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Environmental Quality of Underground Spaces

Ar. Apoorva Thakkar

M. Arch (Chandigarh College of Architecture)

Abstract

This research focuses on various aspects of subterranean architecture and the issues. The research will focus on how to improve the overall environmental qualities of these spaces and there role in maintaining the human's well-being and their feasibility to stay in such structures for a long time. However, this was never a new concept in India as the land of unique architecture is filled with numerous astonishing sub-ground architectural marvels. Since the ground is more petite and global warming is a threat, this is the time to go in the past and understand our valuable historical civilizations in detail, which has a lot of empirical meanings in subterranean spaces for gatherings. These variations led me to research the notions of these spaces to recognize the spirit of space hidden in them so that it could be reinterpreted in the contemporary world. The understanding of existential space through the relationship of man and environment is developed in this research. Various literature studies that have been taken to relate to the topic will emphasize understanding subterranean architecture and there issues.

1. Introduction:

General

Architectural history in India has had dwelling structures with underground spaces. The initial settlement such as Ellora , Hampi had a lot of examples of underground building . But in the contemporary world, these underground spaces are just used for non-habitable purposes such as parking, storage etc because of the confined environment that is created.

Aside from that with the expansion of area globally urban land is awaited to become a limited resource of area. Environmental change is also a significant occurrence, so we can give better living conditions by planning underneath and thus expanding natural open spaces on the land. With the decline of environments disturbance, because of urbanization the population of urban areas has increased, less number of buildable areas in urban areas encourages high rise building so architects, urban planners and other professional expert should focus more on the development of these underground structure.

The word ' underground spaces' is misjudged by only basements which creates a symbol of undesirable ambience and because of it these spaces are not used very commonly in today's time . In fact these are the spaces which are designed below the ground level and they have a very high scope of living.

Need and relevance of problem

The need of this study is the lack of knowledge which brings about the misconception in the society about the underground spaces. This problem is addressed with the interrogation to find out the solution for the positive upbringing of underground spaces in urban area in terms of the environmental quality.

This problem will inquire into spatial, and environmental quality of underground spaces that improves the experience and use within such spaces.

Aim: - To analyze the environmental quality of public underground spaces .

Research objectives:

1. To study various definition and types of underground spaces in an urban area.
2. To identify parameters for environmental quality.
3. To analyze the case studies and survey questionnaire of the above mention environmental quality parameters
4. To frame design guidelines for enhancing the environmental quality of underground spaces.

2. Literature review

An attempt is made to briefly introduce the research problem by taking into consideration a review of literature from various sources, namely, e –resources, books, and knowledge sharing from the experts in the field of research work. A detailed study of all the literature review is shown in table (refer to appendix)

This study will offer a retrospect with an emphasis on contemporary underground space problems and their fixes. According to the principles of sustainable development, a high degree of indoor environmental quality (IEQ) is a crucial part of healthy buildings.

So this study is divided into various parts which are as follows:

1. Definition and types of underground spaces
2. Indoor environmental quality
3. Environmental quality of underground space

The categorization of research paper is done as shown in figure no 12.

2.1 Definition and types of underground spaces

There are various types of underground structure in an urban area as stated by researcher in figure no 1 [Wright, A. 2012]

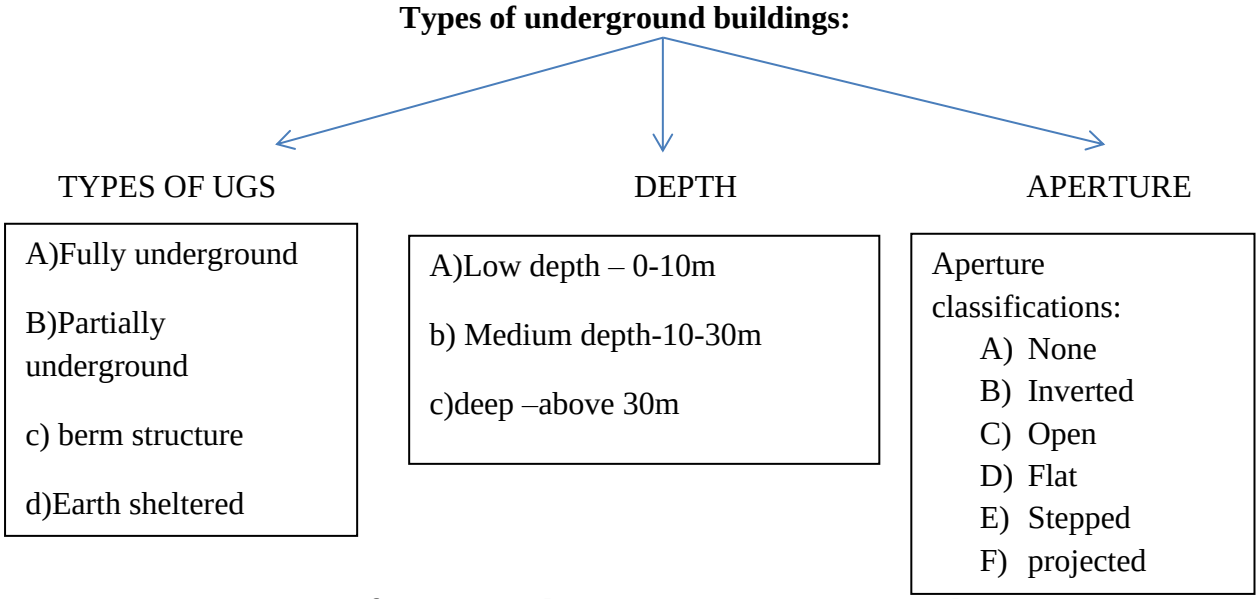


Figure 1 Types of UGS according to aperture (source Wright, A. 2012)

2.2 Indoor environmental qualities:

In modern developments, the majority of people spent their time indoors. For the designers and engineers to assure the comfort of the project from inception to completion, thermal comfort is crucial.

Depending on where they are in the globe, individuals display different behaviors in terms of their needs for indoor thermal comfort. Therefore, the condition of the indoor environmental quality (IEQ) has a big effect on people's health. Experts and researchers in subjects like chemical, pharmacy, and ventilation system design have been particularly interested in air quality inside buildings [Balazova, I., Clausen, G., & Wyon, D. P. 2007, Hantani,2009]. An increase in the incidence of numerous forms of modern disease may be greatly influenced by poor indoor air quality in different types of public utility structures. Because that can affect a building's inhabitants' health, comfort, well-being, and productivity, indoor air quality (IAQ) is a significant issue for businesses, institutions, management companies, renters, and employees.[Peretti , 2011] .According to the principles of sustainable development, a high degree of indoor environmental (IEQ) is a crucial part of healthy buildings. Poor indoor air quality is linked to a variety of illnesses and symptomatology, commonly referred as Sick Building Syndrome a combination of nonspecific symptoms including headache, dizziness, nausea, eye irritation, respiratory problems, chronic cough, dry skin, and itchiness [Ng, L. C,2012 & Olesen, B. W.,2007]. The following are the most important parameters for indoor environmental quality that were identified from the various researchers:

1. Thermal comfort
2. Air quality and ventilation
3. Lighting comfort
4. Humidity

According to Indoor environmental quality standards – ISHRAE(Book) , following standards were given for each of the parameters in composite climate:

The term "thermal comfort" refers to conditions governed by many environmental and human factors. Various other factors include physical health, mental state, air temperature, air velocity, humidity, radiant temperature, and relative humidity. For thermal comfort the acceptable air temperature in summers and winters mention in table no 1 for acceptable range of air velocity 0.2m/s.

Table 1 Thermal comfort standard (ASHRAE)

		Summer (Cooling season) ~0.5 clo	Winter (Heating season) ~1.0 clo
Low	Offices, Conference room, Auditorium, Cafeteria / Restaurant, Classroom	24.5 ± 2.5	22.0 ± 3.0
Medium	Retail stores, Shopping Malls	23.0 ± 3.0	19.0 ± 4.0

For air quality and ventilation following standards are mentioned in table 2:

Table 2 Air Quality Standards (ASHRAE)

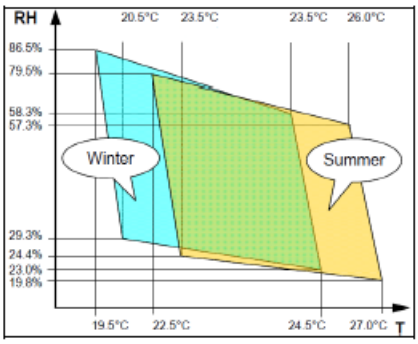
Parameters		Units	Class A
Basic IAQ parameters	CO_2	ppm	Ambient + 350
	PM 2.5	µg/m³	<15
	CO	ppm	<2
	TVOC (equivalent to isobutylene)	µg/m³	<200
Complementary IAQ parameters	PM 10	µg/m³	<50
	CH_2O	µg/m³	<30
	SO_2	µg/m³	<40
	NO_2	µg/m³	<40
	O_3	µg/m³	<50
	Total Microbial Count	CFU/m³	Indoor ≤ ambient
Occupant Satisfaction		%	90

Spatial Daylight Autonomy (sDA) :

The value of sDA result ranges from 0 to 100%. If the value is above 75%, the daylight in the given space is regarded “preferred”; if it is in the range of 55%-74%, the daylight is “accepted”. The main aspects of lighting comfort are luminous intensity (intensity or brightness), contrast, and glare. The required light intensity depends on the type of activity in the building. Light has a frequency that depends on the color of the surface it hits. For example, a white surface reflects most of the incident light, while a black surface absorbs most of it.

