Study on Changes in Micro-climatic Parameters and Domestic Energy Consumption Influenced by Changes in Urban Morphology in Hatirjheel Area, Dhaka.

by

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THESIS APPROVAL

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The thesis titled "STUDY ON CHANGES IN MICRO-CLIMATIC PARAMETERS AND DOMESTIC ENERGY CONSUMPTION INFLUENCED BY CHANGES IN URBAN MORPHOLOGY IN HATIRJHEEL AREA, DHAKA" Submitted by Hassan Mahbub Reza, Roll No-0413012018 P, Session- April 2013, has been accepted as satisfactory in partial fulfillment of the requirements for the Degree of MASTER OF ARCHITECTURE on this day 20th March, 2019.

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DEDICATION

For being my source of Affection, Inspiration, Guidance and source of Love

Mahamuda Begum [Mother]	**Taz Mohammad** [Father]
Hassan Mahmud Reza [Brother]	**Hasan Mahfuz Reza** [Brother]
Mahafuza Ferdous [Wife]	**Sumaiya Bint Reza** [Daughter]

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LIST OF ABBREVIATIONS

ASHRAE	:	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AT	:	Air Temperature
BMD	:	Bangladesh Meteorological Department
BPDB	:	Bangladesh Power Development Board
CD	:	Climate Division
^0C	:	Degree Celsius
DBT	:	Dry Bulb Temperature
DPDC	:	Dhaka Power Distribution Company Ltd
DESA	:	Dhaka Electric Supply Authority
DESCO	:	Dhaka Electric Supply Company
DWASA	:	Dhaka Water and Sewerage Authority
FAR	:	Floor Area Ratio
IPCC	:	Intergovernmental Panel on Climate Change
km	:	Kilometer
kV	:	Kilovolt
Kwh/sqm	:	Kilo Watt Hour per Square Meter
LCZ	:	Local Climate Zones
m/s	:	Meter/ Second
MVA	:	Megavolt-ampere
MW	:	Megawatt
MRT	:	Mean Radiant Temperature
NOCs	:	Network Operation & Customer Service Offices
PGCB	:	Power Grid Company of Bangladesh Ltd.
PPD	:	Percentage People Dissatisfied
POBA	:	Poribesh Bachao Andolon
PMV	:	Predicted Mean Vote
REB	:	Rural Electrification Board
RAJUK	:	Rajdhani Unnayan Kartripakkha
RH	:	Relative Humidity
SBS	:	Sick Building Syndrome
Sqm	:	Square Meter
UHI	:	Urban Heat Island
WS	:	Wind Speed
WZPDCL	:	West Zone Power Distribution Company Limited

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ABSTRACT

Although there are several control measures for morphological changes in urban residential areas, it's seldom followed or maintained because of the growing community demand. Hence, once planned residential areas transforms into an unplanned state in relation to their physical layout and distribution of non-residential function. These morphological changes may affect the urban microclimate in either positive or negative way and that might affect the urban energy consumption in return. Therefore, it is paramount that these effects should be observed, because these changes and effects might lead to a situation where we may need to re-evaluate morphological changes to aid or counter its effects on urban microclimate and energy consumption.

To understand the influence of changed morphology on microclimate and energy consumption of an urban domestic area of Dhaka, Mohanagar Housing has been selected since this residential area underwent a large scale morphological changes in the resent years through the renovation work of Hatirjheel Lake and two periods (2007 and 2017) were observed, which are pre and post renovation respectively. The effect of renewed morphological changes (lake, roads adjacent to the lake, boundary wall, bridges, overpasses etc.) on the Micro-climatic parameters (temperature, mean radiant temperature, relative humidity and wind speed) and domestic energy consumption (electricity billing data) has been observed.

Analysis shows that, there is an obvious influence of the urban morphological changes on the Micro-climatic parameters and domestic energy consumption. Specifically, for this research area, with the change of 1°C in temperature due to the morphological changes, the rate of change of energy consumption is 17.67%. The Air Temperature increases and the RH is dramatically lowered due to the excessive heat gain at day and inadequate heat release at night from the pavements, roads and overpass near the Hatirjheel Lake. The malfunction of advection of humidity and inversion layer effect also plays a major role in this scenario throughout the day and night alike. Additionally, newly erected non porous wall and overpass too close to the water body created a barrier in between the water body (Hatirjheel Lake) and the residential (Mohanagar Housing) area, which obstructs the advection of humidity and wind flow. It is further perceived that although the morphological parameters of that area is changed as a whole, individual micro-domain samples are showing unique role to this due to their individual micro-domain parameters. Specially, the open area and the built area largely contributes to the change of micro-domain attributes.

Chapter 1:
PREAMBLE

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Chapter 1: PREAMBLE

1.1. Introduction:

Cities which are covered with large heat capacity structure such as concrete and asphalt are easier to get heated by the sun than its suburbs. Therefore, buildings located in the city have an increased energy demand for cooling (Han et al., 2007). Comfortable outdoor spaces have a significant bearing on the comfort perception of the indoor ambience. The demand for comfort conditions in buildings is significantly increased as a result of exposure to uncomfortable outdoors (Ahmed, 2003).

According to Intergovernmental Panel on Climate Change (IPCC) (2007), the global surface temperature has increased 0.74 ± 0.18 degree Celsius during the last 100 years ending in 2005. And this phenomenon is also observed in Dhaka city as well. Studies found that, in the last 100 years, the average temperature in Dhaka has increased by 0.5 degree Celsius, and in the next 50 years it is expected to increase by another 1.5–2 degrees (Dhaka Structure Plan, 2015). It is imperative that a thermally comfortable climate should be maintained. A thermally comfortable outdoor environment will also have a positive influence on the indoor climate, which will lead to lower energy use for space conditioning (Johansson et al., 2006). Therefore, creating a thermally comfortable microclimate in an urban environment is of utmost importance.

There are ample reasons to revive urban spaces and secure their future in our socio-cultural domain. Ensuring an acceptable standard in the quality of urban life in the present dynamic urban environment is a great challenge for the architects, urban designers, planners and policy makers (Ahmed, 2003).

1.2. Statement of the Problem:

In context of Dhaka city, it is observed that in spite of several controls, the planned residential areas have experienced morphological transformation in land use pattern with a minor change in the spatial layout to adapt with the community need. As a result, the planned residential areas tend to become transformed into an unplanned state in relation to their physical layout and distribution of non-residential function (Khan et al., 2009). Dhaka city's overheated outdoor environment has contributed to a growing preference for a lower comfort temperature indoors. This in turn has put an immense pressure on the energy demand in the cities (Ahmed, 2003). To control progressive energy demand, it is required to control alteration of the microclimate. But in order to do so, it is necessary to control the morphological alteration of that area, since that controls and alters the microclimate. Therefore, it is paramount that an observation is to be established on how the alteration of morphology controls the microclimate and energy consumption respectively.

Mondal and Denich (2010) found that, the electricity consumption of Dhaka's residential buildings nearly doubled between 2005 and 2011. The main reason for the increased consumption was identified as the increased standard of living of the higher-income group, which led to the use of more Air Conditioning (AC). Another study conducted in a typical apartment building with upper middle-income people found that on average, the use of AC and ceiling fans accounts for 38% of the total household electricity consumption (Ahsan, 2009).

Parveen, Soebarto and Williamson's (2015) study, focusing on the impact of Urban Heat Island (UHI) on energy consumption in a typical planned residential area of Dhaka, found that the cooling energy consumption of the buildings in the studied area increased by 5.1% for every $1^{0}C$ air temperature increase.

A study by Ahmed (2010), which investigated the effect of the surrounding built environment on residential energy consumption, found that apartments that have higher surrounding open spaces or in, other words, are situated in a less density-built environment, are more energy efficient.

A number of later studies have examined the micro-climatic impact of the existing urban development practices, primarily focusing on outdoor thermal comfort and the phenomenon known as the "Urban Heat Island (UHI)" (Ahmed, 2003; Das & Karmakar, 2015; Kakon & Nobuo, 2009; Kushol, Ahmed, Mohataz & Hossain, 2013; Sharmin, Steemers & Matzrakis, 2015). In addition, a number of studies are available regarding the indoor thermal comfort and indoor thermal performance of different types of urban buildings in Dhaka (Ahmed, 1994; Ali, 2007; Hafiz, 2004; Islam, 2011; Mallick, 1994).

Although there are plenty number of studies on urban morphology, urban micro-climatic parameters and urban domestic energy consumption individually, it is difficult to locate any paper that studies and explores these three factors within a single cover. Additionally, a paper that has exclusive research on all three topics together, and the links in-between is yet to be surfaced. This thesis paper is developed with a view of evaluating the influence of urban morphological change on microclimate and domestic energy consumption.

1.3. Objective of the Thesis:

The key objectives of the thesis are as follows:

1. To observe the influence of urban morphological change on urban micro-climatic parameters and domestic energy consumption.
2. To find the role of micro-domain against the morphological change of the whole-domain.

1.4. Methodology:

The objective of this thesis was "Correlational Research". Multiple variables were identified as depended and independent variables. This thesis was an attempt to observe the scenario of influence between these variables. Table 1.1 shows different variables, their definitions and units.

The possible major independent variables are as follows:

A. Urban Microclimate:

a. Temperature

b. Mean Radiant Temperature
c. Relative Humidity
d. Wind Speed.

B. Urban Morphology:

a. Built area percentage
b. Open space percentage
c. Road area percentage
d. Water body area percentage.

The possible dependent variable is:

C. Energy:

a. Energy consumption.

Table 1.1: Different Variables, their Definitions and Units:

Variables	**Definition / Consideration**	**Scale/ unit**	**Comments**
• **Independent Variables:**	**Urban micro-climatic parameters**		
Temperature	Temperature of air	^{0}C	Field Data from survey and weather data from BMD
Mean Radiant Temperature	The uniform surface temperature of an imaginary black enclosure with which man exchanges the same heat by radiation as in the actual environment	^{0}C	Data found from ENVI-met simulation
Relative Humidity	The ratio of the actual amount of moisture present, to the amount of moisture the air could hold in the given temperature	Percentage (%)	Field Data from survey and weather data from BMD
Wind Speed	The motion of the air	m/s	Field Data from survey and weather data from BMD

• **Independent Variables:**	**Urban morphological parameters**		
Built area percentage	Percentage of built area = (built area / total area) X 100	Percentage (%)	Calculated from Google map and RAJUK map
Open space percentage	Percentage of open area = (open area / total area) X 100	Percentage (%)	Calculated from Google map and RAJUK map
Road area percentage	Percentage of road area = (road area / total area) X 100	Percentage (%)	Calculated from Google map and RAJUK map

Variables	Definition / Consideration	Scale/ unit	Comments
Water body area percentage	Percentage of wetland area = (wetland area / total area) X 100	Percentage (%)	Calculated from Google map and RAJUK map

• **Dependent Variables:**	**Energy consumption**		
Energy Consumption	"Energy" means electricity energy for this study. Energy Consumption is the electricity consume by urban built forms	kwh/sqm	Collected data from DPDC

"Control variables" are widely used in correlational study with the intent of providing more accurate estimates of relationships among variables. The possible control variables for this thesis are as follows:

Urban- level parameters:

- Canyon geometry/ Aspect Ratio
- Vegetation
- Canyon/ Road orientation
- Materials albedo and colors

Building- level parameters:

- Building shape and compactness
- Opening size, type and ratio
- Shading devices
- Building orientation
- Building materials
- Building envelop

Occupancy- level parameters:

- Life Style (Standard of living)
- Occupant's awareness
- Affordability
- Appliance efficiency

Other parameters:

- Population Density
- Other sources of energy
- Renewable Energy
- Utility Services

To achieve the goal of the thesis, it was necessary to go through some sequential steps, which makes up the structure of the thesis. The structure of the thesis are as follows:

Influence of changes of morphology
on change of micro-climatic parameters and domestic energy consumption

Urban Area

Step 1: Literature review:		Literature review: • Micro-climatic parameters • Morphological parameters • Energy consumption
	• Literature review was conducted on published data (example: journals, research papers, books and websites).	

Step 2: Field study and data collection:		Field study and data collection: • Data collection from BMD • Map collection from RAJUK • Data collection from DPDC
	• Primary data collection was done from field survey and secondary data from Bangladesh Meteorological Department (BMD) and evaluated to determine the urban micro-climatic changes. • Area map was collected from Rajdhani Unnayan Kartripakkha (RAJUK) and Google Map, and evaluated to determine the rate of morphological change. • Electricity billing data was collected from Dhaka Power Distribution Company Ltd. (DPDC), which was then evaluated to find the energy consumption and its rate of change.	

Step 3: Simulation, data processing:		Simulation, data processing: • Simulation on ENVI-met • Excel data processing
	• Data collected from field survey and BMD was respectively simulated to observe the urban micro-climatic change. • Data collected from RAJUK map and Google map were considered to determine the percentage of morphological changes. • Data collected from DPDC indicates towards energy consumption and its percentage of change.	

Step 4: Observation, findings and possibilities		Observation on: • Change of micro-climatic parameters • Change of morphological parameters • Change of energy consumption
	• Influence of micro-climatic parameters on domestic energy consumption is shown. All micro-climatic parameters were converted to Predicted Mean Vote (PMV) to establish a relation in-between energy consumption and thermal comfort, which collectively represents micro-climatic parameters. • Influence of morphological changes on micro-climatic parameters is shown. • Access the role of individual micro-domain in respect to the whole-domain effect. • Probable design concepts (micro-domain and urban) may be considered which can be used in future design.	

1.5. Organization of the Thesis Paper:

This thesis paper is organized in five chapters to attain set objectives. The chapters are arranged in such a sequence that ultimately the objectives can be obtained.

Chapter 1: Rationalizes the background of the project, states the thesis problem, objectives, scopes and limitation of the study.
Chapter 2: Presents literature review, which sheds light on the various aspects of the thesis.
Chapter 3: Consists of field study and data collection, which accumulates all the required raw materials.
Chapter 4: Consists of simulation and data processing, in which all the collected data were simulated and processed.
Chapter 5: Contains observations, findings, probable design concepts (micro-domain and urban) and conclusion.

1.6. Quality Consideration:

While considering the quality of the research, the following issues are necessary to be considered.

1.6.1. Internal validity:

Internal validity refers to how well an experiment has been conducted, especially whether it avoids confounding (more than one possible independent variable [cause] acting at the same time). The less chance for confounding in a study, the higher its internal validity is (Indiana University, Bloomington).

To increase the internal validity of this thesis, intensive literature study and triangulation through observation and computer simulation analysis was conducted.

1.6.2. External validity:

External validity refers to how well data and theories from one setting apply to another (Indiana University, Bloomington). This thesis also have potential, which can be utilized for another country or region.

The thesis outcomes for microclimate can be applicable in the climatic context of Dhaka city and any other countries of similar climatic context. For other climatic situation, the climate data must be changed according to the context of that research area for simulation. If similar morphological phenomenon exists in any area, this research method would be applicable for it.

1.6.3. Reliability:

The software (ENVI-met, Microsoft Excel, Auto CAD) used for this thesis are recognized and accepted internationally which confirm the reliability of the quantitative results. The energy data have been collected directly from DPDC (appendix 8), and the climate data have been collected from BMD office (appendix 3). The thermal condition level was recorded consistently by Data Logger (appendix 5 and 9) and for the parametrical study using the simulation software ENVI-met (chapter 4, appendix 6 and 7) was used in the whole study. Therefore, the results of the study would be quantitative and reliable.

1.7. Scope and Limitations:

The thesis work focused on energy consumption, various environmental parameters of the microclimates and urban morphology. Again, these three variables might affected by many other variables which cannot be considered in this thesis for time constraints and complexity. There were also some limitations found in the survey, data collection and compilation of work. Some of the limitations of the thesis are as follows:

- The energy consumption of different buildings has been calculated by individual electricity billing meter. Some of the meters show unreliable electricity consumption due to the vacancy of the unit or not to use by the dwellers. In this situation, some samples may show less consumption per square meter. Although this fact is a common phenomenon in perspective of electricity billing data, for the samples which were considered for the thesis, this was not the case.
- Number of occupants is very important for energy consumption. Some electricity billing meter shows more electricity consumption due to guests or additional occupants to the dwelling unit during the study time. Since this thesis observes two different times, even though it is possible to calculate recent or current occupancy numbers and their consumption ratio, it is not possible to do so for the earlier times. As such, this fact has not been taken into account for this thesis observations.
- If the field study could be concluded in-between 6:00:00am to 6:00:00am (24 hours), the accuracy of the collected data of the nocturnal period would be better.
- If a questionnaire survey could be conducted, the opinions of the subjects could be included in this study.

1.8. Conclusion:

This chapter introduced the thesis subject and methodology, along with the statement of the problems, objectives of the thesis. Along with these, the organization of the thesis paper, quality consideration, scope and limitations of the thesis are also introduced.

Firstly, the aim of this thesis is to explore the influences of urban morphology on urban micro-climatic parameters and domestic energy consumption of an urban area. Beside this, the second aim is to find the role of micro-domain against the morphological change of the whole-domain. The objective of this thesis is “Correlational Research”. It is found that among energy consumption, microclimate and urban morphology, energy consumption are the dependent variable and microclimate and urban morphology are independent variables. This chapter shows and proves the integrity and validity of the thesis. Although there are a few limitations, the achievement of the goal of the thesis has been undertaken boldly.

The next chapter introduces and discusses the related theory and literature studies of this thesis.

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Chapter 2: LITERATURE REVIEW

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Chapter 2: LITERATURE REVIEW

2.1. Introduction:

This chapter explains the literature review. The entirety of the chapter is divided into three sections. The first section explains about the basic introductions about micro-climatic parameters and the climate of Bangladesh and Dhaka. Second section elaborates basic knowledge about energy consumption and the current scenario of energy supply and consumption in Bangladesh and Dhaka. Lastly, the third section dictates introductory knowledge about urban morphology and the morphological changes of Dhaka, and how these influences and connects the previous mentioned factors.

2.2. Urban Microclimate and Micro-climatic Parameters:

2.2.1. Urban microclimate:

The urban microclimate is determined by the local air velocity, temperature, humidity, solar irradiation and diffuse reflection, the surface temperature of building and ground, the respective long-wave radiation exchange, and the sky condition (Dorer et al., 2013). The microclimate can also be thought of, in the dimension of time, a sequence of atmospheric changes that occur within a small region (Oke, 1987).

The microclimate of a site is affected by the following factors: (a) Landform (b) vegetation (c) water bodies (d) street width and orientation (e) Open spaces and built form (Markus and Morris, 1980; Nayak et al., 1999). Shishegar (2013), also elaborates that, “The microclimate of urban open spaces is influenced by several parameters such as the urban form and geometry, urban density, the vegetation, the water levels and the properties of surfaces”.

In this thesis work, the following micro-climatic parameters are considered because these are directly connected with building energy performance and thermal comfort.

1. Air Temperature (AT)/ Dry Bulb Temperature (DBT)
2. Mean Radiant Temperature (MRT)
3. Relative Humidity (RH)
4. Wind Speed (WS).

2.2.2. Air Temperature:

Air temperature or dry bulb temperature is a value taken in shade with a thermometer (Koenigsberger et al., 1973). Air temperature measures the intensity of hot or coldness of the air. Air temperature is one of the most important climatic parameters, which directly influence the thermal comfort (Rahman, 2015). Air temperature also affects nearly all other weather parameters. For instance, air temperature affects: the rate of evaporation, relative humidity, wind speed and direction, precipitation patterns and types, such as whether it will rain, snow, or sleet. (Fondriest, 2010).

Temperature is expressed in degrees Fahrenheit or Celsius. A more scientific way to describe temperature is in the standard international unit Kelvin (Fondriest, 2010).

The temperature has an impact on energy consumption in the urban area. The rise of temperature is responsible for more energy consumption. The extreme temperature raises the energy demands, primarily for cooling load to obtain a thermal comfort level (Ali et al., 2013). Cities have produced the most notable man-made changes like, three dimensional urban forms, surface paving, population density, density of activity, etc. that affect the ambient climate (Ahmed, 1995).

2.2.3. Mean Radiant Temperature:

Mean radiant temperature is defined as follows- "if all surfaces in an environment were uniformly at this temperature; it would produce the same net radiant heat balance as the given environment with its various surface temperatures" (Koenigsberger et al., 1973). For indoor conditions, the concept of Mean Radiant Temperature (MRT) was developed. This is defined as- "the uniform temperature of an imaginary enclosure in which radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure" (ASHRAE, 1997).

Mean radiant temperature is an indicator of the combined effect of the temperatures of surrounding surfaces which affects the radiative heat loss of the body. Low radiant temperatures can contribute to the cooling of the body even if the air temperature is high. (McDowall, 2007).

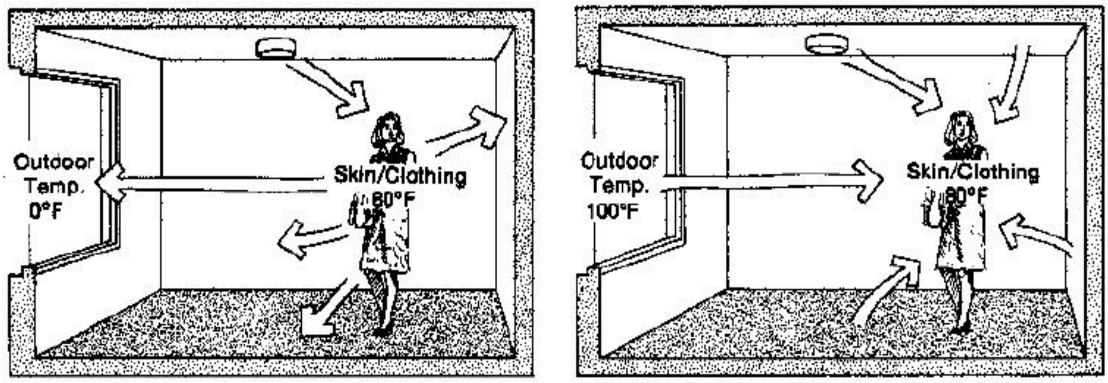

Fig 2.1: Radiant Heat Transfer with Surrounding Surfaces (Emery, 2010)

Mean Radiant Temperature can be measured using a black-globe thermometer, as is common practice in building sciences. The black-globe thermometer consists of a black globe with a temperature sensor probe placed in the center. The smaller the diameter of the globe, the greater the effect is of air temperature and air velocity on the internal temperature (Calabrò et al., 2015).

According to Toudert (2005), the mean radiant temperature is the prime micro-climatic parameter for influencing the outdoor comfort. The amount of solar radiation received on a site largely affected by the physical characteristics of that site and surrounding, which is the major modifier of microclimate or site climate. On a vegetated surface, some of the solar energy is converted into chemical energies and some of the incoming heat is also released by evaporation, but a stone, concrete or especially an asphalt surface cannot do these and can reach a temperature up to 44^0 C higher that the surrounding air temperature (Koenigsberger et al., 1975). Tuli (2015), found that, there is a linear relationship between Mean Radiant Temperature and Energy Consumption. Higher Mean Radiant Temperature value causes higher energy consumption.

2.2.4. Relative Humidity:

Relative humidity indicates how moist the air is. "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" (Koenigsberger et al., 1973).

Comfort is directly affected by humidity as moisture in the air affects evaporative heat losses. The moisture content of the air is related to wetness of the skin which also affects the sensation of comfort (Mallik, 1994). Evaporative heat loss is affected by humidity and influenced by air movement. At air temperatures above 24ºC, the body begins perspiring. If the surrounding relative humidity is low enough, a significant amount of this perspiration undergoes a change of state and evaporates as water vapour (Wilson et al, 2007).

At lower temperatures (15.5ºC and below), the convective and radiant heat loss from a human body are approximately seven times greater than evaporative losses (from perspiration and respiration). At temperatures above normal body temperatures (37ºC), convective and radiative heat loss from a human body will be zero; thus the only means for cooling is through evaporation from either perspiration, or respiration (Heinen et al, 1994). Moreover, the high level of humidity in the air increases temperature perception of human from the actual air temperature (Table 2.1).

Table 2.1: Impact of Relative Humidity on Sensed Temperature (Heinen et al., 1994)

RH (%)	Air Temperature (^{0}C)						
	21.1	23.9	26.7	29.4	32.2	35.0	37.8
0	17.8	20.6	22.8	25.6	28.3	30.6	32.8
10	18.3	21.1	23.9	26.7	29.4	32.2	35.0
20	18.9	22.2	25.0	27.8	30.6	33.9	37.2
30	19.4	22.8	25.6	28.9	32.2	35.6	40.0
40	20.0	23.3	26.1	30.0	33.9	38.3	43.3
50	20.6	23.9	27.2	31.1	35.6	41.7	
60	21.1	24.4	27.8	32.2	37.8	45.6	
70	21.1	25.0	29.4	33.9	41.1		
80	21.7	25.6	30.0	36.1	45.0		
90	21.7	26.1	31.1	38.9			
100	22.2	26.7	32.8	42.2			
	Sensed temperature (^{0}C)						

Relative Humidity is usually expressed in percent (University of Illinois). Relative humidity is conventionally measured with a hygrometer or a sling psychometer (Brower et al., 1998).

Both very low and high relative humidity may cause some physical discomfort, as the relative humidity of the air directly affects temperature perception (McNall, 1986). Extremely low (below 20%) relative humidity may also cause eye irritation (McIntyre, 1978) and moderate to high levels of humidity have been shown to reduce the severity of asthma (Strauss et al., 1978). Relative humidity also has a significant and direct adverse effect on health when high humidity is combined with high temperatures. This combination reduces the rate of evaporative cooling of the body and can cause considerable discomfort or lead to heat stroke, exhaustion, and possibly death (Arundel et al., 1986).

2.2.5. Wind speed, Wind direction, Roughness length:

Wind speed/ Air speed:

Air speed is a major factor affecting the state of thermal comfort. Outdoors, winds change speed and direction rapidly and a high degree of turbulence makes the wind speed feel higher than the measured mean value (Glaumann and Westerberg, 1988). Both the convective heat loss and the evaporation of sweat increase with increasing air speed because both the convective and evaporative heat transfer coefficients increase in magnitude (the insulating boundary layer around the body becomes smaller). Strong air movement is thus a disadvantage in cold climates, but a clear advantage in hot climates (Johansson E., 2006).

According to Auliciems and Szokolay (2007), under everyday conditions the average subjective reactions to various velocities are:

Table 2.2: The Average Subjective Reactions to Various Velocities.

Speed (m/s)	Subjective Reactions
< 0.25	Unnoticed
0.25-0.50	Pleasant
0.50-1.00	Awareness of air movement
1.00-1.50	Draughty
> 1.50	Annoyingly draughty

However, these human responses depend on the air temperature. Under hot conditions, 1 m/s is pleasant and indoor air velocities up to 1.5 m/s are acceptable (Auliciems et al., 2007).

Wind direction:

Wind direction is an indicator of the direction from which the wind comes from. Free wind speed is recorded in an open flat area of a country at a height of 10 meter. But in the urban area, the wind speed is guided by urban forms and obstructions. 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 (Koenigsberger et al., 1973).

A number of different units are used to indicate wind speed, including meters per second (m/s), kilometers per hour (km/h), miles per hour (mph), feet per second (ft/s) and knots (kt). On the other hand, wind is described in terms of the direction from which it blows, and is given as compass-point expressions graduated into 8 or 16 directions clockwise from true north. Surface wind is usually measured using a wind vane and a cup or propeller anemometer. (Japan Meteorological Agency).

Roughness length:

The frictional forces are caused by the surface layer of earth which is called roughness length. Roughness length are varies for each different type of terrain. Basically, there are four main terrain type categories classified in all major codes of practice. Category 1 is classified as any structure located on the water surface such as lake and sea surface. Category 2 is classified as any structure located on the earth which has open surface area with a slight obstruction. Category 3 is known as sub-urban area with average obstruction like building and tree with height of 10 meter from surface and category 4 is classified as urban area or high vegetation crops (Ramli et al., 2009). Wierringa (1992), have derived the roughness length more specifically based on four basic terrain types that classified in all codes of practice as listed in Table 2.3.

Table 2.3: Roughness Length for Different Terrains (Wierringa, 1992).

Terrain	Class	Surface	Landscape Description	Z_0 (m)
1	1	Sea	Open sea, Fetch at least 5 km	0.0002
1	2	Smooth	Mud flats, snow, little vegetation, no obstacles	0.005
2	3	Open	Flat terrain: grass few isolated obstacles	0.03
3	4	Roughly open	Low crops: occasional large obstacles	0.10
3	5	Rough	High crops: scattered obstacles	0.25
3	6	Very rough	Orchards, bushes: numerous obstacles	0.5
4	7	Closed	Regular large obstacle coverage (suburban area, forest)	1.0
4	8	Chaotic	City center with high and low rise buildings	≥ 2

2.2.6. Thermal comfort and Predicted Mean Vote (PMV):

Thermal comfort:

Thermal Comfort is that condition of mind, which expresses satisfaction with the thermal environment (ASHRAE standard 55). Comfort is not completely a sensory phenomenon but largely one of perception (Bansal, 1994). Thermal comfort can be defined operationally as the range of climatic conditions considered comfortable and acceptable inside buildings. It implies an absence of any sensation of thermal (heat or cold) discomfort (Givoni, 1998). Factors associated with olfactory, acoustic and visual environment can considerably influence thermal comfort judgment (Ahmed, 1995). In terms of occupants in a building it is best defined as the conditions where most of the people are unaware of the thermal conditions around them and do not feel the need to adjust to it (Mallick, 1994).

According to ASHRAE standard 55, there are six primary factors that directly affect thermal comfort that can be grouped in two categories: personal factors- because they are characteristics of the occupants and environmental factors- which are conditions of the thermal environment. The former are metabolic rate and clothing level, the latter are air temperature, mean radiant temperature, air speed and humidity.

Predicted Mean Vote (PMV):

In recent years, different researches have encouraged field studies in addition to laboratory experiments, in order to get more reliable information about the actual workplace comfort and the relevant interacting parameters. As a result, another development in comfort indices, adaptive approach is formulated. Basically, it is derived from field studies, having the purpose of analyzing the real acceptability of thermal environment, which strongly depends on the context, the behavior of occupants and their expectations (Djongyang et al., 2010).

The PMV/ PPD model was developed by P.O. Fanger using heat-balance equations and empirical studies about skin temperature to define comfort. Standard thermal comfort surveys ask subjects about their thermal sensation on a seven-point scale from cold (-3) to hot (+3). Fanger's equations are used to calculate the Predicted Mean Vote (PMV) of a large group of subjects for a particular combination of air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate, and clothing insulation (Fanger, 1970). Zero is the ideal value, representing thermal neutrality, and the comfort zone is defined by the combinations of the six parameters for which the PMV is within the recommended limits (-0.5<PMV<+0.5) (ASHRAE standard 55). Although predicting the thermal sensation of a population is an important step in determining what conditions are comfortable, it is more useful to consider whether or not people will be satisfied (Fanger, 1970).

ASHRAE standard 55 uses the PMV model to set the requirements for indoor thermal conditions. It requires that at least 80% of the occupants be satisfied (ASHRAE standard 55).

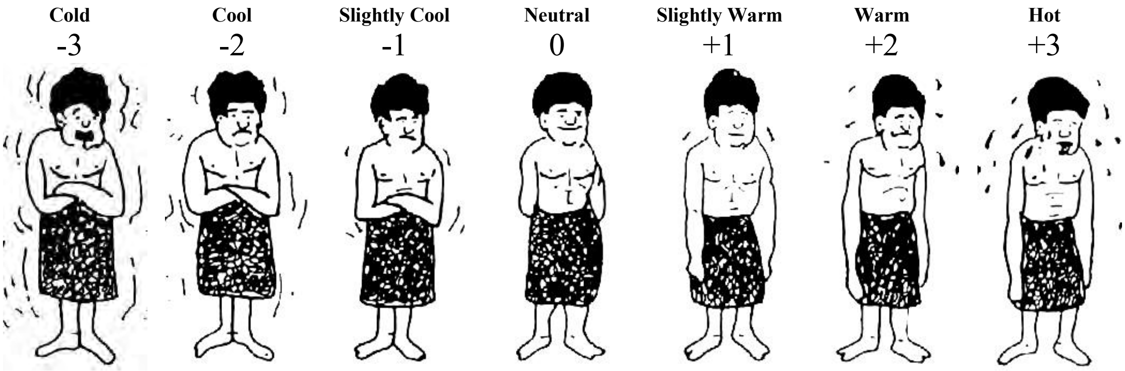

Fig 2.2: Graphic Seven Point Thermal Sensation Scale (Auliciems et al, 2007).

The CBE Thermal Comfort Tool for ASHRAE 55 allows users to input the six comfort parameters to determine whether a certain combination complies with ASHRAE 55. The results are displayed on a psychrometric or a temperature-relative humidity chart and indicate the ranges of temperature and relative humidity that will be comfortable with the given the values input for the remaining four parameters (Hoyt et al,. 2013).

2.2.7. Inversion layer over water body:

Fraedrich K. (1972), observed a shallow stably stratified layer over the water of the lake which he named as "inversion layer". This layer produced by a negative downward flux over a water surface, when the air is blowing from the warmer land. Also, if the advected air is relatively dry, evaporative cooling amplifies the stable inversion layer. The inversion can also happen even if the air temperature of the environment is equal or less compared with the temperature of the water surface at the shore. The reason is interaction between the air and the water varies (decreases) the water surface temperature along the air trajectory. Inversion layer also increasingly suppresses the evaporation from the lake which increases with the travel distance of the air over the lake by creating a "Vapor blanket".

Shahjahan (2018) observed that, in Hatirjheel Lake, the Relative Humidity increases with the distance from the surface of the water, whereas it decreases gradually when closer to the water surface. But in general case, the opposite was supposed to happen. Therefore, this indicates that there is an active inversion layer on the water body of the Hatirjheel Lake.

2.2.8. Advection:

The Royal Meteorological Society states advection as, “the transfer of some property (example: temperature or moisture) by the horizontal movement of air or water, such as wind or ocean current”. Warm advection is the process in which the wind blows from a region of warm air to a region of cooler air. And, Moisture advection is horizontal transport of moisture, which plays a very important role in the development of precipitation. If little moisture is available, it is unlikely that precipitation will form (University of Illinois).

World of Earth Science states that, “In the atmosphere, advection is the sole process of lateral transfer of mass. In contrast, vertical transfer occurs via conduction, convection, and radiation. Just as ocean currents permit heat transfer from areas of warm water to an area of water with cooler temperatures, advective winds allow the transfer of both sensible heat and latent heat (a function of humidity)”.

2.3. Climatic Characteristics of Bangladesh and Dhaka:

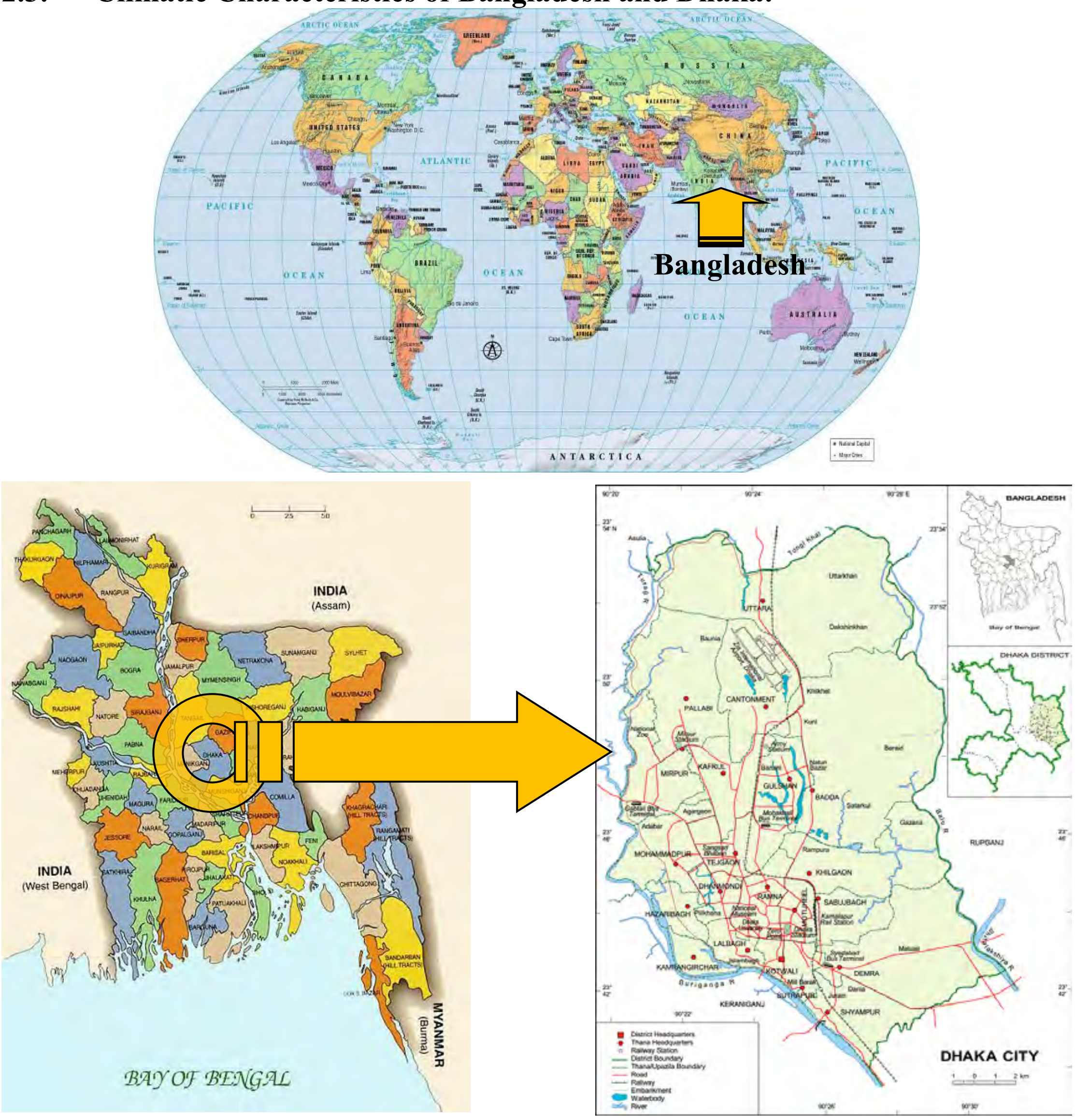

Fig 2.3: Geographical Location of (Top) Bangladesh in World Map, (Bottom) Dhaka in Map of Bangladesh (Google).

Bangladesh, with an area of about 1,47,570 square kilometers (km^2), is located in the tropics between 20°34'N and 26°38'N north latitudes and 88°01'E and 92°41'E east longitudes in South Asia, and is bounded by India on the west, the north, and northeast, and by Myanmar on the southeast (ADB, 2006). It is surrounded by land mass on three sides and to its south lies the Bay of Bengal. Except the hilly southeast, most of the country is a low-lying plain land (Ahmed, R., 2014). It is a tropical country lying on the edge of the Tropic of Cancer, with a composite monsoon climate having a rather long warm humid season (Ahmed, Z. N., 1994).

As Bangladesh is located in the tropical monsoon region, its climate is characterized by high temperature, heavy rainfall, often-excessive humidity, and fairly marked seasonal variations. The most striking feature of its climate is the reversal of the wind circulation between summer and winter, which is an integral part of the circulation system of the South Asian subcontinent (Ahmed, R., 2014). Meteorologically the climate of Bangladesh is categorized into four distinct seasons- pre-monsoon, monsoon, post-monsoon and winter (Ahsan, 2009), where the winter is cool and dry, the pre-monsoon is hot and dry, monsoon and post-monsoon periods are hot and wet (Ahmed, 1995).

Dhaka is located in central Bangladesh at 23°42′N 90°22′E, on the eastern banks of the Buriganga River. The city lies on the lower reaches of the Ganges Delta and covers a total area of 306.38 square kilometres. Tropical vegetation and moist soils characterize the land, which is flat and close to sea level (Hough et al., 2004). Figure 2.3 shows the geographical location of Dhaka and Bangladesh.

The environmental variables directly affecting thermal comfort are temperature, humidity, solar radiation and air movement; these are the four constituents of climate most important for the purposes of building design in Dhaka (Fatemi, 2012). The following review of these climatic factors is based on various investigations and on data collected from meteorological stations of the city.

Temperature:
A comprehensive harmony with the regional pattern is observed in the temperature profile of Dhaka, based on the measurements made at the Bangladesh Meteorological Office, Agargaon. The profile indicates that the highest temperatures are recorded in pre- monsoon period (March, April and May), reaching the highest in April of 34.6°C (Fig 2.4).

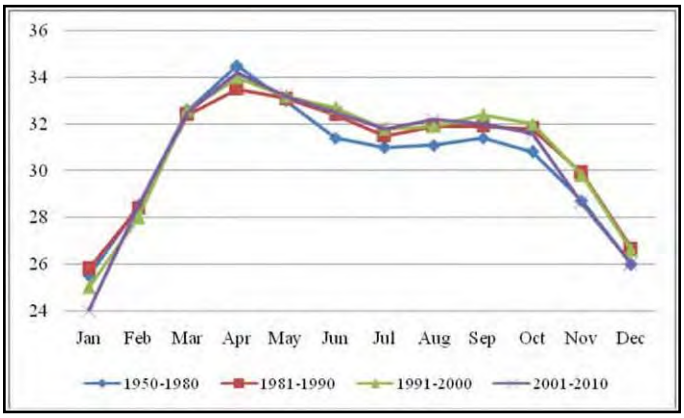

Fig 2.4: Monthly Mean Maximum Temperature (1950-2010) (Fatemi, 2012).

Table 2.4: Monthly Mean Maximum Temperature (1950-2010) (CD, 2010).

Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Season	Hot-Dry			Hot-Wet						Cool-Dry		
	Pre-Monsoon			Monsoon				Post-Monsoon		Winter		
1950-1980	32.6	34.5	33.0	31.4	31.0	31.1	31.4	30.8	28.7	26.0	25.5	28.5
1981-1990	32.4	33.5	33.1	32.4	31.5	31.9	31.9	31.8	29.9	26.7	25.8	28.4
1991-2000	32.6	34.0	33.2	32.7	31.8	31.9	32.4	32.0	29.8	26.6	25.0	28.0
2001-2010	32.5	34.6	33.2	32.5	31.8	32.2	32.0	31.6	28.6	26.0	24.0	28.5

Clear sky, dry weather, higher solar altitude angle, higher solar intensity and higher duration of sun-shine have given April the status of hottest month in this region (Roy, 2010).

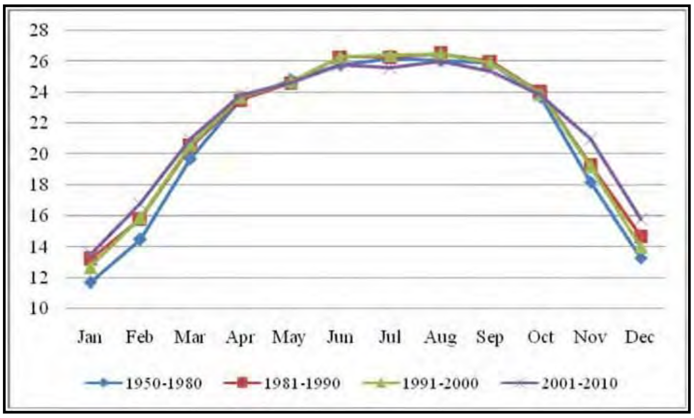

Fig 2.5: Monthly Mean Minimum Temperature (1950-2010) (Fatemi, 2012).

Table 2.5: Monthly Mean Minimum Temperature (1950-2010) (CD, 2010).

Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Season	Hot-Dry			Hot-Wet						Cool-Dry		
	Pre-Monsoon			Monsoon				Post-Monsoon		Winter		
1950-1980	19.7	23.5	24.8	25.8	26.2	26.1	25.9	23.7	18.2	13.3	11.7	14.5
1981-1990	20.5	23.5	24.6	26.3	26.3	26.5	26.0	24.0	19.3	14.7	13.2	15.8
1991-2000	20.6	23.7	24.7	26.3	26.4	26.5	25.9	23.9	19.2	14.0	12.7	15.9
2001-2010	21.0	23.8	24.6	25.8	25.6	26.0	25.4	23.8	21.0	15.8	13.5	16.8

During the monsoon the mean maximum temperature swings between 31- 32.5°C and average temperature remains steady at 29°C. Monthly mean maximum temperature in winter is found gradually decreasing and temperature drops to an average of 18.9°C while mean minimum is 11.7°C (Figure 2.5).

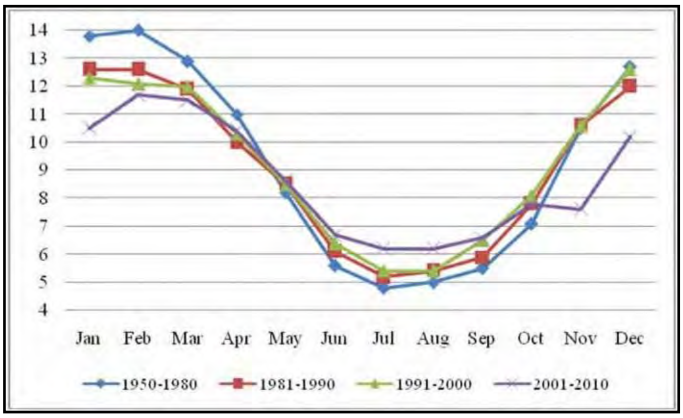

Fig 2.6: Monthly Mean Diurnal Ranges (1950-2010) (Fatemi, 2012).

