Study of The Thermal Performance of Closed courtyard of Institutional Campus in Dhaka

by

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Salma Begum

DEDICATION

To My Parents,

Md. Anwar Hossain Mojumder
A.K.M Alauddin

Dilara Begum
Dilruba Begum

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Chapter 4

AUST	Ahsanullah University of Science and Technology
^{O} C	Degree Celsius
EWU	East West University
IUB	Independent University
K	Kelvin
RH	Relative Humidity
RHc	Relative Humidity of Court
RHd	Relative Humidity of Dhaka
T	Temperature
Tc	Temperature of Court
Td	Dhaka's Temperature
WS	Wind Speed

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Abstract

Dhaka is a growing city and expanding in an uncontrolled way. Due to land scarcity buildings are now becoming high rise especially private educational institutions. Educational Environments/atmosphere in any school is important and interrelation of indoor/ outdoor spaces is crucial for the students' life. The interface of indoor and outdoor spaces in buildings where social interactions and gathering takes place, can be termed or denoted as *'Courtyard'*. The modern and contemporary architecture of educational building consists of elements that are derived of ancient cultural values and built forms. *'Courtyards'* as being one of these elements which have multifaceted characteristics are becoming the heart of these institutional buildings. Thermal environment of courtyard plays a great role on the quality of an institution. It directly affects people's behavior and usage of outdoor spaces. Therefore, an environmentally conscious design solution of courtyard should be given high priority to the thermal comfort implications of any institutional buildings.

Environmental behavior is an abstract concept resulting from both the human interventions and natural factors operating at different spatial scales. In urban areas the local scale is dominated by individual buildings, streets, trees, courtyards along with their materials and surface treatments. This type of urban developments can be made sustainable by creating sustainable context and by using details that enhance human activities. The aim of this study is to investigate the influence of the built surface along with its material both in the ground and in surrounding wall surface on thermal environment of '*courtyard*' of three different institutional campuses in the warm humid city of Dhaka.

The study is twofold. Firstly, the impact of built surface on the microclimatic conditions was assessed through field measurements and questionnaire survey on thermal sensation in the campus environs of three institutions were conducted to study the subjective response of students to the outdoor thermal environment in a warm humid climate. The field measurements included the monitoring of microclimatic parameters such as air temperature (Ta), relative humidity (RH) and wind speed (v). The influence of various built parameters such as building materials, green cover, etc., on microclimatic conditions and the daytime thermal sensation were assessed. Hand held instruments were used to record climatic data.

Secondly finding out the thermal conditions of courtyards during daytime in three institutional campus through computational simulation with Envi-met 3.1. The research shows that courtyards with paved exposed to sun have higher temperature and solar radiation whereas paved area under shade showed lower temperature. Again green areas under shade shows low air temperature than paved area.

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Chapter 01: Preamble

Introduction

Statement of the Problem

Objective of Research

Research Methodology

Quality Consideration

Limitation

Conclusion

Chapter 01: Preamble

1.1: Introduction

“There are children and I have met some of them, who want to know what a black hole looks like, what is the smallest piece of matter, why we remember the past and not the future, how it is there was chaos early, that there is apparently, order today, and why there is a universe” - said by Carl Sagan, describes the human nature to search for knowledge, that most fundamental urge to comprehend, measure and some way control his environment and this quest for knowledge was the drive behind the establishment of the formal education as university. Evolution of education can be traced back from the prehistoric cave painting from Altamira and Lascaux 35000 years ago.

World‟s first University was established in „Takshila‟(*figure 1-1*) now in Pakistan, 50km west from Rawalpindi. It was an important Vedic/Hindu and Buddhist center of learning. More than 10,500 students from all over the world studied there in over sixty different courses in various fields such as science, mathematics, medicine, politics, philosophy, religion, music etc. The image shows that all the cells were arranged around courtyards.

Figure 1-1 Takshila University

„Nalanada‟ (500 AD-1200 CE) (*figure 1-2*) is one of the first greatest university in history. Nalanda (Sanskrit: meaning giver of knowledge) Known as center of Buddhist Learning, Practicing & Teaching (through the world). The plan shows that the cells were all built around a closed courtyards.

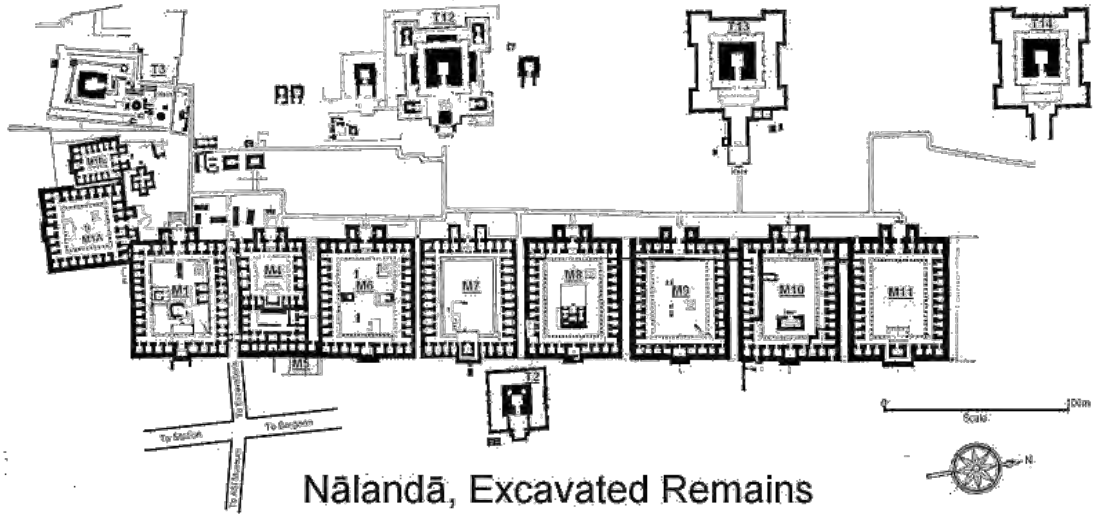

Figure 1-2 Nalanda University

University education in 19th century specifically 1916 to 17 and 1946 to 47 saw some outstanding developments. It has observed the establishment of fourteen new universities in the whole of India, both unitary as well as affiliating owes. The University of Dhaka (Dacca), established in 1921, was a part of the expansion program. University of Rajshahi, the second in the province, was established in 1954 and Chittagong, the third, in 1965. There was no increase in the number of universities till about 1985 when the Islami University became operational. These were all public universities and a demand of private universities aroused due to the lack of seats. A large number of prospective students could not get admission due to limited seats available in small numbers of public universities. In 1992, the government, by an act of Parliament, allowed establishment of private universities in Bangladesh. Since then, a large number of private universities started playing role in the country -mostly located in Dhaka and Chittagong.

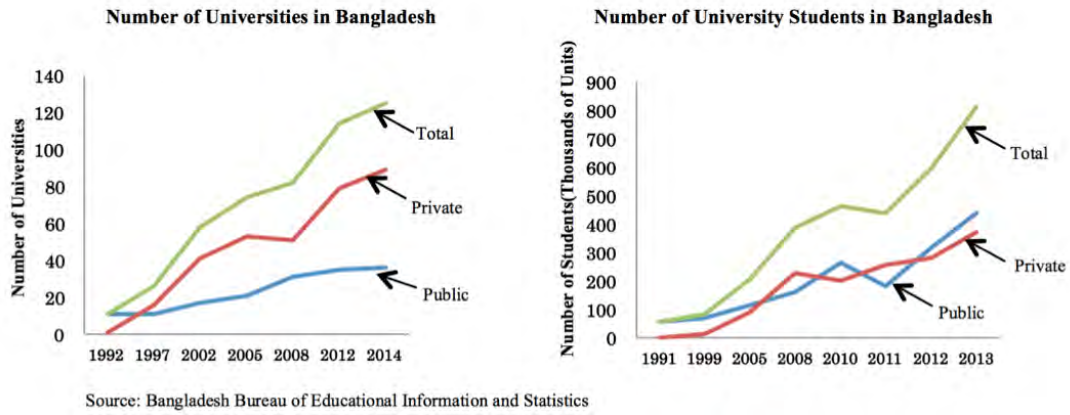

Figure 1-3 Growth and number of students in universities from 1992-2014

The Figure 1.1c shows the spectacular growth of the public and private universities in Bangladesh along with the number of students. The first private university, named as the North South University (NSU), was approved by the government of Bangladesh (GoB) on 5th November 1992. The first graph of figure 1.1c shows that from 1992 to 2014 the growths of public universities are approximately 39 whereas the growth of private universities shows a remarkable rise in graph, almost 85 universities. The second graph of figure 1.1c shows that the rate of admitted students in private is almost equal to the public universities 350 students per 100- students. After 2001, the private university concept got a significant boost again. At present the number of private universities is 85 among these 45 universities are in Dhaka. 8 private universities has their own campuses and five of them developed in a courtyard form. Dhaka is considered as a mega city of 14.5 million populations (City-population, 2012). Due to space constraints buildings are rising vertically and the only breathing area is the central open courtyards. As this is the growing typology now a days so the performance of this outdoor space is important. Thermal environment of urban spaces like courtyards plays a great role on the quality of life in a city affecting people‟s behavior and uses of space. Especially in institutional buildings where courtyards are the only gathering area for interactions and other activities. Uses of courtyards in institutional campus depend on many issues but this paper will only discuss the environmental aspect of it.

This research is focused on a very contemporary urban design aspect, which is, to study the thermal performance of closed courtyards of institutional campus. It aims to identify the relationship between urban microclimate and morphological characteristics of closed courtyard of institutional campus.

1.2: Statement of the Problem

Courtyard is a traditional architectural element that has been used in public and private buildings for centuries (Asofour, 2008). The design from of courtyard can be fully enclosed (four sided), semi-enclosed (three sided) or in some cases even two sided (Meir, Pearlmutter & Etizon, 1995). Now a day‟s courtyards being the major elements as an urban open space in institutional buildings in Dhaka. So, the study of thermal performance and outdoor comfort of closed courtyards (courtyard that is fully enclosed in four sides) in Dhaka demands an urgent thought. The courtyard geometry as well as its material makeup should be considered in the design stage in order to provide the highest level of thermal comfort possible (Meir,2000).The existence of a comfortable living environment is necessary for a healthy and productive life (Mallick, 1996). It directly affects people‟s behavior and usage of outdoor

spaces (Sharmin, 2012).The thermal environment can have several effects on people who use outdoor spaces; especially on university campuses where the thermal environments of educational living spaces are important (Srivanit, 2013). For a compact campus, as their surroundings may limit the size of an open space and may handicap circulation and accessibility; on the other side, a small open space may provide its users more intimate contact with natural restorative elements and also a more controllable microclimate for physical comfort (Lau,2014). A healthy campus should encompass diverse open spaces to satisfy different purposes (Lau, 2014).

1.3: Objective of Research

The research work concentrates on the environmental performance in terms of temperature, humidity, wind speed and radiant temperature to attain thermal comfort and thereby promote the use of spaces in courtyards. The study of courtyards has two main objectives:

- To identify the environmental conditions (i.e. Temperature range, humidity, radiant temperature and wind speed) in reference to outdoor comfort.
- To explore how the geometry, orientation and choice of materials used on the ground and on vertical surfaces around courtyard impact the environmental behavior of courtyard

The study on the thermal performance of courtyards can advise in designing of such typology buildings.

1.4: Research Methodology

The study is based on field survey data (observation in different activity zones and non-activity zones of courtyard at Institutional campus in reference to users‟ response and simulation. Few existing designed Institutional campus with closed courtyards of Dhaka referred to in the thesis as Study Sites (or S sites) will be selected as study area with different morphology. Correlations will be drawn among existing environmental parameters of the microclimates of courtyards through parametric studies. An indication for the development of existing situations and guideline for courtyards will be made.

1.4.1 Literature Survey

This phase of work will help developing a theoretical framework for this study. Research previously conducted on courtyards along with its use and function, microclimatic condition, thermal performance, morphology and parametric study of different context will be studied.

1.4.2 Field Study and Data Collection

Field investigation has been conducted to identify and map the existing use of comfortable spaces and in-situ microclimatic condition. Here the climatic data has been collected from met office and reviewed against the existing microclimatic conditions through environmental monitoring. This research has followed four steps of field survey and these are:

- Study of architectural drawing to find out the height width ratio of the campus.
- A photographic survey and observational field work in the study area to investigate the context.
- Questionnaire survey on randomly selected respondents has been done to find out the comfort voting and the use of spaces within courtyards
- Thermal conditions have been measured through spot measurements by pocket weather meter.

Collection of Data:

For this research, climatic data of last five years has been collected from MET office (Bangladesh Meteorological Department).

1.4.3 Simulation Study

To find out the microclimatic parameters, different courtyards have been simulated by simulation software of various time and different seasonal conditions to determine the microclimate and its impact. These simulations draw a comparative analysis of data between the field survey and the simulation result. For microclimatic simulation, a software named „ENVI-met" has been used.

ENVI-met Simulation: ENVI-met 3.1 version has been exercised in this research for microclimate simulation (ENVI-met). The simulation has been done for the Pre-Monsoon (March) and at three different times of a day, 9.00 hours, 12.00 hours and 15.00 hours.

1.4.4 Data Plotting for Analysis

The microclimatic condition of the study area found from the field survey and parametric study have been discussed to draw the possible relationship. In this research, the structural analysis is used for categorizing, tabulating and recombining the qualitative data [collected through questionnaire survey] and quantitative data [collected by instruments] to reveal the

answers of the set research questions. All the collected data in this research was analyzed by using information through specific techniques [tables, graphs and excel spreadsheets).

Urban Morphology						Microclimatic Parameters						
Address	Orientation	Width/height ratio	Size and Shape	Pecentage of Green and Paved area			Time	Cut Layer (Z=2 (1.60M))	Temperature (C)	Mean Radiant Temperature (C)	Relative Humidity (%)	Wind Speed (m/s)
ILAB 01						March	At 09.00	Z=2				
							At 12.00	Z=2				
							At 15.00	Z=2				

Table 1.4.4a Chart for data plotting

The morphological calculations have been calculated by following methods.

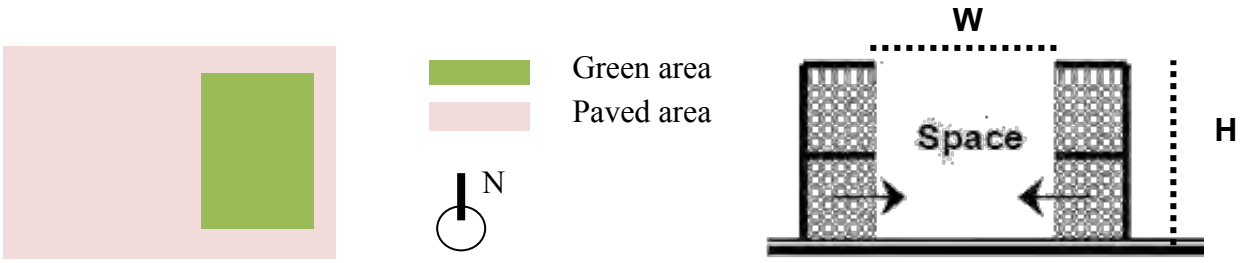

Figure 1-4 Calculation method of morphological parameters (percentage of green and paved space, orientation, courtyard ratio)

Percentage of Green space= (green space in court/ total area of court) x 100

Percentage of Paved space= (paved space in court/ total area of court) x 100

Courtyard ratio = court height / court width

All data have been plotted to the figure 1-5 for analysis

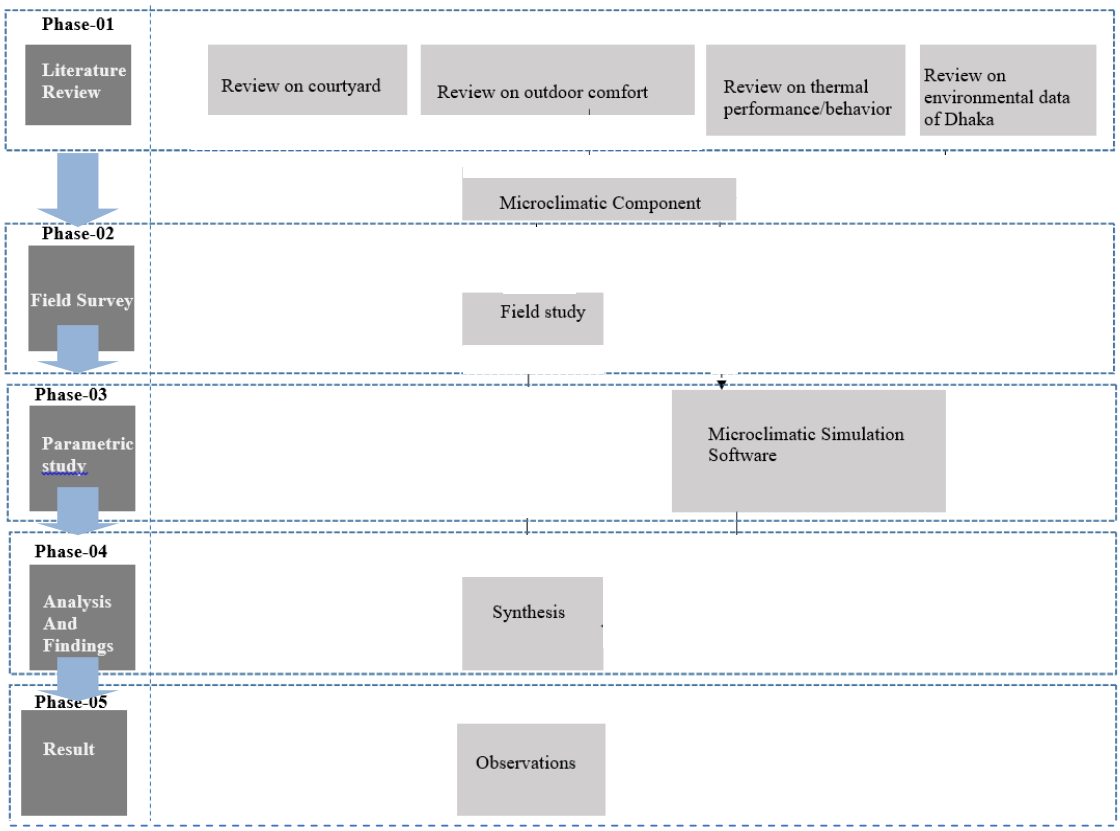

Figure 1-5 Research steps

1.5: Quality Consideration

The study has been carried out with three selected urban institution of Dhaka city with different morphology, surface character and landscape elements to find out the result. While considering the quality of the research, the following issues are necessary to be considered.

1.5.1 Internal Validity

To increase the internal validity, intensive literature study and triangulation through observation parametric study have been conducted in this research. ENVI-met 3.1 version software has been used which is an internationally established software increases the research validity.

1.5.2 External Validity

The research observation and findings for the outdoor microclimate can be used in the climatic context of Dhaka city and any other countries of similar climatic context. For simulation climatic data‟s of other areas must be changed according to the climate of the country to determine the microclimate.

1.5.3 Reliability

The software used for this research are internationally recognized and accepted, which confirm the reliability of the quantitative results. Climatic data have been collected from MET office. The instrument used for field survey is also accepted internationally which also confirm the reliability of the results. So, the result would be quantitative and reliable.

1.5.4 Objectivity

According to the literature review and theoretical perspective, there is a physical reality of the object. Specified data have been recorded with repetitions for achieving more objectivity.

1.6: Limitation

The research work focus on various environmental parameters of microclimate and courtyard morphology. These variables might get affected by many other variables which was not considered in this research for the time constraints and complexity. For this research institutional buildings have been chosen as samples result might get different for different typology and for different number of user and activity. Social behavioral and psychological parameters were not taken into consideration, only the environmental parameters were research element. Due to restriction one case study could not be surveyed though it was simulated through ENVI-met to find out the results.

1.7 Conclusion

This chapter has been described the statement of problem, objective of the research, methodology, quality considerations and limitations of the research. The independent variables and dependent variables have been defined with measuring units in this chapter. Here it is found that morphology of court is independent variable and microclimate is dependent variables. This chapter also describes the morphological aspects. This chapter also described the simulation software which have been exercised in this research. Microclimatic parameters were temperature, mean radiant temperature, relative humidity and wind speed which have been taken into consideration for this research. Percentage of green and paved area, courtyard ratio was the morphological aspect.

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Chapter 02: Climate, Urban Context of Dhaka, Outdoor Comfort and Courtyards

Introduction

Climate of Dhaka

Urban Microclimate

Urban Microclimatic Parameters

Courtyard and Private Institutional Campus

Outdoor Thermal Comfort

Conclusion

Chapter 02: Climate, Urban Context of Dhaka, Outdoor Comfort and Courtyards

2.1: Introduction

This chapter reviews the literature study of climatic context of Dhaka, microclimate-focusing air temperature, radiant temperature, relative humidity and wind speed, courtyard typology for private institutional campuses and outdoor thermal comfort.

2.2: Climate of Dhaka

Dhaka is the capital of Bangladesh. It is located at 23.24^{O}N.90.23^{O}E with an elevation between 2 and 14m above main sea level (MSL) with an average of 6.5 m (Sharmin, 2015). According to Ahmed, there are three distinctive climates in Dhaka in terms of outdoor comfort (Ahmed, 1995). According to Hossain and Nooruddin, meteorologically Bangladesh has four seasons *(table 2*.2a December to February is winter which is cool and dry, March to May is the pre-monsoon with hot and dry climate, June to September is monsoon, and October and November is post-monsoon with hot and wet climate (Hossain & Nooruddin, 1993).

Table 2.2a: Climatic division

Month	**Period**	**Wind direction**
March, April, May,	**Pre Monsoon_hot dry**	**Southwest**
June, July, August, September	Monsoon	Southeast
October, November	Post Monsoon	Northeast
December, January, February	**Winter**	**Northwest**

The winter has cold northern wind and infrequent rainfall with the average temperature ranging from 17.90^{O}C to 22.26^{O}C (MET data). The pre-monsoon period is warm with occasional heavy rainfall and average maximum temperature 36^{O} C. The highest peak temperature has been recorded in April. The monsoon is the longest period with torrential rain and high humidity (82%) with average temperature (31^{O} C). The post-monsoon is the transitional period between monsoon and winter. In this research, for microclimatic

simulations and field study, March has been chosen. As the pre-monsoon dry period starts with the month of March and temperature also found higher in this month so it has been taken as study period.

Wind rose graph shows a triangle representing the direction of air with its temperature and relative humidity. In this chart the colors are showing the speed, intensity of temperature and relative humidity from low to high and also showing which amount stays for what time period. From the wind rose graph it is found that, the highest temperature prevails in the month of March, April, May, June and July. Maximum relative humidity found in June, July, August and September. Solar radiation is high from February to May and Wind speed is high in April and May.

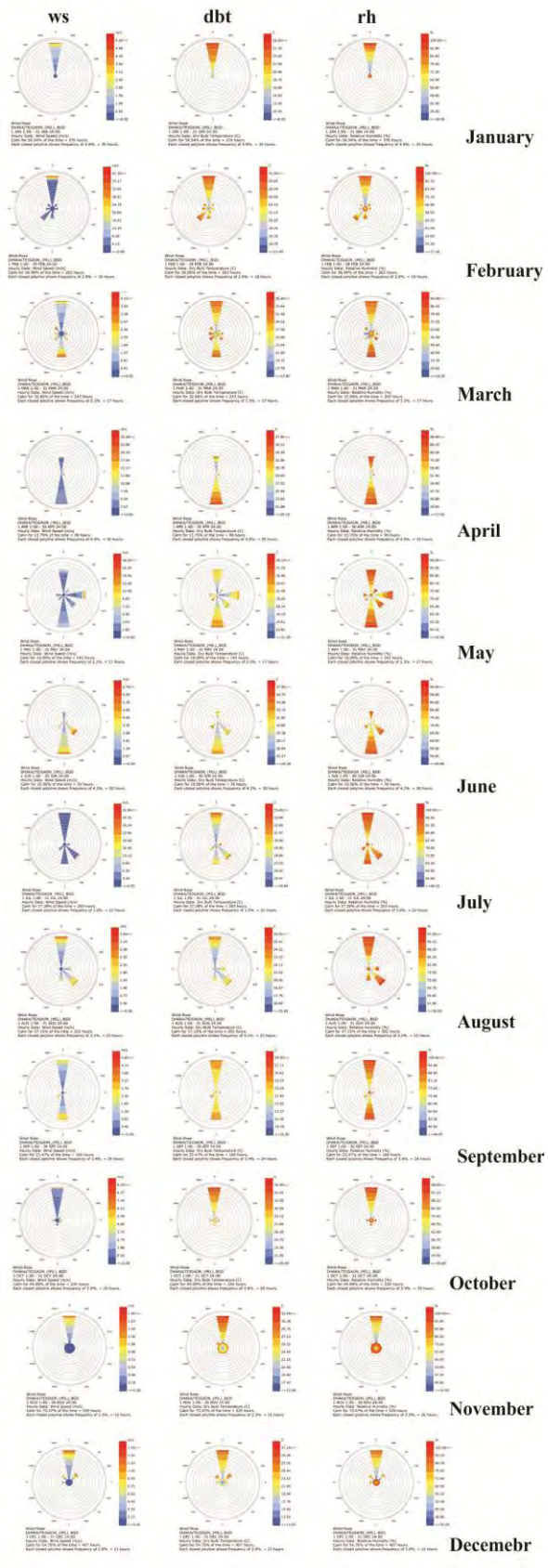

Figure 2-1: Rose graph of wind speed, wind direction, temperature and relative humidity, (MET Data 2000-2015)

From the environmental matrix chart it is found that, though the average temperature of June and July is higher (Fig 2-2), still the mean maximum temperature of April is higher (Fig 2-2) than all other months. December and January characterized with the lowest temperature. Relative Humidity is related with temperature and it is higher throughout the year in whole country indicating high moisture content of air. From the chart it is found that June, July, August and September are the more humid months, whereas February and March are the less humid months. Wind speed and direction are important for thermal comfort. In the hot period, the wind direction is from the south, mostly from the south-east direction with a speed ranging from 2.2m/s to 3.00 m/s. In the cool period, wind comes mostly from north-west with a speed ranging from 1.6 m/s to 1.8 m/. Solar radiation data shows maximum intensity occurs in pre-monsoon- the hot dry period.

High Medium Low

Month >> / Environmetal Factors	JANUARY	FABRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Temperature	17.90	22.26	27.21	29.23	29.23	29.49	29.41	28.93	29.05	27.79	23.98	19.44
Relative Humidity	69	56	56	64	73	79	78	81	79	74	68	74
Radiation	157.7	210.7	225.4	227.3	230.6	183.5	186.9	165.9	170.6	184.0	173.7	135.6
Wind Speed	1.6	1.8	2.2	3.0	3.0	2.8	2.7	1.9	1.7	1.5	1.6	1.8
Wind Direction				SW	S	SE	SE					

Figure 2-2: Environmental Matrix chart of Average temperature, relative humidity, radiation, wind speed and wind direction (MET Data 2000-2015)

Figure 2-3 shows the variations of temperature in different year. From 2010 to 2014 temperature reaches its peak in the month of April of 2014 and lowest temperature is seen in the month of January of 2011.

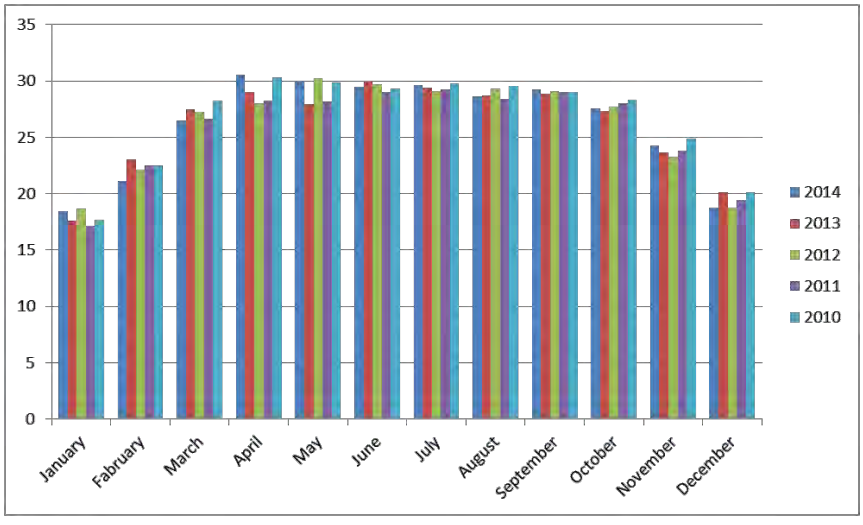

Figure 2-3: 5 years average temperature data (MET Data, 2010, 2011, 2012, 2013, 2014)

Figure 2-4 shows the variations of solar radiation in different year. From 2008 to 2012 radiation reaches its peak in the month of March 2011 and April of 2009 and 2011 and lowest radiation is seen in the month of December of 2011.

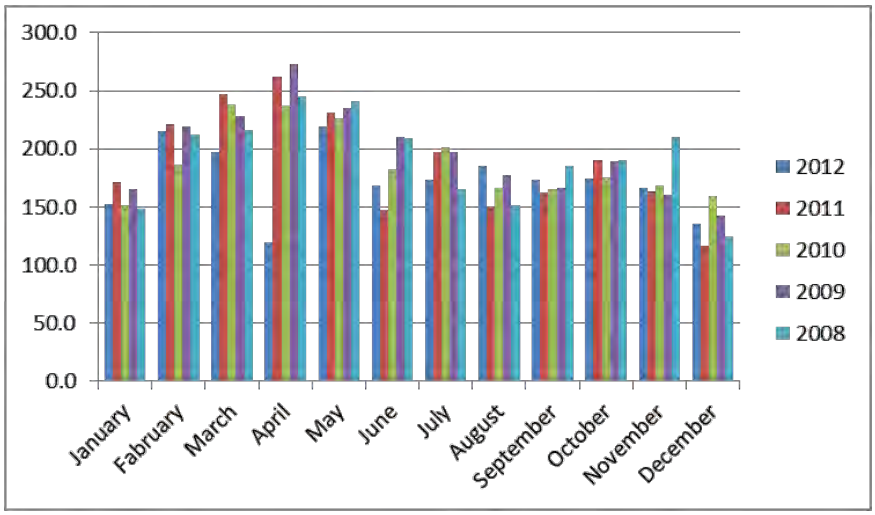

Figure 2-4: 5 years average solar radiation data (MET Data, 2010, 2011, 2012, 2013, 2014)

Figure 2-5 shows the variations of solar radiation in different year. From 2010 to 2014 relative humidity reaches its peak in the month of August of 2011 and lowest relative humidity is seen in the month of February of 2012.

