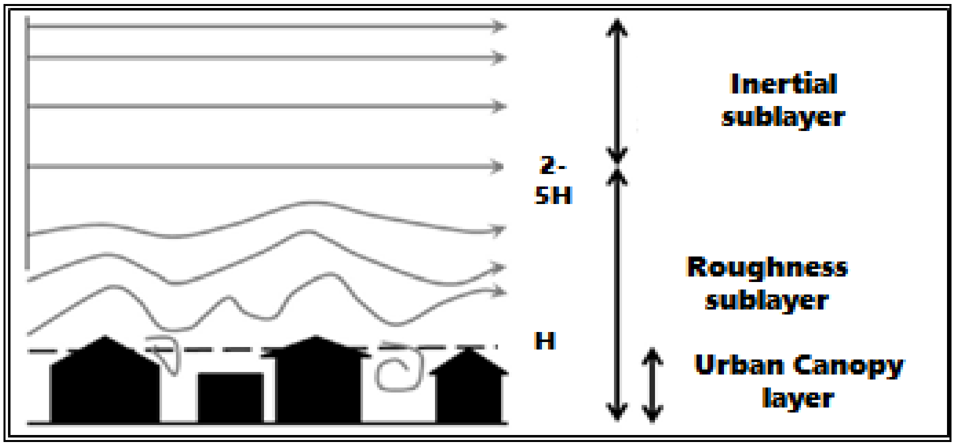

Figure-4

Schematic diagram of roughness and inertial sub-layers, Grey arrows indicate streamlines. Dashed line indicates mean building height H

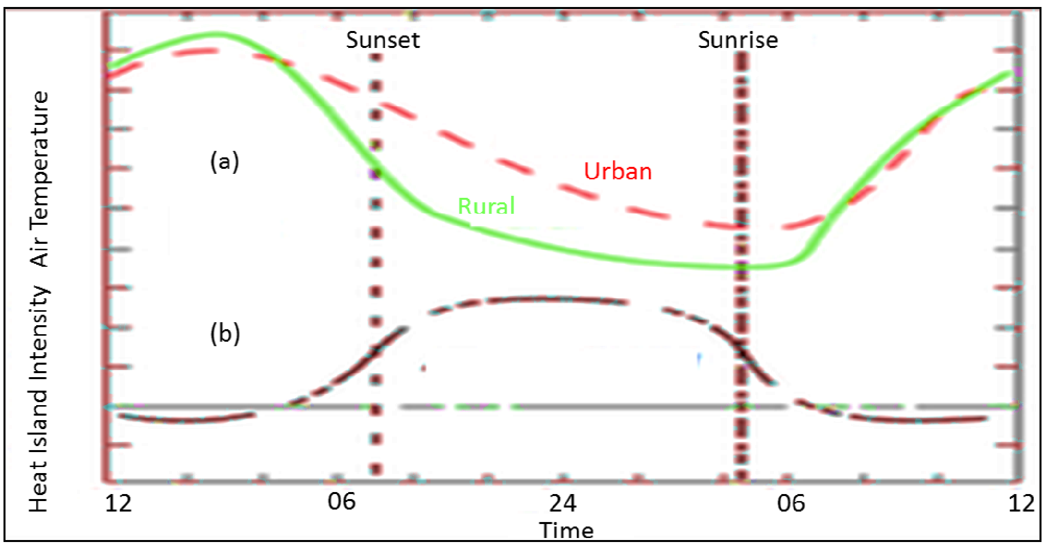

Figure-5

Diurnal Heat Change with Calm Atmospheric Conditions (Runnels and Oke, 2000)

From Figure-5 As shown in Section A During the day the heat is absorbed by the building surface material and during nights it reemits that is why the cooling is far lesser in urban area in the Time 18:30 to 5:30. So in nights temperature is higher in the urban areas as compared to the rural areas.

Urban areas are characterised very high more than 70% impermeable material and experience has lesser evapo transpiration as compared to rural areas. This difference contributes between urban and rural area to higher surface area temperatures[5].