A comparison of data in four sets from 1950-2010 shows, the diurnal range was found increasing during the month of May and throughout the monsoon period (Figure 2.6). Both incoming and outgoing solar radiation and gradually increasing hard surfaces in the city are the main factors behind increased diurnal range during the monsoon (Fatemi, 2012).

Due to rapid urbanization and population growth quick densification process is taking place in residential areas of Dhaka (Ahmed, 1994) and is increasing concentration of hard mass or hard surfaces, all of which influence the thermal environment and may result in increased heat absorption and decreased heat emission. On the other hand existing vegetation, water bodies and other natural elements, which constitute soft textures and help increase cooling effect, are destroyed mercilessly in Dhaka city (Mahmud, 2008; Roy, 2010).

To determine the temperature variation based on location inside Dhaka, a survey was conducted from 11th to 18th April, 2016. It showed that the temperature of Polton Junction, Bangabandhu Stadium Gate 1, Shapla Chattar and Newmarket Bus-stand is 1.5 to 4^0 C higher than the other areas. The cause for this was estimated as vehicle fumes, pitch road heat trap, over population, low quality public transport and the AC from buildings and vehicles. In the mentioned areas, the temperature was 1 to 2.5^0 C higher in the middle of the highway than that of the footpath (POBA, 2016).

Relative Humidity:
Relative Humidity in Dhaka is very high throughout the year with high moisture content of the air and the mean annual relative humidity is 76%. However, it is comparatively low in Pre-Monsoon and winter season, lowest being in March (61%). During the rainy season, June, July, August and September and part of October it is between 80-85% (Figure 2.7) (Fatemi, 2012).

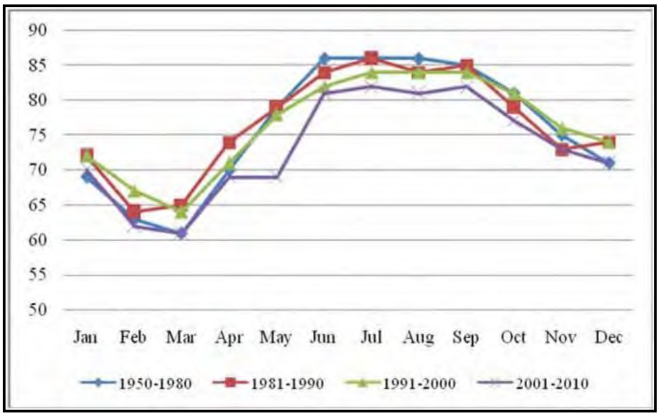

Fig 2.7: Monthly Mean Relative Humidity (1950-2010) (Fatemi, 2012).

Table 2.6: Monthly Mean Relative Humidity (1950-2010) (CD, 2010).

Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Season	Hot-Dry			Hot-Wet						Cool-Dry		
	Pre-Monsoon			Monsoon				Post-Monsoon		Winter		
1950-1980	61	70	79	86	86	86	85	81	75	71	69	63
1981-1990	65	74	79	84	86	84	85	79	73	74	72	64
1991-2000	64	71	78	82	84	84	84	81	76	74	72	67
2001-2010	61	69	69	81	82	81	82	77	73	71	70	62

Relative humidity has been found to be inversely related with the prevailing temperature and the increase of temperature reduces the level of relative humidity in a given situation, all other conditions remaining same (Mridha, 2002). The rise of temperature increases the moisture holding capacity of air and thus with the existing level of absolute humidity the measurement of relative humidity will show lower value (Roy, 2010).

In an investigation, Hossain and Noornddin (1993) found 2-4% variation in annual average relative humidity between Dhaka and adjacent rural areas. With 50% impervious cover of an area, the runoff increases 200% compared with ruraI conditions and thus urban humidity near the surface decreases due to the rapid runoff (Ahmed Z.N., 1994). Urban, suburban and rural relative humidity exhibits a marked diurnal variation and generally decreases towards city center. During the afternoon in the dry seasons differences may be as high as 12% (Ogunloyinbo, 1984) and nocturnal difference can be as high as 13% in the same seasons (Mridha, 2002).

Wind Flow:
Wind flow/ Air flow is an important consideration for comfort. Meteorological data are based on conditions measured in open locations and are valid as general conditions for the city as a whole (Mallik, 1994).

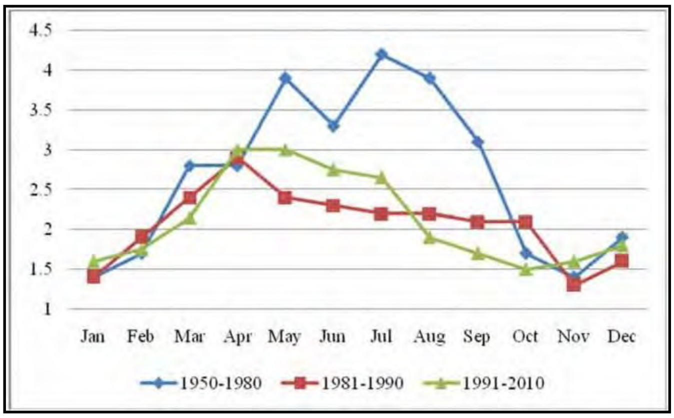

Fig 2.8: Monthly Mean Wind Speed (1950-2000) (Fatemi, 2012).

Table 2.7: Monthly Mean Wind Speed and Direction (1950-2010) (CD, 2010).

Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Season	Hot-Dry			Hot-Wet						Cool-Dry		
	Pre-Monsoon			Monsoon				Post-Monsoon		Winter		
1950-1980	2.8	2.8	3.9	3.3	4.2	3.9	3.1	1.7	1.4	1.9	1.4	1.7
1981-1990	2.4	2.9	2.4	2.3	2.2	2.2	2.1	2.1	1.3	1.6	1.4	1.9
2091-2000	2.2	3.0	3.0	2.8	2.7	1.9	1.7	1.5	1.6	1.8	1.6	1.8
Direction	SW	SW	S	SE	SE	SE	SE	N	NW	NW	NW	N

The data (1950-1980) of figure 2.8 shows that, prevailing wind speed in Dhaka is comparatively high in monsoon period starting from June to September where the value is over 3 m/s and the highest being in July (4.2 m/s). The prevailing wind direction is south-easterly during, this season: while the lowest speed is recorded in November and January (1.4 m/s) and wind direction is predominantly north-westerly for both months.

Data for the last Decade (1981-1990) illustrates significantly low magnitudes of wind speed (Figure 2.8). From March to October, there is no significant variation in wind speed (2.1-2.9 m/s). Highest, wind speed occurred in April (2.9 m/s) while lowest in November (1.3 m/s).

Data for the last Decade (2000-2010) shows that prevailing wind speed in Dhaka (Figure 2.8) is comparatively high in pre-monsoon period starting from March, April and May where the highest being in April and May (3 m/s). Lowest wind speed occurs in October (1.5 m/s). Prevailing wind direction is same as for last 60 years.

Numerous obstacles of the city are continuously modified the prevailing wind direction and speed (Ahmed, 1994). There found stagnant air trapped in the narrow gaps in between built forms, due to the buildup areas with closely placed tall buildings (Sharma, 2002). Low-density developments put less obstruction to airflow and can accelerate the convective cooling process, especially during night time. As soon as density changes, this balance is found to alter. Comparatively cooler temperatures were measured in shaded areas of the planned residential neighborhoods of Dhaka than in the closely packed unplanned parts of-the city (Ahmed. 1994).

Windrose:
BMD uses "Windrose" to explain wind direction. Windrose (using R software) of 34 stations of BMD are prepared for different seasons. Actually, Windrose is a method of graphical representation of the distribution of winds (speed and direction) at a location showing their strength, direction and frequency. It is a very useful and simplified representation of a large quantity of data in a simple graphical plot (BMD, 2016). Wind distribution (as Windrose) for Dhaka is given in Figure 2.9.

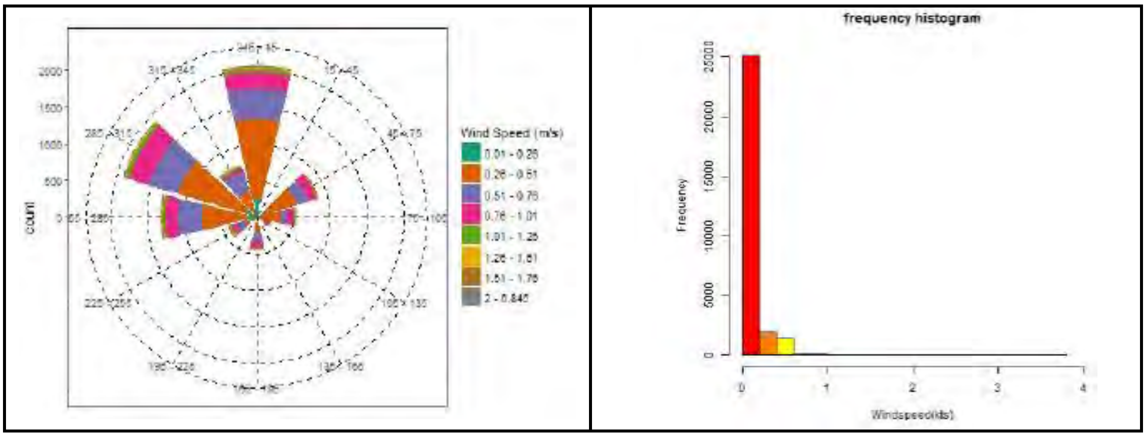

Fig 2.9: Distribution of (Left) Wind Direction,
(Right) Wind Speed of Dhaka during Winter Season (BMD, 2016).

The field survey for this study was conducted in December, 2017. Therefore, for the simulation purpose, the wind direction was taken as 345^0 since "Windrose" suggests as such.

2.4. Energy Consumption:

2.4.1. Energy:

In a joint research and studio report by Massachusetts Institute of Technology and Tsinghua University, it is written that, "If we look across the physical fabric of the city, we see that it is composed of a collage of intersecting patterns, each with its own integrity. Designers tend to think of these as physical forms, but they also represent patterns of human interaction that consume energy at different rates. We call these, form-energy systems" (Frenchman et al., 2011).

The total energy consumed by each of these systems is a resultant of four key factors: 1) Embodied energy: in materials, construction, and eventual disposition of buildings, sites, and streets over the lifecycle of the system 2) Operational energy: used in the day to day function of the system, including heating, cooling, elevators, water, and lighting consumed by private households and in the common areas of the public realm 3) Travel: required to negotiate the required system to participate in regular activities, work, school, shopping, socializing, etc. 4) Energy produced: by the system from on-site renewable sources including the sun, wind, and geothermal production. Such sources will become increasingly important in the future, and some forms of urban development are more conducive to on-site production than others (Frenchman et al., 2011).

Among them, operational energy was the main concern for this study. Operational energy includes heating, cooling, elevator operation, water pumping and lighting, which is commonly known as "Electricity Energy". In this thesis, the "Electrical Energy" is termed as "Energy".

2.4.2. Energy use in urban area:

Urban parameters such as road width, configuration and orientation, building heights, compactness or dispersion, surface materials, vegetation, open spaces and water bodies have an effect on the energy consumption of buildings (Golany, 1996; Ratti et al., 2003; Santamouris, 2006; Steemers, 2003). The existing literature suggests that urban-level parameters affect the energy consumption of buildings both directly and indirectly (Ratti et al., 2003; Raydan & Steemers, 2006).

The direct influence occurs because of direct obstruction or enhancement of solar penetration and airflow, such as a tall structure casting a shadow or obstructing the wind flow, which can result in higher or lower energy consumption. For example, a study conducted in the UK using computer-based image processing found that 10^0 increase in obstruction angle increased the energy consumption of an office building by 10%. The same study also found that increasing the plot density ratio from 1.25:1 to 5:1, or spacing the buildings more closely, resulting in 25% more energy consumption (Steemers, 2003). A computer simulation study by Wong, Jusuf, Syaffi, Chen, Hajadi, Sathyanarayanan & Manickavasagam (2011), in Singapore found that increasing building height and surrounding density reduces the cooling energy consumption of an office building by 5%, because of the obstruction to direct solar radiation.

The indirect influence occurs due to microclimate modifications around building as a result of urban design decisions. As Givoni (cited in Ratti et al., 2003) noted: The outdoor temperature, wind speed and solar radiation to which an individual building is exposed is not the regional "synoptic" climate, but the local microclimate as modified by the "structure" of the city, mainly of the neighborhood where the building is located.

2.5. Present Scenario of Energy (Electricity) Consumption:

The demand for electricity energy is increasing rapidly in Bangladesh. Due to the social progression and the up-gradation of living standard in urban life, the energy consumption is growing rapidly. Urban life allows the excessive use of electrical devices to ensure sufficient lighting and thermal comfort in interior spaces. The rapid unplanned growth, inadequate breathing spaces between urban blocks, use of excessive cooling devices, indoor lighting system and modern appliances have been created additional loads on energy production (Tuli, 2015).

The only company that works for the transmission of electricity in Bangladesh is the Power Grid Company of Bangladesh Ltd. (PGCB). As of June 2013, there is almost 3,020 km of 230 kV and 6,148 km of 132 kV transmission line available in the country. The number of 230/132 kV substations is 16 and combined capacity of those entire substations is 7,525 MVA. Besides, there are 103 substations of 132/33 kV available throughout the country with a capacity of 11,792 MVA. The distribution network is the biggest of the lot, with 3,728 km, 13,128 km and 21,839 km of 33 kV, 11 kV and 400 V lines, respectively. There are 158 substations of 33/11 kV for distribution of power around the country (Khan et al., 2015).

Four companies are distributing the generated power along with Bangladesh Power Development Board (BPDB). BPDB is responsible for distribution of electricity in most of the urban areas in Bangladesh except Dhaka Metropolitan City and its adjoining areas under Dhaka Electric Supply Authority (DESA) and Dhaka Electric Supply Company (DESCO), areas under West Zone Power Distribution Company Limited (WZPDCL) and some of the rural areas under Rural Electrification Board (REB) (Khan et al., 2015).

Table 2.8: Share of Electricity Distribution in Bangladesh (Khan et al., 2015).

Authority	BPDB	DPDC	DESCO	REB	WZPDC
Share (in %)	24.64	18.59	10.51	40.10	6.17

The share of electricity distribution by the relevant authorities is shown in Table 2.8. BPDB distributes 24.64% of the power among the urban consumers. DPDC and DESCO distribute 18.59% and 10.51%, respectively of the power among the consumers in Dhaka metropolitan area. The rest 6.17% of the power is distributed by WZPDC in Khulna and Barisal divisions (Khan et al., 2015). According to DPDC Annual Report (2015), DPDC is divided into three parts and these are DPDC north, central and south. These parts are served by 38 NOCs (Network Operation & Customer Service Offices) under 18 circle offices.

The area selected for this study is under the distribution zone of Mogbazar of DPDC. Hence, any kind of analysis based on energy consumption, the data collected from DPDC was termed as the primary source of information. Figure 2.10 shows different distribution zones of Dhaka city by DPDC.

Dhaka is the primary consumer (55%) of Bangladesh’s total generated electricity (Haider & Ahmed, 2016). Without exception, the most important city of the country suffers from an unreliable and inadequate energy supply. A study conducted by Kabir, Endlichar and Jägermeyr in 2010 found that the peak electricity demand of the city at that time was around 2000MW, whereas the city was supplied with only about 1000-

1200MW, resulting in 8-10 hours daily load shedding in many parts of the city. Although the current power situation of the city is better than earlier, it will experience 2.5- 3.5 hours of daily load shedding, particularly during summer (DESCO, 2015).

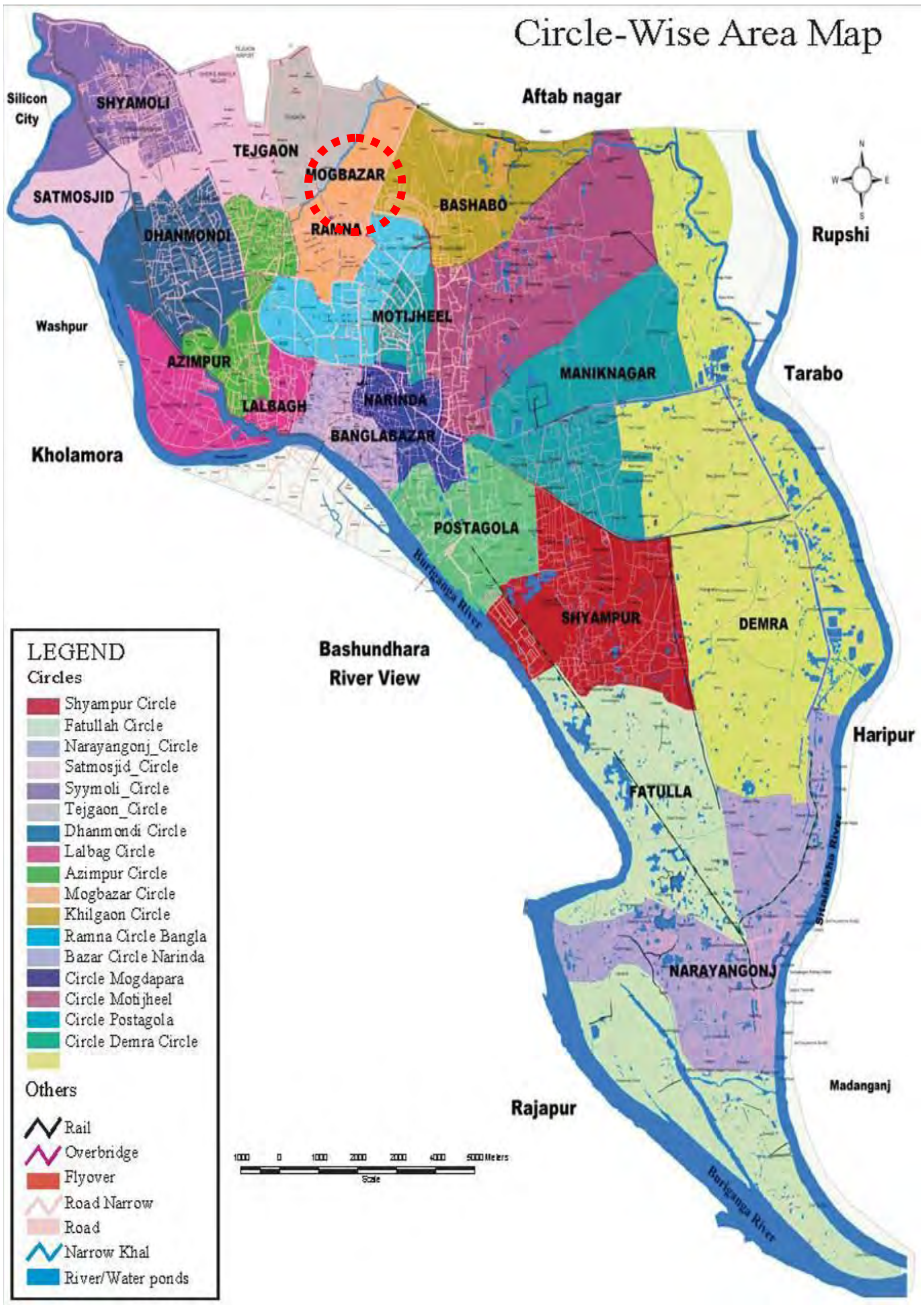

Fig 2.10: Area Map of DPDC Showing Zones of Distribution (DPDC, 2015).

2.6. Urban Morphology and Morphological Parameters:

2.6.1. Urban morphology:

Urban morphology is the study of city appearance, its gradual formation, and the interaction among components of the tissue that defines specific compounds and urban faces, such as streets, squares, and other public spaces. Urban morphology is divided among several fields of knowledge. Its theoretical aspects are related to urban geography, history, and architecture (Ahmadi et al., 2012).

The study of urban morphology seeks to understand the spatial structure and character of a city by identifying the patterns of its components and the process of its development. This study can involve analyzing physical structures at different scales (Ahmadi et al., 2012). According to Conzen in 1960, land use, building structures, plot patterns, and street pattern are considered. Analysis of physical forms focuses on street patterns, plot patterns, and building patterns by comparing cartographic sources and historic maps (Carmona, 2003).

Urban morphology is one of the most important physical descriptions of a city. Morphology is a science that investigates the form, shape, external structures, and arrangement of matter (Madanipour, 1996). In 1997, Moudon argued that, urban morphology focuses on city studies as a physical environment, but establishes an implicit link between the space elements, material, social, and economic forces of the city.

2.6.2. Morphological parameters:

Table 2.9 shows a summary of studies of urban form affecting urban climate in tropical and sub-tropical regions done by Ho. et al, 2015.

Table 2.9: Studies on Urban Forms Affecting Urban Climate (Ho. et al, 2015).

Researchers	City	Climate	Spatial scale	Morphological parameters	Approaches
Emmanuel & Fernando (2007)	Colombo, Sri Lanka; Phoenix, Arizona	equatorial wet; sub-tropical dry	Micro scale	Density	Numerical simulation
Johansson & Emmanuel (2006)	Colombo; Sri Lanka	equatorial wet	Micro scale	H/W, SVF, Orientation	Numerical simulation, Field measurements
Ali-Toudert et al. (2005); Ali-Toudert & Mayer (2006)	Beni-Isguen & Ghardaia, Algeria	sub-tropical dry	Micro scale	H/W	Numerical simulation, Field measurements
Johansson (2006)	Fez, Morocco	sub-tropical dry	Local scale	H/W, Orientation	Field measurements
Fahmy & Sharples (2009)	Cairo, Egypt	sub-tropical dry	Local scale	compactness factor	Numerical simulation
Middel et al. (2014)	Phoenix, USA	sub-tropical dry	Local scale	LCZ classification	Numerical simulation
Krüger et al. (2011)	Curitiba, Brazil	sub-tropical highland	Local scale	SVF	Numerical simulation, Field measurements

Table 2.9: Studies on Urban Forms Affecting Urban Climate (Ho. et al, 2015).

Researchers	City	Climate	Spatial scale	Morphological parameters	Approaches
Chen et al. (2012)	Hong Kong	sub-tropical humid	Local scale	SVF	GIS-based simulation
Ng et al. (2011)	Hong Kong	sub-tropical humid	Local scale	Frontal area density, Ground coverage ratio	Numerical simulation
Yuan & Ng (2012)	Hong Kong	sub-tropical humid	Local scale	Different building morphologies	Numerical simulation
Hwang et al. (2011); Lin et al. (2012)	Huwei Township, central Taiwan	sub-tropical humid	Local scale	SVF	Numerical simulation, Field measurements

Some studies mainly focused on street scale by investigating the aspect ratio (H/W) and street orientation effects in the following cities: Colombo in Sri Lanka with hot and humid summer (Emmanuel et al., 2007; Emmanuel and Fernando, 2007; Johansson and Emmanuel, 2006); Beni-Isguen and Ghardaia in Algeria with hot and dry summers (Ali-Toudert et al., 2005; Ali-Toudert and Mayer, 2006); Fez in Morocco with hot dry summer (Johansson, 2006). These studies found that deeper street canyon (high H/W ratio) is beneficial to thermal comfort in summer.

For larger urban scales, some factors and methods which can parameterize the urban fabric characteristics were adopted. Fahmy & Sharples (2009) investigated the impacts of different urban forms at a neighborhood scale in Cario, Egypt by adopting an urban morphological factor called compactness factor, which together with other parameters are related to urban thermal comfort represented by PMV values. Middel et al. (2014) studied the microclimate effects in Phoenix, the United States under five different scenarios, which can be fitted into the classification of Local Climate Zone (LCZ) (Stewart and Oke, 2012). Among the five different urban forms, they found that "Local Cool Islands" can be formed in more compact urban geometry (0.2-0.4 SVF) in mid-afternoon. Another studies of Sky View Factor (SVF) conducted in Taiwan and Brazil indicated that the higher SVF may cause thermal discomfort during daytime (Hwang et al., 2011; Krüger et al., 2011; Lin et al., 2010). However, for high-rise, high-density Hong Kong with hot and humid summers, Chen et al. (2012) mapped the SVF for the entire city using a GIS-based method. The results of their studies show that "a decrease of 0.15 in a 100-m radius neighborhood average of SVF may result in 1^{o}C temperature elevation".

As natural ventilation is an important factor contributing to thermal comfort under hot and humid climates (Ahmed, 2003; Chen and Ng, 2012; Ng and Yuan, 2012). Some urban morphological parameters such as Frontal Area Density (FAD), Ground Coverage Ratio (GCR) were mapped in Hong Kong to understand the relationship between urban wind environment and urban form for better ventilation (Ng et al., 2011). Another study in Hong Kong investigated the natural ventilation effects at pedestrian level by modifying building morphologies (Yuan and Ng, 2012).

Study of Ho. et al, (2015), states different types of morphological parameters. Such as, Density, H/W, SVF, Orientation, Compactness factor, LCZ Classification, Frontal Area Density and Ground Coverage Ratio. It is clear that these parameters are picked from specific locations based on their needs and influence. This is also the case for this thesis, where the parameters are picked based on their specific characteristics, role and influence on the selected research area, which is the Hatirjheel Lake. The major changes of morphological parameters after the renovation of Hatirjheel Lake are as follows:

1. Build area percentage.
2. Open space percentage.
3. Water body area percentage.
4. Road area percentage.

Considering major changes of morphological parameters, theses for were taken as the morphological parameter of this research.

An urban area is composed with built and open spaces. In general, buildings and urban structures are built forms, and roads, setback areas, fields, urban parks, urban green, water bodies etc. are open spaces (Tuli, 2015).

Build (building, road) area:
Nowadays, almost all cities are sources of heat due to the complexity of urban-designed structures with higher thermal admittance and anthropogenic heat. The conversion of the natural landscape to a built, largely impermeable landscape and the introduction of new surface materials such as asphalt, concrete, tiles and others has dramatically modified the radiation, thermal, moisture, roughness and emissions properties of the surface and the atmosphere above (Gartland, 2008). These modifications of land cover and urban surface cause the local air and surface temperatures to rise several degrees higher than the surrounding rural areas (Thani et al., 2013).

Open (setback area, field, urban park, urban green and water body) space:
In the built-up areas with closely spaced tall buildings, there remains every possibility that there would be stagnant air trapped in narrow gaps in between built-masses. The air flowing through the open country might skip the built structures. Cool air cannot enter in these areas; in addition, heat trapped in narrow gaps cannot escape. Water bodies, green trees, grasses etc reduce heat by the process of evaporation of water. In congested cities these factors constantly go on decreasing (Sharma, 2002). The process of evaporation related to water bodies can contribute to decrease the air temperature and increase the humidity of the surroundings and distribute wind flows efficiently, so that both the temperature range as the possibility of heat islands may be minimized (Masiero et al., 2012).

In the study conducted by London Architectural Association School of Architecture (AASA), climatologists have shown that all areas of Dhaka do not get heated in a similar pattern due to differences in the presence of trees, ponds or water bodies in different areas. In peak summer Motijheel or Tejgaon or Karwan Bazar area gets more heated (temperature can rise as high as 42^0 to 43^0 Celsius and creates urban heat island) than Ramna Park or Dhanmondi residential area. Ahmed (1995), has shown that Motijheel commercial area (old Central Business District) of Dhaka develops about three 3^0C higher temperature than in Ramna Park (largest green park located in the central part of Dhaka city) during a typical summer day (during April to July). Nuruzzaman and Ershad Hossain, Department of Environment, Bangladesh, have shown in their study that temperature of Mirpur area remains above average though there is enough green vegetation. They pointed out that high-density living and adjacent smoke emitting brick kiln are responsible for this situation. During summer Dhaka city receives solar radiation during daytime for about 14 hours, while it reradiates heat during nighttime for about only 9 hours. A thin layer of cloud and closely built-up buildings also impede noctutna1 cooling process and thus cumulative heating goes on. On top of that, artificial heat emitting sources (both indoor and outdoor) aggravate the summer situation and hot discomfort in Dhaka city (Roy, 2010).

2.6.3. Micro-domain:

"Micro-domain" means any of several small regions that have a distinct function (Biological Theory). "Micro-domain" could be defined as the surrounding open area of the particular built form (building). The micro-domain of a built form (building) is the area that surrounded by the immediate buildings in all side (Tuli, 2015).

There were small scale domain has been considered for measuring the microclimates of the each urban form, which could be named as "micro-domain". It was difficult to calculate the numerical value of the micro-climatic parameters of the entire (all points) micro-domain. Therefore, the Micro-climatic parameters of the different samples have been taken the average value of the midpoints of all sides of the urban forms in the micro-domain (Figure 2.11).

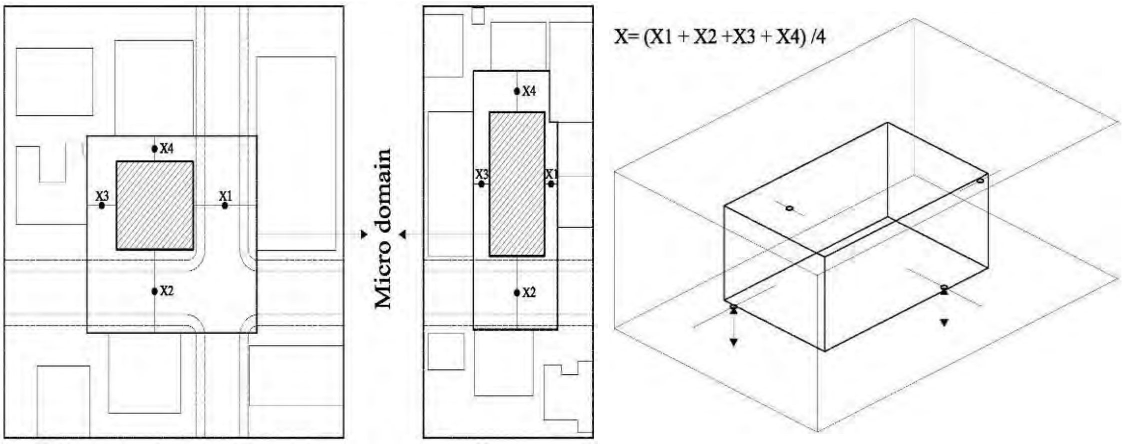

Fig 2.11: Selection Method of Micro-domain (Tuli, 2015).

2.7. Morphological Scenario of Dhaka:

Before becoming megacity in the 21st century, Dhaka went through several phases under different rulers, each of which left a mark on the growth of the city. The literature shows five major periods that shaped the growth and development pattern of the city, namely, the Pre-Mughal, Mughal, Colonial, Pakistan and Bangladesh periods (Ahmed, 1986; Ahsan, 1991; Chowdhury & Faruqui, 1991; Chowdhury & Hasan, 2011; Islam, 1996; Nilufar, 1997). In same periods, the city experienced expansion and in others, the opposite (Ahmed, 2006; Hafiz, 2011; Nilufar, 2010).

Two main types of development pattern can be found in Dhaka city: spontaneous and planned (Hafiz, 2011; Khan & Nilufar, 2009; Nilufar, 2010). According to Nilufar (2010), the city has a composite character, with patches of planned development surrounded by spontaneous ones. The main reason the city developed such a mixed character is that the city grew unexpectedly after the liberation war in 1971, with the development authority unable to keep pace and thus, substantial spontaneous growth occurred alongside planned growth (Islam, 1996; Jahan, 2011; Rahman, 2008).

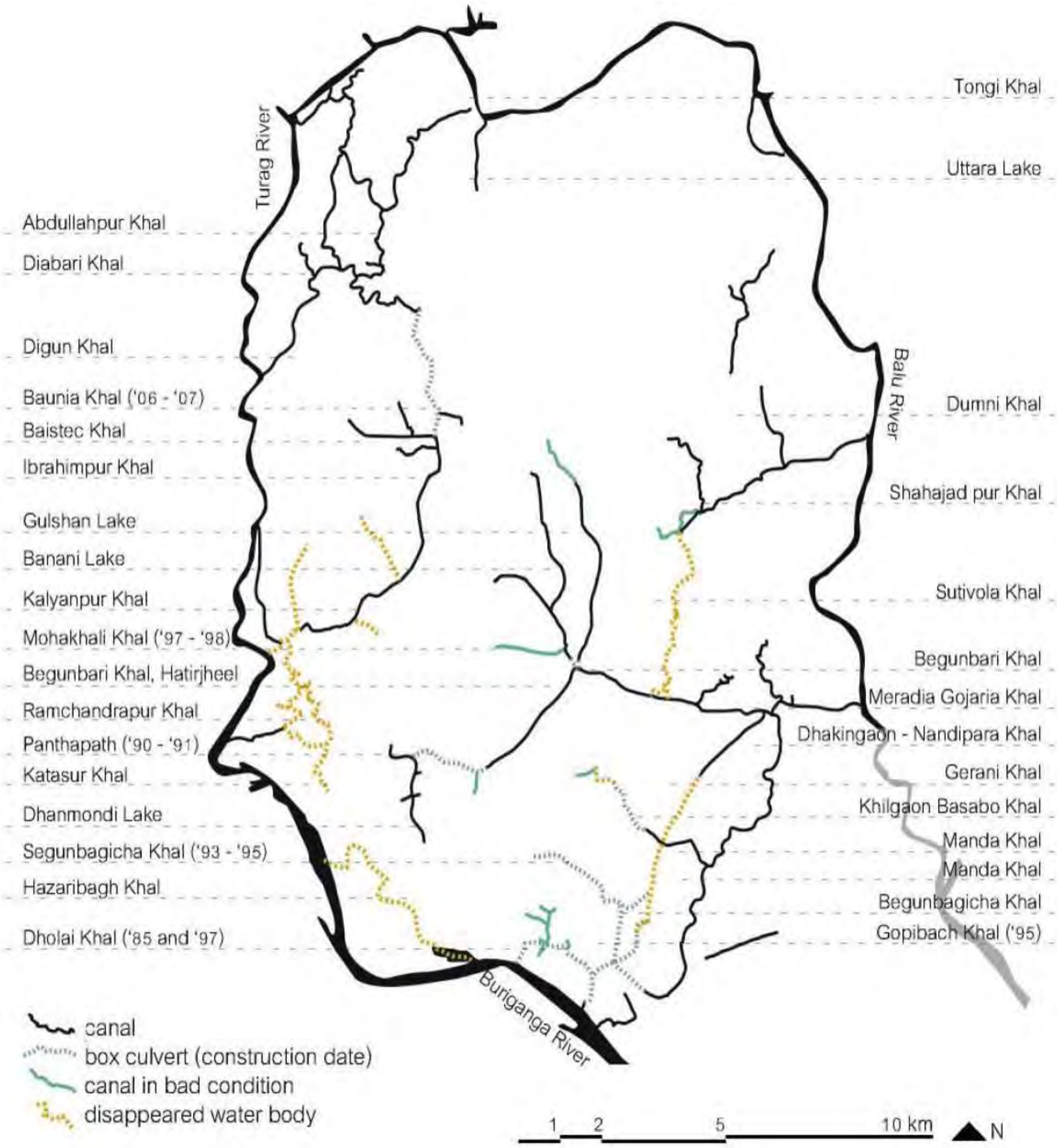

Fig 2.12: Dhaka's Khals 1955 to 2009. (Peeters, S., & Shannon, K., 2011).

The spontaneous or unplanned developments of the city are often described as informal developments. Typically, they develop at an individual level with independent landowners developing buildings in an incremental way (Nilufar, 2010; Parveen, 2006). During the exceptional expansion of the city in the 1970s and 1980s, these type of developments took place at an extraordinary rate (Islam, 1996). Broadly speaking, spontaneous developments are organic in character, with narrow serpentine streets and irregular, inconsistently sized and asymmetric building plots (Parveen, 2017). Planned developments are recognized as the formal developments of the city and are undertaken by the public sector or the formal private sector (Nilufar, 2010; Seraj, 2012). The public sector includes different governmental organizations, while the formal private sector includes a number of registered real estate developers (Dhaka Structure Plan, 2015).

Inside the city, there is a system of khals (often translated as "canals"), ponds, lakes and reservoirs, which serves as a natural drainage system (Peeters & Shannon, 2011). According to Dhaka's Water and Sewerage Authority (DWASA), there were once 43 canals in Dhaka. Seventeen of them have disappeared completely. The remaining 26 are in bad condition, while DWASA is presently recovering 15 of them. Eight of the disappeared canals have been replaced by box culverts- a hollow concrete box section under the ground- and consequently covered by important roads. Other canals exist but are rarely seen, because of the encroachment and filling- in either by developers, squatters or the government itself (Alam et al., 2007) (Figure 2.12).

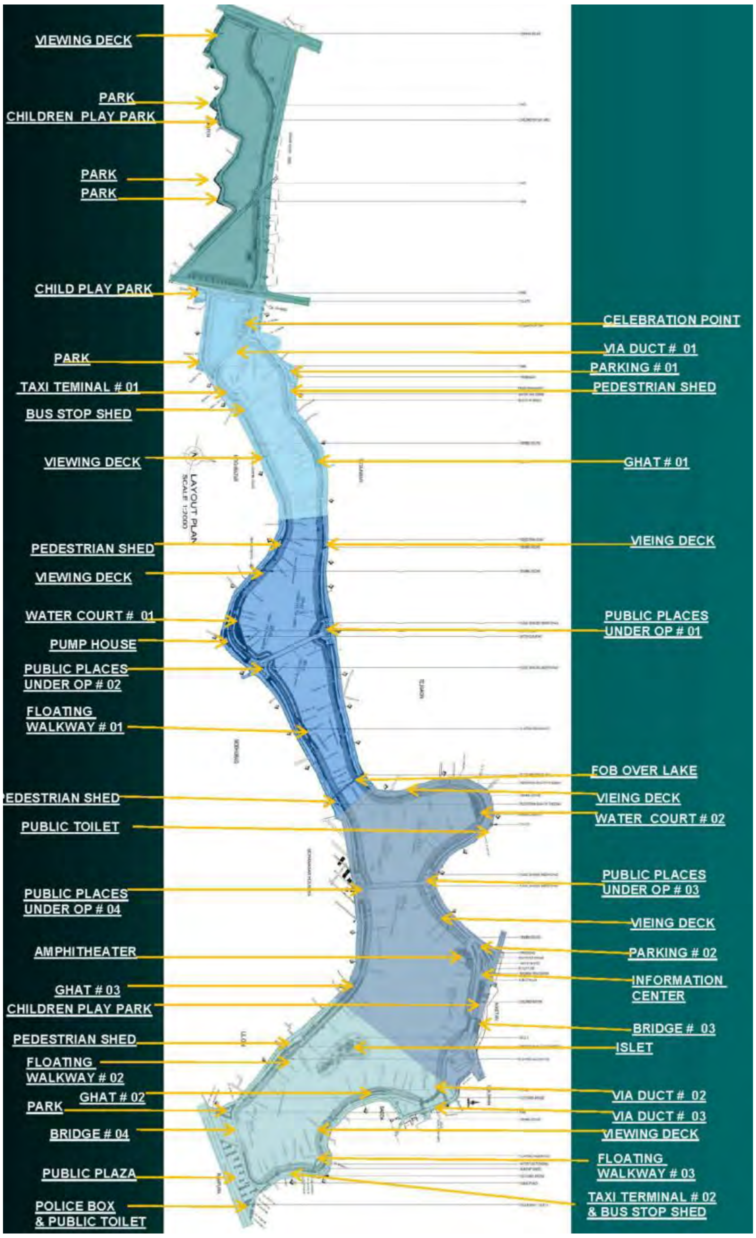

Fig 2.13: Development Plan of Hatirjheel Project (VITTI Sthapati Brindo Ltd.)

Hatirjheel Lake is the city's largest reservoir. It is located in the center of Dhaka and is a crucial element in the city's drainage system. It used to be connected to a string of other lakes, the Banani, Dhanmondi and Gulshan Lakes, and to the Begunbari Khal at the Rampura Bridge (Ferdous and Nilufar, 2007) (Figure 2.13).

The Hatirjheel Lake renovation project was first permitted in October 2007, and was said to be completed within three years (by June 2010). However, the construction began on December 2008, which took a further half year of time for expanding it. The Hatirjheel-Begunbari project was inaugurated on January 2, 2013. The Hatirjheel project opened for the general use of people after the inauguration. The entire area of Hatirjheel is designed with about four main and four minor bridges (viaducts), and several overpasses (flyovers) and footbridges (over bridges). There are sitting arrangements for pedestrians by the riverside. A lake flows through the heart of the project with a 16 km road surrounding it. During the dry season, the Hatirjheel Lake can hold approximately 3.06 billion liters of water, and during the rainy season about 4.81 billion liters of water, making it the largest body of water inside the capital of Bangladesh (The Daily Ittefaq, 2 January 2013).

2.8. Urbanization in Megacities and Impacts of Climate Change:

Urban development, including land use changes, dense building developments, heat emissions, human activities, etc., has a great impact upon the local climate of a city. One of the best-known effects of urbanization is the Urban Heat Island (UHI) effect, which develops when urban cooling rates are slower than rural ones. Some of the main factors that may bring about the difference in temperatures between urban and rural areas includes: 1) The high heat capacity of the buildings in the urban area compared to surrounding rural areas, resulting in more of the sun's energy being absorbed and stored in urban; 2) The high-density buildings in urban areas block the view of the sky and reduce the heat release back to space; 3) Man-made heat emissions by buildings, air conditioning, transportation and industries in urban areas; 4) Dense development in urban areas, which reduces wind speeds and inhibits cooling by convection (Hong Kong Observatory).

As an important source of considerable human activities, urbanization causes changes of the land-use/cover over the urban areas (Singh et al., 2014). Many experiments have been conducted to understand that there is close relationship between urbanization and climate change (Singh & Shi, 2014). The research by Kalnay and Cai (2003), for instance, suggested that half of the observed decrease in diurnal temperature range is due to urban and other land-use changes.

With the growing population, an informal economy in the form of street-based self-business, home-based works and construction labor provides employment to a significant number of people in megacities in parallel with formal job sectors (Daniels, 2004). The process both exerts pressure on infrastructure and leads to a vulnerable urban environment with fragile urban governance systems. Urban scientists suggest that megacities are at increasing risks of uncontrolled urbanization, social disparity and segregation and fragmented urban governance systems. The vulnerabilities have been further multiplied by global environmental change and anthropogenic hazards (Roy, 2009). With this added dimension of urban challenge, growth dynamics and management perspectives have become more complex and compound in nature. Recently, scholars have embarked upon more sustainable and resilient urban growth in these large urban agglomerations (Kraas, 2007). The sustainability discourse of urban growth in megacities highlights comprehensive understandings of magnitude and interrelationships of urban problems. It also suggests an array of adaptive measures related to policy framework, appropriate infrastructure development and improving social capital to become a more resilient community (Roy, 2009).

The trend of urbanization in Dhaka city shows typical growth dynamics of megacities. There is pressing demands for urban infrastructure, utilities, and services such as drainage, water supply, solid waste management, sewerage, sanitation, housing, and transportation. In addition, the ever-growing population puts significant pressure on the city, as well as on the surrounding environment. The multifaceted challenges have emerged from informal urbanization and have been further deteriorated by natural and man-made hazards (Swapan et al., 2017).

Over 90% of all urban areas are coastal, putting most cities on Earth at risk of flooding from rising sea levels and stronger and more frequent storms (C40, Online) and Dhaka is no exception with regards to vulnerability to climate change. Climate change will affect Dhaka severely through flooding and water congestion and heat stress (Alam & Rabbani, 2007). A number of studies suggest that climate change will lead to compound problems of environmental degradation (Amin & Rahman, 2014; Araos et al., 2017; Banu et al., 2014; Black et al., 2011).

Although there have been considerable reports of current researches, there is still much unknown about the impact of regional land-use change and urbanization on climate change. As the surface physical, chemical, and biological characters vary greatly across regions, the climatic influences of urbanization and land-use change vary correspondingly (Deng et al., 2013). Due to the lack of data and knowledge, it has been widely recognized that this issue is of great importance for further exploration and discussion (Feddema et al., 2005).

2.9. Conclusion:

Literature review is very important in case of identifying the problem of the study, which can be solved through gathering of data, parametric studies and others.

This chapter introduced and discussed the related literature and theory of the thesis. Initially, basic knowledge and definitions of urban microclimate (2.2). Along with this microclimate of Dhaka, Bangladesh (2.3) was also discussed. Then, basic knowledge and definitions of energy consumption (2.4) and urban morphology (2.6) has been discussed, along with their present condition in Dhaka, Bangladesh (2.5 and 2.7) respectively.

To gather data and information for further progression of this thesis, the next chapter introduces the field study and data collection methods.

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Chapter 3:
FIELD STUDY AND DATA COLLECTION

Introduction	:	**3.1**
Morphological Field Study and Data Collection	:	**3.2**
Selection of the Study Area	:	**3.2.1**
Generate the Maps of Selected Area	:	**3.2.2**
Sample Selection	:	**3.2.3**
Micro-domain calculation	:	**3.2.4**
Micro-climatic Field Study and Data collection	:	**3.3**
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Chapter 3: FIELD STUDY & DATA COLLECTION

3.1. Introduction:

This chapter is consists of three sections. The first section presents the morphological field study, among which, selection of the study area, along with the generation of the map of 2007 using Google historical archive data in respect to the map of 2017, sampling procedure, calculation process of micro-domain are introduced. The second section is about micro-climatic field study along with data collection. The third section zeroes down the samples from collected data from DPDC.