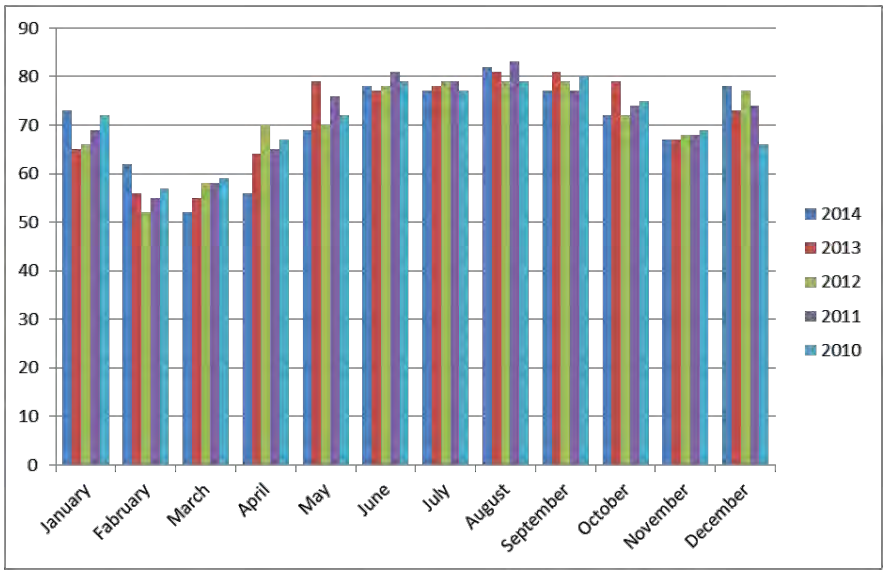

Figure 2-5: 5 years average relative humidity data (MET Data, 2010, 2011, 2012, 2013, 2014)

Figure 2-6 shows the variations of wind speed in different year. From 2000 to 2010 wind speed reaches its peak in the month of April and May and lowest wind speed is seen in the month of October

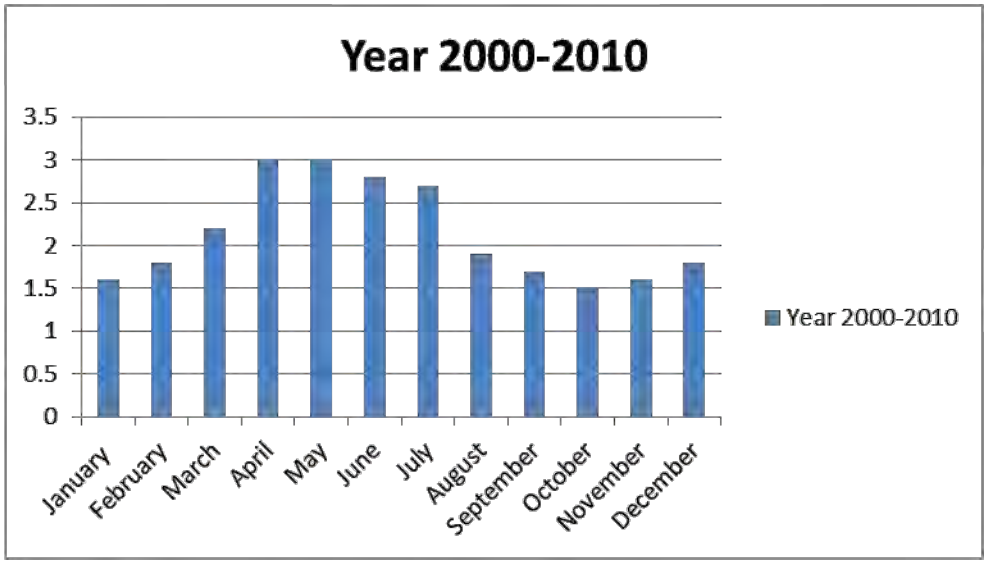

Figure 2-6: 10 years average wind speed data (MET Data, 2000-2010)

2.3 Urban Microclimate

Climate is the long term behavior of the surroundings in a selected region, with specific features such as, temperature, pressure, wind, precipitation, cloud cowl and humidity (Amany et al., 2016). An urban area is an area with a high density of human created structures in comparison with the regions surrounding it (Mahgoub et al., 2013 and El-Shimy et al., 2015). A microclimate is a local atmospheric region where the climate differs from the encircling area (Amany et al., 2016). The term may refer to areas as small as a few square meters or as large as many square kilometers (Erell et al., 2011). Microclimates exist, as an example, close bodies of water which may cool the local atmosphere, or in heavily urban regions where brick, concrete, and asphalt absorb the solar energy, heat up, and reradiate that warmness to the ambient air; the resulting urban heat island is a type of microclimate (Amany et al., 2016).

2.4 Urban Microclimatic Parameters

There are different microclimatic parameters. Some are very important to develop design solutions. Specially air temperature, direct and diffuse solar radiation, wind direction and wind speed are important to develop better design options for passive building design and renewable energy systems implementation within urban environment (Shahrestani, Yao, Luo,

Turkbeyler, and Davies, 2015).For this research work, four microclimatic parameters have been considered as variables. These are:

- Air Temperature or Dry Bulb Temperature (DBT)
- Mean Radiant Temperature (MRT)
- Relative Humidity (RH)
- Air/Wind Speed (WS)

2.4.1 Air Temperature

Air temperature is a weather parameter through which we measure how hot or cold the air is. Air temperature or dry bulb temperature is a value taken in shade with a thermometer (Koenigsberger et al., 1973). Air temperature is one of the most important climatic parameters which directly influence the termal comfort (Reported in Rahman, 2015). It is generally measured by Celsius or Kelvin or Fahrenheit scale.

2.4.2 Mean Radiant Temperature

This is one of the important factor of thermal comfort. The mean radiant temperature is defined as the uniform surface temperature of an imaginary black enclosure, with which human being exchanges the same heat by radiation as in the actual environment (Reported in Tuli, 2015). The rate of radiant heat exchange between body and its surroundings is dependent upon the surface temperature differences between these two (Reported in Tuli, 2015). It can affect air temperature. MRT is measured by Celsius or Kelvin or Fahrenheit scale.

2.4.3 Relative Humidity

Relative humidity indicates the presence of moisture in the air. “Relative humidity is the ratio of the actual amount of moisture present, to the amount of moisture the air could hold in the given temperature” (Koenigberger et al., 1973). It is expressed through percentage. Relative humidity decreases with the rise of air temperature and increases with the decrement of air temperature.

2.4.4 Wind Speed

Wind speed is the *average* speed of the wind over a 10-minute period at a height of 10 metres above the surface (Beaufort Wind Scale). Wind direction is the indication of wind from

where it is coming. For an open flat area it is measured at a height of 10 meter but in urban area this is guided by urban forms. Wind direction can be grouped into 8 or 16 categories, the four cardinals (North (N), South (S), East (E) and West (W)), four semi-cardinal (North-East (NE), South-East (SE), South-West (SW) and North-West (NW)) and eight tertiary compass point (Koenigberger et al., 1973). It is measured by meter per second (ms^{-1}) or nautical mile per hour (knot) or mile per hour (mph)

2.5 Thermal Comfort

According to ANSI/ASHRAE Standard 55-2013, thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation (ANSI/ASHRAE Standard 55) (Wikipedia). There are three determinant factors of comfort; (i) physiological determinants, for example metabolic rate and acclimatization, (ii) behavioral determinant, for example, clothing and migration, (iii) environmental determinants, for example, Dry Bulb Temperature, radiant Temperature, Relative Humidity and Airflow (Ahmed, 1995).

Figure 2-7: ASHRAE Thermal sensational scale

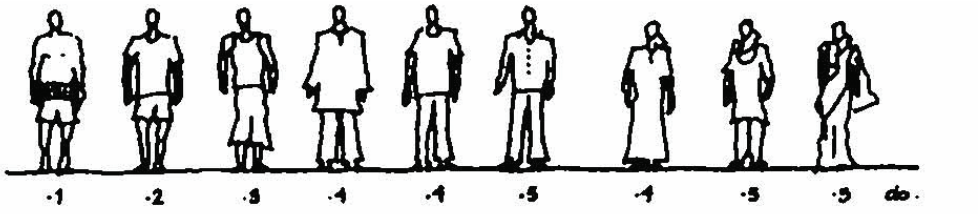

Figure 2-8: Typical domestic clo value (Mallick, 1996)

2.6 Outdoor Thermal Comfort in Dhaka

Comfort preferences are subjective and it varies with the locations, acclimatization to a particular climate. Dhaka is in a Tropical Monsoon climate with a distinct warm-humid rainy season. Comfort in Outdoor space is important in tropical countries like Dhaka. Figure 2-9 shows the comfort zone for summer in Dhaka. It shows that Dhaka under still air conditions for people wearing typical summer clothes (.4 to .5 clo) and being involved in sedentary activities, the comfortable temperature ranges from 28.5^{O}C to 32^{O} C at an average relative

humidity of 70%. The range is suggestion of tolerance to high temperature and humidity (Sharmin, 2012).

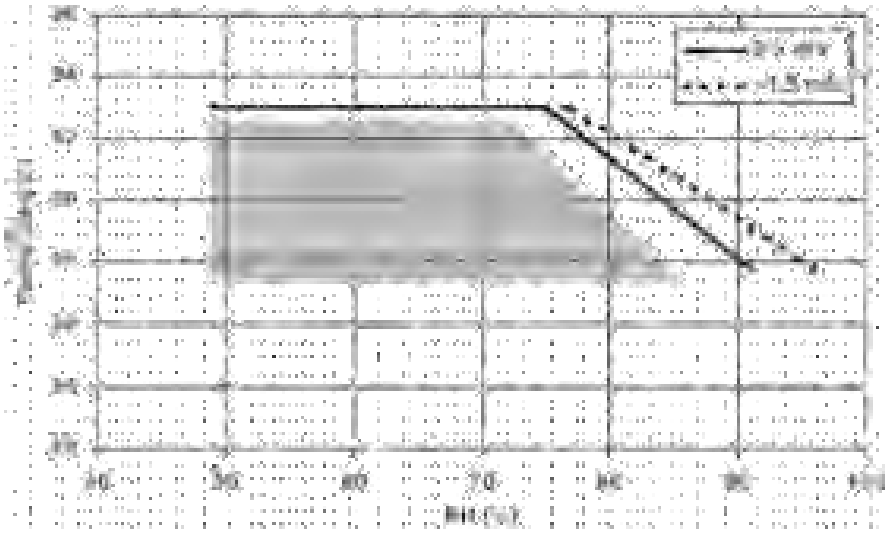

Figure 2-9: outdoor comfort zone for summer in Dhaka (Ahmed, 2003)

2.7 Courtyards and Institutional Campus in Dhaka

Courtyard is a traditional architectural element that has been used in public and private buildings for centuries (Asofour, 2008). Courtyard is an architectural design element commonly applied in tropical buildings for its social, environmental and therapeutic potentials (Almhafdy, 2013).The main design concept in such buildings is creation of internal open space to which other internal spaces are oriented (Asofour, 2008). It does not have a fixed plan though the basic plan of a residential courtyard is usually rectangular or square. The design form of courtyard can be fully enclosed (four side). Semi-enclosed (three side) or in some cases even two sided (Meir, Pearlmutter & Etizon, 1995). A courtyard on a micro and a more domestic scale can provide privacy, a change from the ruptured pace of the everyday life, have a societal impact as a meeting space in an urban context, and also have an environmental impact on the internal conditions in a hot and humid climate (Patherya, 2012). A study by Patherya and Lau has been conducted to assess the behavior of courtyard as a design element in India and its implication as an environmental solution. Research was done on two different areas for a specific type of courtyard that is closed courtyard standing as an island without urban context. The aim was to develop an optimum width to height ration of the courtyard form that remains shaded mostly through the summer and monsoon, whilst in

winter letting the sun in. The research found out some width to height ratios of closed courtyard to have preferable conditions. The ratios found from the study are w2/h=1/1 vs w1/h=1/1, w2/h=1/1 vs w1/h=2/1, w2/h=2/1 vs w1/h=2/1 and w2/h=2/1 vs w1/h=4/1 where w2 and w1 are the width of enclosing surface and h is the height. Figure 2-10 a shows a typical section of courtyard where the enclosure is about the same height as its width.

Another study by Lau & Yang (2009) has been conducted on university campus courtyard in Hong Kong to find out the user experience. Results found out from the study showed that meditation garden was good for academic ambience.

Another research by Abdulbasit and Sabarinah has been conducted on Closed Courtyards of Hospitals in Malaysia. This research was done on rectangular shape closed courtyard for different orientation to find out the usability. Result showed that courtyards with shading devices had more positive effect as more people used it.

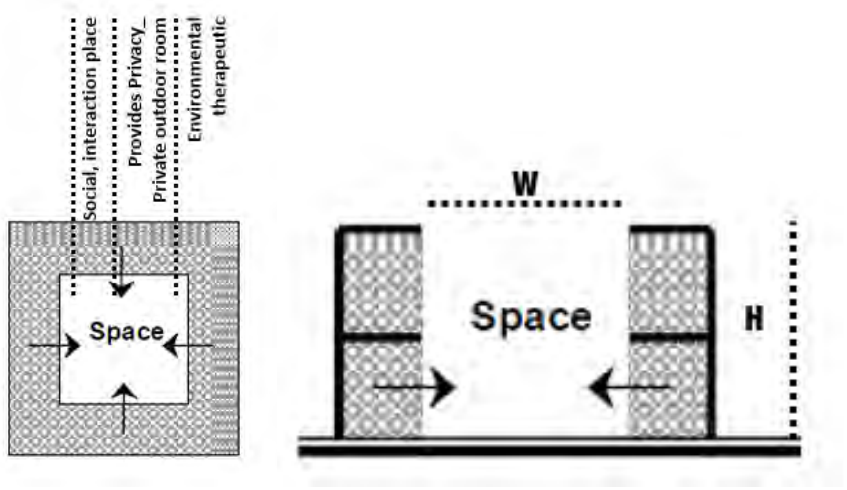

Figure 2-10 Schematic diagram of a courtyard where w=h (w=width, h= height)

In the context of Bangladesh currently the number of private universities is 85 among these 45 universities are in Dhaka. Among these 8 private universities has their own campuses and five of them developed in a courtyard form. Dhaka is considered as a mega city with a huge number of populations. Due to space scarcity buildings are rising vertically and the only breathing area is the central open courtyards. This has become the growing typology now days so, the performance of this outdoor space is important. Thermal environment of urban spaces like courtyards plays an important role on the quality of life in a city which affects people"s behavior and uses of space. This is very important for institutional buildings where closed courtyards are the only gathering area for interactions and other activities.

2.8 Conclusion

This chapter has been stated all key words and variables of the research. Thermal parameters for example air temperature, solar radiation, relative humidity, wind speed which are the major concern for Dhaka. It was observed that, from March to May, the climate found with high temperature associated with high solar radiation while from June to July, the climate found with high humidity associated with high temperature. It also covered the outdoor thermal comfort of Dhaka city and the emerging institutional building typology with closed courtyard.

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Chapter 03: Field Study and Analysis

Introduction

Methodology

Selection of the study area

Field Study

Data Collection

Analysis and Discussion

Conclusion

3.1 Introduction

This chapter discusses broadly on the field survey done to conduct the research. This chapter also explains the study area, selection of samples, etc. This chapter also discusses broadly on the data, chart, image and graph found from field survey done for this research. Field data collection is made within a limited period of time during extreme discomfort condition of the year. March has been chosen as the study period. Again the diagrams has been analyzed to find out the comparison of the study areas. This chapter also discusses the observation and findings of the research. The observation and findings portrays the relationship among microclimate, courtyard geometry, orientation, surface characteristics, and landscape elements of the study area.

3.2 Methodology

The research was done in two steps. Firstly, field survey has been done on three existing designed institutional campus with closed courtyards in Dhaka to identify and map the existing use of comfortable spaces and in-situ microclimatic condition. Four types of field study have been done and these were:

- Physical survey is made on the basis of architectural plan and visual observation.
- To understand the context and built forms, a photographic survey, observational field investigation and have been done in the Study Sites.
- Questionnaire survey on randomly selected respondents (40 people) has been done to find out the comfort voting and use of zones within courtyards.
- Thermal conditions are measured through spot measurements by the pocket weather meter.

The second step is microclimatic parameters study of closed courtyards by simulation. Simulation has been done with ENVI-met simulation software for different seasonal conditions. Four microclimatic parameters, temperature, relative humidity, radiant temperature and wind speed have been considered for this research.

The third steps is to find out a correlations among the existing environmental parameters of the microclimates of courtyards through parametric studies.

3.3 Selection of the study area

The study areas were chosen from different zones of the metropolitan area of Dhaka city. The criteria for selection were based on three factors. Firstly the areas must have an institutional building. Secondly, the study sites had to be of same size and volume. Thirdly, the urban situations of study sites should have distinctive microclimatic profiles so that variations can be studied. The following section discuss the considerations for the selection of the three study areas (fig. 3-1) in Dhaka, namely:

1. Study Site I (AUST,Tejgaon)
2. Study Site II (EWU, Aftabnagar)
3. Study Site III (IUB, Bashundhara R/A)

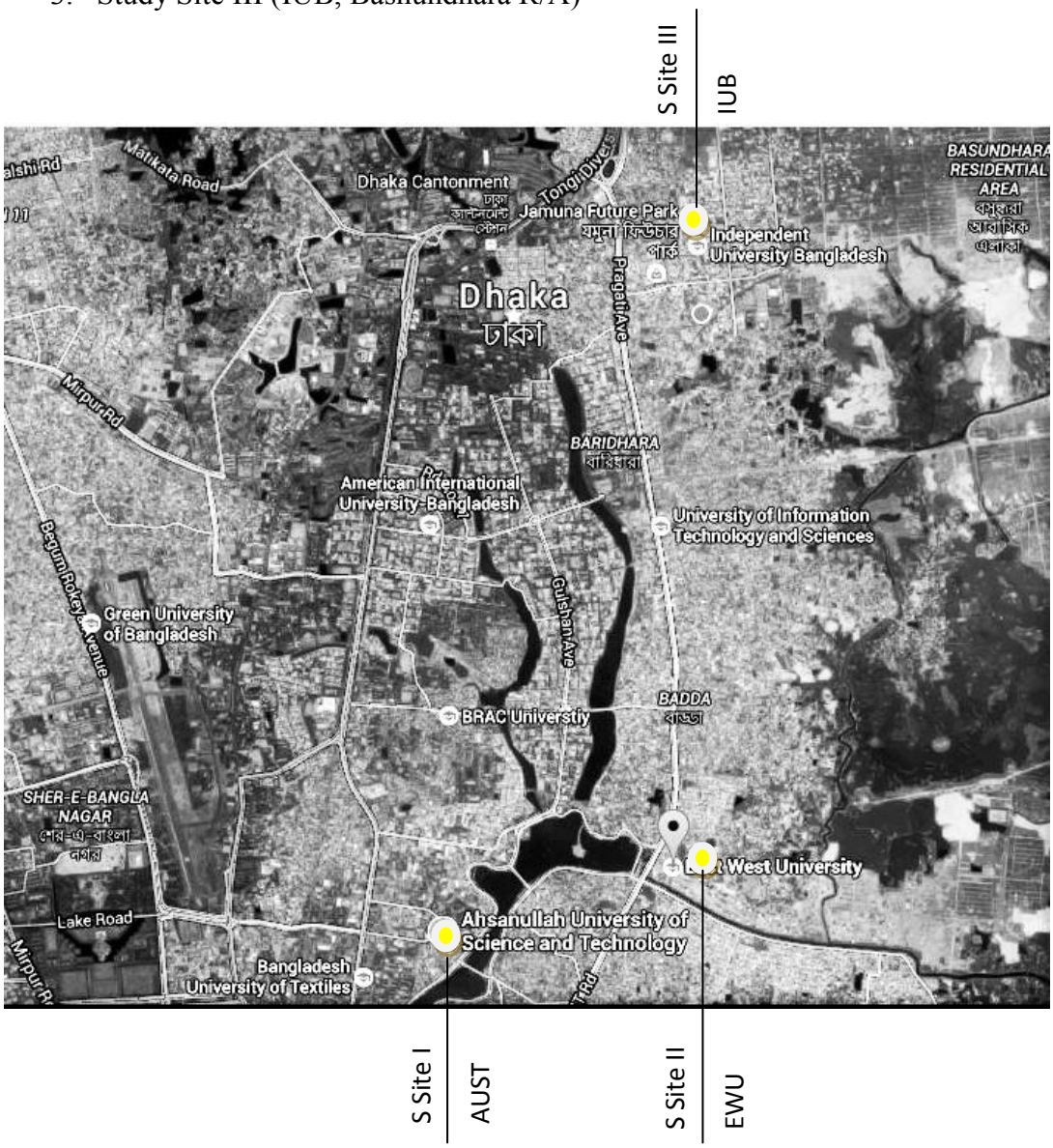


Figure 3-1 Location of the Study Site in Dhaka City

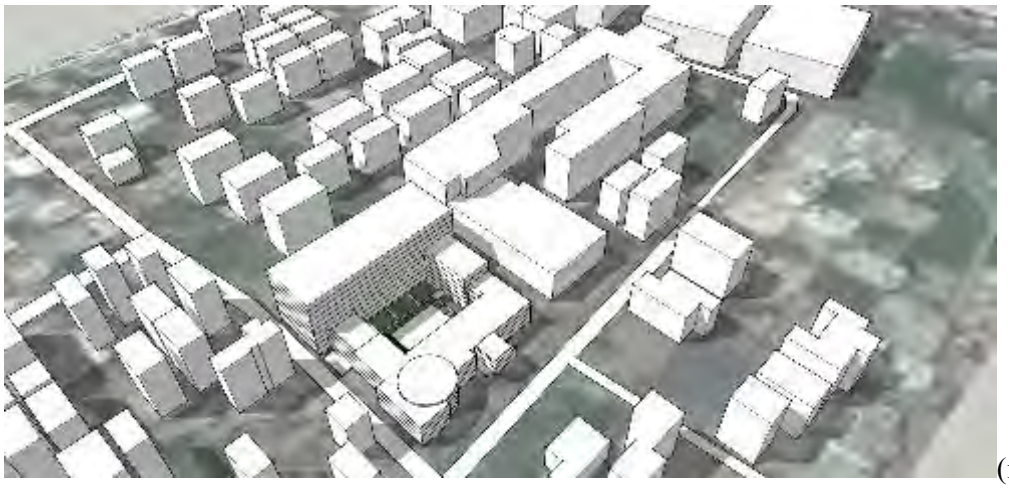
Study Site I has a distinct feature, a courtyard with paved and green surface with free circulation around. This Lab is situated within an Industrial area. Most of the buildings are low rise around it.

Study Site II has a full paved courtyard and circulation on three side. This is situated in Jahurul Islam City, Aftabnagar. This building has almost nothing on its three sides and a slum area on the rear side or north side of the building.

Study Site III has a mixture of green, pave and soft green with circulation on two side. This is situated in Bashundhara residential area. This building has two roads on its east and north side, on it west is shadowed by North South University and the south is open. Figure 3-2 showing the three SSites with its surroundings.

(i)

(ii)



(iii)

Figure 3-2 Location of the Study Site in Dhaka City (i)AUST (ii) EWU (ii)IUB

3.4 Description of the selected area

Each of the three survey spots is taken to represent a typical institutional building typology. Ground floor is chosen for climatic data recording. All the data recorded at 2m level due to human activity and ease of access.

3.4.1 S Site I Ahsanullah University of Science and Technology

Ahsanulla University is a private engineering university in Dhaka, Bangladesh. The university was founded by the Dhaka Ahsania Mission in 1995. Dhaka Ahsania Mission is a non-profit voluntary organization in Bangladesh. The Mission was established in 1958 by Khan Bahadur Ahsanullah. The permanent Campus of the University has been built on 5-bighas (1.6 acre) of land at Tejgaon Industrial Area which is located in the heart of Dhaka City. The land use in this area is quickly changing from an industrial area to a commercial area. The 10-storied building including 2-level basement has a total floor area of more than 4 lac sq. Figure 3-3 showing the location map of AUST in the context of Dhaka city. It is situated on Love road in the Tejgaon Industrial area. Most of the structures in this area are old and 2 to 5 story high.

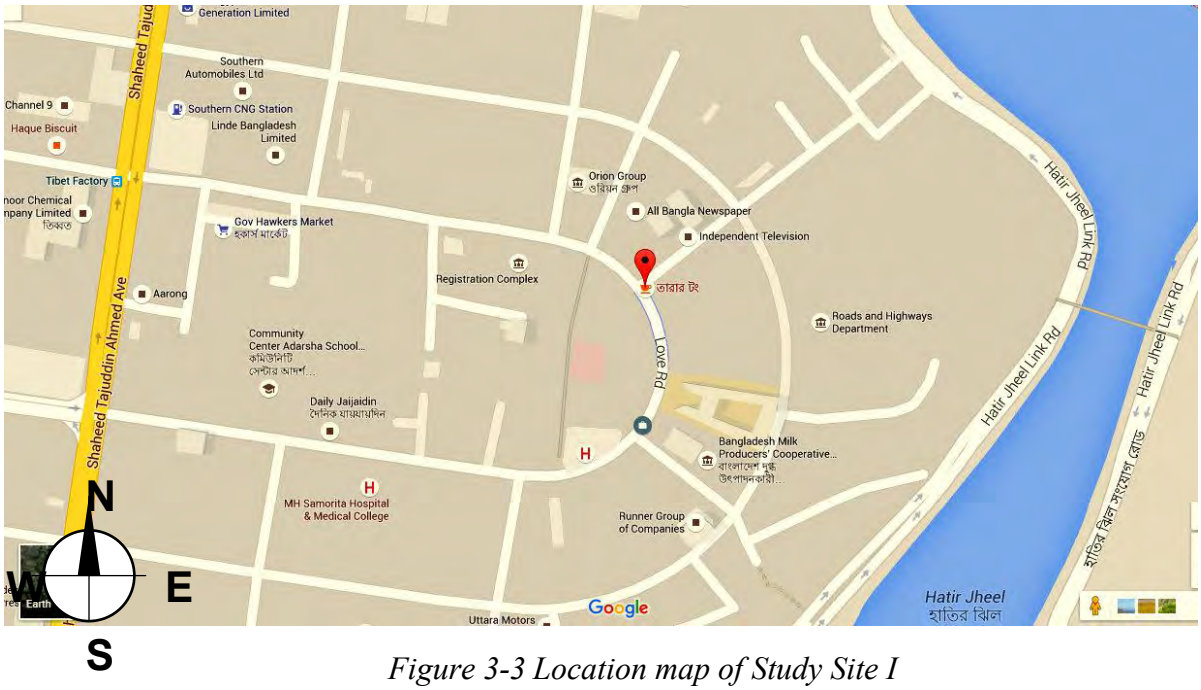


Figure 3-3 Location map of Study Site I

Figure 3-4 is showing its site surroundings. On its north side it has roads and highway office which is a 2 story building and some 1 storied small shops. On its south it has milk vita office which is one storied. On its east it has some one storied building and on its west it has few

one storied building with open area. There are two 8 storied buildings within a close proximity

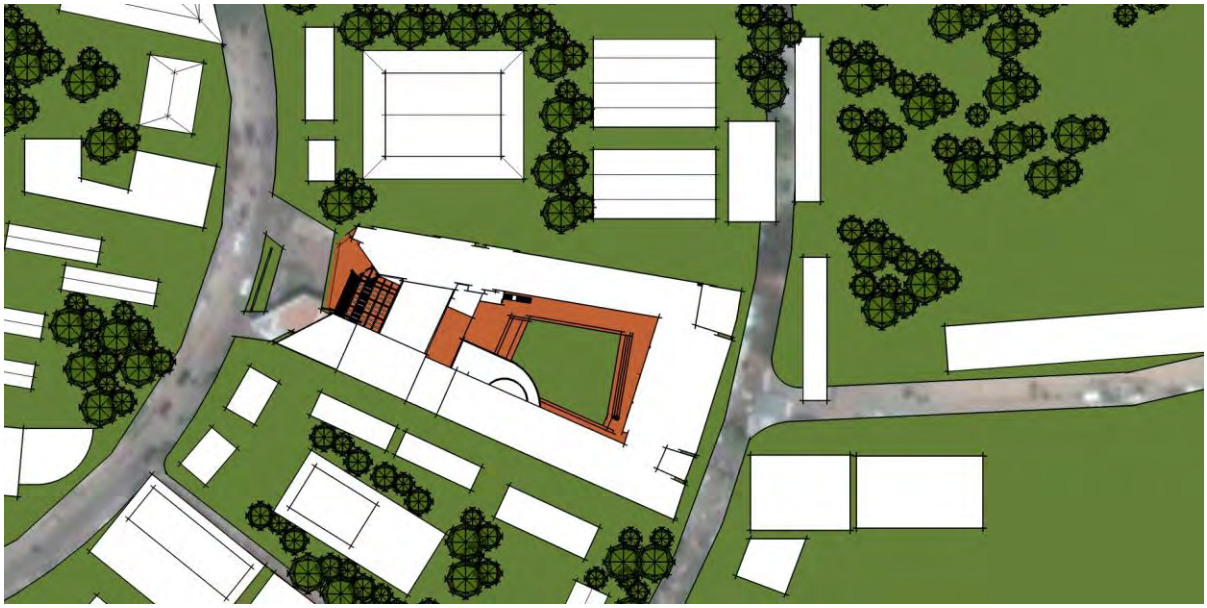


Figure 3-4 Site Surroundings

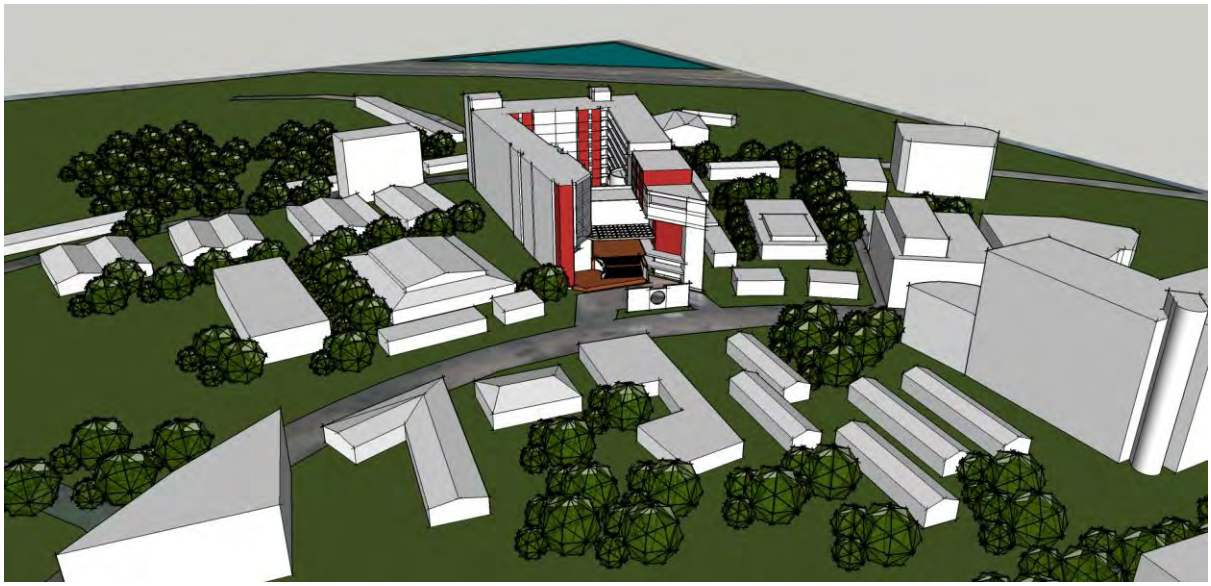


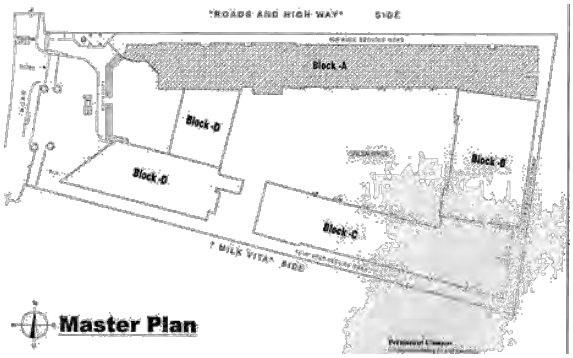
Figure 3-5 Site Surroundings in 3d

Figure 3-6 Site Surroundings in reality

View from North View from West View from south West

Figure 3-7 Site Surroundings in reality

This building is a 10 storied institutional building covering almost 42,185 sft in ground. Figure 3-8 is showing the basic zoning of the institution. North block that is block A houses different departments, block B houses library and lab facilities, block C houses architecture and BBA departments with some common facilities and block D houses administration. Figure 3-9 is showing the ground floor plan. The ground floor is occupied by common facilities. The courtyard is surrounded by circulation area on its two side, and the other sides have some functions including cafeteria, indoor game area, and bank and ladies common room.



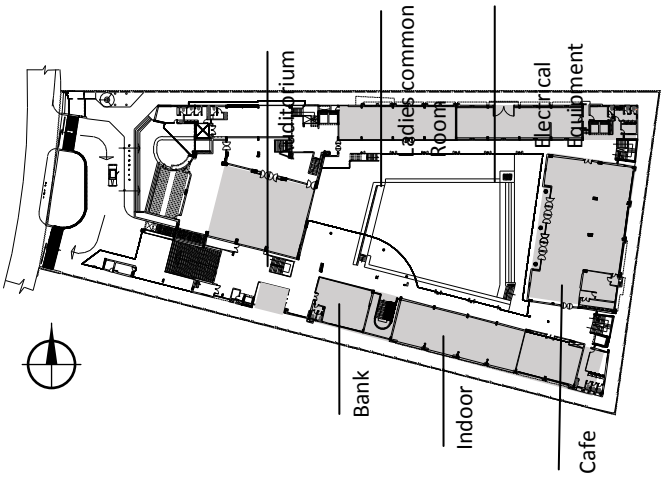


Figure 3-8 Functional zoning *Figure 3-9 functions around courtyard*

Figure 3-10 View of courtyard

Figure 3-10 is showing the view of courtyard with its enclosure. This court is partly covered by pave and partly by green. The percentage of green and pave ratio is 44:56. Figure 3-11 is showing the material mapping of courtyard where we find different types of pavement. One is made of concrete and other one is paved with tiles. The green portion has small shrubs and a tree at the center. Some part of the green is partly shaded by overhang. Most of the section is covered by shade in day time.