The Pollutants when in atmosphere are either of these fates in their lifespan which are Advection Moving along with air in the atmosphere which is given by expression J=C*U

Where J=Advection, C=concentration, U=Velocity of the flow, Diffusion process through which pollutant molecules move through air which is given by Jd=-D $\partial C/\partial x$ or Dispersion, When a pollutant moves dissolved in volatilized in air. Change in pollutants concentration= Ma-Sd, Where Ma = Movement due to advection Sd = Spreading due to Diffusion/dispersion.

Street Canyon Modelling

The issue of dispersion of the atmospheric air pollutants is completely different in case of street. The results of this air quality models can be used for air quality management and traffic control, urban design planning, interpretation of monitoring data, time scale pollution forecasting, etc. Although there are no clear-cut distinctions between different categories, models might be classified into groups according to their physical (or mathematical principles and their level of sophistication Dispersion models gives current and impending air pollution levels air quality by providing forecasting with time-based and three-dimensional variations [5]

Wind flow: In the street canyon we take into consideration the microclimate and the urban geometry rather than the mesoscale forces regulatory the environment of the Boundary Layer A clear discrepancy is made between the synoptic above roof-top wind conditions and the local wind flow within the cavity of the canyon (figure -6).

Depending on the free stream winds having velocity can be having 3 main dispersion circumstances can be identified: i. Condensed winds lower than 1.5m/s, ii. Upright flow for synoptic winds over 1.5 m/s blowing at an angle which is more than 30° to the canyon area, iii. Lateral or just lateral flow for winds over 21.5 m/s. In the case of Upright flow, the Windward side of the canyon is usually called leeward.

Typical regimes of winds might be observed in the case of study of cross section in the mid-canyon region with speed of the winds greater than 2 m/s [5] (figure-7). i. Isolated Roughness Flow, ii. Wake Interference Flow, iii. Skimming Flow.

For wide canyons (H/W<3), the buildings are well spaced and act essentially as isolated roughness elements, since the air movements a sufficient distance downwind of the first building beforehand coming across the next hindrance.