Humidity: ASHRAE guidelines recommend a relative humidity (RH) of 30 to 60 percent. At higher relative humidity (RH) levels (more than 60%) can encourage the growth of mold and mildew. Dust mites, bacteria, and fungi all thrive under moist, humid conditions. At lower relative humidity (RH) (less than 30%), occupants might experience eye irritation or a stuffy nose. For some individuals low relative humidity (RH) may aggravate allergies. Low relative humidity can also lead to increased survival of some viruses, thereby increasing the spread of viral infections.A graph is shown in Table 3

Table 3 relative humidity / temperature diagram (ASHRAE)



2.3 Environmental quality of underground space

It is important to prevent negative psychological and physical effects from underground structures. Previous studies have looked into the psychological and physical elements of underground areas. Earlier studies have uncovered a variety of potential problems with underground places that need to be examined. There are several parameters that determine the structures overall environment as discussed below by various researchers:

2.3.1 Air quality control and ventilation

Depending on the forces that propel airflow, there are two forms of ventilation: Natural ventilation and mechanical ventilation. Usually, environmental forces like wind, temperature buoyant, and geothermal power are used to power natural ventilation. The concept of organic ground- connected circulation, uses constant soil temperature to preheat or precool air for buildings. Iranian architects employed wind towers and underground air tunnels for passive cooling and ventilation in the first millennium B.C. In Iran, the well-known qanat systems which are often dug into the side of a mountain or hillside are combined with naturally ventilated options. The effects of exterior season wind speed and direction should be considered when designing natural ventilation in underground areas, and outdoor air should be enhanced by using wind load. [Vaezizadeh, F., & Kazemzade, M. (2013)].

2.3.2 Moisture transfer

High humidity, especially during the summer, is one characteristic of underground places that sets them apart from above-ground ones.. Local hydrology and geologic conditions, rock ruptures, structural

coating types, building materials, moisture diffusion from the construction process, external climate (seasons), and airflow use are all specifically correlated to humidity. The absorption of building leftover water is one of the reasons for the high humidity in underground spaces during the early stages of development. Water is needed during the building process to create the walls and the gardens. When the partial pressure of water vapor inside the constructed spaces is lower than that outside the constructed spaces, a typical humidity transfer process takes place in underground rooms. Water vapor diffuses into the interior of the envelope from the exterior. Insulation sheet and plastic sheets are required to remove humidity. [Ashrafian,2011].

2.3.3 C02 Concentration/radon

[Li, Y,2018] examined how high CO2, RH, and temperatures together affected people's reactions. They discovered that high levels CO2 impair air quality, and that the combined impacts of high ambient temperature, RH, and CO2 concentrations cause a range of reactions. [Li et al. , 2006] looked into the radon concentrations in underground structures in China's biggest cities on a daily and annual basis. The radon levels in the subsurface structures change twice daily. They suggested proper natural ventilation can help to control co2 from underground spaces.

2.3.4 Thermal comfort

For subterranean structures, a thorough and comparable study of the thermal sensation and air quality inside was also noted. In order to look into the thermal comfort and indoor air quality of five underground shopping malls in China, Gaoet al. [Hwang, S.H,2010] conducted a survey using questionnaires. According to their findings, people are less comfortable thermal comfort , women are generally less satisfied with indoor environment quality than men.

2.3.5 Psychological and physiological considerations [Soh, C. K,2016]

Various psychological problems were noted down by the researchers and they are as follows.

1. Lack of natural light: Natural light is essential to users of the building if the total proportion of the daylight to artificial light is comparatively low. There can be different passive strategies to be used to allow natural light to enter the building. The use of reflectors along the skylight can allow more natural light to enter the building
2. Need for exterior view: Underground space lacks an external view of the aboveground surface, ultimately dissatisfaction for users. Besides providing direct sunlight, windows also provide a picture of the weather, give a sense of interaction with the outdoors, and visually relieve the immediate environment.
3. Lack of spatial orientation: A windowless structure also produces a loss of spatial direction because exit locations are not apparent and create a fear that they could not leave in an emergency. The use of proper sign board inside the underground building can provide a solution for this problem
4. Perception of comfort: Some individuals have a highly negative response to subterranean structures. They hold unpleasant feelings towards them in their subconscious. People also combine underground areas with wet and unpleasantly poorly built and ventilated basements.There should be no hidden corners inside the building and all the corners should be properly lit with artificial light so that a comfortable environment is created
5. way finding- Another possible cause of negative attitudes to underground spaces is lack of perceived control over the environment. Lack of direct access to outdoors and expected difficulty in way finding can cause a lack of confidence, resulting in reduced perceived control, in turn resulting in an impression that the underground environment is dangerous and unsafe . It was observe that linear

planning of underground building is much better than a complex planning because in linear planning it is better to find way.

2.5 Research gap

While underground areas can serve a variety of purposes, including storage, shelter, and public facilities, underground buildings have gotten less attention, largely because it is difficult to design conditions that are acceptable for living and working. The current work conducts a comprehensive study of the indoor comfort as well as psychological problems in an effort to design a healthy, pleasant, and comfortable underground construction in composite region.

3. Methodology

3.1 Introduction

The modes through which the aim and objectives of the research to be achieved is discussed in this chapter. This chapter acts as the most important chapter, since all the activities starting from selection of each and every component in the research such as understanding the type of data required, mode of collection, sampling technique, suitable technique for data analysis, identifying suitable software for undertaking data analysis is discussed.

3.2 Research methodology

This research was carried in various phases which are described below and also shown in figure no 5.

Phase 1 : in this stage through various literature studies parameters of the environmental qualities of underground spaces were identified

Phase 2: In this stage two secondary case studies were done in order to understand what all passive strategies are used to improve the environmental qualities of underground spaces.

Phase 3 : In this stage 3 commercial underground buildings were identified in composite region and these case studies were analysis using various techniques such as survey questionnaire and with the help of software simulation was carried out

Phase 4 : In this stage of the research discusses about the attainment of the objectives from the literature, data analysis and findings. The chapter finally provides the recommendation, conclusion and future works on the research.

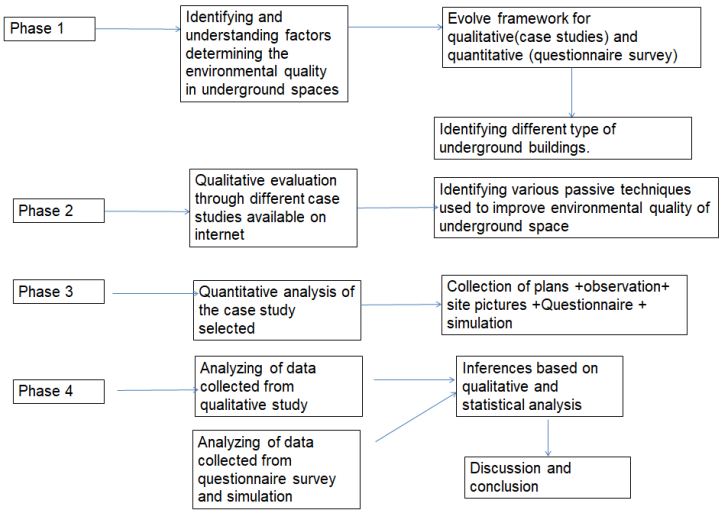


Figure 5 Flow chart of research methodology (Source: Author)

3.2.1 Data collection:

Collection of data and literature is undertaken with due consideration of aim and objectives of the research.Further, primary and secondary data collection methods and sources of data re discussed in detail.

3.2.1. Primary data

Primary data basically involve collection of data from the field as first hand information through questionnaire survey.

The questionnaire:

All parameters determining the environmental quality in underground space, as explained in the literature review chapter , So the parameters that I will be looking at my research is as follows along with the questionnaire are given below in table no 4 and table no 5.

Table 4 Questionnaire about indoor comfort

ENVIRONMENTAL FACTOR	RELATED QUESTIONS
AIR TEMPERATURE IN SUMMERS	HOW DO YOU FEEL ABOUT THE TEMPERATURE IN SUMMERS EVEN WITH THE HELP OF COOLING DEVICES?
AIR TEMPERATURE IN WINTERS	HOW DO YOU FEEL ABOUT THE TEMPERATURE IN SUMMERS EVEN WITH THE HELP OF COOLING DEVICES?
HUMIDITY	THERE IS A SUITABLE LEVEL OF HUMIDITY IN THIS PLACE
NATURAL DAY LIGHT	HOW WOULD YOU RATE THE NATURAL DAYLIGHT OF THIS PLACE

Table 5 Questionnaire about psychological factors

PSYCHOLOGICAL FACTOR	RELATED QUESTIONS
WAYFINDING	HOW WOULD YOU RATE THIS BUILDING IN TERMS OF WAY FINDING/DIFFICUTY IN FINDING SATIRS, ROOM NO.ETC
PERCEPTION OF COMFORT	HOW WOULD YOU RATE THIS BUILDING IN TERMS OF SAFETY.