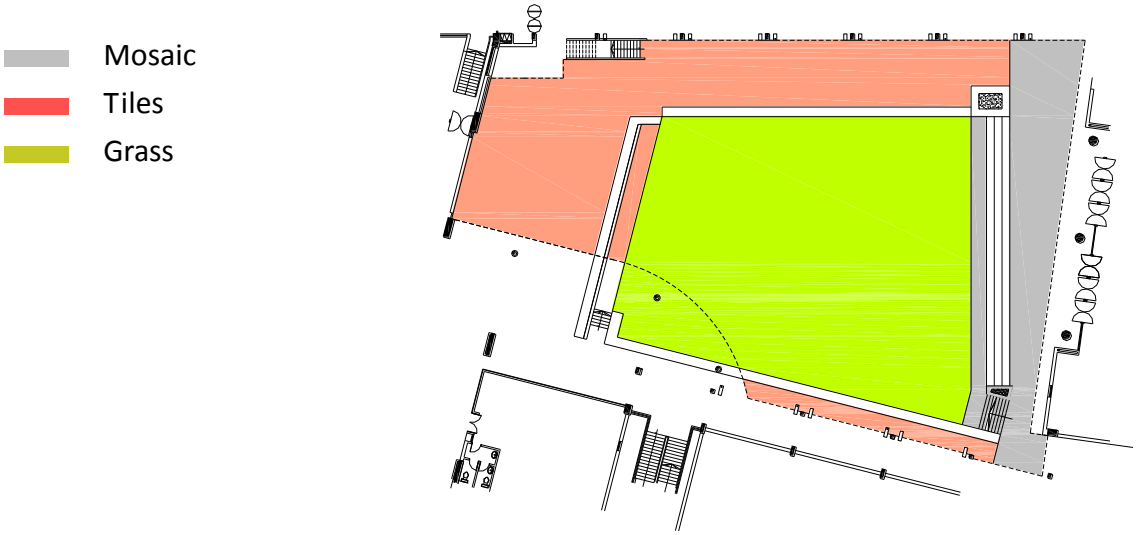
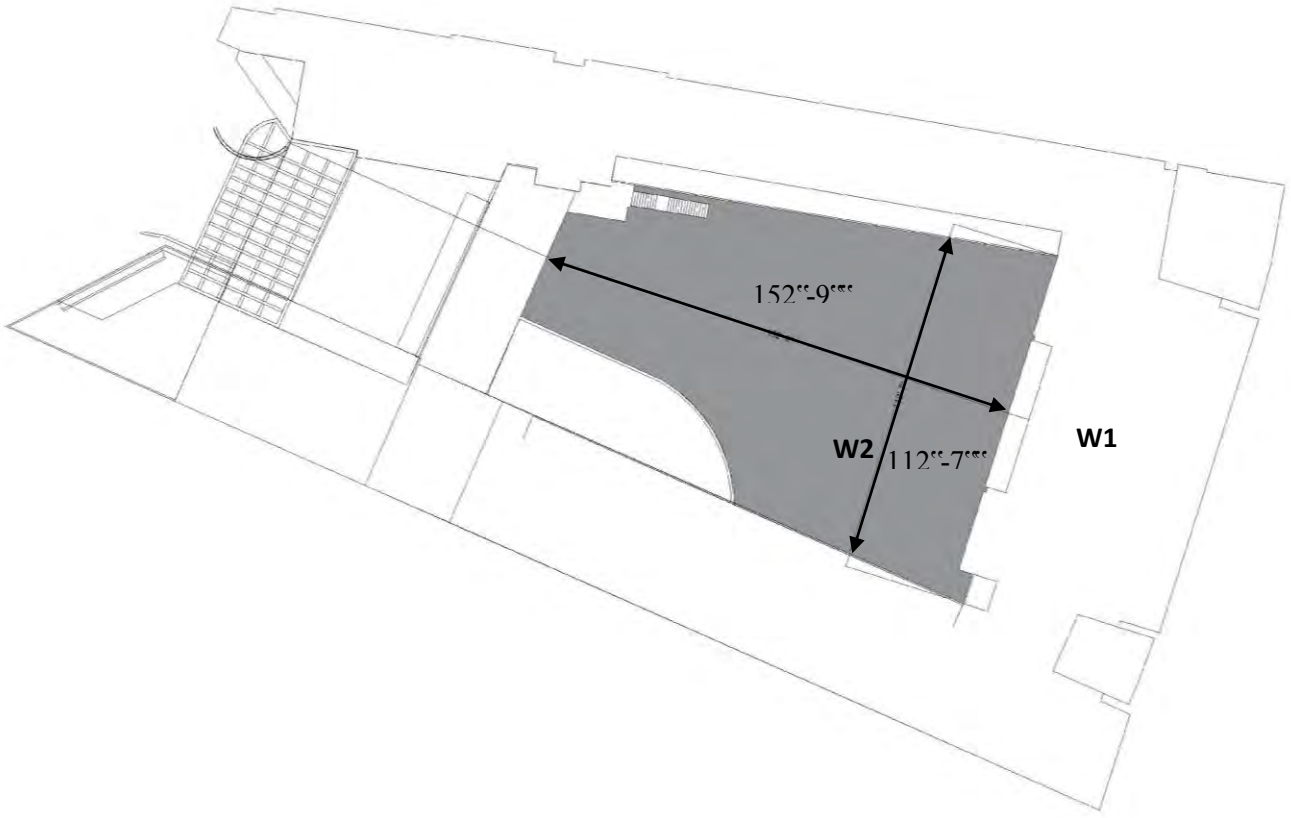


Figure 3-11 Material Mapping

Figure 3-12 is showing the shape and size of the court. The shape is irregular and elongated in east west orientation. The area of the court is 12,498 sft. Figure 3-12 is showing the dimensions of arms where the regular shape arms are denoted as w1 and w2. Figure 3-13 and

figure 3-14 shows the section aa and section bb respectively from where we get the information of height width ratio of courtyard. From its ratio it is found that it has a good enclosure.



W1-Width 1

W2- Width 2

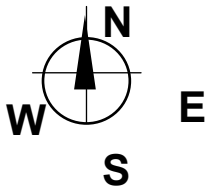


Figure 3-12 Size and Shape of court (not to scale)

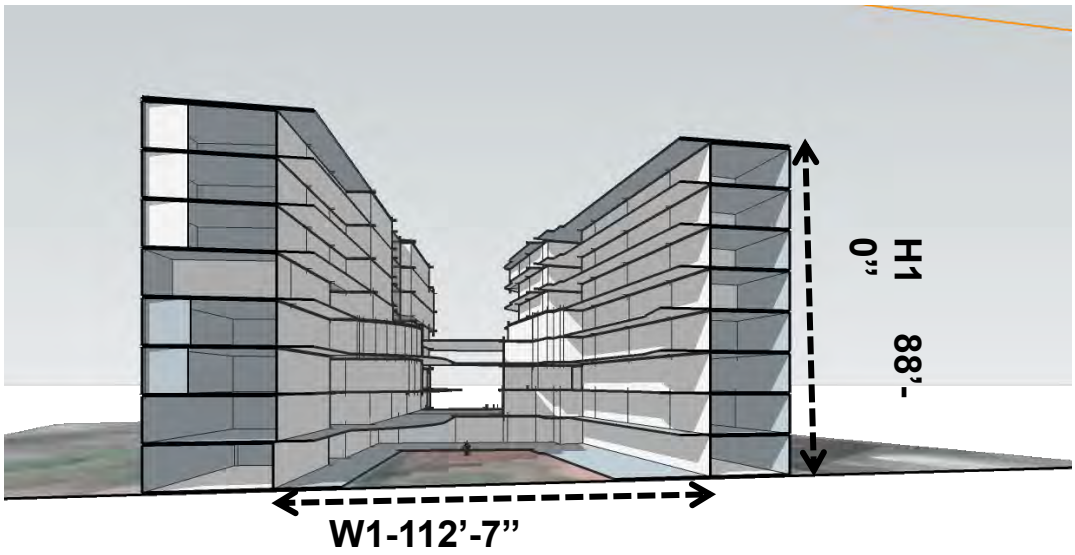


Figure 3-13 Section AA showing W1/HI=1.27:1

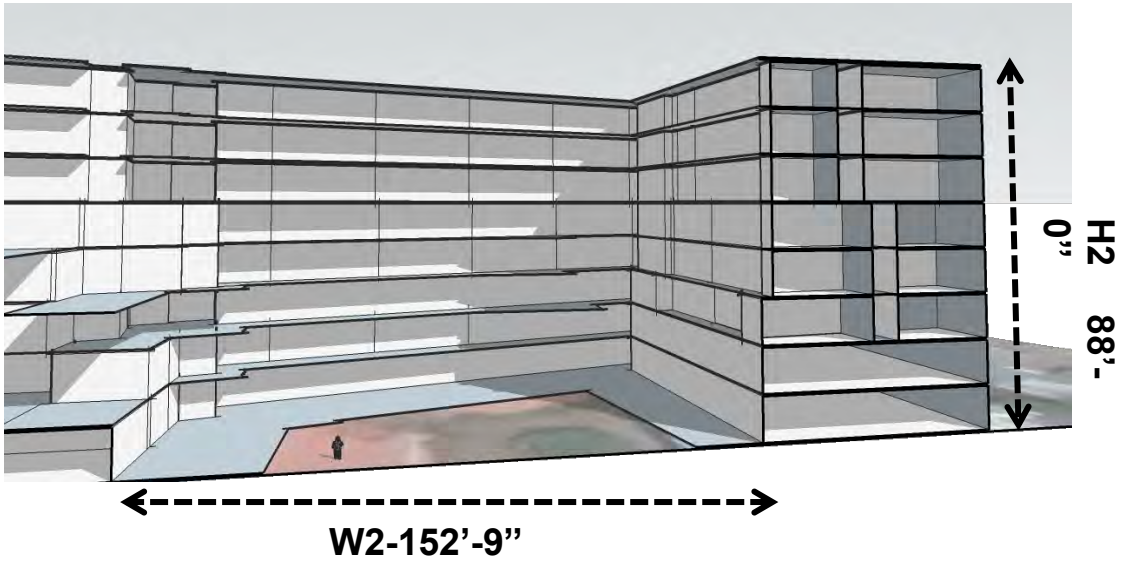
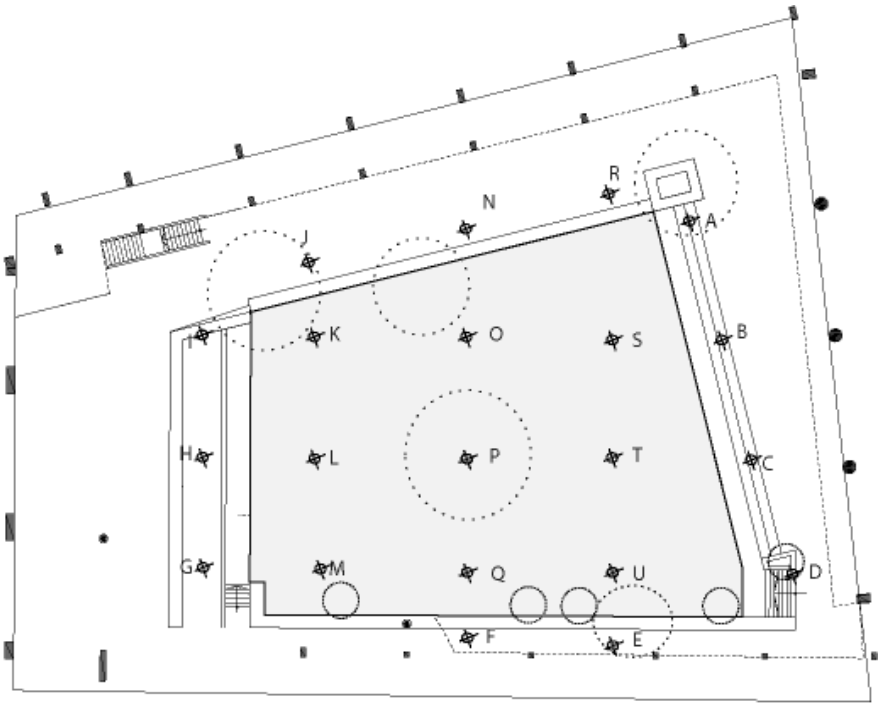


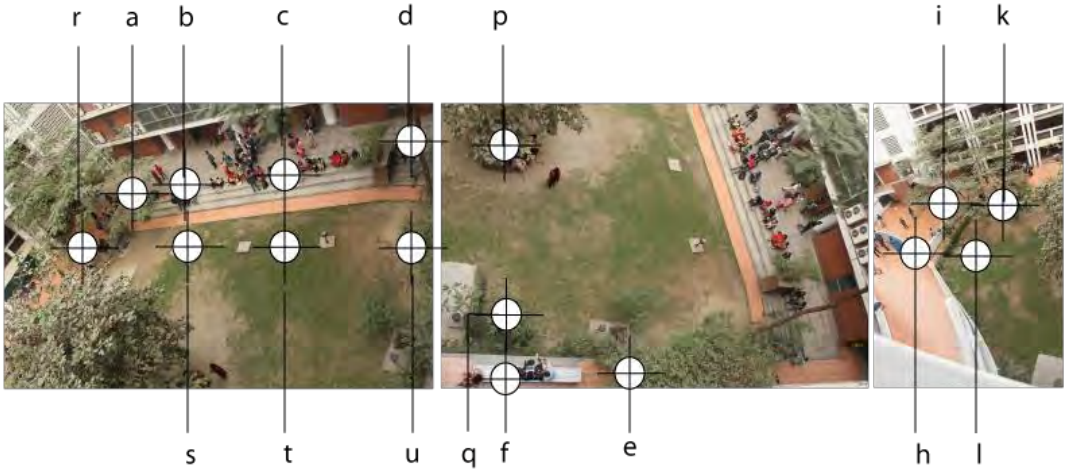
Figure 3-14 Section BB showing W1/HI=1.72:1

To find out the most useable space, unusable space an observation was done and an observation map was developed with some station points. Climatic data was recorded on this points. Figure 3-15 is showing an image of observation of used and non-used spaces. Figure 3-16 is showing these weather station points.

Figure 3-15 Observation image



(a)



(b) *(c)* *(d)*

Figure 3-16 (a) top view of court showing weather station points (b) point a,b,c,d,s,t,u,r (c) point e,f, q,p (d) point I,k,h,l

A	Pave with tiles under tree	K	Located on a concrete block beside a tall tree exposed to sun most of the time
B	Paved with tiles exposed to sun	L	Located in green space
C	Paved with tiles exposed to sun	M	Located in green space beside a small shrub
D	Paved with tiles partialy under tree	N	Located in paved with tiles exposed to sun
E	Paved with tile under tree and shade	O	In green
F	Paved with tile under shade with some creepers behind	P	Located under a big tree
G	Paved with tile under mass	Q	Located in green shaded by mass mostly
H	Paved with tile exposed to sky	R	Paved with tiles exposed to sun
I	Paved with tile exposed to sun	S	Located in green exposed to sun
J	Paved with tile partially under tree	T	Located in green exposed to sun
		U	Located in green with some shrubs shaded by mass mostly

Table 3.4.1a Description of weather station point

3.4.2 S Site II East West University

EWU is a private university in Dhaka, Bangladesh. It was established in 1996. Its campus is in Jahrul Islam City, Aftab Nagar.The permanent campus of East West University is located in Aftabnagar, Rampura on the Progoti Sarani (fig 3-17) close to Bangladesh Television on 7.4 bighas of land. Total floor area of the 9 storied university complex is 4,58,957.04 square feet with modern facilities. Most of the buildings are above 6 story. Figure 3-18 & 3-19 are showing its site surroundings. On its north side it has slum area *(figure 3-22)* mostly 1 storied in heights. On its south it has some 1 storied small shops. On its east it has some residential building of 5 to 9 storied and on its west it has few one storied building with open area. It has a wide road (*figure 3-20*) on its south from which building is accessible.

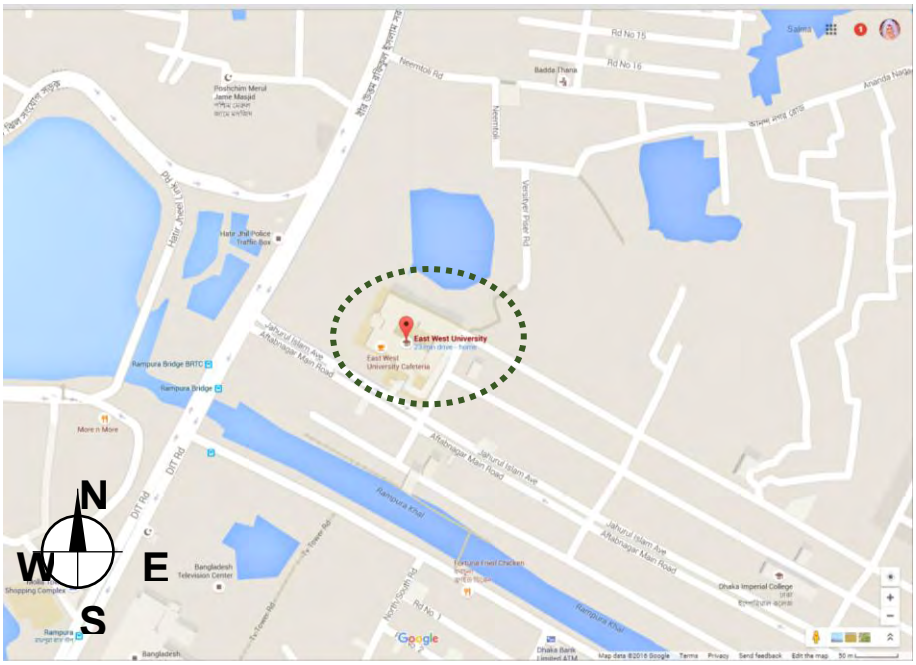


Figure 3-17 Site Locations

Figure 3-18 Site Surroundings

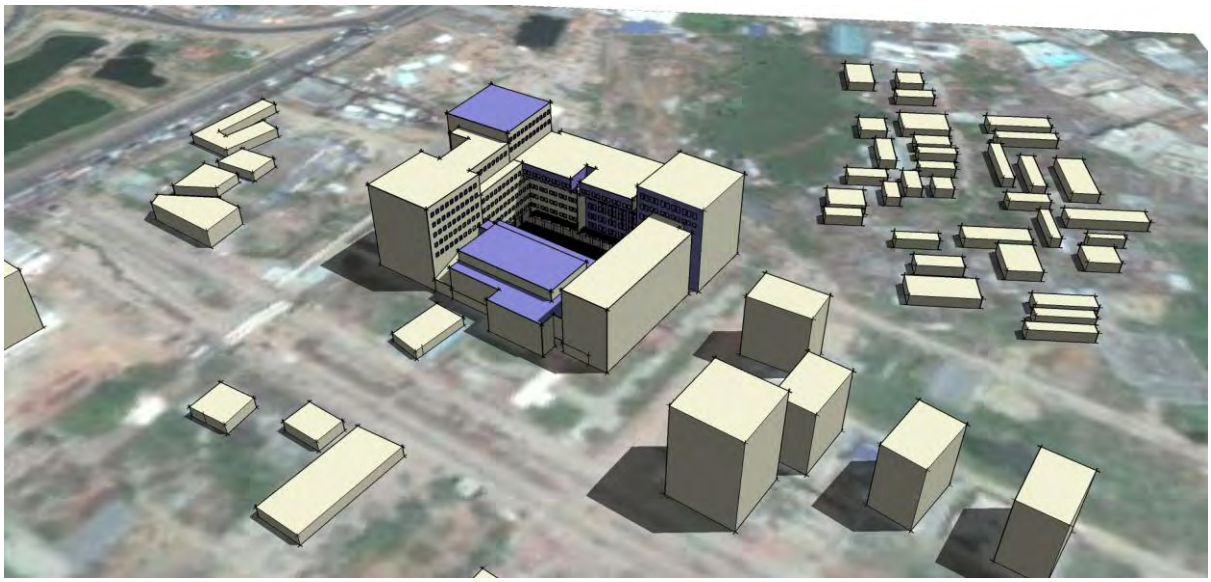


Figure 3-19 Site Surroundings in 3d

Figure 3-20 Site Surroundings in reality from south

Figure 3-21 Site Surroundings in reality view from north

Figure 3-22 Arial view of north side of building

This building is a 9 storied institutional building covering almost 75,014 sft in ground. Figure 3-23 is showing the basic zoning of the institution. North block houses all the class rooms with double loaded corridor, block west block houses seminar room at ground, south block houses some common facilities and east block houses administration. The ground floor is occupied by different facilities. The courtyard is surrounded by circulation area on its three sides, and the other side have some functions.

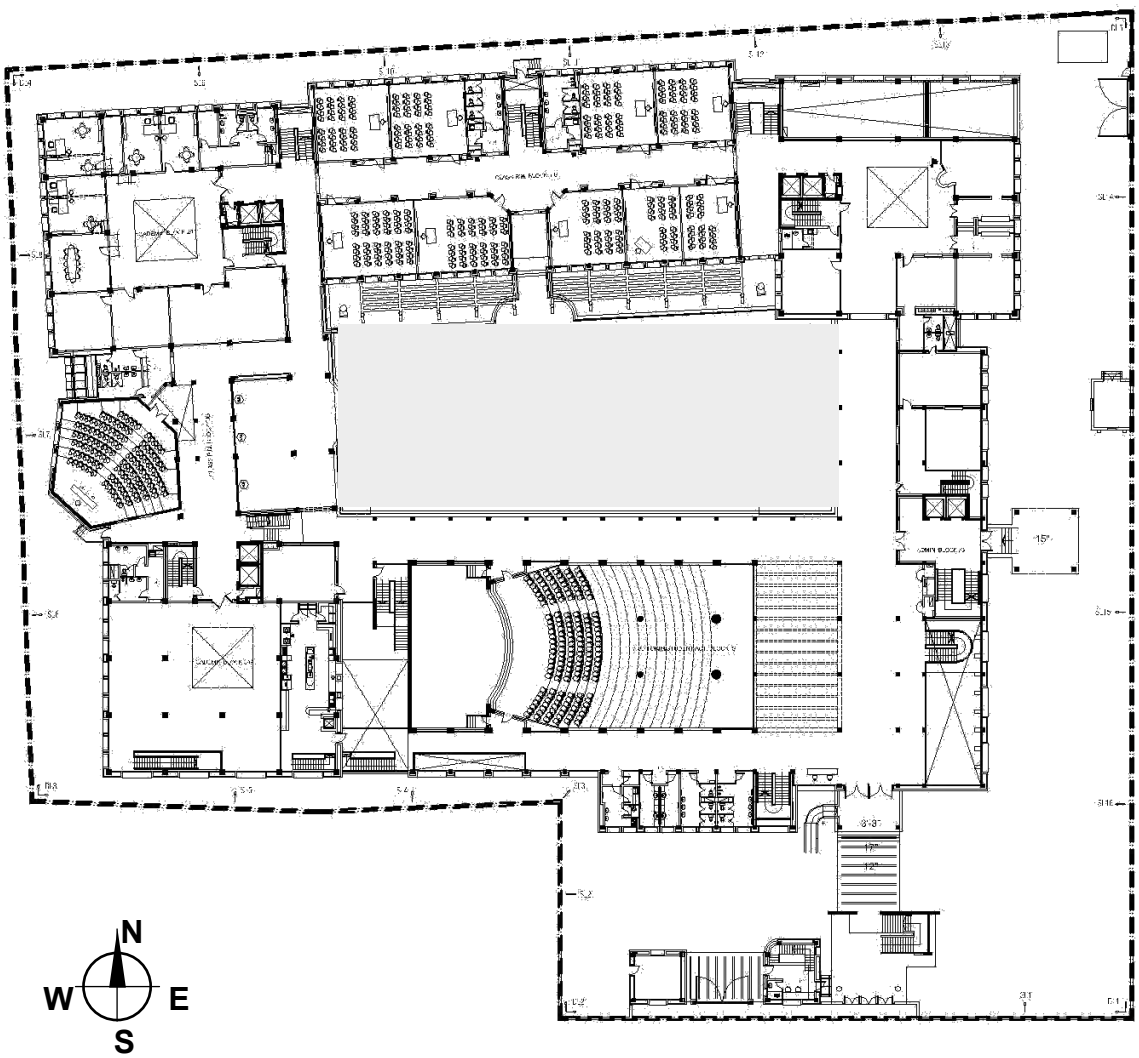


Figure 3-23 Ground floor plan (not in scale)

Figure 3-24 is showing the view of courtyard with its enclosure. This court is fully covered by pave with some low height sitting on its north. The court is paved by red brick with some black strips dividing into squares. Most of the section is covered by shade in day time by the south block. There are some steps around the court which is used by the students. This court is seen crowded mostly during any program.

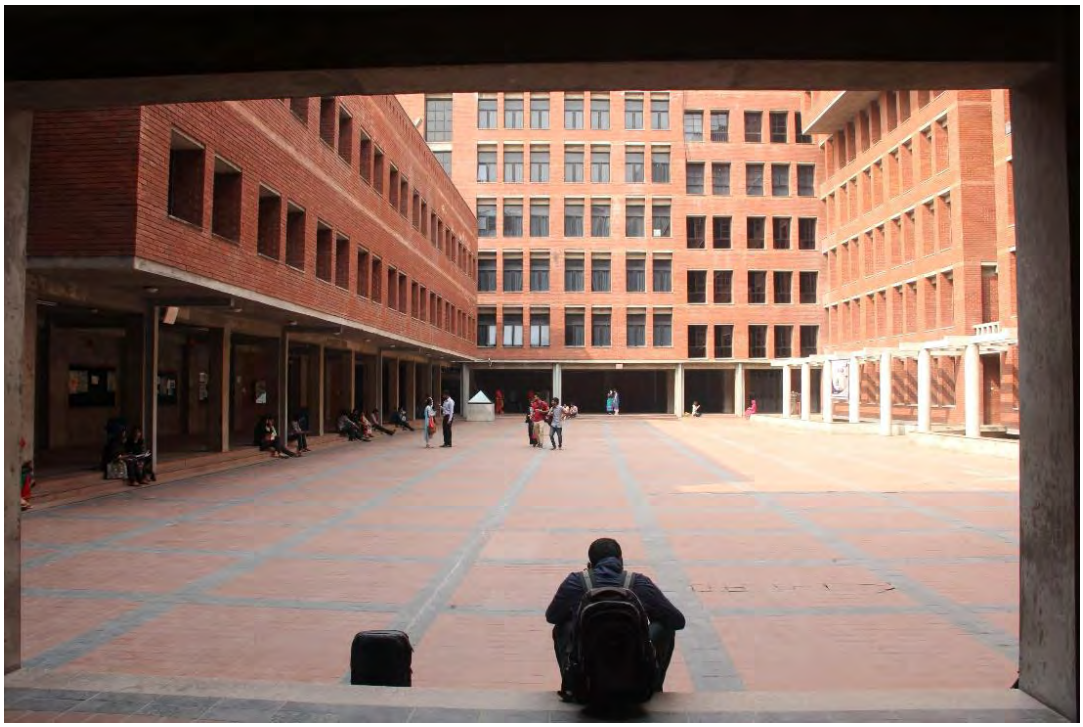


Figure 3-24 view of courtyard

Figure 3-25 view of courtyard from top

Figure 3-26 is showing the shape of the court. The shape is rectilinear and elongated in east west orientation. The area of the court is 12,101 sft. Figure 3-26 is showing the arms of court denoted as w1 and w2. Figure 3-27 and Figure 3-28 shows the section aa and section bb

respectively from where we get the information of height width ratio of courtyard. From its ratio it is found that it has a good enclosure.

