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ENVIRONMENTAL QUALITIES OF UNDERGROUND TRANSITION SPACES IN MUMBAI

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ABSTRACT

Underground system have been constructed to improve the quality of public transportation and considered to be the most convenient mode of pedestrian transportation in the World. But these spaces are sensitive in terms of Environmental quality. This paper based on research of Environmental quality of underground transition spaces in Mumbai.

Since people spend a considerable amount of time in Churchgate, CST subway daily, there has been growing concern over the regulation of indoor air quality. Various types of pollutant like Particulate Matter, Carbon di oxide remain accumulated in the subway due to heavy use, overcrowding and inadequate indoor ventilation system.

Key aspects that could have an influence on underground space design include: accessibility and closest surrounding, orientation and spatial proportions, human comfort, natural and artificial lighting, material and colors, noise levels and air quality.

The aim of research paper is to design strategy based on continuous monitoring for three working days in order to construct data base for understanding the actual condition during rush hours.

A ventilation system is widely used to control indoor air quality in underground subway. After studying Metro,Churchgate,CST and Borivali shows that increasing mechanical ventilation can help to cool the environmental comfort. However improper ventilation leads to hazardous pollutant accumulation and also has negative health impact.

Keywords: ***underground environment, air quality, health impact***

1. INTRODUCTION

1.1 Background

Urban and rural areas are requiring an increasing variety of services – including better transportation, utility and recreational services. The state of Urban traffic congestion and urban infrastructure development in many urban areas of world is at critical level for the support of basic human living standards but it is difficult, if not impossible, to add new infrastructure at ground level without causing an unacceptable relocation of existing land uses and neighbourhood.

Underground subway is one of the major transportation modes in most metropolitan areas worldwide, due to convince, safety, efficiency, high speed, large transport capacity (in terms of number of commuters). It is also a distinctive microenvironment since it is a confined space poorly ventilated that may promote the concentration of pollutants both from outside atmosphere and also generated internally.

With increased environmental awareness and standard of living, aspects such as built environmental quality and thermal comfort have gained importance. The indoor environmental quality and thermal comfort directly affect the health of occupant and utilisation of the space. Moreover, the built environment quality is directly proportional to energy efficiency and sustainability in buildings. Indoor environment quality is an important aspect to be considered in large commercial developments such as transition cum shopping spaces, where there is a huge footfall. On an urban or local level, the use of underground facilities is also on the rise to provide new services, improve the environment and accommodate the complex demands of today's society.

1.2 Underground Mass transportation in the world

About one and half century ago (on 10th January 1863), mass-transportation was first operated underground in London. Since then, the idea of underground mass-transportation has been spreading, creating the huge potential to transit passengers efficiently over the underground spaces which have never been developed before.
Presence of the underground mass-transportation soon appeared in the European countries and the United States in the late 19th century. In the early 20th century, some leading countries in Asia and South America began to establish underground mass-transportation as well.
Development of underground mass-transportation will continue to grow, even in cities which already have well-developed underground mass-transportation network like in New York (the extension of 7-Line and the development of the Second Avenue Subway). Opened in 1979, Hong Kong's underground mass-transportation (Mass Transit Railway, MTR) is among the most heavily used systems in the world.
The underground mass-transportation is well-perceived for its effectiveness in carrying massive volume of passengers so that emissions and the impact to air pollution are kept minimal. (Szeto Ying Ho)

1.3 Need for Indoor Air quality Management in Underground Mass Transportation

Recently, more and more people spend their time inside building. Due to the rise in indoor air pollution sources and the lack of ventilation, indoor air pollution is worsening.

Indoor air pollution and its harmful impact on human health have been concerns for the WHO and advanced countries around the world. According to the WHO report, an estimated upto 6 million people die annually as a result of air pollution, and indoor air pollution is responsible for about 2.8 million premature deaths. Moreover, it is reported that the odds for indoor air pollution to reach the lungs are 1000 times higher than outdoors, and a 20% reduction of indoor air pollution can decrease death rate of acute respiratory diseases by 4-8%.

In an efforts to adequately maintain and manage indoor air quality at public use facilities and newly constructed collective building the ministry of environment has introduced a wide range of policies to control indoor air quality including the revision of the Air quality Control in Underground Location Act to Indoor Air Quality Control in Public Use Facilities and the enhancement of the Indoor Air Quality Management Plan.

1.4 Policy Background of Underground Air Quality

The Korean ministry revised the Air Quality Control in Underground Location Act in May 2003 to the Indoor Air Quality in Public Use Facility Act, which was enacted since May 2004, in order to expand management target facilities such as underground subway stations, underground passage shopping centres, waiting rooms.

In addition, the ministry established the Indoor Air Quality Management in a joint move with other relevant government agencies in December 2004 to identify precise status for effective indoor air quality policy, establish standards, and restrict the use pollutant emitting construction material and expand the use of eco-friendly construction material, in order to provide a foundation for indoor air quality management.

In December 2005, indoor air quality recommendation standards for newly constructed collective buildings were set in an attempt to improve indoor air quality through public release of indoor air quality levels.

Various types of hazardous pollutants, such as particulate matters (PMs) and carbon dioxide (CO_2) remain accumulated in the subway (especially located in underground) space due to heavy use, overcrowding, and inadequate indoor ventilation system. To attempt to address this social concern, Korean Ministry of Environment (MOE) enacted Indoor Air Quality Control in Public Use Facilities Act (IAQCPUF) to control the pollutants in indoor environments including the underground subway station.