3.2. Morphological Field Study and Data Collection:

3.2.1. Selection of the study area:

Climate-based classification of cities in previous studies (Chandler, 1965; Auer, 1978; Ellefsen, 1991; Oke, 2004) is mostly based on the form and function of modern, developed cities which are less suitable for more diverse economic settings (Stewart and Oke, 2012). In order to address this limitation, Stewart and Oke (2012) suggested a new system of classification, called "Local Climate Zones" (LCZs), that is: "inclusive of all regions, independent of all cultures, and, for heat island assessment, quantifiable according to class properties that are relevant to surface thermal climate at the local scale." The main variables of the LCZ system include sky view factor, aspect ratio, building surface fraction, roughness length, surface cover (pervious or impervious) and anthropogenic heat output. However, the system is essentially generic and unable to address the diversity of every urban and rural site. The disorganized and unplanned nature of Dhaka city makes it complicated to classify urban areas of Dhaka according to the LCZ system (Sharmin et al., 2015).

Initially, according to the 1950-60 master plans, Dhaka was divided into different land-use zones which included residential, commercial, industrial, agricultural and administrative activities. Like any other developing country cities, these boundaries are not properly defined. Due to a lack of adequate planning rules and control, all zones have developed mostly as mixed-use areas (Sharmin et al., 2015).

To represent the meteorological environment, as a place for general climatological purpose, the spatial and temporal scales of interest must be defined (Oke, 2006). In order to achieve the goal of the study, a planned residential area was required, which has seen extensive morphological changes to its close proximity. Thus, the Mohanagar housing area has been selected since the Hatirjheel Lake adjacent to it underwent large-scale morphological changes in the recent years. Furthermore, this is the only housing area near Hatirjheel Lake, which has grid iron pattern roads, and the buildings are arranged in a specific order. Along with these, it was also important to have access to energy data from before the morphological changes till date, which was collected from DPDC. In addition, an area with accurate and accessible map was required, and in this case, the required map was collected from RAJUK.

With all the above-mentioned advantages in mind, Hatirjheel Lake and adjacent Mohanagar Housing Area was selected as study area of the thesis.

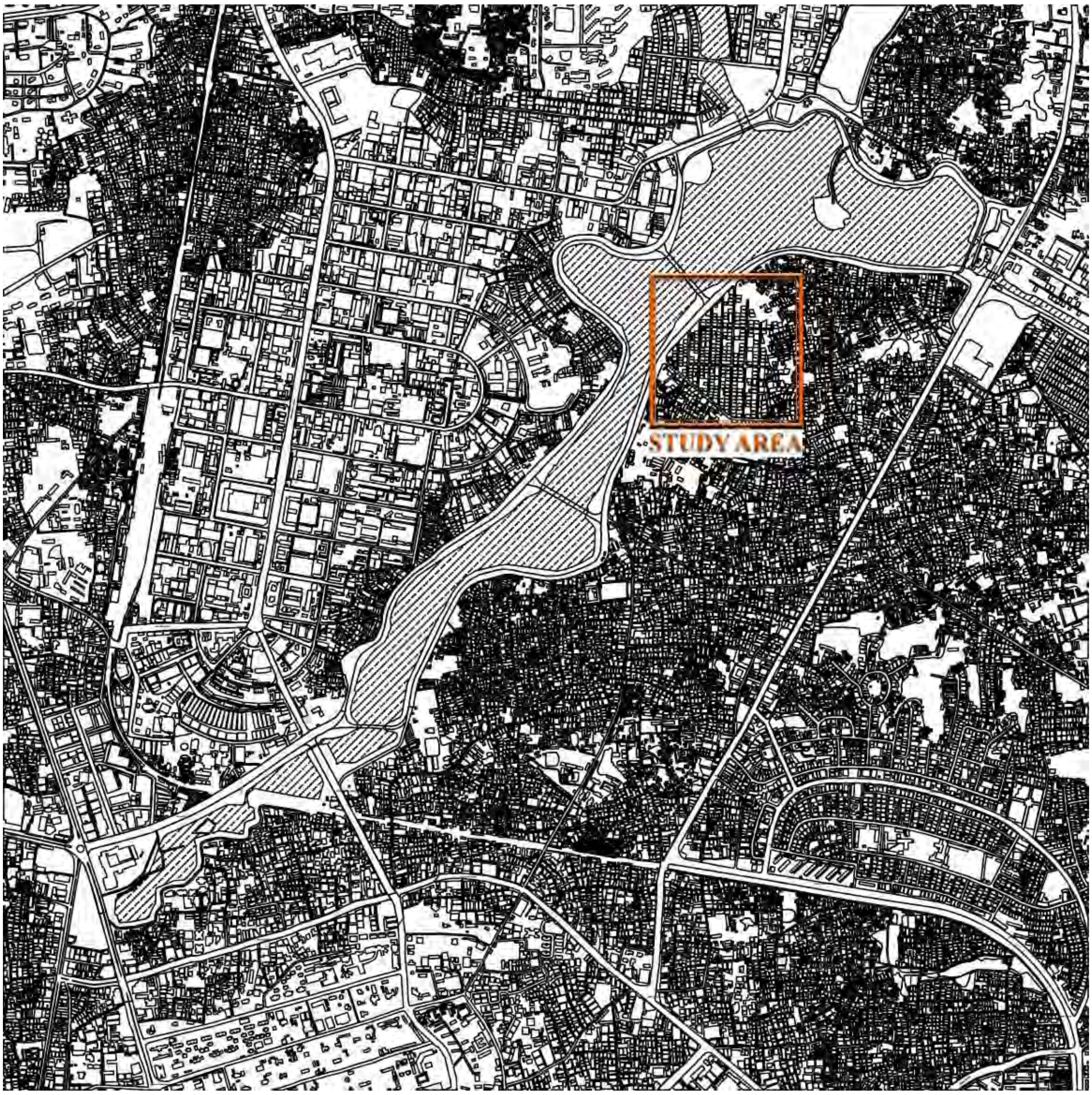


Fig 3.1: Arial View Showing Study Area (RAJUK).

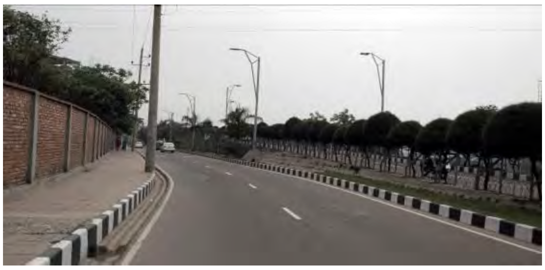


Fig 3.2 (i)


Fig 3.2 (ii)


Fig 3.2 (iii)


Fig 3.2 (iv)

Fig 3.2 (i) – (iv): Photographs Showing Major Morphological Changes.

Fig 3.3: Arial View Showing Points and Directions of Photographs.

Fig 3.4 (i)


Fig 3.4 (ii)


Fig 3.4 (iii)

Fig 3.4 (iv)

Fig 3.4 (v)

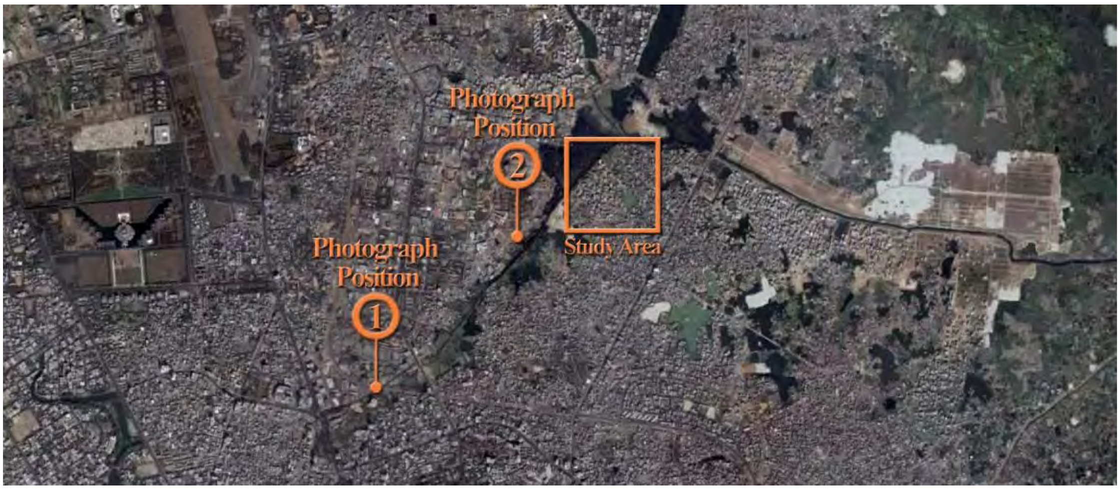
Fig 3.4 (vi)

Fig 3.4 (vii)

Fig 3.4 (viii)

Fig 3.4 (ix)

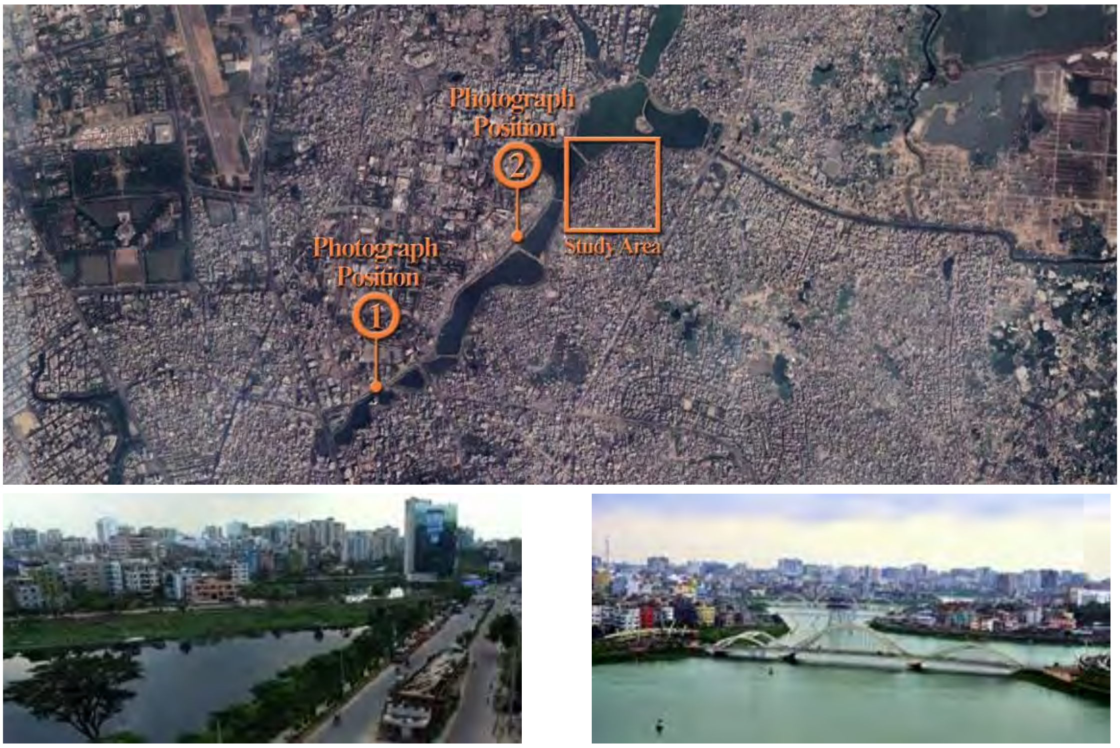
Fig 3.4(i) – 3.4(ix): Photographs of Current Morphological Situation of Mohanagar Housing and Hatirjheel Area.



Photograph position- 1

Photograph position- 2

Fig 3.5: Morphological Condition in 2007 Showing Hatirjheel Area and Photographs Before Renovation (Google Earth; 22 January 2007).



Photograph position- 1 Photograph position- 2

Fig 3.6: Morphological Condition in 2017 Showing Hatirjheel Area and Photographs After Renovation (Google Earth; 18 January 2017).

Figure 3.1 shows the Arial view of study area located adjacent to Hatirjheel Lake and 3.2 (i) to (iv) shows major morphological changes in the recent years of the selected study area. Figure 3.2 (i) to (iv) shows that there is a wall surrounding the selected Mohanagar Housing area which isolates it from the lake and its adjacent asphalt road. Figure 3.2 (iii) shows, earth-filled and seamless overpass. Figure 3.2 (iv) shows, there is a bridge connecting Begunbari with Mohanagar Housing area, which is through the middle of the overpass, where it is hollow and supported by columns.

Figure 3.3 shows positions of Hatir Jheel Area where the photographs were taken. In Figure 3.4 (i) to 3.4 (ix) shows the current morphological situation of that area. Figure 3.5 shows 2007, and figure 3.6 shows 2017 and their morphological condition respectively, which describes the pre and post conditions of morphological changes of Hatir Jheel Lake area.

It is clear that from figure 3.2 (i) to (iv), 3.5 and 3.6, there was a drastic change that occurred over the period in morphology in Hatirjheel Lake area. There are still some minor construction and renovations taking place in the area. Hence, for this study, 2007 and 2017 was considered to access the maximum and final result of the changes.

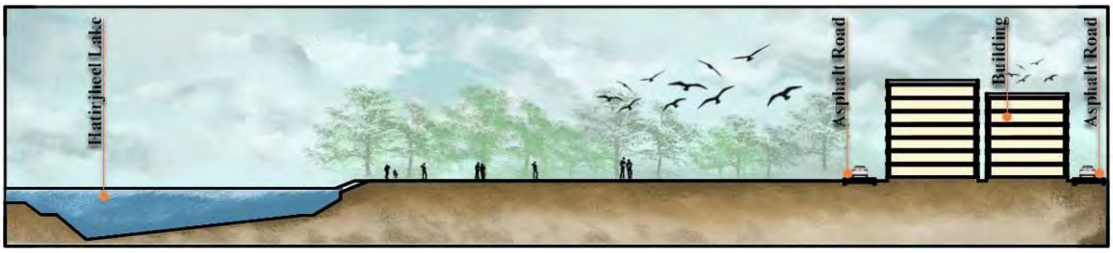


Fig 3.7: Sectional diagram (A-A) of 2007 (Before Renovation of the Study Area).

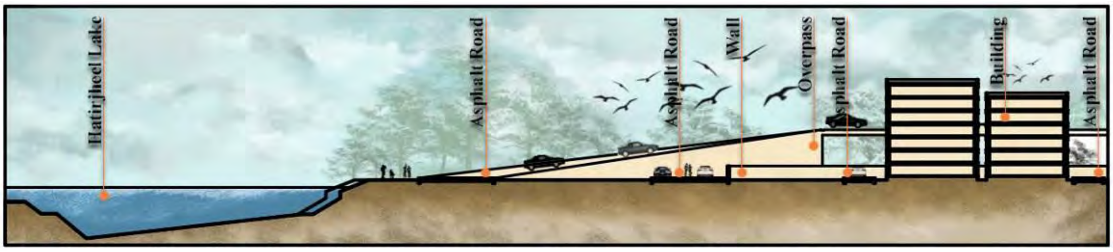


Fig 3.8: Sectional diagram (A-A) of 2017 (After Renovation of the Study Area).

Figure 3.7 and 3.8 are the sections of Figure 3.9 and 3.10 respectively, depicting the land use pattern in details in respect to the change of time. These Figures shows that the major morphological changes for Mohanagor Housing Area are the newly constructed roads, bridges and wall adjacent to Mohanagor Housing and Lake. While renovating the Lake the percentage of water body was also altered.

3.2.2 Generate the maps of selected area:

Fig 3.9: 400m X 400m Map of 2017, Showing Selected Sample Points.

For the simulation modeling and any other analysis, two maps from 2007 and 2017 was necessary. The map from 2017 was collected from RAJUK (Figure 3.9), and the map from 2007 was developed from historical image collected from Google Earth (Figure 3.10), where the morphological changes of the map was altered in respect to that of 2017, keeping the buildings intact, as the map from 2007 was not available.

Fig 3.10: 400m X 400m Map of 2007, Showing Selected Sample Points (Developed by Historical Image of Google Earth).

3.2.3. Sample selection:

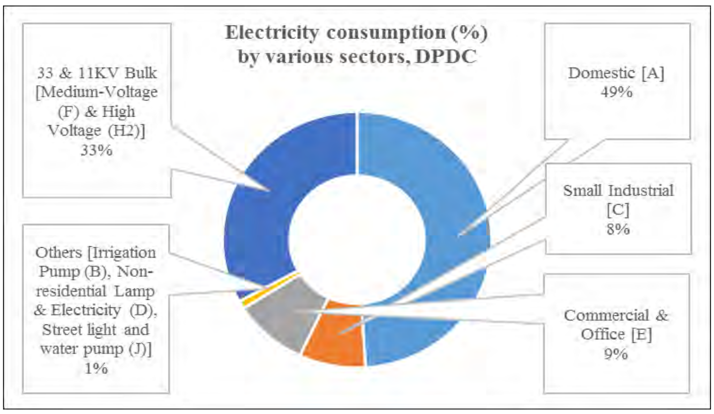


Fig 3.11: Electricity Consumption (%) by Various Sector in the Financial Year 2014-2015 (DPDC, 2015).

The demand for electricity energy in domestic sector is increasing day by day. The consumption of electricity has almost doubled within the years 2006 to 2012 in the residential sector of Dhaka (Rahman et al., 2017). The residential sectors consume more energy than other sectors, and this is the key contributor to greenhouse gas emission (Chen et al., 2013). Even in Bangladesh, the residential sector consumes more amount of energy. In the DPDC area of Dhaka city, domestic category used 48.57% of total consumed electricity in the financial year 2014-2015 (DPDC, 2015) (Figure 3.11). Therefore, domestic energy consumption may be considered as a factor for sample selection.

Wong and Huang (2004), made a comparative study on the indoor air quality of naturally ventilated and air-conditioned bedrooms of residential buildings in Singapore. They observed that CO_2 levels of bedrooms using air conditioners are consistently higher than those utilizing natural ventilation. Thermal comfort comparison of the air-conditioned bedrooms and naturally ventilated bedrooms indicate that the air-conditioned bedrooms are usually substantially overcooled, resulting in extremely high PPD (Percentage People Dissatisfied). Whereas, in natural ventilated bedrooms, the utilization of fans was sufficient to achieve the required thermal comfort. They also found that occupants utilizing air conditioners exhibited more SBS (sick building syndrome) symptoms than those utilizing natural ventilation. Liping et al. (2007), also conclude that natural ventilation is an attractive alternative to reduce the associated problems with air-conditioned buildings because natural ventilation has potential benefits such as reduced operation costs, improved indoor air quality and satisfactory thermal comfort. Mallick (1996), elaborated the role of ceiling fans as a reliable source of cooling in dense urban conditions of Dhaka if they are set at maximum or high speeds. Hence, the non-air conditioned buildings may be a possible factor for sampling.

Since the thesis was conducted on the morphological changes of Hatirjheel and Mohanagar Housing area from 2007 to 2017, the sample buildings were selected from among those, who’s electricity billing data exists from DPDC.

Considering the above mentioned factors, the sampling are done as follows:

1. The buildings which are used for residential/ domestic purposes only.
2. The buildings which never had A/C till date.
3. The buildings which have complete (from 2007 to 2017) electricity billing data.

In respect to the given factors, the micro-domains from the selected area has been categorized as such:

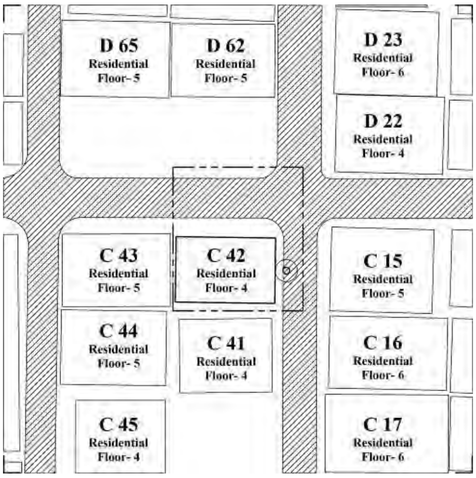
Table: 3.1: Sorting Samples According to the Required Criteria.

Total Building	Availability of Billing data	Complete Residential Building	Never had A/C till date	Building which meets the required criteria
285	285	232	4	4

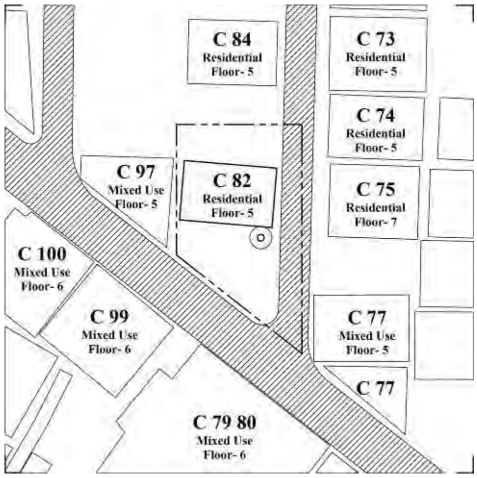
From the Table 3.1, it is observe that four buildings among 285 meets the required criteria to be selected as sample buildings.

3.2.4. Micro-domain calculation:

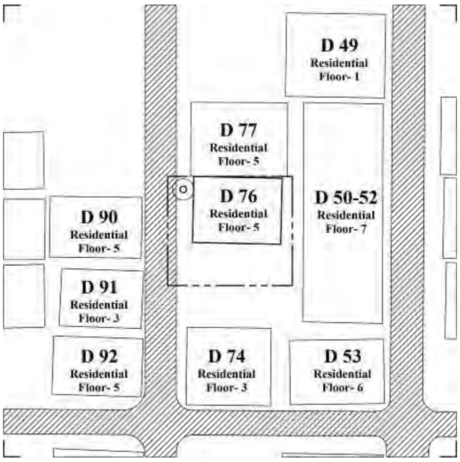
Figure 3.12 shows the four selected micro-domain based on the narrated selection method of micro-domain in Chapter 2.6.3.



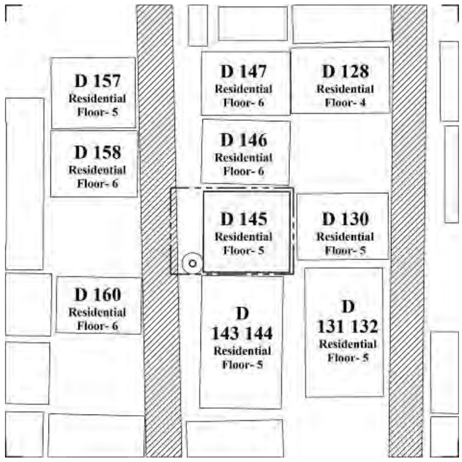
Micro-domain: Sample 1: C 42



Micro-domain: Sample 2: C 82



Micro-domain: Sample 3: D 76



Micro-domain: Sample 4: D 145

Fig 3.12: Selected Samples Showing Micro-domain and Data Logger Installation Points.

Table 3.2: Summary of Micro-domain of Sample Buildings.

Micro-domain Sample	Number of floors	Ground floor Area (Sqm)	Total floor area (Sqm)	Domain Area (Sqm)	Build Area (Sqm)	Open Area (Sqm)	Road Area (Sqm)
C 42	4	144.90	579.60	415.29	144.90	105.66	164.73
C 82	5	123.17	615.85	502.07	123.17	271.94	106.96
D 76	5	139.13	695.65	325.50	139.13	164.23	22.14
D 145	5	166.56	832.80	253.24	166.56	73.20	13.48

Table 3.2 shows the summary of four selected sample buildings. The summary is concluded from the figure 3.12, which isolates the micro-domains of the selected samples.

3.3. Micro-climatic Field Study and Data Collection:

The field survey was conducted on 01.12.2017, 02.12.2017 and 03.12.2017, at four sampling points. Data logger was set at a height of 1.8-2m, with an average distance of 1m from building. Figure 3.12 and 3.13 shows the installation points of the data logger and data collection process with data logger and anemometer respectively.

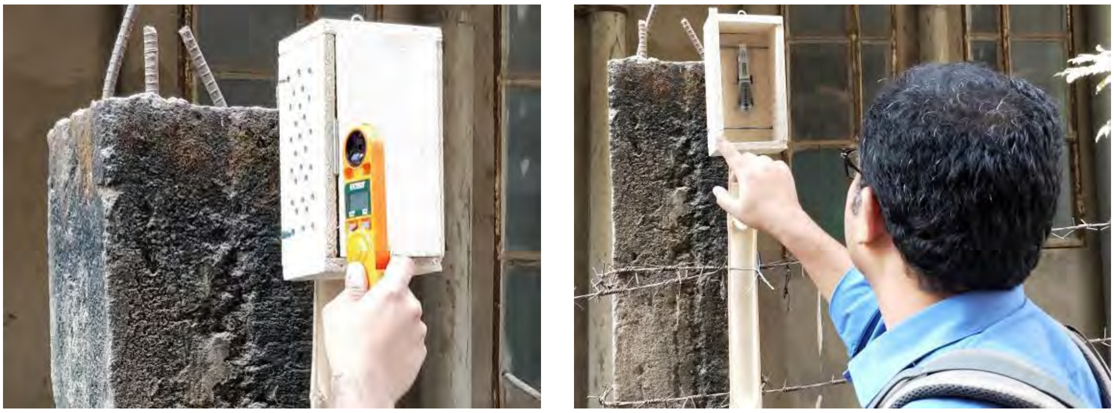


Fig 3.13: Field Data Collection with Instruments.

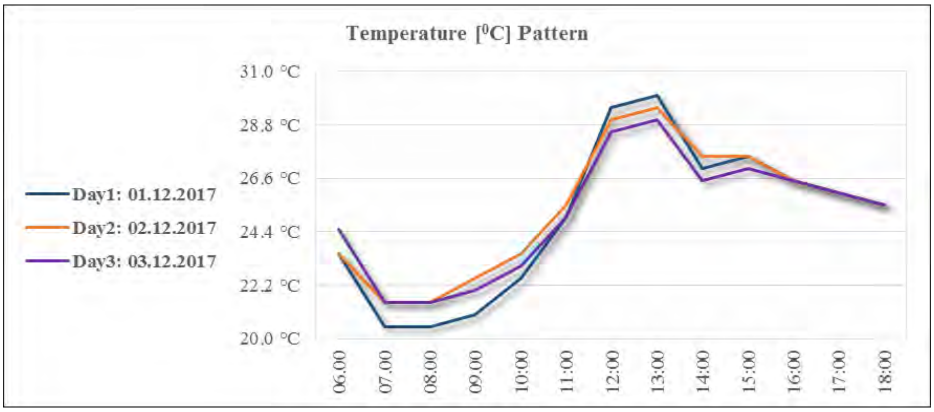


Fig 3.14: Air Temperature (^{0}C) Pattern of Collected Dates.

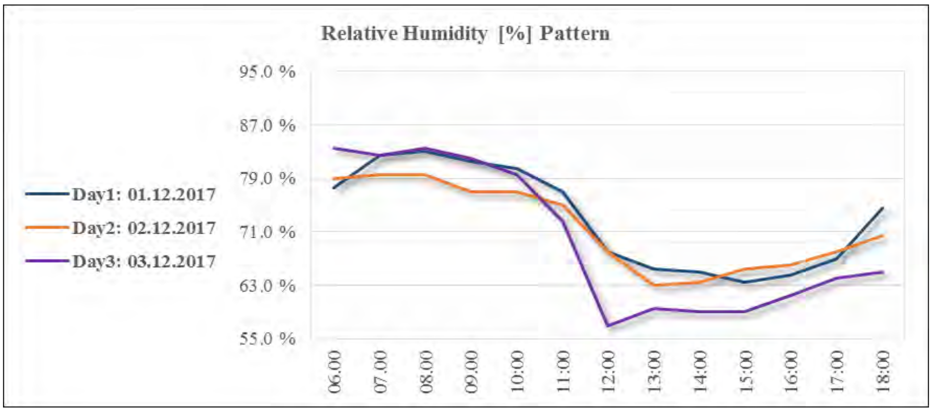


Fig 3.15: Relative Humidity (%) Pattern of Collected Dates.

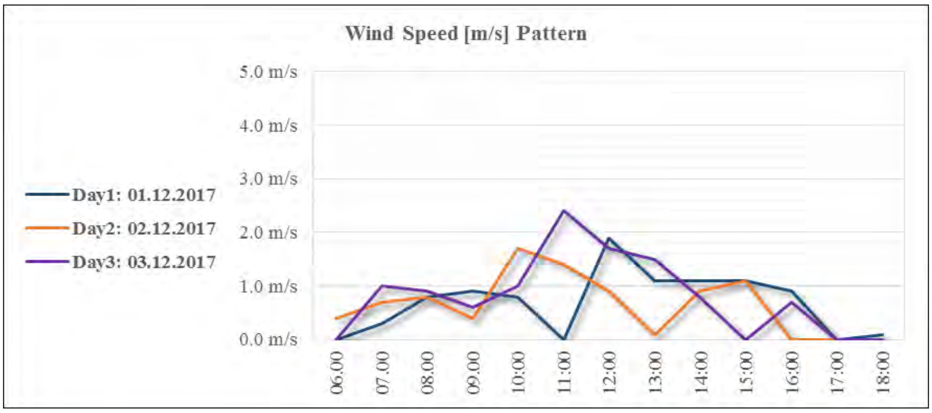


Fig 3.16: Wind Speed (m/s) Pattern of Collected Dates.

Air Temperature, Relative Humidity and Wind Speed has been measured continuously throughout 6:00:00am to 6:00:00pm. Data logger automatically recorded and saved air temperature and relative humidity at 15 minutes interval. Wind speed was recorded and saved manually by using anemometer with the same time interval.

Figure 3.14, 3.15 and 3.16, shows the output result of Air Temperature, Relative Humidity and Wind speed, which was collected from field survey on 01.12.2017, 02.12.2017 and 03.12.2017. From the illustrated figures, it is observed that, the temperature starts to rise from 11:00 am and starts to fall around 2:00pm. Simultaneously, when the temperature rises and falls, the Relative humidity starts to inversely rise and falls in that respect. The wind speed is relatively high throughout the survey days during that time.

The probable phenomenon is that when temperature is high, the relative humidity is low, which is the case in this scenario. Along with this, the high wind speed which is due to light air, contributes to reduction of further relative humidity.

A study was conducted by Kim et al., (2014) which possesses resemblance with this study and analysis process. Kim et al., (2014) elaborates that, “we could obtain the ideal result with the highest temperature, after trying different initial values in the same condition”. The highest Air Temperature is recorded on Day 1 (01.12.2017). Therefore, the initial values of Air Temperature (^{0}C), Relative Humidity (%) and Wind Speed (m/s) were selected at their highest from that day, which was used for all the analysis.

3.4. Energy Consumption Data Collection:

When the data of the required sample buildings is filtered out from the data archive of DPDC, the following table is obtained:

Table 3.3: Summary of Meter Numbers of Sample Buildings.

Sample	Electricity Billing Meter Number								
	Meter 1	Meter 2	Meter 3	Meter 4	Meter 5	Meter 6	Meter 7	Meter 8	Meter 9
C 42	19168 160	19168 175	19169 830	19169 845	19057 050	19057 065	19057 099	X	X
C 82	19058 631	19058 646	19058 650	19058 665	19058 671	19058 843	19058 858	19058 862	19058 877
D 76	19057 224	19057 239	19057 243	19057 258	19057 332	19057 347	19057 351	19057 366	19057 370
D 145	19059 714	19059 729	19059 841	19059 856	19059 860	19059 875	19059 881	19059 894	19059 907

3.5. Conclusion:

For this study, the field visit was conducted in the month of December, which is considered as winter in context to Bangladesh. It is mentioned earlier that the morphological changes went through in the north and north-western side of Mohanagar Housing area. And the direction of wind flow is 345^0, or north-western in December. Therefore, since the morphological changes took place in the north-western side, which is identically also the wind direction, it would yield positive result if the study was conducted in the month of December.

This chapter elaborated the field study and data collection methods. This chapter described briefly, why Hatirjheel and the Mohanagar Housing area has been selected. Sample selection procedure showed the criteria which were considered while selecting the samples. Micro-domain calculation process sheds light on the process of micro-domain and morphological parameter calculations of the selected samples.

The micro-climatic field study and the data collection section elaborated the dates selected for the field study and data collection, which are 1st to 3rd December. Among which, 1st December has been selected as usable date for simulation and analysis for further observation, since that day had the maximum temperature. In Energy consumption data collection, the electricity billing meter numbers of the sample buildings are short listed, because from the detailed data collected from DPDC, only these specific ones will be used.

The next chapter elaborates the simulation and data processing. The next chapter will explain simulation software, simulation process, simulation accuracy and data processing methods.

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Chapter 4:
SIMULATION, DATA PROCESSING

Introduction	:	**4.1**
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Size selection of Simulation Area	:	**4.2.2**
Simulation Input Parameters and Process	:	**4.2.3**
Simulation Output	:	**4.2.4**
Simulation Accuracy	:	**4.2.5**
Morphological Data Processing	:	**4.3**
Energy Consumption Data Processing	:	**4.4**
Conclusion	:	**4.5**
References	:	**4.6**

Chapter 4: SIMULATION, DATA PROCESSING

4.1. Introduction:

This chapter is mainly consists of three sections. First section describes the simulation process. The simulation process will elaborate the basic know-how of ENVI-met simulation, selection process of required domain for the simulation, process of input data and the accuracy of the simulation. The second section elaborates the morphological data processing. Finally, the third section shows the energy consumption data processing.

4.2. Micro-climatic Simulation:

4.2.1. Simulation concept:

"ENVI-met is a three-dimensional microclimate model designed to simulate the surface, plant, air interactions in urban environment with a typical resolution down to 0.5m in space and 1-5 sec in time. Typical areas of application are Architecture, Landscape Architecture, Building Design or Environmental Planning etc. ENVI-met is a prognostic model based on the fundamental laws of fluid dynamics and thermodynamics. The model includes the simulation of, Flow around and between buildings, Exchange processes at the ground surface and at building walls, Building physics, Impact of vegetation of the local microclimate, Bioclimatology and Pollutant dispersion. With ENVI-met, it is possible to simulate the urban microclimate as an interactive system consisting of dozens of dynamic subsystems ranging from atmospheric dynamics, over soil physics, vegetation response down to building indoor climate" (ENVI-met).

In order to find out the influence of morphological change on micro-climatic parameters and energy consumption, along with finding the scenario of both study periods 2007 and 2017 of the study area, the ENVI-met (Version 4.3.0 Winter1718) simulation software has been used.

4.2.2. Size selection of simulation area:

One of the techniques developed by the Martin Centre (Department of Architecture, University of Cambridge) 's urban environmental research team, which has assessed energy demand considering urban form for a particular area (Steemers, 2003). This technique referred to as "LT urban". In "LT urban" technique, a 400m X 400m part of London city is used to demonstrate the technique and its application in establishing the relationship between urban densities and building energy use. In this study, a similar 400m X 400m area has been selected for simulation.

While selecting the required domain of 400m X 400m, precautions were taken so that most of the Mohanagar Housing remains inside. The samples taken are also selected as such, so that they remain within the middle of the concentrated area. Because, the samples which are at the middle of a selected area has the highest probability of representing the micro- climatic condition of the whole sample area. Along with that, the newly constructed roads, bridges, overpasses etc are also kept within the selected area so that their effects may be observed and analyzed.

4.2.3. Simulation input parameters and process:

The process of simulation has been conducted through the following four steps:

Step 1: Modeling (by ENVI-met area input file)
Step 2: Creating configuration file (by .CF file)
Step 3: Simulation (through analysis)
Step 4: Output file (visual illustration by Leonardo)

Step 1: The study areas has been modeled by "Area input file editor" with the proper buildings and building heights (data from field survey), roads and paves (data from field survey and satellite image), open spaces (data from field survey) and other built forms (data from field survey and satellite image).

After creating the model of the study area in "Area input file editor", the following images are obtained. Figure 4.1 as the model of the study area in 2007 and Figure 4.2 as the model of the study area in 2017.

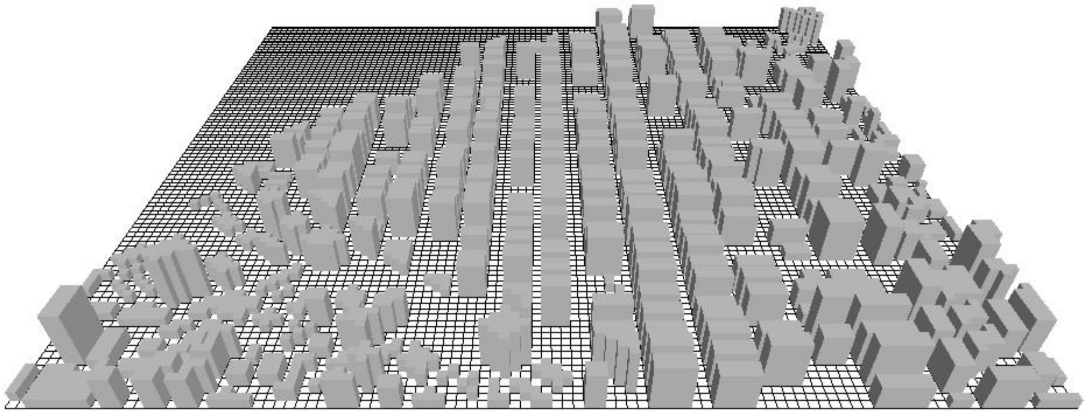

Fig 4.1: 3D Model Generated by ENVI-met of Study Area of 2007.

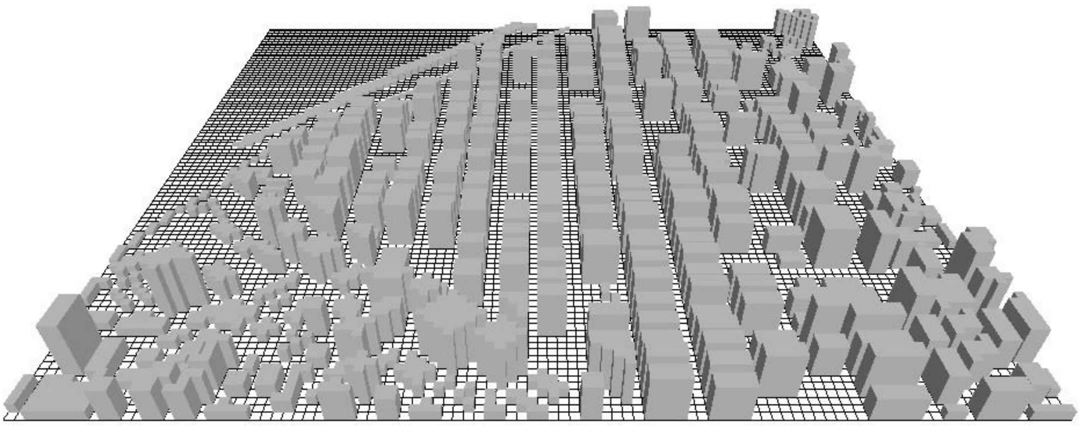

Fig 4.2: 3D Model Generated by ENVI-met of Study Area of 2017.

This is a comparative study in-between 2007 and 2017. Hence, it is not possible to determine the types and number of trees of that area of 2007. So, vegetation is considered as "controlled variables" as discussed earlier in Chapter 1 (1.4). Therefore, the "vegetation" has not been selected as a parameter for this study while generating 3D model for the simulation.

Step 2: The second stage was to create a configuration file for the specific site. This file contains atmospheric data. Data input was given for three simulations. Among them, the simulation from 2007 was given BMD atmospheric data. In 2017, two atmospheric data was given, one from BMD, and the other from field survey.

The output file from 2007 and 2017 which was obtained from BMD input file and field survey file respectively will indicate towards the micro-climatic parameter changes. Whereas, the output file obtained from BMD input file in 2017 along with field data file will determine the accuracy of the simulation software. Table 4.1 illustrates main input data used for creating .CF file.

Table 4.1: Input Data for ENVI-met Simulations.

	2007	**2017**	**2017**
Contents	Simulation by Using BMD Data	Simulation by Using Field Data	Simulation by Using BMD Data
Model size	400m X 400m X 100m		
Longitude	90° 23' 58.0272" E		
Latitude	23° 46' 37.8336" N		
Simulation Day [DD.MM.YYYY]	01.12.2007	01.12.2017	01.12.2017
Total Simulation Time [Hours]	24.00		
Start Simulation Time [HH:MM:SS]	06:00:00		
Save Model State each [Min]	60 min		
Wind Speed (10m above Ground) [m/s]	2.0	1.9	2.0
Wind Direction [0^0:N, 90^0:E, 180^0:S, 270^0:W]	345^0	345^0	345^0
Roughness Length z0 at Reference Point	0.1	0.1	0.1
Initial Temperature Atmosphere [^{0}C]	27.40^0	30.00^0	28.60^0
Specific Humidity (2500m) [g Water/kg air]	7g Water/kg air		
Relative Humidity (2m) [%]	95%	83%	97%

The Longitude and the Latitude is similar for all three simulations. The simulation start date was taken as 1st December as discussed earlier in Chapter 3 (3.3), and kept constant throughout all three. The simulation time was 6:00:00 to 6:00:00 (24 hours) which will provide simulation output data for both day and night. The Initial Temperature, Relative Humidity and Wind Speed for 2007 was taken from BMD, and for 2017 from BMD and Field Data survey. The Specific Humidity and the Roughness length were 7g water/kg air and 0.1 (Chapter 2, 2.2.5) for all three simulations respectively. The wind direction is 345^0 as discussed earlier in Chapter 2 (2.3).

Step 3: The third stage was the simulation. The simulation save time was selected at 60 minutes for each case. Hence, the simulation ran for 48 hours with 60 minutes interval, with the provided parameters as discussed above.

Step 4: ENVI-met calculate numerous numerical values in order to provide an output. After simulation, the results have been generated by "Leonardo Module" as illustrated images. The Air Temperature, Mean Radiant Temperature, Relative Humidity and Wind Speed data of 4 (four) samples have been calculated and plotted. The "Leonardo Module" included in ENVI-met is able of render a visual image based on the numerical output file from the ENVI-met simulation.

4.2.4. Simulation output:

Simulation output, 2007:

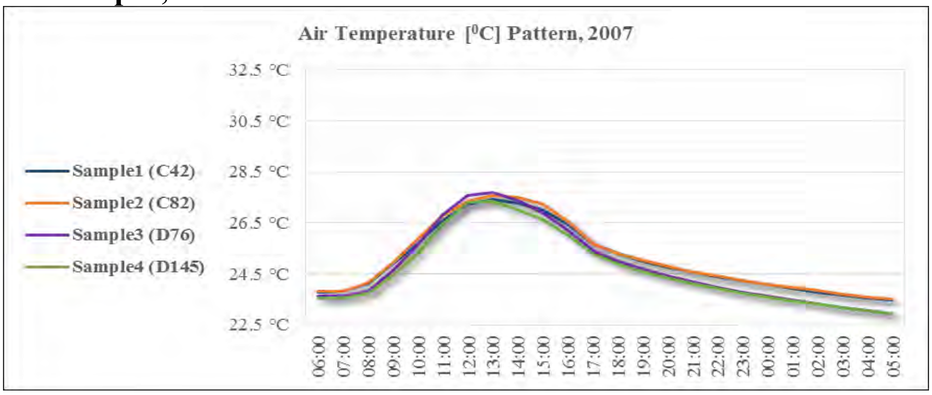

Fig 4.3: Air Temperature Pattern, 2007.

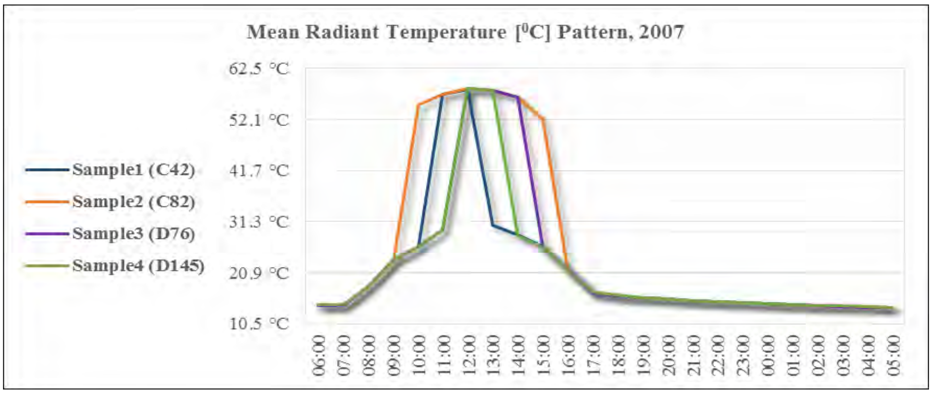

Fig 4.4: Mean Radiant Temperature Pattern, 2007.

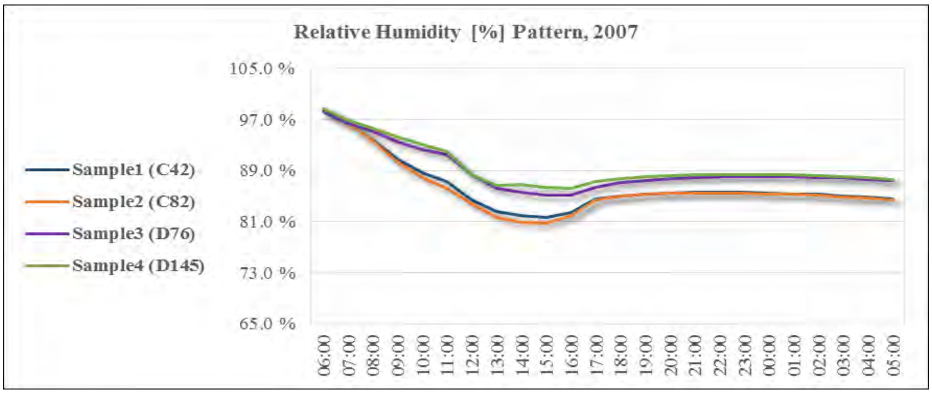

Fig 4.5: Relative Humidity Pattern, 2007.