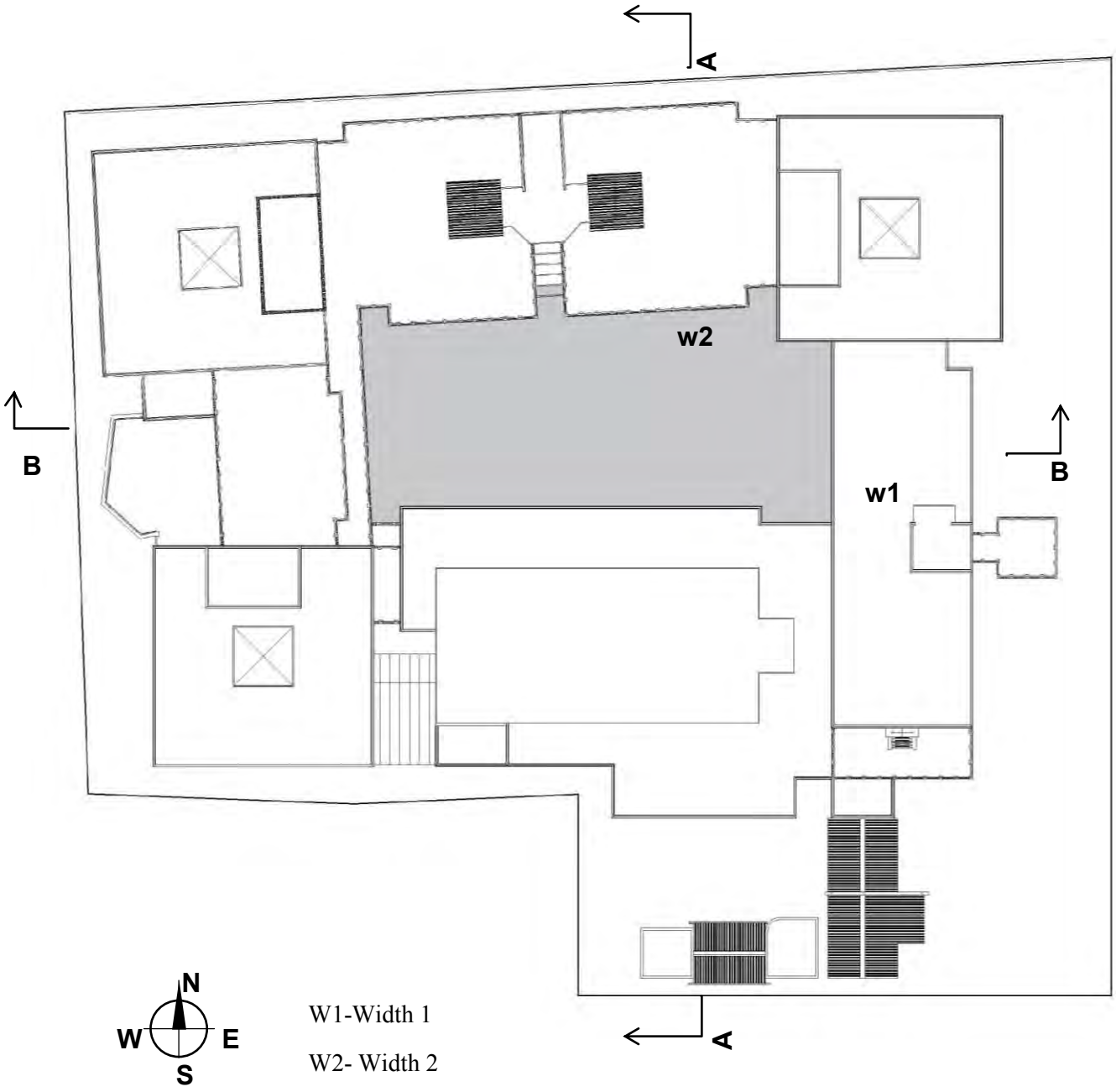


Figure 3-26 shape and size of court (Area of court 12,101.0 sft)

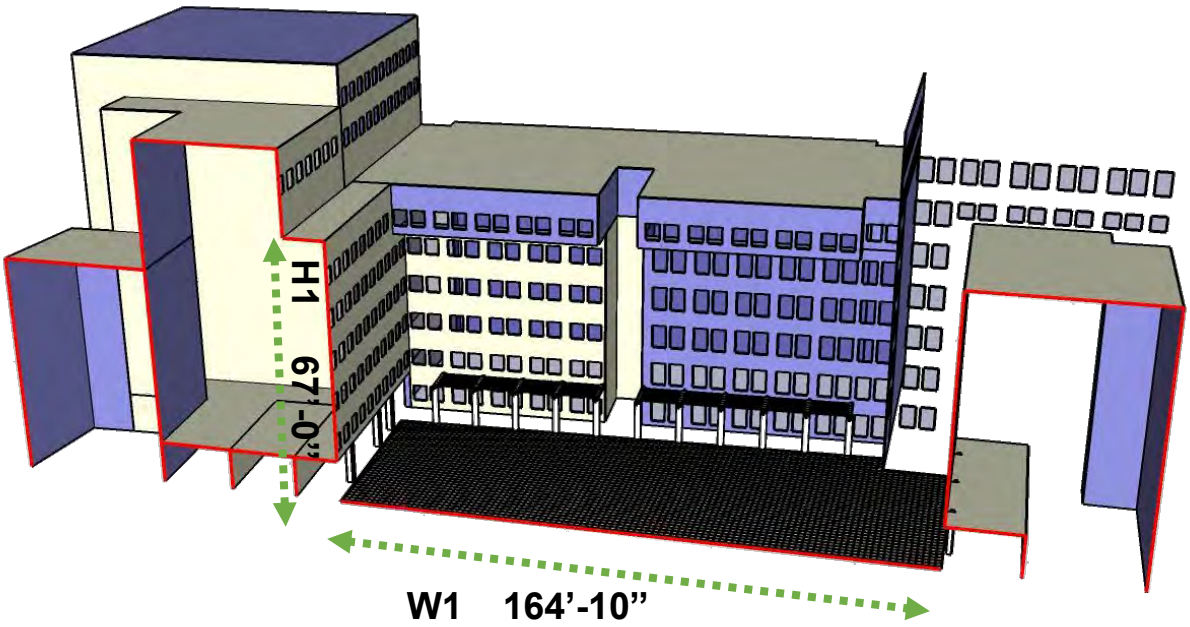


Figure 3-27 section aa (w1/h1=2.4:1)

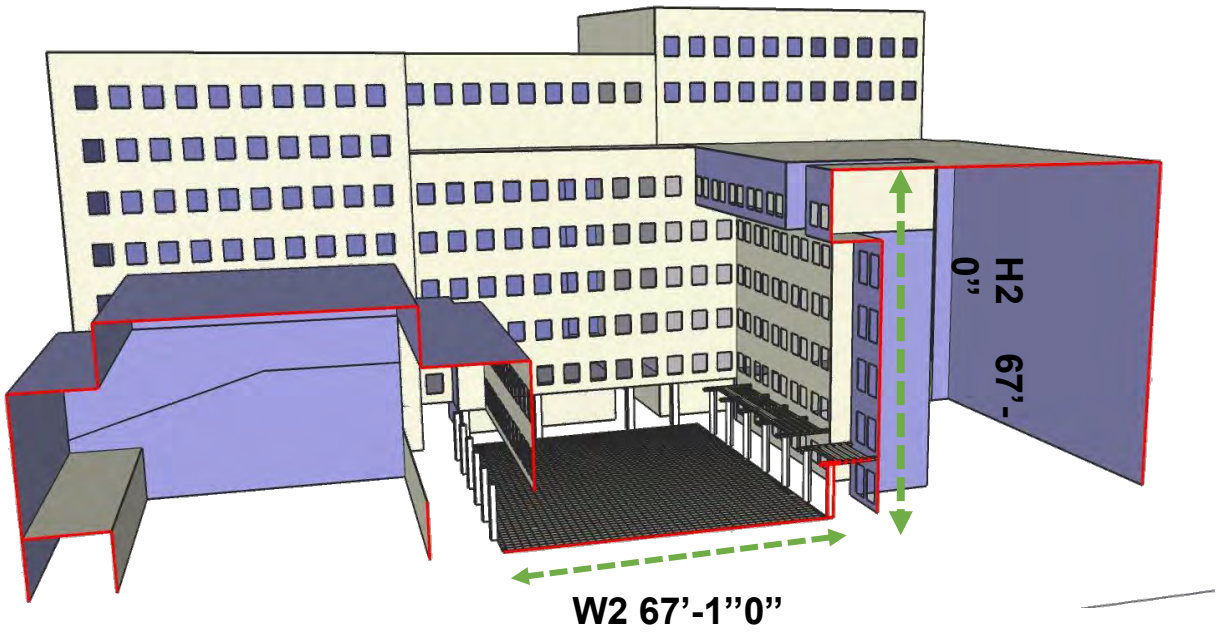


Figure 3-28 section bb (w2/h2=1:.99)

To find out the most useable space, unusable space an observation was done and an observation map was developed with some station points. 19 points have been taken .Climatic data was recorded on this points. Figure 3-30 is showing an image of observation of used and non-used spaces. Figure 3-29 is showing these weather station points.

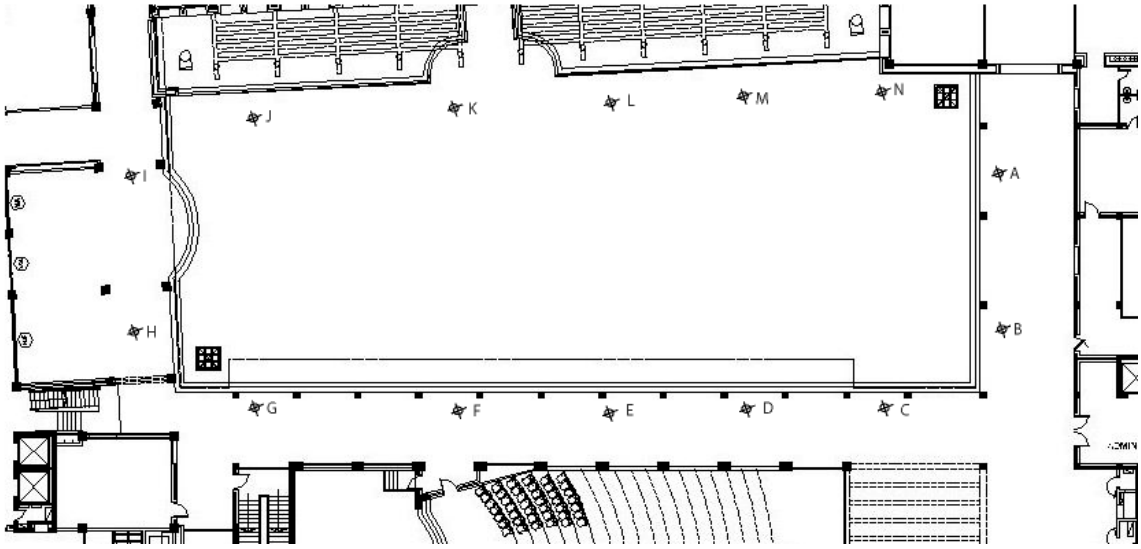


Figure 3-29 weather station points

A	Pave with tiles under shade	H	Paved with tiles under shade
B	Paved with tiles under shade	I	Paved with tiles under shade
C	Paved with tiles under shade	J	Located in brick pave exposed to sun
D	Paved with tiles under shade	K	Located in brick pave exposed to sun
E	Paved with tiles under shade	L	Located in brick pave exposed to sun
F	Paved with tiles under shade	M	Located in brick pave mostly exposed to sun
G	Paved with tiles under shade	N	Located in brick pave mostly exposed to sun

Table 3.4.2a Description of weather station points

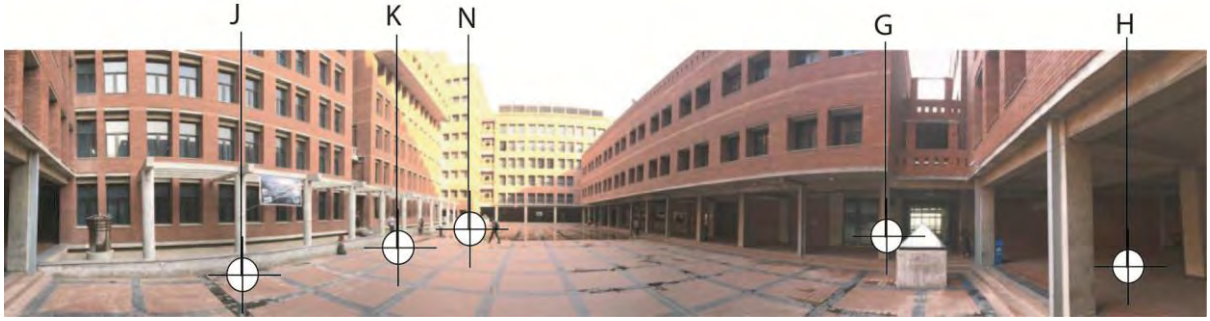


Figure 3-30 observation image and weather points

3.4.3 S Site III Independent University Bangladesh

IUB is one of the oldest, largest and finest private universities in Bangladesh. Its permanent campus is in Bashundhara R/A, Dhaka. Figure 3-31 is showing location map of IUB in the context of Dhaka City. Most of the structures are quite new and 8 to 10 story high.

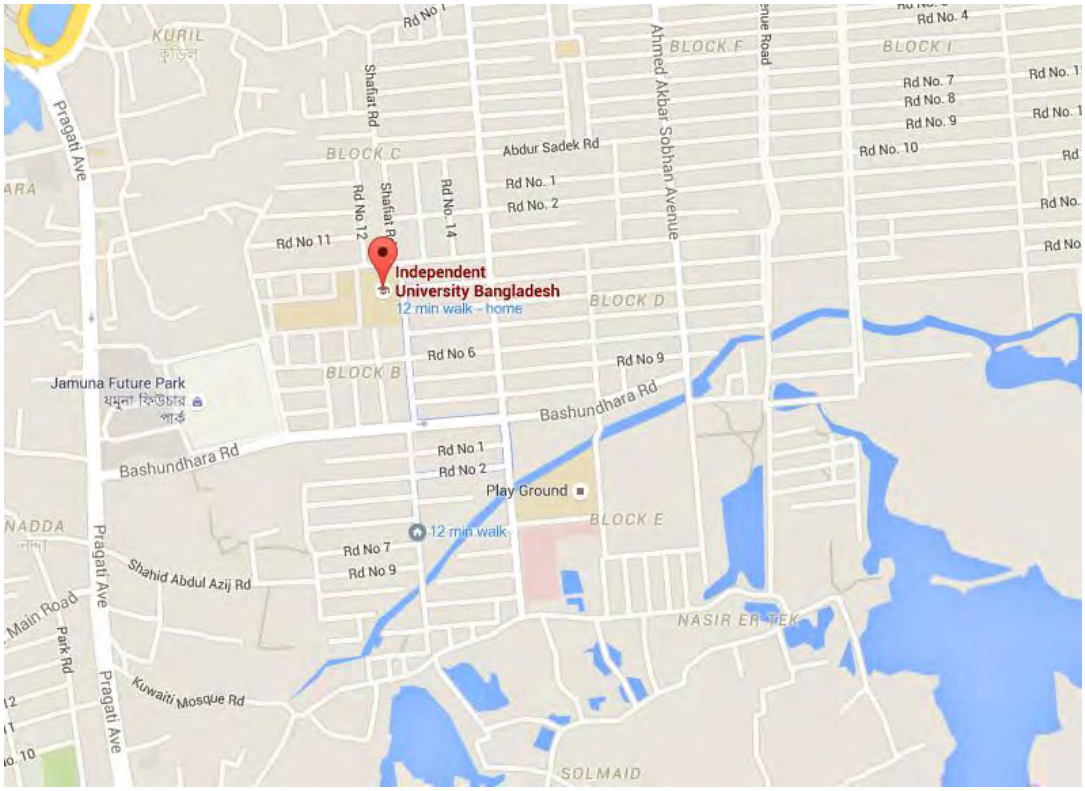


Figure 3-31 location map

Figure 3-32 site surroundings

Figure 3-33 site surroundings in 3d

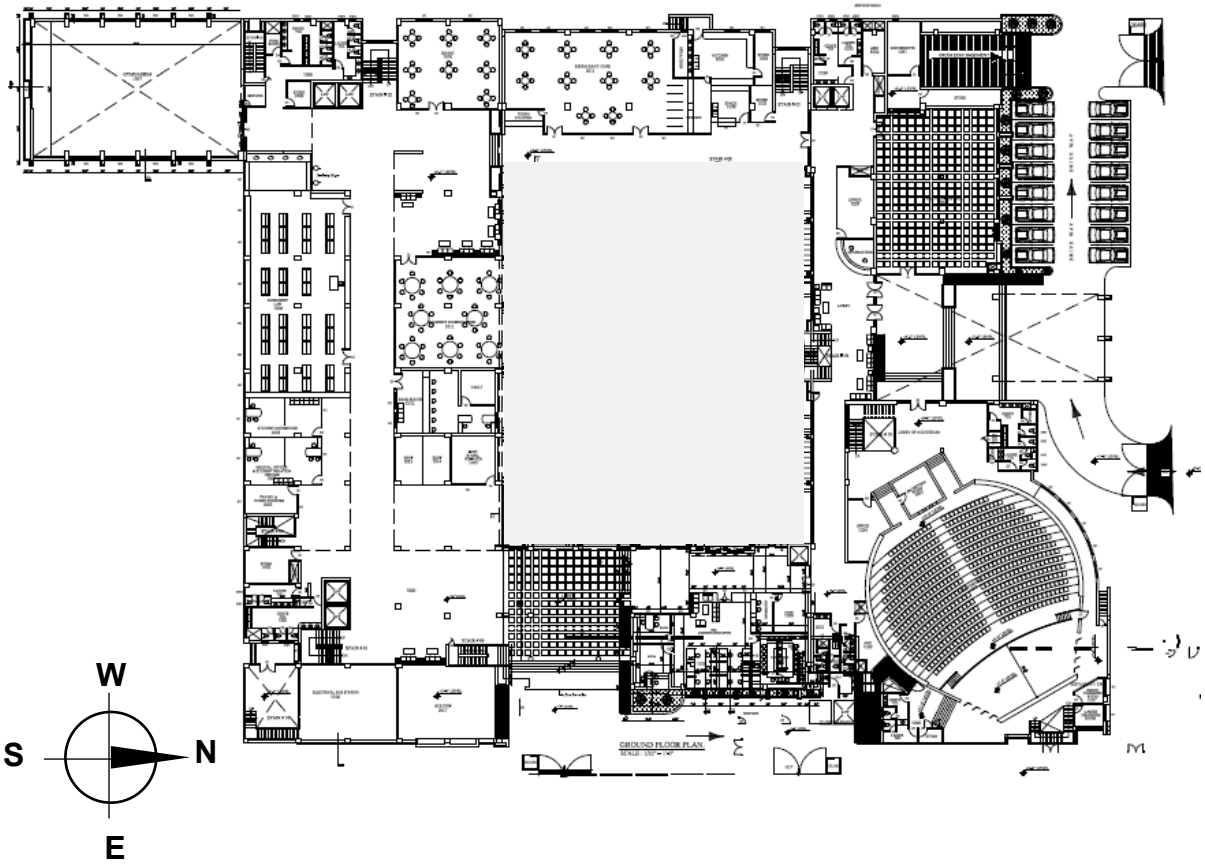


Figure 3-34 functions around courtyard

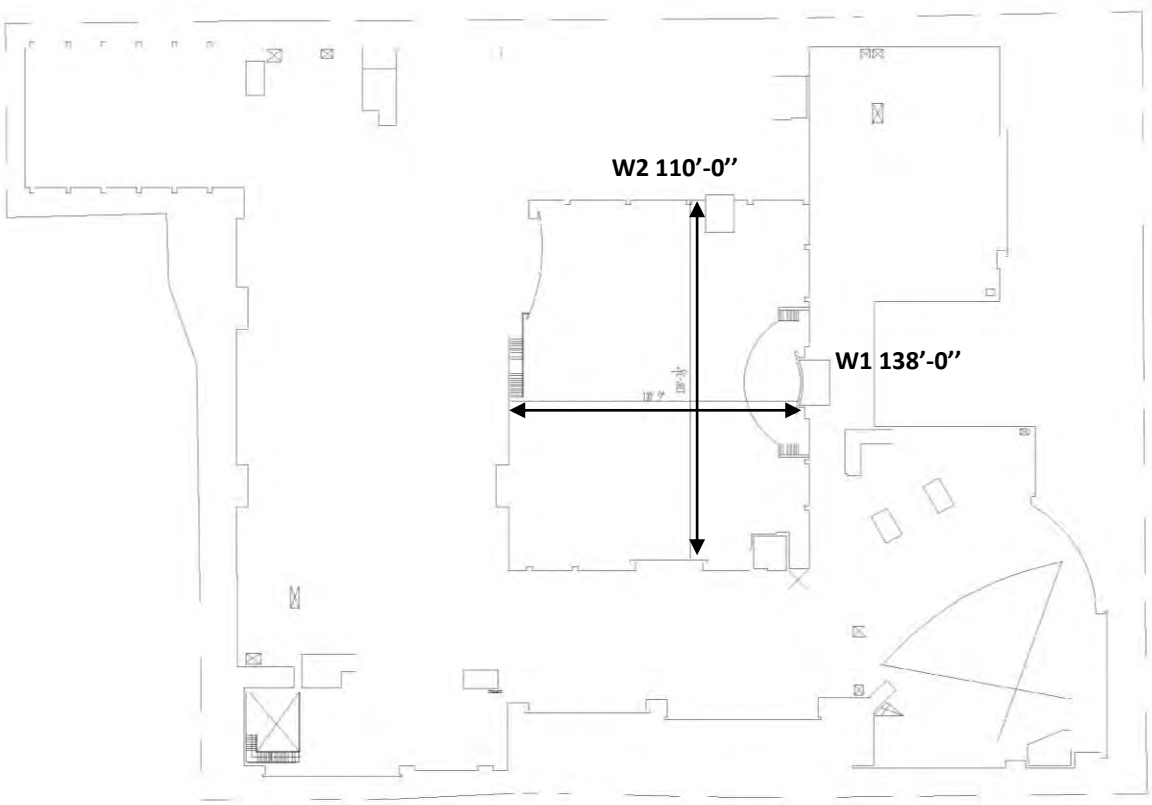
Figure 3-32 is showing the site surroundings. On its north and east it has two wide road *(figure 3-33)*. On its south it has some residential buildings with open spaces. On tis west it has North South University with a small setback. This is an institutional building centered on a courtyard with multiple height buildings covering almost 83,972 sft in ground. Figure 3-34 showing the functions in ground floor. North block houses multipurpose hall and auditorium

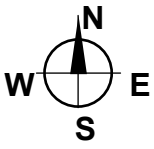
along with entry, west block houses gymnasium and cafeteria, south block houses some common facilities and east block houses administration. The ground floor is occupied by different facilities. The courtyard is surrounded by circulation area on one side, and the other side have some functions. Figure 3-35 is showing the view of courtyard with its enclosure. This court is partly covered by pave and partly by green. The percentage of green and pave ratio is 23:77. Figure 3-36 is showing the material mapping of courtyard where we find different types of pavement. One is made of brick pave. The green portion plotted as soft pave.

Figure 3-35 view of courtyard

Figure 3-36 material of courtyard

Figure 3-37 is showing the size and shape of the court. The shape is almost a square .The area of the court is 16,604 sft. Figure 3-37 is showing the arms of court denoted as w1 and w2. Figure 3-38 and Figure 3-39 shows the section aa and section bb respectively from where we get the information of height width ratio of courtyard. From its ratio it is found that it has a good enclosure.





W1-Width 1

W2- Width 2

Figure 3-37shape of courtyard and size of courtyard (16,604 sft)

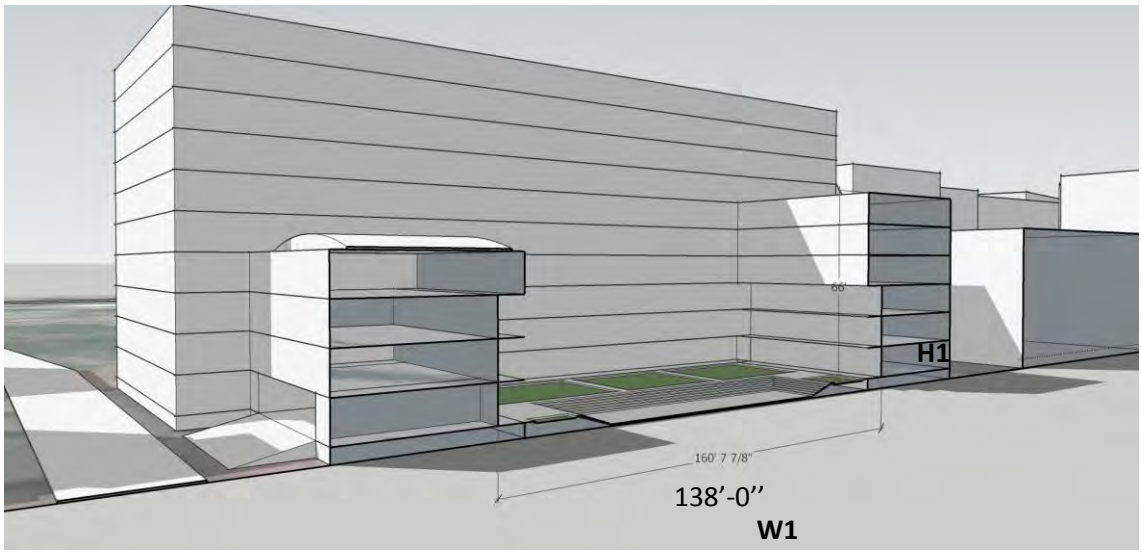


Figure 3-38 section aa showing w1/h1=2.09:1

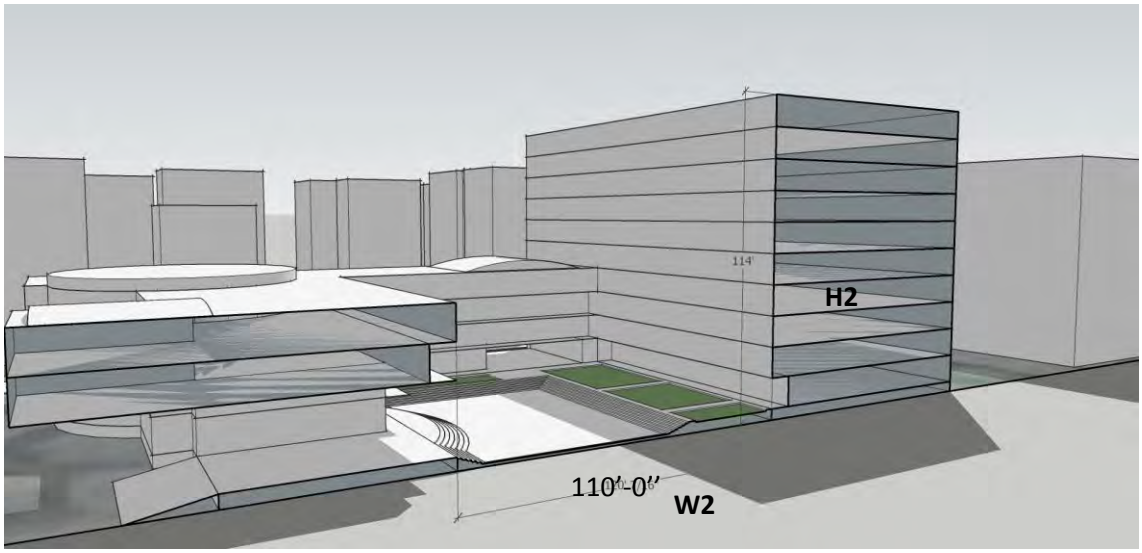


Figure 3-39 section bb showing w2/h2=.96:1

3.5 Data Collection

The field work was conducted in a number of observation points selected in two different urban situations termed as Study Sites (described in the following chapter) in Dhaka which have distinctive microclimates. Spots measurements were taken along with a questionnaire survey recording environmental data and comfort voting. The data was recorded on prepared field sheets generated for the field work (fig 3-41 b & 3-42). The survey was carried out by the help of a pair of students from the department of Architecture of University of Asia Pacific and Ahsanullah University of Sceince and Technology.

3.5.1 Instrumentation

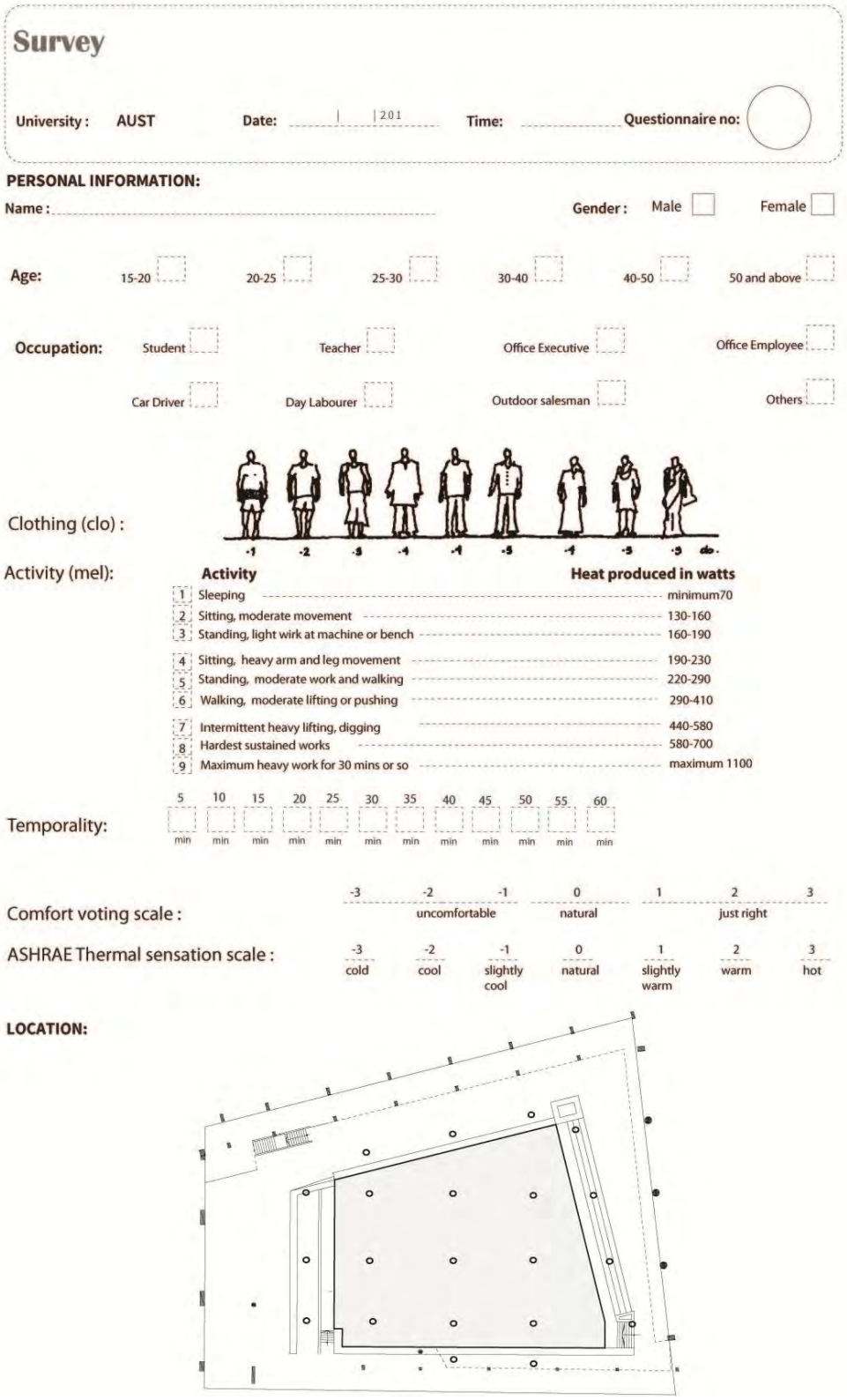
Each of the surveyors was allocated with a set of instruments consisting pocket weather meter and questionnaire. The following portable instruments [see Appendix 1 for specifications] were used for recording the minimum, maximum value of AT, WS, RH in the field work. Kestrel 3500 Pocket Weather Meter (figure 3-40 showing the image of instrument)

Figure 3-40 Kestrel Pocket Weather Meter

3.5.2 Interviewing Technique

The survey included a brief interview of randomly selected participants. The questionnaire was prepared to obtain the subjective responses from the respondents on various thermal comfort parameters such as air temperature, humidity and air velocity, along with a response on overall thermal comfort. Basic data of the respondents, their name, age, sex, occupation, duration of stay, clothing type, and immediate last activity before the survey, etc. were also gathered through the questionnaire. All the questionnaire sheets were distributed among the students and all respondents voted their opinion by filling up the questionnaire format, according to the respective responses [Appendix 02]. The majority of the sampling included responses from participants having been exposed to the environment for more than fifteen minutes. The investigation was done on approximately 26 randomly selected participants on each day for each courtyard.

Format of Questionnaire:



Survey

University : AUST Date: ____ | 201 Time: ____ Questionnaire no:

PERSONAL INFORMATION:

Name : ____ Gender : Male ☐ Female ☐

Age: 15-20 ☐ 20-25 ☐ 25-30 ☐ 30-40 ☐ 40-50 ☐ 50 and above ☐

Occupation: Student ☐ Teacher ☐ Office Executive ☐ Office Employee ☐

Car Driver ☐ Day Labourer ☐ Outdoor salesman ☐ Others ☐

Clothing (clo) :

Activity (mel):

	Activity	Heat produced in watts
1	Sleeping	minimum70
2	Sitting, moderate movement	130-160
3	Standing, light wirk at machine or bench	160-190
4	Sitting, heavy arm and leg movement	190-230
5	Standing, moderate work and walking	220-290
6	Walking, moderate lifting or pushing	290-410
7	Intermittent heavy lifting, digging	440-580
8	Hardest sustained works	580-700
9	Maximum heavy work for 30 mins or so	maximum 1100

Temporality:

5	10	15	20	25	30	35	40	45	50	55	60
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
min	min	min	min	min	min	min	min	min	min	min	min

Comfort voting scale :

-3	-2	-1	0	1	2	3
	uncomfortable		natural		just right	

ASHRAE Thermal sensation scale :

-3	-2	-1	0	1	2	3
cold	cool	slightly cool	natural	slightly warm	warm	hot

LOCATION:

Figure 3-41 questionnaire

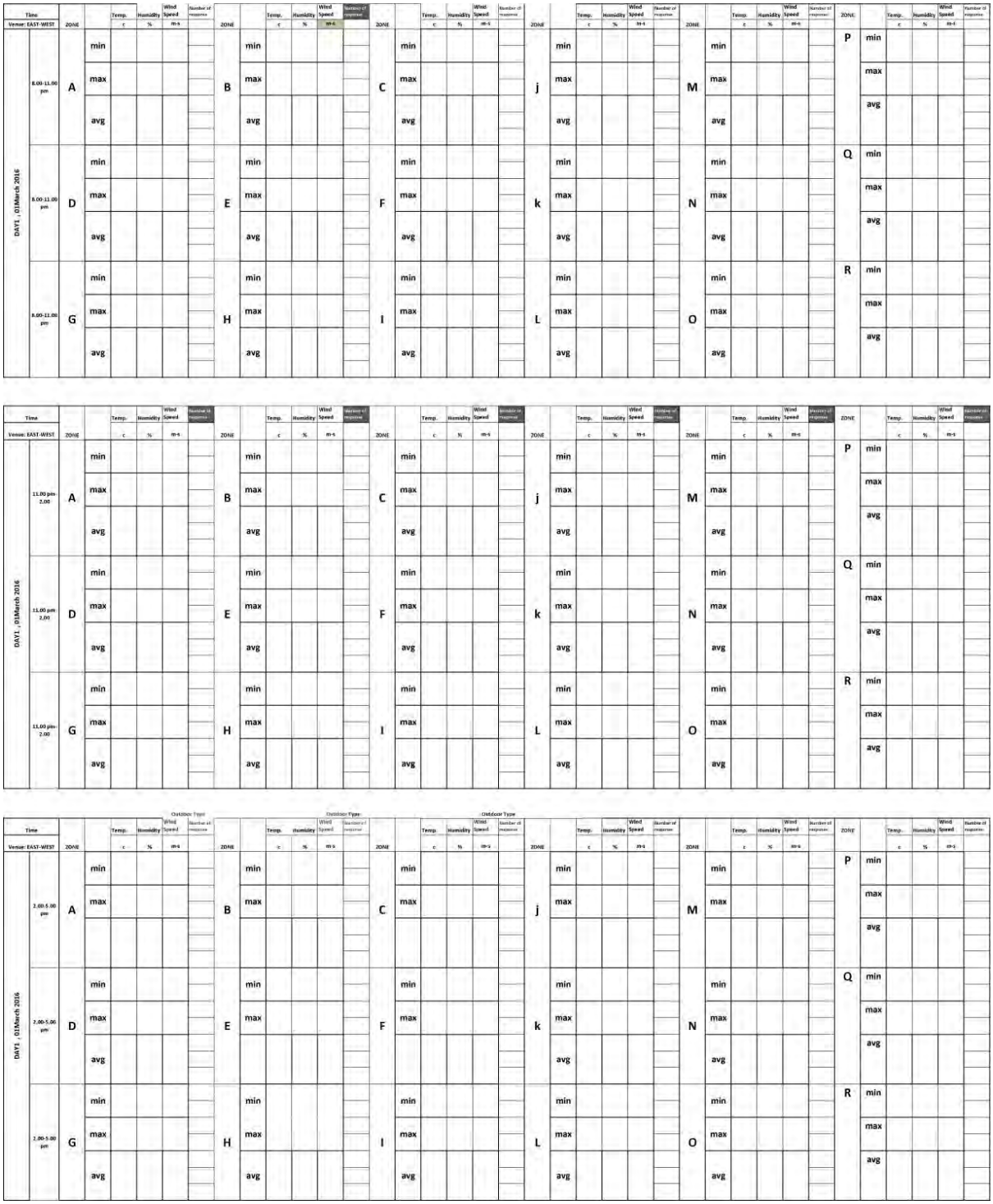


Figure 3-42 field survey chart

3.5.3 Thermal sensational scale and comfort vote assignment

For measuring thermal sensation, ASHRAE Scale was used. Table 3.4.3a shows the ASHRAE Scale. This scale is mostly used for researches to measure thermal performance.