Questionnaire distribution:

The total numbers of questionnaire were decided based on the area and the number of visitors coming to that area.Total number of questionnaire collected in various buildings are as follows:

1. Palika bazaar, CP, new Delhi: 50(38 owner,12 visitors)
2. American institute of Indian studies: 20
3. Earth sheltered: 16

3.2.1. SECONDARY DATA

For the secondary data , base plan elevation section were extracted from various sources and then they were drafted on AutoCAD.The detailed drawings were used for futher analysis

3.2.2 ANALYSIS : TOOLS AND TECHNIQUES

For questionnaire survey : Measurement Scale:

The way data are measured is called the measurement level or measurement scale of a variable (de Vocht, 1996). For higher-level measures, arrange the values themselves in ranking order to create an ordinal scale variable. They are called ordinals because they represent order (Lawson, 1990). Relationships between observations take the form of greater than and less than. Questionnaires most commonly use a 3-point or 5-point scale (Baarda & de Goede, 1997). To generate a more differentiated approach, a 5-point scale was used in the questionnaire developed in this study. Respondents are given the opportunity to 'strongly agree' or 'strongly disagree' with the question.

Software analysis: Design builder

The detailed drawings were transferred to design builder software for the analysis of indoor comfort. Weather file was then added to the file with the detailed information about longitude latitude , soil condition, various material used inside the building , types of glasses uses etc. After adding all the data detailed graphs were generated from the model which helped to know the temperature differences , humidity level , energy consumed and day lighting factors inside the building. Taking all these graph analysis was done for various parameters.

Limitation : the resulted data was not verified on the site with the help of instruments such as lux meters etc. so the result taken out from design builder was considered as final output.

4. CASE STUDY PRESENTATION

4.1 PRIMARY CASE STUDIES

For primary study three case studies are undertaken which are described below . A small introduction about each case studies are as follows:

4.1.1 PALLIKA BAZAAR

Location	Connaught Place, New Delhi
Climate	Composite Climate
Purpose	Market Place
Architect	Delhi government
Status of completion	Completed, 1980
Category	Fully submerged
Area	20911 sq m (225,089.20 ft²)

4.1.1.1 BUILDING PLAN

The building plan of palika bazaar is shown in figure no 13 with entry and exits marked. In total there are 6 entry /exits points to enter palika bazaar

Figure 13 Upper level plan with entry and exits (Source: http://duac.org.in/

4.1.2 AMERICAN INSTITUTE OF INDIAN STUDIES

Location	Gurgaon
Climate	Composite Climate
Purpose	Institutional Building
Architect	Vinod Gupta
Status of Completion	1998
Category	Berm structure
Area	1500 sq m (16145 sq ft)

4.1.2.1 BUILDING PLAN

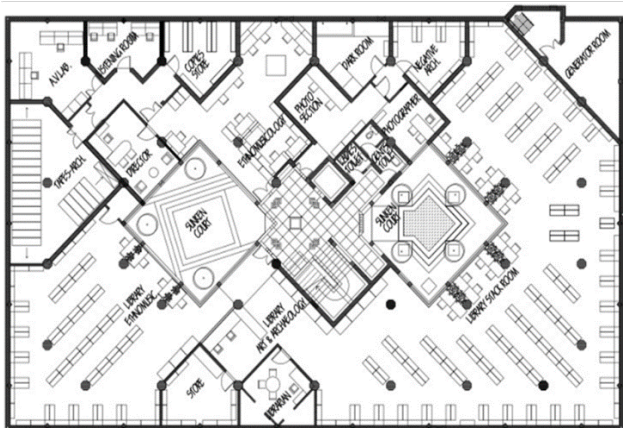


Figure 14 Plan of American institute of indian studies (Source: www.hrpub.org

Building plan showing the position of sunken courtyard is shown in figure no 14.

4.1.3 NATURE INTERPRETATION CENTER

Location	Chandigarh
Climate	Composite Climate
Purpose	Tourism building
Architect	-
Status of Completion	2010
Category	Earth sheltered
Area	200 sq m (2152 sq ft)

4.1.3.1 BUILDING PLAN

Figure 15 shows the building plan of nature interpretation center .

Figure 15 Plan of nature interpretation center(Source: chandigarh.gov.in)

5. ANALYIS AND DISCUSS

The various parameters of the analysis are indoor comfort which include air temperature in summers and winters, relative humidity , Spatial Daylight Autonomy and psychological aspects which include way finding and perception of comfort have been analyzed from literature review ,case studies using simulation and survey questionnaire. There are 3 case studies analyzed using simulation method and the case studies are Palika bazaar, American institute of Indian studies and Nature Interpretation Center.
Each parameters are discussed below :

5.1 AIR TEMPERATURE IN SUMMERS:

The hot season lasts for 2.5 months, from April 22 to July 8, with an average daily high temperature above 36°C. The hottest month of the year in is June, with an average high of 42°C and low of 27°C.

LITERATURE REVIEW - According to Indoor environmental quality standards – ISHRAE(Book) , following Standard was noted down for summers as **23 °C ± 3°C.**

CASE STUDIES: There are 3 case studies analyzed using simulation method and the case studies are Palika bazaar, American institute of Indian studies and Nature Interpretation Center.

The figure 16 shows the range of temperature of palika bazaar using simulation. The range of temperature between April to June is 29°C -33°C.

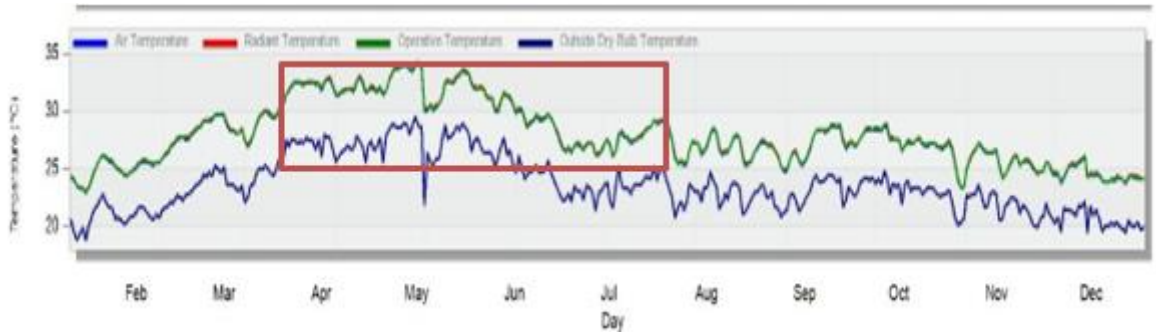


Figure 16 Air Temperature graph of palika bazaar (Source : author)

The figure 17 shows the range of temperature of American institute of Indian studies using simulation. The range of temperature between April to June is 25°C -29°C.

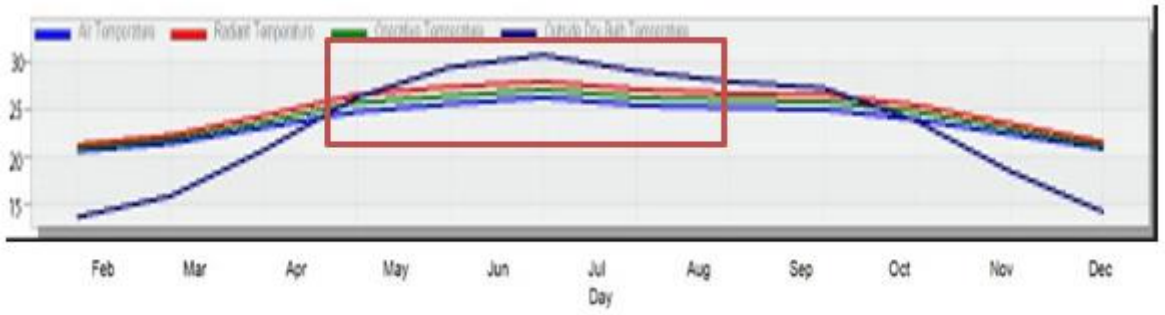


Figure 17 Air temperature of American Institute of Indian studies.(Source: Author)

The figure 18 shows the range of temperature of Nature Interpretation center using simulation. The range of temperature between April to June is 26°C -28°C.