1.5 Justification

More than thousand suburban train operations take place every day at CST with about 4-5 lakh commuters travelling through CST subway. CST subway connected to CST terminal is very important junction.

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In terms of environmental issue a more natural surface landscape may be maintained, preserving surface ecology.

CST subway is public space which people use for shopping and walking. The subway is poorly ventilated, has improper lighting and maintenance which leads to thermal discomfort and skin infections.

1.6 Scope

Transition spaces play a very important role in urban level. A transition space affects the physical environment in which the city functions, in turn affecting the experience of the people. At city level it may vary with in scale but they succeed in creating a fluid and elastic outdoor space.

The subway which is public transit space generally observed are conditioned and non conditional space and also few of them are poorly ventilate it poorly by mechanically. In case of warm and humid city like Mumbai (NBC,2005) it becomes very important to design in terms of location, orientation, light and ventilation, building material, designing.

For any public subway comfort becomes important parameter as pedestrian and occupant spend more than eight hours in a day. The indoor air quality can deteriorate greatly when subways are crowded such as during rush hours. Various types of hazardous pollutants, such as particulate matter ($PM_{2.5}$) remain accumulated in an underground space due to heavy use, overcrowding and inadequate indoor ventilation system.

Aim: To design strategy/guidelines for improving of environmental quality of underground transition spaces in Mumbai

Objective:

1. To identify- mode of transport, usage pattern, activities in underground subway.

2. To find out type of Transition spaces in terms of isolated-unisolated, size, geometry, location, orientation, building fabric, equipment.

- Sources of pollution and discomfort conditions in peak hours

- Parameters related to underground pedestrian transition spaces.

3. To access a footfall of underground pedestrian by Eulerian method.

4. Review benchmarks of environmental quality.

5. To measure existing dry bulb temperature, relative humidity, wind speed, carbon dioxide, particulate matter, artificial lighting and noise level.

6. To develop guidelines for improving environmental quality.

Limitations:

The study will include only the strategies to improve the underground environment of transition spaces in Mumbai means it will deal with the existing condition and its interrelated variables likes indoor air quality, user comfort in terms of lighting and study is restricted to only western, suburb area etc…

Scope -

Following subways have been studied under this project

Metro theatre subway,

Churchgate subway

CST subway

Borivali subway

Parameters which have been monitored are relative humidity, temperature, wind speed, Lux levels,Noise levels, Carbon-di-oxide and Particulate Matter.

Justification

More than thousand suburban train operations take place every day at CST with about 4-5 lakh commuters travelling through CST subway. CST subway connected to CST terminal is very important junction.

CST & Churchgate subway is public space which people use for shopping and walking. The subway is poorly ventilated, has improper lighting and maintenance which leads to thermal discomfort and skin infections. (MARPAKWAR, 2016) and similar conditions are exist in other subways.

2 Literature Review

2.1 Subway systems

Commonly, underground pedestrian spaces combine with a commercial function as underground shopping streets, or combine with a public communication function as underground space nodes (such as underground concourse and atrium), or combine with a public transport function as an underground layer of passenger flow. Subways were regarded as the most vital contribution to underground pedestrian spaces utilization (Barker 1986; Belanger 2007). For grade- separated systems, cities with established subway systems appeared to have underground pedestrian links already in evidence (Carmody and Sterling 1993).Tong (2009) indicated that when subway systems became the main transport mode of a city, there emerged a requirement of considerable spaces for underground transport transfer facilities. To achieve efficient usage of spaces and to satisfy the requirement of shopping co-located with subway transport, underground spaces around subway stations integrated commercial functions more effectively. Improving environmental quality in an urban renewal program would also receive benefits (Zacharias & Xu 2007a).With the increasing dependence on subway transport; spaces around subways have obvious economic benefits by virtue of the large of passing pedestrian traffic accessing or leaving the subway. Surrounding spaces of commerce helped to integrated subways through the expansion of surrounding pedestrian walkways (Bazinet 2004; Liu 2009).

Accordingly the scale of the subway systems of a city is possibly correlated with the size of underground pedestrian systems. The number of lines, stations, passengers serviced and the total length of the subway normally indicates the scale of the subway systems. (Jianqiang Cui A. A.)

2.2 Climate and Thermal Comfort

Certain combination of ambient air temperature, relative humidity, air movement results in what most people consider as thermal comfort. This is defined by area called 'comfort zone' on the psychometric chart. Comfort zones are intended to provide acceptable thermal environment for occupant wearing typical indoor clothing and near at a sedentary activity.

It is important to note that the boundaries of comfort zone are not absolute, as thermal comfort varies with culture, health, time of the year, clothing and most important - physical activity. However, comfort zone should be the goal of thermal design of the building because if defines those conditions that 80% of people find comfortable with. (Olgyay 1983)

(Jianqiang Cui)Thermal comfort defined as per ASHRAE Standards 55-2004 is "The condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation" for detailed understanding of this one need to understand heat balance and heat transfer of human body.

Indoor environment includes all aspects of relationship between the occupants and contents of the space and their surroundings within the building, considered in terms of climatic and non-climatic aspects.