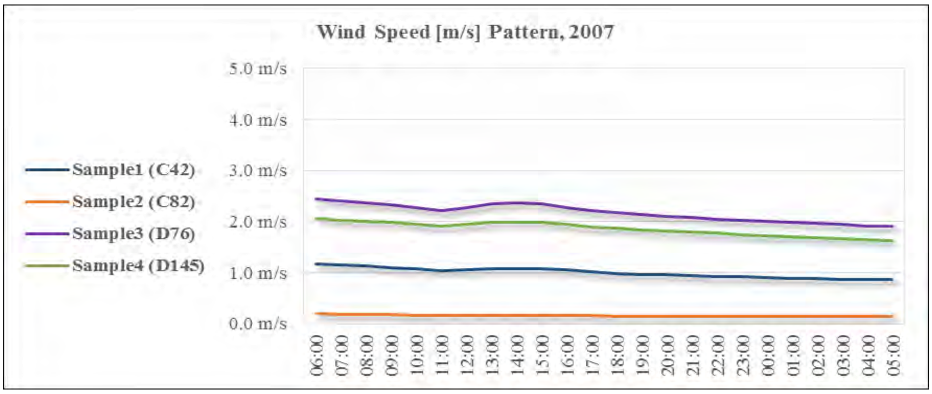

Fig 4.6: Wind Speed Pattern, 2007.

Simulation output, 2017:

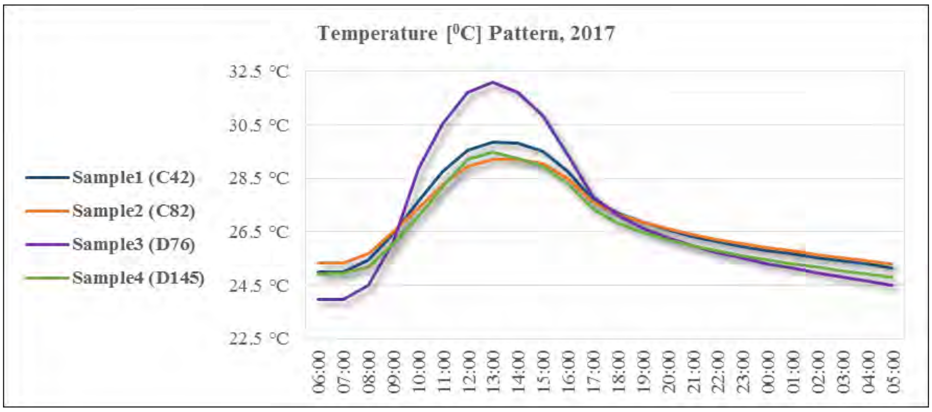

Fig 4.7: Air Temperature Pattern, 2017.

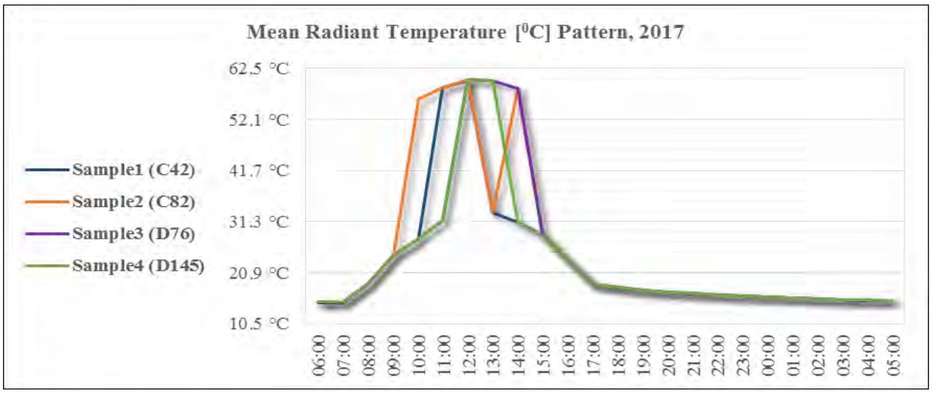

Fig 4.8: Mean Radiant Temperature Pattern, 2017.

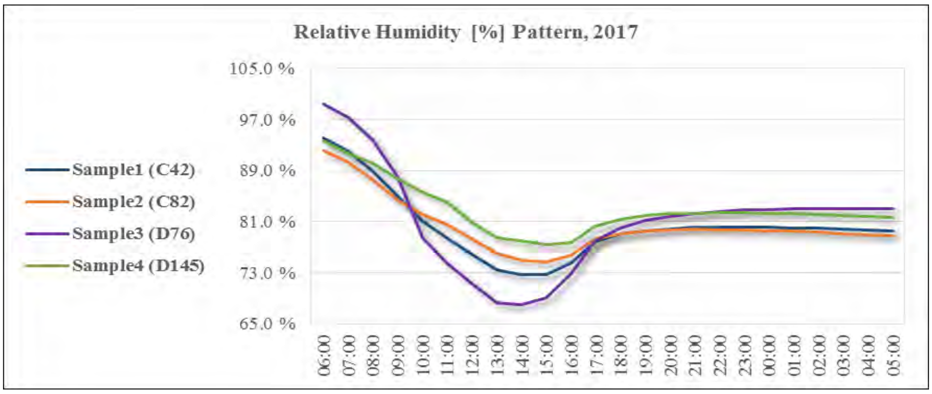

Fig 4.9: Relative Humidity Pattern, 2017.

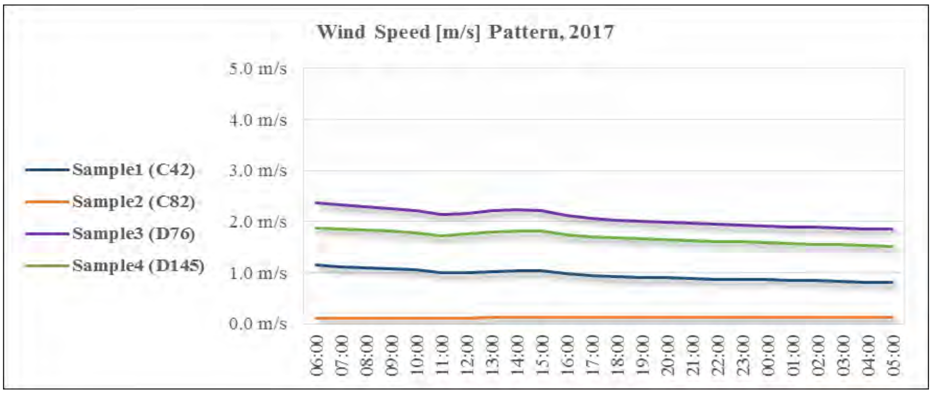

Fig 4.10: Wind Speed Pattern, 2017.

As discussed earlier, BMD data was used to simulate 2007 micro-climatic parameters and field Survey data was used to simulate 2017 micro-climatic parameters. Figure 4.3 to 4.6 and Figure 4.7 to 4.10 shows the Air Temperature, Mean Radiant Temperature, Relative Humidity and Wind Speed pattern of 2007 and 2017 respectively.

From the outputs of 2007, it is observed that the maximum air temperature was 27.70^0 and minimum was 23.47^0 at sample 3 (D 76) and sample 1 (C 42), at 13:00:00 and 05:00:00 respectively, maximum Mean Radiant Temperature was 58.44^0 at sample 2 (C 82) at 12.00:00 and minimum was 13.76^0 at sample 3 (D 76) at 05:00:00, maximum Relative Humidity was 98.72% and minimum was 80.72% at sample 4 (D 145) and at sample 2 (C 82), at 06:00:00 and 15:00:00 respectively. The wind speed variation was minimal throughout the day, but with a slight peak around the early hours. Sample 3 (D 76) had the highest variation of wind velocity throughout the day, whereas sample 2 (C 82) had the lowest.

From the outputs of 2017, it is observed that at sample 3 (D 76), the maximum air temperature was 32.07^0 and minimum was 23.96^0 at 13:00:00 and 06:00:00 respectively, at sample 3 (D 76), maximum Mean Radiant Temperature was 60.17^0 at 12:00:00 and minimum was 14.83^0 at sample 1 (C 42) at 05:00:00, maximum Relative Humidity was 99.35% and minimum was 67.93% at sample 3 (D 76), at 06:00:00 and 14:00:00 respectively. Similar to 2007, the wind speed variation was minimal throughout the day, but there was a slight peak around the early hours. Among the samples, sample 3 (D 76) had the highest variation of wind velocity throughout the day, whereas sample 2 (C 82) had the lowest.

In order to select a specific time for both day and night that influences the thermal comfort the most, which is influenced by the micro-climatic parameters, the output result of AT, MRT, RH and WS from 2007 and 2017 were considered. Among all the micro-climatic parameters of 2007 and 2017, similarity based on time was seen only in case of temperature. Therefore, prioritizing the temperature, and its peak variation times, 13:00:00 and 05:00:00 were taken as the standard for all calculation times.

4.2.5. Simulation accuracy:

The simulation conducted in 2017 was done twice, once with the BMD data and again with the Field Survey data. From these two outputs, the difference of Air Temperature, Mean Radiant Temperature, Relative Humidity and Wind Speed was observed. This shows the accuracy of the simulation software.

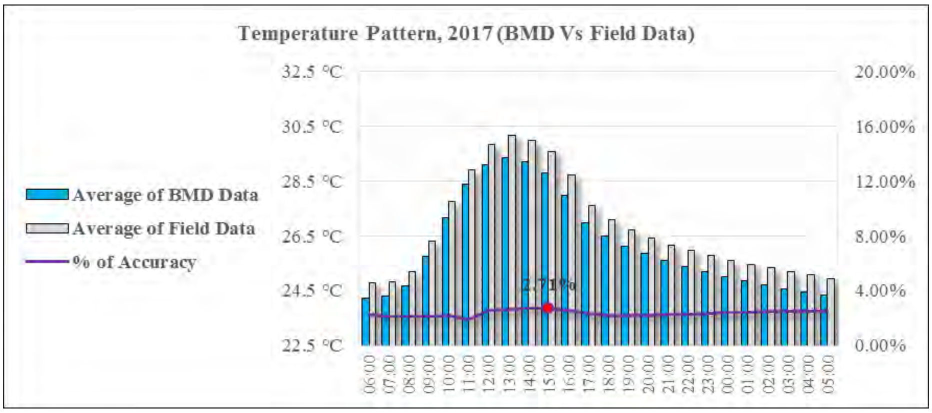

Fig 4.11: Temperature Pattern, 2017 (BMD Data Vs. Survey Data).

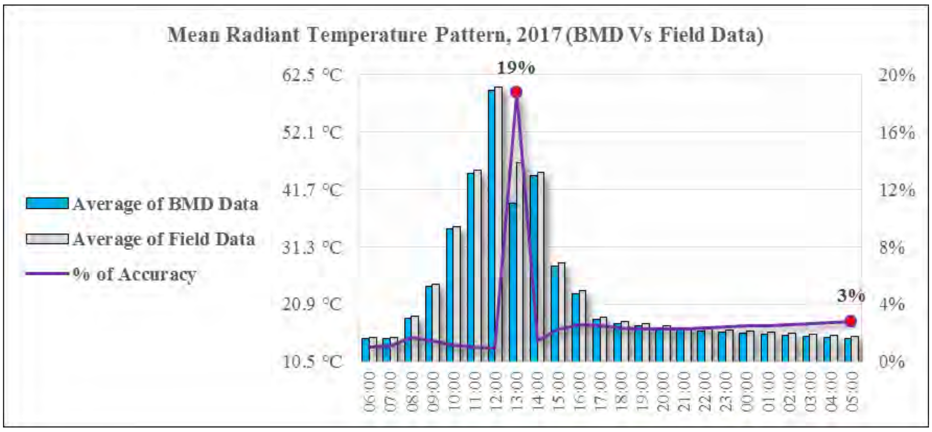

Fig 4.12: MRT Pattern, 2017 (BMD Data Vs. Survey Data).

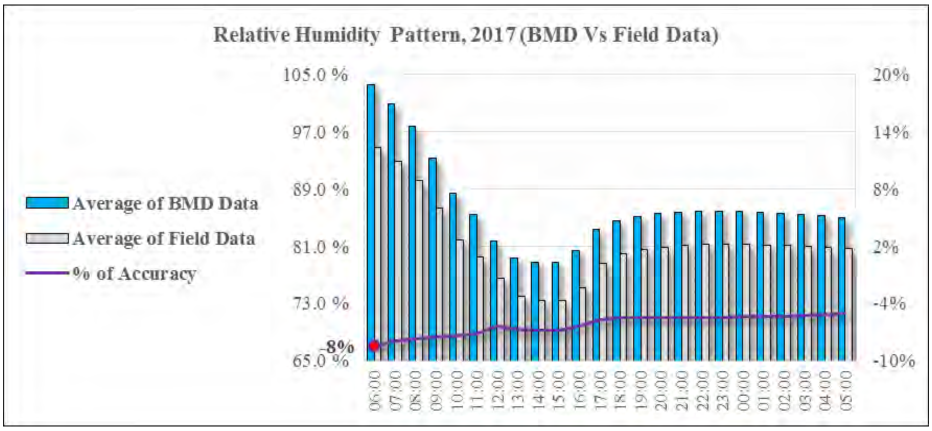

Fig 4.13: Relative Humidity Pattern, 2017 (BMD Data Vs. Survey Data).

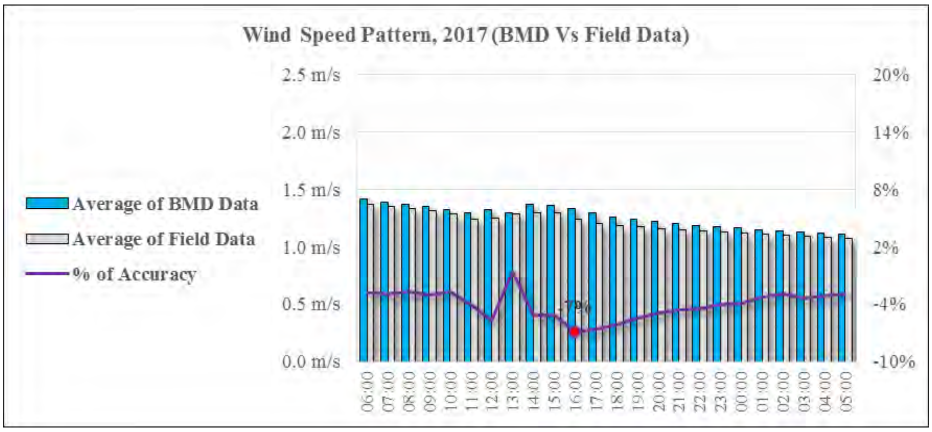

Fig 4.14: Wind Speed Pattern, 2017 (BMD Data Vs. Survey Data).

From the figures 4.11 to 4.14, it is observed that, the maximum difference between the temperatures is approximately 2%, and for Mean Radiant Temperature, except for a variation of 19%, the maximum difference is approximately 3%. Relative Humidity along with Wind Speed is approximately 9% and 7% respectively. Therefore, on average, the difference is minimal, which indicates towards the keen accuracy of the simulation software.

4.3. Morphological Data Processing:

From the maps of 2007 and 2017 (Chapter 3), the morphological changes of the total domain were identified and denoted in percentage. The morphological changes were calculated in percentage to identify the effects of the considered parameters in a single unit. The major changes are as follows:

Table 4.2: Morphological Changes of the 400m X 400m Domain.

Contents	Area (sqm) 2007	Area (sqm) 2017	Percentage of change (%)
Whole-domain area	160000.00	160000.00	-
Build area coverage of whole-domain	54421.32	55907.64	2.73
Open space coverage of whole-domain	61206.75	64062.24	4.67
Water body coverage of whole-domain	26944.28	13676.62	-49.24
Road area coverage of whole-domain	17427.65	26353.50	51.22

The table 4.2 shows that the highest morphological change is occurred in road area coverage and water body coverage.

Although the whole-domain saw morphological changes, the micro-domains of the selected sample buildings remains unchanged. The table 4.3 is obtained by analyzing the morphological parameters of the micro-domain.

In order to bring all the factors within same calculation parameters, the percentage of Built area, Open space, Water body and Road area has been calculated by dividing the individual criteria with that of the total micro-domain space and then multiplying it with 100.

Percentage of built area = (built area / total area) x 100.
Percentage of open space = (open area / total area) x 100.
Percentage of water body = (water body area / total area) x 100.
Percentage of road area = (road area / total area) x 100.

Table 4.3: Morphological Parameters of Micro-domains.

Micro-domain	Domain Area (Sqm)	Build Area (Sqm)	Open Area (Sqm)	Road Area (Sqm)	Build Area (%)	Open Area (%)	Road Area (%)
C 42	415.29	144.90	105.66	164.73	34.89	25.44	39.66
C 82	502.07	123.17	271.94	106.96	24.53	54.16	21.30
D 76	325.50	139.13	164.23	22.14	42.74	50.45	6.80
D 145	253.24	166.56	73.20	13.48	65.77	28.90	5.32

From the table 4.3, it is observed that the build area percentage is highest in sample 4 (D 145) and lowest in sample 2 (C 82). Open area percentage is more in sample 2 (C 82) and sample 3 (D 76) and lowest in sample 1 (C 42) and sample 4 (D 145). Road area percentage is highest in sample 1 (C 42), whereas it is the lowest in sample 3 (D 76) and sample 4 (D 145). From the analysis of micro-domains, it can be observed how despite micro-domains being unchanged along with the morphological changes of the total selected area, are reacting with each other.

4.4. Energy Consumption Data Processing:

The electricity billing data which were collected from DPDC, have been converted to per square meter unit, through adding all the meters present in the building including the service meter and common meter, by total square meter of built area served by the energy. The energy consumption per square meter of each building has been determined by the following method:

Energy consumption per square meter of the Building = Total occupied floor area (Ground floor area X Number of floors)/ Energy consumption of the selected month.

Table 4.4: Consumption per Square Meter of Samples, December 2007.

Sample	Meter Number									Total Watt	Total Area (Sqm)	W/Sqm
	1	2	3	4	5	6	7	8	9			
C 42	102	80	11	42	142	184	109	X	X	670	579.60	1.16
C 82	134	65	160	115	58	120	96	52	190	990	615.85	1.61
D 76	63	120	74	357	120	94	74	15	40	957	695.65	1.38
D 145	130	130	279	70	63	79	60	100	183	1094	832.80	1.31

Table 4.5: Consumption per Square Meter of Samples, December 2017.

Sample	Meter Number									Total Watt	Total Area (Sqm)	W/Sqm
	1	2	3	4	5	6	7	8	9			
C 42	76	137	179	281	326	55	46	X	X	1100	579.60	1.90
C 82	217	48	72	85	68	127	183	43	188	1031	615.85	1.67
D 76	117	69	99	485	168	119	152	123	31	1363	695.65	1.96
D 145	519	125	266	186	245	128	114	110	239	1932	832.80	2.32

Table 4.4 and 4.5 shows the energy consumption per square meter of December of all four samples in 2007 and 2017 respectively. It is seen that the maximum and minimum energy consumption per square meter from 2007 is 1.61 (sample 2, C 82) and 1.16 (Sample 1, C 42) and 2017 is 2.32 (sample 4, D 145) and 1.67 (sample 2, C 82). It is to be noted that, in 2007, sample 2 (C 82) had the maximum energy consumption, which decreased to have the lowest energy consumption in 2017 in respect to the other samples.

Therefore, the processed data of December 2007 (Table 4.4) and December 2017 (Table 4.5) are used to calculate the change of energy consumption in percentage.

Table 4.6: Percentage of Change of Energy Consumption.

Sample	Energy Consumption (Kwh/sqm) December, 2007	Energy Consumption (Kwh/sqm) December, 2017	Percentage of change (Increment/ Decrement)
C 42	1.16	1.90	63.79%
C 82	1.61	1.67	3.73%
D 76	1.38	1.96	42.03%
D 145	1.31	2.32	77.10%

From the table 4.6, it is observed that Sample 2 (C 82) has the lowest energy consumption change considering 2007 and 2017, whereas sample 4 (D 145) has the highest.

4.5. Conclusion:

This chapter described the simulation process of the micro-climatic parameters and the data analysis process of the morphological parameters and the energy consumption. This chapter elaborates the gradual working process of ENVI-met software. The output file from 2007 and 2017 which was obtained from BMD input file and field survey file respectively will indicate towards the micro-climatic parameter changes. Whereas, the output file obtained from BMD input file in 2017 along with field data file will determine the accuracy of the simulation software. From the software accuracy, it is observed that the difference is minimal which indicates towards the keen accuracy of the simulation software. Moreover, from the simulation output, 13:00:00 and 05:00:00 are taken as the standard for all calculation times. Morphological data processing shows the highest morphological change is in road area coverage (51.22%) and water body coverage (49.24%). Energy consumption data processing shows that at same interval of time, one of the sample held the highest percentage of change of consumption, 77.10%, while another had the lowest at 3.73%.

From the simulation output and analysis data from this chapter, the next chapter would shed light on observation on the outcome and the final goal.

4.6. References:

ENVI-met. (n.d.). Accessed in 20 February 2019. Retrieved from: http://www.envi-met.info/doku.php?id=root:start.

Steemers, K. (2003). Energy and the city: density, buildings and transport. *Energy and Buildings, 35*(1), 3-14.

Chapter 5:
OBSERAVTIONS, FINDINGS AND CONCLUSION

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Influence of Micro-Climatic Parameters on Energy consumption	:	**5.3**
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Chapter 5: OBSERAVTIONS, FINDINGS AND CONCLUSION

5.1. Introduction:

This chapter consists of four sections. The first section is the observation of this thesis. Four major micro-climatic parameters- Air temperature, Mean Radiant Temperature, Relative Humidity and Wind Speed are observed by visual image rendered by ENVI-met software. The second section depicts the influence of morphology on microclimate and the influence of microclimate on energy consumption respectively and the sequence of analysis was done in that order as well. In the third section, micro-domain analysis is elaborated. And finally, the fourth section is composed of some findings, which are extracted from the observations of the thesis and probable design concepts (urban and micro-domain) which may reform design criteria. Besides all these, some future research possibilities are also introduced.

5.2. Observations:

5.2.1. Observation on micro-climatic parameters:

The “Leonardo Module” included in ENVI-met (V4.3.0 Winter1718) is capable of rendering a visual image based on the numerical output file from the ENVI-met simulation. The images observed and analyzed in this thesis to determine the micro-climatic parameters are rendered by the “Leonardo Module”.

The image output from Leonardo divides the given parameters into 10 parts, and uses a color coding accordingly in order to show the relations, differences and gradual increase or decrease of the values of those parameters as well as the maximum and the minimum values found. This study is conducted in-between two different periods, 2007 and 2017. Therefore, both of their parameters and values must be brought to the same level in order to establish a relation in-between them.

The “Data layer legend” function under the “Options” from settings converts all the require parameters under similar level. For this study, all the parameters from both times are brought under same level, which is divided into 10 sections and depicted in color coding accordingly.

The micro-climatic output based on time are shown below. Here, 13:00:00 is considered as diurnal period, and 05:00:00 is considered as nocturnal period. The parameters are arranged side by side based on time difference, so that the difference is clearly understood.

Following parameters are considered sequentially as micro-climatic parameters for observation:

1. Air Temperature
2. Mean Radiant Temperature
3. Relative Humidity and
4. Wind Speed.

Air Temperature:

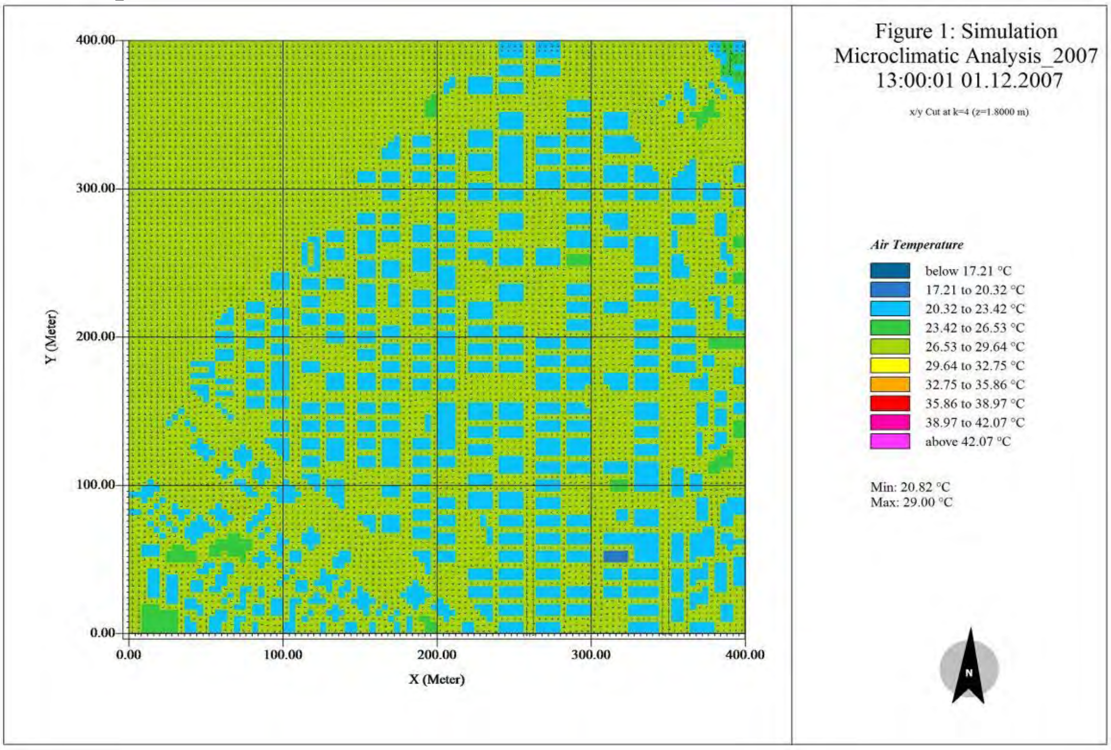

Fig 5.1: Air Temperature, 2007 at 13:00:00.

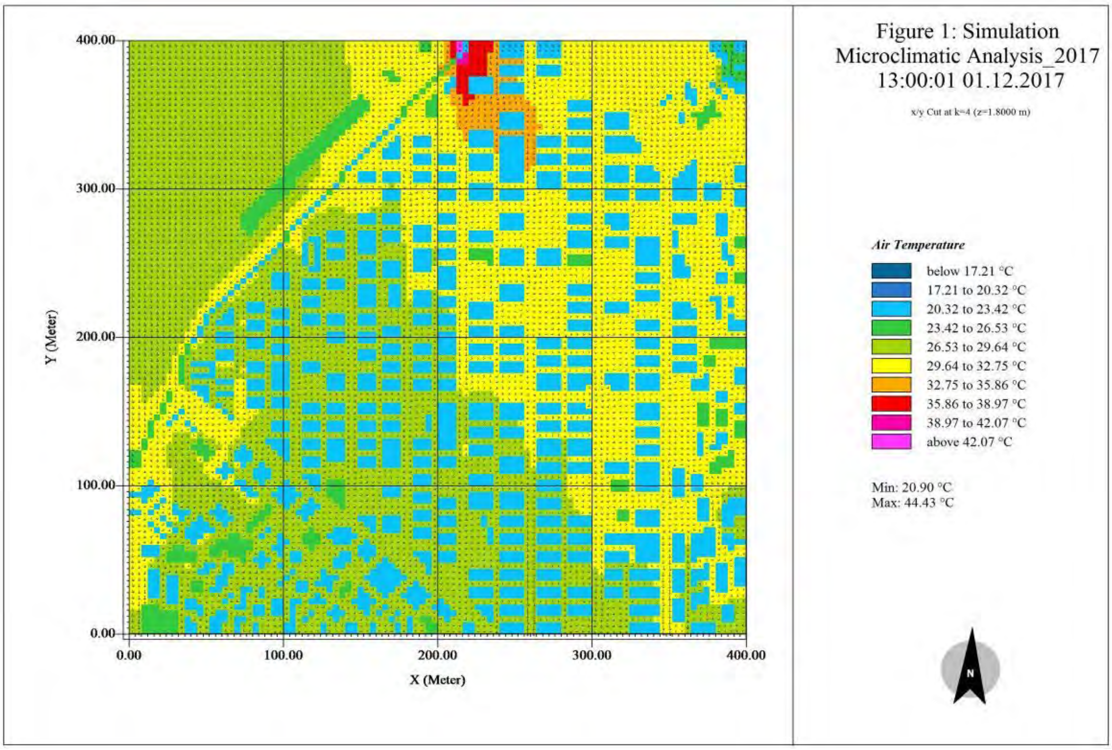

Fig 5.2: Air Temperature, 2017 at 13:00:00.

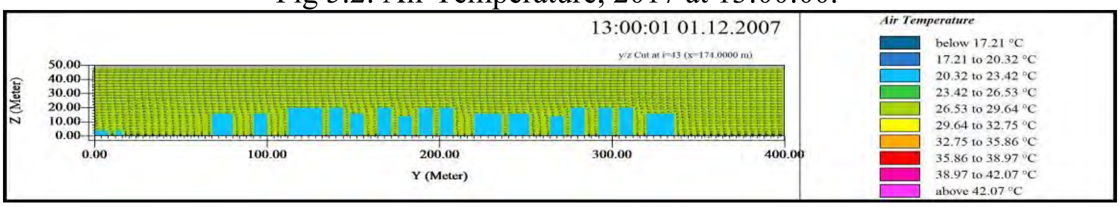

Fig 5.3: Air Temperature, Section y/z Cut at i=43 (x=174m), 2007 at 13:00:00.

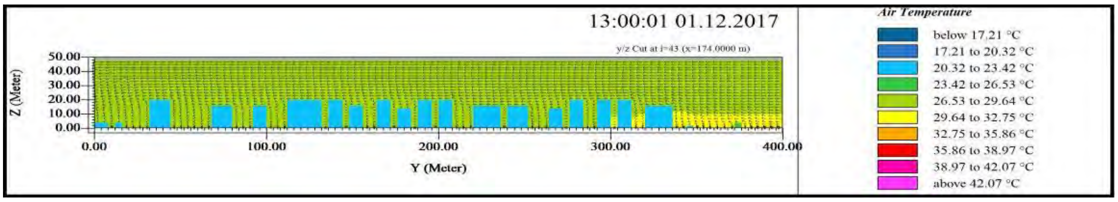

Fig 5.4: Air Temperature, Section y/z Cut at i=43 (x=174m), 2017 at 13:00:00

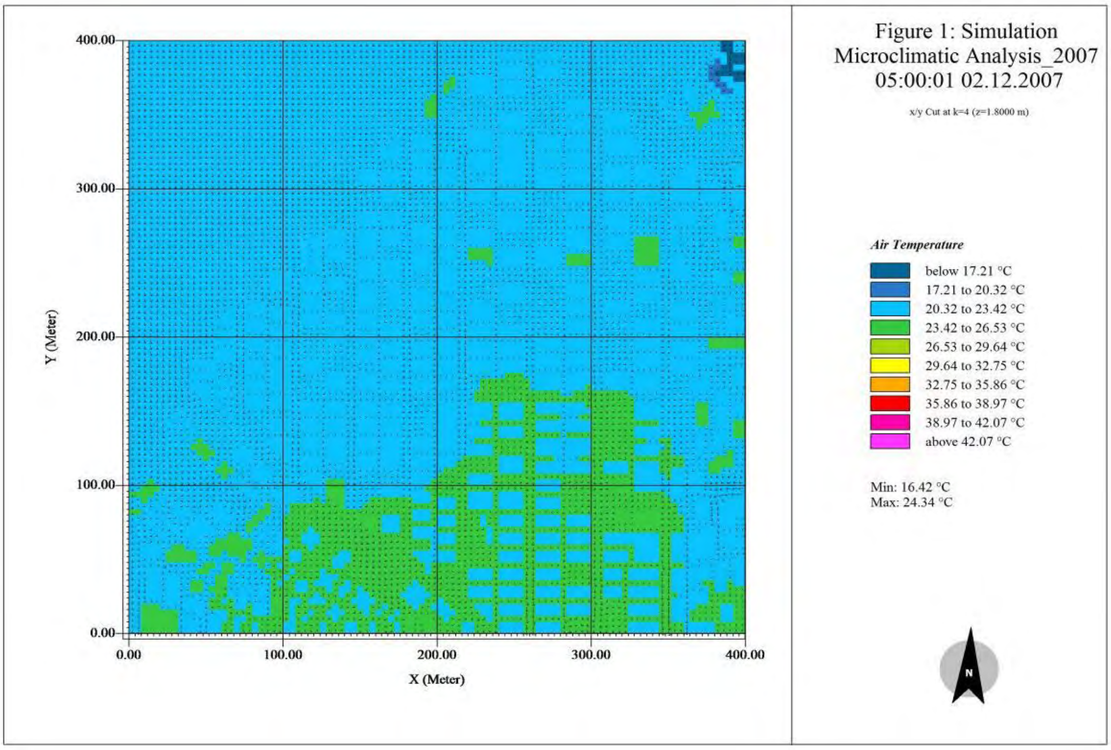

Fig 5.5: Air Temperature, 2007 at 05:00:00.

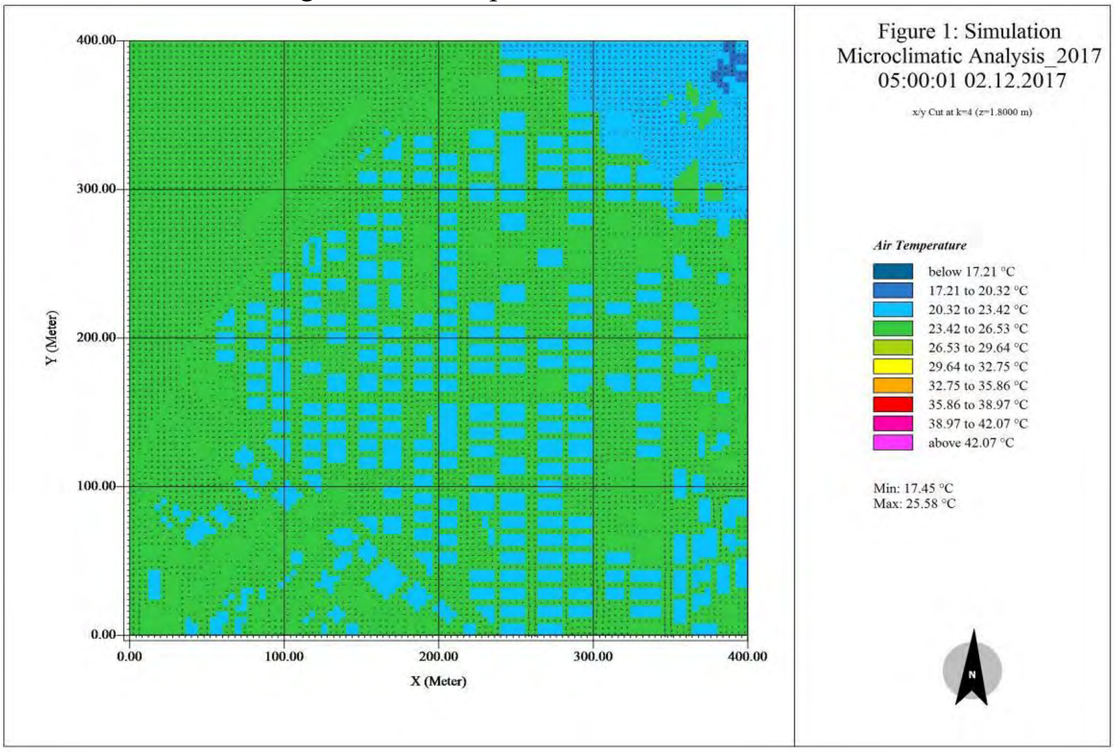

Fig 5.6: Air Temperature, 2017 at 05:00:00.

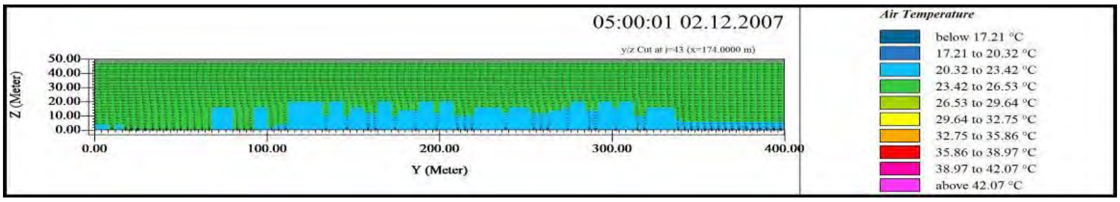

Fig 5.7: Air Temperature, Section y/z Cut at i=43 (x=174m), 2007 at 05:00:00.

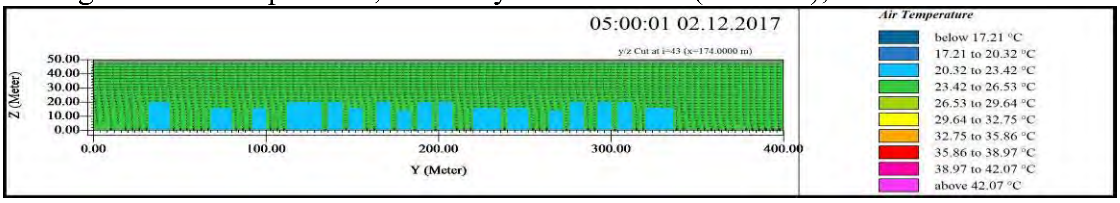

Fig 5.8: Air Temperature, Section y/z Cut at i=43 (x=174m), 2017 at 05:00:00.

The Figures 5.1, 5.2 shows that, the Air Temperature has increased at 13:00:00 around the pavements, roads and overpass near the lake from 2007 to 2017. This phenomenon is clearly observed from the sectional figures 5.3, 5.4 as well as the blow up sectional diagrams 5.9, 5.10 respectively. Again, from the figure 5.5, 5.6 it can be observed that in 2017, the heat that is generated throughout the day remains somewhat constant even at 05.00.00. From sectional figures 5.7, 5.8 and the blow up sectional diagrams 5.11, 5.12 it is observed that the water body and the gaps in-between the buildings had a cooler layer of air in 2007, which it is completely absent in 2017.

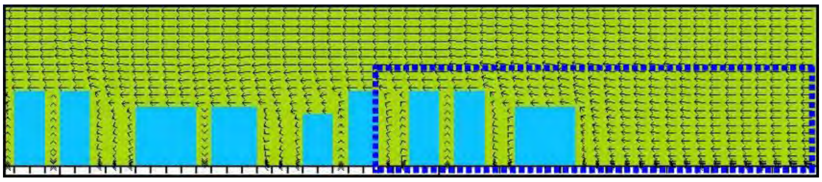

Fig 5.9: Blowup Section showing Minimum Heat Trap, 2007 at 13:00:00.

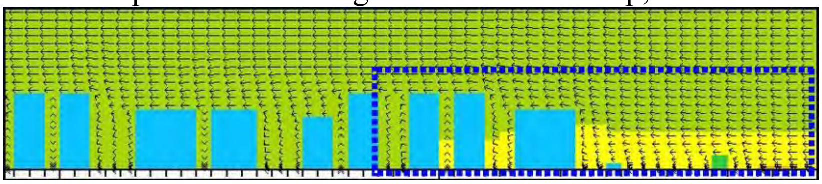

Fig 5.10: Blowup Section showing Maximum Heat Trap, 2017 at 13:00:00.

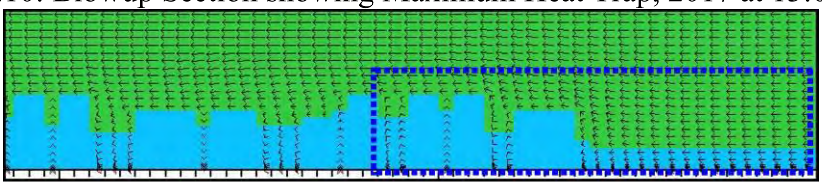

Fig 5.11: Blowup Section showing Maximum Heat Release, 2007 at 05:00:00.

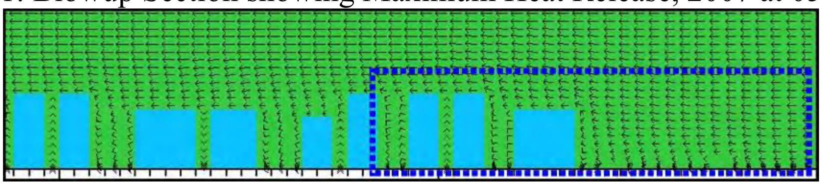

Fig 5.12: Blowup Section showing Minimum Heat Release, 2017 at 05:00:00.

The air temperature has significantly increased since 2007. The roads, pavements, bridges, overpasses etc. gains excess heat and traps it. Since the amount of heat trap is higher than the amount of heat released in the atmosphere, it is observed that the temperature is higher around the day as well as at the night.

Mean Radiant Temperature:

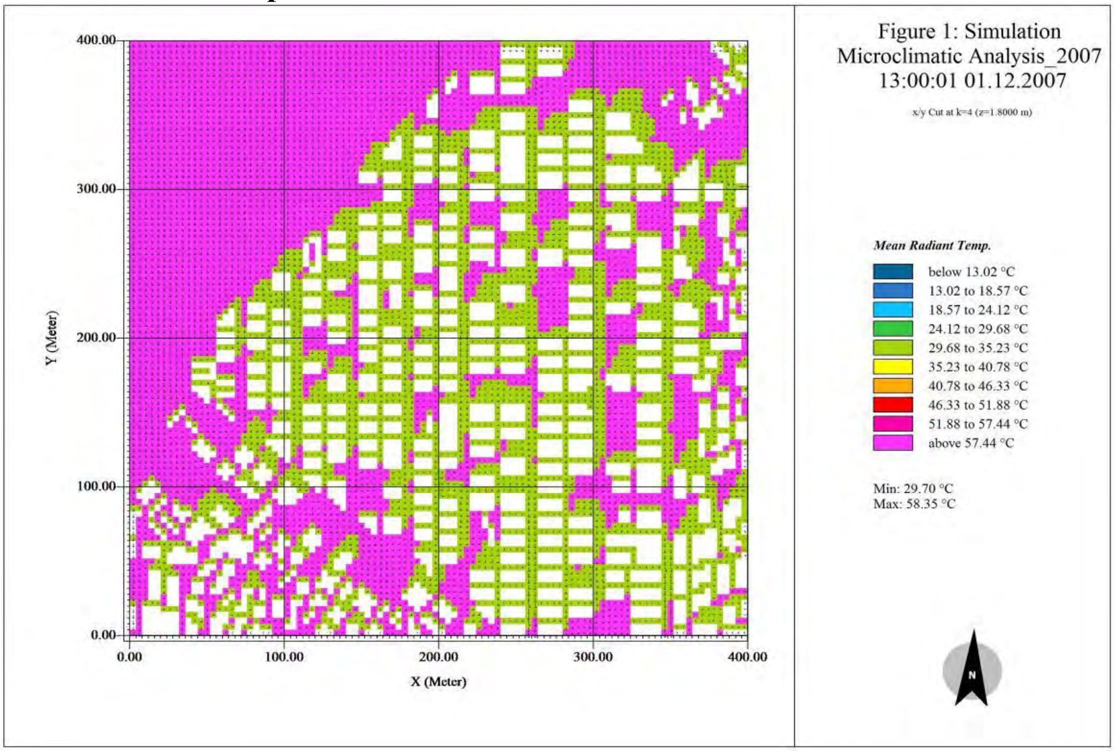

Fig 5.13: MRT, 2007 at 13:00:00.

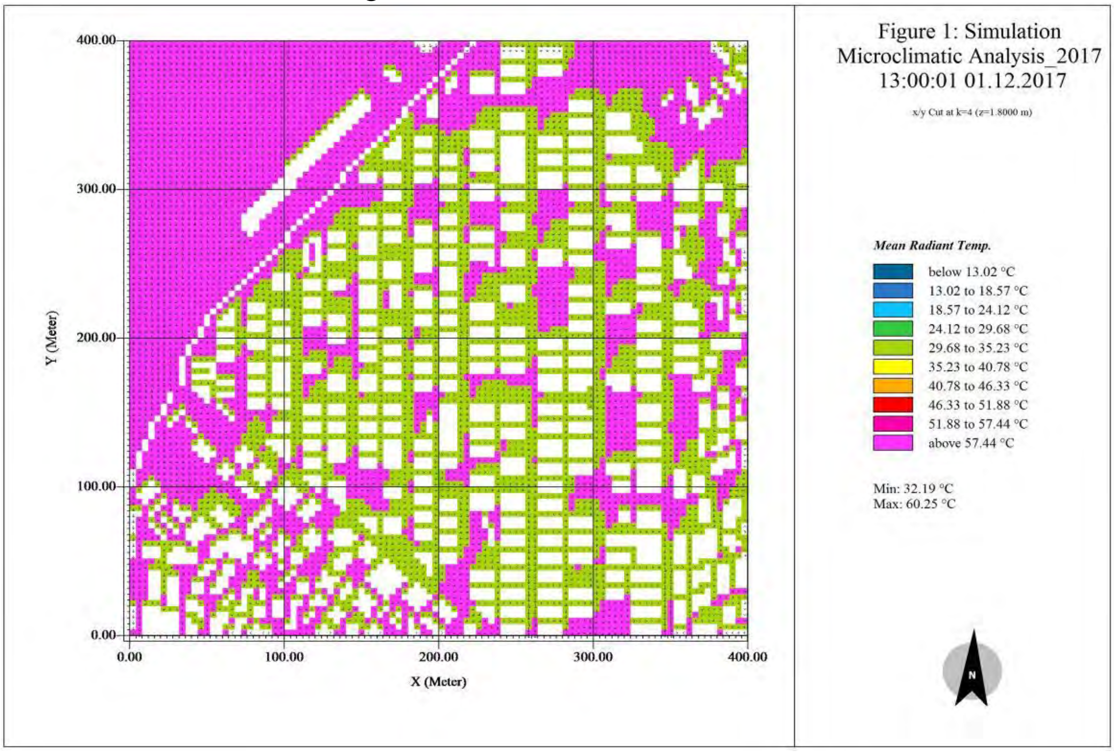

Fig 5.14: MRT, 2017 at 13:00:00.

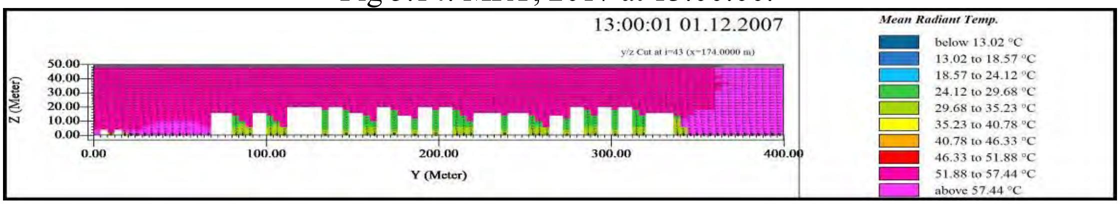

Fig 5.15: MRT, Section y/z Cut at i=43 (x=174m), 2007 at 13:00:00.

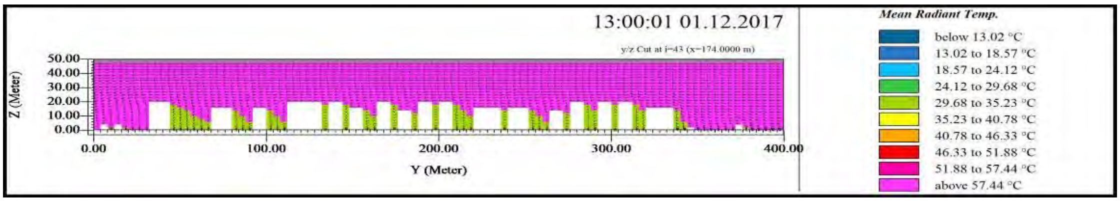

Fig 5.16: MRT, Section y/z Cut at i=43 (x=174m), 2017 at 13:00:00.

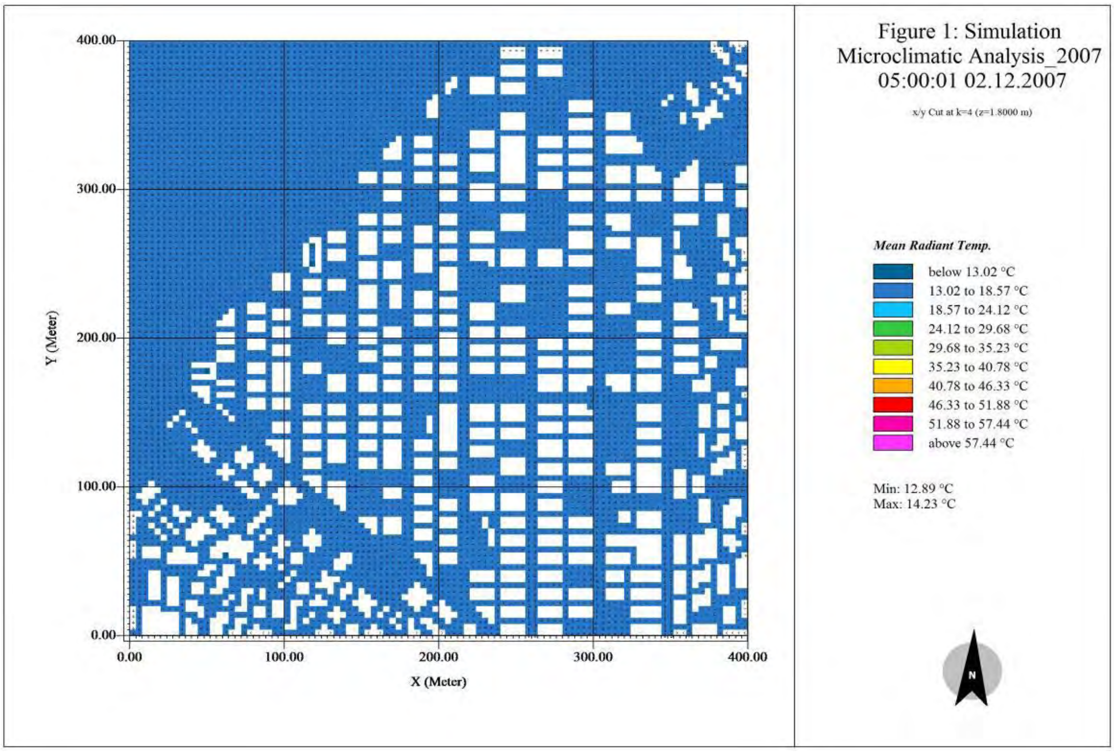

Fig 5.17: MRT, 2007 at 05:00:00.

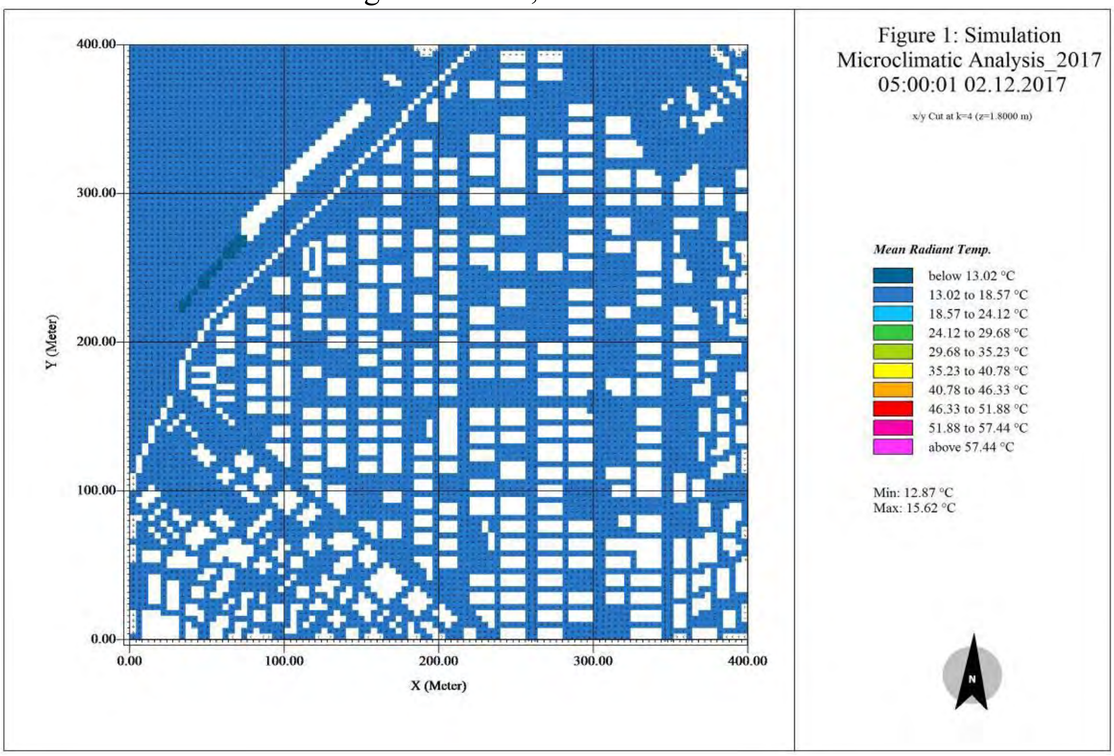

Fig 5.18: MRT, 2017 at 05:00:00.

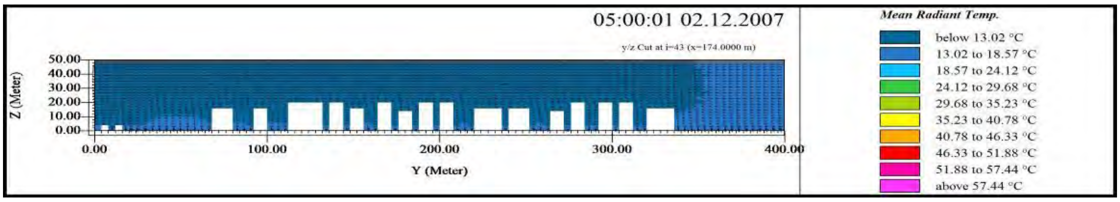

Fig 5.19: MRT, Section y/z Cut at i=43 (x=174m), 2007 at 05:00:00.

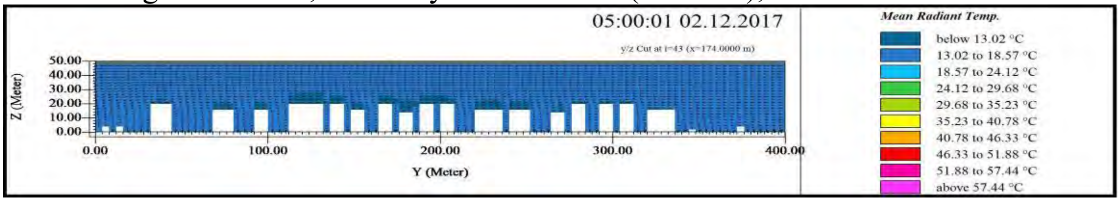

Fig 5.20: MRT, Section y/z Cut at i=43 (x=174m), 2017 at 05:00:00.

The Figures 5.13, 5.14 shows that, at 13:00:00 the MRT has increased from 2007 to 2017. From sectional Figures and blow up sectional diagrams 5.15, 5.16, 5.21 and 5.22, it is observed that at 2007, there was a layer of cooler temperature above and in-between the buildings, which is absent in 2017. Again, from the figures 5.17, 5.18 it is observed that at 13:00:00, the MRT has increased from 2007 to 2017 even at 05:00:00. From the sectional Figures and blow up sectional diagrams 5.19, 5.20, 5.23 and 5.24, it is observed that in 2007, there was a layer of low MRT value above the buildings and the water body. However, in 2017, this low MRT value layer turns to a layer of high MRT value.

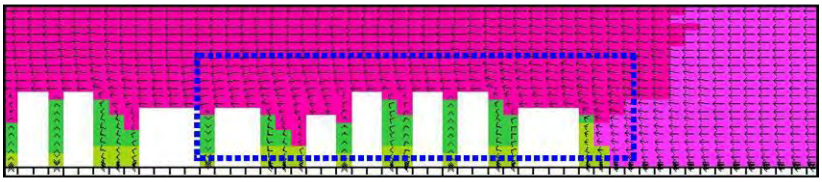

Fig 5.21: Blowup Section showing Low MRT, 2007 at 13:00:00.

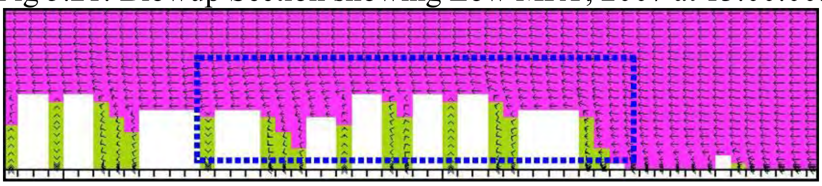

Fig 5.22: Blowup Section showing High MRT, 2017 at 13:00:00.

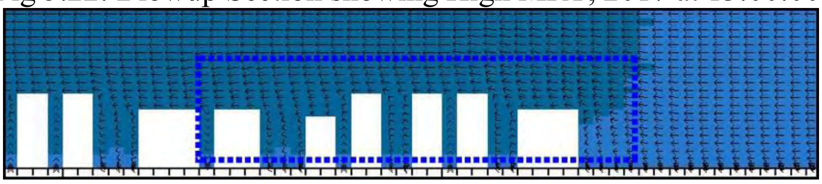

Fig 5.23: Blowup Section showing High MRT Release, 2007 at 05:00:00.

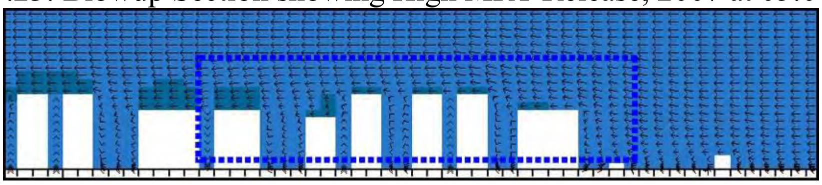

Fig 5.24: Blowup Section showing Low MRT Release, 2017 at 05:00:00.

Mean Radiant Temperature has gone up since 2007. The roads, pavements, bridges, overpass etc. gains excess heat along with minimal gap in-between buildings contribute to the high Mean Radiant Temperature value in 2017.

Relative Humidity:

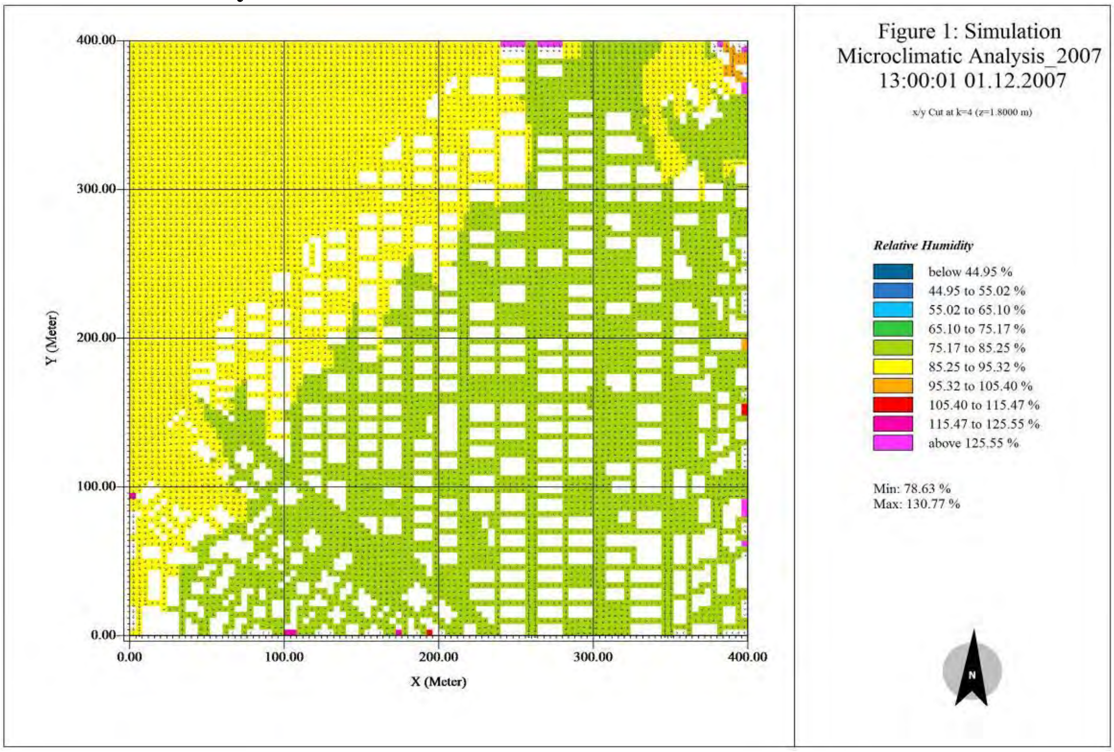

Fig 5.25: RH, 2007 at 13:00:00.

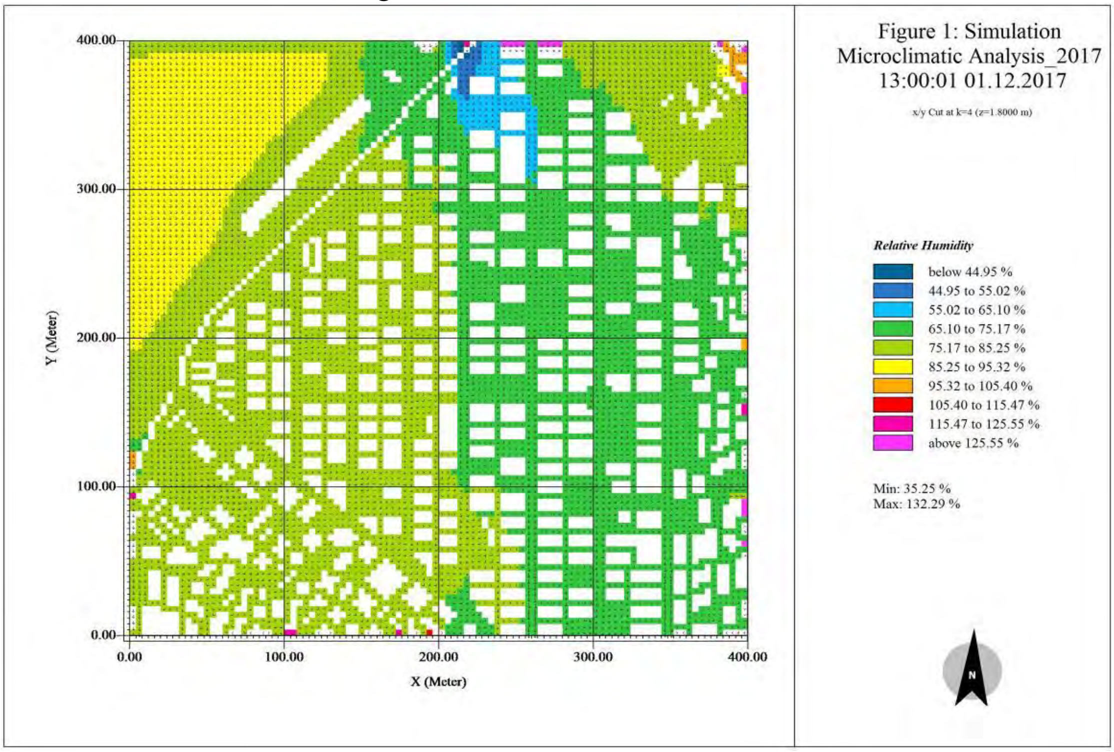

Fig 5.26: RH, 2017 at 13:00:00.

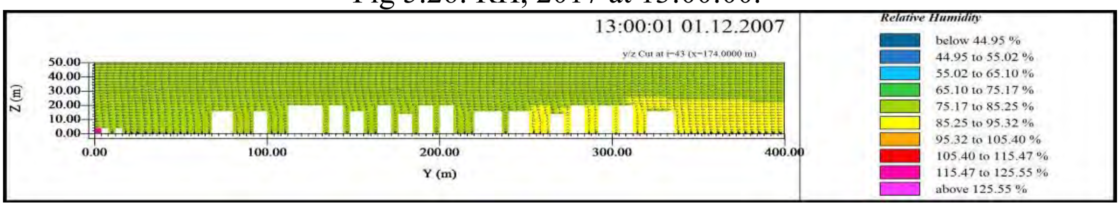

Fig 5.27: RH, Section y/z Cut at i=43 (x=174m), 2007 at 13:00:00.

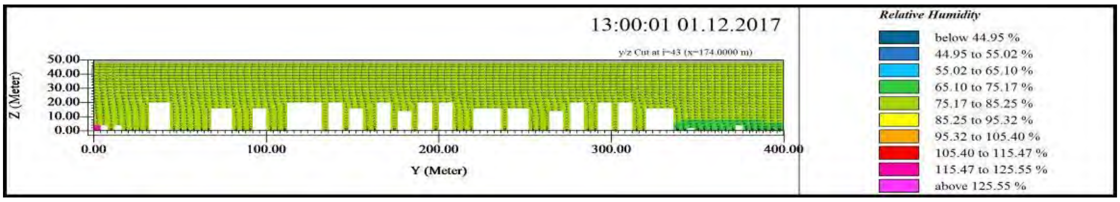

Fig 5.28: RH, Section y/z Cut at i=43 (x=174m), 2017 at 13:00:00.

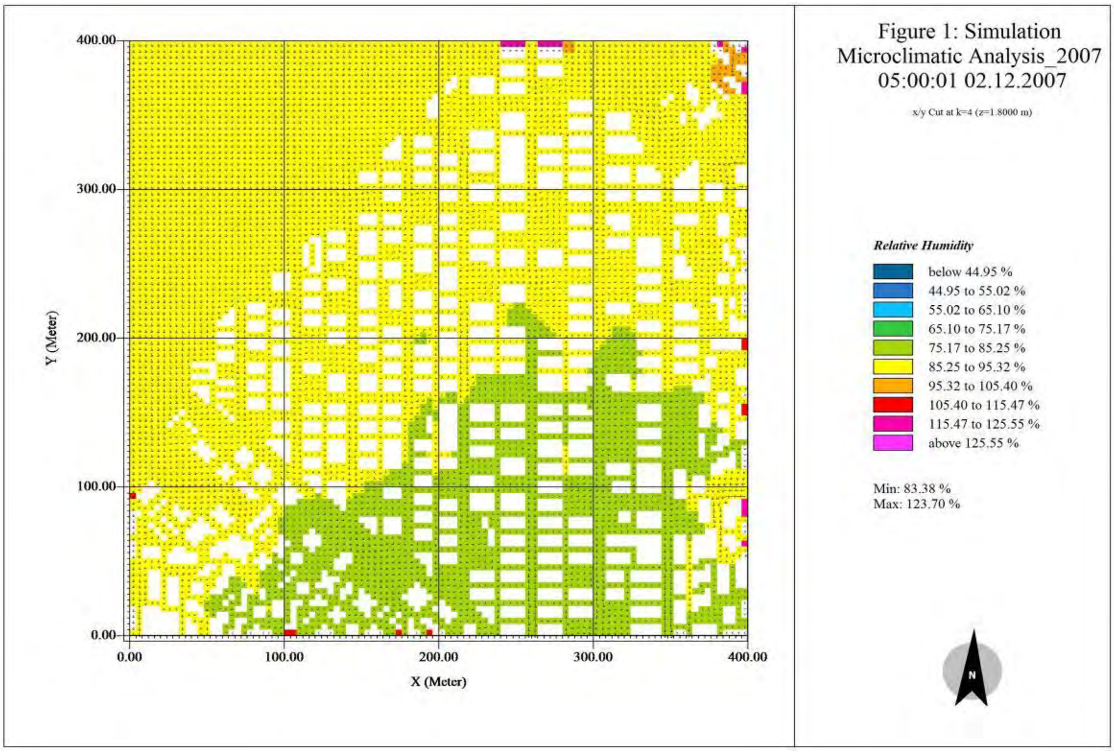

Fig 5.29: RH, 2007 at 05:00:00.

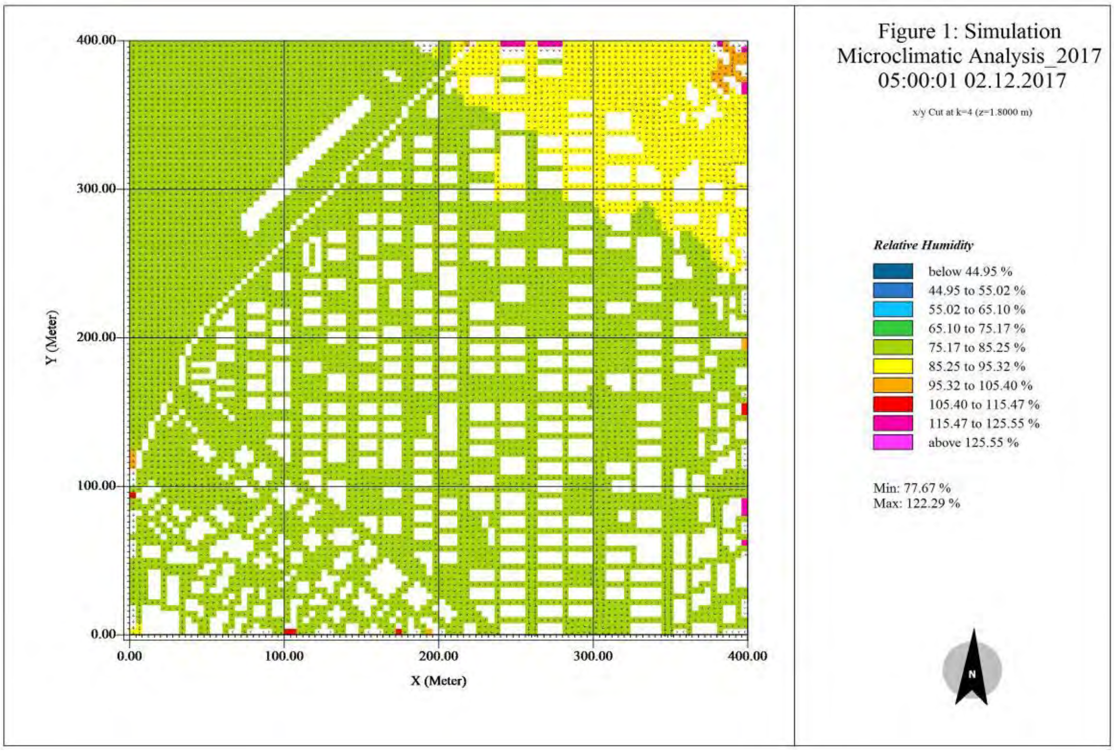

Fig 5.30: RH, 2017 at 05:00:00.

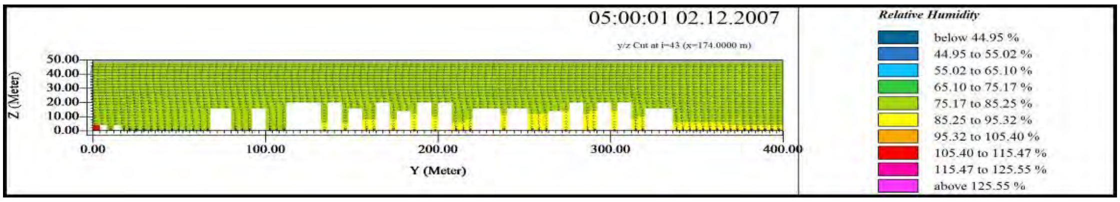

Fig 5.31: RH, Section y/z Cut at i=43 (x=174m), 2007 at 05:00:00.

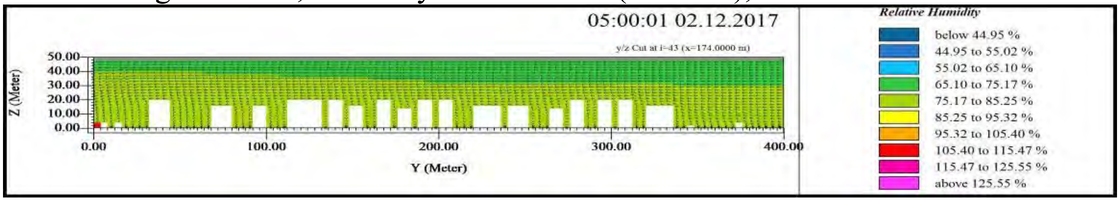

Fig 5.32: RH, Section y/z Cut at i=43 (x=174m), 2017 at 05:00:00.

From Figures 5.25, 5.26, sectional Figures 5.27, 5.28 and blow up sectional diagrams 5.33, 5.34 it is observed that at 13:00:00, the RH has decreased from 2007 to 2017. It is apparent that in 2007, there was a rich layer of humidity above the water body and generous portion of it was in-between the buildings of the Mohanagar Housing. Again, figures 5.29, 5.30, sectional Figures 5.31, 5.32 and blow up sectional diagrams 5.35, 5.36 shows that, the RH is decreased at 05:00:00. It is clear that there was a layer of Relative Humidity in-between the buildings and a uniform layer above the whole-domain, which in 2017 is not the case.

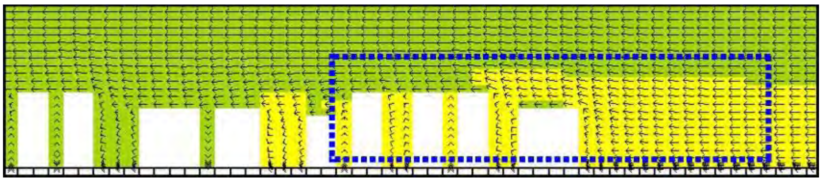

Fig 5.33: Blowup Section showing High Humidity Presence, 2007 at 13:00:00.

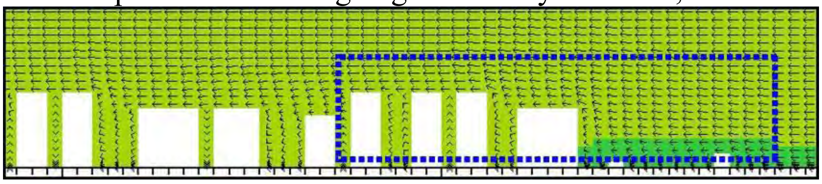

Fig 5.34: Blowup Section showing Low Humidity Presence, 2017 at 13:00:00.

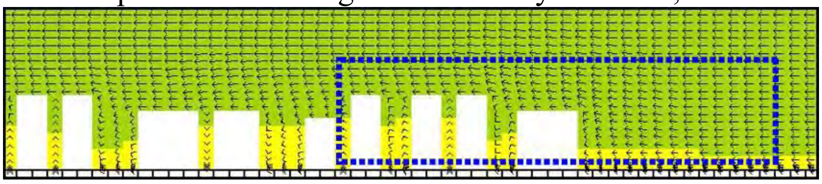

Fig 5.35: Blowup Section showing High Advection of Humidity, 2007 at 05:00:00.

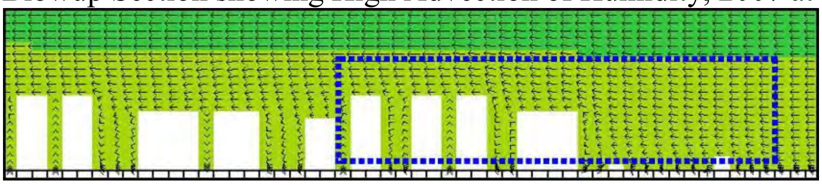

Fig 5.36: Blowup Section showing Low Advection of Humidity, 2017 at 05:00:00.

The Relative Humidity is dramatically lowered due to excessive heat gain of the research area and active inversion layer on the water body of the Hatirjheel Lake. In addition to, the newly erected wall and overpass which are close to the water body created a barrier in between the water body and the housing area, which obstructs the advection of humidity.

Wind Speed:

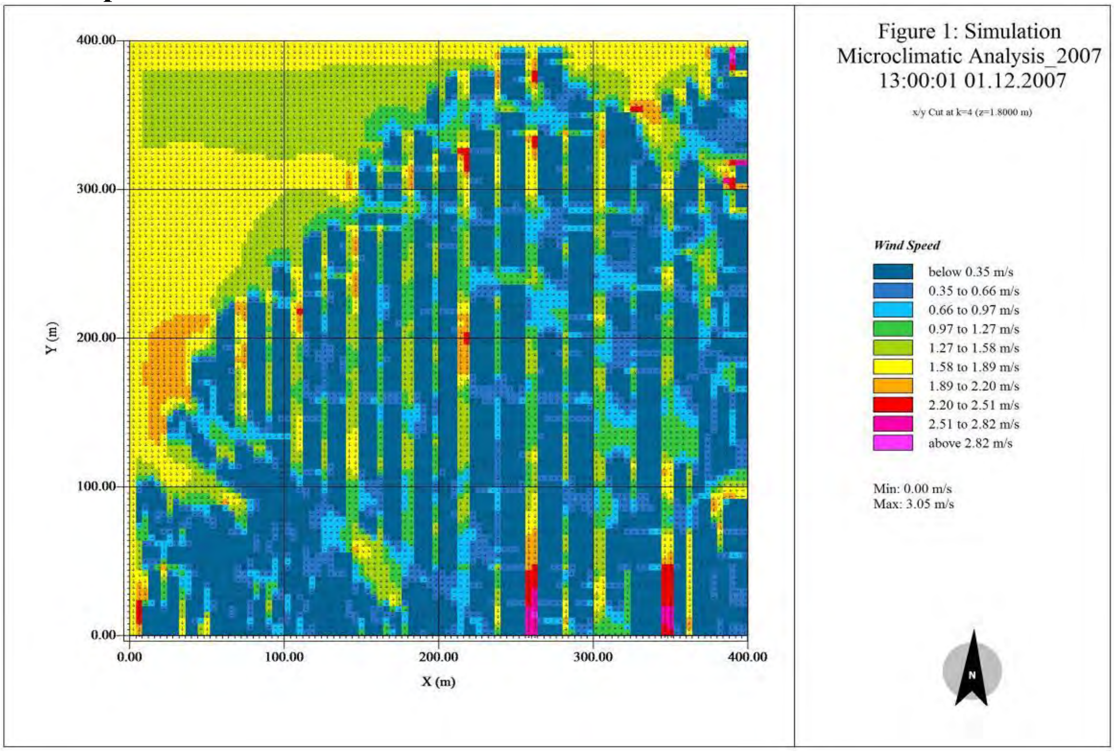

Fig 5.37: WS, 2007 at 13:00:00.

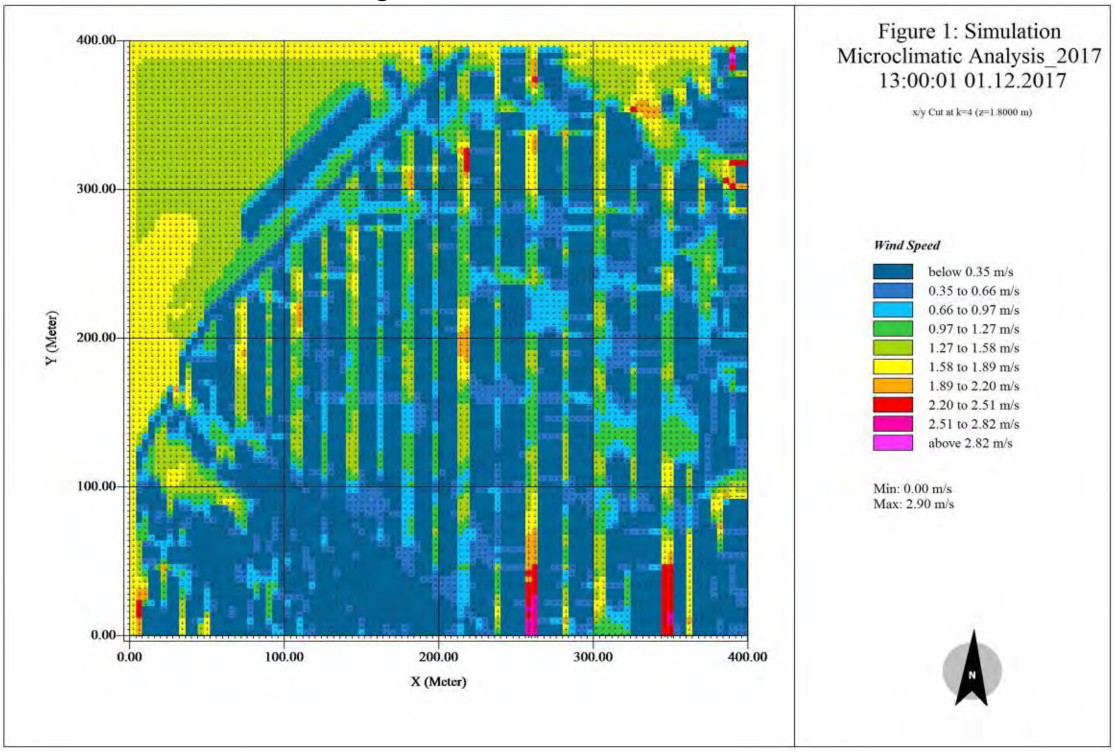

Fig 5.38: WS, 2017 at 13:00:00.

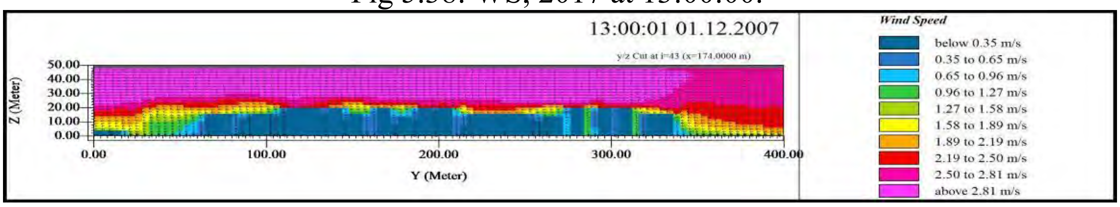

Fig 5.39: WS, Section y/z Cut at i=43 (x=174m), 2007 at 13:00:00.

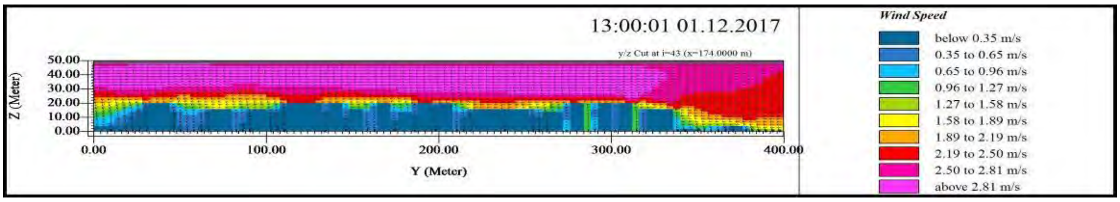

Fig 5.40: WS, Section y/z Cut at i=43 (x=174m), 2017 at 13:00:00.

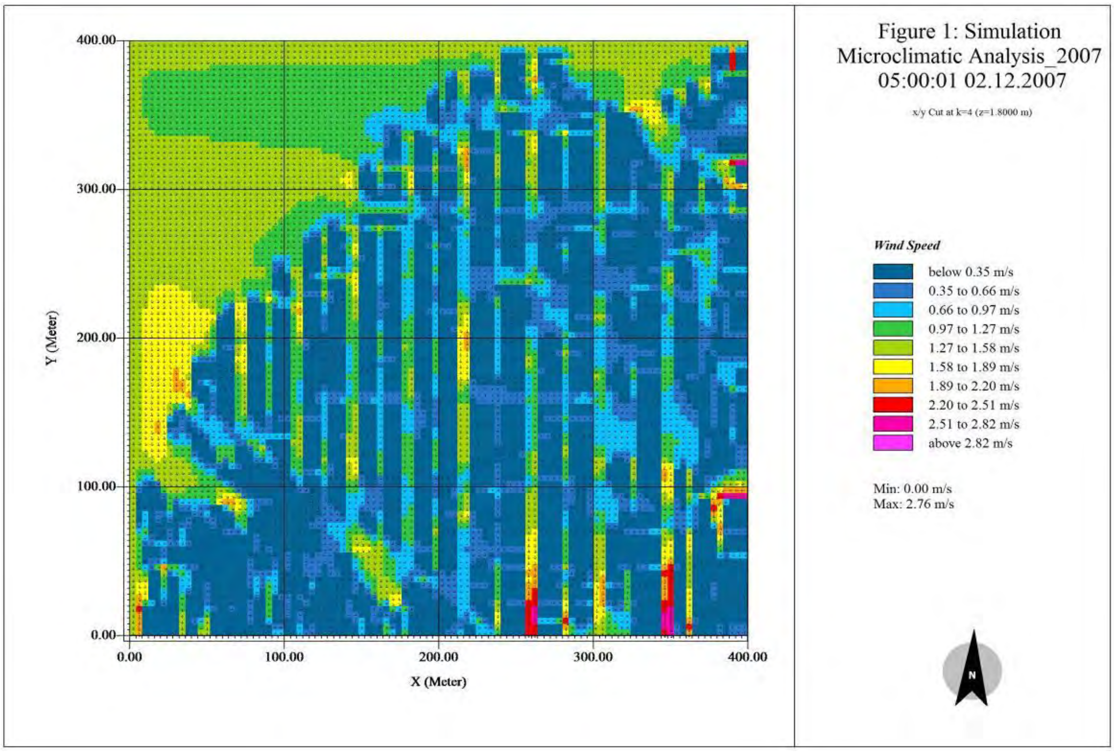

Fig 5.41: WS, 2007 at 05:00:00.

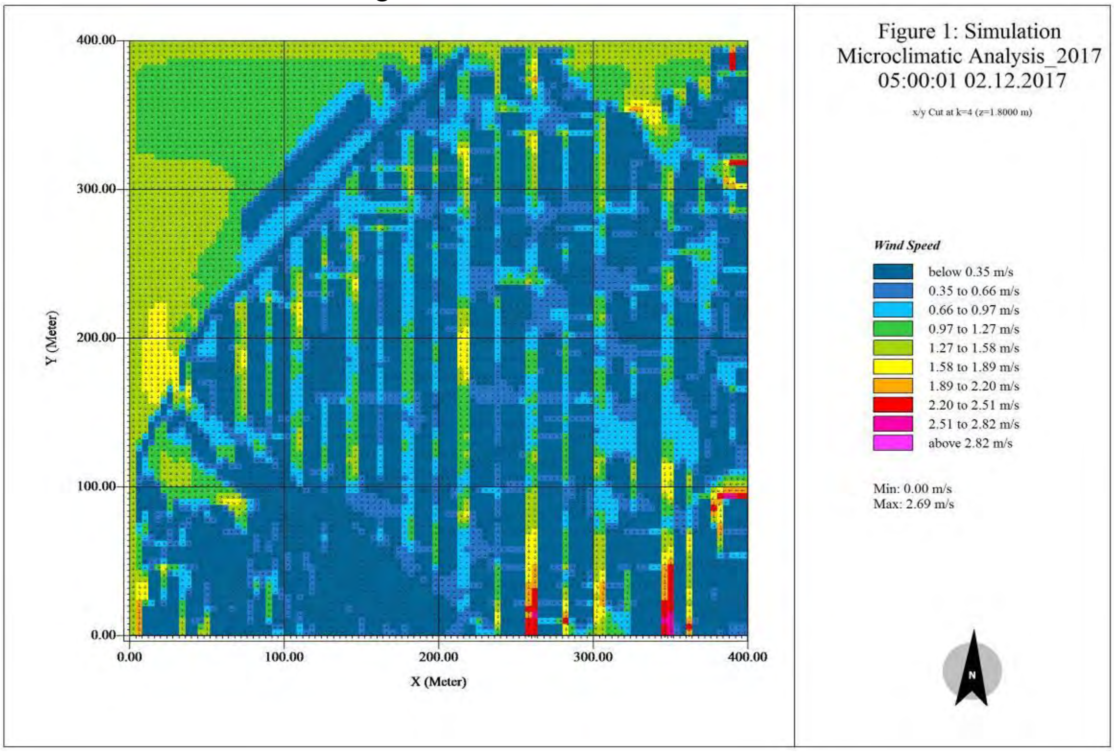

Fig 5.42: WS, 2017 at 05:00:00.

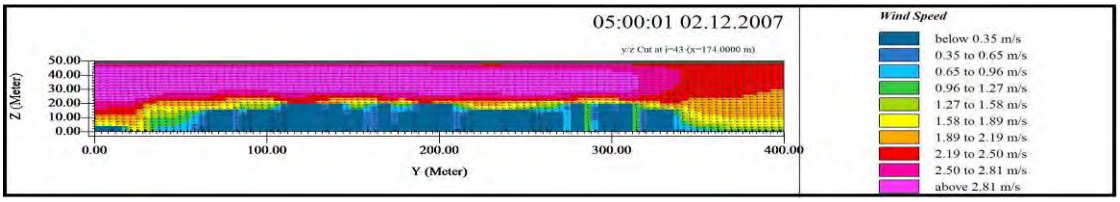

Fig 5.43: WS, Section y/z Cut at i=43 (x=174m), 2007 at 05:00:00.

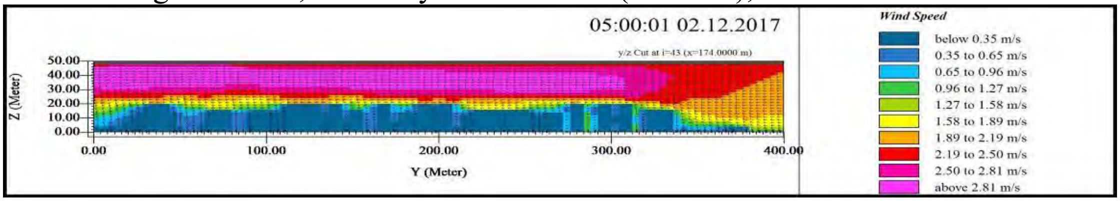

Fig 5.44: WS, Section y/z Cut at i=43 (x=174m), 2017 at 05:00:00.