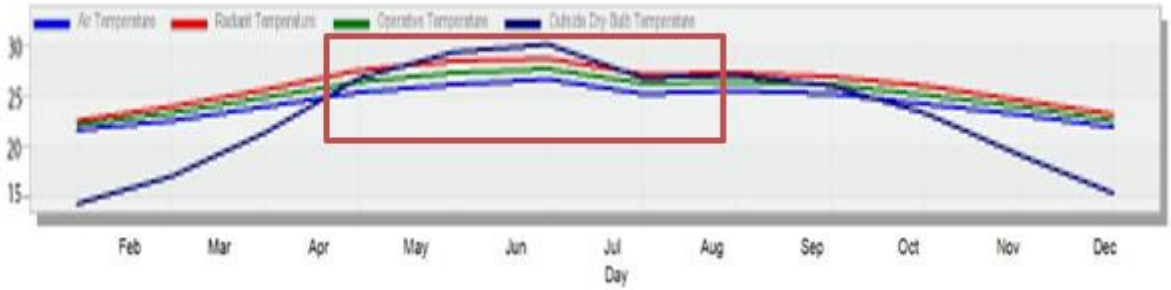


Figure 18 Air temperature of nature interpretation center(Source: author)

Air temperature of summers in palika bazaar using air conditioning system is higher (29°C -33°C) than the desired range that we have got from literature study i.e 23 °C ± 3°C. which creates a discomfort in summers season whereas the air temperature in American institute of Indian studies and Nature interpretation center 29°C -33°C and 26°C -28°C respectively lies within the desired range of the literature study which creates a comfort in summer seasons.

SURVEY (QUESTIONNAIRE) : The respondents in palika bazaar were dissatisfied with the air temperature in summers even with the help of air conditioning system. 55.3% were dissatisfied with the air temperature .95% were satisfied with the air temperature in summers without the help of air conditioning system in American institute of Indian studies. 37.5% were neutral will the air temperature in summers in nature interpretation so no conclusion can be made from the user survey for this building.

Table 6 survey of air temperature in summer

	PALLIKA BAZAAR,CP,NEW DELHI	AMERICAN INSTITUTE OF INDIAN STUDIES	NATURE INTREPRETATION CENTRE
Very Satisfied	0%	55%	25%
Satisfied	2.6%	40%	12.5%
Neutral	42.1%	5%	37.5%
Dissatisfied	55.3%	0%	25%
Very Dissatisfied	0%	0%	0%

5.2 AIR TEMPERATURE IN WINTERS

The cool season lasts for 2.6 months, from December 3 to February 21, with an average daily high temperature below 23°C. The coldest month of the year in Chandigarh is January, with an average low of 9°C and high of 20°C.

LITERATURE REVIEW - According to Indoor environmental quality standards – ISHRAE(Book) , following standard was noted down for winters **as 19 °C ± 4 °C.**

CASE STUDIES

The figure 19 shows the range of temperature of palika bazaar using simulation. The range of temperature between December and February is 19°C -22°C.

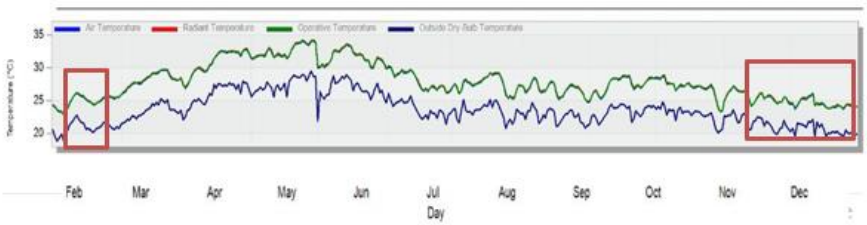


Figure 19 Air temperature graph of palika bazaar(Source: author)

The figure 20 shows the range of temperature of American institute of Indian studies using simulation. The range of temperature between December and February is 21°C -25°C.

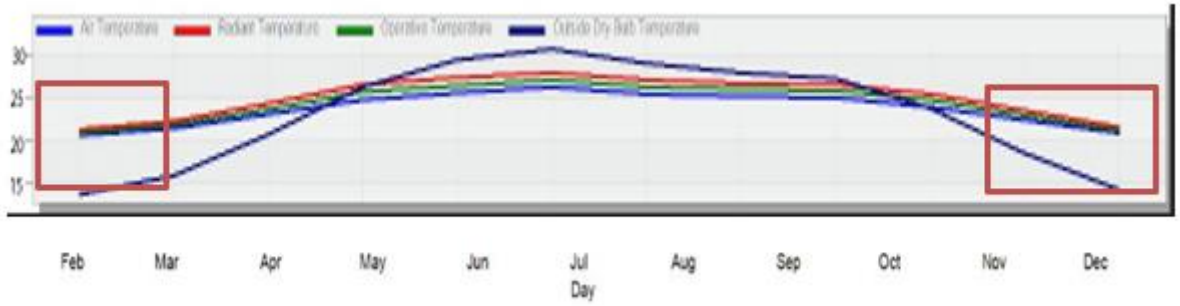


Figure 20 Air temperature graph of American institute of Indian studies (Source:author)

The figure 21 shows the range of temperature of Nature Interpretation center using simulation. The range of temperature between December and February is 21°C -24°C.

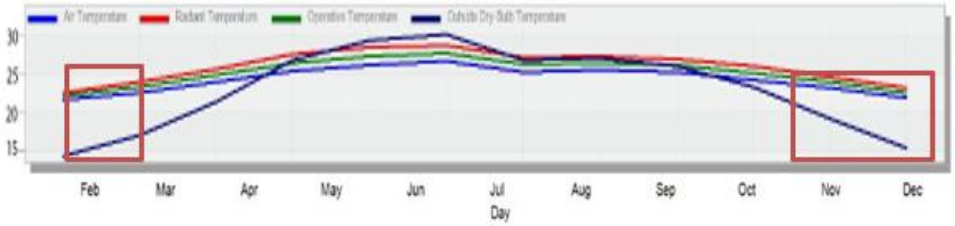


Figure 21 Air temperature graph of nature interpretation cemter (Source: Author)

Air temperature of winters in palika bazaar using air conditioning system is lies within the range of desired standards that we have got from literature study i.e. 19 °C ± 4 °C whereas the air temperature in American institute of Indian studies and Nature interpretation center 21°C -25°C and 21°C -24°C respectively do not lie within the desired range of the literature study.

USERS SURVEY (QUESTIONNAIRE: 55% of respondents were satisfied with the air temperature in winters in palika bazaar. 52.6 % of the respondents in American institute of Indian studies were dissatisfied with the air temperature in winters. Most of them said that in winters they don't feel like sitting in the library as this area gets very cold.50% were dissatisfied with the air temperature in winters in nature interpretation center. .

Table 7 Survey of air temperature in winters

	PALLIKA BAZAAR,CP,NEW DELHI	AMERICAN INSTITUTE OF INDIAN STUDIES	NATURE INTREPRETATION CENTRE
Very Satisfied	0%	0%	0%
Satisfied	40%	10.5%	1%
Neutral	55%	36.8%	45%
Dissatisfied	1%	52.6%	50%
Very Dissatisfied	0%	0%	0%

5.3 Relative humidity

The highest humidity period of the year lasts for 3.6 months, from June 15 to October 3, during which time the comfort level is muggy, oppressive, or miserable at least 24% of the time.

LITERATURE REVIEW- ASHRAE guidelines recommend a relative humidity (RH) of 30 to 60 percent.

CASE STUDIES: The figure 22 shows the range of relative humidity of palika bazaar using simulation. The highest humidity is recorded in the month of august i.e 70% and lowest in the month of april i.e 40% with an average of 65% in other months.

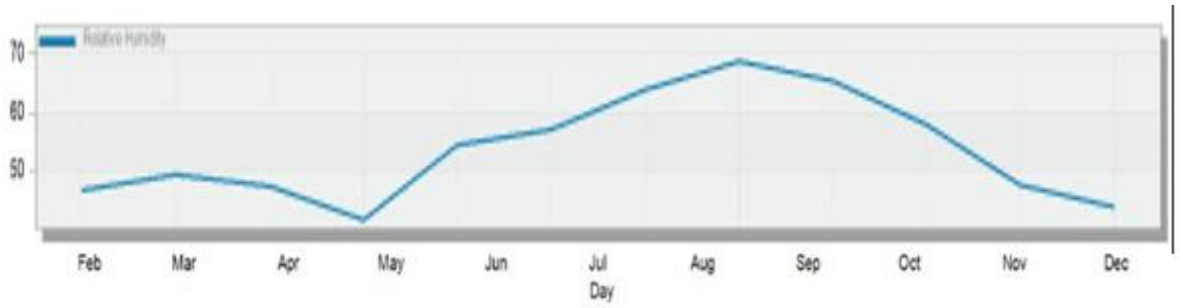


Figure 22 Relative humidity graph in plaika bazaar (Source:author)

The figure 23 shows the range of relative humidity of American institute of Indian studies using simulation. The highest humidity is recorded in the month of july i.e 65% and lowest in the month of april i.e 40% with an average of 55% in other months.