Table 3.4.3a: Thermal sensation scale (ASHRAE Scale)

To assess the comfort, related to three variables, the following voting scale was used (Table 3.4.3b).

comfort						
uncomfortable			just right	comfortable		
-3	-2	-1	0	+1	+2	+3

Table 3.4.3b: Comfort voting of air temperature, relative humidity and air velocity

3.5.4 Days of survey

The days of the survey were selected according to the need of this research and preferable times. Table 3.4.5a shows the days and times of survey execution. This month for survey has been chosen considering its average temperature, humidity, wind speed and solar radiation.

3.5.5 Date and Time of field survey

	Institution	Investigation	Date	Time		
				8.00 a.m-11.00 a.m	11.00 a.m-2.00 p.m.	2.00 p.m.-5.00 p.m
1	AUST	1	9/3/2016	10:30 a.m	12:40 p.m	3:10 p.m
		2	10/3/2016	10:20 a.m	12:50 p.m	3:20 p.m
		3	12/3/2016	10:45 p.m	1:30 p.m	3:30 p.m
2	EWU	1	3/3/2046	10:10 a.m	1:20 p.m	4:00 p.m
		2	4/3/2016	10:10 a.m	12:30 p.m	3:30 p.m
		3	5/3/2016	10:10 a.m	1:15 p.m	3:20 p.m
3	IUB					

Table 3.4.5a Date and time of field survey

3.6 Analysis and Observation

3.6.1 Introduction

This section discusses broadly on the data, chart, image and graph found from field survey and simulation done for this research. This chapter also discusses the observation and findings of the research. The observation and findings portrays the relationship among microclimate, courtyard geometry, orientation, surface characteristics, and landscape elements of the study area.

3.6.2 Methodology

The important task was to understand the pattern of microclimatic parameters changes throughout the day at different points and differences among study areas which have been discussed initially.

The analysis was done in two steps. Firstly, the microclimatic parameters have been analyzed to understand the thermal performance by simulation diagrams and graphs. Secondly, three SSites are discussed to draw possible relationships.

3.6.3 Microclimatic Parameters

3.6.3.1 SSite 01

All the datas were plotted to find out what time in which point temperature, humidity and wind speed was highest and lowest.For day 01 Temperature within 8.00 a.m to 11.00 a.m was found highest at point O (figure 3-43) and lowest at point A (figure 3-43). At 11.00 a.m-2.00 p.m temperature was recorded highest at point N(figure 3-43) and lowest at point A(figure 3-43). At 2.00 p.m-5.00 p.m temperature was highest at point S(figure 3-43) and lowest at point A (figure 3-43) . Humidity within 8.00 a.m to 11.00 a.m was found highest at point E (figure 3-43) and lowest at point H (figure 3-43). At 11.00 a.m-2.00 p.m humidity was recorded highest at point B(figure 3-43) and lowest at point R(figure 3-43). At 2.00 p.m-5.00 p.m humidity was highest at point R(figure 3-43) and lowest at point I (figure 3-43). Wind speed at 8.00 a.m to 11.00 a.m was found highest at point A (figure 3-43) and lowest at point D,E,F,G,M &N (figure 3-43). At 11.00 a.m-2.00 p.m wnid speed was recorded highest at point R(figure 3-43) and lowest at point A,E,F,H,K,N,O,T & U(figure 3-43). At 2.00 p.m-5.00 it was highest at point C(figure 3-43) and lowest at point A,D,E,F,G,H,J,K,L,M,N,P,Q,R,S & U (figure 3-43) .

For day 02 Temperature within 8.00 a.m to 11.00 a.m was found highest at point L (figure 3-44) and lowest at point G & U (figure 3-44). At 11.00 a.m-2.00 p.m temperature was recorded highest at point S(figure4-1) and lowest at point D,M & Q(figure 3-44). At 2.00 p.m-5.00 p.m temperature was highest at point K(figure4-1) and lowest at point B (figure 3-44) . Humidity within 8.00 a.m to 11.00 a.m was found highest at point D (figure 4.3.1a) and lowest at point I & L (figure 3-43). At 11.00 a.m-2.00 p.m humidity was recorded highest at point L(figure 3-44) and lowest at point O(figure 3-43). At 2.00 p.m-5.00 p.m humidity was highest at point A(figure 3-44) and lowest at point K & U (figure 3-44). Wind speed at 8.00 a.m to 11.00 a.m was found highest at point L (figure 3-44) and lowest at point A,C,E,F,H,I,K,M,O,Q,R,T &U (figure4-2). At 11.00 a.m-2.00 p.m wnid speed was recorded highest at point O(figure 3-44) and lowest at point A,E,F,G,H,J,K,L,M,N,P,Q & S(figure 3-44). At 2.00 p.m-5.00 it was highest at point A(figure 3-44) and lowest at point B,C,E,F,G,H,I,J,K,L,M,N,O,P,R,S,T & U (figure 3-44) . For day 03 Temperature within 8.00 a.m to 11.00 a.m was found highest at point A (figure 3-46) and lowest at point M (figure 3-46). At 11.00 a.m-2.00 p.m temperature was recorded highest at point N & R(figure 4-4) and lowest at point M(figure 4-4). At 2.00 p.m-5.00 p.m temperature was highest at point U(figure 3-46) and lowest at point S (figure 3-46) . Humidity within 8.00 a.m to 11.00 a.m was found highest at point H,J & N (figure 3-46) and lowest at point K (figure 3-46). At 11.00 a.m-2.00 p.m humidity was recorded highest at point Q(figure 3-46) and lowest at point J(figure 4-4). At 2.00 p.m-5.00 p.m humidity was highest at point E&R(figure 3-46) and lowest at point U(figure 4-4). Wind speed at 8.00 a.m to 11.00 a.m was found highest at point B (figure 4-4) and lowest at point A,C,E,F,G,H,I,J,K,L,M,O,P,Q,R,S & U(figure 4-4). At 11.00 a.m-2.00 p.m wind speed was recorded highest at point J(figure 3-46) and lowest at point A,B,C,D,E,F,G,H,I,K,L,N,P,Q,T & U(figure 3-46). At 2.00 p.m-5.00 p.m it was highest at point I(figure 3-46) and lowest at point A,B,C,D,E,F,G,H,K,L,M,O,P,Q,R,S,T & U (figure 3-46) .

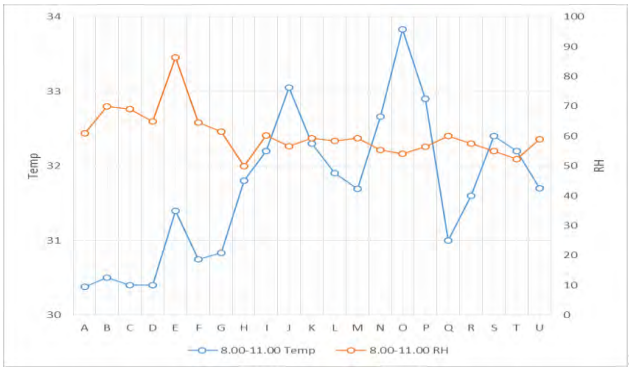
For day 02 an observation was made and datas were recorded to understand the relationship between temperature and no of respondents. All three regression graph shows a negative corelation. With the rise of temperature the number of respondents decreases. At 8.00 a.m to 11.00 a.m the no of respondents are higher where temperature ranges from 31^{O} to 31.5^{O}, but with the increasing temperature the number of respodent decreases(figure 3-43) . At 11.00 a.m-2.00 p.m no of respondents are higher where temperature ranges from 32.5^{O} to 33.5^{O}, but as the temperature rose to 35^{O} the number of respondetns became 0. At 2.00 p.m-5.00 p.m the

number of respondets found higher at temperature 32^{O} and it declined with the rise of temperature. Class hour is also an ipmortant factor in this case.

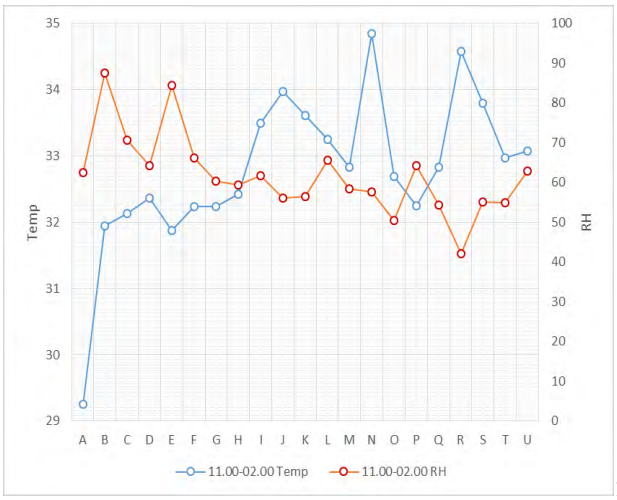
A comfort survey (table 3.6.3.1a)was done to undersand the relationship among air temperature, relative humidity, wind speed at different times. It has been found that at morning from 8.00 a.m to 11.00 a.m the most comfortable range is 31^{O}c temperature where humidity 74% with still air. At 11.00 a.m-2.00 p.m comfort exists with 33^{O}c temperature where humidity 50% with .6m/s wind speed. At 2.00 p.m-5.00 p.m comfort prevails with 32^{O}c temperature where humidity 56% with still air. So it has been found that with still air where temperature ranges from 31^{O}c-33^{O}c with humidity ranges from 50% to 74% a comfort conditions prevails in the court.

Druing the study period the highest temperature of Dhaka as recorded was 35^{O}C(9^{th} March,2016),34^{O}C(10^{th} March,2016),35^{O}C(12^{th} March,2016)and lowest was 23^{O}C,25^{O}Cand 20^{O}C whereas the courtyard temperature was 34.8^{O}C,42^{O}C,35.6^{O}C and 29.2^{O}C,31^{O}C,31.5^{O}C for the same days (considering max temp only).

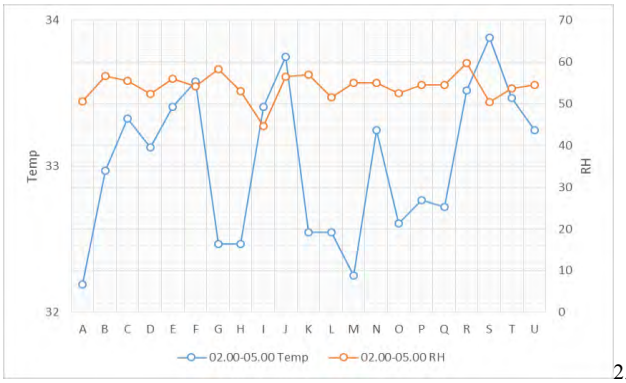
Day 01



8.00 A.M-11.00 A.M



11.00 A.M-2.00 P.Ms



2.00 P.M-3.00 P.M

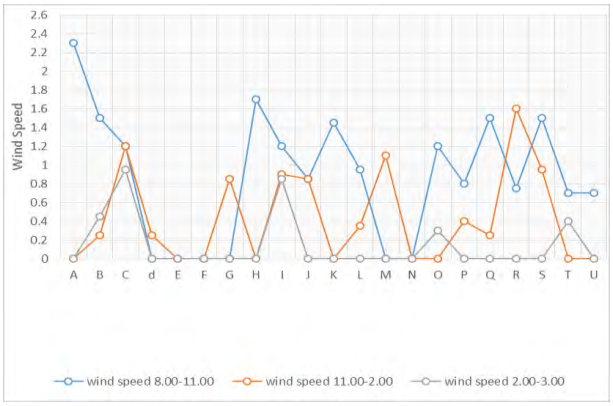
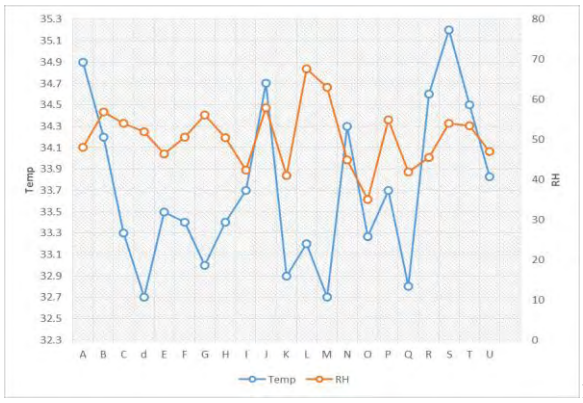


Figure:3-43 Graph of temperature and humidity and wind speed at different time in SSite 01 at day 01

Day 02

8.00 A.M-11.00 A.M



11.00 A.M-2.00 P.M

2.00 P.M-3.00 P.M

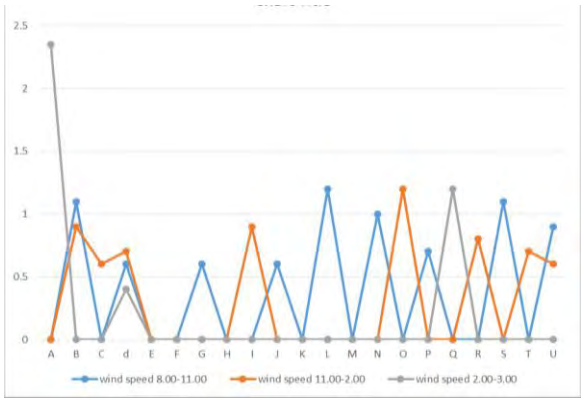
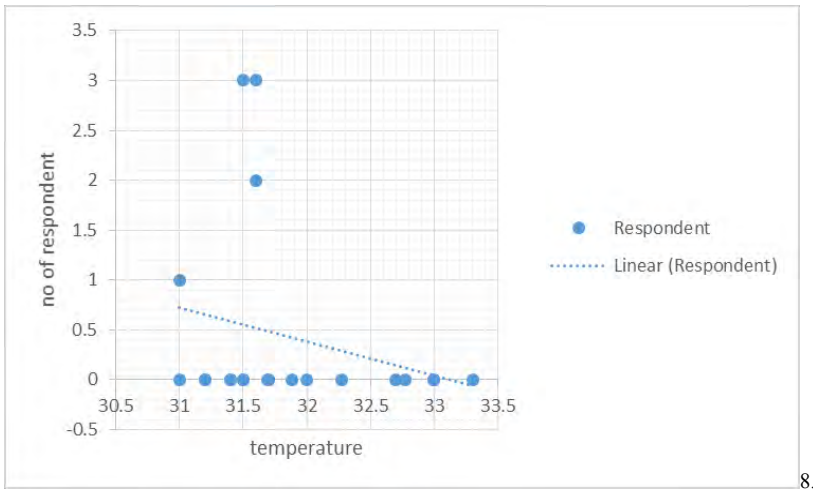
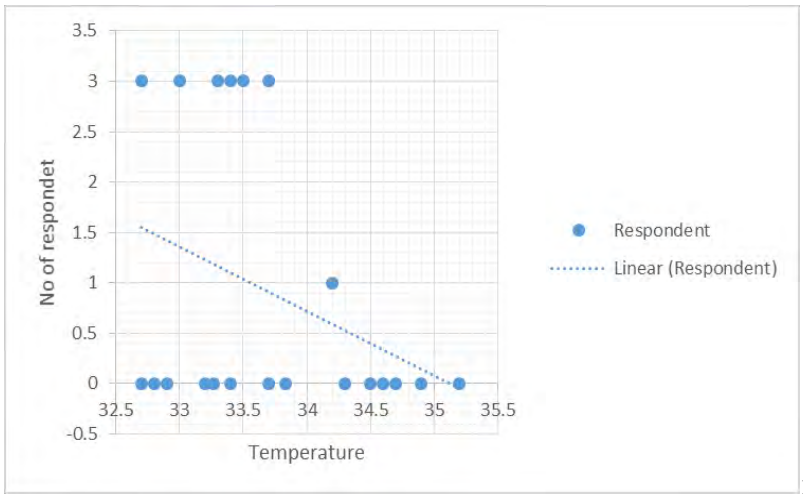


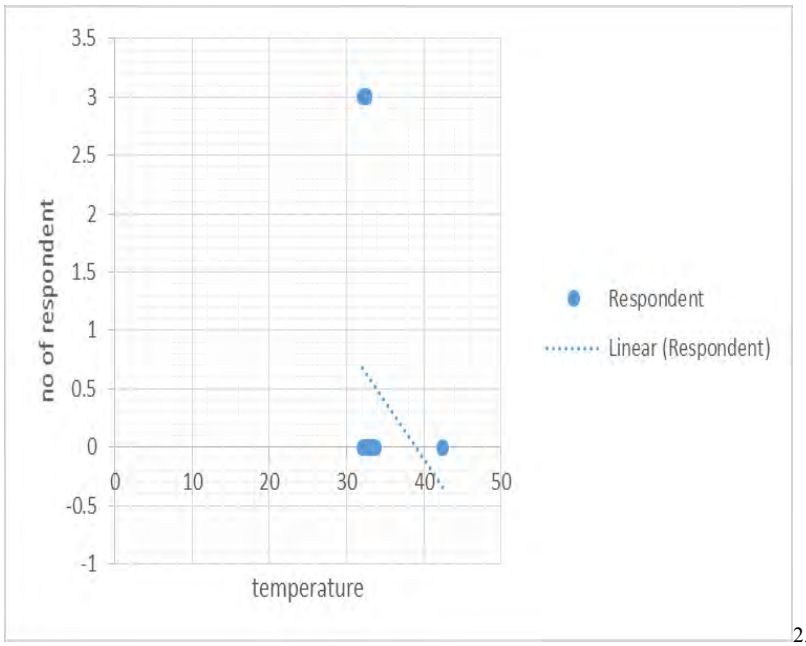
Figure:3-44 Graph of temperature and humidity and wind speed at different time in SSite 01 at day 02



8.00 A.M-11.00 A.M



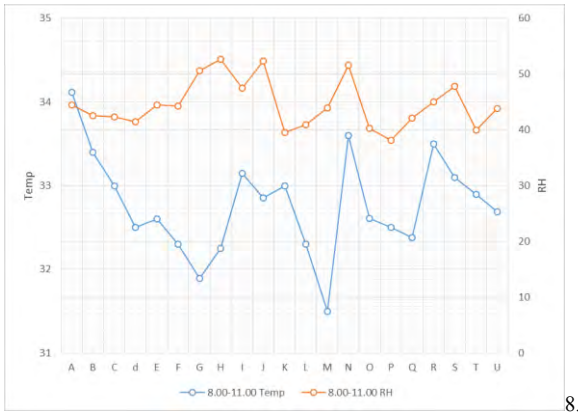
11.00 A.M-2.00 P.M



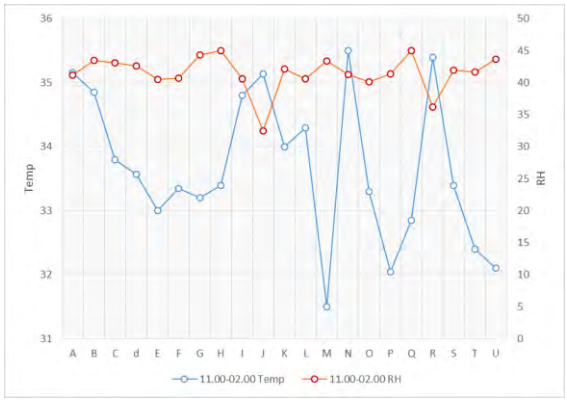
2.00 P.M-3.00 P.M

Figure:3-45 Relation between temperature and no of respondent

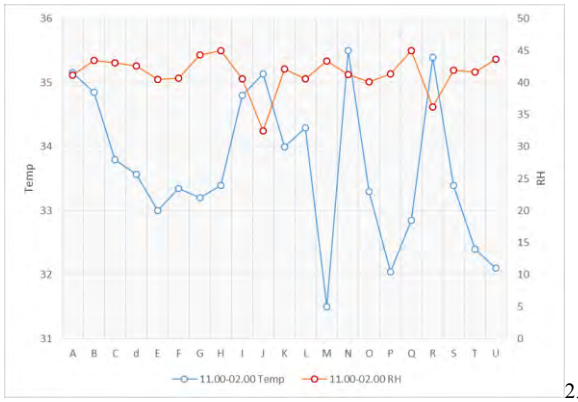
Day 03



8.00 A.M-11.00 A.M



11.00 A.M-2.00 P.M



2.00 P.M-3.00 P.M

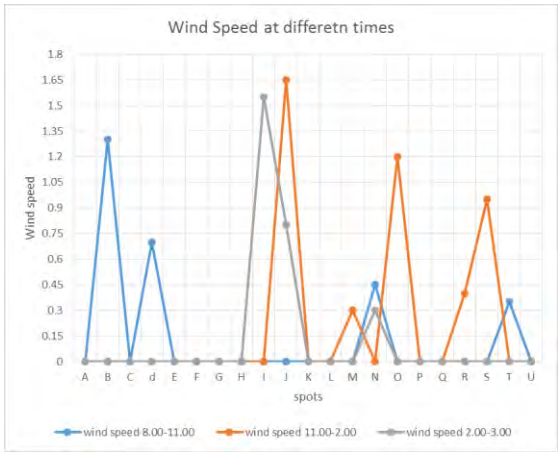


Figure:3-46 Graph of temperature,humidity and wind soeed at different time in SSite 01 at day 03

Respondent type	State of Outdoor Environment					Subjective Response		
						Comfort sensation		Clo
	Day	Time	Air temp (deg C)	RH%	Wind speed(m/s)	general	specific	
Outdoor type	10.03.2016	8.00-11.00	31	74	0	comfortable (100%)	70% Neutral 30% slightly warm	.4-.5
		11.00-2.00	33	50	0.6	comfortable (100%)	80% Neutral 20% slightly warm	.4-.5
		2.00-5.00	32	56	0	comfortable (100%)	90% Neutral 10% slightly warm	.4-.5

Table 3.6.3.1a Comfort responses from outdoor respondents

Findings

For most of the samples, temperature has been found higher at point N and lower at point A. During the study period the highest temperature of this court recorded in the 2nd day of survey at the point K with 42^{O}C (figure 3-44) and the lowest temperature recorded at the point A with 29.2^{O}C (figure4-1). Table 4.3.1b is showing the highest and lowest temperature, humidity and wind speed at different time. The analysis shows that Tc is usually .6^{O}C lower than Td(figure 3-47). This is due to shading of high mass of court and vegetation on ground.The humidity measurements in the site show an occurance of high humidity outside the court(figure 3-48) .

		Spots	8.00-11.00	11.00-2.00	2.00-5.00		Spots	8.00-11.00	11.00-2.00	2.00-5.00		Spots	8.00-11.00	11.00-2.00	2.00-5.00
Temperature	Day 01	H	33.8(N)	34.8(N)	33.9(S)	Humidity	H	85(E)	87(B)	60(R)	Wind speed	H	2.3(A)	1.6(R)	1(C)
		L	30.4(A)	29.2(A)	32.2(A)		L	50(H)	44(R)	44(I)		L	0	0	0
	Day 02	H	33.4(L)	35.2(S)	42(K)		H	75(D)	65(L)	70(A)		H	1.3(L)	1.3(O)	2.3(A)
		L	31(G)	32.6(D)	31.5(B)		L	45(O/L/I/R)	35(O)	44(K)		L	0	0	0
	Day 03	H	34.2(A)	35.4(N/R)	35.6(G)		H	55(H/N/J)	45(H)	50(E/R)		H	1.3(B)	1.65(J)	1.55(I)
		L	31.5(M)	31.5(M)	32(S)		L	40(K)	32.5(J)	U(40)		L	0	0	0

Table 3.6.3.1b Highest and lowest temperature of three days at different points

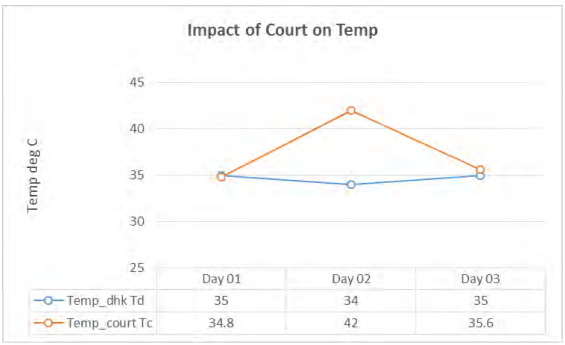


Figure:3-47 Comparison between court temp(Tc) local temp of Dhaka(Td)

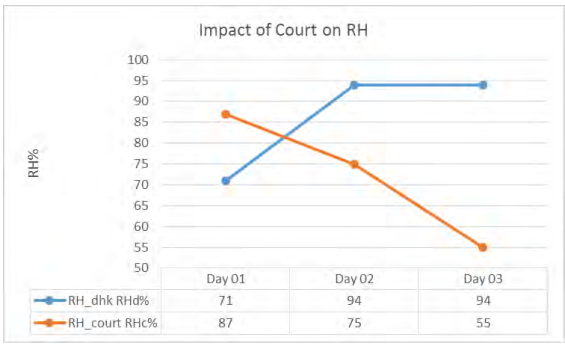


Figure:3-48 Comparison of Relative Humidity and between study court(RHc) and Dhaka(RHd)

3.6.3.2 SSite 02

All the datas were plotted to find out what time in which point temperature, humidity and wind speed was highest and lowest.For day 01 Temperature within 8.00 a.m to 11.00 a.m was found highest at point M (figure 3-49) and lowest at point L (figure 3-49). At 11.00 a.m-2.00 p.m temperature was recorded highest at point N(figure 3-49) and lowest at point G(figure 3-49). At 2.00 p.m-5.00 p.m temperature was highest at point N(figure 3-49) and lowest at point I (figure 3-49) . Humidity within 8.00 a.m to 11.00 a.m was found highest at point I (figure 3-49) and lowest at point N (figure 3-49). At 11.00 a.m-2.00 p.m humidity was recorded highest at point G(figure 3-49) and lowest at point N(figure 3-49). At 2.00 p.m-5.00 p.m humidity was highest at point I (figure 3-49) and lowest at point E (figure 3-49). Wind speed at 8.00 a.m to 11.00 a.m was found highest at point H (figure 3-49) and lowest at point B,C,D,E,F,I,J,K,M &N (figure 3-49). At 11.00 a.m-2.00 p.m wnid speed was recorded highest at point L(figure 3-49) and lowest at point A,E,& F (figure 3-49). At 2.00 p.m-5.00 it was highest at point B(figure 3-49) and lowest at point J,N (figure 3-49) .

For day 02 Temperature within 8.00 a.m to 11.00 a.m was found highest at point K (figure 3-51) and lowest at point C(figure 3-51). At 11.00 a.m-2.00 p.m temperature was recorded highest at point K(figure 3-51) and lowest at point B(figure 3-51). At 2.00 p.m-5.00 p.m temperature was highest at point N(figure 3-51) and lowest at point A & J(figure 3-51) . Humidity within 8.00 a.m to 11.00 a.m was found highest at point F (figure 3-51) and lowest at point N(figure 3-51). At 11.00 a.m-2.00 p.m humidity was recorded highest at point F & K(figure 3-51) and lowest at point L & N(figure 3-51). At 2.00 p.m-5.00 p.m humidity was highest at point G(figure 3-51) and lowest at point L (figure 3-51). Wind speed at 8.00 a.m to 11.00 a.m was found highest at point M (figure 3-51) and lowest at point J (figure 3-51). At 11.00 a.m-2.00 p.m wind speed was recorded highest at point L(figure 3-51) and lowest at point J(figure 3-51). At 2.00 p.m-5.00 it was highest at point L(figure 3-51) and lowest at point J(figure 3-51) .

For day 03 Temperature within 8.00 a.m to 11.00 a.m was found highest at point L & M (figure 3-52) and lowest at point A (figure 3-52). At 11.00 a.m-2.00 p.m temperature was recorded highest at point M(figure 3-52) and lowest at point A(figure 3-52). At 2.00 p.m-5.00 p.m temperature was highest at point K & L(figure 3-52) and lowest at point C (figure 3-52) . Humidity within 8.00 a.m to 11.00 a.m was found highest at point K (figure 3-52) and lowest at point L (figure 3-52). At 11.00 a.m-2.00 p.m humidity was recorded highest at point K(figure 3-52) and lowest at point L(figure 3-52). At 2.00 p.m-5.00 p.m humidity was

highest at point D(figure 3-52) and lowest at point G(figure 3-52). Wind speed at 8.00 a.m to 11.00 a.m was found highest at point G(figure 3-52) and lowest at point D(figure 3-52). At 11.00 a.m-2.00 p.m wnid speed was recorded highest at point J(figure 3-434) and lowest at point A(figure 3-52). At 2.00 p.m-5.00 p.m it was highest at point G(figure 3-52) and lowest at point A.(figure 3-52) .

For day 01 an observation was made and datas were recorded to understand the relationship between temperature and no of respondents. It has been seen that from time 8.00 a.m to 11.00 a.m and 11.00 a.m. to 2.00 p.m regression graph shows a negative corelation. With the rise of temperature the number of respondents decreases. At 2.00 p.m to 5.00 p.m the graph shows a positive corelation. The no of respondents are higher where temperature ranges from 28^{O} to 33^{O}. At 8.00 a.m to 11.00 a.m no of respondents are higher where temperatue ranges from 26^{O}C to 31^{O}C but the no decreases when temperaue rises to 34^{O}C. At 11.00 a.m-2.00 p.m no of respondents are higher where temperature ranges from 31^{O} to 32.5^{O}, but as the temperature rose to 34^{O} the number of respondetns became 0.

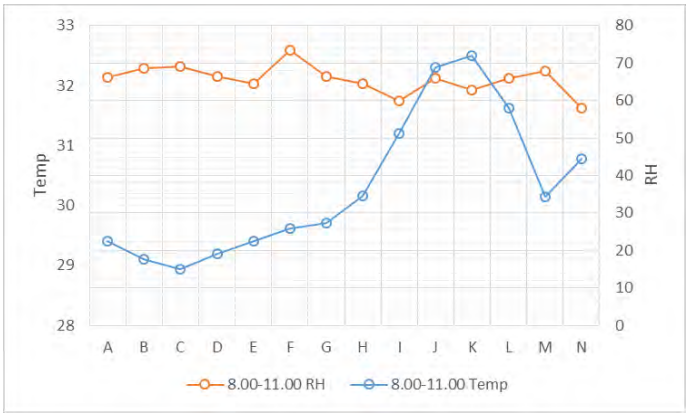
A comfort survey (table 3.6.3.2a)was done to undersand the relationship among air temperature, relative humidity, wind speed at different times. It has been found that at morning from 8.00 a.m to 11.00 a.m the most comfortable range is 29^{O} temperature where humidity 74% with still air. At 11.00 a.m-2.00 p.m comfort exists with 31^{O} temperature where humidity 62% with 1m/s wind speed. At 2.00 p.m-5.00 p.m comfort prevails with 30^{O} temperature where humidity 60% with .7m/s. So it has been found that with an average wind speed .56 m/s where temperature ranges from 29^{O}-31^{O} with humidity ranges from 60% to 74% a comfort conditions prevails in the court.