The figures 5.37, 5.38, sectional Figures 5.39, 5.40 and blow up sectional diagrams 5.45, 5.46 shows that, at 13:00:00, the change of wind speed in-between 2007 to 2017 is minimal among the Mohanagar Housing area, except for on top of the Hatirjheel Lake and that in 2007, there was a strong flow of wind, which is plummeted and altered its direction in 2017. The figures 5.41, 5.42, sectional Figures 5.43, 5.44 and blow up sectional diagrams 5.47, 5.48 represents similar scenario from 13:00:00.

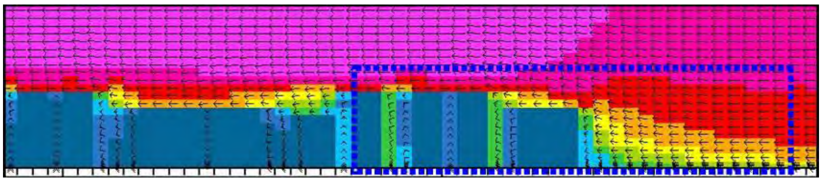

Fig 5.45: Blowup Section showing Continuous Wind Flow, 2007 at 13:00:00.

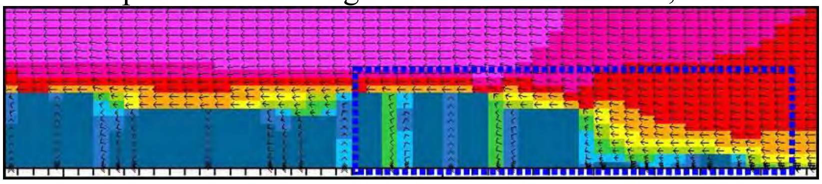

Fig 5.46: Blowup Section showing Change in Wind Direction, 2017 at 13:00:00.

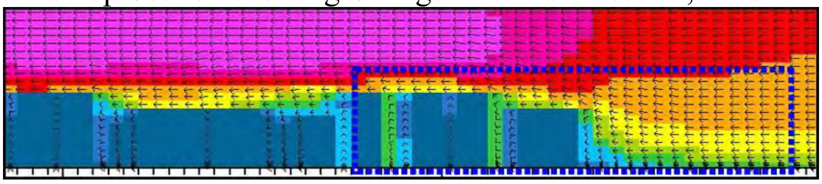

Fig 5.47: Blowup Section showing Continuous Wind Flow, 2007 at 05:00:00.

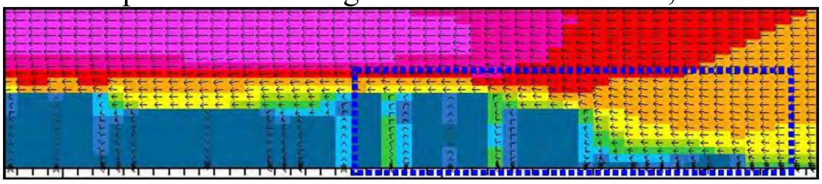

Fig 5.48: Blowup Section showing Change in Wind Direction, 2017 at 05:00:00.

It is seen that, the wall and the earth-filled seamless overpass acts as possible barrier which is obstructing the air flow while altering the flow direction.

5.2.2. Observations on energy consumption:

The previously processed data in chapter 4 (4.4) of 2007 and 2017 were utilized to calculate the change of energy consumption in percentage.

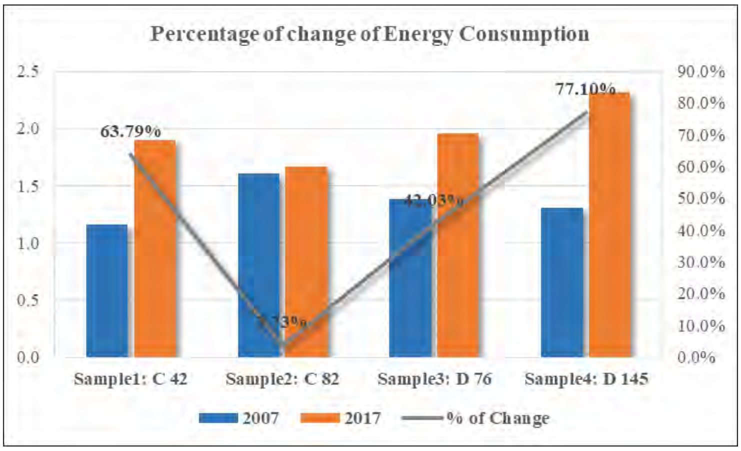

Fig 5.49: Percentage of Change of Energy Consumption.

From the figure 5.49, it is observed that sample 2 (C 82) has the lowest energy consumption change in percentage considering 2007 and 2017, whereas sample 4 (D 145) has the highest.

5.2.3. Observations on urban morphology:

The previously processed data in chapter 4 (4.3) of 2007 and 2017 were utilized to calculate the change of morphological parameters in percentage.

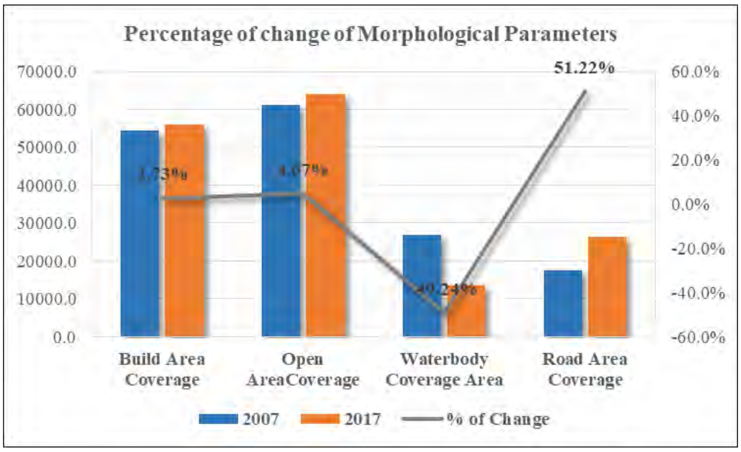

Fig 5.50: Percentage of Change of Morphological Parameters.

From the figure 5.50, it may be concluded that the major changes in morphological parameters of the selected domain are in road area coverage and water body area coverage which are 51.22% and 49.24%, approximately half of 2007 for water body and double increment for road area. Since they are a part of the total domain, these parameters effects the micro-domains as well, even though the micro-domains themselves remains unchanged.

5.3. Influence of Micro-climatic Parameters on Energy consumption:

All the micro-climatic parameters individually show relationship with energy consumption. But these micro-climatic parameters have impact on each other. For example, the MRT value increases due to direct solar radiation, which elevates the urban temperature; again, the lower relative humidity and higher temperature create upward movement of hot wind. Urban microclimate is the collective result of all the micro-climatic parameters. So it is difficult to find the individual impact. (Tuli, 2015). Hence, the best possible way to determine their combined influence on thermal comfort, the micro-climatic parameters are to be converted to PMV. Then the change of PMV value can be relate with that of energy consumption change.

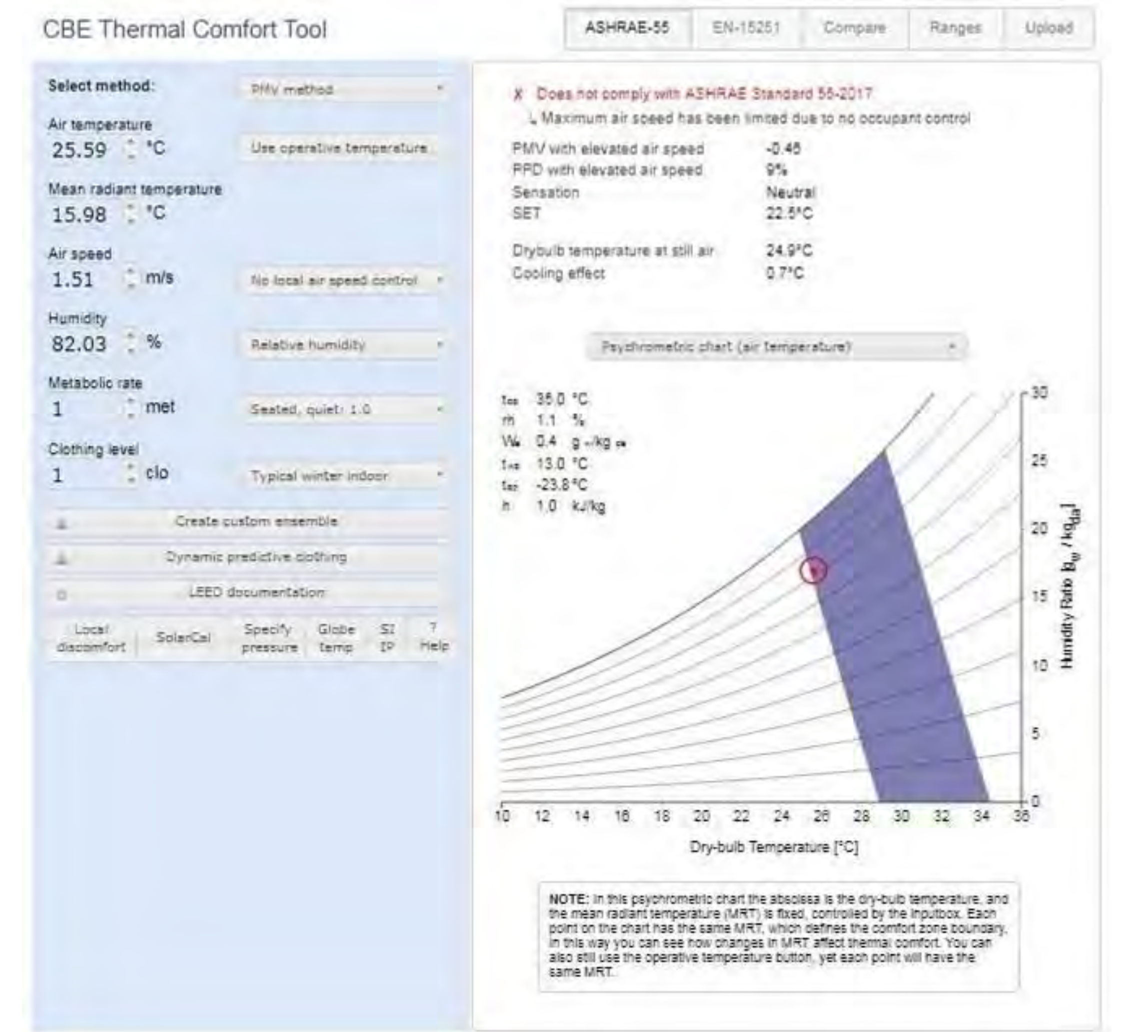

Fig 5.51: Measuring PMV by CBE Thermal Comfort Tool
(Center for the Built Environment, University of California, Berkeley).

All the considered micro-climatic outputs are converted into PMV by CBE Thermal Comfort Tool (Figure 5.51). Six type of data have been needed to use this tool; Air Temperature, Mean Radiant Temperature, Relative Humidity, Wind speed, Metabolic rate and Clothing. The Metabolic rate 1.0 met (for seated) and Clothing (typical winter indoor clothing) 0.5 clo have been considered for calculating the PMV values. Here the other four micro-climatic parameters, Air Temperature, Mean Radiant Temperature, Relative Humidity and Wind Speed, found from micro-climatic simulations, have been plotted to the respective places in the left part of the tool find the PMV value. In the right part, there shows the PMV value with psychometric chart.

When the micro-climatic parameters of 2007 and 2017 are given as an input in CBE Thermal Comfort Tool, the PMV of both times are obtained. From the obtained PMV, the change of PMV in percentage is derived. Furthermore, along with PMV, the change of sensation is also deduced.

Table 5.1: Calculation of PMV Change at 13:00:00 and 05:00:00.

Sample	13:00:00		Change of PMV (%)	05:00:00		Change of PMV (%)
	PMV in 2007	PMV in 2017		PMV in 2007	PMV in 2017	
Sample 1: C 42	0.90 (Slightly Warm)	1.59 (Warm)	76.67 %	-1.07 (Slightly Cool)	-0.61 (Slightly Cool)	-42.99 %
Sample 2: C 82	5.54 (Hot)	2.46 (Warm)	-55.60 %	-0.85 (Slightly Cool)	-0.44 (Neutral)	-48.24 %
Sample 3: D 76	2.46 (Warm)	3.56 (Hot)	44.72 %	-1.26 (Slightly Cool)	-0.80 (Slightly Cool)	-36.51 %
Sample 4: D 145	2.53 (Hot)	3.09 (Hot)	22.13 %	-1.24 (Slightly Cool)	-0.71 (Slightly Cool)	-42.74 %

Table 5.1 shows, at 5:00:00, all the samples shared similar sensual alterations. In each case, the sensation went from cold towards warm. On the other hand, at day, 13:00:00, it is observed that the sensation shifts from cold towards warm for three samples (sample 1, C42; sample 3, D76; sample 4, D145), whereas, it stays within cold range for the remaining sample (sample 2, C 82).

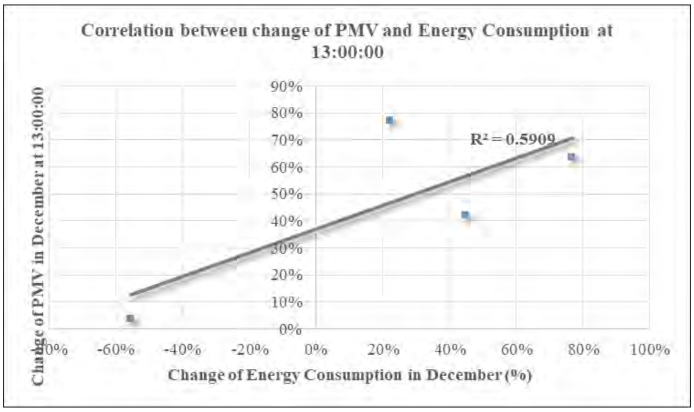

Fig 5.52: Correlation Between Change of PMV and Energy Consumption at 13:00:00.

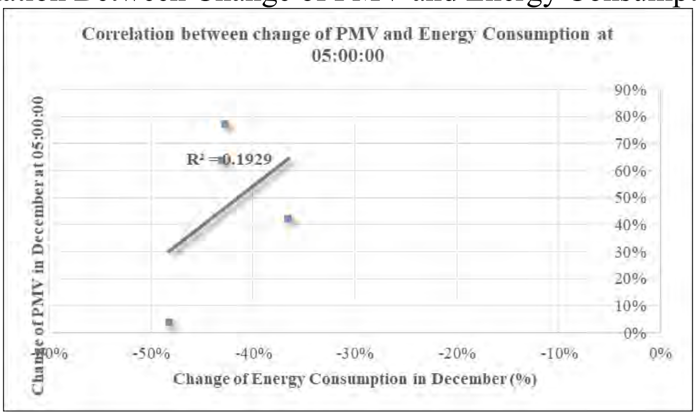

Fig 5.53: Correlation Between Change of PMV and Energy Consumption at 05:00:00.

When the changed PMV of all the samples (chapter 5.3) and the changed energy consumption of all the samples (chapter 5.2.2) of the said times are correlated, above graph is obtained. From figure 5.52, the correlational graph shows that the linear trend is positive, and the value of R^2 is 0.5909. This indicates towards a high relation in-between the given variables. In figure 5.53, the graph shows relatively lower relation in the linear trend line, with a value of R^2 of 0.1929.

These two graph shows a positive trend line with energy consumption. So, the microclimate and thermal comfort have influence on energy consumption.

5.4. Influence of Urban Morphology on Micro-climatic Parameters:

From the observation on micro-climatic parameters, Figure 5.1 to 5.48, it is clear that, the following micro-climatic changes takes place:

1. Increase of Air Temperature and Mean Radiant Temperature.
2. Decrease of Relative Humidity and Wind speed.

On the other hand, from the observation on morphological parameters (Figure 5.50), it is understood that, built area, open area and road area coverage is increased 2.73%, 4.67% and 51.22% respectively. And, water body coverage area is decreased 49.24%.

Table 5.2: Relationship Between Changes of Urban Morphology and Changes of Micro-climatic Parameters

			Morphological Parameters			
			Build area changed	Open area changed	Water body area changed	Road area changed
Micro-climatic Parameters	T [^{0}C]	↗	↗	↗	↘	↗
	MRT [^{0}C]	↗	↗	↗	↘	↗
	RH [%]	↘	↗	↗	↘	↗
	WS [m/s]	↘	↗	↗	↘	↗
Here, ↗ increase, ↘ decrease.						

From the discussion, a chart has been produced above for the detail and comparative analysis. From the table 5.2 it is found that,

1. Increase of Temperature and Mean Radiant Temperature is much related to increase of built area, open area and road coverage area.
2. Decrease of Relative Humidity and wind speed is only related to decrease of water body coverage area.

From the findings, it is clear that, there is an influence of morphological change on the micro-climatic change.

5.5. Micro-domain Analysis:

Micro-domain is a part of the selected whole-domain. Therefore, even if the morphology of micro-domain does not change itself, the effect of the total selected domain will affect the micro-domain, and vice-versa. For this reason, the morphological parameters of the micro-domain may be considered as to see how the morphological change of whole-domain is affecting them, and how they are responding in return.

Table 5.3: Change of Morphology and Energy Consumption in Different Samples.

Sample	Build Area Percentage (%)	Open Space Percentage (%)	Road Area Percentage (%)	Change of Energy Consumption (%)
Sample 1: C 42	34.89%	25.44%	39.67%	63.79%
Sample 2: C 82	24.53%	54.16%	21.30%	3.73%
Sample 3: D 76	43.01%	50.15%	6.84%	42.03%
Sample 4: D 145	65.77%	28.91%	5.32%	77.10%

Table 5.3 Shows that, the build area is the highest in sample 4 (D 145), whereas is the lowest in sample 2 (C 82). The open area is highest and lowest respectively in sample 2 (C 82) and 1 (C 42). Sample 3 and 4 has approximately similar road area coverage (6.84% and 5.32% respectively) and are lower compared to the other two samples. With the passage of time, the highest energy consumption change is in sample 4 (D 145) and the lowest is in sample 2 (C 82).

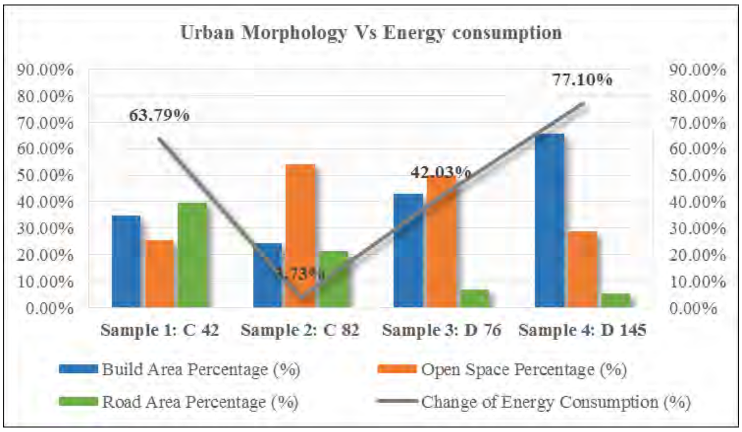

Fig 5.54: Change of Morphology and Energy Consumption in Different Samples.

In figure 5.54, a relation is deduced among the samples and their micro-domains, with that of their morphological parameters and energy consumption. It was found earlier that the energy consumption is closely related with that of the feeling of sensation. Therefore, analyzing the morphological parameters of the micro-domain and the energy consumption of the selected samples would yield the effect and reaction of the change of total morphological parameters.

It is observed from the figure 5.54 that with passage of time, that is from 2007 to 2017, even though the morphology of the selected domain is changed (50% increment of road area and 50% decrease of water body), because the build area is less and open area is more in sample 2 (C 82), the rate of change of energy consumption is the lowest. This is because the open area helps is quick temperature release and free air circulation. Whereas in sample 4 (D 145), the build area is highest and the open area is the lowest, and as a result, the rate of change of energy consumption is the highest.

From the previous discussions, it is clear that the change of morphology exerts an active influence on the energy consumption of that area, since the morphological changes are the major reason for influencing the temperature. And along with the rise of temperature, the energy consumption also rises proportionally. Although, the increment of energy consumption in respect to that of temperature growth may vary from place to place, which is prominent for this research area.

Table 5.4: Relation between changed Temperature and Energy Consumption.

Sample	T [^{0}C] 2007	T [^{0}C] 2017	T [^{0}C] Increment	Average T [^{0}C] Increment	Energy Consumption Increment [%]	Average energy consumption Increment [%]
C 42	27.41	29.86	2.45	2.64^0	63.79	46.66%
C 82	27.58	29.22	1.64		3.73	
D 76	27.70	32.07	4.37		42.03	
D 145	27.35	29.46	2.11		77.10	

From table 5.4, it is observed that, for both 2007 and 2017, at same date and time, 13:00:00 (since the highest recorded temperature is at this time) the average temperature change is 2.68°C, and the average change in energy consumption is 46.66%. This means, for this research area, with the change of 1°C in temperature, the rate of change of energy consumption is 17.67%. And this change is solely due to the morphological changes of this area.

5.6. Findings:

1. There is an obvious influence of changed microclimate on changed energy consumption. Again, the change of microclimate is influenced by the change of morphology. So, it can be said that, the urban morphology of an area have an influence on microclimate and domestic energy consumption of said area. Micro-domain analysis shows that, for this research area, with the change of 1°C in temperature due to the morphological changes, the rate of change of energy consumption is 17.67%.

2. After the morphological change (road area increment 50%, water body area decrement 50%), the Air Temperature and Mean Radiant Temperature is significantly increased and the Relative Humidity and wind speed is decreased. The Air Temperature increases and the RH is dramatically lowered due to the excessive heat gain at day and inadequate heat release at night from the pavements, roads and overpass near the Hatirjheel Lake. The malfunction of advection of humidity and inversion layer effect also plays a major role in this scenario throughout the day and night alike. Additionally newly erected non porous wall and overpass too close to the water body created a barrier in between the water body (Hatirjheel Lake) and the residential (Mohanagar Housing) area, which obstructs the advection of humidity and wind flow.

3. Micro-domain may resist any negative impact of morphological change to a certain degree. The open area and the built area largely contributes to the change of micro-domain attributes.

5.7. Probable Design Concepts:

Micro-domain design concepts:

The Mohanagar Housing is a planned residential area, where most of the plots are complete with buildings. Hence, this area cannot be considered as an area with abundant empty plots. Therefore, probable micro-domain design concepts for this area should be considering the present buildings, while keeping the future constructions in mind.

- Regulatory compliance of setback and Floor Area Ratio (FAR) must be maintained. It will ensure increased open area and decreased build area. Open area of a building contributes in urban heat release and reduction of MRT respectively.
- The materials and colors selected for construction should be that which are low heat absorbing materials and colors. Increasing low heat absorbing properties, building contributes in urban heat release and reduction of MRT.
- The existing buildings should be recolored with such colors which reflects solar radiation, and has low heat absorption characteristics.
- Vegetation should be introduced as much as possible within the present setback.

Urban design concepts:
The morphological parameters which were considered in this thesis were all individually effected due to the change. Some of the parameters increased, whereas the others decreased. But they exerts the effect as a whole, rather than individual properties of their own. Hence, considering this, some of the urban design concepts are as follows:

- Proper landscaping in setback and open area of a building will help in reducing heat absorption, increase humidity through transpiration and provide shading.
- The road side landscaping should consist of large shading tree, providing shade over the roads. The roads may be constructed/ reconstructed with materials and colored with low heat absorbing colors and materials, which will reduce heat absorption, heat trap and reflect solar radiation.
- Shading above urban water body (Hatirjheel Lake) must be increased for it to be able to contribute in urban cooling system by advection of temperature and humidity. Shading over water body with urban green/ structure will also help to mitigate inversion layer effect.
- The walls surrounding the Mohanagar Housing must be constructed with porous material/ design to maximize circulation of air, relative humidity. The bridges and overpasses which will be constructed in the future, should also follow this procedure.

5.8. Scope of the Future Study:

- This thesis only considered limited morphological parameters which were more associated to researched site. In future, study may be done with other morphological parameters (example: FAR, Sky View Factor (SVF), H/W Ratio, compactness factor etc.) as well.
- This is a comparative study in-between two periods, hence, it is not possible to determine the types and number of trees of that area of previous time. Therefore, the vegetation parameter is reduced from this thesis. Future study may include the vegetation and analyze its effect.

- The effect of water body largely depends on the quality. Thus, a future study may be conducted on these factors.
- The construction materials (example: concrete, bricks, asphalt, color etc.) majorly influences the morphology as well as the micro-climatic parameters. An elaborate of such materials may provide further insight on how they react to natural factors, energy consumption etc.
- Research may be done on design and types of wall and overpass in an area which will have desired effect on its micro-climatic parameters.

5.9. Conclusion:

After analyzing all the observations of the thesis, it is apparent that the morphology influences the micro-climate and that in return influences the energy consumption. In a nutshell, morphology influences energy consumption. Considering this fact, a guideline may be introduced on how the morphology should be altered, which will lead to a more controlled alteration of microclimate and energy use. This may play a key role in fighting progressive energy demand.

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APPENDICES

Letter to the Director of Operation, DPDC	:	**Appendix 1**
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Appendix 1: Letter to the Director of Operation, DPDC.

18 February, 2017

To,
The Director Operation,
Dhaka Power Distribution Company Limited (DPDC),
Dhaka.

Dear Sir,
I am **Hassan Mahbub Reza.** I am currently doing my M.Arch Thesis on **"Impact of Micro-climate on Energy Consumption"**. For my M.Arch Thesis I urgently need some information from DPDC, example, electricity consumption and distribution rates and billing data of some particular places of some specific times. Here I can assure you that, this information will be used for academic purposes only.

So I hope you will be kind enough to provide me the information.

Thank You.

Hassan Mahbub Reza
M.Arch Student, Roll no: 0413012018 P
Department of Architecture
Bangladesh University of Engineering & Technology, Dhaka 1000.

GM (ICT)
Pl. do needful.
28/2/17
(A T M Harun Or Rashid)

FORWARDED
16/2/17
Prof. Dr. KhandakerShabbir Ahmed
Head | Department of Architecture
Bangladesh University of Engineering & Technology, Dhaka-1000, Bangladesh

DGM (ICT), Rev
01/03/17

Appendix 2: Survey Permission Letter.

স্থাপত্য বিভাগ
বাংলাদেশ প্রকৌশল বিশ্ববিদ্যালয়
B.U.E.T
Department of Architecture
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Engineering and Technology
Dhaka-1000, Bangladesh
Tel : 9665633, PABX 9665650-80, Ext: 7128, 7153,
e-mail : head@arch.buet.ac.bd, Fax : 9665633

19 November, 2017

TO WHOM IT MAY CONCERN

This is to certify that **Hassan Mahbub Reza** Student No. 0413012018P a student of M.Arch of Department of Architecture, Bangladesh University of Engineering and Technology. As part of his thesis project of **"Impact of Micro-climate on Energy Consumption"** he is to conduct a survey and/ or required some information and related documents of your locality.

On this regard, any help and co-operation extended to him will be highly appreciated. On his behalf, I can assure that these documents will be used for academic purpose only.

Thank you in anticipation.

Sincerely yours.

Prof. Dr. Khandaker Shabbir Ahmed
Head, Department of Architecture,
Bangladesh University of Engineering and Technology (BUET)
Dhaka 1000.

Appendix 3: Climate Data Collected from BMD.

The climatic data for the year 2007 and 2017 were collected from Bangladesh Meteorology Department. From the collected data, only December 2007 and December 2017 are shown here:

Three Hourly Temperature data, December 2007:

T [°C]	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00
01.12.2007	18.2	23.6	27.0	27.4	24.8	20.2	19.2	18.2
02.12.2007	17.1	22.6	26.6	26.4	22.6	21.3	20.4	19.4
03.12.2007	19.6	23.2	26.1	25.5	21.6	19.6	18.6	18.2
04.12.2007	16.9	22.0	25.0	26.3	22.4	19.8	18.8	17.3
05.12.2007	18.7	20.9	24.6	25.8	22.6	19.6	18.0	16.5
06.12.2007	16.4	21.0	26.2	27.6	22.8	19.6	18.6	17.4
07.12.2007	16.2	22.8	26.6	27.0	22.3	19.7	18.2	16.8
08.12.2007	16.1	22.4	25.6	26.6	22.6	19.0	17.4	17.4
09.12.2007	17.4	20.6	25.0	25.3	20.8	20.4	18.2	15.2
10.12.2007	15.5	19.8	24.4	25.1	21.2	20.0	16.0	15.4
11.12.2007	14.2	20.2	24.3	25.8	21.4	17.8	16.0	15.6
12.12.2007	13.4	21.4	25.2	25.8	22.2	19.3	17.6	17.0
13.12.2007	14.7	21.1	25.1	26.4	23.1	19.3	18.4	16.4
14.12.2007	15.4	21.6	25.6	25.6	23.6	21.2	21.1	20.5
15.12.2007	19.6	19.8	23.6	25.0	22.4	19.7	19.8	17.8
16.12.2007	17.1	19.6	23.8	25.2	22.0	20.0	17.6	14.6
17.12.2007	14.3	14.2	21.0	23.2	18.8	19.0	17.7	15.8
18.12.2007	15.0	18.8	23.4	24.7	21.2	18.0	17.4	16.6
19.12.2007	15.1	18.3	22.7	25.0	21.4	17.4	17.8	16.6
20.12.2007	15.1	17.8	22.6	24.6	19.6	18.0	15.1	14.8
21.12.2007	12.4	17.8	21.2	22.8	18.2	14.8	13.6	13.0
22.12.2007	11.5	16.6	23.0	24.3	19.4	17.0	15.5	14.3
23.12.2007	13.8	17.2	22.8	23.8	19.0	16.0	14.8	14.4
24.12.2007	12.5	18.1	22.7	24.2	19.6	16.4	15.0	14.6
25.12.2007	13.4	17.3	23.3	24.6	19.7	17.0	15.6	14.6
26.12.2007	13.8	18.6	23.4	25.4	21.3	17.6	16.7	16.0
27.12.2007	14.8	18.2	23.6	24.3	21.6	18.4	18.5	16.5
28.12.2007	15.2	17.4	23.0	24.3	21.0	19.2	17.5	14.8
29.12.2007	14.6	16.1	21.0	24.1	24.1	18.0	17.4	17.0
30.12.2007	15.9	18.4	23.3	24.8	21.4	18.6	18.0	17.4
31.12.2007	16.2	17.8	22.8	24.6	21.4	19.6	18.2	17.2

Three Hourly Relative Humidity data, December 2007:

RH [%]	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00
01.12.2007	95.0	70.0	36.0	45.0	55.0	84.0	86.0	94.0
02.12.2007	95.0	77.0	43.0	45.0	73.0	83.0	90.0	93.0
03.12.2007	96.0	81.0	58.0	56.0	77.0	90.0	94.0	88.0
04.12.2007	96.0	76.0	58.0	49.0	72.0	86.0	92.0	93.0
05.12.2007	87.0	83.0	58.0	54.0	67.0	90.0	95.0	96.0
06.12.2007	96.0	76.0	43.0	36.0	69.0	86.0	88.0	94.0
07.12.2007	96.0	66.0	45.0	43.0	66.0	81.0	91.0	93.0
08.12.2007	97.0	65.0	43.0	36.0	63.0	84.0	91.0	86.0
09.12.2007	78.0	58.0	33.0	40.0	63.0	59.0	72.0	95.0
10.12.2007	92.0	72.0	45.0	41.0	58.0	65.0	89.0	91.0
11.12.2007	93.0	65.0	44.0	40.0	55.0	74.0	91.0	93.0

RH [%]	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00
12.12.2007	94.0	60.0	47.0	41.0	56.0	71.0	81.0	85.0
13.12.2007	94.0	70.0	48.0	32.0	47.0	68.0	74.0	85.0
14.12.2007	91.0	56.0	39.0	47.0	52.0	66.0	66.0	69.0
15.12.2007	72.0	72.0	57.0	48.0	65.0	78.0	57.0	67.0
16.12.2007	75.0	60.0	49.0	41.0	58.0	56.0	48.0	60.0
17.12.2007	62.0	62.0	52.0	44.0	75.0	66.0	67.0	72.0
18.12.2007	72.0	59.0	49.0	42.0	57.0	76.0	78.0	83.0
19.12.2007	79.0	58.0	47.0	40.0	53.0	77.0	72.0	70.0
20.12.2007	69.0	58.0	43.0	34.0	50.0	55.0	73.0	82.0
21.12.2007	86.0	51.0	43.0	36.0	69.0	89.0	92.0	95.0
22.12.2007	97.0	83.0	40.0	28.0	64.0	78.0	88.0	94.0
23.12.2007	97.0	83.0	50.0	46.0	73.0	87.0	95.0	94.0
24.12.2007	96.0	80.0	53.0	49.0	76.0	89.0	95.0	93.0
25.12.2007	97.0	92.0	55.0	48.0	79.0	91.0	92.0	89.0
26.12.2007	97.0	86.0	52.0	44.0	67.0	87.0	93.0	90.0
27.12.2007	94.0	83.0	54.0	48.0	61.0	76.0	74.0	90.0
28.12.2007	95.0	85.0	51.0	47.0	71.0	83.0	88.0	95.0
29.12.2007	98.0	90.0	64.0	57.0	57.0	87.0	90.0	92.0
30.12.2007	91.0	74.0	58.0	47.0	64.0	79.0	78.0	79.0
31.12.2007	80.0	71.0	54.0	46.0	61.0	69.0	67.0	74.0

Three Hourly Wind Speed data, December 2007:

WS [m/s]	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00
01.12.2007	0.0	0.0	1.5	2.0	0.0	0.0	0.0	0.0
02.12.2007	0.0	0.0	3.1	3.2	0.0	0.0	0.0	0.0
03.12.2007	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0
04.12.2007	0.0	0.0	1.5	1.0	0.0	0.0	0.0	0.0
05.12.2007	1.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0
06.12.2007	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
07.12.2007	0.0	0.0	1.0	1.5	0.0	0.0	0.0	0.0
08.12.2007	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0
09.12.2007	0.0	3.0	3.0	1.0	1.0	0.0	1.5	0.0
10.12.2007	0.5	0.5	1.5	1.5	1.0	1.5	0.0	0.0
11.12.2007	0.0	1.0	1.5	0.0	0.0	0.0	0.0	0.0
12.12.2007	0.0	1.0	1.0	1.0	1.5	0.0	1.0	0.0
13.12.2007	0.0	0.0	1.0	1.5	1.0	1.0	1.0	0.0
14.12.2007	0.0	1.5	1.5	1.5	1.0	0.0	1.0	0.0
15.12.2007	0.0	1.0	1.5	1.5	0.0	0.0	2.0	0.0
16.12.2007	2.5	1.5	1.0	3.0	1.0	2.5	3.0	0.0
17.12.2007	1.0	1.5	0.0	1.5	0.0	1.5	2.0	0.0
18.12.2007	0.0	2.0	2.0	1.5	1.0	1.0	0.0	0.0
19.12.2007	1.0	0.0	2.0	2.0	1.0	0.0	1.0	0.0
20.12.2007	1.5	1.5	1.5	1.5	0.0	0.0	0.0	0.0
21.12.2007	0.0	2.0	2.0	2.5	0.0	0.0	0.0	0.0
22.12.2007	0.0	0.0	1.5	1.5	0.5	0.0	0.0	0.0
23.12.2007	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
24.12.2007	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25.12.2007	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0
26.12.2007	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0
27.12.2007	0.0	0.0	1.0	1.5	0.0	0.0	1.0	0.0
28.12.2007	0.0	0.0	0.0	1.0	1.0	0.0	1.5	0.0
29.12.2007	1.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0

WS [m/s]	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00
30.12.2007	0.0	0.0	1.0	1.0	0.0	0.0	1.0	0.0
31.12.2007	1.0	1.0	2.0	1.5	1.5	1.0	1.5	0.0

Three Hourly Temperature data, December 2017:

T [°C]	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00
01.12.2017	16.9	22.0	27.2	28.6	22.8	19.8	18.8	18.2
02.12.2017	17.2	24.0	27.4	28.6	22.6	20.4	19.4	18.0
03.12.2017	16.8	22.9	27.0	28.2	22.4	20.4	19.0	18.0
04.12.2017	17.0	22.4	25.6	26.7	22.8	19.6	18.4	17.8
05.12.2017	17.2	22.2	26.6	27.4	21.6	19.3	18.0	16.5
06.12.2017	16.6	23.0	25.8	28.5	23.7	22.3	20.7	20.6
07.12.2017	16.6	23.0	25.8	28. 5	23.7	22.3	20.7	20.6
08.12.2017	20.7	22.7	25.3	25.4	23.0	22.2	22.0	21.0
09.12.2017	18.8	20.0	22.2	22.3	21.6	21.0	21.0	21.2
10.12.2017	21.2	21.4	22.0	23 .4	22.8	22.2	22.2	21.8
11.12.2017	21.7	22.4	23.0	25.0	24.1	22.0	22.6	21.2
12.12.2017	20.8	24.2	27.8	28.4	24.8	21.6	20.4	19.4
13.12.2017	19.2	22.8	27.0	28.0	24.0	22.0	20.9	19.2
14.12.2017	18.7	22.0	27.0	28.4	24.0	19.8	18.8	17.4
15.12.2017	16.8	22.0	25.2	26.8	22.4	19.8	16.8	15.7
16.12.2017	14.7	20.2	24.5	25.4	21.6	18.0	17.0	16.4
17.12.2017	15.8	20.0	24.0	24.4	21.3	20.0	19.4	19.3
18.12.2017	19.2	20.0	23.0	25.0	21.3	19.7	18.5	17.5
19.12.2017	17.4	18.0	18.9	20.8	19.3	16.8	16.2	16.2
20.12.2017	16.0	17.0	22.0	25.0	21.5	18.0	17.0	16.2
21.12.2017	16.6	18.5	24.0	26.0	22.0	19.2	18.6	17.6
22.12.2017	16.6	20.0	23.8	26.6	21.6	19.7	18.6	17.3
23.12.2017	17.3	21.3	25.0	25.6	22.6	20.6	18.2	17.4
24.12.2017	16.4	20.6	24.6	26.0	22.7	21.0	20.0	18.8
25.12.2017	17.8	19.8	25.7	26.5	22.5	20.6	20.0	18.9
26.12.2017	17.8	20.0	24.6	26.0	22.8	21.0	20.0	18.6
27.12.2017	17.4	19.4	25.0	26.8	22.2	19.8	19.8	18.5
28.12.2017	17.2	16.6	22.0	24.2	21.4	19.8	17.4	16.4
29.12.2017	15.3	16.6	23.9	26.2	21.5	19.0	18.2	17.2
30.12.2017	16.4	21.1	26.8	28.2	23.1	20.6	19.0	17.4
31.12.2017	15.6	21.9	27.0	28.2	22.1	19.7	19.5	18.4

Three Hourly Relative Humidity data, December 2017:

RH [%]	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00
01.12.2017	97.0	73.0	42.0	29.0	63.0	86.0	94.0	96.0
02.12.2017	97.0	64.0	45.0	41.0	65.0	84.0	89.0	92.0
03.12.2017	96.0	66.0	40.0	29.0	62.0	70.0	84.0	89.0
04.12.2017	93.0	61.0	49.0	45.0	67.0	82.0	85.0	92.0
05.12.2017	96.0	70.0	43.0	32.0	62.0	76.0	88.0	95.0
06.12.2017	93.0	60.0	49.0	44.0	67.0	72.0	79.0	80.0
07.12.2017	93.0	60.0	49.0	44.0	67.0	72.0	79.0	80.0
08.12.2017	82.0	66.0	49.0	53.0	67.0	70.0	77.0	90.0
09.12.2017	96.0	96.0	96.0	95.0	97.0	96.0	93.0	97.0
10.12.2017	98.0	96.0	94.0	89.0	94.0	96.0	98.0	97.0
11.12.2017	97.0	94.0	92.0	81.0	89.0	97.0	95.0	95.0
12.12.2017	98.0	78.0	63.0	58.0	71.0	89.0	96.0	96.0
13.12.2017	98.0	87.0	65.0	62.0	81.0	94.0	96.0	96.0

RH [%]	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00
14.12.2017	97.0	85.0	51.0	37.0	54.0	86.0	92.0	91.0
15.12.2017	93.0	61.0	44.0	38.0	53.0	63.0	81.0	86.0
16.12.2017	91.0	53.0	43.0	40.0	61.0	85.0	89.0	96.0
17.12.2017	98.0	84.0	70.0	68.0	86.0	90.0	92.0	89.0
18.12.2017	88.0	82.0	60.0	55.0	75.0	89.0	93.0	95.0
19.12.2017	96.0	92.0	85.0	77.0	86.0	96.0	98.0	100.0
20.12.2017	100.0	98.0	73.0	65.0	84.0	92.0	97.0	98.0
21.12.2017	98.0	88.0	54.0	51.0	72.0	88.0	91.0	95.0
22.12.2017	98.0	88.0	64.0	49.0	78.0	90.0	96.0	96.0
23.12.2017	92.0	72.0	58.0	48.0	67.0	78.0	92.0	91.0
24.12.2017	93.0	73.0	55.0	47.0	67.0	71.0	79.0	86.0
25.12.2017	92.0	82.0	56.0	50.0	71.0	82.0	84.0	84.0
26.12.2017	84.0	69.0	58.0	53.0	68.0	76.0	76.0	79.0
27.12.2017	81.0	71.0	53.0	45.0	70.0	88.0	82.0	87.0
28.12.2017	92.0	98.0	72.0	67.0	80.0	86.0	96.0	96.0
29.12.2017	98.0	100.0	66.0	49.0	72.0	92.0	96.0	98.0
30.12.2017	98.0	74.0	41.0	35.0	61.0	73.0	76.0	83.0
31.12.2017	93.0	64.0	43.0	35.0	58.0	77.0	70.0	77.0

Three Hourly Wind Speed data, December 2017:

WS [m/s]	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00
01.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
02.12.2017	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
03.12.2017	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
04.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
05.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
06.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
07.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.12.2017	0.0	0.0	0.0	2.0	4.0	3.0	0.0	0.0
10.12.2017	2.0	2.0	3.0	0.0	0.0	0.0	0.0	0.0
11.12.2017	0.0	2.0	2.0	2.0	0.0	0.0	2.0	0.0
12.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.12.2017	0.0	0.0	2.0	2.0	0.0	0.0	0.0	0.0
16.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24.12.2017	0.0	0.0	0.0	2.0	0.0	2.0	2.0	0.0
25.12.2017	0.0	0.0	2.0	2.0	2.0	0.0	2.0	0.0
26.12.2017	0.0	3.0	2.0	2.0	0.0	0.0	2.0	0.0
27.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0
28.12.2017	0.0	2.0	2.0	0.0	0.0	0.0	0.0	0.0
29.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30.12.2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31.12.2017	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0

Appendix 4: Details of the Selected Samples.

Sample:1: C42
Sample details:
- Made of RCC frame structure with brick infill and partition walls.
- The windows were made of glass and aluminum frame with steel grill.
- Continuous verandah in North and East side.
- Very few plants within the setback space.
- Road on two sides (North and East).
- Empty plot in North side.
- Build area: 34.89%, open area: 25.44% and road area: 39.66% (within micro-domain).

Sample:2: C82
Sample details:
- Made of RCC frame structure with brick infill and partition walls.
- The windows were made of glass and aluminum frame with steel grill.
- East or road side verandah.
- Very few plants within the setback space.
- Road on one side (East).
- Empty plots in North and South side.
- Build area: 24.53%, open area: 54.16% and road area: 21.30% (within micro-domain).

Sample:3: D76
Sample details:
- Made of RCC frame structure with brick infill and partition walls.
- The windows were made of glass and aluminum frame with steel grill.
- Road side verandah (West).
- Few plants (only in front side) within the setback space.
- Road on one side (West).
- Empty plot in South side.
- Build area: 42.74%, open area: 50.45% and road area: 6.80% (within micro-domain).

Sample:4: D145
Sample details:

- Made of RCC frame structure with brick infill and partition walls.
- The windows were made of glass and aluminum frame with steel grill.
- Road side verandah (West).
- Very few plants within the setback space.
- Road on one side (East).
- Empty plot in West side.
- Build area: 65.77%, open area: 28.90% and road area: 5.32% (within micro-domain).

Appendix 5: Micro-climatic data from Field Survey.

Field Survey Data, 2017, T [°C]:

01.12.2017

Sample	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
C 42	23.5	20.5	20.5	21.0	22.0	23.5	28.0	26.0	26.0	25.5	25.5	25.0	24.5
C 82	23.5	20.0	20.0	21.0	22.5	25.0	29.5	29.0	27.0	27.5	26.5	26.0	25.5
D 76	23.5	20.0	20.0	20.5	22.0	23.5	27.5	30.0	26.5	26.0	26.0	25.5	24.5
D 145	23.5	20.5	20.5	21.0	22.5	23.5	25.0	26.5	26.0	26.0	26.5	26.0	25.0

02.12.2017

C 42	23.0	21.5	21.5	22.5	23.0	24.5	28.5	27.5	27.0	26.5	26.0	25.0	25.0
C 82	23.5	21.5	21.5	22.5	23.5	25.5	29.0	28.5	27.5	27.5	26.5	26.0	25.5
D 76	23.5	21.0	21.0	21.5	23.0	24.0	27.5	29.5	27.0	26.5	26.0	25.0	24.5
D 145	23.5	21.5	21.5	22.5	23.5	24.5	26.0	27.0	27.0	27.0	26.5	25.5	25.0

03.12.2017

C 42	23.0	21.5	21.0	21.5	22.5	23.5	28.5	26.0	25.5	26.0	25.5	25.0	24.5
C 82	24.0	21.5	21.5	21.5	23.0	25.0	28.0	29.0	26.5	27.0	26.5	26.0	25.5
D 76	24.5	21.0	20.5	21.0	22.5	24.0	27.0	28.0	26.0	26.0	25.5	25.5	24.5
D 145	23.5	21.5	21.5	22.0	23.0	24.0	25.5	26.5	26.0	26.5	26.0	26.0	25.0

Field Survey Data, 2017, RH [%]:

01.12.2017

Sample	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
C 42	77.5	82.5	83.0	81.5	80.5	77.0	65.0	65.5	65.0	63.5	64.5	67.0	74.5
C 82	76.5	82.0	82.5	81.0	77.5	71.5	57.0	54.0	58.0	55.0	57.0	60.5	62.5
D 76	75.5	81.5	82.0	80.0	77.5	72.5	63.0	56.0	59.5	55.0	57.0	59.5	64.0
D 145	76.0	82.5	83.0	81.0	79.0	74.5	68.0	64.0	63.0	57.0	58.0	62.5	65.0

02.12.2017

C 42	79.0	79.5	79.5	76.0	77.0	75.0	64.0	63.0	63.5	65.5	66.0	68.0	70.5
C 82	75.0	77.5	78.5	73.5	74.5	70.0	59.0	57.0	59.5	58.5	58.5	60.5	62.5
D 76	73.0	77.0	79.0	76.5	76.0	71.0	64.5	58.0	59.5	60.0	59.5	61.0	62.5
D 145	74.0	78.5	79.5	77.0	76.5	72.0	68.0	63.0	62.5	61.5	63.0	65.0	67.5

03.12.2017

C 42	83.5	82.5	83.5	81.5	79.5	72.5	57.0	59.5	59.0	59.0	61.5	64.0	65.0
C 82	78.5	80.0	81.5	79.5	75.5	65.5	52.5	48.0	48.5	51.5	52.0	55.0	58.5
D 76	77.5	80.0	82.5	81.5	77.0	65.5	53.0	50.5	51.5	54.5	53.5	57.5	58.5
D 145	75.5	81.0	82.0	82.0	77.0	66.0	55.5	54.0	52.5	56.0	55.0	57.5	59.5

Field Survey Data, 2017, WS [m/s]:

01.12.2017

Sample	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
C 42	0.0	0.0	0.3	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C 82	0.0	0.0	0.1	0.0	0.0	0.0	1.9	0.7	0.0	0.0	0.0	0.0	0.1
D 76	0.0	0.0	0.4	0.9	0.8	0.0	0.8	0.0	1.1	1.1	0.8	0.0	0.0
D 145	0.0	0.3	0.8	0.0	0.0	0.0	0.0	1.1	0.9	0.3	0.9	0.0	0.0

02.12.2017

C 42	0.0	0.7	0.0	0.0	1.2	0.1	0.1	0.1	0.2	0.0	0.0	0.0	0.0
C 82	0.4	0.1	0.8	0.2	1.7	1.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0
D 76	0.0	0.0	0.3	0.4	0.2	1.4	0.9	0.0	0.9	1.1	0.0	0.0	0.0
D 145	0.0	0.0	0.0	0.1	0.8	0.0	0.0	0.1	0.7	0.0	0.0	0.0	0.0

03.12.2017

C 42	0.0	0.6	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C 82	0.0	1.0	0.3	0.5	0.4	0.3	1.1	0.5	0.0	0.0	0.3	0.0	0.0
D 76	0.0	0.0	0.0	0.6	1.0	2.4	1.4	1.5	0.4	0.0	0.0	0.0	0.0
D 145	0.0	0.0	0.0	0.6	0.4	1.1	1.7	1.0	0.8	0.0	0.7	0.0	0.0

Appendix 6: Micro-climatic Data from Envi-met Simulation output.

Simulation Output Data, 01.12.2007, x/y Cut at K= 4 (1.8m), Using BMD data:

T [°C]

Sample	C 42	C 82	D 76	D 145
06:00	23.80	23.83	23.62	23.56
07:00	23.82	23.83	23.62	23.57
08:00	24.14	24.16	23.81	23.74
09:00	24.91	24.97	24.65	24.46
10:00	25.71	25.89	25.69	25.35
11:00	26.59	26.77	26.82	26.45
12:00	27.24	27.34	27.59	27.29
13:00	27.41	27.58	27.70	27.35
14:00	27.27	27.51	27.37	26.99
15:00	27.00	27.25	26.90	26.64
16:00	26.44	26.55	26.22	26.02
17:00	25.66	25.67	25.43	25.28
18:00	25.28	25.29	25.00	24.89
19:00	25.01	25.02	24.68	24.59
20:00	24.77	24.79	24.42	24.34
21:00	24.57	24.59	24.19	24.13
22:00	24.39	24.41	23.98	23.93
23:00	24.22	24.25	23.79	23.75
00:00	24.07	24.10	23.62	23.59

MRT [%]

Sample	C 42	C 82	D 76	D 145
06:00	14.27	14.31	14.28	14.32
07:00	14.26	14.31	14.27	14.31
08:00	18.07	18.18	18.14	18.13
09:00	23.51	23.37	23.39	23.46
10:00	26.30	55.10	26.25	26.30
11:00	57.12	57.14	29.57	29.61
12:00	58.23	58.44	58.37	58.36
13:00	30.56	58.01	58.01	58.07
14:00	28.51	56.52	56.53	28.48
15:00	26.20	52.11	26.03	26.13
16:00	21.56	21.39	21.41	21.51
17:00	16.85	16.87	16.85	16.89
18:00	16.25	16.27	16.25	16.29
19:00	15.84	15.86	15.83	15.88
20:00	15.51	15.52	15.50	15.55
21:00	15.23	15.24	15.22	15.27
22:00	14.99	15.00	14.97	15.02
23:00	14.77	14.78	14.75	14.81
00:00	14.58	14.58	14.56	14.61

Sample	C 42	C 82	D 76	D 145
01:00	23.93	23.96	23.47	23.44
02:00	23.80	23.84	23.33	23.31
03:00	23.68	23.72	23.19	23.18
04:00	23.57	23.61	23.07	23.06
05:00	23.47	23.51	22.96	22.95

Sample	C 42	C 82	D 76	D 145
01:00	14.40	14.39	14.37	14.43
02:00	14.24	14.22	14.21	14.26
03:00	14.08	14.06	14.05	14.11
04:00	13.94	13.91	13.90	13.96
05:00	13.81	13.78	13.76	13.83

RH [%]

Sample	C 42	C 82	D 76	D 145
06:00	98.66	98.54	98.26	98.72
07:00	96.54	96.48	96.43	96.88
08:00	93.79	93.70	95.15	95.63
09:00	90.72	90.35	93.48	94.23
10:00	88.66	87.84	92.23	93.10
11:00	87.30	86.22	91.54	91.91
12:00	84.42	83.73	88.32	88.26
13:00	82.54	81.63	86.15	86.72
14:00	81.96	80.86	85.62	86.87
15:00	81.67	80.72	85.20	86.37
16:00	82.40	81.95	85.07	86.16
17:00	84.51	84.45	86.41	87.22
18:00	85.05	85.00	87.08	87.74
19:00	85.33	85.27	87.47	88.03
20:00	85.49	85.42	87.73	88.22
21:00	85.57	85.48	87.91	88.33
22:00	85.59	85.49	88.02	88.39
23:00	85.56	85.44	88.07	88.40
00:00	85.48	85.35	88.07	88.36
01:00	85.37	85.23	88.02	88.28
02:00	85.23	85.08	87.93	88.17
03:00	85.06	84.90	87.80	88.03
04:00	84.84	84.67	87.63	87.84
05:00	84.58	84.40	87.42	87.62

WS [m/s]

Sample	C 42	C 82	D 76	D 145
06:00	1.18	0.20	2.44	2.06
07:00	1.15	0.19	2.40	2.03
08:00	1.13	0.18	2.37	2.01
09:00	1.10	0.18	2.32	1.98
10:00	1.07	0.17	2.28	1.95
11:00	1.04	0.16	2.22	1.91
12:00	1.05	0.16	2.28	1.94
13:00	1.07	0.17	2.35	1.98
14:00	1.08	0.17	2.36	1.99
15:00	1.07	0.17	2.34	1.98
16:00	1.05	0.16	2.28	1.94
17:00	1.02	0.16	2.21	1.90
18:00	0.99	0.15	2.17	1.87
19:00	0.97	0.15	2.14	1.84
20:00	0.96	0.15	2.11	1.81
21:00	0.94	0.15	2.08	1.79
22:00	0.93	0.14	2.05	1.77
23:00	0.92	0.14	2.02	1.74
00:00	0.90	0.14	2.00	1.72
01:00	0.89	0.14	1.98	1.70
02:00	0.88	0.14	1.96	1.68
03:00	0.87	0.14	1.94	1.66
04:00	0.86	0.14	1.92	1.65
05:00	0.86	0.14	1.91	1.63

Simulation Output Data, 01.12.2017, x/y Cut at K= 4 (1.8m), Using BMD data:

T [°C]

Sample	C 42	C 82	D 76	D 145
06:00	24.37	24.68	23.54	24.41
07:00	24.43	24.72	23.60	24.48
08:00	24.84	25.05	24.11	24.71
09:00	25.83	25.88	25.70	25.57
10:00	27.00	26.74	28.29	26.57
11:00	28.10	27.58	30.13	27.69
12:00	28.76	28.12	31.03	28.49
13:00	29.03	28.38	31.36	28.70
14:00	28.97	28.39	30.97	28.49
15:00	28.68	28.23	30.12	28.19
16:00	27.97	27.69	28.73	27.58

MRT [%]

Sample	C 42	C 82	D 76	D 145
06:00	14.69	14.77	14.75	14.76
07:00	14.73	14.82	14.80	14.81
08:00	18.36	18.45	18.49	18.45
09:00	24.12	24.12	24.06	24.11
10:00	27.48	55.75	27.46	27.50
11:00	58.10	58.16	31.18	31.22
12:00	59.45	59.59	59.59	59.59
13:00	32.49	32.51	59.27	32.47
14:00	30.46	57.80	57.73	30.44
15:00	27.90	27.85	27.73	27.84
16:00	22.91	22.90	22.80	22.88

Sample	C 42	C 82	D 76	D 145
17:00	27.01	26.90	27.26	26.75
18:00	26.56	26.51	26.59	26.30
19:00	26.23	26.22	26.13	25.96
20:00	25.96	25.98	25.77	25.69
21:00	25.72	25.77	25.46	25.45
22:00	25.52	25.58	25.20	25.24
23:00	25.34	25.42	24.97	25.05
00:00	25.17	25.26	24.76	24.88
01:00	25.02	25.12	24.58	24.73
02:00	24.88	24.99	24.41	24.59
03:00	24.75	24.87	24.25	24.46
04:00	24.63	24.76	24.10	24.34
05:00	24.52	24.65	23.96	24.23

Sample	C 42	C 82	D 76	D 145
17:00	18.09	18.17	18.14	18.16
18:00	17.41	17.48	17.46	17.48
19:00	16.94	17.01	16.98	17.00
20:00	16.57	16.64	16.61	16.63
21:00	16.26	16.32	16.29	16.32
22:00	15.99	16.05	16.02	16.05
23:00	15.75	15.81	15.78	15.81
00:00	15.54	15.60	15.56	15.59
01:00	15.35	15.40	15.37	15.40
02:00	15.17	15.23	15.18	15.22
03:00	15.00	15.06	15.01	15.05
04:00	14.85	14.90	14.85	14.89
05:00	14.70	14.75	14.70	14.74

RH [%]

Sample	C 42	C 82	D 76	D 145
06:00	103.31	101.40	107.47	101.76
07:00	100.57	98.89	104.69	99.23
08:00	95.97	96.76	100.76	97.24
09:00	92.40	91.93	94.37	94.38
10:00	88.04	89.18	84.26	91.84
11:00	85.06	87.25	79.71	89.98
12:00	81.72	84.40	75.24	85.80
13:00	79.38	82.17	72.40	83.58
14:00	78.53	81.08	72.40	83.13
15:00	78.40	80.51	73.76	82.65
16:00	80.00	81.38	77.31	82.87
17:00	82.96	83.52	82.16	84.71
18:00	84.00	84.22	84.16	85.68
19:00	84.56	84.57	85.32	86.22
20:00	84.88	84.75	86.08	86.54
21:00	85.06	84.81	86.60	86.71
22:00	85.13	84.79	86.95	86.78
23:00	85.11	84.69	87.16	86.77
00:00	85.02	84.55	87.27	86.69
01:00	84.89	84.36	87.32	86.56
02:00	84.72	84.14	87.30	86.39
03:00	84.51	83.90	87.24	86.19
04:00	84.23	83.63	87.14	85.96
05:00	84.01	83.33	87.00	85.69

WS [m/s]

Sample	C 42	C 82	D 76	D 145
06:00	1.18	0.11	2.44	1.92
07:00	1.15	0.11	2.41	1.90
08:00	1.12	0.11	2.37	1.88
09:00	1.10	0.11	2.33	1.86
10:00	1.07	0.11	2.28	1.83
11:00	1.04	0.11	2.23	1.80
12:00	1.05	0.12	2.30	1.84
13:00	1.08	0.12	2.36	1.61
14:00	1.08	0.13	2.36	1.90
15:00	1.08	0.13	2.35	1.90
16:00	1.05	0.13	2.29	1.86
17:00	1.01	0.13	2.21	1.82
18:00	0.98	0.13	2.16	1.78
19:00	0.96	0.13	2.12	1.75
20:00	0.94	0.13	2.09	1.72
21:00	0.93	0.13	2.06	1.70
22:00	0.91	0.13	2.03	1.68
23:00	0.90	0.13	2.01	1.66
00:00	0.89	0.13	1.99	1.64
01:00	0.87	0.12	1.97	1.63
02:00	0.86	0.12	1.95	1.61
03:00	0.86	0.12	1.94	1.60
04:00	0.85	0.12	1.92	1.58
05:00	0.84	0.12	1.91	1.57

Simulation Output Data, 01.12.2017, x/y Cut at K= 4 (1.8m), Using Survey data:

T [°C]

Sample	C 42	C 82	D 76	D 145
06:00	24.99	25.34	23.96	24.92
07:00	25.01	25.34	23.98	24.95
08:00	25.44	25.68	24.52	25.19

MRT [%]

Sample	C 42	C 82	D 76	D 145
06:00	14.83	14.92	14.92	14.92
07:00	14.88	14.97	14.98	14.97
08:00	18.67	18.76	18.82	18.77

Sample	C 42	C 82	D 76	D 145
09:00	26.44	26.52	26.15	26.07
10:00	27.65	27.39	28.86	27.09
11:00	28.74	28.24	30.55	28.17
12:00	29.56	28.94	31.70	29.19
13:00	29.86	29.22	32.07	29.46
14:00	29.81	29.22	31.71	29.23
15:00	29.51	29.06	30.84	28.93
16:00	28.74	28.48	29.35	28.30
17:00	27.70	27.61	27.82	27.35
18:00	27.20	27.17	27.11	26.83
19:00	26.85	26.86	26.64	26.48
20:00	26.57	26.61	26.27	26.21
21:00	26.34	26.40	25.98	25.98
22:00	26.14	26.22	25.73	25.78
23:00	25.96	26.06	25.51	25.60
00:00	25.81	25.91	25.31	25.45
01:00	25.66	25.78	25.13	25.31
02:00	25.53	25.65	24.97	25.17
03:00	25.40	25.53	24.81	25.05
04:00	25.28	25.42	24.66	24.92
05:00	25.16	25.31	24.52	24.81

Sample	C 42	C 82	D 76	D 145
09:00	24.47	24.47	24.43	24.46
10:00	27.85	56.23	27.86	27.88
11:00	58.56	58.62	31.62	31.65
12:00	60.00	60.15	60.17	60.15
13:00	33.11	33.14	59.89	59.94
14:00	31.09	58.43	58.37	31.08
15:00	28.53	28.49	28.39	28.48
16:00	23.49	23.49	23.41	23.48
17:00	18.53	18.62	18.61	18.61
18:00	17.80	17.89	17.88	17.89
19:00	17.31	17.39	17.39	17.39
20:00	16.93	17.01	17.00	17.01
21:00	16.61	16.69	16.68	16.69
22:00	16.35	16.42	16.41	16.42
23:00	16.12	16.19	16.17	16.19
00:00	15.91	15.98	15.96	15.98
01:00	15.72	15.79	15.77	15.79
02:00	15.55	15.62	15.60	15.61
03:00	15.39	15.46	15.43	15.45
04:00	15.24	15.30	15.28	15.30
05:00	15.10	15.16	15.13	15.16

RH [%]

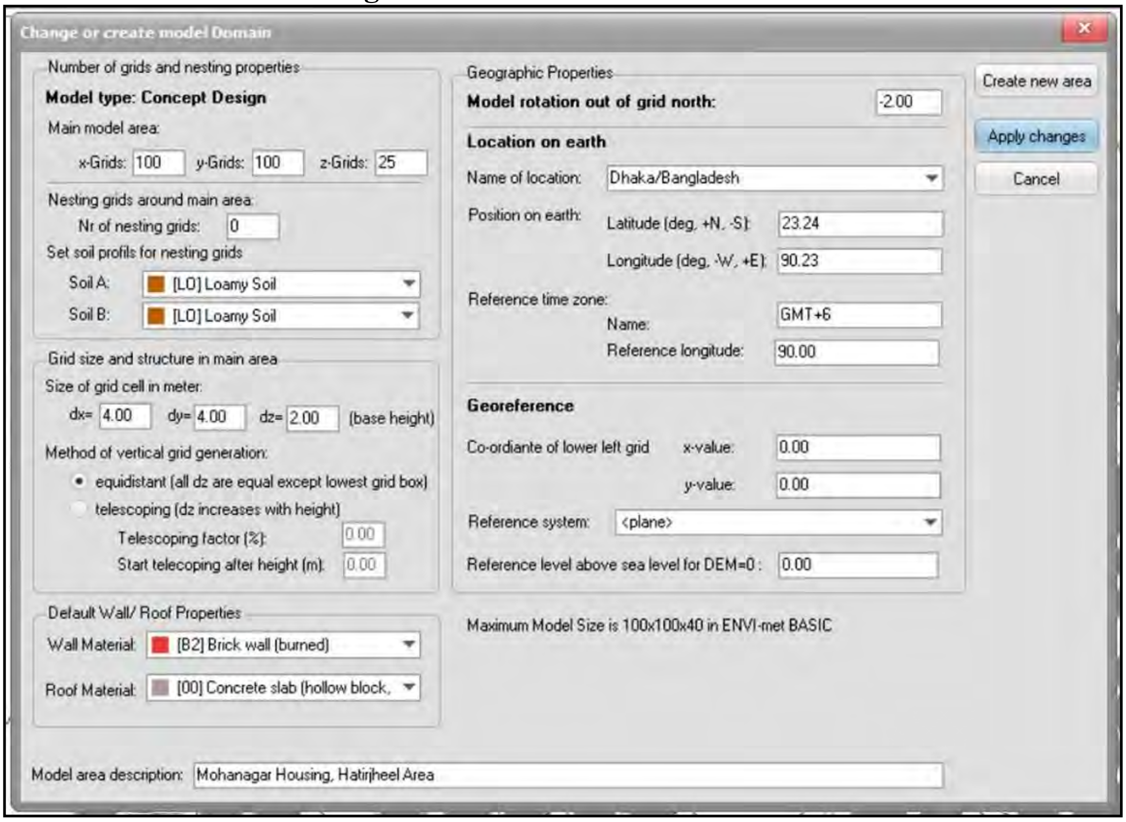
Sample	C 42	C 82	D 76	D 145
06:00	94.04	92.05	99.35	93.57
07:00	92.02	90.24	97.28	91.73
08:00	88.91	87.59	93.81	90.18
09:00	84.92	84.32	88.03	87.77
10:00	81.03	82.05	78.49	85.65
11:00	78.49	80.61	74.54	84.08
12:00	75.83	78.27	71.27	80.95
13:00	73.50	76.01	68.23	78.44
14:00	72.68	75.05	67.93	77.96
15:00	72.65	74.64	69.11	77.44
16:00	74.57	75.74	72.92	77.76
17:00	77.87	78.29	78.00	80.27
18:00	79.01	79.11	80.03	81.38
19:00	79.59	79.49	81.14	81.91
20:00	79.91	79.68	81.83	82.19
21:00	80.09	79.76	82.30	82.33
22:00	80.17	79.75	82.61	82.38
23:00	80.17	79.69	82.81	82.36
00:00	80.13	79.59	82.94	82.29
01:00	80.05	79.46	83.01	82.20
02:00	79.95	79.31	83.05	82.08
03:00	79.83	79.15	83.05	81.94
04:00	79.69	78.98	83.04	81.78
05:00	79.52	78.78	82.99	81.60

WS [m/s]

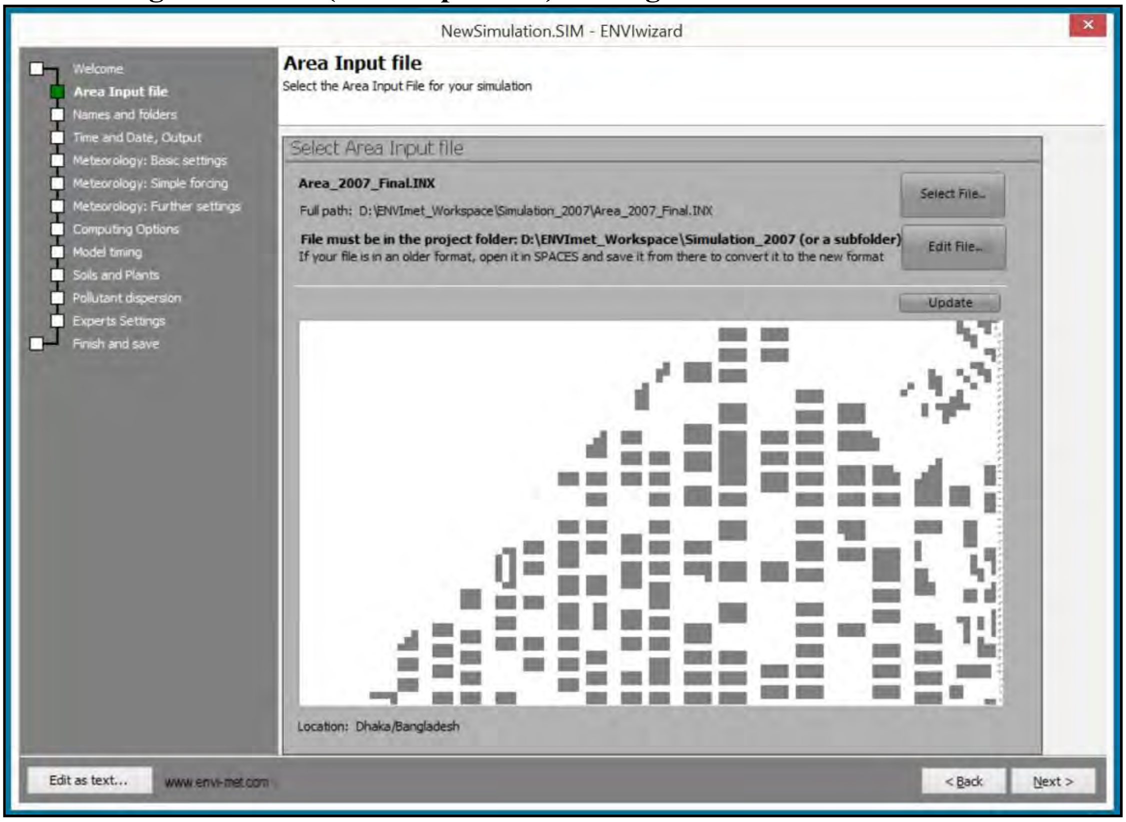
Sample	C 42	C 82	D 76	D 145
06:00	1.15	0.11	2.36	1.87
07:00	1.12	0.11	2.33	1.85
08:00	1.10	0.11	2.29	1.83
09:00	1.07	0.11	2.25	1.81
10:00	1.05	0.11	2.21	1.78
11:00	1.00	0.11	2.13	1.73
12:00	1.00	0.11	2.15	1.75
13:00	1.02	0.12	2.21	1.79
14:00	1.03	0.12	2.23	1.81
15:00	1.03	0.12	2.22	1.81
16:00	0.98	0.12	2.12	1.74
17:00	0.95	0.12	2.06	1.70
18:00	0.92	0.12	2.02	1.68
19:00	0.91	0.12	2.00	1.66
20:00	0.90	0.12	1.98	1.64
21:00	0.89	0.12	1.96	1.63
22:00	0.87	0.12	1.94	1.61
23:00	0.86	0.12	1.93	1.60
00:00	0.86	0.12	1.91	1.58
01:00	0.85	0.12	1.90	1.57
02:00	0.84	0.12	1.89	1.56
03:00	0.83	0.12	1.87	1.55
04:00	0.82	0.12	1.86	1.53
05:00	0.82	0.12	1.85	1.52

Appendix 7: ENVI-met Settings.

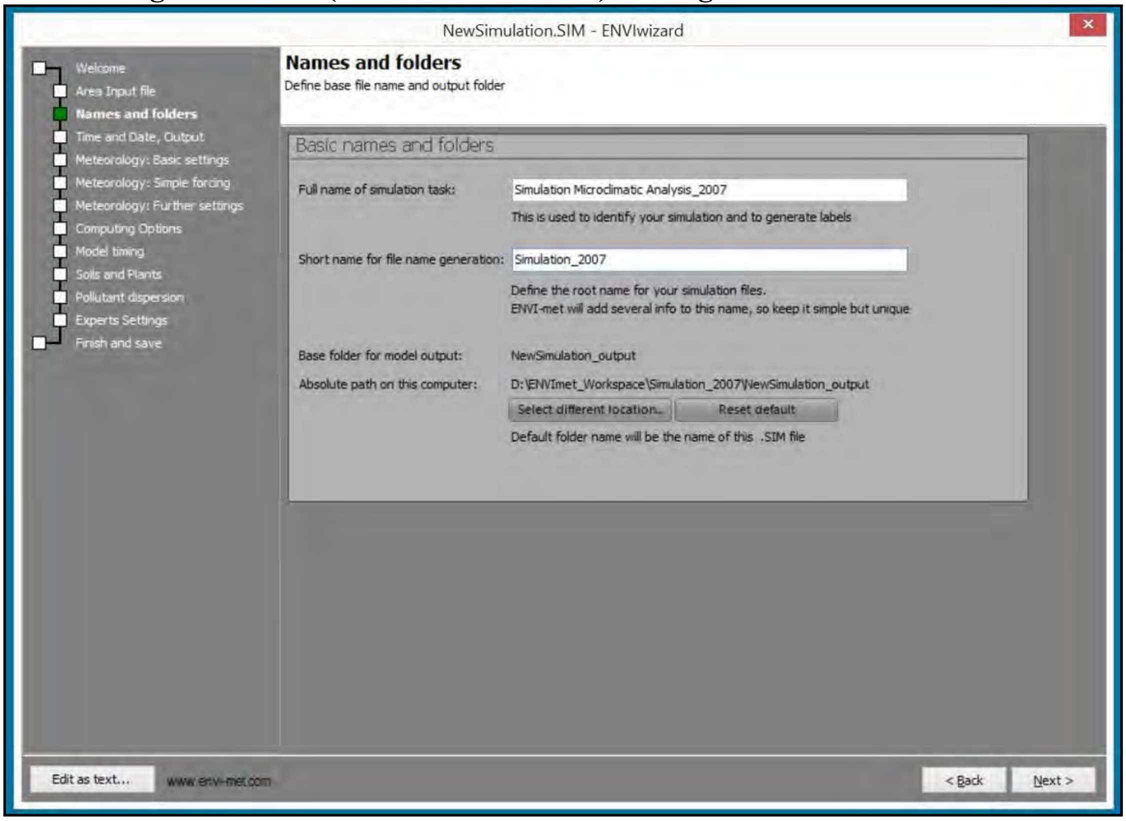
7.1. Model Domain Setting:



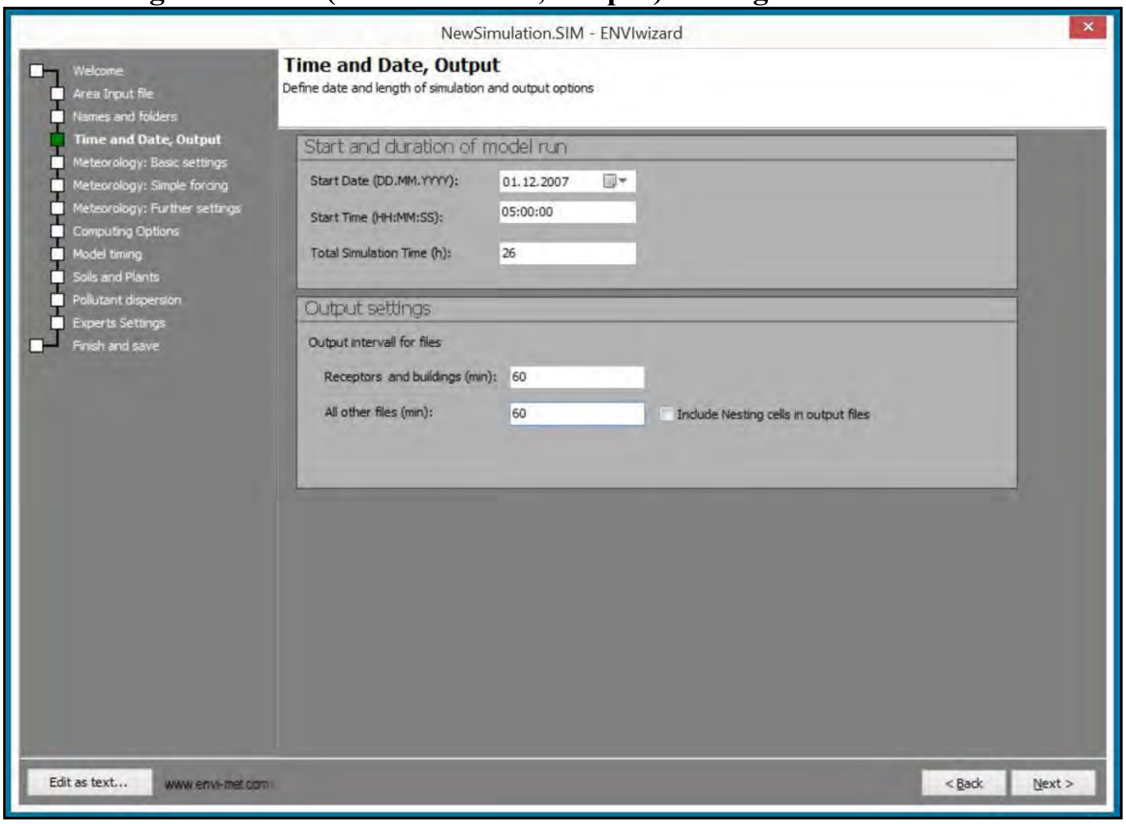
7.2. Configuration file (Area Input File) Setting:



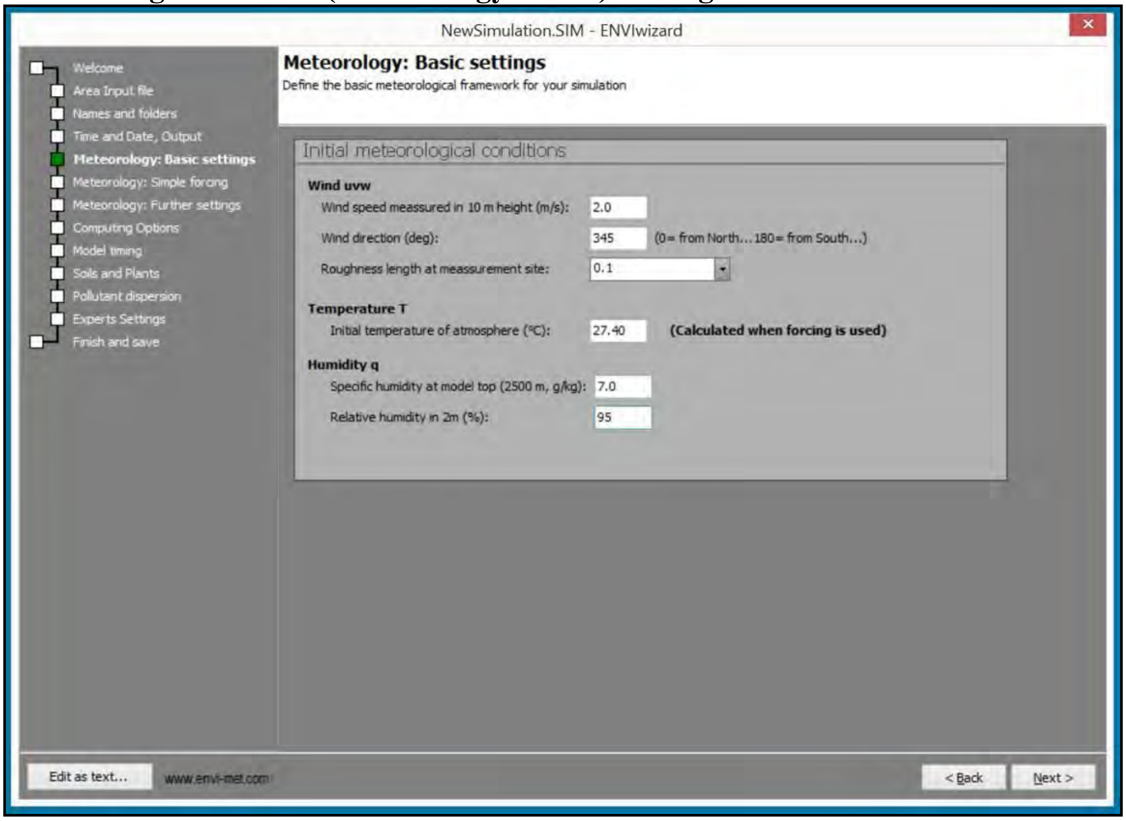
7.3. Configuration file (Names and Folders) Setting:



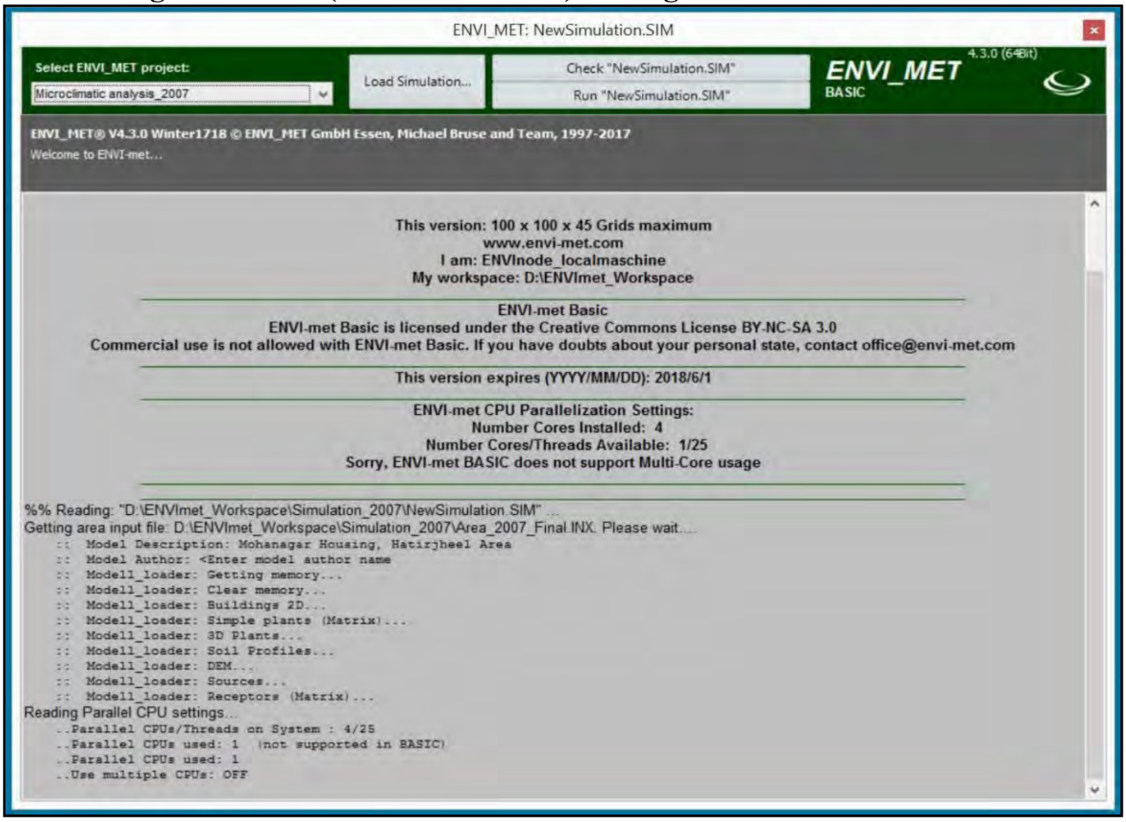
7.4. Configuration file (Time and Date, Output) Setting:



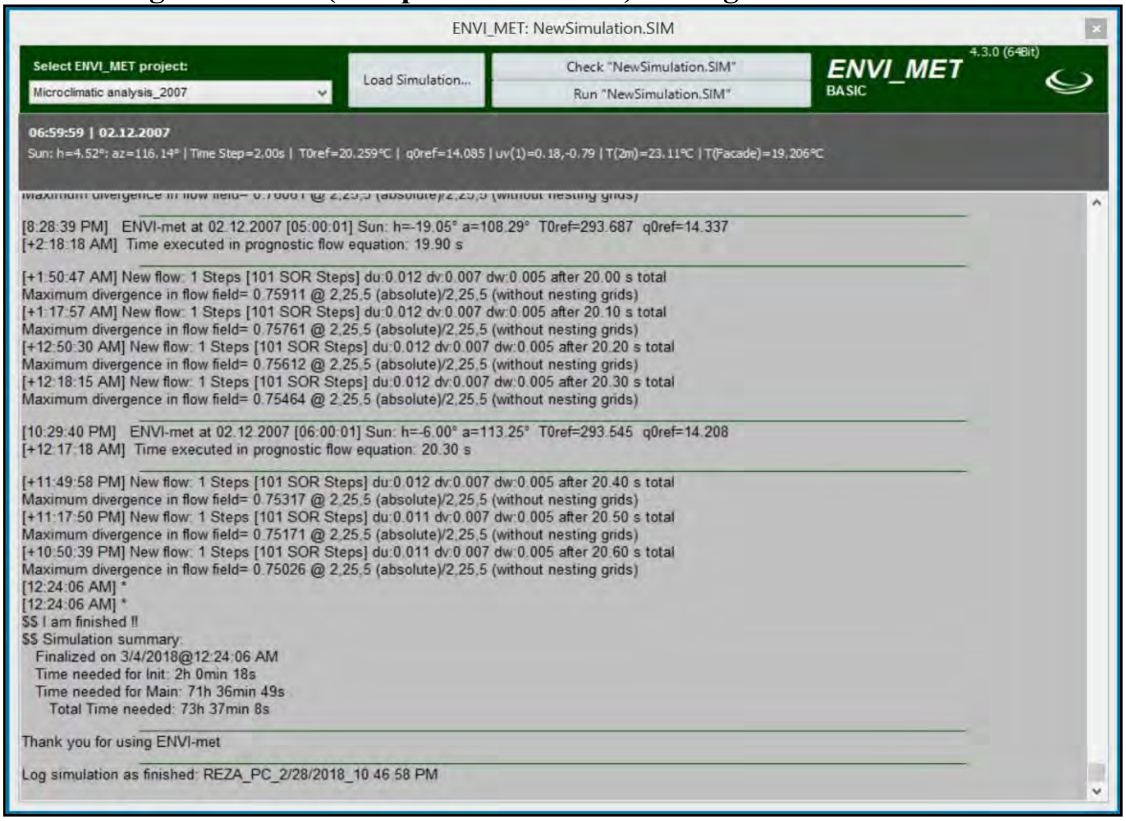
7.5. Configuration file (Meteorology: Basic) Setting:



7.6. Configuration file (Load Simulation) Setting:

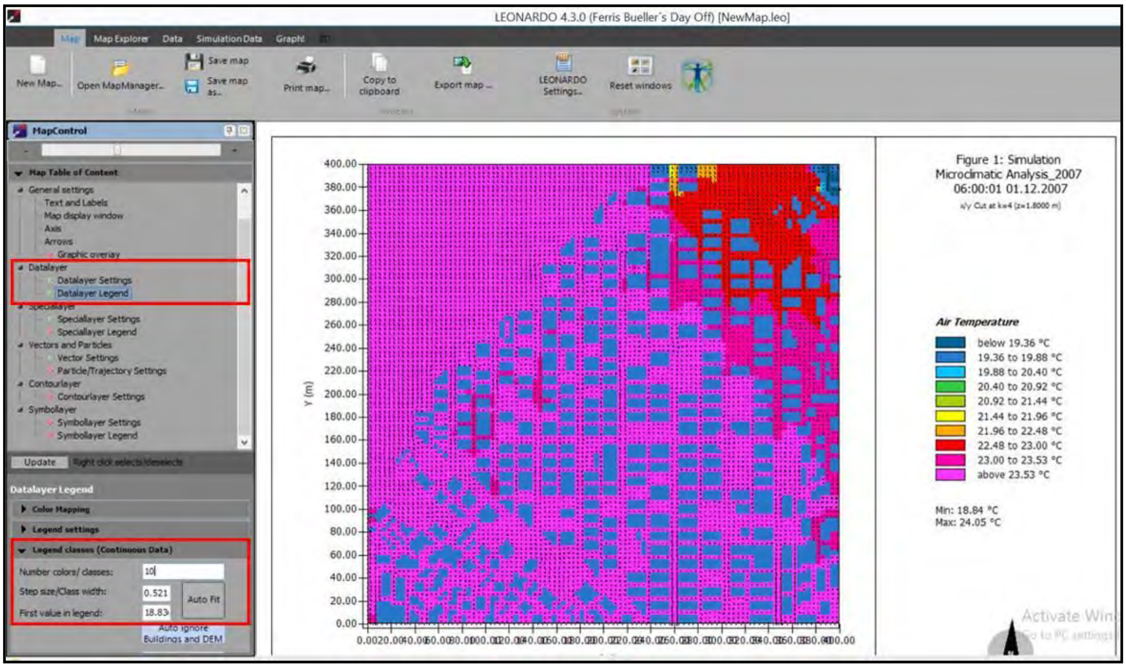


7.7. Configuration file (Complete Simulation) Setting:



7.8. Leonardo Module Setting:

The "Data layer legend" function under the "Options" from settings converts all the require parameters under similar level. For this thesis, all the parameters from both times are brought under same level, which is divided into 10 sections and depicted in color coding accordingly.



Appendix 8: Energy Consumption Data Collected from DPDC.

From the raw file of energy consumption which was collected from DPDC, only the files of sample buildings are presented below:

Sample: 1:

Address:	**C-42, Mohanagar Project.**		
Customer's Name:	Mr. Md. Alamgir		
No. of Floors:	4	Building Area (SQ. M):	144.90

2007

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19168160	19168175	19169830	19169845	19057050	19057065	19057099	X	X	
Jan	78	80	10	35	272	99	120	X	X	694
Feb	100	82	14	27	284	78	99	X	X	684
Mar	110	86	10	34	174	180	116	X	X	710
Apr	156	151	24	52	157	237	207	X	X	984
May	192	159	33	54	176	201	177	X	X	992
Jun	155	146	42	60	192	198	170	X	X	963
Jul	109	170	0	41	193	167	164	X	X	844
Aug	152	170	61	62	145	190	169	X	X	949
Sep	211	178	33	71	191	203	190	X	X	1077
Oct	184	135	21	42	142	184	132	X	X	840
Nov	167	131	30	77	192	238	181	X	X	1016
Dec	102	80	11	42	142	184	109	X	X	670

2008

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19168160	19168175	19169830	19169845	19057050	19057065	19057099	X	X	
Jan	89	100	11	51	170	194	140	X	X	755
Feb	80	97	13	36	192	110	114	X	X	642
Mar	128	98	44	38	182	158	126	X	X	774
Apr	231	170	10	77	192	236	191	X	X	1107
May	211	185	27	140	205	256	148	X	X	1172
Jun	252	177	33	145	219	224	133	X	X	1183
Jul	270	190	10	120	300	315	165	X	X	1370
Aug	251	193	15	98	267	308	204	X	X	1336
Sep	273	169	10	106	327	323	210	X	X	1418
Oct	242	139	1	91	346	295	188	X	X	1302
Nov	190	94	5	93	236	243	142	X	X	1003
Dec	222	101	1	72	243	254	149	X	X	1042

2009

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19168160	19168175	19169830	19169845	19057050	19057065	19057099	X	X	
Jan	128	83	4	37	296	224	118	X	X	890
Feb	147	92	2	38	382	50	126	X	X	837
Mar	201	126	40	52	523	133	172	X	X	1247
Apr	193	192	0	97	35	284	166	X	X	967
May	259	208	0	84	349	177	120	X	X	1197

Meter no:	1 19168 160	2 19168 175	3 19169 830	4 19169 845	5 19057 050	6 19057 065	7 19057 099	8 X	9 X	Total
Jun	282	203	41	78	374	176	187	X	X	1341
Jul	181	133	12	41	210	92	114	X	X	783
Aug	447	325	72	101	537	319	297	X	X	2098
Sep	261	206	49	65	336	154	176	X	X	1247
Oct	261	173	39	48	314	176	170	X	X	1181
Nov	227	151	18	57	248	145	141	X	X	987
Dec	124	120	103	43	254	79	64	X	X	787

2010

Meter no:	1 19168 160	2 19168 175	3 19169 830	4 19169 845	5 19057 050	6 19057 065	7 19057 099	8 X	9 X	Total
Jan	117	94	0	40	502	43	86	X	X	882
Feb	168	117	82	44	411	135	111	X	X	1068
Mar	285	176	0	84	304	187	163	X	X	1199
Apr	225	146	38	114	315	179	171	X	X	1188
May	260	183	42	107	284	167	181	X	X	1224
Jun	253	161	43	147	263	158	182	X	X	1207
Jul	279	193	36	144	266	141	193	X	X	1252
Aug	273	28	67	76	295	165	196	X	X	1100
Sep	239	194	22	115	273	150	201	X	X	1194
Oct	246	175	53	236	270	126	180	X	X	1286
Nov	626	135	50	151	201	114	142	X	X	1419
Dec	28	123	289	131	271	157	114	X	X	1113

2011

Meter no:	1 19168 160	2 19168 175	3 19169 830	4 19169 845	5 19057 050	6 19057 065	7 19057 099	8 X	9 X	Total
Jan	1	120	309	91	654	68	99	X	X	1342
Feb	280	105	40	180	387	95	106	X	X	1193
Mar	330	222	27	116	220	118	176	X	X	1209
Apr	337	189	45	130	186	224	179	X	X	1290
May	324	221	96	105	227	191	179	X	X	1343
Jun	325	222	9	150	230	215	287	X	X	1438
Jul	353	218	0	92	288	258	82	X	X	1291
Aug	175	179	106	90	187	158	229	X	X	1124
Sep	262	203	54	55	244	142	228	X	X	1188
Oct	184	204	51	96	232	225	206	X	X	1198
Nov	152	133	14	61	156	139	156	X	X	811
Dec	126	110	17	54	341	139	111	X	X	898

2012

Meter no:	1 19168 160	2 19168 175	3 19169 830	4 19169 845	5 19057 050	6 19057 065	7 19057 099	8 X	9 X	Total
Jan	135	115	123	72	426	46	96	X	X	1013
Feb	133	115	186	54	255	0	93	X	X	836
Mar	203	194	200	96	236	17	151	X	X	1097
Apr	198	203	0	105	267	303	179	X	X	1255
May	217	251	20	103	329	220	215	X	X	1355

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19168160	19168175	19169830	19169845	19057050	19057065	19057099	X	X	
Jun	160	241	42	58	251	210	209	X	X	1171
Jul	212	218	19	59	251	6	191	X	X	956
Aug	194	217	43	66	284	56	211	X	X	1071
Sep	25	229	26	92	288	145	207	X	X	1012
Oct	4	236	36	84	321	117	207	X	X	1005
Nov	40	117	7	55	223	91	119	X	X	652
Dec	52	105	0	58	223	69	81	X	X	588

2013

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19168160	19168175	19169830	19169845	19057050	19057065	19057099	X	X	
Jan	41	108	11	55	471	74	85	X	X	845
Feb	55	119	4	67	277	89	105	X	X	716
Mar	138	195	15	73	211	141	178	X	X	951
Apr	180	205	103	110	197	162	194	X	X	1151
May	187	215	76	147	178	196	200	X	X	1199
Jun	183	231	29	171	259	145	228	X	X	1246
Jul	185	237	50	151	220	214	239	X	X	1296
Aug	179	242	33	106	188	151	228	X	X	1127
Sep	176	214	100	118	233	224	218	X	X	1283
Oct	132	202	40	109	250	121	196	X	X	1050
Nov	135	119	17	101	276	115	144	X	X	907
Dec	114	91	100	77	264	112	111	X	X	869

2014

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19168160	19168175	19169830	19169845	19057050	19057065	19057099	X	X	
Jan	100	100	0	118	484	101	87	X	X	990
Feb	101	94	221	120	235	98	91	X	X	960
Mar	150	143	69	142	194	161	155	X	X	1014
Apr	198	223	150	216	239	184	210	X	X	1420
May	203	226	86	222	274	161	240	X	X	1412
Jun	185	237	328	182	0	143	208	X	X	1283
Jul	180	263	286	200	452	133	198	X	X	1712
Aug	240	224	236	198	266	185	257	X	X	1606
Sep	195	271	320	172	368	141	222	X	X	1689
Oct	75	172	0	206	33	148	174	X	X	808
Nov	87	178	8	184	169	157	120	X	X	903
Dec	39	126	0	127	274	94	70	X	X	730

2015

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19168160	19168175	19169830	19169845	19057050	19057065	19057099	X	X	
Jan	47	119	0	143	394	75	197	X	X	975
Feb	42	138	87	156	250	37	5	X	X	715
Mar	96	214	14	214	236	82	159	X	X	1015
Apr	97	204	2	322	231	94	168	X	X	1118
May	129	239	0	362	253	123	207	X	X	1313

Meter no:	1 19168 160	2 19168 175	3 19169 830	4 19169 845	5 19057 050	6 19057 065	7 19057 099	8 X	9 X	Total
Jun	149	224	0	383	221	91	214	X	X	1282
Jul	143	206	0	278	195	8	198	X	X	1028
Aug	173	233	0	410	237	14	217	X	X	1284
Sep	175	208	23	426	219	38	225	X	X	1314
Oct	164	203	73	256	212	194	209	X	X	1311
Nov	137	180	45	261	228	190	186	X	X	1227
Dec	56	154	111	200	344	100	115	X	X	1080

2016

Meter no:	1 19168 160	2 19168 175	3 19169 830	4 19169 845	5 19057 050	6 19057 065	7 19057 099	8 X	9 X	Total
Jan	87	96	95	198	371	104	99	X	X	1050
Feb	94	184	0	235	245	139	131	X	X	1028
Mar	128	214	0	251	178	184	175	X	X	1130
Apr	165	217	0	317	288	225	213	X	X	1425
May	161	205	220	335	259	195	192	X	X	1567
Jun	200	217	166	384	266	204	232	X	X	1669
Jul	187	216	50	306	235	205	227	X	X	1426
Aug	175	209	0	272	224	212	178	X	X	1270
Sep	186	234	31	228	205	229	5	X	X	1118
Oct	124	258	0	243	210	192	0	X	X	1027
Nov	91	124	100	150	241	122	0	X	X	828
Dec	82	112	0	93	358	60	1	X	X	706

2017

Meter no:	1 19168 160	2 19168 175	3 19169 830	4 19169 845	5 19057 050	6 19057 065	7 19057 099	8 X	9 X	Total
Jan	76	121	49	112	389	67	49	X	X	863
Feb	90	137	48	138	176	95	80	X	X	764
Mar	103	170	55	191	161	155	92	X	X	927
Apr	131	262	0	199	198	208	113	X	X	1111
May	153	242	0	238	233	191	102	X	X	1159
Jun	180	252	200	205	238	187	97	X	X	1359
Jul	162	271	37	235	223	158	75	X	X	1161
Aug	152	292	122	212	206	140	76	X	X	1200
Sep	139	278	169	214	162	157	81	X	X	1200
Oct	110	257	150	263	201	130	90	X	X	1201
Nov	87	195	113	317	219	87	80	X	X	1098
Dec	76	137	179	281	326	55	46	X	X	1100

Sample: 2:

Address:	**C-82, Mohanagar Project.**		
Customer's Name:	Mrs, Amena Begum		
No. of Floors:	5	Building Area (SQ. M):	123.17

2007

Meter no:	1 19058 631	2 19058 646	3 19058 650	4 19058 665	5 19058 671	6 19058 843	7 19058 858	8 19058 862	9 19058 877	Total
Jan	221	59	103	94	70	96	53	18	103	817

Meter no:	1 19058 631	2 19058 646	3 19058 650	4 19058 665	5 19058 671	6 19058 843	7 19058 858	8 19058 862	9 19058 877	Total
Feb	179	46	75	114	75	84	59	38	100	770
Mar	175	32	27	121	132	86	71	73	136	853
Apr	197	58	78	181	167	132	94	82	182	1171
May	300	94	165	152	189	157	111	146	231	1545
Jun	314	96	210	220	214	191	94	126	263	1728
Jul	167	81	106	153	160	130	74	70	181	1122
Aug	296	106	131	179	187	155	86	80	232	1452
Sep	365	131	265	231	271	199	130	133	343	2068
Oct	202	102	132	162	181	141	83	64	192	1259
Nov	240	31	256	143	77	146	139	68	230	1330
Dec	134	65	160	115	58	120	96	52	190	990

2008

Meter no:	1 19058 631	2 19058 646	3 19058 650	4 19058 665	5 19058 671	6 19058 843	7 19058 858	8 19058 862	9 19058 877	Total
Jan	140	40	187	144	10	91	82	24	113	831
Feb	105	51	128	79	40	103	30	45	85	666
Mar	136	107	226	92	71	140	162	86	176	1196
Apr	156	148	166	122	117	167	216	116	249	1457
May	120	142	104	94	82	141	177	120	261	1241
Jun	141	140	150	120	94	170	110	130	250	1305
Jul	124	136	50	94	87	155	84	130	214	1074
Aug	201	182	26	138	108	192	291	160	282	1580
Sep	210	190	34	146	116	200	300	168	290	1654
Oct	281	140	180	152	40	150	11	170	204	1328
Nov	251	123	100	143	60	150	110	113	194	1244
Dec	201	34	87	134	7	118	64	54	144	843

2009

Meter no:	1 19058 631	2 19058 646	3 19058 650	4 19058 665	5 19058 671	6 19058 843	7 19058 858	8 19058 862	9 19058 877	Total
Jan	218	32	84	117	38	102	80	41	127	839
Feb	286	32	91	125	40	106	108	93	150	1031
Mar	343	36	109	150	49	127	129	111	180	1234
Apr	164	130	153	175	132	152	240	127	194	1467
May	252	174	50	37	114	151	207	118	182	1285
Jun	284	247	175	155	104	186	274	194	211	1830
Jul	272	254	194	92	103	182	316	161	188	1762
Aug	278	234	192	95	155	161	270	173	197	1755
Sep	270	109	153	125	69	288	265	115	211	1605
Oct	254	126	183	73	72	276	304	117	184	1589
Nov	280	70	133	95	65	205	280	110	155	1393
Dec	195	40	77	65	45	105	135	65	70	797

2010

Meter no:	1 19058 631	2 19058 646	3 19058 650	4 19058 665	5 19058 671	6 19058 843	7 19058 858	8 19058 862	9 19058 877	Total
Jan	240	0	105	90	40	130	165	110	95	975

Meter no:	1 19058631	2 19058646	3 19058650	4 19058665	5 19058671	6 19058843	7 19058858	8 19058862	9 19058877	Total
Feb	160	40	55	85	50	130	150	40	85	795
Mar	200	45	145	75	90	225	215	45	170	1210
Apr	217	135	144	87	133	264	223	102	181	1486
May	173	135	161	108	122	321	217	48	69	1354
Jun	173	-200	150	110	95	302	225	31	65	951
Jul	164	73	170	102	75	303	222	32	72	1213
Aug	206	90	140	143	125	350	278	57	145	1534
Sep	135	40	95	110	30	320	270	40	113	1153
Oct	156	127	125	87	115	278	212	45	81	1226
Nov	166	170	117	99	73	226	230	45	65	1191
Dec	150	153	104	65	52	166	194	145	38	1067

2011

Meter no:	1 19058631	2 19058646	3 19058650	4 19058665	5 19058671	6 19058843	7 19058858	8 19058862	9 19058877	Total
Jan	180	122	104	64	60	150	183	40	61	964
Feb	170	115	125	70	60	110	171	45	90	956
Mar	200	120	140	120	80	170	220	60	140	1250
Apr	200	100	140	150	110	175	220	220	140	1455
May	285	290	200	180	170	200	285	50	150	1810
Jun	225	90	117	269	100	205	245	100	190	1541
Jul	170	119	80	158	118	191	207	40	175	1258
Aug	228	192	105	191	166	270	283	102	224	1761
Sep	192	207	104	193	74	201	217	105	225	1518
Oct	258	170	136	95	88	257	278	108	260	1650
Nov	185	169	72	155	37	195	236	40	113	1202
Dec	495	186	78	88	31	119	191	0	87	1275

2012

Meter no:	1 19058631	2 19058646	3 19058650	4 19058665	5 19058671	6 19058843	7 19058858	8 19058862	9 19058877	Total
Jan	281	206	90	99	55	114	166	0	100	1111
Feb	308	181	81	127	60	118	150	0	99	1124
Mar	366	243	140	175	91	216	221	0	164	1616
Apr	239	226	124	166	141	225	206	20	176	1523
May	492	231	149	192	188	267	187	31	107	1844
Jun	289	232	137	171	156	249	214	25	27	1500
Jul	461	228	103	201	170	179	268	0	137	1747
Aug	302	229	134	208	43	288	239	0	147	1590
Sep	422	255	140	200	100	282	229	0	142	1770
Oct	329	252	125	210	64	233	226	0	132	1571
Nov	254	189	95	131	49	150	131	0	109	1108
Dec	201	123	62	85	65	87	95	40	80	838

2013

Meter no:	1 19058631	2 19058646	3 19058650	4 19058665	5 19058671	6 19058843	7 19058858	8 19058862	9 19058877	Total
Jan	195	136	68	103	0	72	101	0	107	782

Meter no:	1 19058 631	2 19058 646	3 19058 650	4 19058 665	5 19058 671	6 19058 843	7 19058 858	8 19058 862	9 19058 877	Total
Feb	269	162	72	127	23	97	80	0	80	910
Mar	408	240	120	190	70	215	206	0	135	1584
Apr	331	231	123	207	114	202	198	0	127	1533
May	176	226	400	213	94	221	173	0	187	1690
Jun	231	250	201	203	185	200	165	165	310	1910
Jul	497	203	0	248	61	304	53	0	0	1366
Aug	849	282	100	248	141	301	71	0	122	2114
Sep	149	271	250	243	145	264	25	400	99	1846
Oct	269	271	200	227	99	158	36	250	164	1674
Nov	331	254	40	193	85	206	73	100	129	1411
Dec	219	195	40	138	59	208	12	100	109	1080

2014

Meter no:	1 19058 631	2 19058 646	3 19058 650	4 19058 665	5 19058 671	6 19058 843	7 19058 858	8 19058 862	9 19058 877	Total
Jan	170	167	71	95	48	231	8	90	85	965
Feb	125	146	71	155	42	187	21	130	88	965
Mar	126	244	0	240	104	267	52	150	146	1329
Apr	249	283	162	252	123	292	16	184	153	1714
May	50	309	602	273	172	305	13	208	185	2117
Jun	127	251	0	255	172	343	30	195	139	1512
Jul	192	188	0	167	117	257	4	153	104	1182
Aug	363	312	0	277	162	360	14	245	183	1916
Sep	378	249	0	250	138	307	9	191	131	1653
Oct	252	230	13	205	120	247	80	130	121	1398
Nov	264	244	0	64	57	294	8	142	139	1212
Dec	218	138	55	6	46	176	0	75	125	839

2015

Meter no:	1 19058 631	2 19058 646	3 19058 650	4 19058 665	5 19058 671	6 19058 843	7 19058 858	8 19058 862	9 19058 877	Total
Jan	121	131	82	28	67	130	0	1	101	661
Feb	123	150	55	31	83	125	0	37	19	623
Mar	296	215	0	45	11	1	0	94	93	755
Apr	158	210	14	85	103	113	0	112	141	936
May	253	243	226	123	106	147	22	136	222	1478
Jun	235	226	256	117	106	151	17	138	205	1451
Jul	260	231	249	117	118	156	9	101	205	1446
Aug	256	248	281	71	109	160	264	161	282	1832
Sep	308	234	223	70	177	106	271	114	217	1720
Oct	263	228	245	101	140	123	250	124	268	1742
Nov	282	218	213	170	143	127	232	91	287	1763
Dec	779	138	104	71	54	96	84	17	124	1467

2016

Meter no:	1 19058 631	2 19058 646	3 19058 650	4 19058 665	5 19058 671	6 19058 843	7 19058 858	8 19058 862	9 19058 877	Total
Jan	200	31	95	40	68	73	83	40	138	768

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19058 631	**19058 646**	**19058 650**	**19058 665**	**19058 671**	**19058 843**	**19058 858**	**19058 862**	**19058 877**	
Feb	224	4	169	7	96	104	187	53	155	999
Mar	371	19	190	0	32	141	247	96	238	1334
Apr	0	0	253	0	273	204	235	122	284	1371
May	253	5	200	110	146	101	245	88	141	1289
Jun	3290	92	217	183	207	70	234	97	129	4519
Jul	-2725	2	217	155	145	49	235	117	123	-1682
Aug	279	8	210	171	268	5	250	95	153	1439
Sep	248	7	219	134	284	36	232	94	106	1360
Oct	273	130	238	122	260	203	249	91	160	1726
Nov	244	30	209	4	229	145	194	45	204	1304
Dec	245	53	128	12	182	128	147	32	145	1072

2017

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19058 631	**19058 646**	**19058 650**	**19058 665**	**19058 671**	**19058 843**	**19058 858**	**19058 862**	**19058 877**	
Jan	262	42	113	69	157	126	129	33	152	1083
Feb	363	74	156	89	165	141	156	48	197	1389
Mar	363	101	186	112	199	155	159	67	219	1561
Apr	506	97	218	139	175	229	208	120	282	1974
May	179	97	191	159	287	204	227	100	261	1705
Jun	185	110	152	190	314	235	236	129	239	1790
Jul	199	95	56	205	381	259	257	128	301	1881
Aug	275	83	68	180	310	225	234	101	230	1706
Sep	237	50	133	181	276	189	208	113	220	1607
Oct	270	78	119	173	210	207	258	106	284	1705
Nov	121	62	93	110	135	160	212	61	266	1220
Dec	217	48	72	85	68	127	183	43	188	1031

Sample: 3:

Address:	**C-76, Mohanagar Project.**		
Customer's Name:	Mrs. Shireen Sultana		
No. of Floors:	5	Building Area (SQ. M):	139.13

2007

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19057 224	**19057 239**	**19057 243**	**19057 258**	**19057 332**	**19057 347**	**19057 351**	**19057 366**	**19057 370**	
Jan	72	88	80	350	148	111	101	183	103	1236
Feb	64	113	112	437	184	152	86	98	72	1318
Mar	80	129	92	538	183	137	86	23	88	1356
Apr	100	204	133	537	221	260	137	75	137	1804
May	76	198	122	307	63	3	96	192	105	1162
Jun	120	234	165	464	140	122	220	317	141	1923
Jul	71	236	85	357	143	56	200	183	31	1362
Aug	75	213	130	397	207	75	122	151	23	1393
Sep	130	286	132	475	206	110	200	107	40	1686
Oct	112	231	112	343	171	61	182	72	22	1306
Nov	79	235	130	504	160	258	190	83	34	1673
Dec	63	120	74	357	120	94	74	15	40	957

2008

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19057224	**19057239**	**19057243**	**19057258**	**19057332**	**19057347**	**19057351**	**19057366**	**19057370**	
Jan	80	110	190	543	120	107	111	70	48	1379
Feb	90	149	200	660	164	121	100	44	66	1594
Mar	90	184	331	434	170	118	111	60	47	1545
Apr	109	225	162	358	192	158	150	327	72	1753
May	21	215	260	450	218	139	156	432	70	1961
Jun	25	220	262	432	201	142	160	392	72	1906
Jul	276	195	244	579	216	150	190	52	154	2056
Aug	142	230	194	530	264	171	220	473	156	2380
Sep	150	237	202	538	272	179	228	181	164	2151
Oct	0	223	204	371	204	157	172	510	60	1901
Nov	100	180	175	422	230	120	100	160	124	1611
Dec	83	111	141	351	123	92	100	-67	139	1073

2009

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19057224	**19057239**	**19057243**	**19057258**	**19057332**	**19057347**	**19057351**	**19057366**	**19057370**	
Jan	93	137	125	330	180	83	80	189	121	**1338**
Feb	95	132	170	355	158	110	58	57	136	**1271**
Mar	130	180	232	486	216	150	79	78	186	**1737**
Apr	137	177	112	100	154	239	139	470	154	**1682**
May	85	55	235	388	249	206	70	361	50	**1699**
Jun	241	300	209	355	251	96	35	514	164	**2165**
Jul	-186	-293	207	409	263	76	111	308	165	**1060**
Aug	40	8	101	216	132	42	46	133	71	**789**
Sep	121	284	307	618	312	255	150	791	174	**3012**
Oct	91	210	241	462	261	172	109	509	108	**2163**
Nov	100	145	175	350	205	145	135	355	135	**1745**
Dec	80	70	150	450	85	100	25	260	140	**1360**

2010

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19057224	**19057239**	**19057243**	**19057258**	**19057332**	**19057347**	**19057351**	**19057366**	**19057370**	
Jan	85	170	150	330	110	95	120	240	120	1420
Feb	70	105	150	340	105	85	80	200	90	1225
Mar	90	170	245	455	200	155	120	420	135	1990
Apr	70	130	180	390	145	110	140	446	105	1716
May	85	175	215	465	175	140	177	472	105	2009
Jun	85	155	211	445	203	145	141	460	115	1960
Jul	84	171	194	470	219	137	144	522	109	2050
Aug	96	201	222	500	263	58	203	619	128	2290
Sep	40	180	199	499	178	73	158	340	81	1748
Oct	0	176	212	521	217	166	138	548	163	2141
Nov	0	111	203	455	176	250	179	160	116	1650
Dec	0	85	176	388	150	172	187	274	79	1511

2011

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19057224	**19057239**	**19057243**	**19057258**	**19057332**	**19057347**	**19057351**	**19057366**	**19057370**	
Jan	0	66	163	392	154	134	188	90	94	1281

Meter no:	1 19057 224	2 19057 239	3 19057 243	4 19057 258	5 19057 332	6 19057 347	7 19057 351	8 19057 366	9 19057 370	Total
Feb	0	88	195	427	169	210	165	483	92	1829
Mar	155	107	205	463	211	270	235	166	88	1900
Apr	146	99	271	455	235	300	265	214	115	2100
May	169	81	269	460	260	303	295	408	115	2360
Jun	153	80	230	412	235	280	280	622	108	2400
Jul	175	75	245	450	235	255	274	749	128	2586
Aug	118	59	180	322	165	239	208	501	113	1905
Sep	124	90	283	493	220	293	309	842	250	2904
Oct	158	79	266	425	213	264	306	763	175	2649
Nov	79	48	233	375	145	196	207	201	163	1647
Dec	101	10	170	331	148	124	184	239	122	1429

2012

Meter no:	1 19057 224	2 19057 239	3 19057 243	4 19057 258	5 19057 332	6 19057 347	7 19057 351	8 19057 366	9 19057 370	Total
Jan	108	24	206	385	161	116	185	336	150	1671
Feb	117	22	203	350	144	135	144	277	140	1532
Mar	115	61	242	399	175	205	200	173	139	1709
Apr	111	73	49	434	197	203	185	257	119	1628
May	141	95	184	496	225	223	119	521	35	2039
Jun	135	83	167	399	235	197	133	326	235	1910
Jul	131	84	155	484	262	216	145	332	195	2004
Aug	126	91	142	432	206	230	134	373	161	1895
Sep	136	97	171	475	268	220	210	558	202	2337
Oct	102	64	110	334	177	162	140	213	190	1492
Nov	114	52	196	484	222	195	184	211	222	1880
Dec	95	12	30	340	125	121	115	309	90	1237

2013

Meter no:	1 19057 224	2 19057 239	3 19057 243	4 19057 258	5 19057 332	6 19057 347	7 19057 351	8 19057 366	9 19057 370	Total
Jan	104	7	78	361	133	99	88	370	104	1344
Feb	150	22	206	354	144	116	144	427	108	1671
Mar	44	0	31	458	163	203	67	21	169	1156
Apr	126	40	197	493	189	224	179	236	193	1877
May	129	70	150	479	213	209	139	315	166	1870
Jun	141	91	187	487	245	208	181	622	242	2404
Jul	149	101	205	562	264	238	195	351	213	2278
Aug	164	79	169	524	190	225	180	360	154	2045
Sep	155	119	184	522	256	209	178	414	204	2241
Oct	140	107	171	476	205	213	195	132	196	1835
Nov	108	113	173	429	213	178	170	187	171	1742
Dec	103	86	99	385	138	130	146	229	100	1416

2014

Meter no:	1 19057 224	2 19057 239	3 19057 243	4 19057 258	5 19057 332	6 19057 347	7 19057 351	8 19057 366	9 19057 370	Total
Jan	86	74	13	344	127	98	125	275	62	**1204**

Meter no:	1 19057 224	2 19057 239	3 19057 243	4 19057 258	5 19057 332	6 19057 347	7 19057 351	8 19057 366	9 19057 370	Total
Feb	83	81	45	321	127	105	115	199	74	**1150**
Mar	114	115	151	445	194	192	157	75	128	**1571**
Apr	116	177	0	481	228	205	185	634	167	**2193**
May	141	191	110	488	244	203	156	500	163	**2196**
Jun	162	171	130	493	243	242	200	316	158	**2115**
Jul	103	140	43	423	238	157	146	440	160	**1850**
Aug	158	40	65	510	243	269	206	158	198	**1847**
Sep	139	209	106	497	259	232	185	354	187	**2168**
Oct	128	153	67	468	193	228	184	286	145	**1852**
Nov	109	24	62	457	201	199	166	127	129	**1474**
Dec	75	74	21	367	139	106	128	184	86	**1180**

2015

Meter no:	1 19057 224	2 19057 239	3 19057 243	4 19057 258	5 19057 332	6 19057 347	7 19057 351	8 19057 366	9 19057 370	Total
Jan	108	69	51	390	142	104	124	234	94	1316
Feb	92	69	47	323	137	115	102	184	98	1167
Mar	126	87	76	445	207	193	157	769	135	2195
Apr	124	84	81	409	223	186	152	0	140	1399
May	142	105	103	445	265	213	176	249	162	1860
Jun	140	113	104	484	297	217	191	354	196	2096
Jul	119	108	64	643	227	230	164	53	194	1802
Aug	174	126	129	289	275	235	186	464	223	2101
Sep	135	139	104	505	238	237	193	274	206	2031
Oct	163	120	100	478	256	202	167	131	205	1822
Nov	128	101	66	445	216	174	132	206	155	1623
Dec	106	89	22	375	166	115	113	225	115	1326

2016

Meter no:	1 19057 224	2 19057 239	3 19057 243	4 19057 258	5 19057 332	6 19057 347	7 19057 351	8 19057 366	9 19057 370	Total
Jan	113	88	18	367	161	107	112	179	54	1199
Feb	75	84	49	390	186	133	81	221	30	1249
Mar	590	97	162	420	223	329	173	0	394	2388
Apr	419	143	113	537	290	86	240	260	0	2088
May	750	138	253	476	256	193	157	0	70	2293
Jun	133	156	228	447	260	200	159	397	48	2028
Jul	136	146	127	471	182	188	151	272	0	1673
Aug	188	171	162	481	33	37	159	507	0	1738
Sep	153	163	282	510	207	226	117	327	139	2124
Oct	161	212	30	474	385	211	79	202	35	1789
Nov	111	107	122	470	245	153	175	137	40	1560
Dec	69	101	118	465	203	103	151	331	41	1582

2017

Meter no:	1 19057 224	2 19057 239	3 19057 243	4 19057 258	5 19057 332	6 19057 347	7 19057 351	8 19057 366	9 19057 370	Total
Jan	85	98	98	394	108	120	143	222	10	1278

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19057224	**19057239**	**19057243**	**19057258**	**19057332**	**19057347**	**19057351**	**19057366**	**19057370**	
Feb	122	109	102	393	303	132	139	47	80	1427
Mar	106	87	85	452	255	118	104	122	34	1363
Apr	125	152	132	505	288	164	335	0	50	1751
May	210	185	161	531	310	218	194	188	74	2071
Jun	116	182	193	563	313	218	242	164	63	2054
Jul	217	122	193	596	336	221	285	193	109	2272
Aug	129	253	86	620	311	214	306	198	110	2227
Sep	167	140	231	504	220	173	227	45	79	1786
Oct	170	147	226	639	255	219	226	77	104	2063
Nov	140	84	132	600	257	144	168	112	41	1678
Dec	117	69	99	485	168	119	152	123	31	1363

Sample: 4:

Address:	**C-145, Mohanagar Project.**		
Customer's Name:	A.K.M Ibrahim Khalilulla		
No. of Floors:	5	Building Area (SQ. M):	166.56

2007

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19059714	**19059729**	**19059841**	**19059856**	**19059860**	**19059875**	**19059881**	**19059894**	**19059907**	
Jan	121	113	205	122	110	103	112	201	211	1298
Feb	223	160	101	61	63	11	103	40	102	864
Mar	165	155	800	800	250	200	135	150	180	2835
Apr	-34	-25	-214	-687	-143	-159	-80	-37	-59	-1438
May	28	0	739	0	0	74	0	0	0	841
Jun	220	0	960	70	148	90	186	47	134	1855
Jul	112	0	754	47	160	11	131	56	125	1396
Aug	223	168	700	170	90	166	170	151	240	2078
Sep	159	158	780	163	171	180	238	91	293	2233
Oct	156	154	635	144	97	150	45	203	204	1788
Nov	174	139	526	134	150	126	106	245	430	2030
Dec	130	130	279	70	63	79	60	100	183	1094

2008

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19059714	**19059729**	**19059841**	**19059856**	**19059860**	**19059875**	**19059881**	**19059894**	**19059907**	
Jan	194	150	460	53	91	105	83	82	182	1400
Feb	166	146	207	0	95	120	60	140	235	1169
Mar	229	185	260	64	130	191	134	155	338	1686
Apr	252	284	398	131	235	258	168	165	300	2191
May	525	142	318	119	180	205	162	120	462	2233
Jun	670	150	372	140	15	195	124	176	351	2193
Jul	427	200	390	163	0	206	60	180	260	1886
Aug	475	150	400	167	228	228	120	216	281	2265
Sep	450	346	405	174	216	244	128	192	284	2439
Oct	455	395	200	232	241	155	158	227	247	2310
Nov	343	115	237	136	162	171	123	133	233	1653
Dec	261	60	210	40	169	105	89	130	184	1248

2009

Meter no:	1 19059 714	2 19059 729	3 19059 841	4 19059 856	5 19059 860	6 19059 875	7 19059 881	8 19059 894	9 19059 907	Total
Jan	310	141	217	212	150	131	79	143	170	1553
Feb	349	195	322	134	1,175	146	90	141	235	2787
Mar	418	234	386	160	-673	185	108	169	282	1269
Apr	447	291	299	171	130	317	135	257	198	2245
May	409	234	262	193	257	242	135	246	1,158	3136
Jun	457	303	370	199	324	238	21	308	-793	1427
Jul	382	155	318	137	263	207	33	272	186	1953
Aug	425	339	414	165	296	215	108	271	183	2416
Sep	315	269	172	144	315	173	100	270	209	1967
Oct	377	118	147	177	270	222	87	218	195	1811
Nov	367	214	90	107	221	202	91	219	157	1668
Dec	270	136	35	107	130	122	65	147	116	1128

2010

Meter no:	1 19059 714	2 19059 729	3 19059 841	4 19059 856	5 19059 860	6 19059 875	7 19059 881	8 19059 894	9 19059 907	Total
Jan	277	123	245	132	133	127	79	160	103	1379
Feb	321	194	256	113	141	131	90	80	126	1452
Mar	395	332	462	158	229	222	136	124	147	2205
Apr	453	401	407	176	231	257	163	136	187	2411
May	372	350	40	178	241	221	154	183	161	1900
Jun	428	374	40	150	284	232	168	227	188	2091
Jul	468	280	321	157	354	208	164	179	186	2317
Aug	439	349	375	203	309	230	178	209	198	2490
Sep	385	72	373	210	345	175	155	160	135	2010
Oct	410	138	344	156	275	264	135	209	166	2097
Nov	232	108	300	110	190	156	104	100	117	1417
Dec	448	119	276	121	178	188	91	118	140	1679

2011

Meter no:	1 19059 714	2 19059 729	3 19059 841	4 19059 856	5 19059 860	6 19059 875	7 19059 881	8 19059 894	9 19059 907	Total
Jan	147	0	131	45	65	67	22	48	38	563
Feb	780	58	423	173	253	255	141	155	186	2424
Mar	729	118	359	159	230	271	174	150	160	2350
Apr	618	154	376	184	222	356	209	238	160	2517
May	866	115	388	192	222	290	87	234	164	2558
Jun	641	202	392	197	204	631	134	216	153	2770
Jul	269	161	432	140	246	707	153	181	169	2458
Aug	588	180	463	185	238	442	186	208	190	2680
Sep	699	175	492	182	268	463	171	293	155	2898
Oct	699	173	450	161	220	312	161	216	174	2566
Nov	516	137	454	97	165	178	114	144	132	1937
Dec	350	112	360	66	142	129	86	106	100	1451

2012

Meter no:	1 19059 714	2 19059 729	3 19059 841	4 19059 856	5 19059 860	6 19059 875	7 19059 881	8 19059 894	9 19059 907	Total
Jan	643	118	338	112	137	227	95	132	143	1945

Meter no:	1 19059 714	2 19059 729	3 19059 841	4 19059 856	5 19059 860	6 19059 875	7 19059 881	8 19059 894	9 19059 907	Total
Feb	544	137	359	96	152	206	90	101	129	1814
Mar	776	192	467	108	208	329	170	203	172	2625
Apr	509	184	347	95	188	272	152	40	157	1944
May	1,104	289	398	117	212	398	200	110	210	3038
Jun	381	223	369	97	196	942	189	67	165	2629
Jul	704	218	359	159	197	459	204	215	172	2687
Aug	521	217	371	115	232	267	182	164	131	2200
Sep	481	189	310	122	128	321	181	195	165	2092
Oct	443	160	258	102	148	240	173	150	126	1800
Nov	544	232	376	130	146	270	212	179	158	2247
Dec	371	116	170	65	70	141	66	38	93	1130

2013

Meter no:	1 19059 714	2 19059 729	3 19059 841	4 19059 856	5 19059 860	6 19059 875	7 19059 881	8 19059 894	9 19059 907	Total
Jan	338	176	199	86	107	187	91	166	132	1482
Feb	425	169	190	95	131	179	79	107	125	1500
Mar	544	220	220	121	176	220	99	130	140	1870
Apr	438	219	239	144	226	446	50	289	196	2247
May	532	232	245	129	227	283	0	220	167	2035
Jun	612	237	258	182	237	399	70	231	189	2415
Jul	712	225	267	203	253	419	152	265	187	2683
Aug	568	243	263	141	234	302	139	198	148	2236
Sep	700	259	285	161	270	420	141	238	205	2679
Oct	628	239	330	115	223	261	136	134	151	2217
Nov	568	201	282	86	130	265	118	148	136	1934
Dec	521	153	224	71	144	217	86	117	120	1653

2014

Meter no:	1 19059 714	2 19059 729	3 19059 841	4 19059 856	5 19059 860	6 19059 875	7 19059 881	8 19059 894	9 19059 907	Total
Jan	491	133	169	73	143	200	72	83	114	1478
Feb	418	109	141	70	128	167	64	71	95	1263
Mar	631	219	220	109	191	306	126	147	169	2118
Apr	721	267	241	133	242	521	182	192	191	2690
May	683	218	263	135	262	516	182	205	206	2670
Jun	713	228	273	145	272	526	182	215	216	2770
Jul	586	91	207	184	198	184	155	238	168	2011
Aug	688	247	278	162	243	298	175	230	192	2513
Sep	649	206	302	127	233	356	173	214	219	2479
Oct	635	200	329	107	203	247	169	162	218	2270
Nov	609	176	204	131	207	252	120	179	196	2074
Dec	375	147	157	137	198	203	80	129	144	1570

2015

Meter no:	1 19059 714	2 19059 729	3 19059 841	4 19059 856	5 19059 860	6 19059 875	7 19059 881	8 19059 894	9 19059 907	Total
Jan	377	156	185	106	214	197	91	137	165	1628

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19059714	19059729	19059841	19059856	19059860	19059875	19059881	19059894	19059907	
Feb	337	132	190	84	167	178	78	91	21	1278
Mar	437	197	297	149	197	300	137	190	4	1908
Apr	438	190	148	147	271	363	127	178	105	1967
May	532	242	19	164	257	530	174	122	238	2278
Jun	220	277	42	235	284	426	186	321	265	2256
Jul	254	238	334	169	259	349	149	186	209	2147
Aug	465	229	364	164	240	524	158	221	242	2607
Sep	424	131	339	138	181	345	112	194	268	2132
Oct	342	290	353	178	264	360	100	266	274	2427
Nov	342	146	244	198	244	234	103	208	229	1948
Dec	222	142	199	201	212	206	95	148	186	1611

2016

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19059714	19059729	19059841	19059856	19059860	19059875	19059881	19059894	19059907	
Jan	191	148	182	16	202	199	89	199	176	1402
Feb	339	156	198	31	217	208	105	210	214	1678
Mar	376	180	337	233	257	176	127	236	231	2153
Apr	440	236	413	358	316	191	187	298	333	2772
May	387	217	96	281	253	238	152	214	275	2113
Jun	433	212	392	272	269	246	155	271	232	2482
Jul	348	206	396	265	276	243	118	224	265	2341
Aug	450	237	483	315	284	280	159	295	313	2816
Sep	458	271	435	293	317	220	163	254	309	2720
Oct	536	240	358	334	240	242	150	280	237	2617
Nov	409	147	203	204	170	123	93	175	183	1707
Dec	489	163	212	175	189	135	100	192	201	1856

2017

Meter no:	1	2	3	4	5	6	7	8	9	Total
	19059714	19059729	19059841	19059856	19059860	19059875	19059881	19059894	19059907	
Jan	511	157	167	174	162	135	99	143	165	1713
Feb	482	161	210	212	170	191	116	117	215	1874
Mar	579	209	290	268	193	225	160	172	270	2366
Apr	661	257	345	299	263	261	171	202	301	2760
May	698	269	332	290	304	256	171	207	236	2763
Jun	710	307	344	229	317	242	150	206	206	2711
Jul	829	260	356	276	328	295	164	246	243	2997
Aug	728	273	316	217	323	264	174	255	319	2869
Sep	576	226	307	211	287	286	145	269	264	2571
Oct	695	186	343	214	265	278	146	251	264	2642
Nov	618	93	324	214	278	201	156	185	262	2331
Dec	519	125	266	186	245	128	114	110	239	1932

Appendix 9: Instrument used for Field Survey.

9.1. Temperature and humidity data logger:
EL-USB-2-LCD (Lascar Electronics)
Temperature, Humidity and Dew Point Data Logger with LCD Screen.

Controlling Parts:

1. Protective cover.
2. USB connector to PC port.
3. RH and Temperature sensors.
4. Alarm LED (red/yellow).
5. Record LED (green).
6. Mounting clip.

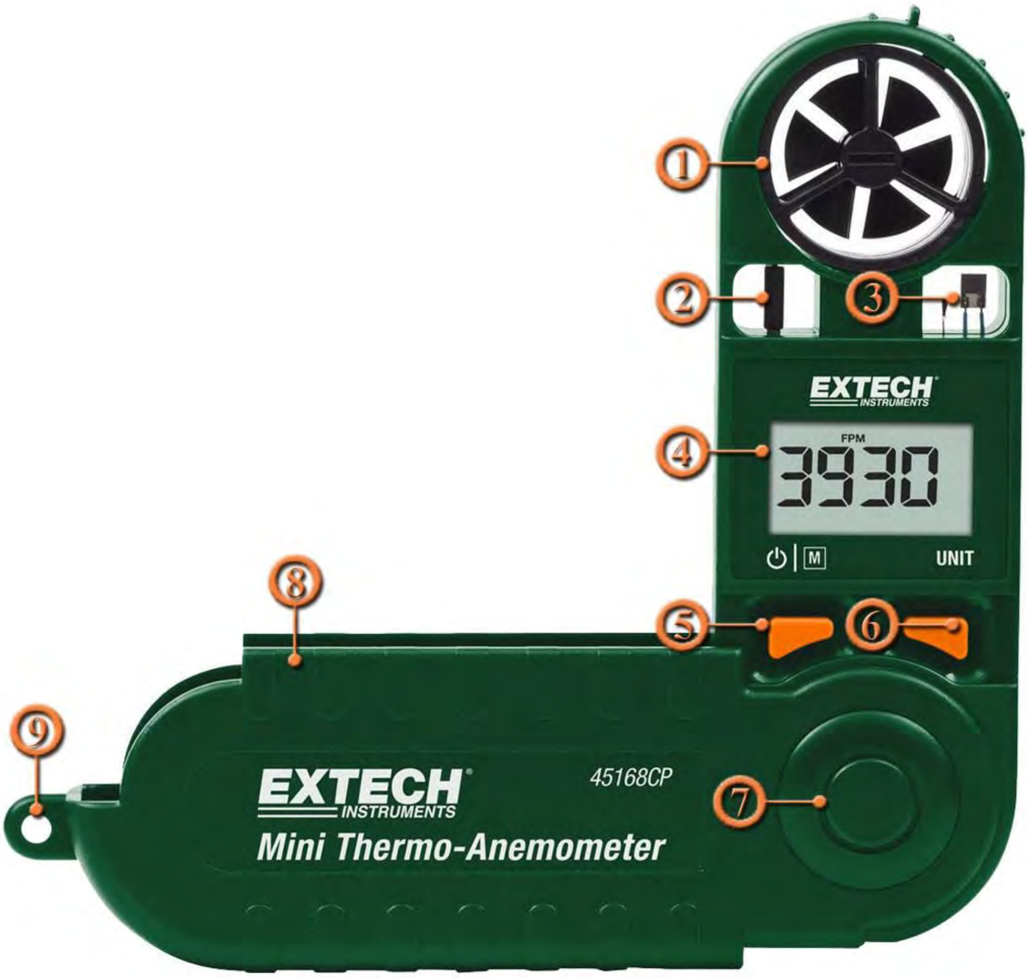
Features:

- 0 to 100%RH measurement range.
- -35 to +80°C (-31 to +176°F) measurement range.
- Dew point indication via Windows control software.
- USB interface for set-up and data download.
- User-programmable alarm thresholds for % RH & T.
- Status indication via red and green LEDs.
- High contrast LCD, with two and a half digit temperature and humidity.
- Immediate, delayed and push-to-start logging.
- Supplied with replaceable internal lithium battery and software.
- Environmental protection to IP67.

Specifications:

		Minimum	Typical	Maximum	Unit
Relative Humidity	Measurement range	0		100	%RH
	Repeatability		±0.1		%RH
	Accuracy		±3.0	±5.0	%RH
	Internal resolution		0.5		%RH
	Long term stability		0.5		%RH/yr
Temperature	Measurement range	-35		+80	°C
	Repeatability		±0.1		°C
	Accuracy		±0.5	±2	°C
	Internal resolution		0.5		°C
Dew Point	Accuracy		±1.1		°C
Logging rate		every 10s		every 12yr	-
Operating temperature range		-35		+80	°C
1/2AA 3.6V Lithium Battery Life			1		Year

9.2. Mini Thermo-Anemometer:
Extech 45118: Mini Thermo-Anemometer
Waterproof pocket size with Air Velocity, Temperature, Relative Humidity, Dew Point.



Controlling Parts:
1. Vane impeller.
2. Wind direction indicator.
3. Temperature and Humidity sensors.
4. LCD Display.
5. ON/OFF, M (MODE) button.
6. UNIT button.
7. Battery compartment (back).
8. Storage case.
9. Lanyard holder.

Features:
- Display Air Velocity, Relative Humidity, Dew Point, Temperature.
- Selectable averaging function of 5, 10, or 13 second intervals.
- Fold up protective housing extends to 9" for better reach, Tripod mount.
- Data Hold with Auto power off.
- Water resistant housing floats.

Specifications:

Measurements	Range	Resolution	Basic Accuracy
ft/min (feet per minute)	100 to 5500 ft/min	20ft/min	± (3%rdg + 40ft/min)
m/s (meters per second)	0.5 to 28m/s	0.1m/s	± (3%rdg + 0.2m/s)

Measurements	Range	Resolution	Basic Accuracy
km/h (kilometers per hour	1.8 to 100.6 km/h	0.7km/h	± (3%rdg + 1.4km/h)
MPH (Miles per hour)	1.1 to 62.5 MPH	0.2MPH	± (3%rdg + 0.4MPH)
knots (nautical miles per hour)	1.0 to 54.3 knots	0.3knots	± (3%rdg + 0.6knots)
Beaufort Force	1 to 17 BF	1 BF	± 1
Temperature	0 to 122°F (-18 to 50°C)	0.1°F/°C	±1.8°F/±1°C
Relative Humidity	10% to 95%	1%	± 4%
Dew Point	32°F to 122°F	1°	± 2%
Power	CR2032 Lithium battery		
Dimensions	5.25 x 2.75 x 0.75" (133 x 70 x 19mm)		
Vane	1"(24mm) diameter		
Weight	3oz (95g)		

...X…