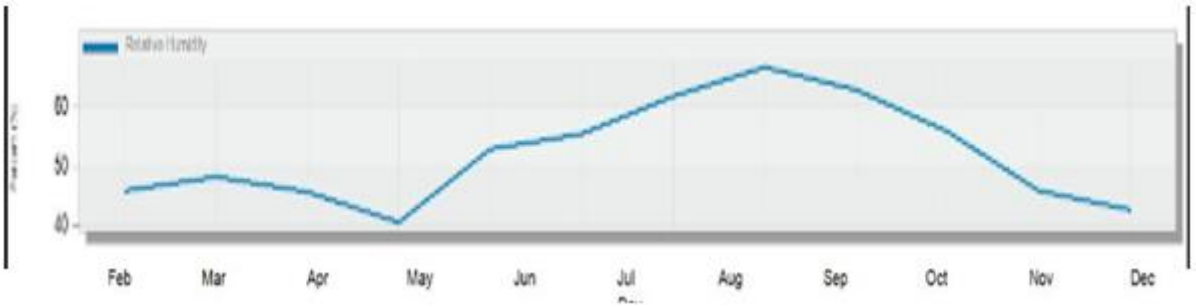


Figure 23 Relative humidity in American institute of indian studies (source: Author)

The figure 24 shows the range of relative humidity of Nature Interpretation center using simulation. The highest humidity is recorded in the month of August i.e 65% and lowest in the month of march i.e 30% with an average of 55% in other months.

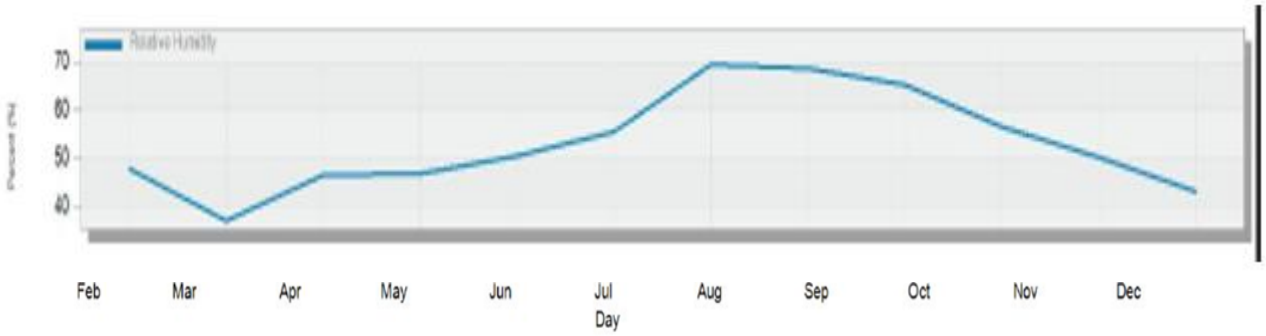


Figure 24 Relative humidity in nature interpretation center (Source: author)

For all the buildings the relative humidity in the month of July and August is higher than standard given in literature review . For palika bazaar the relative humidity is 70% in august , for American institute of Indian studies the relative humidity in the month of July is 65% and for nature interpretation center the relative humidity is 65% in august so these buildings are not functioning well in term of humidity specially in the month of July and August.

USERS SURVEY (QUESTIONNAIRE) : The respondents in American institute of Indian studies were dissatisfied with the humidity.55% of respondents were dissatisfied. 52.6% were dissatisfied with humidity in palika bazaar and 60% were dissatisfied with the humidity in nature interpretation center.In all the building the respondents were dissatisfied with humidity .

Table 8 survey of humidity

	PALLIKA BAZAAR,CP,NEW DELHI	AMERICAN INSTITUTE OF INDIAN STUDIES	NATURE INTREPRETATION CENTRE
Very Satisfied	0%	0%	3%
Satisfied	10.5%	15%	2%
Neutral	36.8%	30%	35%
Dissatisfied	52.6%	55%	60%
Very Dissatisfied	0%	0%	1%

5.4 Natural Daylight/ Spatial Daylight Autonomy (sDA)

LITERATURE REVIEW - The range of 55%-74% is the accepted range of daylight according to the ASHRAE guidelines.

CASE STUDIES:

Figure 25 shows the sources of skylight in palika bazaar. A rough section is made which is showing the height of skylight in figure 26.

Figure 25 Plan showing the position of skylights in palika bazaar (Source: http://duac.org.in/)

Figure 26 section of palika bazaar with heights of skylights(Source: Author)

Figure 27 shows the recorded sDA for palika bazaar building is less than 20% which means that the skylights are not able to transfer the natural daylight inside the building. Most of the daylight doesn't get transfer on the floor and it gets reflected back.This building is completely dependent on artificial lights.

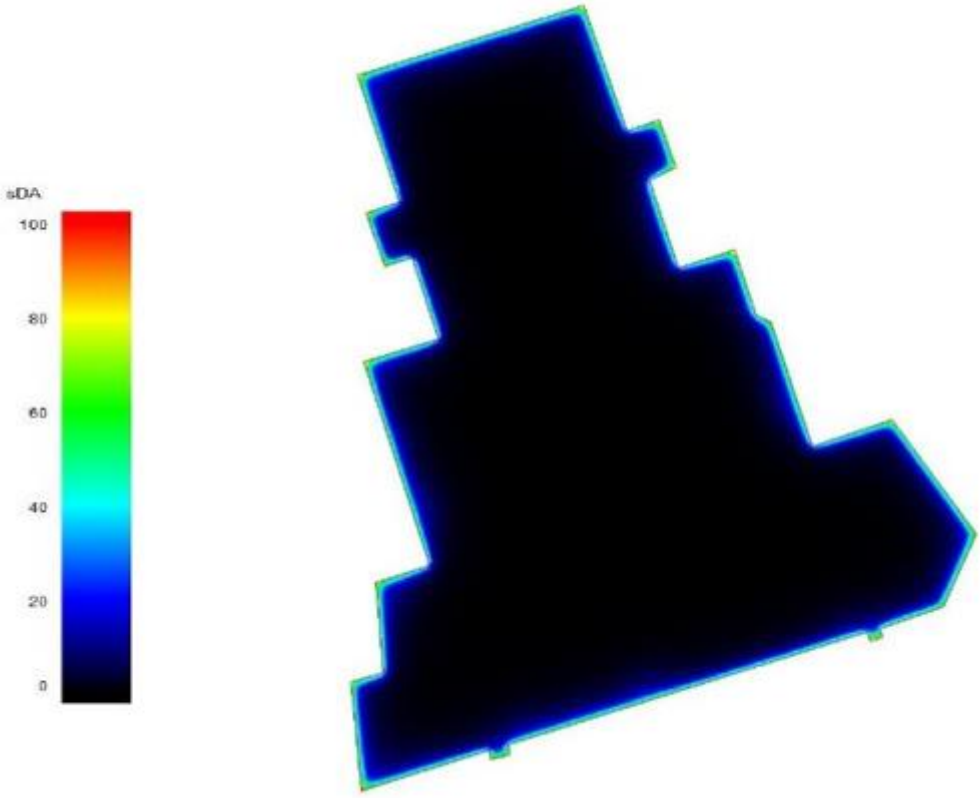


Figure 27 sDA of palika bazaar using simulation (Source: Author)

Figure 28 shows the position of sunken courtyard in American Institute of Indian studies. A section through the sunken courtyard is shown in figure 29.

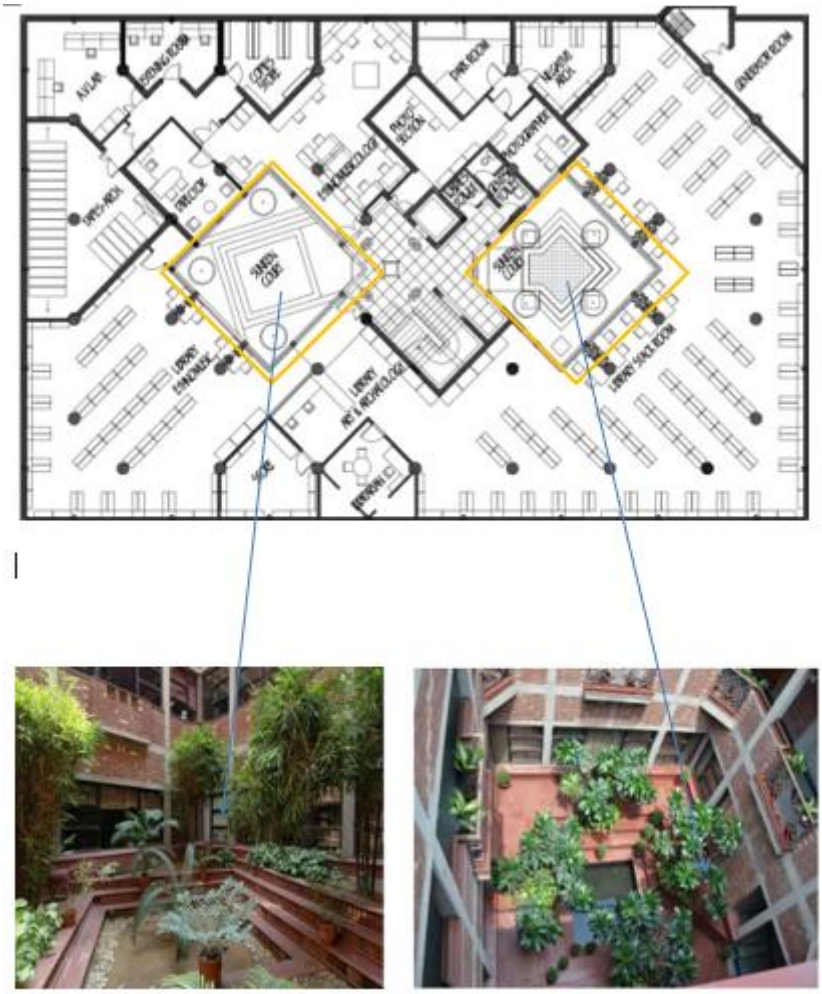


Figure 28 Position of sunken courtyard in American institute of Indian studies (Source: www.hrpub.org)