- **Climatic :**

1. Ambient Temperature
2. Relative Humidity
3. Air Movement

Apart from these factors personal factors which affect thermal comfort of human are

- **Other parameters :**

4. Metabolic Rate-Activity
5. Occupancy density

2.2.1 Human Comfort

Environmental factors that affect perception of thermal comfort are: clothing level (varies), metabolic heat production, air movement (0.03-0.05 m/s), relative humidity (40-70%), surface temperature (2-3°C maximum higher than the air temperature), air temperature (18-21°C relaxed, 15-18°C walking), occupancy level, air compression , air pressure . High radiant temperatures can cause discomfort in parts of the body that are close to the surface even when the air conditions are comfortable due to rapidly increasing skin temperature.[1] Increasing air velocity can improve thermal comfort because it helps to increase the convective heat loss from the body through evaporation of perspiration. Dramatic changes in temperature may make a person uncomfortable by disrupting the heat balance and causing the body to make an effort to re-balance it. (Raines, 2009)

2.2.2 Parameters of Thermal Comfort

2.2.3 Ambient Temperature

Ambient temperature is the symptom of the presence of heat, in air around us. It also determines the rate at which heat is lost to the air. Air temperature mainly changes from morning to evening due to amount of solar radiation that is received during the course of the day. It increases from morning and decrease towards the evening.

A person attains thermal comfort when his body is in equilibrium to the surrounding. This is attained by energy exchanges between the body and its surrounding where the body loses or gains heat to/from the surrounding. The human body experiences thermal stress when the total heat lost from a person's body is not equal to the internal heat generated metabolism. The total amount of radiant energy exchanged between two objects depends upon the temperature difference between them.

2.2.4 Relative Humidity

Relative humidity (RH) is defined as ratio of amount of moisture present in the air to amount of the moisture that air can hold at given temperature. It is expressed in %

It is affected by change in either the moisture content of the air or by the temperature of the air. Dry air readily absorbs moisture from skin but high humidity reduces evaporative cooling and increases sweating. The percentage value of relative humidity indicates the closeness of air to saturation. 100% relative humidity (RH) states that the air is saturated with water vapour and cannot hold any more moisture. Relative humidity thus becomes one of the important parameters when it comes to indoor comfort. Relative humidity cannot be perceived by the body like air temperature; however it contributes to the feeling of comfort. This is because, when a human body sweats, the feeling of cold/hot depends when sweat evaporates into the air. However when relative humidity is high, the air is closer to saturation with moisture; hence not much of the sweat released from the body is evaporated in to the air. This leaves a feeling of discomfort to the person. On other hand if the relative humidity is low, the sweat evaporates from the body making it cooler than the actual temperature. One of the mechanisms of cooling down

[1] (Atmaca)

the human body is by its excretion of sweat on the skin. The body cools down when the sweat evaporates into the air (evaporative cooling). When sweat does not evaporate, it leaves the body feeling heated and uncomfortable.

Relative humidity depends on air temperature. If the vapour content is maintained and the air temperature is increased, then the relative humidity decreases. However when vapour content is kept the same and the air temperature decreased, then the relative humidity is high. Cold air saturated faster because it requires lesser moisture content to saturate it where as warmer air requires more moisture to saturate it.

2.2.5 Air Movement

Movement of air caused by pressure difference and heat is determined as air movement. It affects heat loss rate by both convection and evaporation. It has very pronounced effect on heat loss rate.

Increasing air velocity can improve thermal comfort because it helps to increase the convective heat loss from the body through evaporation of perspiration. With the proper exchange of air through ventilation, the interior mass of the underground building could lose heat at night that had been absorbed throughout the day when internal gains were high because the heat stored in the building mass will flow to the cooler indoor air which will become warm and can be convectively ventilated.[2]

One of the first checks, often overlooked, in a comfort study is making sure that sufficient air is moving in a space. Air movement can affect human comfort level in that too much is perceived as “draftee” or “chilly” and too little may create a sensation of stuffiness.

2.2.6 Other Parameter

2.2.6.1 Human Perception and Thermal Comfort

Studies show that two conditions must be fulfilled to maintain thermal comfort (ASHRAE standard 55-2004). Actual combination of skin temperature and body’s core temperature provide thermal neutrality which leads to thermal comfort of the body.

Fulfilment of body’s energy balance: the heat produced by metabolism should be equal to the amount of heat loss from the body.

The metabolism is energy released by oxidation process in human body, which depends on muscular activity.

2.2.6.2 Envelope Factors Affecting Thermal Comfort

To establish comfort in a built environment it is necessary to analyse the building with respect to its envelope properties such as its materials, orientation and position of the openings. Heat loss and heat gains by the envelope, occupancy and internal gains of the space also contribute to thermal comfort. Thus for any building envelope all above factors contributes to thermal comfort of that space.

[2] (RAINES, Underground Passenger Comfort Rethinking the current thermal and lighting standards, 2009)