Druing the study period the highest temperature of Dhaka as recorded was 33^{O}C(3^{rd} March,2016),34^{O}C(4^{th}March,2016),33^{O}C(5^{th} March,2016)and lowest was 22^{O}C,23^{O}C and 22^{O}C whereas the courtyard temperature was 34.4^{O}C,33.4^{O}C,34.3^{O}C and 27.5^{O}C,29^{O}C,29.7^{O}C,for the same days (considering max temp only).

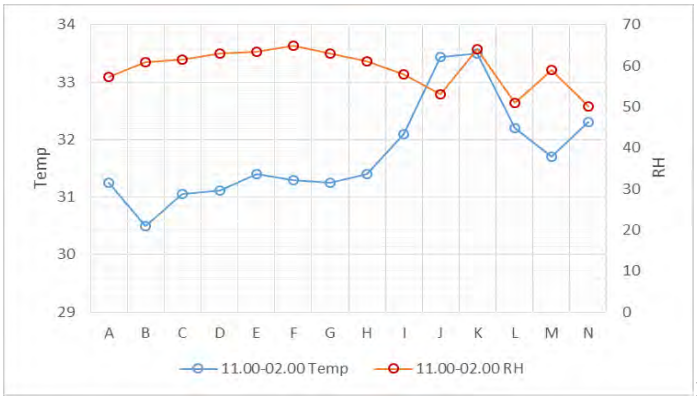
Respondent type	State of Outdoor Environment					Subjective Response		
						Comfort sensation		Clo
	Day	Time	Air temp (deg C)	RH%	Wind speed(m/s)	general	specific	
Outdoor type	3.03.2016	8.00-11.00	29	74	0	comfortable (100%)	11% Neutral 67% slightly warm11% slightly cool 11%	.4-.5
		11.00-2.00	31	62	1	comfortable (100%)	85% Neutral 8% slightly warm 10%slightly cool 2%warm	.4-.5
		2.00-5.00	30	60	0.7	comfortable (100%)	70% Neutral 25%slightly cool 5% slightly warm	.4-.5

Table 3.6.3.2a Comfort responses from outdoor respondents

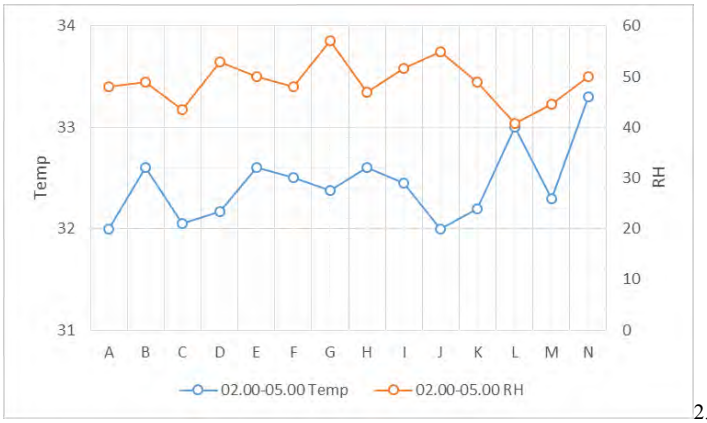
Day 01



8.00 A.M-11.00 A.M



11.00 A.M-02.00 P.M



2.00 P.M-05.00 P.M

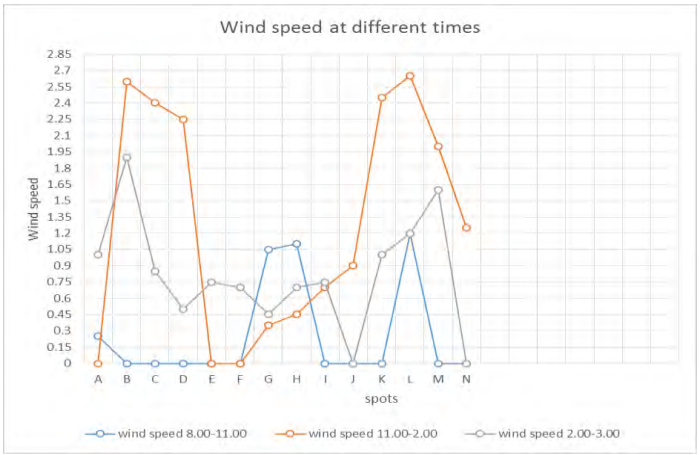
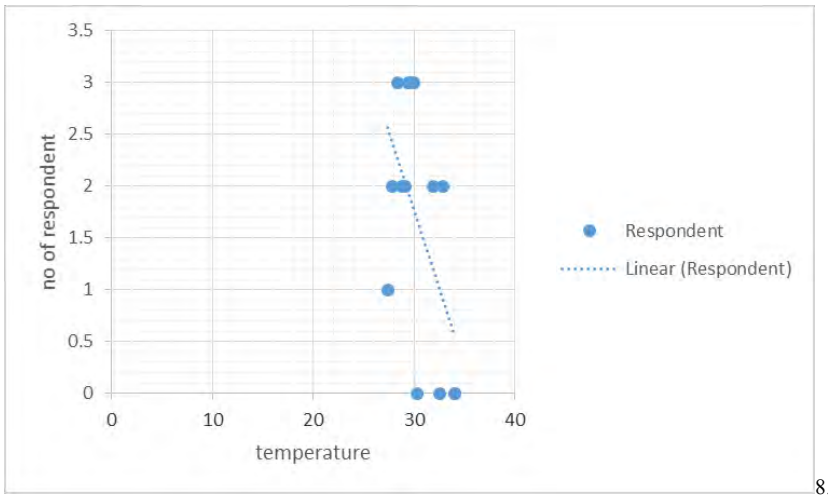
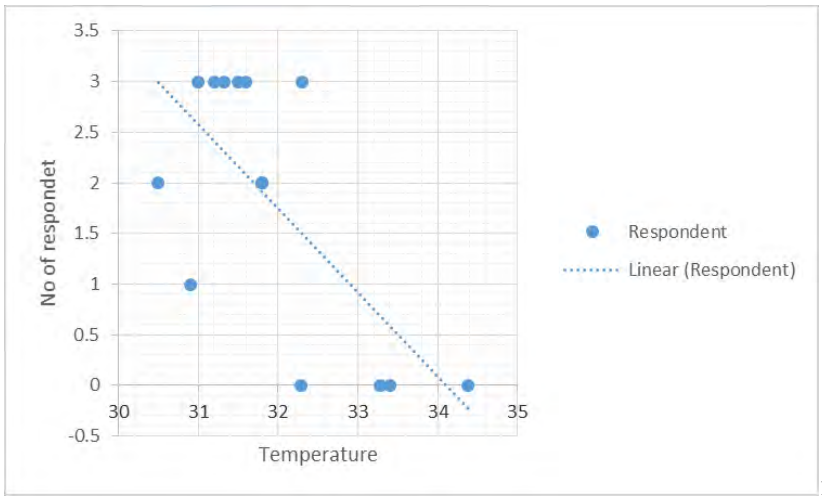


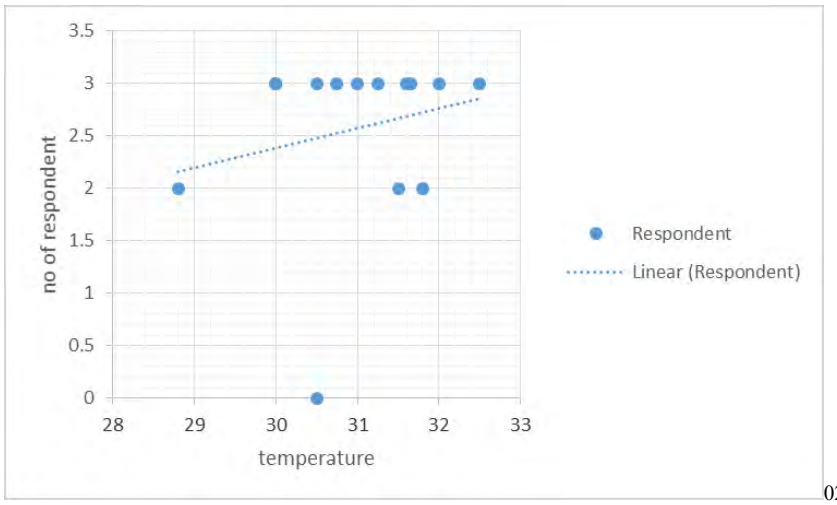
Figure:3-49 Graph of temperature and humidity and wind speed at different time in SSite 02 at day 01



8.00 A.M-11.00 A.M



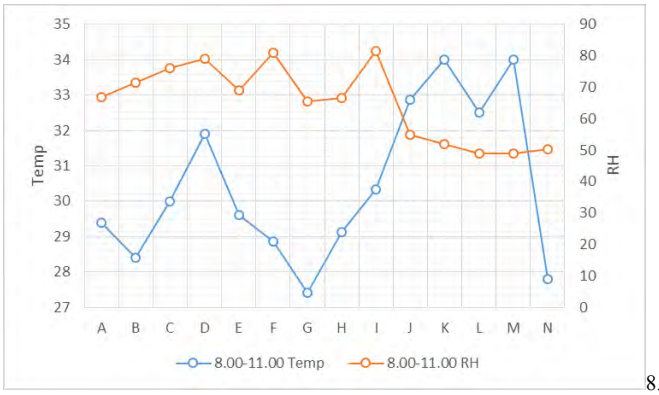
11.00 A.M-02.00 P.M



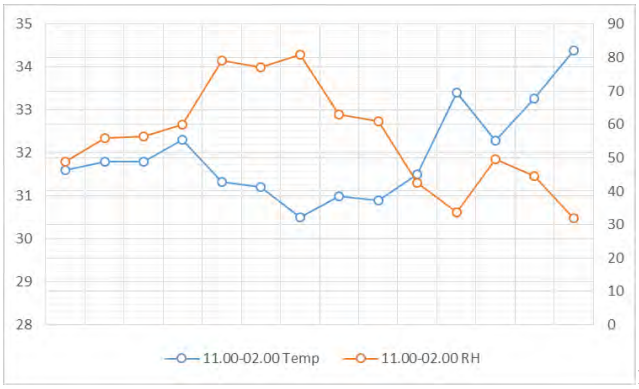
02.00 P.M-5.00 P.M

Figure:3-50 Relation between temperature and no of respondent

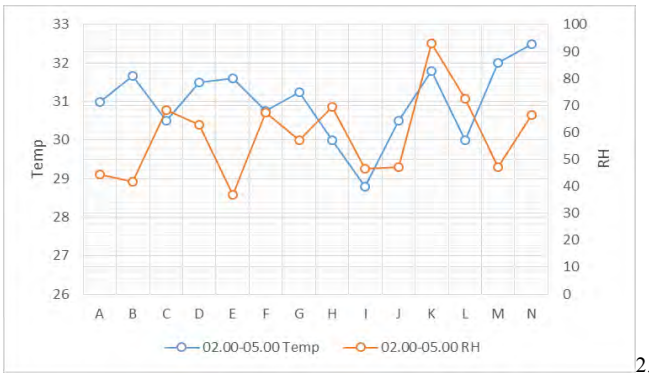
Day 02



8.00 A.M-11.00 A.M



11.00 A.M-05.00 P.M



2.00 P.M-5.00 P.M

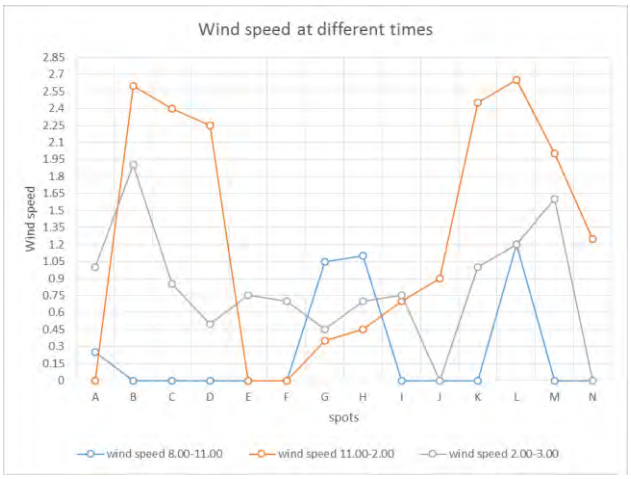
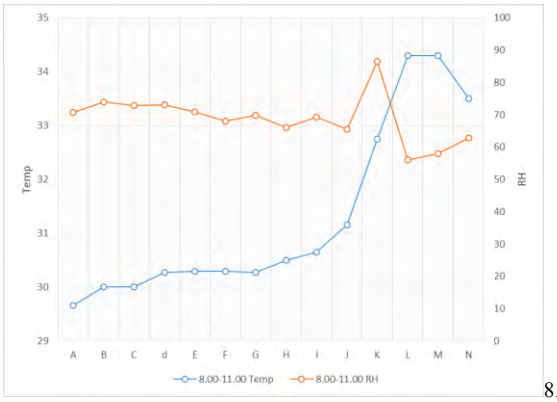
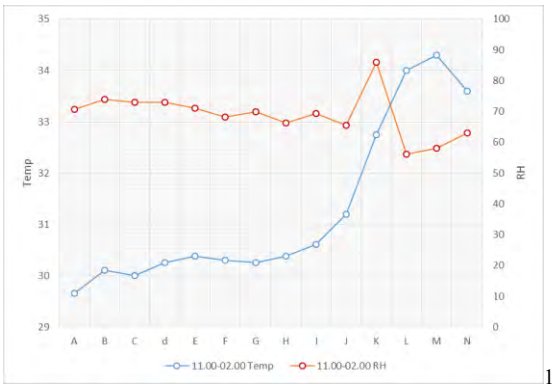


Figure:3-51 Graph of temperature and humidity and wind speed at different time in SSite 02 at day 02

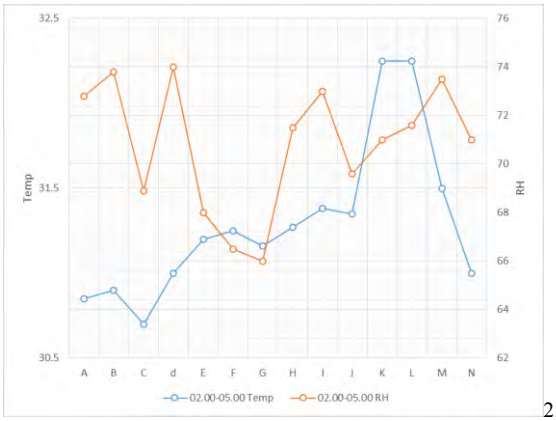
Day 03



8.00 A.M-11.00 A.M



11.00 P.M-02.00 P.M



2.00 P.M-05.00 P.M

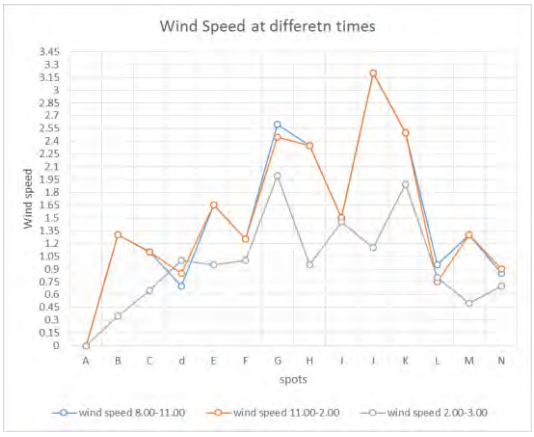


Figure:3-52 Graph of temperature and humidity and wind speed at different time in SSite 02 at day 03

Findings:

For most of the samples, temperature have been found higher at point K,L,M & N and lower at point A & C. During the study period the highest temperature of this court recorded in the 1st day of survey at the point N with 34.4^{O}C (figure 3-51) and the lowest temperature recorded at the point N with 27.5^{O}C (figure 3-51). Table 3.6.3a is showing the highest and lowest temperature, humidity and wind speed at different time. The analysis shows that Tc is usually 1^{O}C higher than Td(figure 3-53). This is due to hard surface and pavement in court on ground.The humidity measurements in the site show an occurance of high humidity inside the court(figure 3-54) .

		Spots	8.00-11.00	11.00-2.00	2.00-5.00		Spots	8.00-11.00	11.00-2.00	2.00-5.00		Spots	8.00-11.00	11.00-2.00	2.00-5.00
Temperature	Day 01	H	34(M)	34.4(N)	32.5(N)	Humidity	H	80(I)	79(G)	95(I)	Wind speed	H	1.06(H)	2.6(L)	1.89(B)
		L	27.5(N)	30.4(G)	29(I)		L	47(N)	32(N)	35(E)		L	B-F,I-K,M,N	0(A,E,F)	0(J,N)
	Day 02	H	32.6(K)	33.4(K)	33.3(N)		H	75(F)	65(F/K)	57(G)		H	2.4(M)	5.1(L)	3.6(L)
		L	29(C)	30.4(B)	32(A/J)		L	59(N)	50(L/N)	40(L)		L	.3(J)	0(J)	.3(J)
	Day 03	H	34.3(L/M)	34.2(M)	32.3(K/L)		H	87(K)	88(K)	74(D)		H	2.55(G)	3.15(J)	1.95(G)
		L	29.7(A)	29.7(A)	30.7(C)		L	55(L)	55(L)	66(G)		L	.7(D)	0(A)	0(A)

Table 3.6.3a Highest and lowest temperature of three days at different points

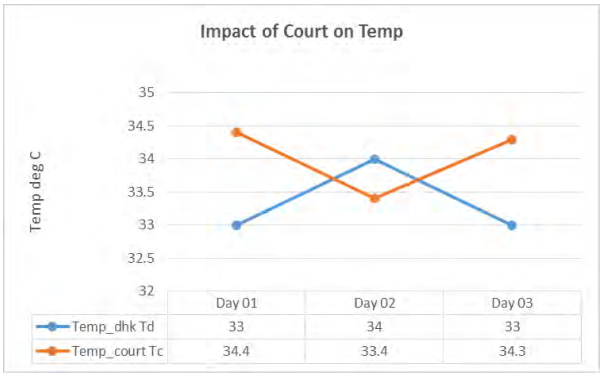


Figure:3-53 Comparison between court temp(Tc) and local temp of Dhaka(Td)

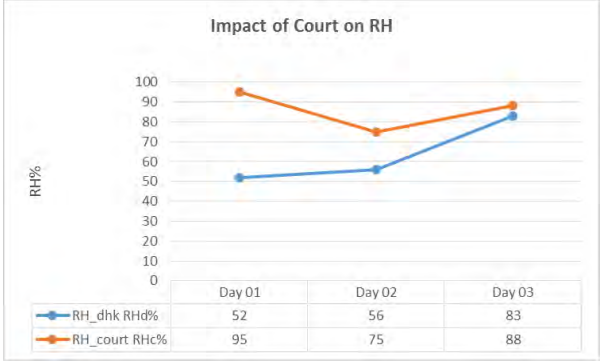


Figure:3-54 Comparison of Relative Humidity between study court(RHc) and Dhaka(RHd)

3.6.4 Findings

It is found from the statistical data of SSite 01 and SSite 02 that air temperature in a green space is remarkably less than a paved or built space in Dhaka. In case of SSite 01, average air temperature in green area varies from 31^{O}C to 33^{O}C where in paved area varies from 32^{O}C to 35^{O}C in some points up to 42^{O}C. In case of SSite 02 air temperature in paved areas under shade varies from 28^{O}C to 30^{O}C where in paved areas open to sky with direct sun varies from 31^{O}C to 34^{O}C.Paved area under shade shows a lesser air temperature value with a higher humidity. Paved area exposed to sun shows higher temperature value with lesser humidity. Another finding is humidity is also found higher under tree and shaded area of green space is much cooler than the exposed area. Again court orientation and width height ratio have significant impact on thermal performance. It is found that courtyards elongated in east-west is preferable.

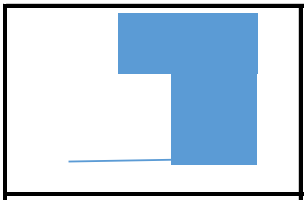
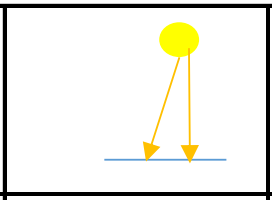
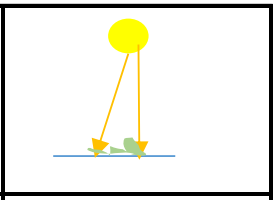
			
Paved under shade	Paved exposed to sun	Green under shade	Green exposed to sun
temp 28-30	temp -32-35	temp -31-32	temp -32-33

Figure:3-55 Temperature in Different conditions found from study

3.7 Conclusion

This chapter states the methodology of the research. This chapter helped to understand the height width ratio of courtyard and its orientation. Data regarding envelop around courtyard found from field survey. Some shows fully enclosed while other have some perforations. From field survey it was found that the study area consisted of green, paved and a mixture of green with pave spaces along with trees, small shrubs and concrete blocks. Some of the spaces is under shade, some are under building mass, some are directly exposed to the sun for most of the time, and some are exposed to the sun for a specific period. Some spaces are under long trees and some are under shrubs.

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https://en.wikipedia.org/wiki/East_West_University, Wikipedia retrieved from May 9, 2016,

Chapter 04: Simulations study

Introduction

Modelling Concept and Simulation

Simulation Parameters

Analysis

Conclusion

4.1 Introduction

To find out the microclimatic parameters, different courtyards has been simulated by simulation software of various time and different seasonal conditions to determine the microclimate and its impact. These simulations draws a comparative analysis of data between the field survey and the simulation result. For microclimatic simulation, a software named „ENVI-met" has been used.

ENVI-met Simulation: ENVI-met 3.1 version has been exercised in this research for microclimate simulation (ENVI-met). The simulation has been done for Pre-Monsoon (March) period at three different times of a day, 9.00 hours, 12.00 hours and 15.00 hours.

4.2 Modelling Concept & Simulation

The whole process of simulation is done in four phases. The phase"s are-

- modeling (ENVI-MET input file)
- creating configuration file (CF file)
- simulation through analysis
- output file by Leonardo

The study area has been modeled by „Area input file editor" with the proper building height (data from field survey and Google street view), roads (field survey and satellite image), paves (field survey), greens and trees (field survey), and other built forms (satellite image and field survey). Figure 4-1 illustrates the main input data of modeling for three study sites.

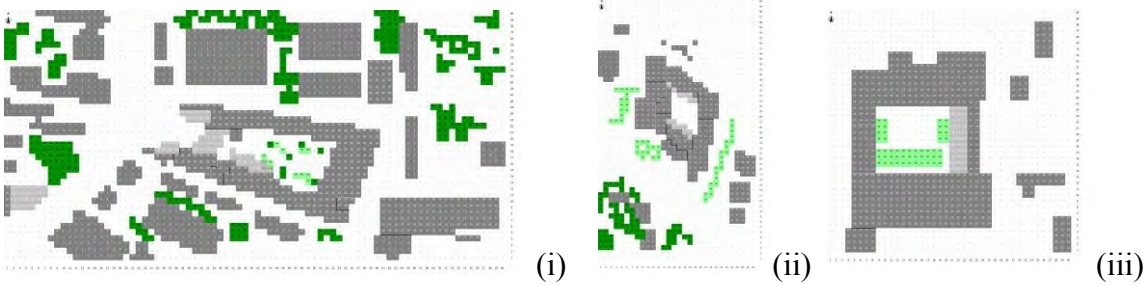


Figure 4-1 Envi-met input file (modelling) (i) AUST (ii) EWU (iii) IUB

The second stage is to create a configuration file for the specific courtyards. This file contains atmospheric data. The input data, for this process, are collected from MET office (Bangladesh Meteorological Department) of required months. Average initial temperature (temperature at 6.00 hours), wind speed of the same day, wind direction and relative humidity

of the day have been used for the configuration file of the software. Table 4.2a illustrates main input data used for creating CF file.

Simulation input	March
Start Simulation at Day(DD:MM:YYYY)	10.03.2015
Start Simulation at Time(HH:MM:SS)	6:00:00
Total Simultaion Time in Hours	12:00
Save Model State each?min	180
Wind Speed in 10 m ab. Ground [m/s]	1.5
Wind Direction (0: N...90: E...180: S...270:W.180)	225
Roughness Length z0 at Reference Point	0.1
Initial Temperature Atmosphere [K]	303
Specific Humidity in 2500 m [g Water/kg air]	7
Relative Humidity in 2m [%]	84

Table 4.2a Input data of configuration file for simulation

The third phase is the simulation. The modeled area has been simulated for a month of four seasons. Simulation have been run for the year 2016 as the met data was collected for the year 2016 and field work done in 2016 (summer). The analysis periods were:

- March Pre-monsoon

Again the simulation process has been run for 12 hours to consider three different times of day with three hours interval, and these were:

9.00 hours 12.00 hours 15.00 hours

After simulation, the results have been generated by „Leonardo-Map" as illustrated images. The temperature, mean radiant temperature, relative humidity and wind speed data of 54 samples have been calculated and plotted in the chart to find out the thermal performance of courtyards.

The four analyzed microclimatic parameters were:

- Temperature
- Mean Radiant Temperature
- Relative Humidity
- Wind Speed

4.3 Simulation Parameters

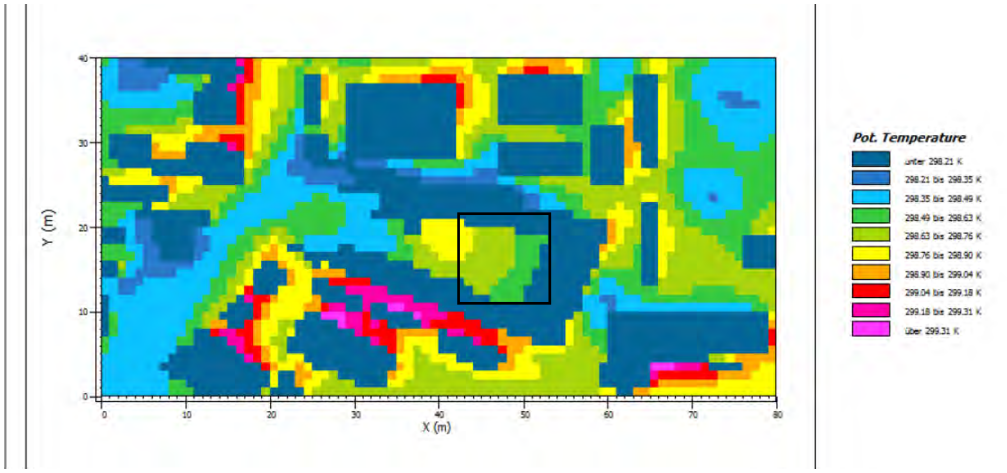
4.3.1 SSite 01

Figure 4-2 is showing the pot temperature of ssite 01(aust) courtyard at three different times at 1.60m level. It has been found from the image that at 9.00 a.m. the temperature of court ranging from 25.48^{O}c to 25.75^{O}c. At 12.00 p.m. temperature rises to 28^{O}c when the outside temperature shows a higher value 29^{O}c. At 3.00 p.m. court temperature rises to 29.28^{O}c.

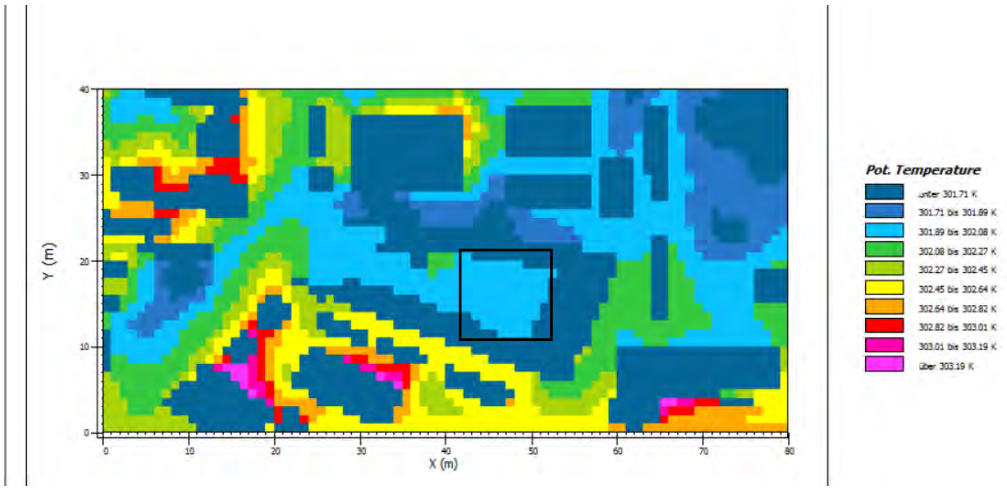
Figure 4-3 is showing the mean radiant temperature of ssite 01(aust) courtyard at three different times at 1.60m level. . It has been found from the image that at 9.00 a.m. the mean radiant temperature of court ranges from 30.38^{O}c to 46.41^{O}c. At 12.00 p.m. temperature rises to 55.97^{O}c in most of the court and 36.58^{O}c in some tiny areas. At 3.00 p.m. it rises to highest peak with 60^{O}c.

Figure 4-4 is showing the wind speed in ssite 01(aust) courtyard at three different times at 1.60m level. . It has been found from the image that at 9.00 a.m. the wind speed of court ranges from .38 m/s to .58 m/s. At 12.00 p.m. wind speed drops to .37 m/s. At 3.00 p.m. it again rises to .38 m/s.