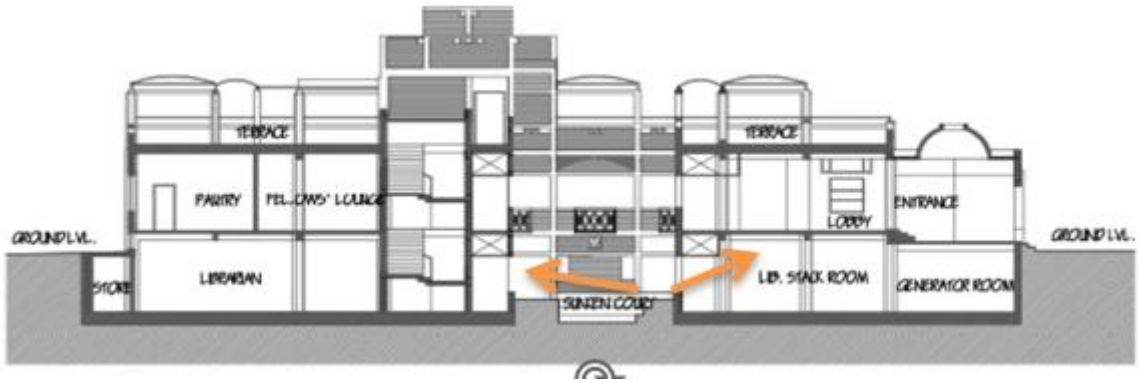


Figure 29 Section cut through sunken courtyard (Source: www.hrpub.org)

Figure 30 shows the area around the courtyard receives a good amount of natural daylight in American Institute of Indian studies i.e 80%-60% . whereas still dark corners are created inside the building which doesn't receive natural light.

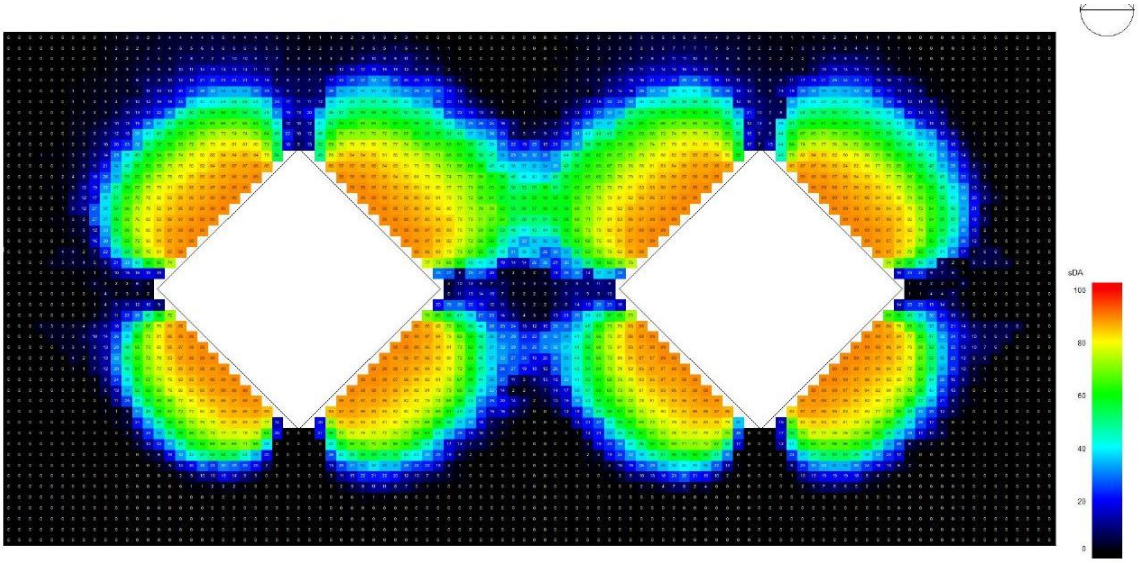


Figure 30 sDA of American institute of indian studies usind simulation (Source: Author)

Figure 31 shows the sources of skylight Nature interpretation center.

Figure 31 The position of skylight in nature interpretation center)Source: chandigarh.gov.in)

Figure 32 shows that the recorded sDA for nature interpretation center is 30% which means that the skylight are not able to transfer a good amount of natural light inside the building.

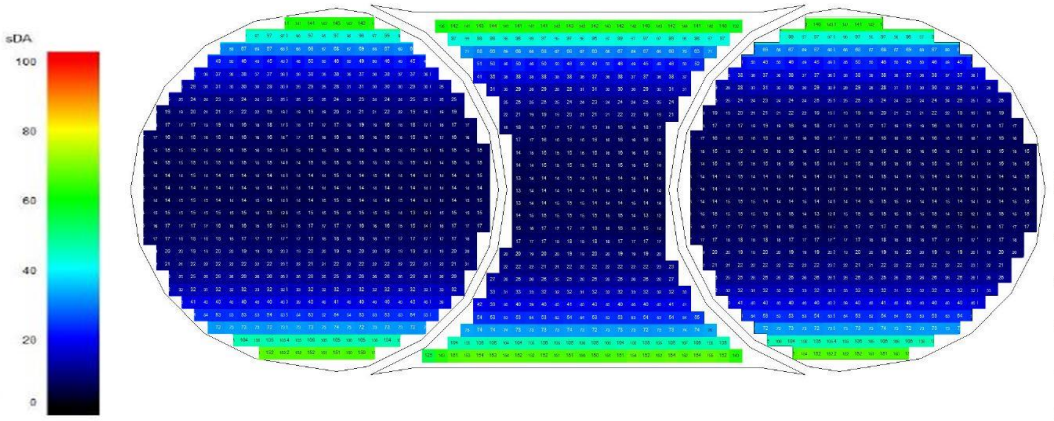


Figure 32 sDA in nature interpretation center using simulation (Source:Author)

USERS SURVEY (QUESTIONNAIRE) : 60% of respondents were satisfied with the daylight inside the building in American institute of Indian studies.47.4% were dissatisfied with the natural daylight in palika bazaar and 81.3% were satisfied with the daylight in nature interpretation center.

Table 9 Survey for natural light

	PALIKA BAZAAR,CP,NEW CELHI	AMERICAN INSTITUTE OF INDIAN STUDIES	NATURE INTREPRETATION CENTRE
Very Satisfied	2.6%	5%	0%
Satisfied	15.8%	55%	81.3%
Neutral	26.3%	40%	6.3%
Dissatisfied	47.4%	0%	12.5%
Very Dissatisfied	7.9%	0%	0%

5.5 Way finding

LITERATURE REVIEW- It was observe that linear planning of underground building is much better than a complex planning because in linear planning it is better to find way.And these building should be connected to above ground with the help of windows which make the sense of direction easy in underground buildings

CASE STUDIES-

Figure 33 shows the internal plan of palika bazaar.As seen in the plan the division of shops is done in a complex form which make it difficult for the user to read the shops number from a distance.

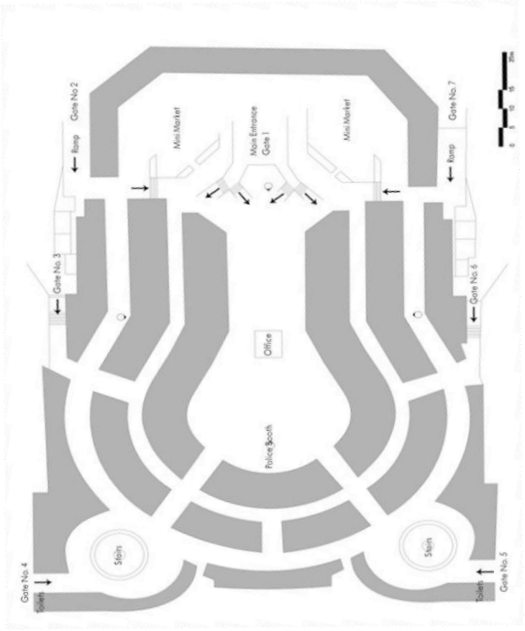


Figure 33 Internal plan of palika bazaar (Source : http://duac.org.in/)

Figure 34 shows the plan of American institute of indian studies which is in linear form and is well connected to outside which makes it easy for user to find way.