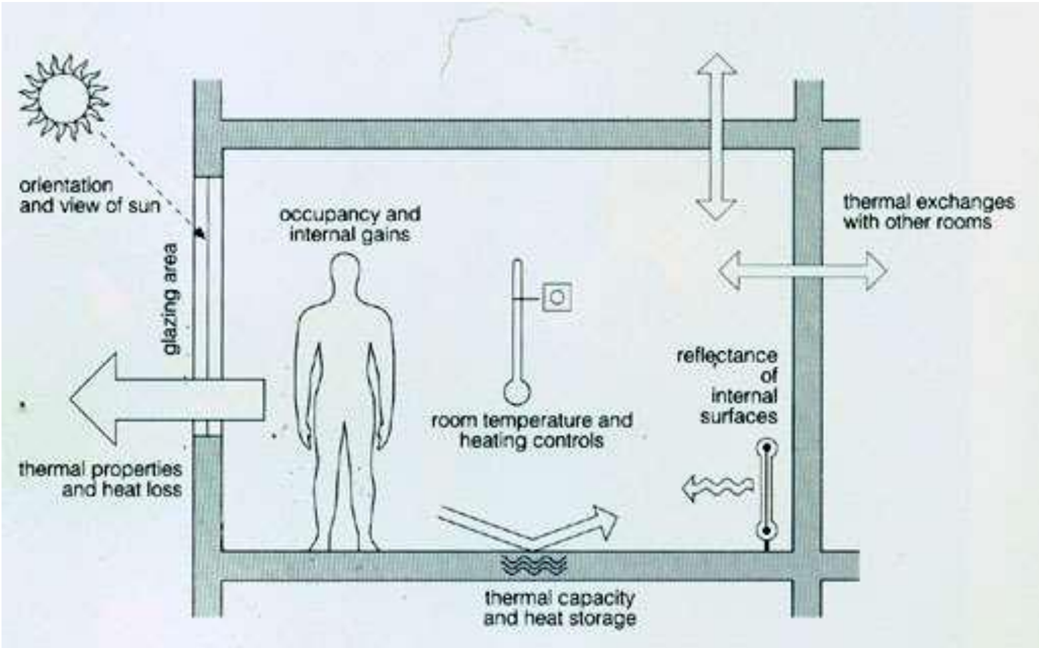

Figure 1 Space Envelope properties which affects thermal *comfort (Source-Designing with Climate,2.4pages)*

2.2.6.3 Heat Gain and Heat Loss

Two basic concepts related to earth performance

1. The earth functions as a thermal insulator between outdoor and indoor environment.

2. The soil functions as a heat retainer and processor between different seasons.

The earth is an excellent insulator; in fact diurnal influence of solar radiation on the earth is limited to 7 to 10 cm, a limited influence that depends much on composition of soil (chemical and physical) and on the level of humidity within the soil. In any case most intense thermal influence takes places 2 to 4pm. Then the earth heat begins to diffuse into the air and continues into evening, reaching maximum diffusion just before sunrise, when thermal cycle begins.

Sources of moisture in underground buildings mainly include the following aspects: construction water, fissure water, surface moisture, moisture in air, human body moisture and technology moisture. It is due to the particularity of the air environment in underground structures that “moisture protection and dehumidification” become a key aspect in the design of ventilation and air conditioning systems in underground buildings. (Golany)

Average outdoor air temperatures in Mumbai range from 19̊ C (December/ January) to 36̊ C April. The lowest temperatures in the diurnal cycle occur in the early morning when sky cloud cover is generally lowest. Daytime temperature peaks are in the afternoon due to solar radiation. During the winter months, the sunshin hours are much less than summer so the solar radiation has less time to warm the earth and the diurnal temperature differences are smallest. The respond to the fluctuations in the ground temperatures of the surrounding ground mass. The ground composition can affect its thermal storage characteristics. The ground can act as a direct heat sink because the building can be in contact with the effective temperature of the ground.[3] The ground has conductivity of 1.4 to 2.1 W/K*m by appropriate varying density ,which is higher than air 0.025 W/K*m. An

[3] (Santamouris)

increase in conductivity of surface in the station can cause a decrease in the internal temperature.The earth surrounding the tunnel is able to absorb upto 30% of the excess heat produced in the subway, but the other 70% of the excess heat contributes to passenger discomfort.[4] The ground temmerature remains very constant and does not experience diurnal or seasonal temperature swings as the outdoor air does. Temperature changes that do occur as a result of exterior fluctions are much slighter and experience a lag of up to a month. This slow fluctuation of temperatures can also mean that dissipation of stored heat is a slow process. Accretion of heat stored in the ground around the underground subway over time has reduced the specific heat of the soil by raising its average temperature. High internal heat gains resulted in exhaustion of the geological capacity around deep level subway to “soak up” heat[5]. A study conducted by Ampofo et.al.[6]found that the average temperature six meters from subway is 19°C due to absorption of the heat in the tunnels and lack of ventilation to dissipate te high level of gains.Increased surface areas of thermal mass to absorb more internal gains coupled with ventilation of the mass to dissipate gains and prevent accretion of heat can prevent this from ocuuring in new subway. The use of building materials with a high thermal capacity can help reduce heat transfer into the building by absorbing radiated heat from the sun or other sources of heat. Ventilation helps reduce the increase in temperature and humidity in the subways. With proper exchange of air through ventilation, the interior mass of the underground building could loose heat at night that had been absorbed throughout the day when internal gains were high because the heat stored in the building mass will flow to the cooler indoo air which will flow to the cooler indoor air which will become warm and can be covectively ventilated. During the night time, the sky temperature drops below the air temperature (creating a sky temperature depression), allowing daytime heat gains to flow from surfaces through the precoess of radiation; the atmpospheric window near the zenith in clear skies acts as heat sink, absorbing longwave radiation so it is important thst the thermal mass has a good, unobstructed ‘view’ to the sky. During summer mornings, reducing the rate at which the building warms up can help to preserve the thermal inertia of the cool night sky; this can be done with insulation and limited air changes.

2.2.7 Artificial Lighting

Generally underground structures, separated from natural light on the ground, are mainly lit by artificial lighting, but the extent to which natural light is taken in will affect in large measure the environmental quality of underground structure. Natural lighting is no doubt very important for the shaping of underground lighting environment, but artificial one remains a major method when it comes to internal underground (Yang Xiaobin, 2014).Artificial lighting has a direct effect on the visual perception given by underground space, the shortage of which will darken the internal environment, confound substances with space and gloom the atmosphere.

The functions of artificial lighting for underground space can be summarized as the following major aspects：

- to direct the space;
- to intensify the visual perception.

2.2.7.1 Glare-

Glare is caused as a result of any excessively bright source of light in the field of view that results in the loss of visibility, discomfort, annoyance, interference with vision, or eye fatigue. Trotter and Louis justified that glare is not only due to bright

[4] (Thompson, 2006)

[5] (London Underground Environmental Report 2006,Section 5.1 Energy,5.2 Air Pollution, Transport for London(TFL)., 15 April 2007)

[6] (Ampofo, 2003)

light; it also depends upon other factors, both physical and technical. Glare may be of two types, namely disability glare and discomfort glare. Disability glare is caused by the action of stray light, which enters the eye and scatters within.

For those underground structures with higher requirements concerning indoor environment, it is expected to increase the use of electric incandescent lamps and decrease the exclusive use of fluorescent lamps with white cold light.

The light is supposed to be weakening from underground to outdoor so as to prepare the vision for the darker environment on the ground. For those underground structures with special demands for light, local lighting can be adjusted to satisfy those special needs without sacrificing basic ones.

For any task to perform safety and efficiently, good illumination should be provided so that one can see the task and its surroundings very clearly. The number of error falls to a minimum with good lighting[7].

Proper selection of light source for particular type of work is very important. By simply providing bigger and brighter lights than the required ones do not necessarily produce better mine illumination (N.Lakshmipathy, 2014)[8], rather, in all probability, it is likely to affect the performance of workers.

Lighting system should always be designed for older eyes.

An effective lighting installation is one, which has been designed and installed so that individual may work with safety and efficiency, and with reasonable comfort. This is influenced by three main lighting design parameters: illuminance level on the surface, uniformity of light distribution and glare from sources. The most important aspect of lighting design is to provide sufficient illuminance on a visual task.

[7]Analysis on the influences of underground space development on urban residential environment.

[8]Problems Encountered in the Types of Lighting Systems Generally Used in Surface Mining Projects A Case Study.

3 Methodology

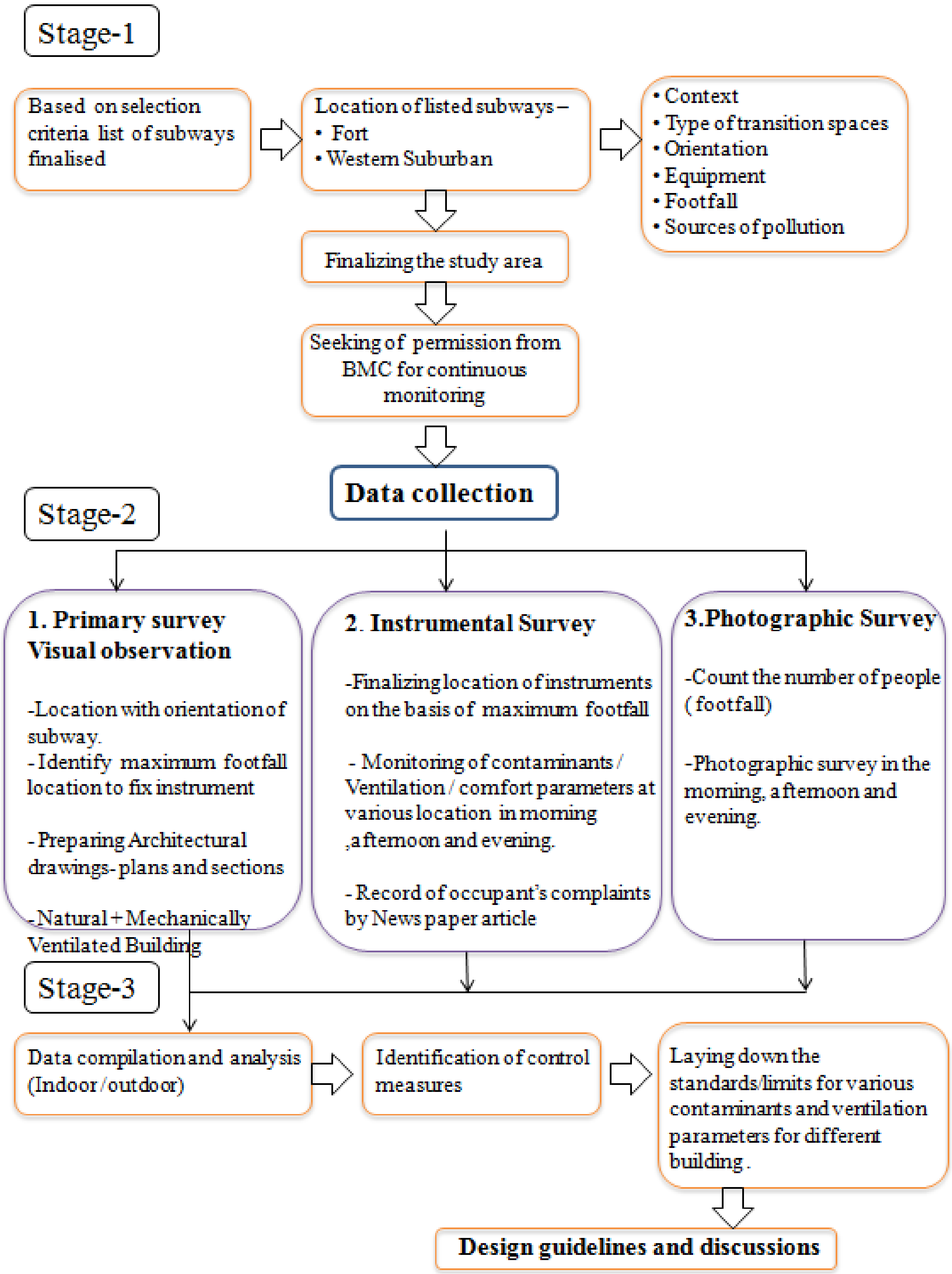

Figure 2 Tree diagram of Methodology used

3.1 Use of Instruments on site

Following table explain in detail how each of the instruments was used at time of field work.

Instrument Name	Company	Range / Accuracy	Use	Photo of Instruments
Anemometer	LTT AM-4201	Air Movements-0.4 to 63.0 m/s	To measure indoor and outdoor Air movements. Compass to mark air direction	
Awair		Temperature-10℃ to 50℃ Humidity- 0-100% RH VOC- 0.1 ppm- 30 ppm Dust($PM_{2.5}$) – 0.01µg/m³-800µg/m³ CO_2- 350ppm-10,000 ppm Light- 0-65535 lux Sound – 50 dBC- 120 dBC	To measure indoor temperature, Relative humidity, $PM_{2.5}$, CO_2, Lux levels, Noise levels.	
Lux level	MECO-930P	0-200000 lux	To measure indoor and outdoor amount of light	

Decibel Meter	CENTER320	30-130 dB	To measure sound pressure level. It has two frequency A & C was used to allow human and machine sound pattern.	
CO_2	INTRAX	350-10000 ppm	To measure indoor and outdoor CO_2 level.	
Sling Psychrometer	JRM Thermometer	In/ Out temperature (-10°C to 50°C)	To measure indoor and outdoor dry and wet bulb temperature	
Digital Thermo-Hygrometer	Hong Kong Cheerman Electronics Co. LTD HTC-1	Input Temperature (-10°C to 50°C) Relative humidity 10% to 99% accuracy- temperature ±1°C & 1% RH	To measure indoor and outdoor temperature and relative humidity	

Table 1 Instruments used on site

Data collection based on the selected Environmental parameters governing underground transition spaces.

To assess the environmental conditions inside underground transition spaces in Mumbai, these subways namely CST subway, Metro Cinema subway and Churchgate subways have been studies. There location and significance is given in following passages.

Parameters studied are as following

- Location and layout of subway
- Footfall
- Usage pattern
- Relative humidity
- Temperature
- Wind speed
- Illuminance / Lux levels
- Noise levels
- Particulate Matter
- Carbon-di-oxide

Figure 3 Interior Pictures of Metro Theater, Churchgate, CST and Borivali subway

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3.2 Data Analysis

		Thermal Comfort			Light Levels	Noise levels	IAQ	
Sr. No	Case Studies	Relative Humidity (Comfort Range as per NBC,GRIHA,ASHRAE,IAQ : 30 to 70%	Temperature (Comfort range as per ASHRAE:55, NBC,IMAC (25.6 deg to 30	Wind speed as per field measurement	Illuminance levels (as per NBC to be maintained between 100 to 200 lux for shopping and for walk-way in between 30-100 lux)	Noise levels (as per Nation Pollution board for normal conversation 50 to 70dB and as per 'Hearing for life', Workplace Safety and Insurance Board Ontario;Norfolk City Council Education, 'Noise at Work' noise level inside supermarket 60dB	Carbon-di-oxide to be maintained below 1000ppm for 8hrs	Particulate Matter ($PM_{2.5}$ as per WHO to be maintained 25 (24hrs) and by NAAQ & IAQ (24hrs) 65 ppm
1	Metro Theatre subway	77	32.16	0.45	13.97	72	886	
2	Churchgate subway Region-1	77	30.7	0.03	86.41	74.66	1565	61.4
					shopping- 150.35			
2a	Churchgate Subway Region-2	77	30.7	0.03	99.16	72.57	1231	
3	CST Subway Region-1	77	32.3	0.029	39.64	77.6	1941	63.45
					shopping- 114.8			
3a	CST Subway Region-2	77	32.3	0.029	13.3	70	1797	55.1
4	Borivali Subway	69	30.42	0.1	7	72	419	112.19

Table 2 On site reading along with Standards

4. Findings and Discussion

Churchgate subway

•In Metro,Churchgate subway Region-1 & 2 & Borivali, the temperature range is 27 to 36ºC,relative humidity 79% to 80% and wind speed ranges 0-0.1m/s and comfort range as per ASHRAE 55 is 26ºC to 27ºC, by IMAC is 18 to 22ºC and by NBC is 27 to 31ºC, the relative humidity 30 to 70% as per NBC,GRIHA,ASHRAE,IAQ. There is low ventilation and lesser air movement of air. In Metro theater subway. Metro subway there is mechanical ventilation which is good, wind speed is in the range of 0.1 to 0.6 m/s. The footfall is high and humidity is high at Churchgate subway .Conditions here are "uncomfortable" for users.

•From Bioclimatic chart of Mumbai, forced ventilation is required in months of May, June, July, August and September.
As per NBC for shops, supermarket & basement the air changes per hour should be 8-15
In Metro subway ACPH is 0.28 which is less than recommended air change.
Considering 12 ACPH = ACPH x Volume of subway
= 12 x 6469
= 77628CFM
= 132470.9 m3 /hr
To reduce high temperature, relative humidity, particulate matter and carbon di- oxide force ventilation is necessary inside the Churchgate

Region-1 & in Region-2, 103146.7 m3 /hr as well as in Metro subway need 775000 m3 /hr

• The illumination is in the range of 10 to 460 lumen/m² at Metro,Churchgate & CST subway as per NBC it should be 30 to 100lux. The color used in Metro and Churchgate region-1 subway is middle tint, whereas in Borivali column cladded by black color tiles and reflection factor of the tint color is 0.3 if the light or white color uses then the refection factor is 0.7. NBC standards (*Building services section 1 lighting and ventilation pg 29*)

Figure 4 Color and ties used in Metro in Metro subway and color and tiles used in Churchgate subway

•In Churchgate subway Region-1 noise levels in the range of 63 to 82 dB because of the hawkers and as per NPB for conversation it should be 50 to 70 dB & as per Hearing for life', Workplace Safety and Insurance Board Ontario Norfolk City Council Education, 'Noise at Work' noise level inside supermarket 60dB so the noise level in region-1 is high.
Whereas the noise level in Region-2 is in the range of 68 to 76 dB because subway use only by pedestrian.

•In Churchgate subway the $PM_{2.5}$ is in the range 43 to 76µg/m³ which is higher than the prescribed limit of 65µg/m³ for 24hr as per National Ambient Air Quality NAAQMS/35/2011-12.

•The CO2 level it is in range of 800 – 1700 ppm of 3348 m3, we infer high level of CO2 content in Churchgate. Hence, we infer high level of CO2 content is due to high footfall, low ventilation and lesser supply of fresh air.

CST Subway

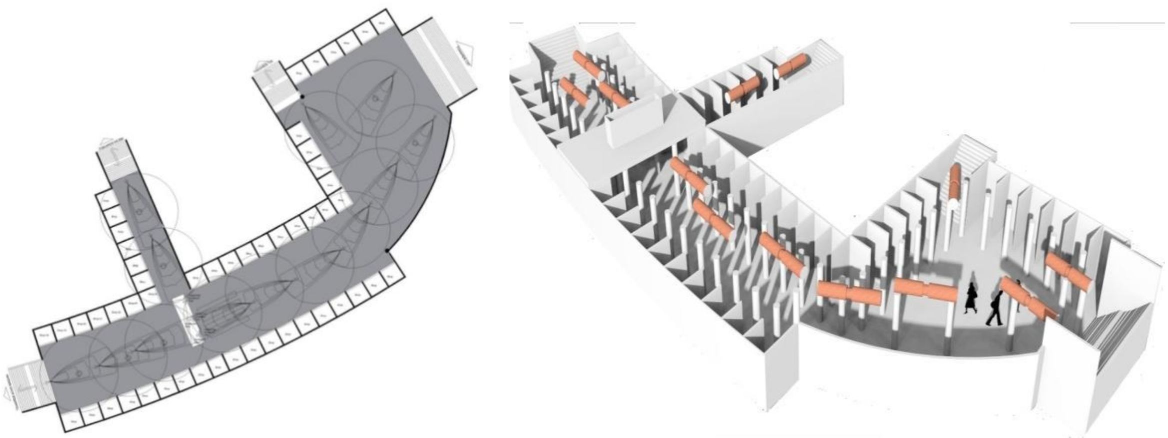

Figure 5 Design proposal for CST Subway

• In CST subway the relative humidity ranges between 76% to 83% as seen from figure 108 the psychometric chart, it is not in comfortable.

• In CST subway the temperature range is 27 to 37ºC, the comfort temperature range for Mixed Mode Building as per NBC is 25 to 32ºC. Due to high footfall, high occupancy, high humidity and poor ventilation, the conditions inside this subway system are not comfortable for users.

• In CST subway, wind speed at exit of ventilation duct is 0.4 – 1.7m/s and in other areas is 0-0.1m/s. Due to extremely high occupancy and obstructions, wind flow and ventilation is minimal. Perspiration is high. Skin irritation is a major observation inside the subway as lack of wind flow results in low evaporation of sweat.

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Calculation of Air Changes per hour in CST subway.

•Area of duct =1.8 m^2, average velocity of duct=1.09m/s, Volume of subway= 4660 m,

Air flow through the duct = Cross sectional area of duct x average velocity x hour

= 1.80 x1.09x 3600

= 7063.2 m^3/hr

Air change per hour = air flow through the duct/ volume of subway

= 7063.2/4660

= 1.5

So the air change per hour at CST subway is 1.5 and as per NBC *(part 8 Building Services lighting and ventilation pg 36)* it should be 8-15.

• Only one blower out of the four blowers is functional at the CST subway. If all four blowers are made functional one can achieve the specified air changes in between 8 to 15 *(NBC part 8 Building Services lighting and ventilation pg 36)*

So considering 12 air changes per hour = ACPH X Volume of subway

= 12 x 17459

= 209508/0.586

= 357522.1 m^3/hr

So to improve air circulation 209508 CFM

•In CST subway Region-1 at the entrance area it ranges from 27 to 100 lumen/m^2 but 97 to 100 lumen/m^2 range come near the shops ,it not satisfying the standard value whereas at the centre the illumination range 13 to 45 lumen/m^2 which is not sufficient as per NBC standards (*section 1 lighting and ventilation pg 13*). The illuminance level near shops side is in the range of 79 to 217 lumen/m^2 which is high as per NBC standards (*section 1 lighting and ventilation pg 13*)

•Noise level in CST subway ranges between 70 - 85 dB.

•In CST Region-1 subway the $PM_{2.5}$ concentration is the range of 40 to 102 μg/m^3 which is too high than the prescribed of 65μg/m^3 for 24hr as per National Ambient Air Quality NAAQMS/35/2011-12. This value is high as the footfall is large and also because of the pollution from vehicles.

Whereas in Region-2 the concentration of $PM_{2.5}$ is in the range of 29 to 68 µg/m³ footfall is low and vehicular movement is less in this region.

•The CO2 level in between 1600 – 2500 ppm of 6839 m3 volume we infer high level of CO2 content at CST subway .This is due to high footfall, low ventilation and lesser supply of fresh air.
So to reduce temperature, relative humidity, CO2, PM2.5 need to increase wind speed inside the subway. Total circulation area inside the subway is 1622 sqm (excluding shops)
Through jet fans taking fresh air inside subway with CO2 sensor and exhaust air pulling outside.

Borivali Subway

- In Borivali subway the relative humidity ranges between 67% to 70% as seen from the psychometric chart figure 128.., the conditions in Borivali subway are within 67 to 70% the comfortable range.
- In Borivali subway the temperature range is 27 to 33ºC, the comfort temperature range for Natural Ventilated Building as per ASHRAE 55 is 26 to 28º C, by IMAC 18 to 22º c and by NBC is 25 to 33ºC.
- In Borivali wind speed ranges 0-0.2 m/s. The ventilation is good and it is comfortable.

  So for 12 CFM = 12 x Volume of subway
  = 12x 1408
  = 16896
  = 28832.7 m^3/hr
  ACPH = 28832.7/1408
  = 20.4
  So 20 air changes per hour required.
- In Borivali subway the illumination levels is in the range of 6 to 11lumen/m² which is low as per NBC standards (*section 1 lighting and ventilation pg 13*)

Figure 6 Interior view of Borivali subway

Instead of using black color tiles on column white colour give 0.7 reflectance which improves visibility, whereas black colour give 0.1 reflectance.

- Even though the occupancy inside the subway is low, noise levels is in between 64 – 75 dB may be because site located in commercial area.
- $PM_{2.5}$ is more than twice of specified levels of 65µg/m³ (24hrs).
- Carbon di-oxide it is lesser than 500 ppm of 1408 m^3 of volume because of less footfall.

5. Guidelines

Guidelines for Underground Transition spaces

- The relative humidity and temperature inside the subways is higher. Contribution by high occupancy level and lack of drying of perspiration, adds to user discomfort. Effect of high relative humidity and temperature can be neutralised by providing adequate wind flow by forced ventilation.
- Illumination levels should be increased in subways. The amount of light greatly depends on the material properties applied on the surface and the color. By using light color on the walls, floors, ceilings and implementing periodic schedule for cleaning of luminaries and group replacement of lamps at suitable interval will appear brighter since these surfaces would reflect more light. If reflective materials are used such as tiles or stainless-steel, mirror these surfaces would reflect more light thereby increasing illumination.
- Choice of light sources with higher luminous efficacy and luminaries with appropriate light distribution is the most effective means of energy saving in lighting. However, choice of light sources also depends on the other lighting quality parameters like colour rendering index and colour temperature or appearance.
- Also the choice of light sources depends on the mounting height in the interiors. Fluorescent lamps are not preferred for mounting beyond 7 m height, Also the choice of light sources depends on the mounting height in the interiors.
- For subway, corridors direct type of luminaries with wide spread of light distributions are recommended.
- Acoustic Construction material to be used to dispel echo in subways.

Absorption Coefficients of Common Surface Materials and Finishes

Material	125 Hz	250 Hz	500 Hz	1,000 Hz	2,000 Hz	4,000 Hz
Brick, unglazed	0.03	0.03	0.03	0.04	0.05	0.07
Brick, unglazed, painted	0.01	0.01	0.02	0.02	0.02	0.03
Carpet, heavy, on concrete	0.02	0.06	0.14	0.37	0.6	0.65
Concrete block, coarse	0.36	0.44	0.31	0.29	0.36	0.25
Concrete block, painted	0.1	0.05	0.06	0.07	0.09	0.08
Floors, concrete or terrazzo	0.01	0.01	0.015	0.02	0.02	0.02
Floors, linoleum, asphalt (vinyl), rubber, or cork tile on concrete	0.02	0.03	0.03	0.03	0.03	0.02
Floors, wood parquet in asphalt on concrete	0.04	0.04	0.07	0.06	0.06	0.07
Glass, large panes of heavy plate glass	0.18	0.06	0.04	0.03	0.02	0.02
Glass, ordinary window glass	0.35	0.25	0.18	0.12	0.07	0.04

Gypsum board, ½ inch, nailed to 2x4 wood frame 16 inches on centre	0.29	0.1	0.05	0.04	0.07	0.09
Marble or glazed tile	0.01	0.01	0.01	0.02	0.02	0.02
Opening, covered by grill (e.g., ventilating)	0.25-0.75					
Plaster, gypsum or lime, smooth finish on tile or brick	0.013	0.015	0.02	0.03	0.04	0.05
Plaster, gypsum or lime, rough finish on lath	0.14	0.1	0.06	0.05	0.04	0.03
Plywood panelling, 3/8 inch thick	0.28	0.22	0.17	0.09	0.1	0.11

Table 3 Sources: NIOSH, 1979; Cox and D'Antonio, 2004.

- In order to reduce $PM_{2.5}$ concentration, the fan needs to be utilized for the optimum operating condition. Instead of using broom for cleaning of the subway use of vacuum cleaner will reduce Particulate Matter.

6. Recommendation

- Data from this study can be further used to assess health risks to improve policies and strategies for an indoor air quality management in the subway transportation system.
- This paper can be a reference of present environmental conditions while designing new subway.

Refrences

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