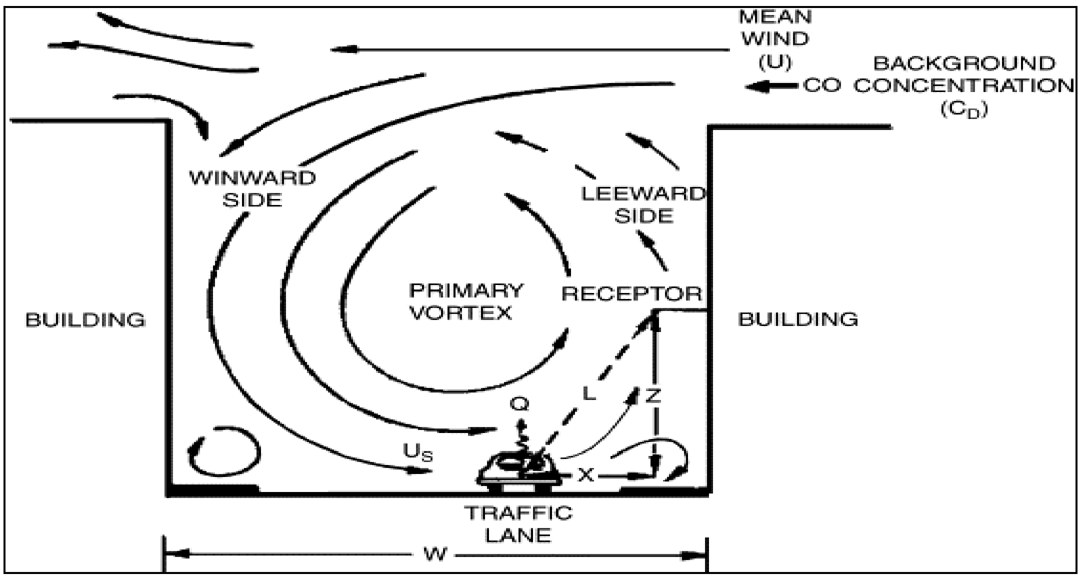

Figure-6
The Flow of the wind in Urban Agglomerate

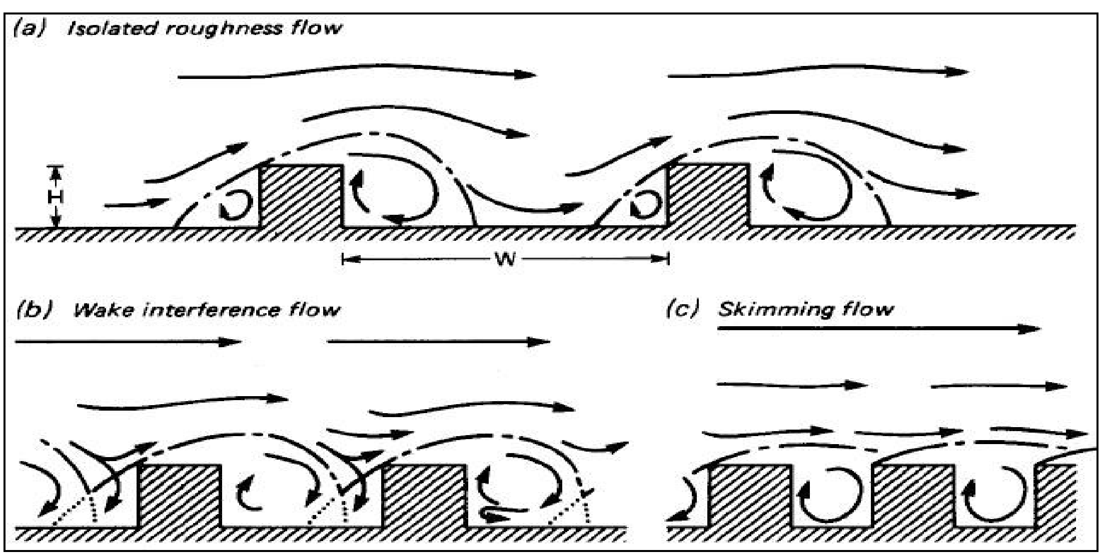

Figure-7
Flow Regimes linked with Air Flow over Building

The stability of the atmosphere and also it has its shape and also heating of walls strength and shape of the wind vortices are affected[7].

A: The robust flow is deflected down the building, B: Calm zone develops amongst buildings, C: Combination of huge buildings with streets forms canyons which yield enhanced wind flow.

Pollutant dispersion: Dispersion of gaseous pollutants in the vertical direction of the atmosphere and in the lateral direction with the associative streets[6] .With greater L/H the maximum street-level concentration occurs when synoptic winds are parallel to the axis of the street. The build-up of emissions on path of line source outweighs the ventilation brought by parallel winds[8].

Due to Low synoptic helps air pollution augmentation in urban zones[9].Whenpthepsynoptic wind speed is below 1.5 m/s, the wind vortex in the canyon vanishes and the air stagnates in the street.[10]declared coarse particles are to be monitored in the street canyon as compared to the finer particles as the later disperses very quickly just like gases into the atmosphere.

Considerations in the Urban Canopy Model: Models are to be designed as according taking into consideration cities urban heat flux, geometry, Atmospheric Stability for that particular geographical location of the city. Urban Canopy Models have three components namely roads, roofs and walls characterized by the width of street canyon and building and is thus possible to taking into version the sink of momentum over the complete structure of the building, along with shadowing energy trapping effects. The Urban Canyon Modelling is essential for the setup of the new industry in Urban so its influence is essential to ensure that the location has its pollutants levels in limits.

Types of Models used in Street Canyon Modelling

Models based on Gaussian Plume Dispersion: These Models are governed on basis of equations the 3 dimensional concentration field made generally by a point source. These Gaussian plume concentrations from a unceasingly releasing source are proportional to the emission rate, inversely proportional to the wind speed, and that the time averaged pollutant concentrations horizontally and vertically are properly defined by Gaussian equation of dispersion.

The Gaussian plume model assumes that there is no chemical or removal processes in process and that pollutant material reaching the ground or the top of the mixing layer as the plume grows is replicated back towards the plume centerline.

Computational Fluid models: In Computational Fluid Dynamics models simulation is done of fluid flow, air flow by means algorithmic based mathematical models.CFD models are widely used in the environmental modelling such as for water pollution and the air pollution.

CFD codes are user friendly consists of three main elements:

The pre-processor, creates a grid of the computational field, is been generated in which all chemical and physical phenomenon to be modelled are displayed.

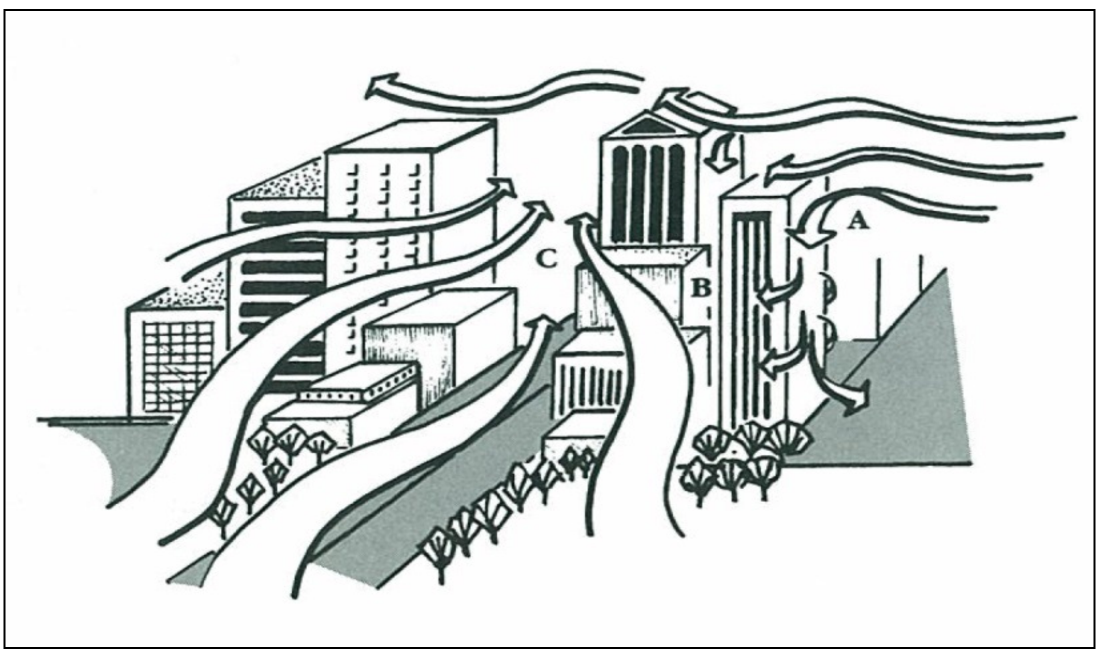

Figure-8
The figure exhibits the wind flow around different structures such as tall and short buildings

The solver, for computation of flow variables governing atmospheric flow using the mathematical equations.

The post-processor gives the results in plots or graphs vectors like showing wind direction and contours showing varied pollutant concentration can also give the result in graphic animated form.

FLUENT is widely used CFD Software for Modeling Complex Fluid Stream and Heat Transfer in varied geometries. It calculates using finite volume structure on non-orthogonal using a collected variable arrangement

Reduced scale Wind tunnel: Having the similar urban scenario like the Roof Shape Emissivity, Wind Characteristics, Fixed and Moving obstacles in the wind tunnel is performed by the researcher. In this research the tracer also can be used in the study the air dispersion the sulphur hexafluoride (SF_6) analyser is the common tracer generally used and its concentration is measured.

Models based on Box Dispersion: These Models have a restricted set of boundary conditions the pollutants are set to be content within this set of atmospheric air pollutant concentration is termed as the Accumulation is equal to Input to the box – Output from the box (+ or -) rate of transformation of pollutant[11]. used a single box model and calculated initial dispersion and car induced turbulence called STREET BOX Model[9] concluded based on the assumption that concentrations of the pollutant occurring on the roadside consist of both the components, the urban background concentration and the concentration component because of vehicular emissions created in the specific street. Then, it calculates pollutant concentrations, taking in account the mixing height of pollutants, lateral distance of the simulated receptor.

Results and Discussion

A typical urban street of Katraj Box modelling is been done taking into consideration the vehicular traffic flow for the peak traffic hours (9:30 to 9:45),(9:45 to 10:00),(20:00 to 20:15) and (20:15 to 20:30) categorizing the vehicles into different sub-groups as Light Duty Vehicles Two Wheelers , Three Wheelers, Passenger Cars (Petrol), Passenger Cars (Diesel), , Buses,, Heavy Duty Vehicles taking into consideration respective pollution potential as in table-1 the vehicular traffic flow in (vehicles/hour) as in table-2.

Table-1
Vehicular traffic flow converted into vehicles/hour

Timings	9:30-9:45	9:45-10:00	20:00-20:15	20:15-20:30
Two Wheeler	1387	1455	1206	1040
Three Wheelers	255	245	190	164
Passenger Cars (Petrol)	455	551	352	574
Passenger Cars (Diesel)	28	13	18	31
Light Duty Vehicles	74	81	31	25
Heavy Duty Vehicles	147	155	175	125
Bus	70	65	45	36

Table-2
Vehicular their emission potential in µg/km as per ARAI, India

Vehicle Category	CO	NOx	SPM	PM10
Two Wheelers	1	0.19	0.05	0.1
Three Wheelers	1.4	1.28	0.2	0.2
Passenger Cars (Petrol)	1.2	0.2	0.03	0.1
Passenger Cars (Diesel)	0.8	0.5	0.07	1
Light Duty Vehicles	2.5	2	0.56	1.25
Heavy Duty Vehicles	3	6.3	0.28	2
Buses	4.8	12	0.56	1.5

Table-3
Vehicular emissions in µg/km/hour

	9:30-9:45				9:45-10:00			
Vehicle Category	**CO**	**NOx**	**SPM**	**PM10**	**CO**	**NOx**	**SPM**	**PM10**
Two Wheelers	1387	263.53	69.35	138.7	1455	276.45	60.3	13.87
Three Wheelers	357	326.4	51	51	343	313.6	38	10.2
Passenger Cars(Petrol)	546	91	13.65	45.5	661.2	110.2	10.56	4.55
Passenger Cars (Diesel)	22.4	14	1.96	28	10.4	6.5	1.26	28
Light Duty Vehicles	185	148	41.44	92.5	202.5	162	17.36	115.625
Heavy Duty Vehicles	441	926.1	41.16	294	465	976.5	49	588
Buses	336	840	39.2	105	312	780	25.2	157.5

Table-4
Vehicular emissions in µg/km/hour

	20:00-20:15				20:15-20:30			
Vehicle Category	**CO**	**NOx**	**SPM**	**PM10**	**CO**	**NOx**	**SPM**	**PM10**
Two Wheelers	1206	229.14	60.3	120.6	1040	197.6	52	104
Three Wheelers	266	243.2	38	38	229.6	209.92	32.8	32.8
Passenger Cars (Petrol)	422.4	70.4	10.56	35.2	688.8	114.8	17.22	57.4
Passenger Cars (Diesel)	14.4	9	1.26	18	24.8	15.5	2.17	31
Light Duty Vehicles	77.5	62	17.36	38.75	62.5	50	14	31.25
Heavy Duty Vehicles	525	1102.5	49	350	375	787.5	35	250
Buses	216	540	25.2	67.5	172.8	432	20.16	54

Pollutants	**CO**	**NOx**	**SPM**	**PM10**
Average Vehicular Emissions	3011.075	2324.46	208.6175	725.2363
Background Concentration	0.71	12.25	153.25	210

Pollutants	**CO**	**NOx**	**SPM**	**PM10**
Total Calculated concentration (µg/m^3)	4.602294	12.26454	164.4371	248.8908

Calculating Concentrations Using Box Model: Formula used: $C= Q/(U_{ll}*H/L*W+(D+ lU_p))W/H + C_b$

Where: C: Calculated concentration in the street (µg/m^3)C_b: Background Concentration (µg/m^3), Q: Discharge source strength (µg/m^3), H: Avg Building Height (m)= 11m, W : Size of street (m) = 8m, L : Length of the street (m) = 100m, U_{ll} : Parallel Wind speed = 1 m/s, U_p : Perpendicular Wind speed =2.8 m/s, l : Characteristic Mixing Length (m) = 1m, D : Diffusion Coefficient (m^2/s) = 1.5 m^2/s .

After Application of Box Model to the street of Katraj, Result ant pollutant concentrations are NOx are 19.77 µg/m^3. Like-wise we can calculate for other pollutants by this box model.

Conclusion

Indian Environmental agency like CPCB, SPCB's are suggested undertake this project of Urban Canyon Modeling for the future cities of India. Analysing Pollutant dispersion for a particular location through Urban Canyon Dispersion Model essential for the urban city planner as to how to tackle this increasing Urban Heat Island Effects in the city and a health risk to the urban dwellers as the natural dispersion, wind flow, turbulence Innovative solutions are to be found out by a proper designing the Future cities in India such by the for this problem.

Scientists experimented with different street canyon geometry using Urban Canyon Models for analysis it was recommended by them for the city planners is that trees shall have smaller foliage as it will restrict the dispersion of air pollutants and as far as spacing is concerned it shall have sufficient spaces so as it enables atmospheric overflow and disperses the Polluted Air.

Increasing vehicular traffic growth and emissions and their impact on human health and urban air quality there is an urgent necessity for a new pollution control regulatory framework for the management of vehicular traffic, air quality and emissions at all scales from local to global [13]Air quality models can help to develop air quality management action plans and serves as an effective tool for improving air quality in urban centers.

Air quality models predicts the dispersion and dilution processes of the pollutants in the atmosphere using the releases, prevailing meteorological conditions and street configurations to determine the ambient air concentrations [8].

Recommendations to avoid the Negative Impact of Urban Street Canyon: The primary reason of heat island in cities is due to the absorption of solar radiation by massive building structures, roads and urban surfaces contained within the street canyon. The absorbed heat is subsequently reradiated to the settings and increase in ambient temperatures at night. To reduce the heat island effect it is advisable to use appropriate materials in order to improve the thermal characteristics of the urban environment. For example, light coloured surfaces are environmentally more beneficial as compared to dark coloured surfaces in urban areas. This can be used to increase the alertness among urban planners, designers and decision makers on the importance of construction material choices which may be not only for aesthetic aspect but also for their effect local microclimate and indirectly on energy usage of buildings.

In order to avoid the urban canyon effect, materials of surfaces that affect the environment in the canyon may be wisely chosen. Alternatives for a few examples of certain materials commonly used on building surfaces are mentioned below:

Light coloured concrete may prove to be effective in reflecting up to 50% more light as compared to asphalt which will further reduce heat absorption eventually reducing the heat island effect.

In place of clay bricks wool bricks or mud bricks may be used in buildings because wool and mud bricks are sun-dried unlike clay bricks which are dried in kilns. Being sustainable in production these two types of bricks offer better sound absorption, higher thermal mass and are manufactured from natural resources.

Using coated glass or double glazed glass reduces the heat gain and loss into the building, keeping the surrounding environment of the building sustainable. In extremely hot climates solar control glass can be used which minimizes the solar heat gain and helps control glare. Glass may be a very good substitute instead of other opaque materials used on fenestrations of buildings since it helps control the exterior as well as the interior energy consumption of the building.

Similarly many other building materials may have alternatives that may be used to keep the environment of urban canyons clear of dispersions and enhance the quality within them.

To avoid urban street canyon effect, planting of trees along the street may prove to be beneficial. Trees lined along the street become obstacles in the path of wind flow and dampen the air thus reducing the dispersion and number of pollutants in the canyon. Thus, by providing trees the atmospheric wind is able to intrude avoiding relevant concentration increase in the street canyon.

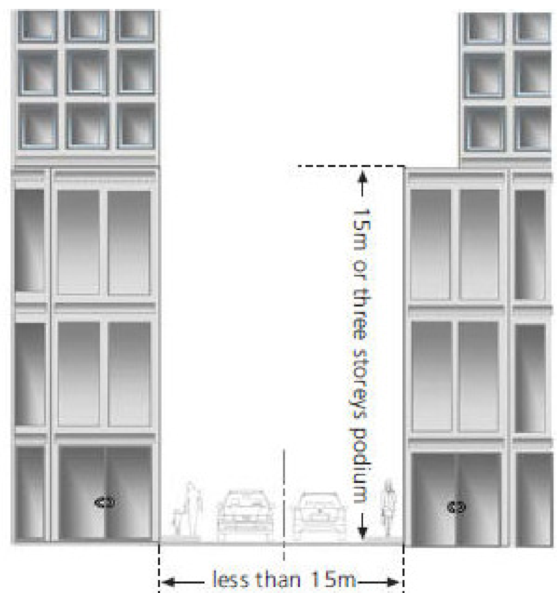

Figure-9
The "Canyon" effect takes place when taller buildings are Adjoining narrower streets that results in poor wind flow, higher temperature and deteriorated air quality

References

1. Gour A.A., Singh S.K., Tyagi S.K. and Mandal A., Variation in Parameters of Ambient Air Quality in National Capital Territory (NCT) of Delhi (India), *Atmospheric and Climate Sciences*, **5,** 13-22 **(2015)**
2. Sobrino J.A., Emissivity mapping over urban areas using a classification-based approach: Application to the Dual-use European Security IR Experiment (DESIREX), *International Journal of Applied Earth Observations and Geo information,* 08 **(2012)**
3. Klein M.P., Metropolitan effects on atmospheric patterns: important scales, Metropolitan sustainability, **(2012)**
4. Gartland on Urban Heat Island " www.hindawi.com" thebritishgeographer.weebly.com, **(2015)**

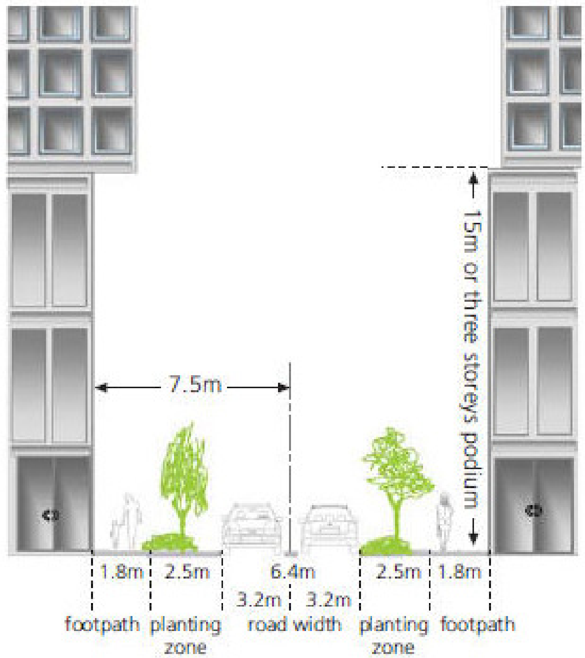

Figure-10
Building setback can improve the wind flow either, through or around the building, enhance air quality, in the neighbourhood and provide a better environment

5. Riain C.M.N., Fisher B., Martin C.J., Littler J.,. Flow field and pollution dispersion in a central London street. Environmental Monitoring and Assessment, **52,** 299-314 **(1998)**

6. Watson I.D. and Johnson G.T., Graphical estimation of sky viewfactors in urban environments, *J. Climatology*, **7,** 193–197 **(1987)**

7. Ganguly R. and Broderick B.M., Estimation of CO concentrations for an urban street canyon in Ireland, *Air Qual Atmos Health,* **3,** 195–202 **(2010)**

8. Sotiris Vardoulakis, Bernard E.A. Fisher, Koulis Pericleous and Norbert Gonzalez-Flesca. Modelling air quality in street canyons: a review, *Atmospheric Environment, Elsevier,* **37(2),** 155-182 **(2003)**

9. A brief definition of the main heat island types February 23, **(2010)**

10. http://www.urbanheatislands.com/home, **(2015)**

11. Oke T.R., Urban environments. The Surface Climates of Canada, Bailey, W.G., T.R. Oke, and W.R. Rouse McGill-Queen's University Press, Montreal, 303-327 **(1997**