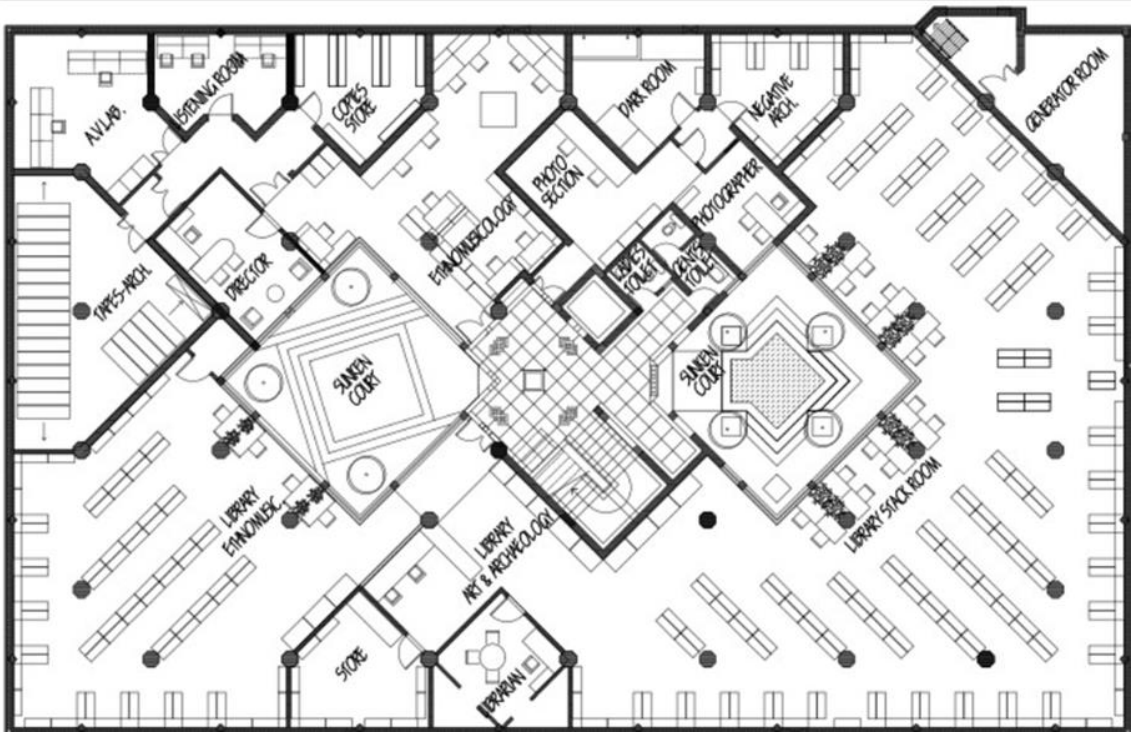


Figure 34 Plan of American institute of Indian studies (Source: www.hrpub.org)

Figure 35 shows the plan of Nature interpretation centre which is not in a linear form and its in complex form which makes the user difficult to find way.

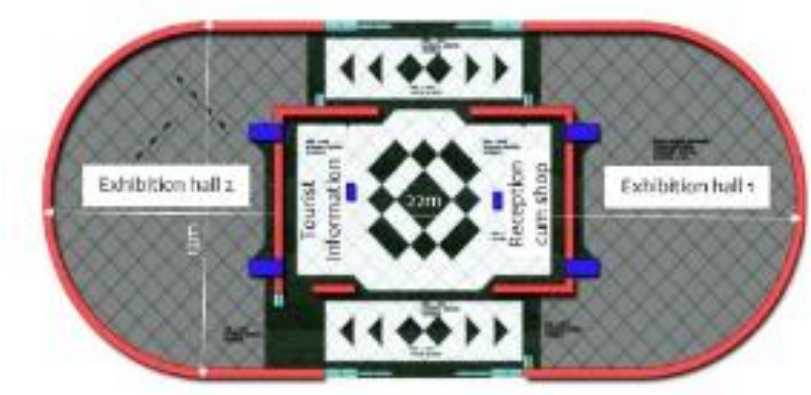


Figure 35 Internal plan of nature interpretation center(Source: chandigarh.gov.in)

American institute of Indian studies has a linear form and is well connected with outside which means it is functioning well in terms of way finding whereas palika bazaar and nature interpretation centre has complex plan which means that they are not functioning well in terms of way finding.

USER SURVEY- More people rely on their intuition or comprehension of space when it comes to way finding in palika bazzar. Around 79% of respondents were dissatisfied and they mention that they use their sense of direction to find ways .80.6% were satisfied with way finding in American institute of Indian studies and 51% were neutral in nature interpretation center and respondents mention that they rely more on signs to find ways inside the building.

Table 10survey of way finding

	PALIKA BAZAAR,CP,NEW CELHI	AMERICAN INSTITUTE OF INDIAN STUDIES	NATURE INTREPRETATION CENTRE
Very Satisfied	2%	55.6%	16%
Satisfied	5%	25%	30%
Neutral	14%	18%	51%
Dissatisfied	30%	1%	2%
Very Dissatisfied	49%	0%	1%

5.6 Perception of comforts

LITERATURE REVIEW - There should be no hidden corners inside the building and all the corners should be properly lit with artificial light so that a comfortable environment is created.

CASE STUDIES

Figure 36 shows some hidden corners in palika bazaar . most of the corners around staircase were not properly lit which creates unsafe environment inside the building.

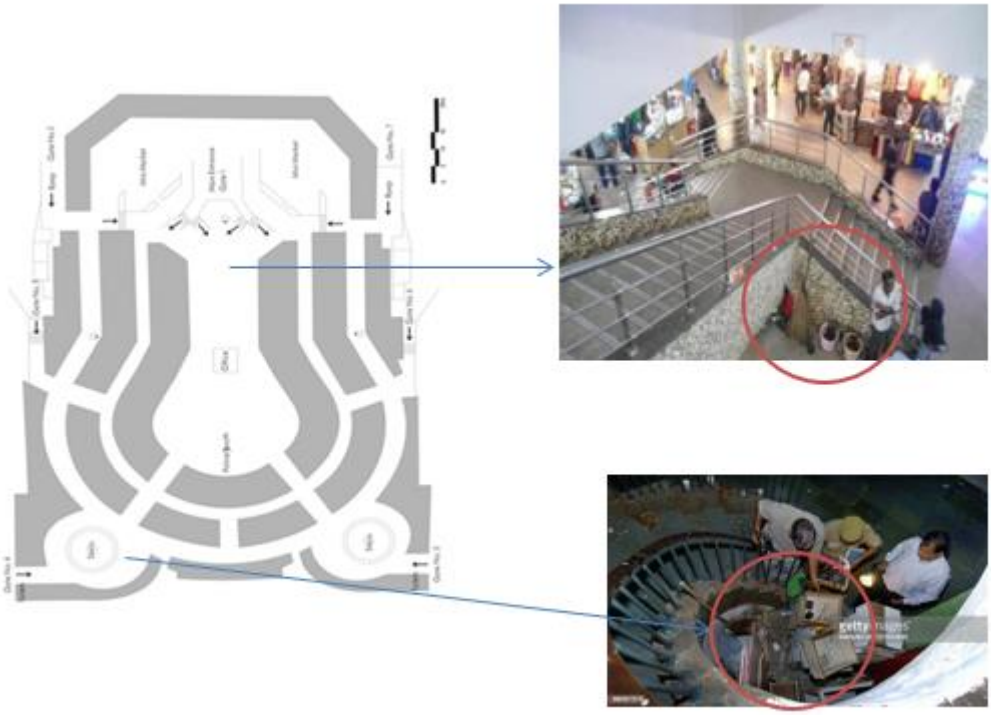


Figure 36 Hidden corners in palika bazzar 9source:gettyimagges.com)

Figure 37 shows that artificial light is used in all the corners of American institute of Indian studies .Wall mounted light is used in the corner rooms which creates a sense of safety inside the building .

Figure 2 artificial corners used in american institude of indian studiesSource:Author)

Figure 38 shows that artificial light is used in all the corners of Nature interpretation center

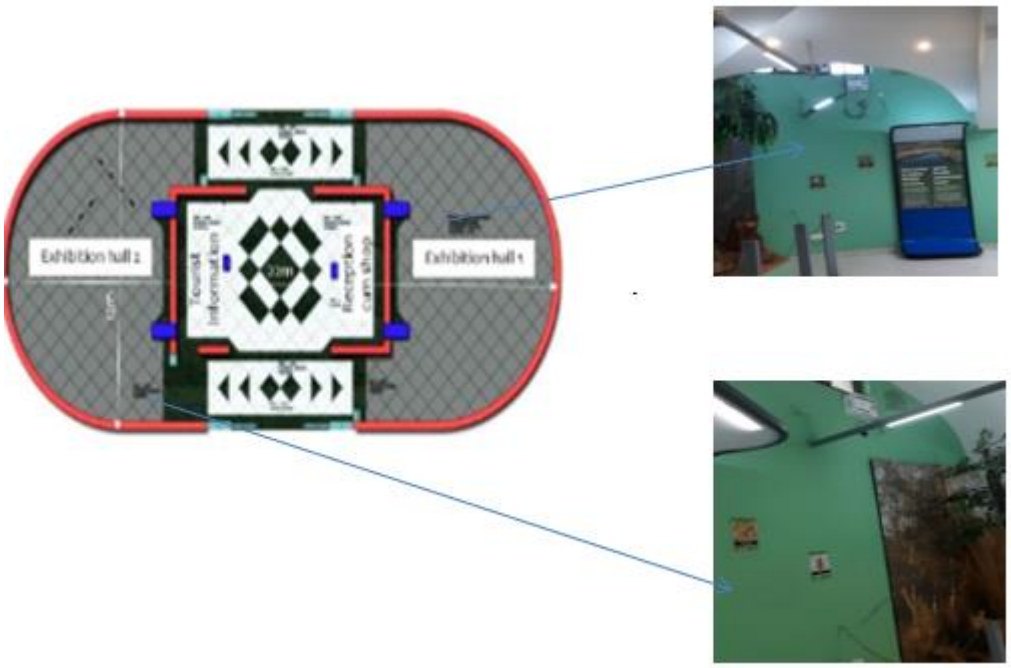


Figure 38 Artificial lights in nature interpretation center Source:Author)

American Institute of Indian studies and nature interpretation center is working well in terms of perception of comfort as there are no hidden corners which are not properly lit by artificial light whereas in palika bazaar hidden dark corners are created which creates unpleasant environment inside the building.