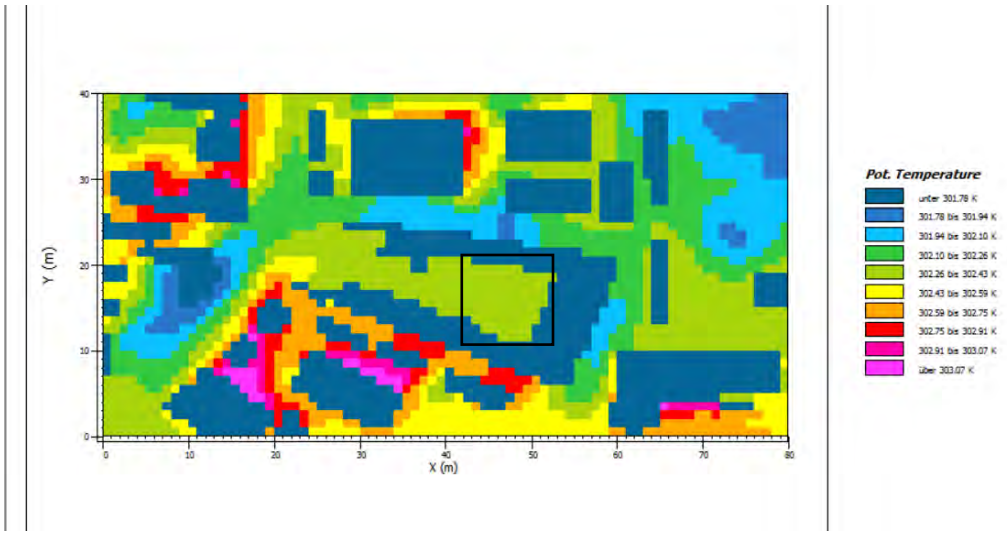
Figure 4-5 is showing the relative humidity of ssite 01(aust) courtyard at three different times at 1.60m level. . It has been found from the image that at 9.00 a.m. the relative humidity of court is 75.57% whereas inside of building shows a high humidity 87.6%. At 12.00 p.m. relative humidity drops to 69.14% and in some parts 70.47%. At 3.00 p.m. it again drops to 68.35%. Some small portion of court shows 69.71%



At 09.00 A.M

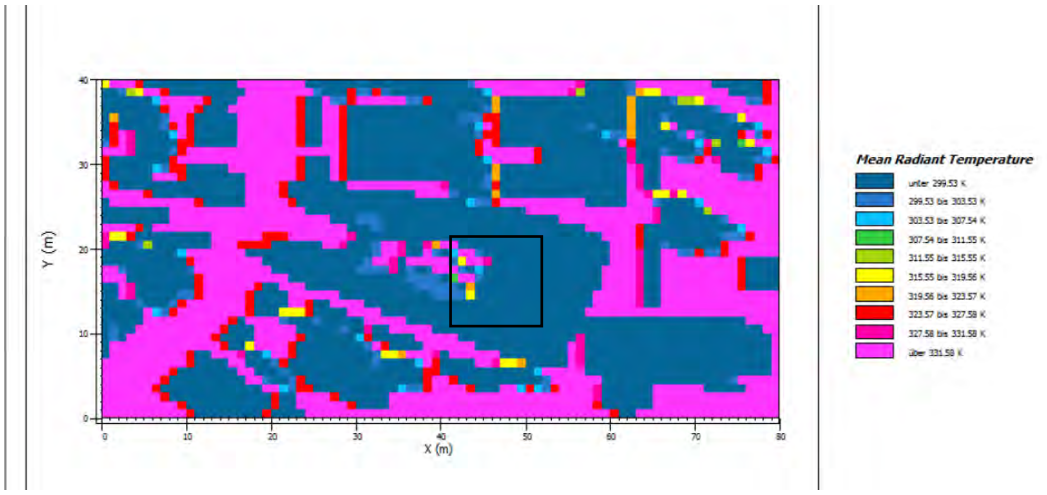


At 12.00 P.M

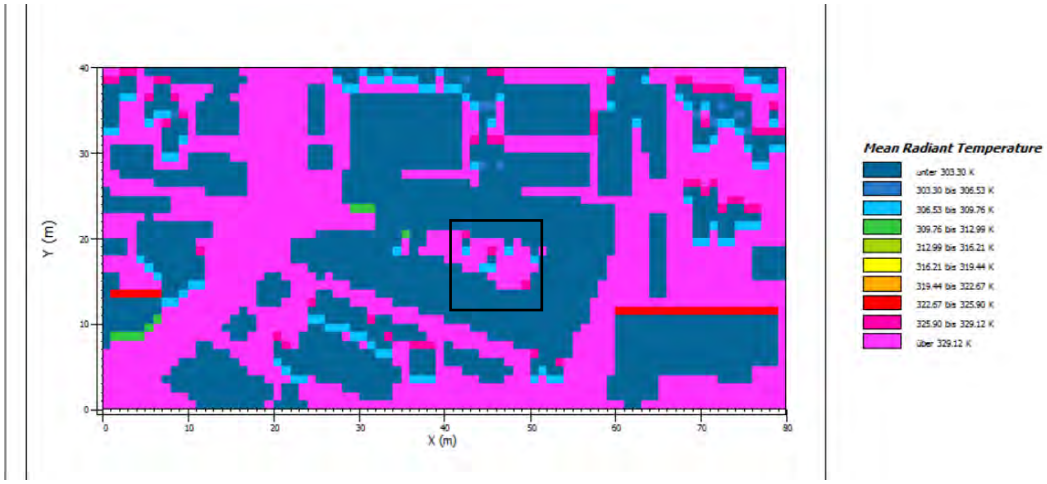


At 03.00 P.M

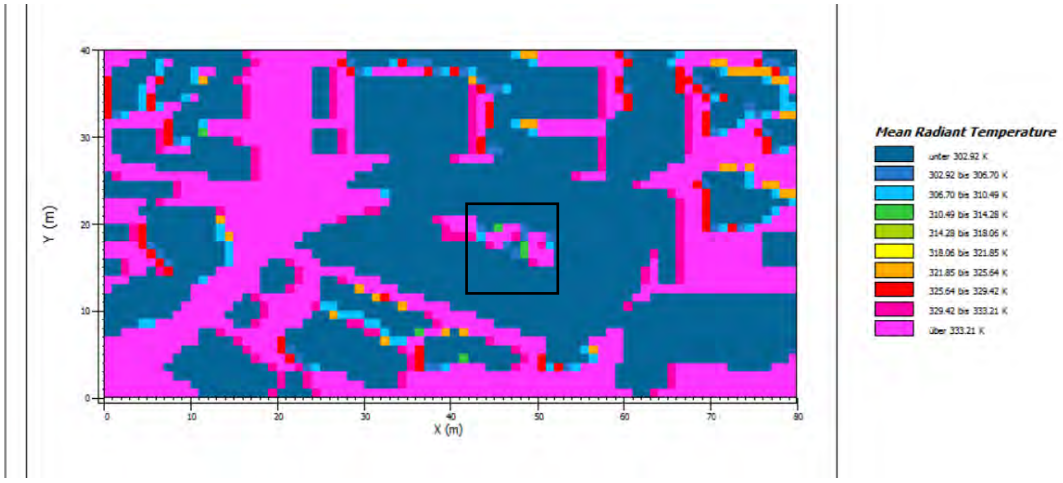
Figure:4-2 simulation Pot temperature of SSite 01 on 10.03.16 at different time



at 09.00 A.M

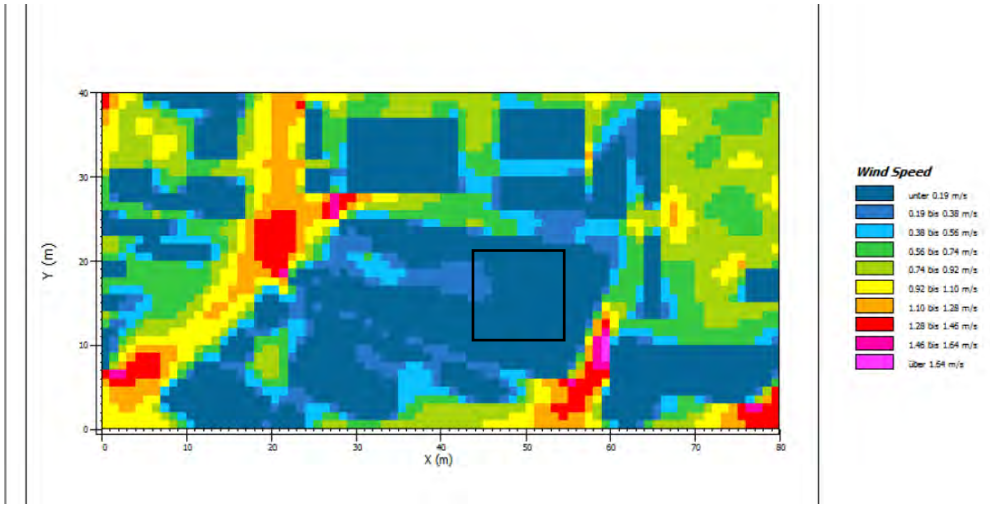


At 12.00 P.M

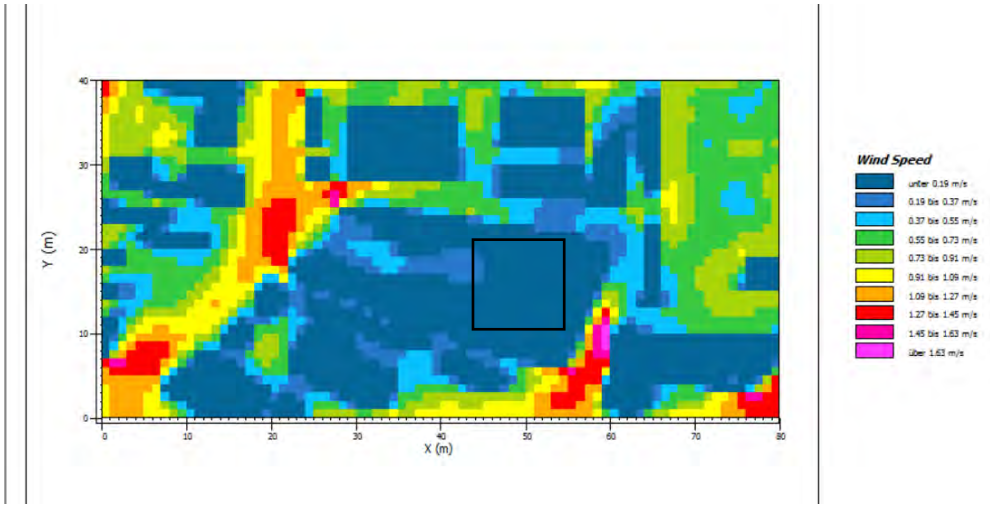


At 03.00 P.M

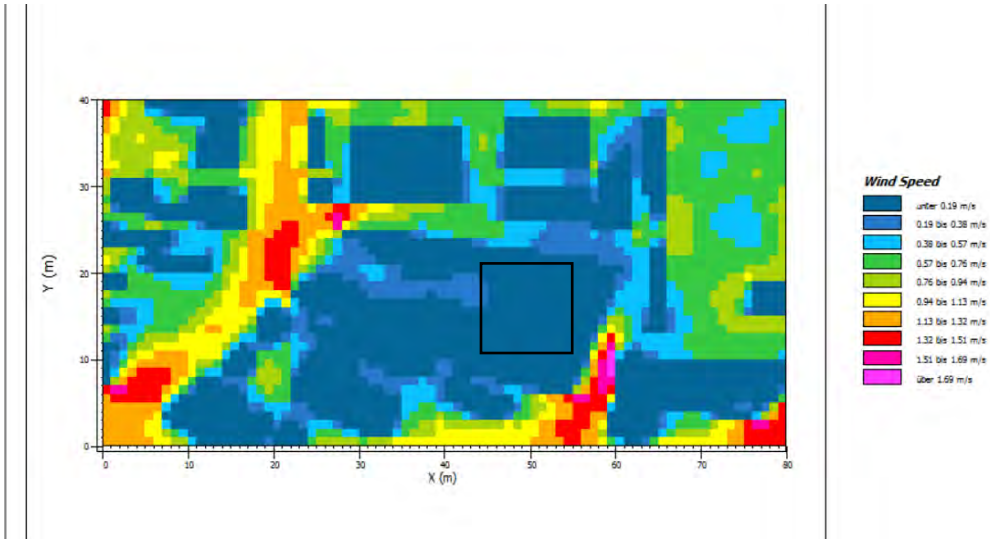
Figure:4- 3 simulation of Mean Radiant Temperature of SSite 01 on 10.03.16 at different time



At 09.00 A.M

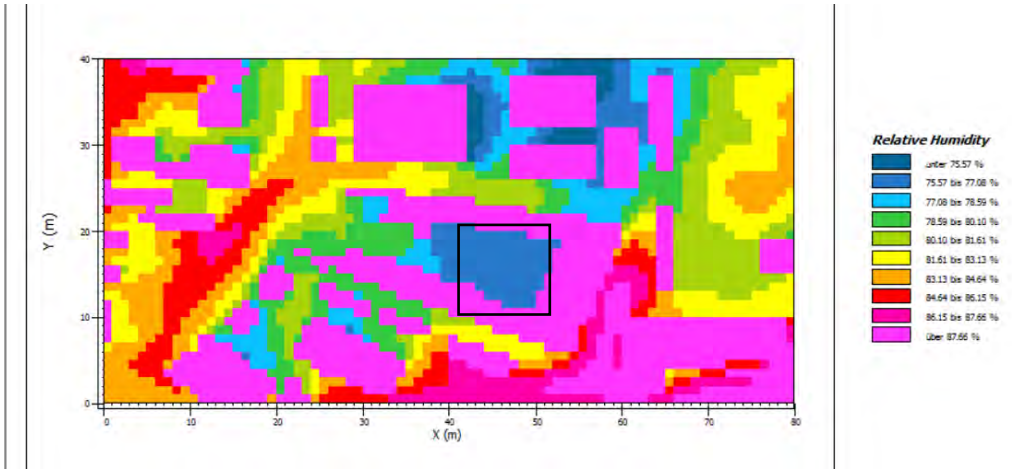


At 12.00 P.M

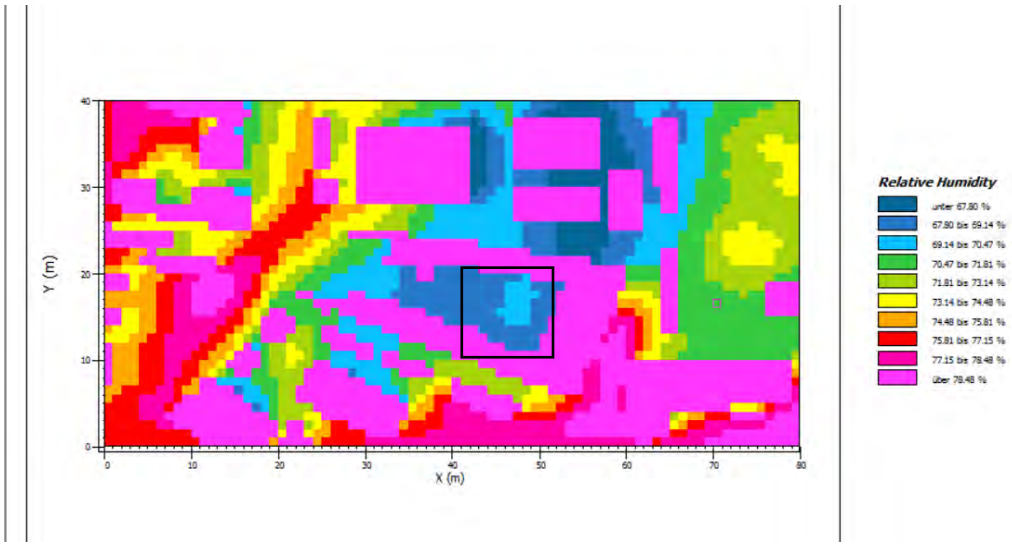


03.00 P.M

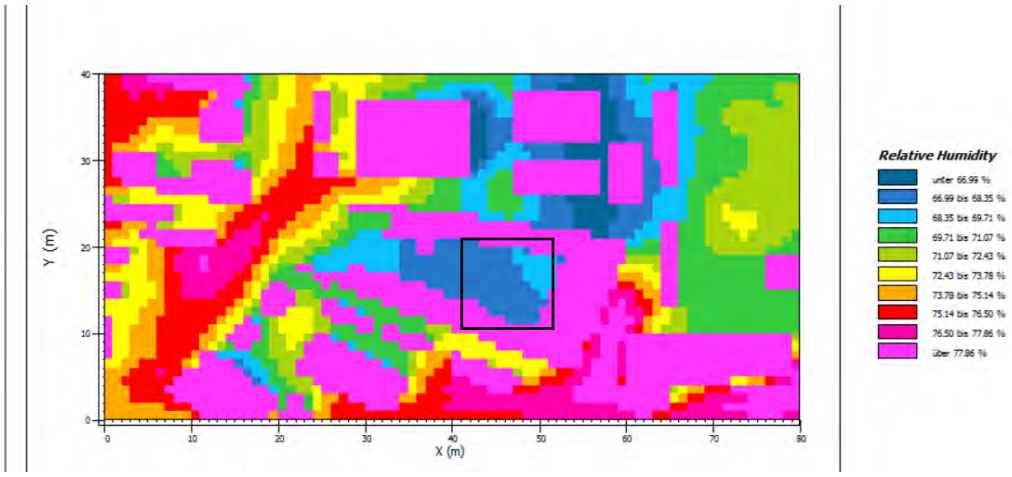
Figure:4-4 simulation of wind speed of SSite01 on 10.03.16 at different time



At 09.00 A.M



At 12.00 P.M



At 03.00 P.M

Figure:4-5 simulation of relative humidity of SSite01 on 10.03.16 at different time

Findings:

			09.00 a.m.	12.00 p.m.	03.00 p.m			09.00 a.m.	12.00 p.m.	03.00 p.m
10.03.2016	Temperature	H	25.75°C	28°C	29.28°C	Humidity	H	75.57%	70.47%	69.71%
		L	25.48°C	28°C	29.28°C		L	75.57%	69.14%	68.35%
	Mean Radiant Temperature	AVG	38	55	60	Wind Speed	H	.58m/s	.37m/s	.38m/s
							L	.38m/s	.37m/s	0.37m/s

Table 4.4.1a Highest and lowest temperature, humidity, wind speed and mean radiant temperature found from simulation

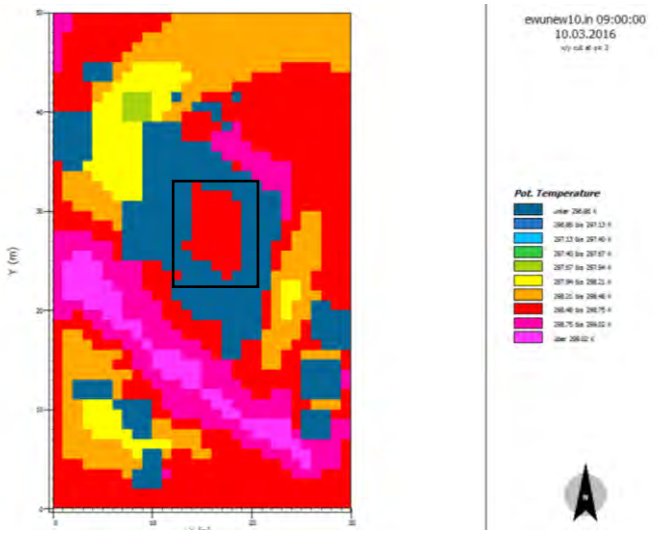
4.3.2 SSite 02

Figure 4-6 is showing the pot temperature of ssite 02(ewu) courtyard at three different times at 1.60m level. It has been found from the image that at 9.00 a.m. the temperature of court is 25.60°c whereas the road temperature shows a higher value with 26°c. At 12.00 p.m. temperature rises to 29.55°c when the outside temperature shows a lesser value 29.10°c. At 3.00 p.m. court temperature rises to 29.86°c.

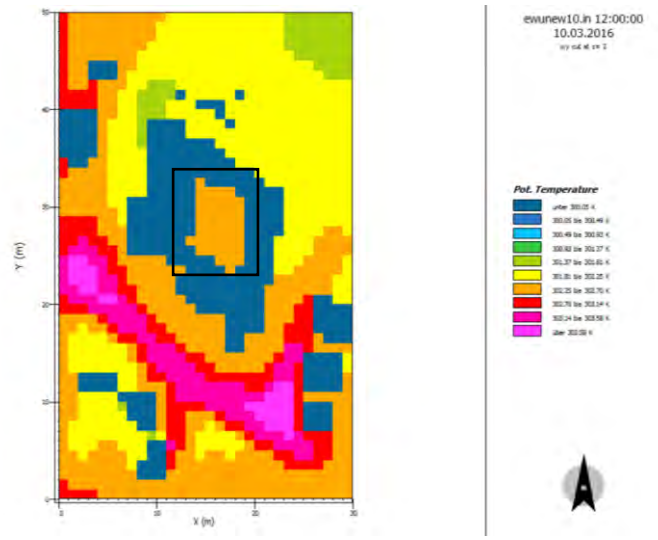
Figure 4-7 is showing the mean radiant temperature of ssite 02(ewu) courtyard at three different times at 1.60m level. . It has been found from the image that at 9.00 a.m. the mean radiant temperature of court is 27.22°c. At 12.00 p.m. temperature rises to 64.58°c in most of spaces in the court and 60.46°c in other areas of court. At 3.00 p.m. it rises to highest peak with 67.47°c along with a lesser value of 35.76°c in some areas.

Figure 4-8 is showing the wind speed in ssite 02(ewu) courtyard at three different times at 1.60m level. . It has been found from the image that at 9.00 a.m. the wind speed of court is .20 m/s. At 12.00 p.m. wind speed drops to .19 m/s. At 3.00 p.m. it again rises to .20 m/s.

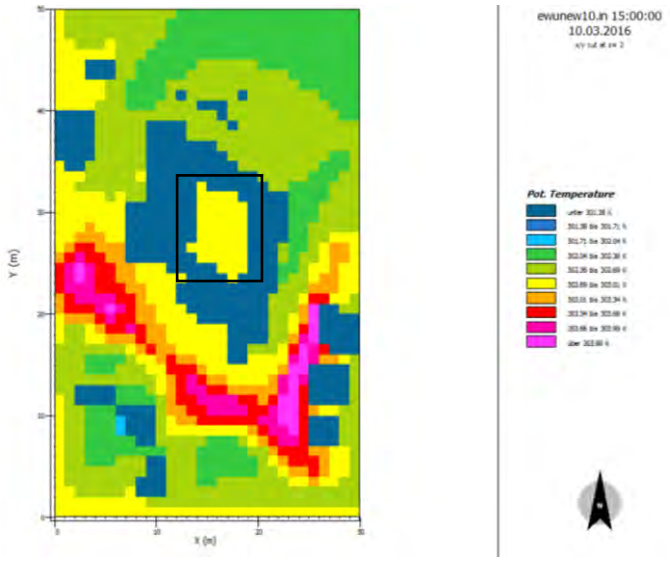
Figure 4-9 is showing the relative humidity of ssite 02(ewu) courtyard at three different times at 1.60m level. . It has been found from the image that at 9.00 a.m. the relative humidity of court is 81.99% whereas inside of building shows a high humidity 96%. At 12.00 p.m. relative humidity drops to 69.40%. At 3.00 p.m. it again rises to 72.39%.



At 09.00 A.M

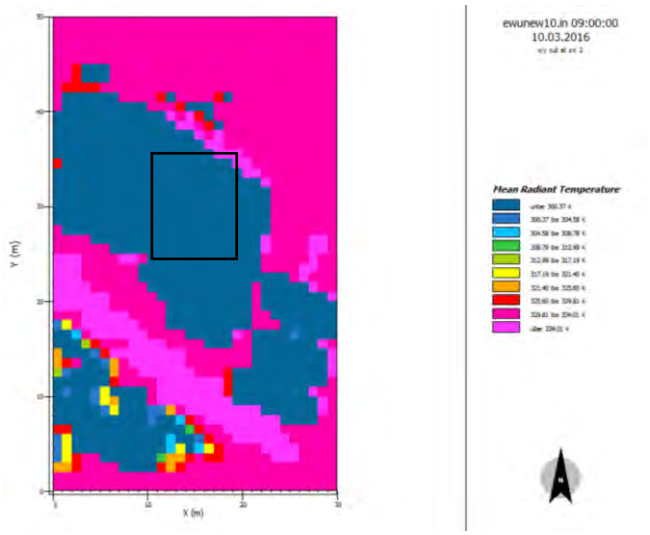


At 12.00 P.M

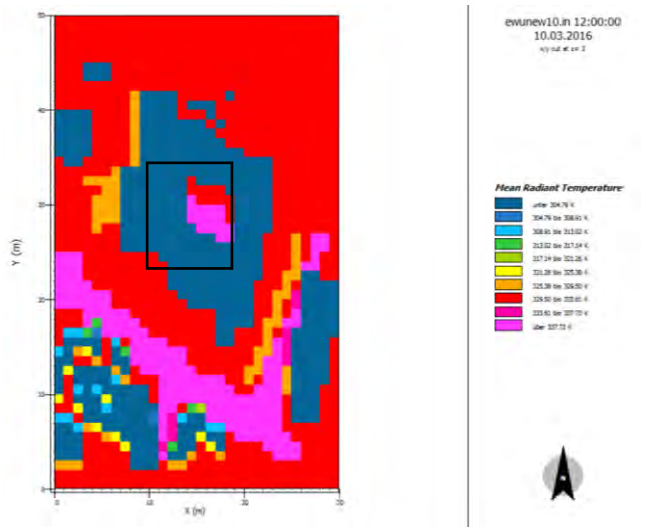


At 03.00 P.M

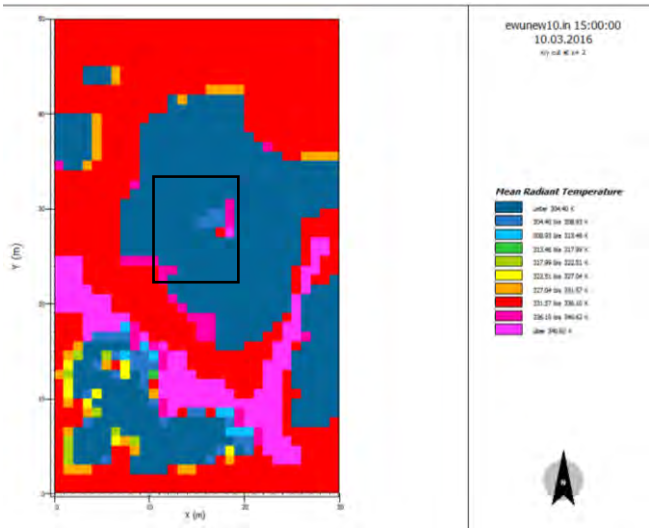
Figure:4-6 simulation Pot temperature **of** *SSite 02 on 10.03.16 at different time*



At 09.00 A.M

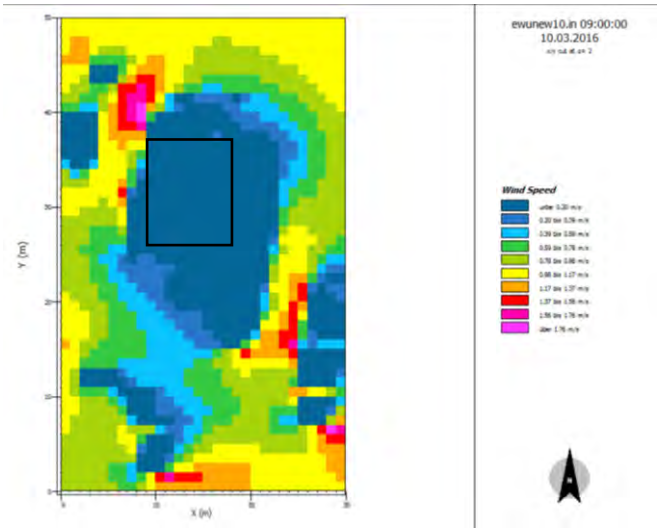


At 12.00 P.M

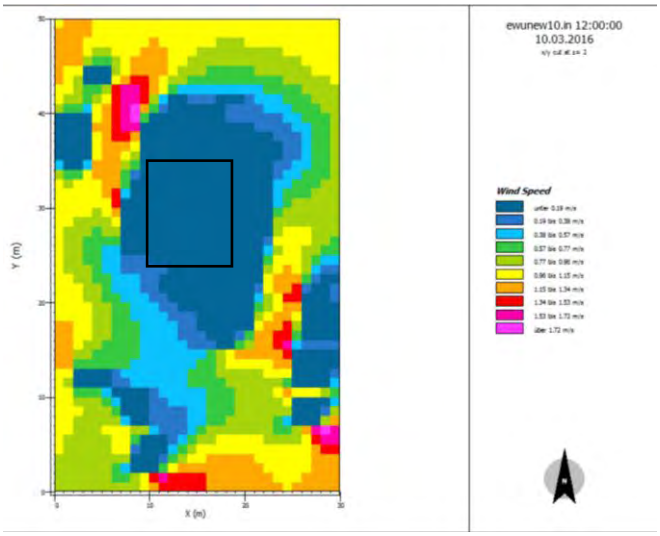


At 03.00 P.M

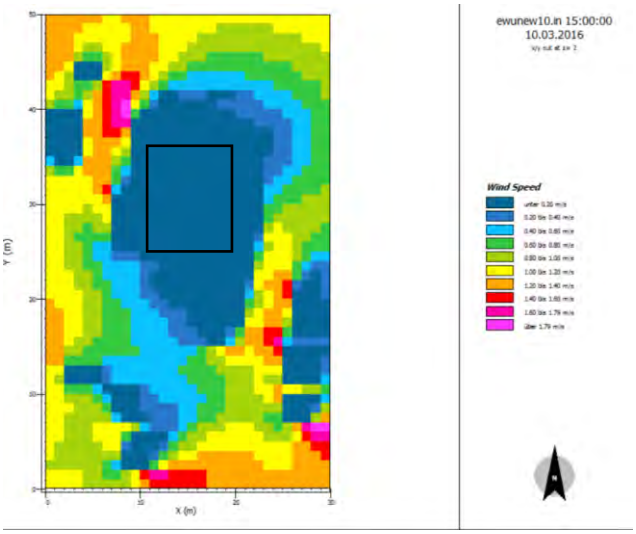
Figure:4-7 simulation of Mean Radiant Temperature of SSite 02 on 10.03.16 at different time



At 09.00 A.M

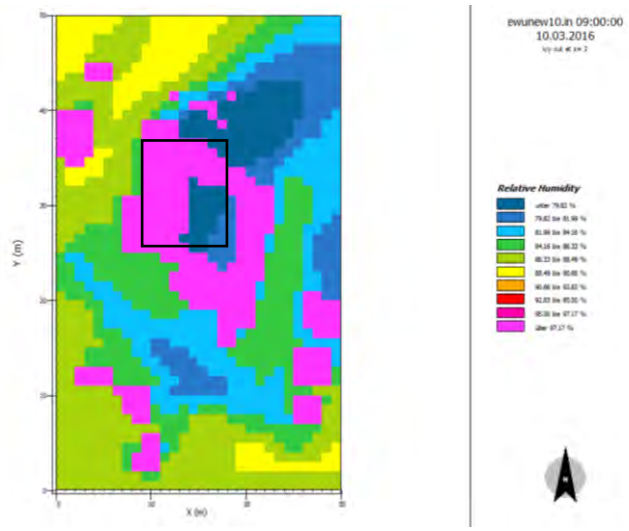


At 12.00 P.M

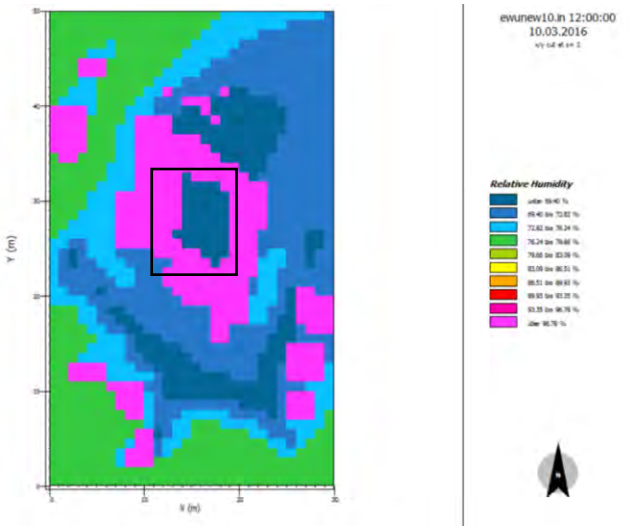


At 03.00 P.M

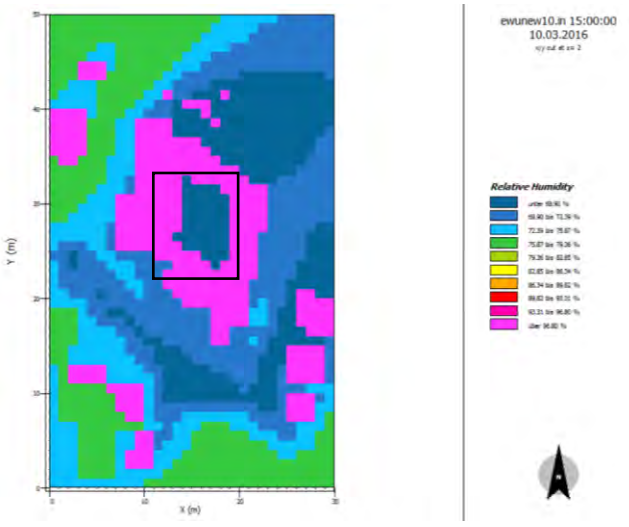
Figure:4-8 simulation wind speed of SSite 02 on 10.03.16 at different time



At 09.00 A.M



At 12.00 P.M



At 03.00 P.M

Figure:4-9 simulation of relative humidity of SSite 02 on 10.03.16 at different time

Findings:

			9 a.m.	12 p.m.	3 p.m.			09.00 a.m.	12.00 p.m.	03.00 p.m.
10.03.2016	Temperature	H	25.60°C	29.55°C	29.86°C	Humidity	H	81.99%	69.40%	72.39%
		L	25.60°C	29.55°C	29.86°C		L	79.82%	69.40%	72.39%
	Mean Radiant Temperature	AVG	27.22	62.52	51.65	Wind Speed	H	.20m/s	.19m/s	.20m/s
							L	.20m/s	.19m/s	.20m/s

Table 4.4.2a Highest and lowest temperature, humidity, wind speed and mean radiant temperature found from simulation

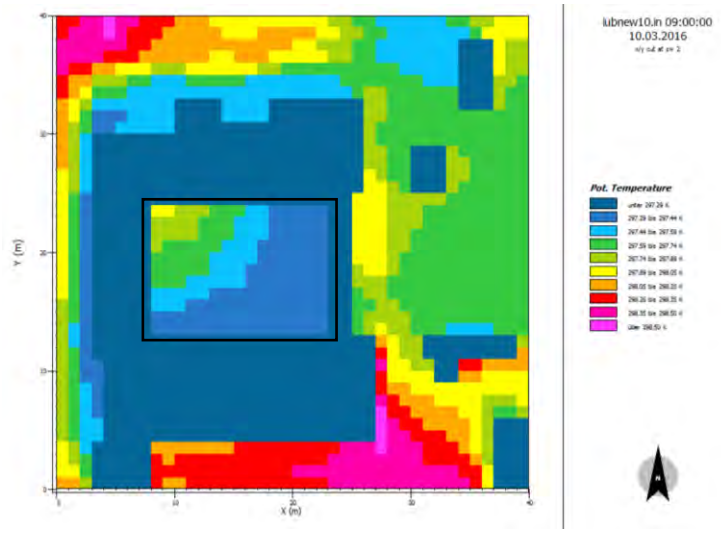
4.3.3 SSite 03

Figure 4-10 is showing the pot temperature of ssite 03(iub) courtyard at three different times at 1.60m level. It has been found from the image that at 9.00 a.m. the temperature of court varies from 24.14°c (mostly green areas) to 24.90°c. At 12.00 p.m. temperature rises to 29.94°c in paved areas and 29.24°c in green areas. At 3.00 p.m. court temperature rises to 30.26°c (totally paved area exposed to sun). At 3.00 p.m court temperature in green areas which is under shade varies from 29.70°c to 29.84°c.