USER SURVEY-74% of the respondents felt unpleasant inside palika bazaar whereas 54% of the respondent felt pleasant inside the American institute of indian studies . 66.4% of the respondent felt pleasant inside Nature interpretation center.

Table 11 survey of perception of comfort

	PALIKA BAZAAR,CP,NEW DELHI	AMERICAN INSTITUTE OF INDIAN STUDIES	NATURE INTREPRETATION CENTRE
VERY UNPLEASANT	40%	2%	1.7%
UNPLEASANT	34%	6%	7.9%
NEUTRAL	5%	38%	24.1%
PLEASANT	14%	33%	47%
VERY PLEASANT	7%	21%	19.4%

CONCLUSIONS – Palika bazaar is not functioning well in term perception of comfort as there are hidden corners created inside the buildings and users are also not satisfied with the same. American institute of Indian studies and nature interpretation center is working well in terms of perception of comfort as all corners are properly lit with artificial light and users are also satisfied with the same.

5.7 Conclusions

Total 6 parameters were selected for the study and the analysis of each parameters is done on the basis of literature review, case study and survey questionnaire. The forthcoming chapter discusses about the attainment of the objectives based on literature, data analysis and findings and few recommendation are given of the basic of these analysis.

6. RECOMMENDATIONS AND CONCLUSIONS

6.1 Introduction

The research has focused on bringing out the significance of underground space use and attempted to improve the overall environmental quality of underground building. This chapter will discuss about the various design strategies to improve the environmental qualities of underground spaces and concludes the current research with further prospective means of undertaking the research ahead.

6.2 Summary of findings

The findings are categorized into various parameters :

6.2.1 Air temperature in summers:

According to the literature review 23°C ±3°C was the acceptable range in summers and the air temperature in palika bazaar is within the range of 29°C -33°C and the respondents were dissatisfied with the same , therefore this building doesn't function well in summers even with the help of air conditioning system

Whereas the respondents were satisfied with the air temperature in summers in American institute of Indian studies and the recorded temperatures is 25°C -29°C which lies within the ashrae standards so this type of building functions well in summer season without air conditioning system.

A neutral response was collected from the nature interpretation center so no conclusion can be made from user survey but the recorded temperature is 26°C -28°C which lies within the desired range so this building function well in summer seasons.

6.2.2 Air temperature in winters

According to the literature review 19°C was the acceptable range in winters and the air temperature in palika bazaar was 19°C -22°C which lies within the range and the respondents were also satisfied with air temperature in winters so this building is functioning well in winters.

Whereas the respondents were dissatisfied with the air temperature in winters in American institute of Indian studies and the highest recorded temperature is 25°C which do not lies within the range with the ashrae standards, therefore this building is not functioning well in winters

The respondents were dissatisfied with the air temperature in winters in Nature interpretation center and the highest recorded temperature is 24°C which do not lies within the range with the ashrae standards, therefore this building is also not functioning well in winters.

6.2.3 Humidity

According to the literature review 30% - 60% is the acceptable range of relative humidity and in all the buildings the humidity recorded is more than the range i.e f or palika bazaar the relative humidity is 70% in august , for American institute of Indian studies the relative humidity in the month of July is 65% and for nature interpretation center the relative humidity is 65% in august and all the users were not satisfied with the humidity level inside the building. So all the buildings are not functioning well in terms of humidity specially in the month of July and August.

6.2.4 Natural Daylight/ Spatial Daylight Autonomy (sDA)

According to the literature review 55% -74% was the acceptable range of sDA inside the building and in American institute of Indian studies this desired range i.e 80%-60% was achieved and the users were also satisfied with the natural light inside the building. So this building is functioning well in terms of natural daylight.

For palika bazaar the desired range of SdA was not achieved inside the building i.e less than 20 % and users were also dissatisfied with the same so this building is not functioning well in terms of natural light**.**

For nature interpretation center the desired range of SDA was not achieved i.e 30% but the users were satisfied so this building is can be concluded from the case study that it is not functioning well in terms of natural light.

6.4.5 Way finding

Palika bazaar is not functioning well in terms of way finding as the plan is not linear and the users were also dissatisfied with the same. The plan of nature interpretation center is a not linear which makes it difficult for users to find way but the building has sign board which gives clarity to the visitors so this building is functioning well in terms of way finding . For American institute of Indian studies the plan is linear and users were also satisfied with the same so this building is functioning well in terms of way finding.

6.4.6 Perception of comforts

Palika bazaar is not functioning well in term perception of comfort as there are hidden corners created inside the buildings and users are also not satisfied with the same. American institute of Indian studies and nature interpretation center is working well in terms of perception of comfort as all corners are properly lit with artificial light and users are also satisfied with the same.

6.3 CONCLUSIONS

BERM STRUCTURE: AMERICAN INSTITUTE OF INDIAN STUDIES:

- Research has shown that these spaces offer a strong connection to green spaces, incentives for learning, comfortable temperature levels in the summer, and greater concentration and creativity. But since courtyard is covered from all the 4 sides the cold air gets trapped inside the courtyard and it becomes very cold in winters .
- Research has shown that these building provides problem for psychological problems as they have a strong linkage with outside.
- In general, the positives outweigh the negatives and disadvantages, along with the fact that courtyards have energy-saving potential.

FULLY SUMERGED BUILDING-PALIKA BAAZAR

- Research has shown that these spaces provide no natural light inside the building which is leading to increase in the lighting load of the building.
- Furthermore, with no natural light inside the building a lot of psychological problems are created such as people don’t feel confortable as some hidden corners are created inside the building.
- The percentage of humidity is very high in these type of building which creates uncomfortable environment.

EARTH SHELTERED BUILDING- NATURE INTERPRETATION CENTER

- Research has shown that these type of buildings provide a comfortable temperature in summers. and since these type of building is still connected to ground these type of building do not provide a lot of psychological problems.
- The percentage of humidity is very high in these type of building which creates uncomfortable environment

6.4 Recommendations

- For increasing the natural light inside these building it is important to use reflectors along the skylights and the use of lighter colors inside the building which will help to radiate more light inside the building.
- For improving the air temperatures in winters some strategies such as adding double grazed doors and windows can help to significantly reduce the heat loss from inside to outside which will help to maintain the air temperatures in winters.
- For improving the humidity inside the building insulation of charcoal which helps to absorb humidity or plastic sheet can prevent the transfer of water vapours from the soil to the interiors of the wall.
- The placement of sunken courtyard should be such that the natural light reaches almost all the corners of the building.
- For improving the way finding it is important to use signage and the placement of staircase and lefts should be in the center or near the skylight so that it can be visible from all areas
- Hidden corners should be properly lid with artificial light so that people don't feel uncomfortable inside the building.

6.5 Limitations

- On site verification of the result taken out from simulation was not done as proper instruments such as lux meters etc. were not available.
- All the aspect related to psychological problems were not covered in this research due to the limitation of time.
- Concentration of carbon dioxide inside these building was not undertaken from indoor comfort because of the lack of resources to measure the quality of air
- Due to the lack of time a proper analysis between different types of underground buildings was not done as only one building from each type was selected.
- As the concept of underground development and use of space is a new phenomenon in the study area, development of guidelines for questionnaire surveys has been limited.
- A detailed study about the importance of underground spaces in urban redevelopment was not taken up .
- A detailed study about the site selection for improving the overall environmental quality was not covered up .

6.6 Future research

- A detailed study about people's perception or the psychogical problems can be taken forward.
- A analysis of historical underground spaces can be done in order to understand various passive strategies that were used and can be implemented in contemporary underground buildings

- A lot of contemporary underground buildings are done by B.V doshi which include CEPT library, B.v gufa , IIM Bangalore and many more . So a detailed analysis about what all strategies that are used to improve the environmental qualities can be taken forward.

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