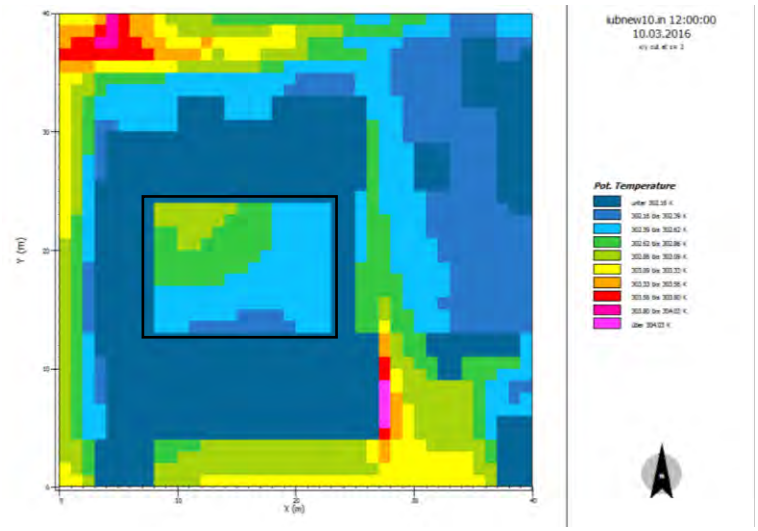
Figure 4-11 is showing the mean radiant temperature of ssite 03(iub) courtyard at three different times at 1.60m level. . It has been found from the image that at 9.00 a.m. the mean radiant temperature of court varies from 53.07°c to 64.25°c. At 12.00 p.m. it varies from 57.90°c to 66.51°c. At 3.00 p.m. the range is 59.84°c to 69.3°c

Figure 4-12 is showing the wind speed in ssite 03(iub) courtyard at three different times at 1.60m level. . It has been found from the image that at 9.00 a.m. the wind speed of court varies from .24 m/s to .45 m/s. At 12.00 p.m. wind speed drops to .23 m/s. At 3.00 p.m. it again rises to .25 m/s.

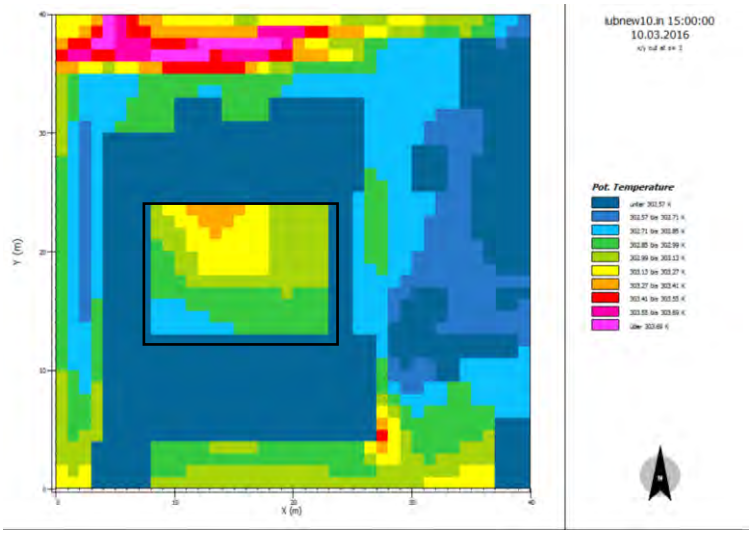
Figure 4-13 is showing the relative humidity of ssite 03(iub) courtyard at three different times at 1.60m level. . It has been found from the image that at 9.00 a.m. the relative humidity of court is 89.11% in most of the section with a small variation in two different areas ranging from 86.59% to 91.63%. At 12.00 p.m. relative humidity drops to 69.87% and in some areas 67.23%. At 3.00 p.m. it again drops to 67.23% and only a small portion shows 69.18%.



At 09.00 A.M

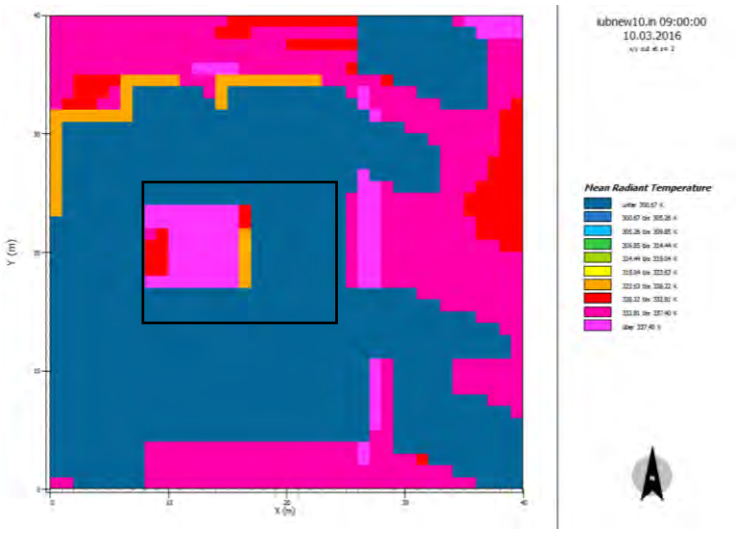


At 12.00 P.M

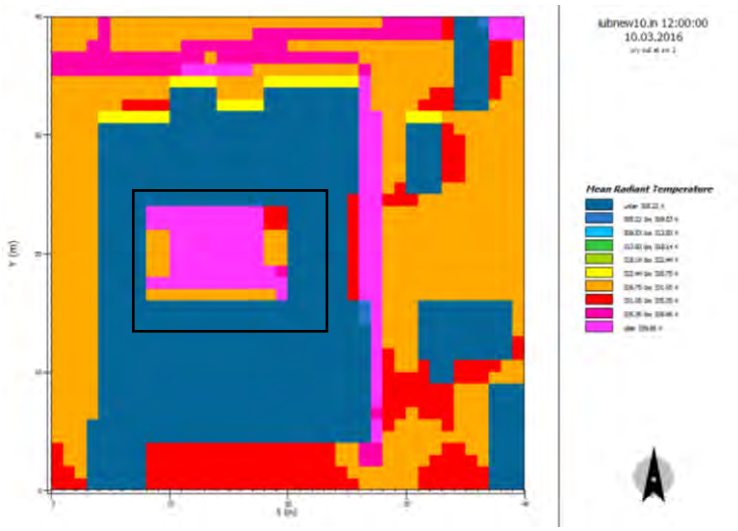


At 03.00 P.M

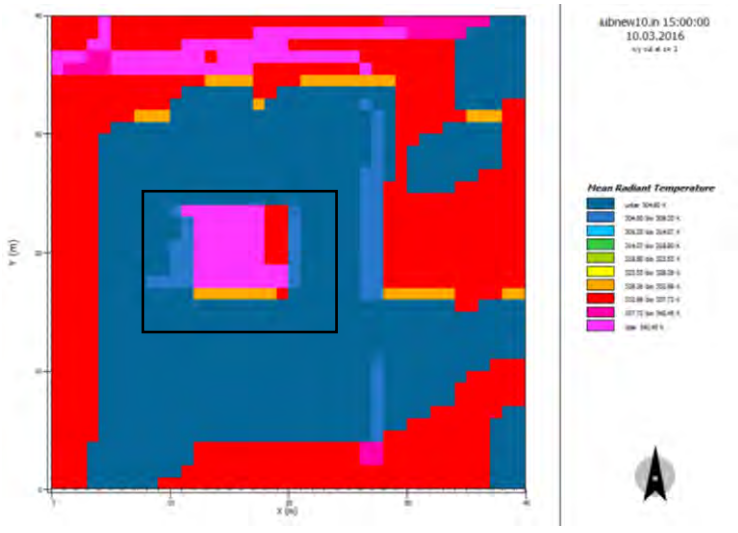
Figure:4-10 simulation Pot temperature of SSite 03 on 10.03.16 at different time



At 09.00 A.M

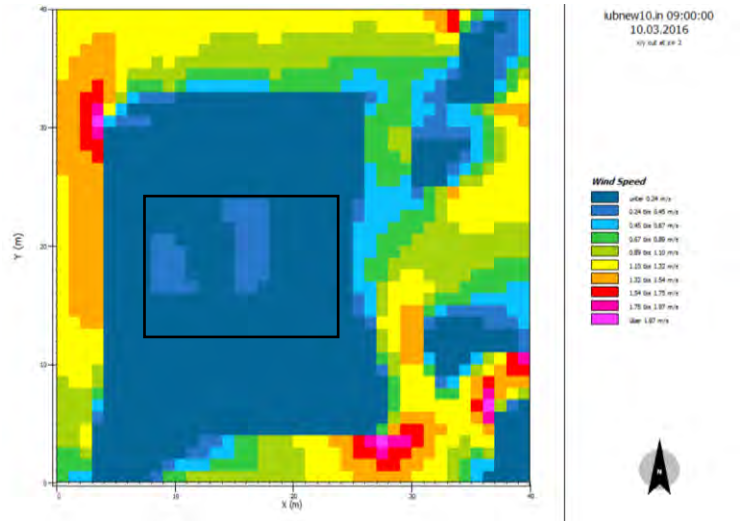


At 12.00 P.M

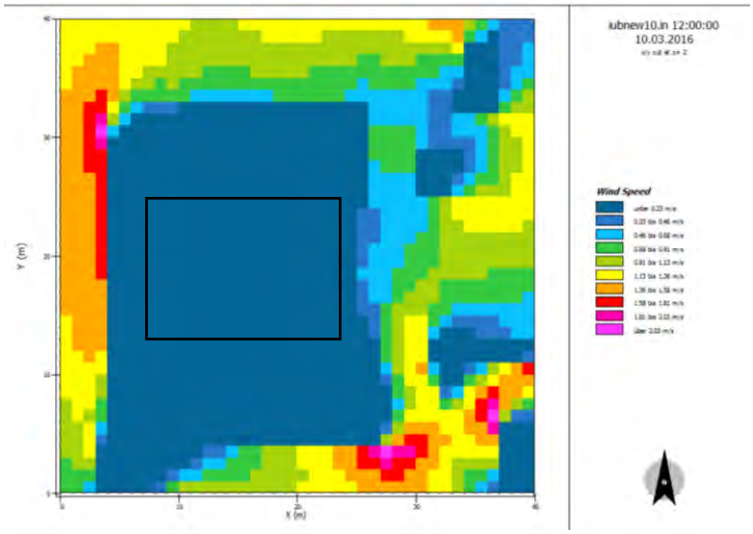


At 03.00 P.M

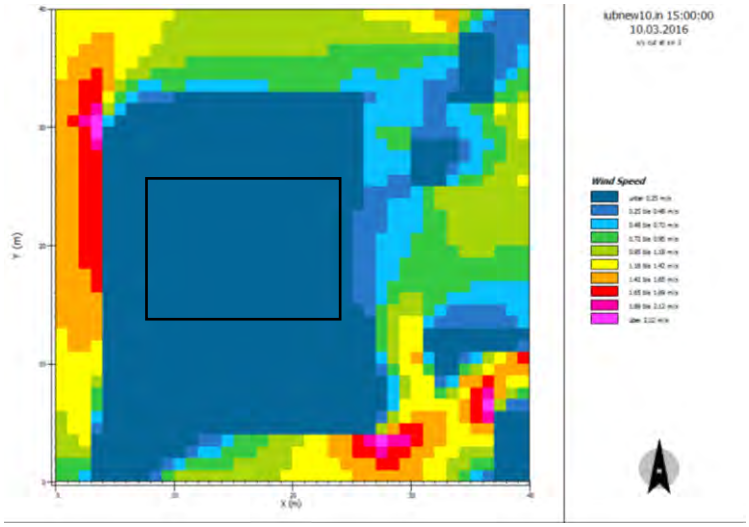
Figure:4-11 simulation of Mean Radiant temperature of SSite 03 on 10.03.16 at different time



At 09.00 A.M

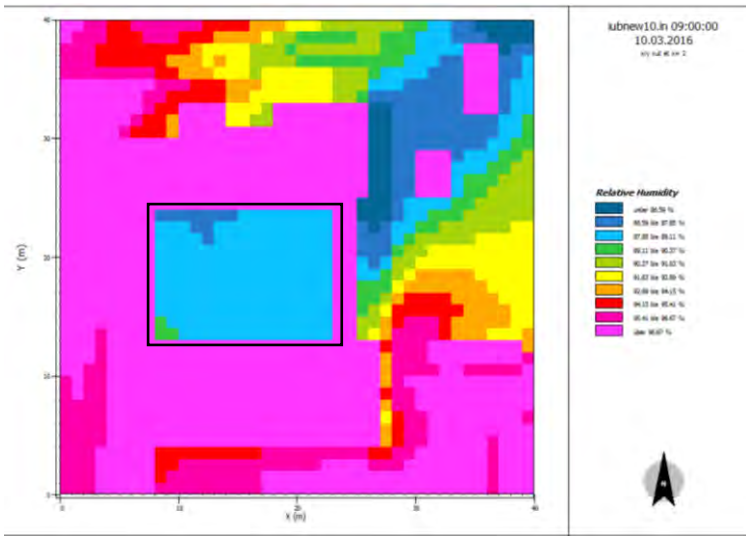


At 12.00 P.M

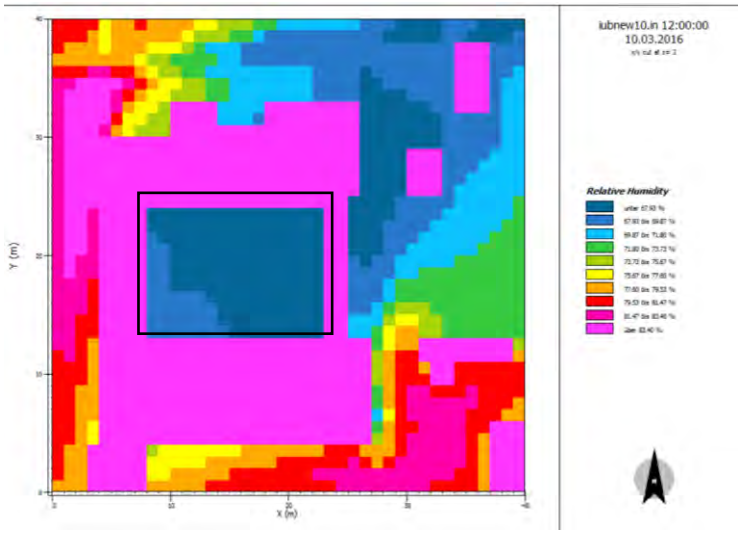


At 03.00 P.M

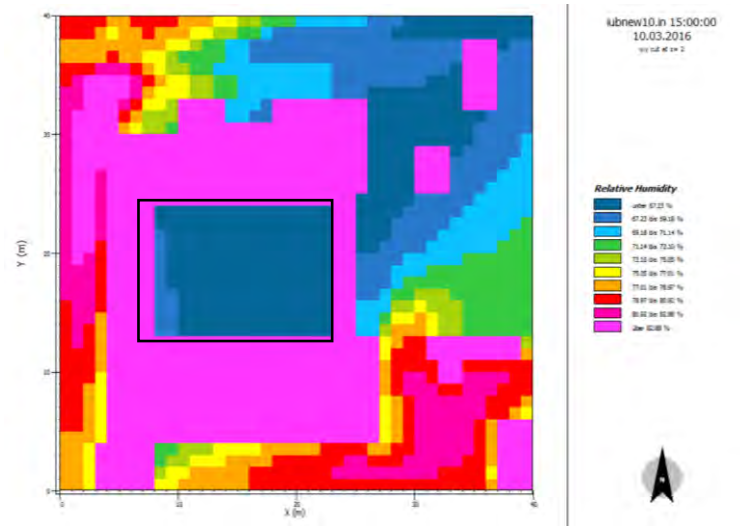
Figure:4-12 simulation Wind Speed of SSite 03 on 10.03.16 at different time



At 09.00 A.M



At 12.00 P.M



At 03.00 P.M

Figure:4-13 simulation of Relative Humidity of SSite 03 on 10.03.16 at different time

			09.00 a.m	12.00 p.m.	03.00 p.m.			09.00 a.m	12.00 p.m.	03.00 p.m.
10.03.2016	Temperature	H	24.90°C	29.94°C	30.26°C	Humidity	H	91.63%	69.87%	69.18%
		L	24.14°C	29.24°C	29.70°C		L	89.11%	67.93/%	67.23%
	Mean Radiant Temperature	AVG	58.5	62.2	64.4	Wind Speed	H	.45m/s	.23m/s	.25m/s
							L	.24m/s	.23m/s	.25m/s

Table 4.4.3a Highest and lowest temperature, humidity, wind speed and mean radiant temperature found from simulation

4.4 Analysis

		Temperature range found from simulation diagram(°c)			Mean Radiant Temperature range found from simulation diagram(°c)			Relative Humidity range found from simulation diagram(%)			Wind Speed range found from simulation diagram(m/s)		
		AUST	EWU	IUB	AUST	EWU	IUB	AUST	EWU	IUB	AUST	EWU	IUB
March	9.00 hours	25.48°-25.75°	25.60°-25.60°	24.14°-24.90°	38°	27.22°	58.5°	75.57%-75.57%	79.82%-81.99%	89.11%-91.63%	.38m/s-.58m/s	.20m/s-.20m/s	.24m/s-.45m/s
	12.00 hours	28°-28°	29.55°-29.55°	29.24°-29.24°	55°	62.52°	62.2°	69.14%-70.47%	69.40%-69.40%	67.93%-69.87%	.37m/s-.37m/s	.19m/s-.19m/s	.23m/s-.23m/s
	15.00 hours	29.28°-29.28°	29.86°-29.86°	29.70°-30.26°	60°	51.65°	64.4°	69.71%-68.35%	72.39%-72.39%	67.23%-69.18%	.37m/s-.38m/s	.20m/s-.20m/s	.25m/s-.25m/s

Table 4.4a ENVI-met Simulation parameters for three sites, month and time

4.4.1 Discussion:

Simulation done for three SSites on the same day shows a comparative results among three SSites (table 4.4a). It has been found that air temperature is lower in ssite 01 among the three sites where large amount of space is green. It has been also found that in case of ssite 03 the temperature in green areas is lower than the paved Areas. Temperature found higher mostly in ssite 02 29.86°c which is totally paved and also in ssite 03 the paved area exposed to sun shows highest temperature 30.26°c at 3.00 p.m. MRT is found higher in ssite 03 at 9.00 a.m and in 3.00 p.m. MRT fund lower in ssite 01 at 9.00 a.m. Relative humidity found higher in ssite 02. Wind speed found higher in ssite 01.

4.5 Conclusion:

The ENVI-met simulation and graph have been discussed to draw a possible relationship. Again the diagrams have been analyzed to find out the comparison of the study areas. 36 simulation diagrams for three different day times of a month have been found comparing with the field survey. Microclimatic condition found differs in different daytime.

Chapter 05: Observation and Recommendation

Introduction

Review of Research Objectives

Observations

Scope for Future Research

Conclusion

5.1 Introduction

The findings and analysis of the research have been discussed in the previous chapter. This final chapter will conclude the overall findings of the research. The application of the research findings are also discussed in relation to the aims and objectives of the study discussed in chapter 1. Finally, further scope related to this study will be suggested in this chapter in order to strengthen this research.

5.2 Review of Research objectives

As stated in Chapter 1, the main aim of this study was

- To identify the environmental conditions (i.e. Temperature range, humidity, radiant temperature and wind speed) in reference to outdoor comfort.
- To explore how the geometry, orientation and choice of materials used on the ground and on vertical surfaces around courtyard impact the environmental behavior of courtyard

The study addressed the following issues

- The present thermal conditions of closed courtyards due to its ground materials
- Identify the thermal condition in respect to Human comfort
- Impact of building morphology and orientation on thermal behavior

5.3 Observation

- Vegetation has impact on local microclimate. Vegetation affects the local air temperature. It can keep the air temperature lower whereas presence of hard exposed materials or structure in the green area is responsible for increasing the air temperature. Temperature in the study area was to be found 1°C higher than Dhaka‟s temperature in the paved courtyard and found 1°C lower in the court with vegetation (Fig 3-47 and Fig 3-48). This indicates that open to sky court spaces to be landscaped with hard or soft material to have desirable condition.
- Compared to the open lawn, the grass shaded by trees or building mass produced lower air temperature and greater cooling affect during daytime (fig 3-43 and table 3.4.1a).
- Compared to the exposed paved area, the paved surface shaded by building performs better in terms of air temperature.(Fig 3-49) . This indicates that shading can be an important strategy for achieving desirable thermal environment.

- The influence of vegetation on humidity and air temperature is affected by the configurations of greenery and height of trees, plants, etc.
- Humidity found higher in the court with pave than Dhaka‟s humidity for a specific day and found lower in the court with open lawn which has lesser vegetation having few tall trees and small shrubs mostly exposed to sun (Fig 3-48 and Fig 3-54)
- Another finding from this study is that the wind velocity is typically low within the court, but it is higher if the surrounding plots are vacant while envelop of courtyard have some perforation or windward openings.
- MRT found higher in the court with paved surface in caomparison to the green surface. It was found higher at 9.00 hours and 15.00 hours in March 10th, 2016 in the closed courtyard with paved surface and it was found lower at 09.00 hours in March 10th, 2016 in the closed court with green bed in ssite 01 (table 4.4.1a). This indicates that ground material is inflenced by sorrounding wall surfaces.
- Orientation is another important factor. It has been found that courtyards elongated in N-S orientation with increased number of floors reduces solar radiation.
- Deep courtyard performs better in terms of air temperature (ssite 01) has been found lower than that of Dhakas‟s maximum ranges as recorded in the meteorological data. This indicates air temperature is lower when building massess are taller with light perforated envelop.

5.4 Scope for Future Research

1. The research work has been done on three study area in Dhaka. The further long term studies can be done on other area with complex situation to find rational relation.
2. The research can be done for different periods of time for different years to find out the deviation or changes.
3. Social behavioral component have been considered less which need to be included in the further studies.
4. A study can be done to find out the impact of building code, FAR on the courtyard design.
5. Study on thermal performance of internal envelope‟s finishing and materials can be studied.

5.5 Conclusion

This research describes an effort that contributes towards understanding the thermal performance of closed courtyards of institutional campus in Dhaka. The he result revealed that knowledge of thermal performance of various urban surfaces and landscape elements is an important design tool for designers and planners. Proper utilization can bring improvement of the outdoor thermal environment. The use of courtyard can be enhanced by appropriate microclimatic planning through offering proper uses of surface materials along with landscape elements. The outcome and observation of this research can be applied to design further closed courtyard buildings.

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Appendix 1

APPENDIX 01: INSTRUMENT

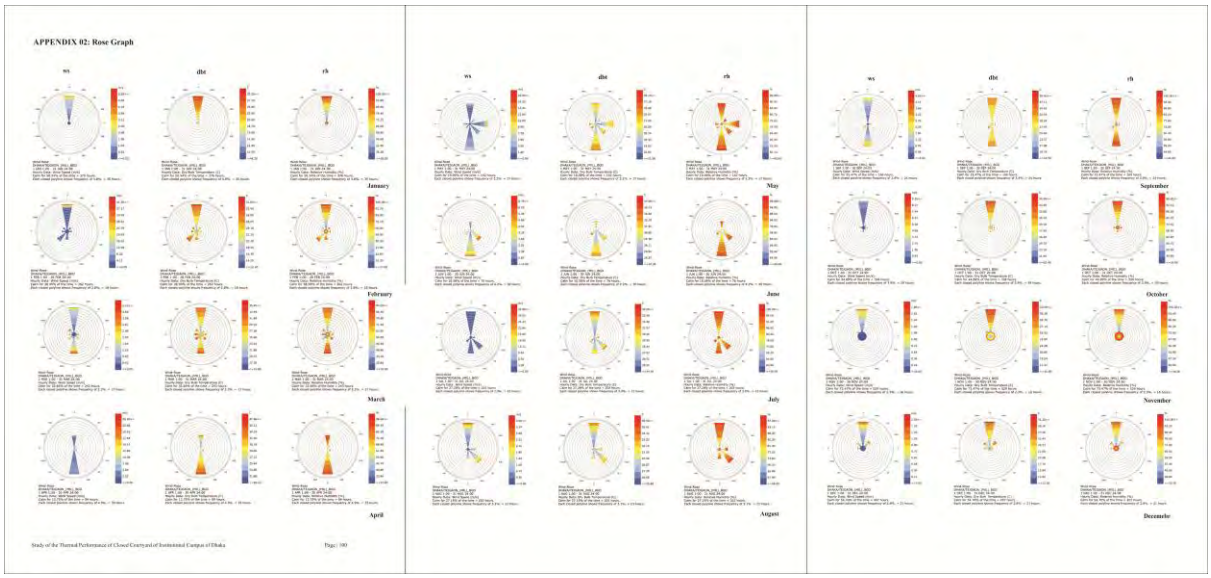
Kestrel 3500 Pocket Weather

Meter

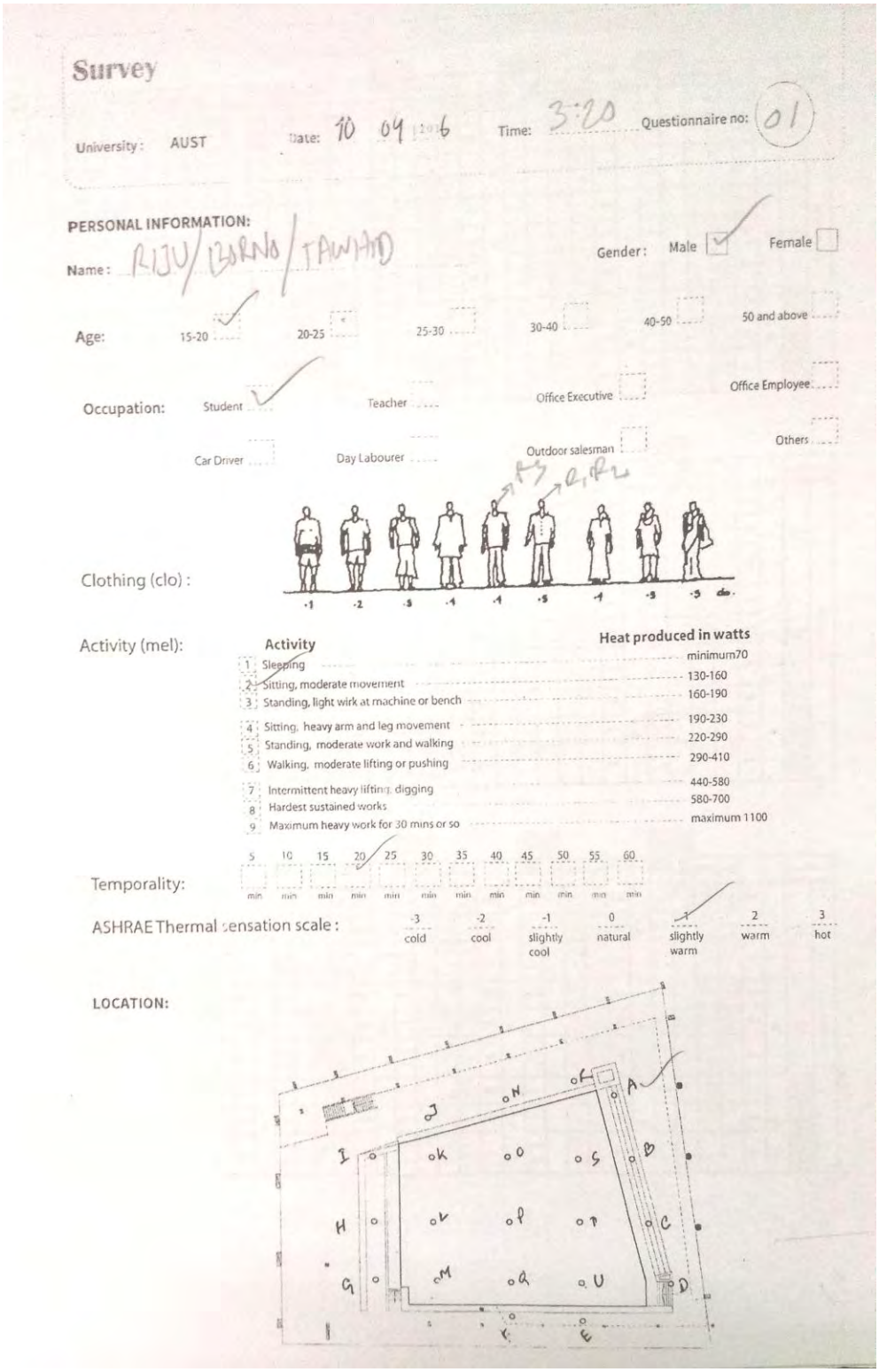
All Kestrel Pocket Weather Meters are made in the USA and covered by a 5-year warranty against manufacturing defects. Additionally, every single Kestrel manufactured is calibrated for every single value, either directly against NIST-traceable standards or against an intermediary standard that is calibrated daily. Every unit is shipped with a Free Certificate of Conformity that states what calibrations were performed, and the certified performance specifications.

The Kestrel 3500 Pocket Weather Meter is the handheld weather-monitoring device that provides a wide range of functions, plus accurate relative humidity measurements. The Kestrel 3500's sensitive and user-replaceable impeller technology provides accurate wind speed info. Additionally, an external temperature sensor and waterproof casing allow you to gauge the temperature of water (it even floats) and snow, as well as the open air. A hard slide-on case, lanyard, and battery are included. The Kestrel 3500 accurately measures: Wind Chill; Air, Water, and Snow Temperature; Displayed in Fahrenheit or Celsius w/ accuracy of +/-1°; Current, Average, and Maximum Wind Speed; Wind Speeds displayed in: Beaufort Wind Scale, Knots, MPH, KPH, or Feet per Minute; Relative Humidity; Dew point and Heat Stress Index

APPENDIX 02: Rose Graph



APPENDIX 03: Questionnaire filled up by participants



Survey

University: AUST Date: 10 04 2016 Time: 3:20 Questionnaire no: 01

PERSONAL INFORMATION:

Name: RIJU/BORNO/TAWHID Gender: Male ✓ Female

Age: 15-20 ✓ 20-25 25-30 30-40 40-50 50 and above

Occupation: Student ✓ Teacher Office Executive Office Employee

Car Driver Day Labourer Outdoor salesman Others

Clothing (clo):

Activity (mel):

	Activity	Heat produced in watts
1	Sleeping	minimum70
2	Sitting, moderate movement	130-160
3	Standing, light wirk at machine or bench	160-190
4	Sitting, heavy arm and leg movement	190-230
5	Standing, moderate work and walking	220-290
6	Walking, moderate lifting or pushing	290-410
7	Intermittent heavy lifting, digging	440-580
8	Hardest sustained works	580-700
9	Maximum heavy work for 30 mins or so	maximum 1100

Temporality: 5 min | 10 min | 15 min | 20 ✓ min | 25 min | 30 min | 35 min | 40 min | 45 min | 50 min | 55 min | 60 min

ASHRAE Thermal sensation scale: -3 cold | -2 cool | -1 slightly cool | 0 natural | 1 ✓ slightly warm | 2 warm | 3 hot

LOCATION: