Study of Thermal Environment in Relation to Human Comfort in Production Spaces of Ready Made Garments Factories in the Dhaka Region

by

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Md. Nawrose Fatemi

DEDICATION

To My Parents,

Md. Azizul Hakim

Rokeya Hakim

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Abstract

The actual performance of a building sustains rational occupancy and use in terms of individual and organizational well-being, health and productivity. Poor building performance is a result of the conflict between different indoor environmental attributes like lighting, ventilation and thermal comfort. A thermally comfortable indoor environment is essential for the wellbeing of the occupants. As an energy deficient country Bangladesh, it is not viable to use artificial means here to ensure indoor environmental comfort.

Bangladesh is a developing country. The economic development of the country depends firstly on agriculture and then on industry. Ready Made Garments (RMG) sector plays a pivotal role in its economy. A large population employed in this sector, especially at the production area. But the garment factories in Bangladesh have been heavily criticised over the last 30 years for the working environment in which employees have to work. The research work concentrates on the existing thermal conditions within the production spaces with respect to thermal comfort. The indoor environment affects several human responses, including thermal comfort, perceived air quality, sick building syndrome symptoms and performance in work. Among these, this specific study focuses on the correlation between thermal comfort and work productivity with a view to improve the workplace environment in production spaces of RMG factories. It also evaluates the effects of the environmental comfort factors (air temperature, relative humidity and air movement) on the physiological comfort of the workers.

The implication of this study anticipates having a clear understanding on indoor environment of RMG factories in Bangladesh. So the determination of the environmental conditions that is perceived as comfortable by the workers in the production spaces is the primary concern. The study on thermal comfort extracts from the results of the field survey carried out with the workers in the production spaces where the environmental variables that relate to different thermal sensations were recorded over a period of time. This study also aims to set an outline for thermal comfort (required temperature levels along with other comfort factors i.e. humidity and wind speed) to attain comfortable conditions for the improvement of the workers' work efficiency in production spaces.

1. INTRODUCTION

1. INTRODUCTION

Ready Made Garments (RMG) sector is the single major export earning sector of Bangladesh. This sector has proved to be a success story for the country. The industry started in the late 1970s, expanded heavily in the 1980s, boomed in the 1990s (Robbani, 2000) and presently this sector is tried to improve as per international standard. The RMG factories are categorized as mass production industries as they involve production of a large volume of products by continuous and repetitive action by man and machine on a particular manufacturing process. Thus it is fully supported by the workers who work in the factory building all day long. The economy of this sector depends on the performance of the workers. The physiological comfort of the workers within an industrial building, as with the inhabitants of practically any other building, is largely dependent on indoor environment of their working areas (Ahmed, N. 1992).

Recently, a growing concern has developed to understand the effects of indoor environmental conditions on workers' performance. As production, especially garments' production involves many complex operations and relationships, no standard method or way exist to measure workers' productivity. There are, however, many studies that have identified factors influencing workers productivity and attempted to measure their individual effects. One of these effects is thermal environment by which the efficiency of workers and their productivity is affected (i.e. negative effect reduces productivity). For this, the indoor environment becomes much more important for health and comfort. The relationship between indoor environment, workers' performance and their productivity are shown by the following diagram:

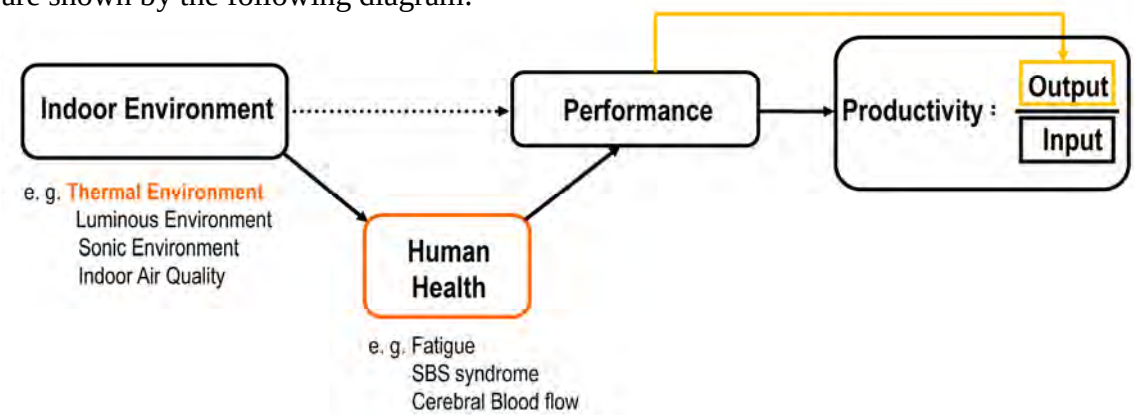

Figure1.1: Conceptual Diagram for the Evaluation of the Negative Effect of Indoor Environment on Productivity (Tanabi, Haned & Nishipana, 2007)

The indoor environment affects several human responses, including thermal comfort, perceived air quality, sick building syndrome (SBS) symptoms and performance in work. Among these, this specific study focuses on the correlation between thermal comfort and work productivity to improve the workplace environment in production spaces of RMG factories. It also evaluates the effects of the environmental factors (air temperature, relative humidity and air movement) on the physiological comfort of the workers.

1.1. PROBLEM STATEMENT

Since 1988, when the export-oriented Ready Made Garment (RMG) sector for the first time overtook the traditionally dominant jute sector in terms of gross export accruals, the garment sector has continued to consolidate its predominant position in Bangladesh. The sector's contribution to export earnings has increased steadily, with all other sectors being comparatively static (Majumder et al, 2000). In financial year 2007-08, earnings in the export-oriented garment sector were 10699.8 million dollars, which constituted 75.83 percent of total export earnings (EPB, 2010). RMG exports from Bangladesh have been achieved remarkable success since the last two decades and exceeded the most optimistic expectations. Today this export sector is a multi-billion-dollar manufacturing and export industry in the country. The overall impact of this sector is certainly one of the most considerable social and economic developments in contemporary Bangladesh.

There are about 8000 export oriented ready-made garment industry in Bangladesh, those are clustered over mainly Dhaka (Naz, 2008). And at present approximately 2.5 million workers (among which 80% are female) are working in this sector which is a great source of employment (Adhikary et al, 2007). So, those factory buildings accommodate the largest volume of population, especially at production area. Efficiency and sustainability of this sector depends on the performance of those workers. It is widely accepted that productivity of the workers in the production line is highly dependent on the quality of indoor environment (Ahmed, N. 1992).

However, garment factories in Bangladesh have been heavily criticized over the last 30 years for the working conditions in which employees have to work, causing health hazards for the workers (Naz, 2008). Previously different aspects of the garment industry in Bangladesh have been investigated. Of the various aspects, the problems in indoor

environment (especially on thermal comfort) and the working conditions in the production area of the RMG industry should be given the highest priority in the present day.

The overcrowding of workers in the small production areas, obsolete working equipment, poor ventilation and artificial lightings are the reasons for high indoor temperatures. During summer, extensive working hours of 10-12 hours per day also become most exhaustive. Especially in the two main workspaces, sewing and ironing, the impact of overheating is the most critical. Uncontrolled usage of artificial lighting in sewing spaces and steam irons in the ironing space are the major causes of high indoor temperatures. Moreover, the cooling solutions for such factories usually comprise ceiling fans, exhaust fans and recently evaporative coolers. The potential for natural ventilation is minimal with deep floor plans with low ceiling heights. The resulting lack of heat dissipation leads to an oven-like working environment, and is fast becoming a prime health and safety concern for the industry (Naz, 2008). Therefore effort should be placed to predict the thermal environment conditions (temperature, humidity and air velocity) so that thermal comfort of the workers could be achieved in production spaces.

Figure1.2: Temperature Hazard by Extensive Usage of Artificial Lighting and Steam Irons in the Production spaces (in Sewing and Ironing Area) ; Use of Ceiling Fans and Table Fans as Cooling Solution (Marked With Golden Outline)

Recently, in RMG sector, the issues of Social Compliance has also become a burning issue and lots of pressure have been imposed on the industry proprietors as well as on the Government regarding the safety of workers and their overall welfare which has resulted into growing emphasis on the issue of safety and welfare of workers. So concentration of

the researches should be focused more towards these crucial matters. Previously, research carried out in this field usually focused on the social issues of RMG workers. But the workers' response towards the physical environment of the workplace and it's relation with their productivity has not been examined, especially in Bangladesh which will be very significant for the overall welfare of the workers.

Therefore, to overcome these stated problems, a proper study is needed to develop an analytical model which will focus on the indoor environmental condition of the production spaces with respect to thermal comfort.

1.2. RESEARCH QUESTION

Generally to narrow down the research focus, it is better to begin with a more focused question. So in this research, the focus is on the thermal condition with respect to human comfort in production areas of readymade garments within Dhaka Region. Again, to strengthen the research idea, it should pass the "so what" test. For this the potential impact of the research is very important. Here, the comfort zone has to be determined through research, to ensure appropriate indoor thermal condition and to open potential avenues for the architectural design solutions for production spaces in the RMG Factories of Dhaka. Here the research questions for this research are:

- What is the thermal condition with respect to human comfort of the production spaces in RMG factories in Dhaka?

- How do the Thermal Comfort Factors (temperature, humidity, wind speed, radiation) influence the work efficiency or productivity of the workers in production spaces?

1.3. AIM AND OBJECTIVES:

The research work concentrates on the existing thermal conditions within the production spaces with respect to human comfort. The research aims to suggest a required level of thermal variables (temperature, humidity and air velocity) to attain thermal comfort and thereby improve work efficiency of the workers in ready-made garments factories in Dhaka. So, the investigation has two main objectives:

- To identify the environmental conditions those are perceived as comfortable by the workers (i.e. response of the workers) in the production spaces and their effect on their work efficiency.

- To determine comfort conditions (i.e. temperature range, humidity and wind speed) for people working at readymade garments factories and doing work at production area to attain thermal comfort.

These objectives attempt to be reached by fieldwork (in different activity zones at RMG factories from workers' response) and analysis of the thermal environment (of production areas with the help of a suitable method) for the assessment of human comfort in production space.

1.4. SCOPE OF WORK

This research is concerned with human response in indoor spaces (production area) & assumes that thermal comfort in interior is influenced by the environmental factors (temperature, humidity, wind speed) of the industry. This research also assumes that here works are performed with little or no radiant heat. For the workers, it is considered that they are wearing regular summer clothing. Here the study also presumes that the indoor thermal comfort at an industry building is different than that of residential buildings. It is conducted within a limited extent with a limited number of workers' responses. But further research on this can be made working with more samples, others issues and with reference to other context.

The outcome of the research would give some indication that can be used to develop the building code, the factory rules and local compliances for the RMG factories in future. It would also establish a comfort zone to ensure appropriate indoor thermal condition and later it may open some potential avenues for the architectural design solutions for production spaces in the RMG Factories of Dhaka Region. But the research-outcomes can be applicable in the climatic context of Dhaka city and any other countries of similar climatic context. For other countries, the climatic data must be changed according to the context of that country. But some general recommendations can be applied to all the production spaces of RMG buildings.

1.5. RESEARCH METHODOLOGY

The study was conducted through three main phases. The first phase consisted of desk research that was executed for theoretical framework and data analysis. The second phase was a field research (i.e. to conduct case study for parametric study, environmental monitoring and workers' response for comfort condition determination) that was conducted through a questionnaire survey. And the last phase comprised of analyzing and evaluating the data from the first and second phase studies using qualitative and quantitative methods to establish a comfort zone. Sequentially, the process can be described as:

- Desk research- review on indoor comfort, existing indoor condition of RMG factories and climatic influence
- Field survey (parametric study, environmental monitoring and questionnaire survey)
- Data Analysis (statistical analysis and comparison through software analysis)

The methodological framework is discussed elaborately along with conceptual framework, process of analysis and structure of investigation in the next chapter (**Chapter 2**).

1.6. ORGANIZATION OF THE RESEARCH

This study is organised in several chapters. 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 research problem and questions, objectives, scopes and limitation of the study.

Chapter 2 deals with the methodology of the research. The conceptual framework, method and the process of analysis are explained here.

Chapter 3 develops an understanding of the microclimate of Dhaka to formulate an environmental database for simulation studies and field work of the study.

Chapter 4 attempts to establish a knowledge base for overall research background and it describes the context of the research, the origin of the variable and control group for this study and also focuses on causality (cause and effect relationship) to identify the effects of thermal comfort on work efficiency of production space.

Chapter 5 elaborates the growth of RMG factories, work flow in production spaces and workers, general working environment at the RMG factories in Bangladesh. It also states present codes, rules and regulations for Bangladesh and other countries.

Chapter 6 explains the selected cases, response of the workers and the results. It also contains the results and analyses of the case studies.

Chapter 7 contains the discussions and recommendations for further development and study of thermal comfort within the defined context.

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2. RESEARCH FRAMEWORK

2. RESEARCH FRAMEWORK

2.1. INTRODUCTION

According to Mouly (1978), '*Research is best conceived as the process of arriving at dependable solutions to problems through the planned and systematic collection, analysis, and interpretation of data'*. And Research methodology controls the study, dictates how the data are acquired, and arranges them in logical relationships, sets up main approach for refining and synthesizing the raw data (Leedy et al., 2001). This chapter describes the type of research design, overall procedure and strategy involved for the study as well as the tool for data collection, data analysis and interpretation for this research. This study was conducted through three main phases. The first and last phases consisted of desk studies that were executed for theoretical framework and data analysis. The middle phase was a field research that was conducted through a questionnaire survey.

2.2. CONCEPTUAL FRAMEWORK

Based on the theoretical perspective and other literature studies, the conceptual frame work of this research can be developed. It can be shown through the following diagram:

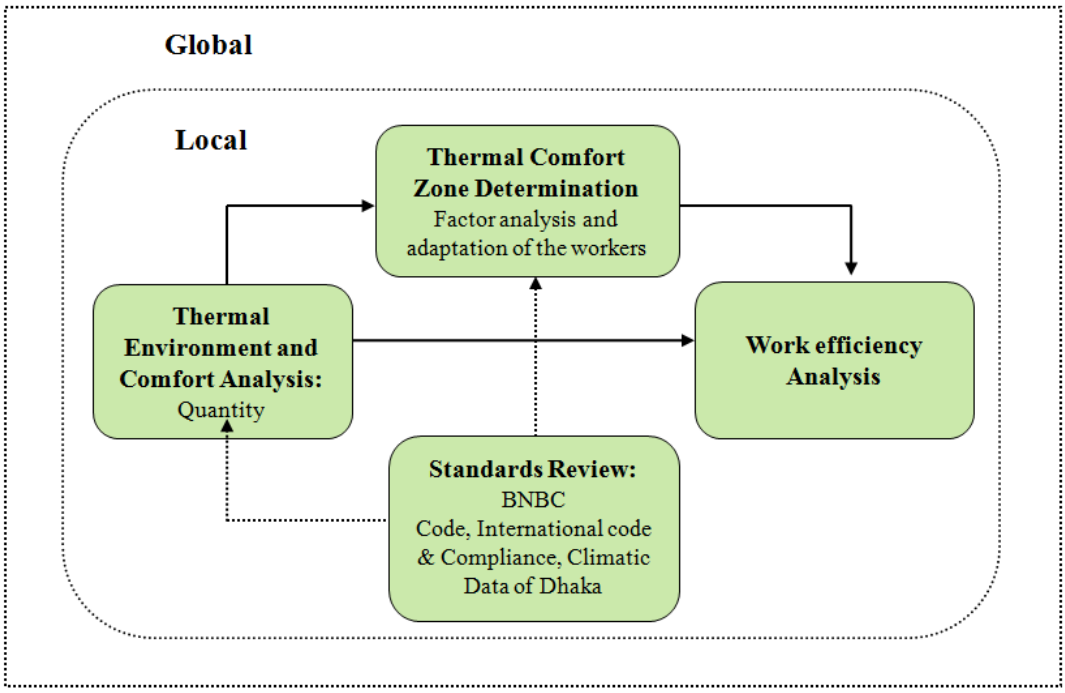

Figure 2.1: Conceptual framework of the research

Basically, conceptual framework of the study is a structure that can hold or support a theory of a research work. It presents the theory which explains why the problem under study exists. Thus, the conceptual framework is nothing but a theory that serves as a basis for conducting research. It helps the researcher see clearly the variables of the study and provide a general framework for data analysis (Khan, 2010)

2.3. RESEARCH METHOD

The first phase defined the theoretical framework for this study. This phase, mainly a desk study, encompassed extensive literature reviews of books, journal papers, research and documents to predict the temperature or combination of thermal variables (temperature, humidity and air velocity) which will be found comfortable for the workers in production spaces in the context of Dhaka. In this phase, related climatic factors for Dhaka city, indoor thermal condition and other comfort issues like humidity level, indoor wind velocity is analysed from previously published data. The local standards, Bangladesh National Building Code, Bangladesh factory Act 1965, local and international compliances are also studied thoroughly.

The second phase involved a field survey mainly in overheated period (from April to June). This field survey consisted of visits to the instrumental case study with embedded units (RMG Buildings' Production Space) and questionnaire survey with the workers of those buildings. Those case study RMG buildings are both multi-storied and single-storied, representative of typical RMG buildings in Dhaka region. All the information that were analyzed during this phase was intended to satisfy the structure outlined in theoretical framework formed in the first phase. The detailed field measurement has been carried out in overheated period to collect indoor environmental factors along with personal factors for human comfort in the existing condition. All measurements were carried out following the recommendations of the Standard ISO 7726 (1998). The entire field measurements conducted in this research used the following instrumentation:

HOBO U30 was the basic monitoring system to collect the continuous data for overall indoor environmental condition to calculate the temperature range, RH and wind speed and Kestrel 3000 Pocket Weather Meter was the handheld weather-monitoring device for

spot measurements to calculate local environmental condition. The specifications are as follows:

HOBO U30 monitoring system

Figure 2.2: Measurement setup at study area and measurement tools- HOBO data logger

Temperature measurement range: -40° to 75°C

Temperature accuracy: ±0.21° at 25°C

RH measurement range: 0-100% RH

RH accuracy: ± 2.5% typical, 3.5% maximum, from 10 - 90% RH

Wind Speed range: 0 to 44 m/s

Wind Speed accuracy: Greater of ± 0.5 m/s or ±4% of reading

Kestrel 3000 Pocket Weather Meter

Figure 2.3: Measurement tools- Kestrel 3000 Pocket Weather Meter

Temperature measurement range: -29° to 70°C

Temperature accuracy: ±1°

RH measurement range: 5-95% RH non-condensing

RH accuracy: ± 3% RH

Wind Speed range: 0.4 to 40 m/s

Wind Speed accuracy: Greater of ±3% of reading or least significant digit

The last phase involved in analyzing and evaluating the data from the first and second phase studies using qualitative and quantitative methods. The environmental conditions that were perceived as comfortable by the workers (i.e. response of the workers) in the production spaces were analyzed and a thermal comfort index is developed for the production spaces of RMG Factories.

2.4. RESEARCH TYPE AND STRATEGY

Case studies have been viewed as a useful tool for the preliminary, exploratory stage of a research project, as a basis for the development of the 'more structured' tools that are necessary in surveys and experiments (Rowley, 2002). Yin (2003) defines case study research as an empirical enquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and the context are not evident. Anderson (1993) sees case studies as being concerned with how and why things happen, allowing the investigation of contextual realities and the differences between what was planned and what actually occurred. Stake (1995) described that case study can be regarded as a research that incorporates several different methods for the collection of data and for the analysis and processing of findings. The possible methods used in this study under case study research strategy are:

Methodology	Possible methods
Case Study as Research Strategy	Statistical analysis
	Observation
	Interview
	Questionnaire for user feed back
	Comparative analysis
	Computer software analysis

Table 2.1: possible methods used in case study research strategy

According to Rowley (2002), case studies can be divided into holistic or embedded studies. Holistic case studies examine the case as one unit. They focus on broad issues of organisational culture or strategy. Embedded designs identify a number of sub units each of which is explored individually; results from these units are drawn together to yield an overall picture. The biggest challenge with embedded designs lies in achieving a holistic perspective from the analysis of the sub-units.

Yin (2003) distinguishes between a single-case design and a multiple-case design. Single-case design uses only one case to deal with the research questions and in multiple-case design, two or more cases are studied. In this study, the production space in RMG buildings that accommodates a large number of workers is the primary case and the different RMG buildings (with either Multi-Storied Production Space or Single-Storied Production Space) surveyed are the multiple-case design. The case study performed in this research is a multiple-case design with embedded units.

Stake (1995) uses three terms to describe case studies: intrinsic, instrumental and collective. Intrinsic case study is the one in which study is undertaken because one wants better understanding of that particular case, where as in an instrumental case study, a particular case is examined to provide insight into an issue or refinement of theory. And a collective case study is an instrumental study that is extended to several cases (Stake, 1995). The case study in this research is collective in nature.

2.5. INVESTIGATED ISSUES

The following issues in the case studies have been investigated:

- The overall indoor environmental condition (the temperature range, RH and wind speed) of the production spaces
- The sensation of the workers on the indoor environmental condition and their prediction on thermal comfort.
- The localized environmental condition in respect of the prediction of the workers on thermal comfort.
- The personal factors (clothing and metabolic rate) of the workers in the production spaces

- The factors related to workers (Absenteeism rates, sickness records, discontinued work flow, speed and accuracy of work, number of error etc) that affect the production process.

The table below (table 5.2) shows the indicators, variables and sources.

Research Questions		Variables	Indicators	Sources
What is the thermal condition in respect of human comfort of the production spaces at RMG factories in Dhaka?	:	Environmental	- Air Temperature, - Air Velocity, - Relative Humidity	Primary data and Questionnaire survey
	:	Personal	- Clothing Insulation - Activity Level, i.e. Metabolic Rate	Primary data and Observation
How the Thermal Comfort Factors influence the work efficiency or productivity of the workers in production spaces?	:	Individual Performance	- Absenteeism Rates - Sickness Records	Primary data and Archival records
	:	Group tasks	- number of error - speed and accuracy of work	Primary data and Observation Archival records,

Table 2.2: indicators and variables

2.6. SELECTION OF SAMPLE

The technical criteria to select of the sample (case study buildings) were:

Production Capacity	:	10 tons/ day (min.)
Plot Area	:	2000 m^2 (approx.)*
Building Size	:	1350 m^2/ floor (approx.) *
Compliance Issues	:	Satisfies Environmental Management, Production Management and Human Resource Management
Purpose Built	:	Designed by architect
Composite	:	Knitting, Cutting, Sewing and Finishing

*According to plot distribution rule by EPZ Authority, Bangladesh.

The selection was also based on the following criteria:

- They represent the typical volume of the production space (either Multi-Storied or Single-Storied) for RMG buildings in Dhaka
- They are located in two different industrial zones in Dhaka
- They are accessible to collect data and information
- Workers and owners cooperate to conduct questionnaire and photographic survey.

2.7. DATA ANALYSIS AND EVALUATION

The two popular types of analysis used in case study research are structural analysis and reflective analysis. Structural analysis is the process of examining case study data for the purpose of identifying patterns inherent in discourse, text, events, or other phenomena. And reflective analysis refers to using primarily intuition and judgment to portray or evaluate the phenomenon (Dooley, 2002).

Here the structural analysis was followed to identify patterns in the research. Qualitative data (collected through questionnaire survey) and quantitative data (collected by instruments) were categorized, tabulated, and recombined to address the initial purpose of the study. Facts and discrepancies in accounts have been crosschecked by using triangulation (computer software analysis). Data was analyzed by placing information through specific techniques (include placing information into array, creating matrices of categories, tables and excel spreadsheets).

2.8. VALIDATION OF RESULTS

Good research practice obligates the researcher to triangulate, that is, to use multiple methods, data sources, and researchers to enhance the validity of research findings (Mathison, 1988). According to Johansson (2003), *'Triangulation provides an important way of ensuring the validity of case study research. Normally, data collection methods are triangulated (many methods are combined), but in addition to this, data sources, theory, or investigators might also be triangulated'.* Patton (2001) advocates the use of triangulation by stating '*triangulation strengthens a study by combining methods. This can mean using several kinds of methods or data, including using both quantitative and qualitative approaches*'.

Again, Garson (2002) stated that the case study method, with its use of multiple data collection methods and analysis techniques, provides researchers with opportunities to triangulate data in order to strengthen the research findings and conclusions. In his explanation of how to use triangulation as a research strategy, Denzin (1978) outlines four types of triangulation:

(a) Data triangulation including time, space, and person,
(b) Investigator triangulation,
(c) Theory triangulation, and
(d) Methodological triangulation.

Among the different methods of triangulation described above, data triangulation and method triangulation were used in this study. Data triangulation was used to investigate indoor environmental condition through two different instruments. Method triangulation was used to investigate the personal factors through Questionnaire survey and Observation.

2.9. STRUCTURE OF INVESTIGATION:

The study is being conducted as per the following subcomponents:

- Objective Formulation
- Review of Meteorological Data of Dhaka; Indoor Comfort Issues and Existing Condition of Local Compliant Factories
- Case Studies on Local Compliant Factories
- Environmental monitoring of factory buildings
- Questionnaire survey on indoor thermal comfort
- Determine thermal comfort index

The Schematic Diagram of Research Methodology is as follows:

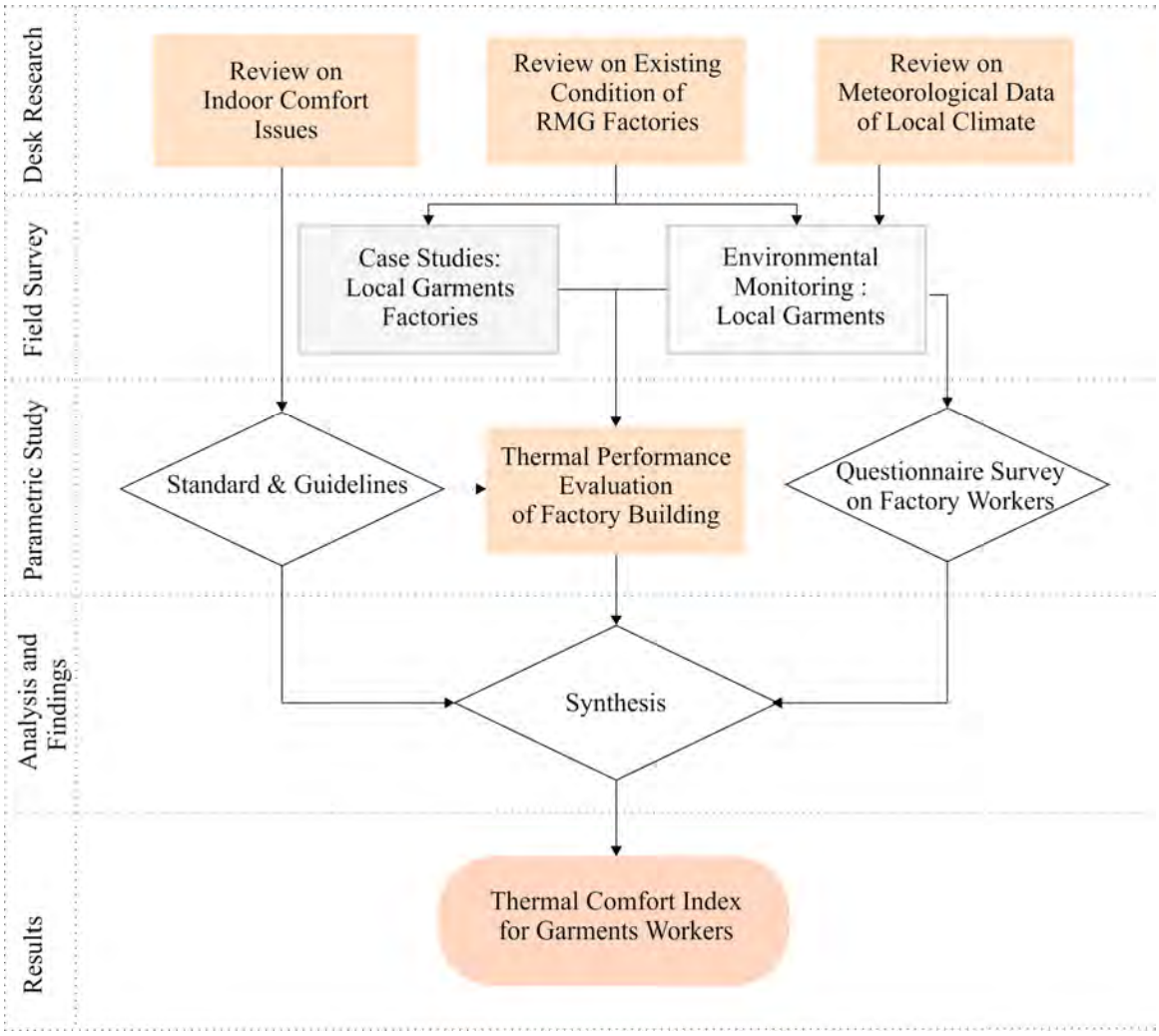

Figure 2.4: Schematic Diagram of Research Methodology

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3. CLIMATE AND INDOOR ENVIRONMENT

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3.1. INTRODUCTION

A building may be defined as a structure that provides spaces having an environment that is amended from that of its surroundings to suit particular purposes (Groth, 2007) such as living, working and multiple other activities. Primary objective of buildings is the protection of the people who live and work within them from the weather. According to Vitruvious, one of the most fundamental functions of architecture is to provide shelter from the dynamic conditions of our environment. But he also mentioned: *'We must at the outset take note of the countries and climates in which building are built.'* So architecture initiates from function, local climate and availability of local resources (Looman, 2007). The creation of a comfortable indoor environment is one of the basic requirements of building design. The successful design of buildings relies on an appropriate understanding of the climate (Pretlove and Oreszczyn, 1998).

Eventually architecture advanced along with humanity, emerging into a craft where aesthetic and impression gained importance. More functions became subject of the built environment and the original function of giving shelter had transformed into providing comfort. The desire to control the indoor environment for the occupants' comfort requirement resulted in the implementation of mechanical climate control systems that operate completely separate from the rest of the building. And buildings themselves become completely separated from the (outdoor) environment they were placed in (Looman, 2007). As Bangladesh is an energy deficient country, it is no longer acceptable to rely solely on energy consuming mechanical devices to supply the comfortable indoor conditions that we require.

In order to take advantage of the climate to comply with the thermal needs of a building, it is critical to analyze the climate within which the site is located and to collate relevant data that will support an appropriate strategic design. The different climate regions of the world are commonly categorized in terms of their thermal and seasonal characteristics e.g. hot-dry, warm-humid, composite, moderate and cold (Upadhya, 2007). Each region requires distinctive design responses. In order to define local climate more precisely, according to the generic typologies, detailed information about the local air temperature,

humidity and wind patterns is required (Gonzalo and Habermann, 2006). These climatic factors also influence the indoor conditions of the built environment.

According to Katzschner (1988), *'Climate is an ever existing factor in a built environment and the objective of studying climate is to improve the living condition'.* The environmental factors (i.e. air temperature, humidity, air movement and radiant temperature) which determine the indoor thermal conditions are of primary importance for the performance of human activities, and maintenance of health and well-being. According to Zain *et al*. (2007), '*Factors that have influence on thermal comfort to human include dry bulb temperature, relative humidity and air flow'*. These factors are measured singly but they act in combination, while the strength of one factor can be outbalanced by the strength of one or more other factors. The combination of the factors is often referred to as the indoor microclimate. The building design has to relate appropriately to the outdoor climate to assure a better indoor microclimate.

This microclimate varies both in space and in time. The indoor microclimate is particularly strongly influenced by temporary outdoor climatic conditions in the immediate surroundings. The combination of the factors determines indoor thermal comfort which is based on human judgement. This thermal comfort is determined by the relationship between outdoor and indoor thermal climate (WHO, 1991).

3.2. CLIMATE OF BANGLADESH: OVERVIEW AND CLASSIFICATION

Bangladesh, with an area of about 147,570 square kilometres (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 et al, 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, 2006). 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, 1994). Generally the climate has short and dry winters while the summer is long and wet.

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. 2006). Meteorologically the climate of Bangladesh is categorised 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, K. S. 1995).

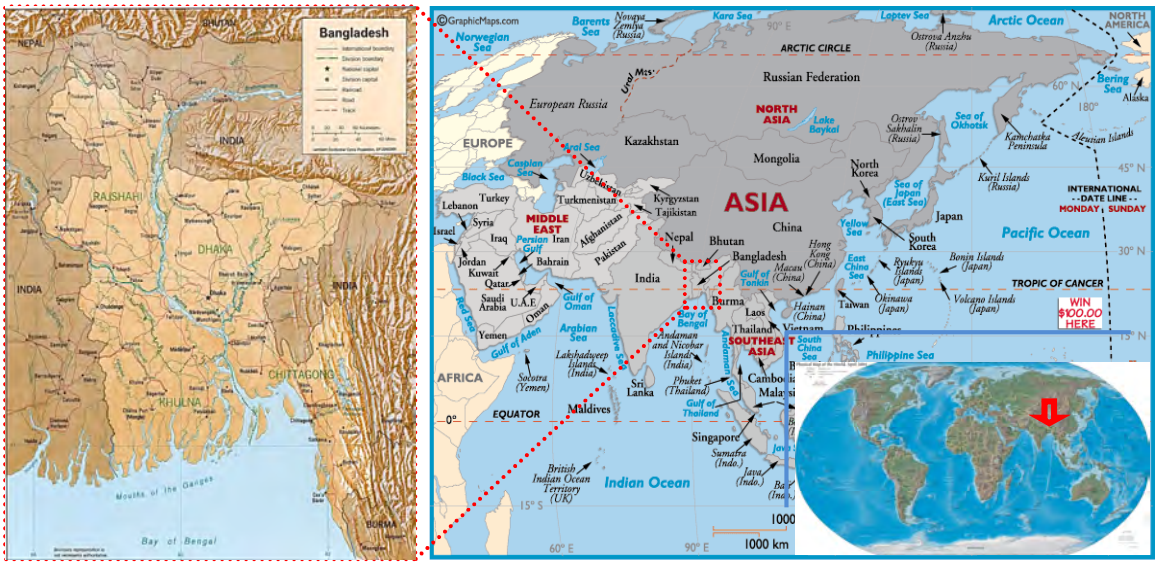

Figure 3.1: Location of Bangladesh (World Atlas, 2010)

The pre-monsoon season is between March and May. April is the hottest month. Generally it is hot and sunny. Mean monthly maximum temperature hovers around 33-34°C and the mean monthly minimum varies around 21-22°C. Approximately 15% of the annual rainfall occurs in this season. During summer, winds are mainly from the southwest.

The monsoon is between June and September. It is characterized by high rainfall, humidity and cloudiness. About 80% of the annual rainfall occurs in this period. This season experiences mean maximum temperatures of around 31°C and mean minimum temperatures of around 25.5 °C. Humidity is around 85%. During the monsoon or rainy season, winds are from the southeast.

The post-monsoon is the transition period from monsoon to winter and it is between October and November. In this season, the rainfall and relative humidity decreases along with the wind speed. In this period, the prevailing wind direction is from the northeast.

The winter or cool dry season is in between December and February. It is characterized by its low temperature, low humidity and clear blue skies. The coldest month is normally January. Mean monthly maximum temperature lingers around 26°C and the mean monthly minimum varies between 11-13 °C. About 5% of the annual rainfall occurs in this season. In winter, the general wind direction is from the northwest.

Season	Meteorological Months	Characteristics
March	Pre-Monsoon (hot-dry)	Mean monthly max. Temp. 33-34°C Mean monthly min. Temp. 21-22°C. Annual rainfall - 15% (Approximately) Wind direction - Southwest.
April	Pre-Monsoon (hot-dry)	
May	Pre-Monsoon (hot-dry)	
June	Monsoon (hot-wet)	Mean monthly max. Temp. 31°C Mean monthly min. Temp. 25.5°C. Humidity 85% Annual rainfall - 80% (Approximately) Wind direction - Southeast.
July	Monsoon (hot-wet)	
August	Monsoon (hot-wet)	
September	Monsoon (hot-wet)	
October	Post-Monsoon (hot-wet)	The rainfall and relative humidity decreases along with the wind speed. Wind direction - Northeast.
November	Post-Monsoon (hot-wet)	
December	Winter (cool-dry)	Mean monthly max. Temp. 26°C Mean monthly min. Temp. 11-13°C. Annual rainfall - 5% (Approximately) Wind direction - Northwest.
January	Winter (cool-dry)	
February	Winter (cool-dry)	

Table 3.1: Classification of Seasons in Bangladesh (modified by Author after Ahmed, K. S. 1995)

3.3. THE CLIMATIC ASPECTS OF DHAKA

The primary concern of this chapter is to develop an understanding of the overall climate of Dhaka region and the basis for other relevant environmental concerns. The city of

Dhaka, lies between 23°40'N and 23°55'N north latitudes and 90°20'E and 90°30'E east longitudes, with three sides bounded by the river Buriganga on the south, the Tongi khal on the north and Turag River on the west. 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. The following review of these climatic factors is based on various investigations and on data collected from meteorological stations of the city.

3.3.1. 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. 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).

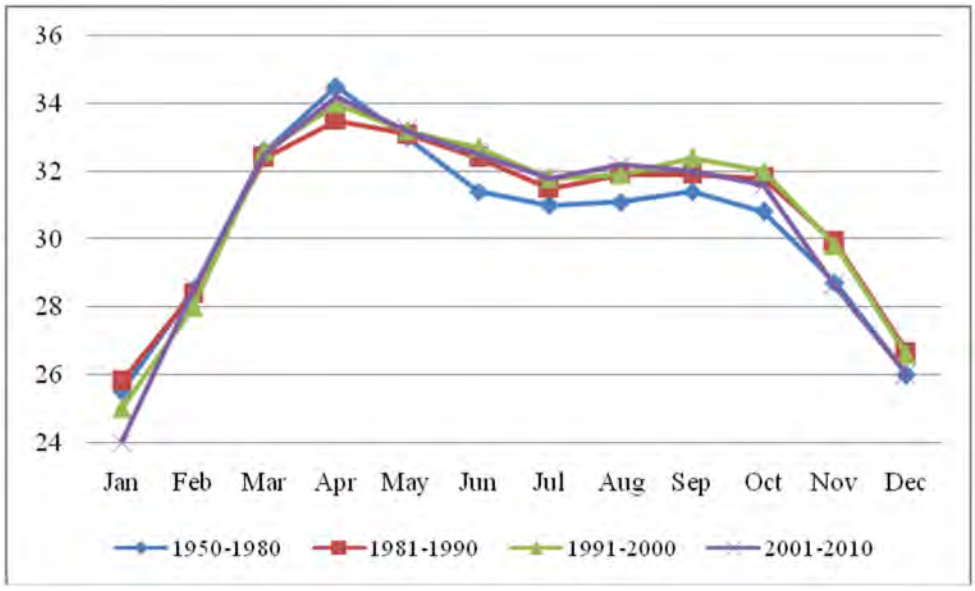

Figure 3.2: Monthly Mean Maximum Temperature (1950-2010)

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.

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**	**31.4**	**31**	**31.1**	**31.4**	**30.8**	**28.7**	**26**	**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**	**33.2**	**32.7**	**31.8**	**31.9**	**32.4**	**32**	**29.8**	**26.6**	**25**	**28**
2001-2010	**32.5**	**34.6**	**33.2**	**32.5**	**31.8**	**32.2**	**32**	**31.6**	**28.6**	**26**	**24**	**28.5**

Table 3.2: Monthly Mean Maximum Temperature (1950-2010) (CD, 2010)

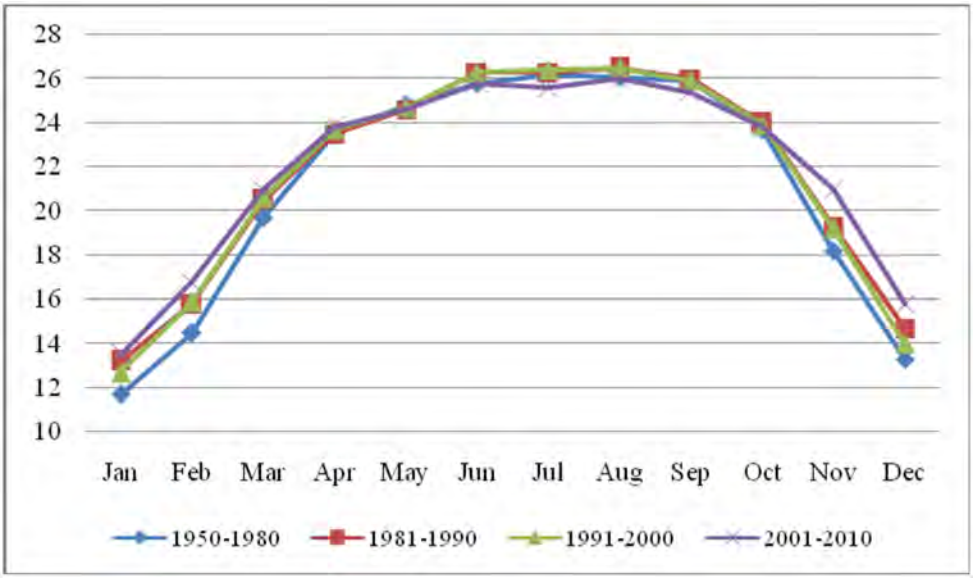

Figure 3.3: Monthly Mean Minimum Temperature (1950-2010)

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**	**24**	**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**	**12.7**	**15.9**
2001-2010	**21**	**23.8**	**24.6**	**25.8**	**25.6**	**26**	**25.4**	**23.8**	**21**	**15.8**	**13.5**	**16.8**

Table 3.3: Monthly Mean Minimum Temperature (1950-2010) (CD, 2010)

A comparison of data in four sets from 1950-2010 shows the Diurnal Range increasing during the month of May and throughout the monsoon period (Figure 3.4). 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.

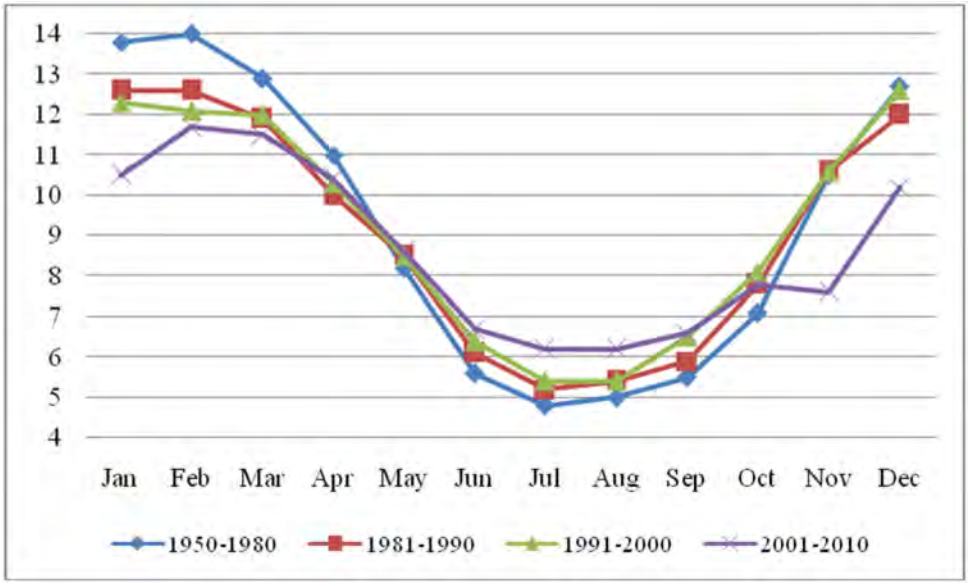

Figure 3.4: Monthly Mean Diurnal Range (1950-2010)

3.3.2. 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%.

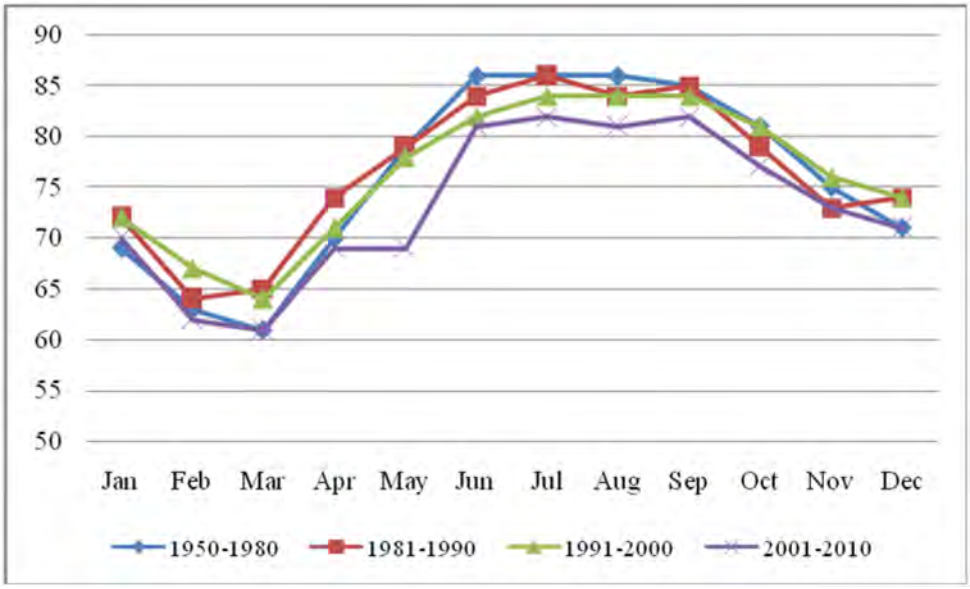

Figure 3.5: Monthly Mean Relative Humidity in Dhaka

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).

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

Table 3.4: Monthly Mean Relative Humidity in Dhaka (CD, 2010)

3.3.3. Air 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). The data (1950-1980) 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.

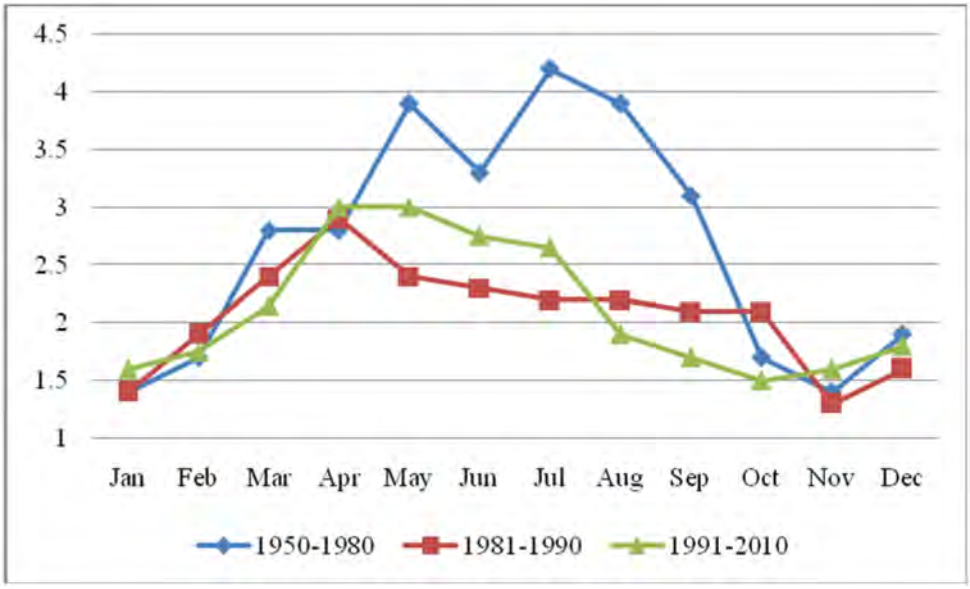

Figure 3.6: Monthly Mean Wind Speed in Dhaka

Data for the last Decade (1981-1990) illustrates significantly low magnitudes of wind speed (Table 3.5). 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).

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**
2000-2010	**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

Table 3.5: Monthly Mean Wind Speed and Direction in Dhaka (CD, 2010)

Data for the last Decade (1981-1990) shows that prevailing wind speed in Dhaka (Table 3.5) 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.

3.3.4. Solar Radiation

Before 2000, radiation data were not collected regularly by the meteorological department of Dhaka and the raw data are not processed yet (Mridha, 2002). So, solar radiation data is collected from the next reliable source - Mechanical Engineering Department, Bangladesh University of Engineering and Technology (BUET), Dhaka and NASA, SSE Database.

In the Pre-Monsoon season, particularly during the months of March, April and May, Solar Radiation on a horizontal surface is high in comparison with the rest of the year and is maximum in April (5.76 $kWh/m^2/d$) . Higher ambient temperatures during these months indicate the casual link with such levels of insolation (Ahmed, K. S. 1995).

Month	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
NASA	**5.59**	**5.76**	**5.3**	**4.53**	**4.23**	**4.29**	**4.02**	**4.32**	**4.28**	**4.21**	**4.36**	**4.92**
BUET	**4.66**	**5.05**	**4.55**	**4.01**	**3.65**	**3.75**	**3.75**	**3.60**	**3.61**	**3.15**	**3.25**	**4.01**

Table 3.6: Solar Radiation in Dhaka (source: NASA, SSE database and Mojumder, 2000)

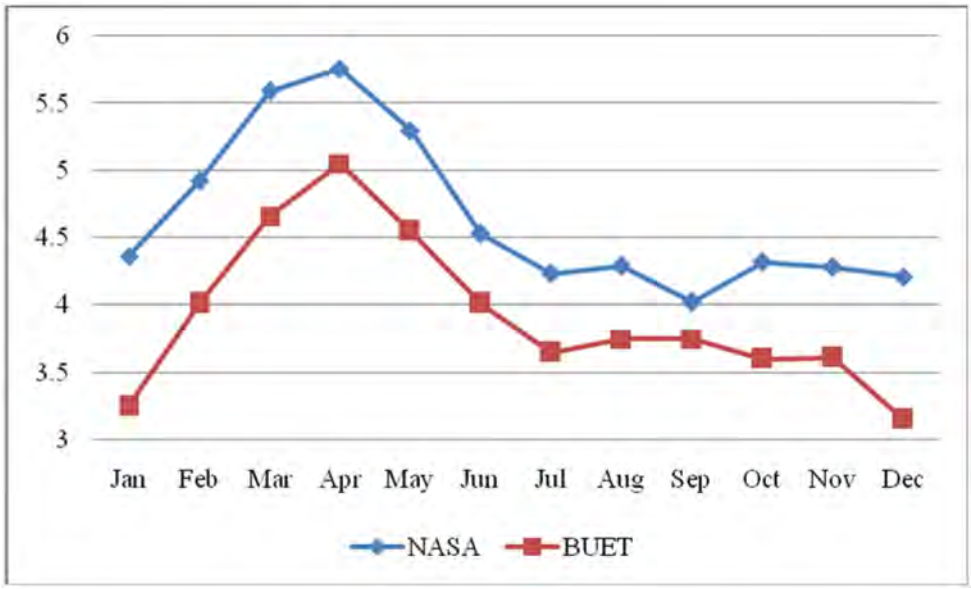

Figure 3.7: Solar Radiation in Dhaka

The insolation level is fairly constant between July to November, while the minimum is recorded in December (3.15 kWh/m^2/d). During the Monsoon to Post-monsoon, i.e., from July to October, the radiation is mostly diffused due to cloud cover and recorded minimum was in September (4.02 kWh/m^2/d) (Mridha, 2002).

3.3.5. Environmental Matrix

Although for most of the period overheating is a major environmental concern for Dhaka, the nature of the problem is dictated by the combination of the environmental factors in the ambiance during these period, i.e. overheating with humid or dry condition (Ahmed, 1995). Through the discussion of the preceding chapter, the nature of this overheated condition of Dhaka can be understood clearly.

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Air Temp.												
Radiation												
Humidity												
Airflow												

Table 3.7: Environmental Matrix for Dhaka

Scale (of impact):

4 3 2 1

Table 3.7 compares the environmental variables for the whole year and illustrating their potential Impact on the climate. It is observed that pre-monsoon period (March to May) is characterized by very high air temperature and solar radiation, while June to October with very high relative humidity associated with high temperature. In case of the former, reducing the impact of solar radiation can substantially moderate overheating condition and in case of the later, optimizing airflow can play a vital part towards moderation. Humid condition with high ambient temperature is often the most lasting environmental condition in wet tropics like Bangladesh (Mridha, 2002).

3.4. CONCLUSION

This particular study focuses on the thermal environment in production spaces of RMG factories where performance is influenced by human comfort and particularly comfort of the indoor (production spaces). So, the scope of this thesis in terms of the issue raised in the environmental agenda is limited. And the primary concern of this chapter is to develop an understanding of the microclimate of Dhaka to formulate an environmental database for simulation studies and field work.

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4. INDOOR COMFORT ISSUES

4. INDOOR COMFORT AND ISSUES

4.1. INTRODUCTION

In the modern industrial society, over 80% of human being's lifetime is spent indoors (Zhaoa et al, 2004). This large proportion of the population spends more than 20 hours a day in an artificial environment: at home, at the workplace, at shops, at wide variety of recreation places (Markov, 2002). Concerning this fact, it is important for people that they feel comfortable with the environment when they are inside buildings. This is regardless of their role (e.g. employer, employee, resident) in a specific indoor environment (Fransson et al, 2007). The indoor environment has to be comfortable for the occupants' good health and high productivity. It is a holistic phenomenon that involves synergy of thermal comfort, indoor air quality, other environmental factors such as the type of building and its psychological relevance for the occupants (Croome et al, 1992,).

Thermal condition in RMG factories has to be considered carefully mainly because of the high occupant density in production spaces and the negative influences that an unsatisfactory thermal environment has on performance and well being of the workers. While the idea of a comfortable environment for all would involve the consideration of individual preferences, there is a set of general conditions in which a majority of the people would be at ease. They relate to air and radiant temperatures, airflow, humidity etc (Mallik, 1994). A substantial amount of research has therefore been conducted to determine the values of these variables that would make the users feel comfortable (Gonzalez et al, 1997). The following sections evaluate these conditions, on the basis of existing knowledge.

4.2. DEFINITIONS AND CONCEPTS

Thermal comfort is that part of total human comfort which can be attributed to the thermal balance of the body. Specifically, it is the interaction of environmental variables i.e., air temperature, mean radiant temperature, humidity, and air speed with the occupant's personal variables i.e., metabolic rate and clothing (Sherman, 1985). Thermal comfort has been defined by Hensen (1991) as *'a state in which there are no driving impulses to correct the environment by the behaviour'*. The definition put forward by

American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) defines Comfort as a state of mind. *Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation* (ASHRAE Standard 55, 2004). A definition most people can agree on, but also a definition that is not easily converted into physical parameter (Olesen, 2000). The definition of thermal comfort leaves open as to what is meant by condition of mind or satisfaction, but it correctly emphasizes that the judgment of comfort is a cognitive process involving many inputs influenced by physical, physiological, psychological, and other factors (Lin et al, 2008).

The thermal environment incorporates those characteristics of the environment which affect a person's heat loss and heat gain. In terms of bodily sensations, thermal comfort can be regarded as a scale of sensation from hot through warm, slightly warmer, neutral, slightly cooler and cool to cold (Mohamed et al, 2002). From the physiological point of view, thermal comfort occurs when there is a thermal equilibrium in the absence of regulatory sweating between the heat exchange of the human body and the environment (Fanger, 1970). With the growing complexity of the indoor environment, it has become almost impossible to ‘measure’ comfort directly (de Dear et al, 2003). Besides measuring the physical variables that influence the body’s heat balance, questions regarding thermal sensation and preference were also introduced, both in the climate chamber and in the field. Conclusions about satisfaction or dissatisfaction of people were derived from that.

Comfort is alternatively defined as the absence of discomfort or in other words, absence of stimuli which lead to the change in the thermal balance of the body (Ahmed, 1994). In the context of the Tropics, where overheating is a primary environmental concern for most of the year, two independent causes of discomfort have been identified, thermal sensation of excessive heat and skin wetness (Givoni, 1989).

Comfort as a basis for setting environmental standards has developed out of recognition of people’s need to remain more than simply healthy and safe in the buildings they occupy. Comfort connects the psychological aspects of workers’ environmental satisfaction with improved work performance and organizational productivity.

4.3. THERMOREGULATION IN HUMAN BODY

To ensure human comfort in the climatic condition like Dhaka, a basic know-how on 'thermoregulation (the body's ability to physiologically regulate its inner environment to ensure its stability in response to fluctuations in the outside environment and the weather) in human body and body heat balance' is vital.

Humans are homeotherms, means that they keep their body temperature roughly at a constant level, regardless of the ambient temperature. Humans are also endotherms, means that they rely on internal heat production to regulate body temperature. For these, they either lose or gain heat for their survival (Claessens, 2008). Thermal comfort is related to the body's thermoregulatory system where the heat exchanges between the human body and its surrounding maintain deep body temperature at 37°C (Fig.3.2) and skin temperature within the range of 28 to 34°C (Mallik, 1994). Thermal comfort can be maintained by thermal regulation and adaptation of behaviour within certain limits of thermal stress and physical activity (Laschewski et al, 2002).

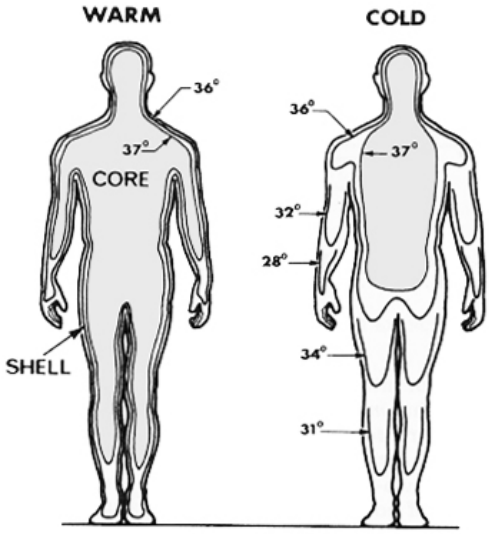

Figure 4.1: Core Body Temperature at Warm and Cold Period (Carey, 2008)

In cold climate, when body temperature falls below the set point, heat gain responses (decreasing blood flow to the skin, shivering) are initiated (Fig.4.2) and the problem of maintaining comfort is largely associated with the loss of heat. And, in the hot climate, when body temperature rises above "set point" temperature, heat loss responses (sweating, increasing blood flow to the skin) are instigated (Fig.4.2) and the problem of maintaining comfort is largely associated with the excess heat gain from the ambient

environment. In order to maintain a thermal balance, the strategy for tropical conditions relates to minimisation of any heat gain and maximisation of excess heat loss.

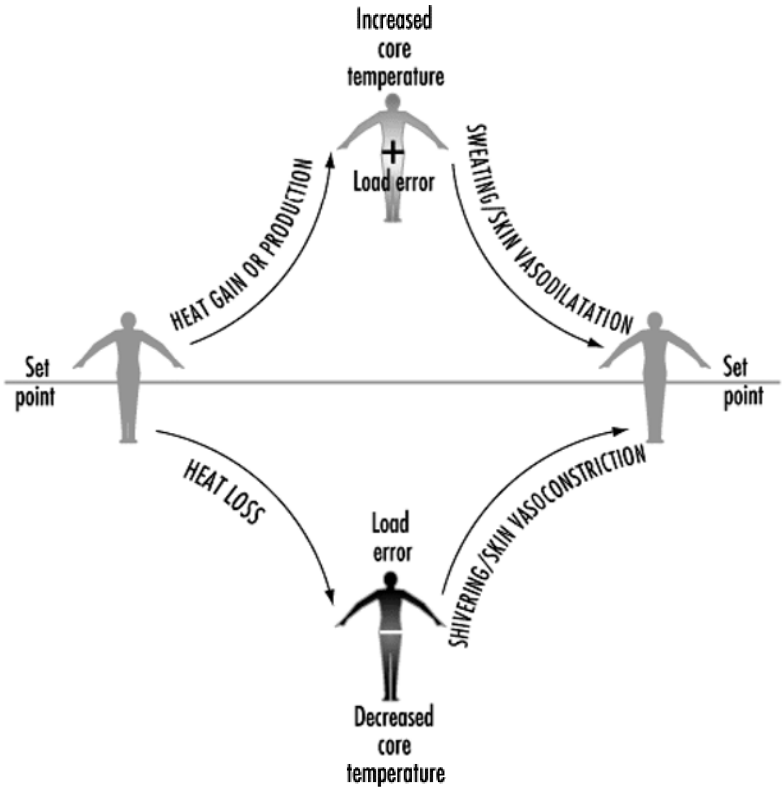

Figure 4.2: A Model of Thermoregulation in the Human Body (Kenney, W. L., 1997)

As a process of thermoregulation, human body generates heat for maintaining homeostasis. Of all the energy produced in the body, only about 20% is utilised, the remaining 80% is 'surplus' heat and must be dissipated by the body (Koenigsberger et al, 1973). Heat transfer between the body and the external environment occurs through the process of conduction, convection, radiation and evaporation (Fig.4.3). Heat transfer through these means is bidirectional, where heat transfer between the skin surface and the environment is driven by the temperature gradient between the skin and the surrounding environment (Lim et al, 2008).

When the skin temperature (along with clothing) is higher than that of the surrounding surfaces, a person can effectuate heat loss by long wave radiation. On the other hand, when the ambient temperature is lower than the body temperature, heat is lost by displacement of the heated air surrounding the body by forced convection (fig.4.3). Efficiency of this process is dependent on air velocity and temperature. Heat is lost by means of insensible sweating (at all times through perspiration, skin diffusion etc.) and by

sensible sweating (in excessive warm conditions). This heat loss by evaporation is dependent on humidity and air temperature.

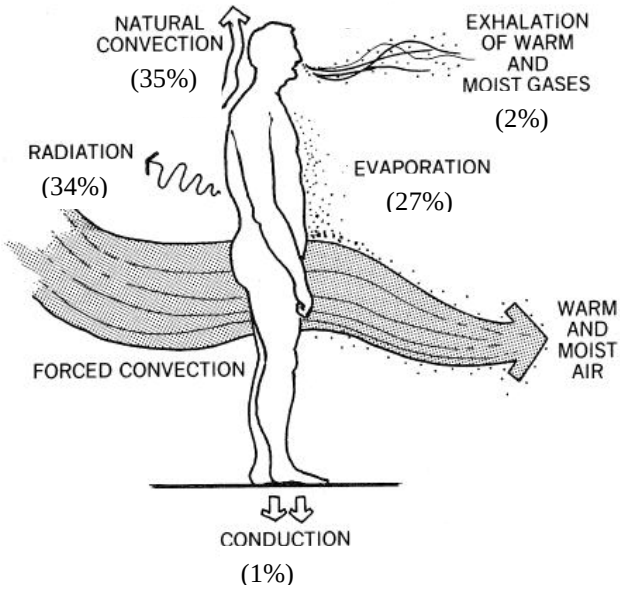

Figure 4.3: Mechanisms of Heat Loss (Lechner, 2001; modified by Author)

To maintain a balance between the heat produced by metabolism and the heat lost from the body, human body employs physiological processes (e.g. sweating, shivering, and regulating blood flow to the skin). Maintaining this heat balance is the first condition for achieving a neutral thermal sensation (Charles, 2003).

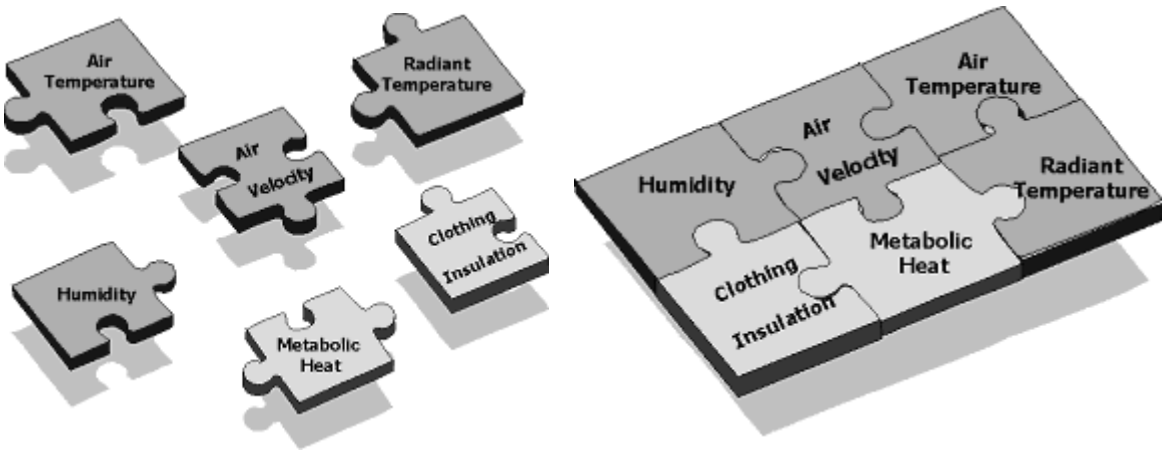

Figure 4.4: Parameters of Thermal Comfort (HSE, 2010)

However, Fanger noted that *'man's thermoregulatory system is quite effective and will therefore create heat balance within wide limits of the environmental variables, even if comfort does not exist'* (Fanger, 1970; cited by Djongyang et al, 2010). These variables may be independent of each other, but together contribute to a worker's thermal comfort. The environmental variables (along with personal variables) that are mentioned by Fanger are discussed in detail in the following section.

4.4. PARAMETERS OF THERMAL COMFORT

Many studies have been conducted to realize building occupants' thermal responses to the combined thermal effect of the personal, environmental and physiological variables that influence the condition of thermal comfort. In 1962, Macpherson defined that 'the following six factors affect thermal sensation: four environmental variables (air temperature, air velocity, relative humidity, mean radiant temperature), and two personal variables (clothing insulation and activity level, i.e. metabolic rate)' (Djongyang et al, 2010). Generally in human biometeorology, the air temperature, humidity, air velocity and mean radiation temperature are regarded as the thermally relevant measures (Hoppe, 1988). So, thermal comfort is the interaction of environmental variables with the occupant's personal variables (Sherman, 1985).

4.4.1. Personal variables

- **Metabolic rate:**

Mackean (1977) defines metabolism as *'All the chemical changes going on in the cells of an organism'* (Jones, 2001). Through the chemical reaction, human body generates energy, only a small part of which is utilised and the remaining is dissipated to environment. According to Koenigsberger (1973), *'The process involved in converting foodstuff into living matter to find useful form of energy is known as metabolism'.* The Chartered Institute of Building Service Engineers (CIBSE) Guide prescribes that an average person emits 115W thermal energy which is a by-product of the body metabolism from the ingested food (Zingano, 2001).

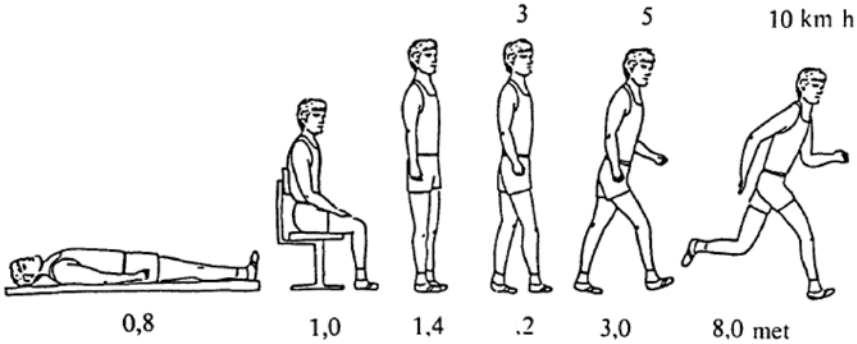

Figure 4.5: Metabolic Rate of Different Activities (Fanger, 1986)

The total metabolic heat production can be divided into basal metabolism i.e. the continuous production of heat through vegetative and automatic process and muscular metabolism i.e. the non-continuous heat produced due to muscular activities (Koenigsberger et al, 1973).

Activity	Heat Generation W/m²	met	Activity	Heat Generation W/m²	met
Resting			**Miscellaneous occupational activities**		
Sleeping	40	0.7	Cooking	90-115	1.5-1.9
Reclining	45	0.8	House cleaning	115-200	1.9-3.3
Seated, quiet	60	1.0	Heavy limb movement	130	2.2
Standing, relaxed	70	1.2	Handling 49 kg bags	235	3.9
			Pick and shovel work	235-280	3.9-4.7
Walking (on the level)					
0.89 m/s	115	1.9	**Machine Work**		
1.34 m/s	150	2.5	Sawing (table saw)	105	1.8
1.79 m/s	220	3.7	Light (electrical industry)	115-200	1.9-3.3
			Heavy	235	3.9
Office activities					
Reading	55	0.9	**RMG Factory works**		
Writing	60	1.0	Fabric cutting	105	1.8
Typing	65	1.1	Bias cutting	85	1.4
Filing, seated	70	1.2	Sewing	85	1.4
Filing, standing	80	1.3	Packing	85	1.4
Walking about	100	1.7	Stamping	100	1.7
Lifting, packing	120	2.0	Button sewing	85	1.4

Table 4.1: Some Typical Values of Metabolic Rate (Butera, 1988; Gouvêa et al, 2006)

For every kind of activity, a typical muscular metabolism has to be added to the basal metabolism to get the total heat production of the body. The range of the work metabolism lies between 0 W for sleep and approximately1000 W for very hard work or intensive sport (Hoppe, 1988). The unit of the metabolic rate is known as 'met' which is equivalent to 58.2 W/m^2.

In warm climates, when thermal discomfort is felt with the increase of metabolic rate, requirement of lower skin temperature is increased (Givoni, 1989; cited by Ahmed, 1995). For a specific climate, like the given indoor climate, there is a threshold of the activity at which the skin wetness reaches 100% (total surface wetted by sweat). A further increase of the activity would demand more sweat evaporation which is not possible anymore. Therefore steady state cannot be maintained for higher activities and over a longer period there would be the risk of circulatory disorders (Hoppe, 1988). Some typical values of metabolic rate are shown in Table 4.1.

- **Clothing:**

Clothing can take care of climatic variations to some extent. Warm clothes may render cooler climates bearable. On the other hand, finer cloth and more exposure of body are helpful in hot climate as it gives more scope to dissipate heat through radiation, convection and perspiration. Clothing acts as an important modifier of body heat loss and comfort through its insulation properties. These insulation properties of clothing are a result of the small air gaps separated from each other to prevent air from migrating through the material. Clothing insulation can be described in terms of its *Clo* value, but the more technical unit m^2°C/W is also seen frequently (1 Clo = 0.155 m^2°C/W). Clo values for common articles of clothing are listed in Table 4.2.

The Clo scale is designed so that a naked person has a Clo value of 0.0 and someone wearing a typical business suit has a Clo value of 1.0. Clothing is taken as an insulating medium next to skin in human energetic evaluation. It impedes heat loss through conduction and convection by entrapment of air next to the skin and in its weave. Radiation loss is also affected by weave of the clothing and it can occur through the

intervening spaces of the fabric or be obstructed by a closely-knit fabric and re-radiate to the skin (Ahmed, 1995).

Men	clo	Women	clo
Sleeveless singlet	0.06	Bra and pants	0.05
T-shirt	0.09	Half slip	0.13
Underpants	0.05	Full slip	0.19
Shirt, light-weight, short sleeves	0.14	Blouse, light-weight	0.20 (*a*)
Shirt, light-weight, long sleeves	0.22	Blouse, heavy-weight	0.29 (*a*)
Waistcoat, light-weight	0.15	Dress, light-weight	0.22 (*a*, *b*)
Waistcoat, heavy-weight	0.29	Dress, heavy-weight	0.70 (*a*, *b*)
Trousers, light-weight	0.26	Skirt, light-weight	0.10 (*b*)
Trousers, heavy-weight	0.32	Skirt, heavy-weight	0.22 (*b*)
Sweater, light-weight	0.20 (*a*)	Slacks, light-weight	0.26
Sweater, heavy-weight	0.37 (*a*)	Slacks, heavy-weight	0.44
Jacket, light-weight	0.22	Sweater, light-weight	0.17 (*a*)
Jacket, heavy-weight	0.49	Sweater, heavy-weight	0.37 (*a*)
Ankle socks	0.04	Jacket, light-weight	0.17
Knee socks	0.10	Jacket, heavy-weight	0.37
Shoes	0.04	Stockings or tights	0.01
Boots	0.08	Sandals	0.02
		Shoes	0.04
		Boots	0.08

(*a*) Deduct 10% if sleeveless or short sleeved.
(*b*) Add 5% if below knee length; deduct 5% if above knee length.

Table 4.2: Clo Values for Individual Items of Clothing (Berglund,1998; Jones, 2001)

Light summer cloth is common in tropical environments have a clo value of 0.35 to 0.5 (Mallik, 1994). In hot humid environmental conditions, the thin clothing enhances evaporative heat loss by acting as a mess and also allows wind action directly to the skin (Ahmed, 1995).

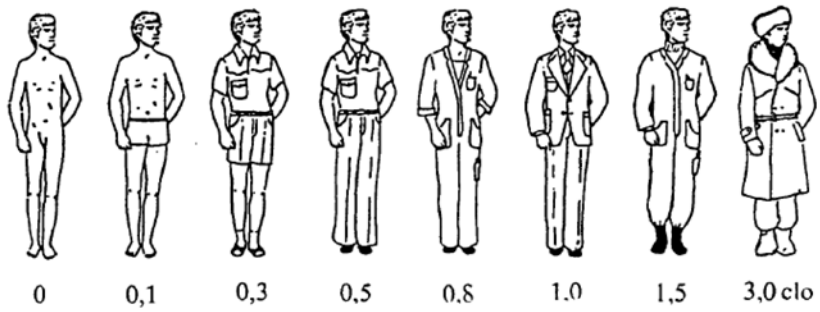

Figure 4.6: Insulation of Clothing in Clo Units (Fanger, 1986)

4.4.2. Environmental variables

- **Air Temperature:**

Air temperature influences heat gain or loss of the body through the rate of convective and evaporative heat exchange and directly affects the comfort status of a person. It is the most important determinant of comfort, since a narrow range of comfortable temperatures can be established almost independently of the other variables. There is a fairly wide range of temperatures that can provide comfort when combined with the proper combination of relative humidity, MRT, and air flow. But if any one of these conditions varies, the air temperature must be adjusted in order to maintain comfort conditions.

To maintain body temperature at the deep body temperature of 37°C, all surplus heat needs to be dissipated to the environment. If there is some form of simultaneous heat gain from the environment, that must be dissipated also. The average skin temperature in warm condition at indoor situation is about 33 to 34°C. With lower temperature the body looses heat and with higher temperature body gains heat by convection. The rate of convective heat exchange depends on airspeed (roughly proportional to the square root of the speed). It is greatly affected by the insulation value of the clothing (clo value) (Mridha, 2002).

- **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).

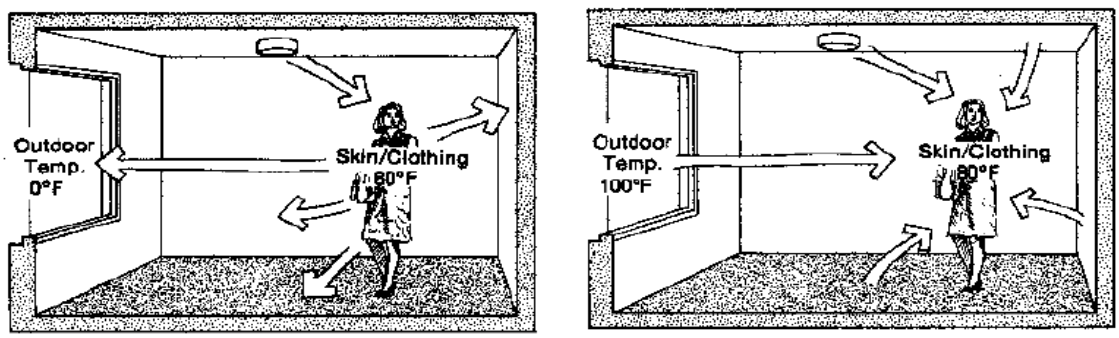

Figure 4.7: Radiant Heat Transfer with Surrounding Surfaces (Emery, 2010)

Although all bodies, exchange heat by radiation continuously, heat gain or loss by this process is determined by the net effect of all the losses and gains. Thus heat loss by radiation is negative when the surrounding surface temperatures are above skin temperature; accordingly a person emits less heat in comparison to the amount gain from the surrounding surfaces (Ahmed, 1995) (Mridha, 2002) (Figure 4.7).

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.The MRT for workers should be depending on the clothing they wear and the activity they do. In winter, when a person is sitting close to a large window, the average radiant temperature may be significantly lower than the air temperature. Similarly, in spaces with radiant floors or other forms of radiant heating, the average radiant temperature will be above the air temperature during the heating season (McDowall, 2007)

- **Relative Humidity:**

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).

When temperatures and humidity levels are high, it becomes difficult for the body to cool by perspiration because the air is unable to accept additional moisture, thus restricting latent heat loss from the individual. Evaporative losses are particularly important at higher air temperatures as convective and radiant heat loss decreases as the environmental temperatures approach, or surpass, the body temperature. If temperature and relative humidity are high, an active person will generate heat faster than the body can dissipate it. Thus perspiration alone becomes a significant element in cooling with moderate to high temperatures.

At lower temperatures, i.e., approximately 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 4.3).

Relative Humidity (%)	**Air Temperature (°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 (°C)						

Table 4.3: Impact of Relative Humidity on Sensed Temperature (Heinen et al, 1994)

- **Air Flow:**

Induction of air flow within a space is important for many reasons, all of which affect human comfort. Supply of fresh air, removal of accumulated heat and moisture next to the body, and mixing of air to avoid thermal stratification, all contribute to perceived comfort. Air motion significantly affects body heat transfer by convection and evaporation. It results from free (natural) and forced convection as well as from the occupants' bodily movements. The faster the motion, the greater the rate of heat flow is by both convection and evaporation. When ambient temperatures are within acceptable

limits to the user, there is no minimum air movement that must be provided for thermal comfort. The natural convection of air over the surface of the body allows for the continuous dissipation of body heat. When ambient temperatures rise, however, natural air flow velocity is no longer sufficient and must be artificially increased, such as by the use of fans.

Typical human responses to air motion are shown in Table 4.4.

Beaufort Number	Description of Wind	Speed (m/s)	Description of Wind Effects
0	Calm	Less than 0.4	No noticeable wind
1	Light airs	0.4-1.5	No noticeable wind
2	Light breeze	1.6-3.3	Wind felt on face
3	Gentle breeze	3.4-5.4	Wind extends light flag, Hair is disturbed, Clothing flaps
4	Moderate breeze	5.5-7.9	Wind raises dust, dry soil, and loose paper, Hair disarranged
5	Fresh breeze	8.0-10.7	Force of wind felt on body, Drifting snow becomes airborne, Limit of agreeable wind on land
6	Strong breeze	10.8-13.8	Umbrellas used with difficulty, Hair blown straight, Difficulty to walk steadily, Wind noise on ears unpleasant, Windborne snow above head height (blizzard)
7	Moderate gale	13.9-17.1	Inconvenience felt when walking
8	Fresh gale	17.2-20.7	Generally impedes progress, Great difficulty with balance in gusts
9	Strong gale	20.8-24.4	People blown over by gusts

Table 4.4: Effects of Different Wind Speeds (Penwarden, 1973)

Thus, it is a common phenomenon that air movement, be it natural, or mechanical (generated by fan, exhaust etc.), has a cooling effect (only when there is less than skin temperature). This largely depends on the velocity of that air movement.

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

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

Table 4.5: The Average Subjective Reactions to Various Velocities (Auliciems et al, 2007)

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).

4.5. COMFORT INDICES

Several experiments and investigations have been conducted to establish the effect from a combination of the environmental variables on the subjective thermal sensation or comfort of men in various levels of activity and clothing. Thus, all the factors are combined into a single formula known as a thermal index (Ahmed, 1994). There are essentially two methods available for ascertaining people's thermal comfort: by questionnaires, with simultaneous measurement of conditions, used mostly in spaces normally occupied by the respondents, i.e. in field studies and by measurements of physiological changes, such as sweating, skin wetness or skin temperature, carried out normally in laboratories (Auliciems et al, 2007).

Among a whole series of thermal comfort indices, two main types can be distinguished: empirical measures (produced by questionnaire studies, under defined environmental conditions) and analytical methods (tracing the flow paths from metabolic heat production to the environment and considering resistances to such flows).

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 analysing the real acceptability of thermal environment, which strongly depends on the context, the behaviour of occupants and their expectations (Djongyang et al, 2010). For this study, the predicted mean vote (PMV) index (suggested by Fanger) was applied in field studies and the neutral temperature model (suggested by Humphreys) was applied to examine the comfort zone.

- **Predicted Mean Vote (PMV) Index**

Fanger developed Predicted Mean Vote (PMV) Index to predict thermal interaction between human body and his surrounding environment (Ahmed, 1994). It provides an estimate of thermal condition of a particular environment based on the mean value derived by the votes for thermal sensation of a large group of people. The thermal sensation for the body as a whole can be predicted by the PMV index, utilizing a seven point thermal sensation scale (from cold to hot) where the central vote relates to the condition of thermal neutrality (Fanger, 1986). It may be possible to specify environments, predicted to be experienced as acceptable by a certain percentage of the occupants. At least 80 per cent of the occupants may specify the comfort requirements of a particular environment.

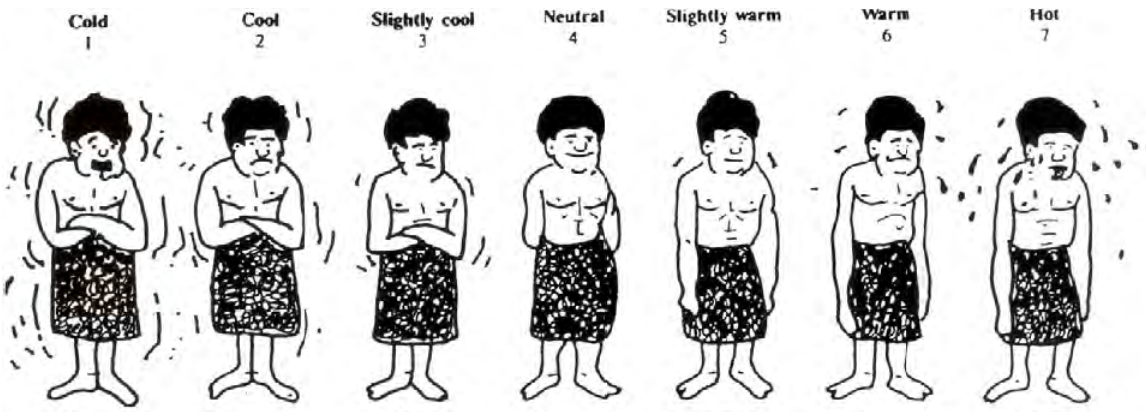

Figure 4.8: Graphic Seven Point Thermal Sensation Scale (Auliciems et al, 2007)

The Predicted Percentage of Dissatisfied (PPD) predicts the percentage of the people who may be inclined to complain or be dissatisfied with the given environment (i.e. the percentage of the people who may feel more than slightly warm or slightly cold). There is a relationship between PMV and PPD which is least for neutral vote (5%) and increases with gradually warmer or cooler sensations.

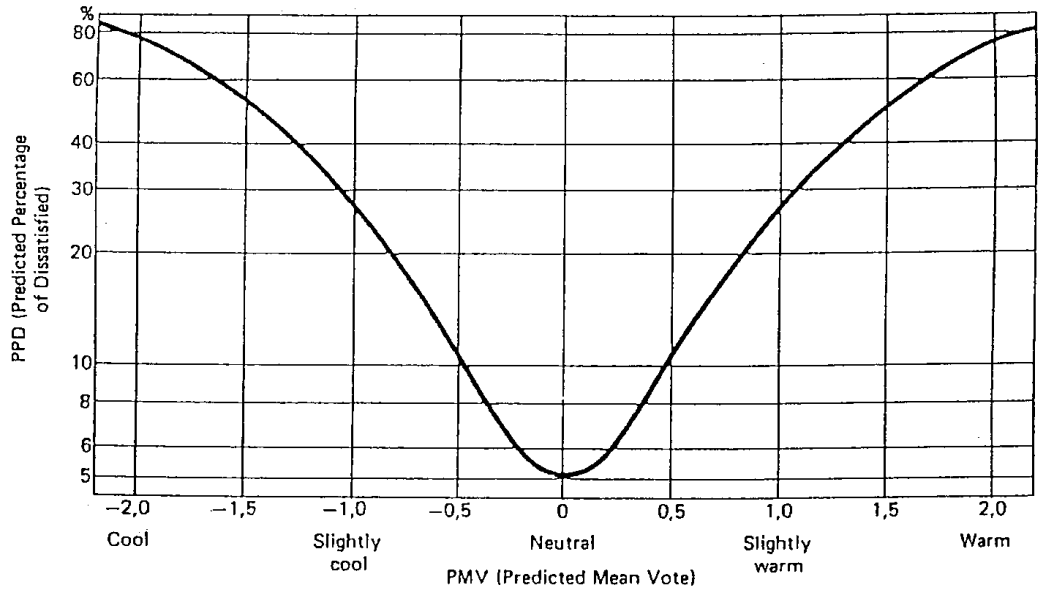

Figure 4.9: Relationship between PMV and PPD

- **Neutral Temperature Model**

According to Humphreys and Nicol, the globe temperature alone can better indicate thermal comfort, rather than a multi-variable index (Ahmed et al, 1990). The concept of Neutral temperature was introduced by Humphreys on the basis of a statistically established relationship between comfort and the outdoor temperatures (Mallik, 1994) and seems most appropriate to the tropical situation. The Neutral temperature, which is dependent on the mean temperature for any period, is defined as that which gives a neutral thermal sensation in the environment, i.e. a sensation neither of warmth nor of chill (Ahmed, 1995). For the free running Buildings where the outside temperature is not extreme, Humphreys suggested neutral temperature as:

$$T_n = 11.9 + 0.534\ T_o\ (°C)$$

Where T_n is the neutral temperature and T_o is the mean outdoor temperature. Humphreys (1976; cited by Heidari et al., 2002) also showed a strong relationship between the mean indoor temperature T_i and neutral temperature T_n.

$$T_n = 0.831T_i + 2.6$$

Later Auliciems modified this for warmer climates and de Dear supported the formulae of Auliciems. And the neutral temperature is:

$$T_n = 0.73\ T_i + 5.41$$

Moreover, Nicol and Roaf (1996) recommended the following model for occupants of natural ventilation buildings:

$$T_n = 0.38\ T_i + 17$$

Normally a band of ± 2.5 °C, centred on the neutral temperature T_n comprises the comfort zone. Neutral temperature model was proposed by Ahmed, Z. N. (1995) as the best fit for Dhaka's Situation.

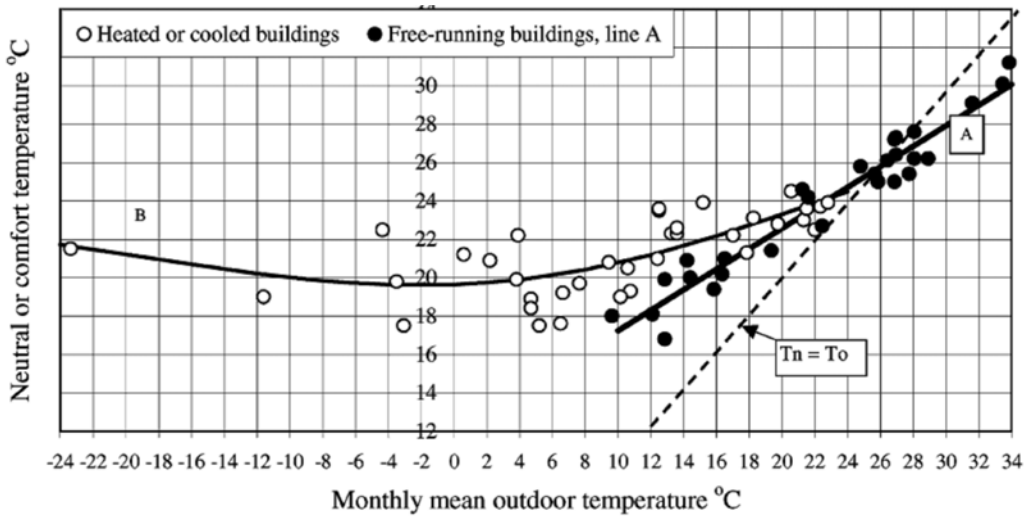

Figure 4.10: Relationship between Comfort and External Temperatures (Humphreys et al, 2002)

4.6. ACCLIMATIZATION AND ADAPTATION

Thermal adaptation can be defined as the adaptation of different species to differences in temperature between species ranges. It is generally recognised that natural acclimatization is the best means by which to acquire heat tolerance (Taylor et al., 1997) Here, acclimatization is a complex set of physiological and psychological adaptations that take place when the organism is exposed to stress (Auliciems et al., 2007). Due to acclimatization, exposure to warm temperatures increases heat tolerance and decreases cold tolerance. Thermal acclimatization refers to biological adaptations that reduce

physiologic strain (e.g., heart rate and body temperature), improve physical work capabilities and improve comfort (Table 4.6).

Physical Condition	Adaptation
Thermal Comfort	Improved
Core Temperature	Reduced
Sweating	Earlier & Greater
Skin Blood Flow	Earlier
Body Heat Production	Lower

Table 4.6: Benefit of Thermal Acclimatization (USAPHC, 2011)

Acclimatization probably begins to occur within days of exposure to the stimulus, but in general it is a prolonged seasonal process where its full attainment results from everyday thermal experiences. It is speeded up in people whose work is sufficiently vigorous to elevate metabolic heat production, which increases stress, thus accelerates adaptation (Auliciems et al., 2007). Humans have remarkable ability to adapt to heat stress which results from the interaction of environmental conditions (temperature, humidity and sun), physical work rate (body heat production) and wearing of clothing or equipment that impedes heat loss. Healthy acclimatized persons can tolerate extended exposure to virtually any natural weather related heat stress (Sawka et al, 2001).

4.7. BUILDING DESIGN STRATEGIES AND INDOOR THERMAL PERFORMANCE

To achieve thermal comfort and energy saving implications for its users, it is important to design climate responsive buildings. The climate should be regarded as a design determinant in building design process. Otherwise, these have contributed to an overall poor thermal performance of the buildings. The building design strategies dependent on climatic factors that affect the indoor thermal performance are as follows:

4.7.1. Planning Aspect

- **Building Orientation**

Appropriate orientation of buildings can provide physically and psychologically comfortable conditions in the building. For example, in hot regions, a building must be oriented to control the amount of solar radiation on one hand, while to admit the cool winds on the other (Nayak et al, 2006). The orientation of a building in a particular direction, therefore, can heat or cool the building depending on the climatic zone in which it is constructed. Proper orientation can help increase or decrease the heat load by 5% (TERI, 2008).

The overall building orientation has an important bearing on reducing the amount of total solar radiation. The amount of indirect radiation falling on a surface is almost independent of surface orientation whereas direct radiation is highly dependent on orientation (Ahmad, 2004). According to Gut and Ackerknecht (1993), the longer axis of the building should lie along east-west direction for minimum solar heat gain by the building envelope. Rilling et al (2007) reported a study in which investigated the impact of changes in orientation and insulation appliances, they showed up to 43% lower cooling load. According to Ahmed (2002), tropical countries like Bangladesh, which are warm and humid for long spells each year, should have buildings that is planned to catch the available breeze.

According to Al-Tamimi et al (2011), ‘selecting the most optimal building orientation is one of the critical energy efficient design decisions that could have impact on building envelope energy performance, as it can be used to minimize the direct sun radiation into the buildings through windows, building openings as well as external opaque walls’.

- **Building Configuration**

Heat exchange between a building and its surroundings occurs primarily through the ‘skin’ of the building. Configuring the geometry of the building appropriate to the climate and usage can control the magnitude of the heat flow (Nayak et al, 2006). The heat flow due to radiation and air movement can be controlled by varying the following aspects of the building configuration:

Surface Area to Volume Ratio (S/V Ratio):

The ratio of the surface area to the volume of the building (S/V ratio) determines the magnitude of the heat transfer in and out of the building. The larger the S/V ratio is, the greater the heat gain or loss for a given volume of space. Conversely, a smaller S/V ratio will result in the reduction of heat gain or loss. For example, in warm humid climates it is preferable to have elongated house forms with maximum S/V ratio. Figure 4.11 shows the surface to volume ratios for various building shapes.

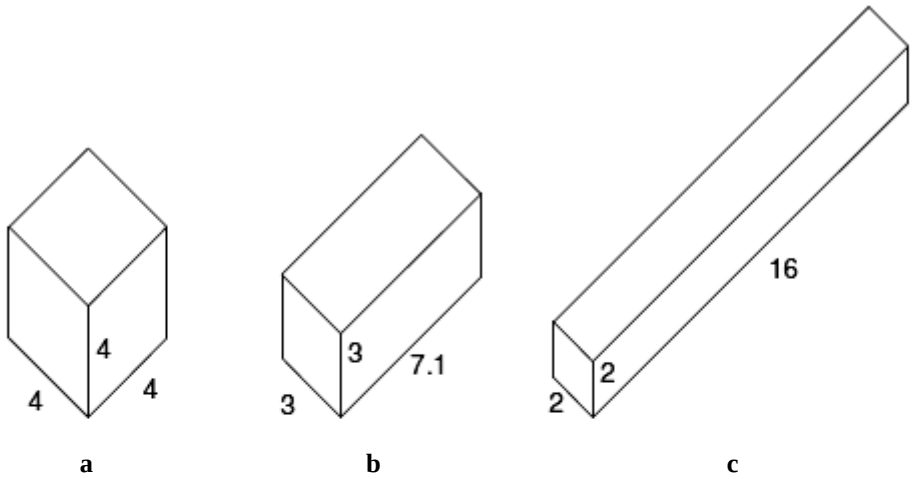

Figure 4.11: Surface area to volume ratio (S/V ratio) for a few building shapes

Shape	Surface area	Volume	S/V ratio
a	96	64	1.5
b	103.2	64	1.61
c	136	64	2.13

Building Shape:

Givoni (1998) states that building form largely depends on whether the building is planned to be air-conditioned or if it is intended to rely on natural ventilation. He recommends a compact shape for the building dwelled by people who are determined to use air conditioners and open forms for naturally ventilated buildings. Wind pattern across a building can be modified by shaping it appropriately. Wind when obstructed by a building, creates pressure differences, that is, positive pressure on the windward side and

negative pressure on the leeward side. Consequently, a new airflow pattern is established around the building (Nayak et al, 2006).

4.7.2. Building Envelope

- **Roof**

The roof of a building receives a significant amount of solar radiation. Thus, the design and construction of roof play an important role in modifying the heat flow and ventilation. According to Kabre (2010), the roof is the most exposed to impacts of solar radiation, as it receives sunlight for practically the whole of the day and in the tropics the angle of incidence is close to the normal in the hotter parts of the day. But the effect is critical for single storied buildings and the top floor of multi-storied buildings.

The intensity of solar radiation is highest on the horizontal plane, which is the roof. Conductance of heat from the roof can be very high, if not insulated well. This can result in increased cooling load, if the space below is air conditioned, or high-discomfort hours, if the space below is naturally ventilated (TERI, 2010). According to Alvarado & Martinez (2008), the heat entering into the building structure through roof is the major cause for discomfort in case of non air-conditioned building or the major load for the air-conditioned building. However, Gut and Ackerknecht (1993) argue that this is true for single storied buildings and the top floor of multi-storied buildings.

Concerning roof shape, Gut and Ackerknecht (1993) note that warm-humid regions should have pitched roofs to drain off heavy rains. Here the building is a pitch roofed building (fig. 6.4). According to Fathy (1986), pitching the roof has several advantages. First, the height of the interior is increased, thereby providing a space far above the heads of the inhabitants for warm air that rises or is transmitted through the roof. Second, the total surface area of the roof is increased with the result that the intensity of solar radiation is spread over a larger area and the average heat increase of the roof and heat transmission to the interior are reduced. Third, for most of the day, part of the roof is shaded from the sun, at which time it can act as a radiator, absorbing heat from the sunlit part of the roof and the internal air, and transmitting it to the cooler outside air in the roof's shade.

- **External wall**

Walls constitute a major part of the building envelope and receive a large amount of direct radiation. Depending on whether the need is for heating or cooling, the thickness and material of the wall can be varied to control heat gain (Nayak et al, 2006). Gut and Ackerknecht (1993) recommended Burnt clay bricks for tropical climates because they have good thermal resistance and good regulating property against humidity. Moreover, the thermal conductivity of burnt brick is 0.81. According to Koenigsberger et al (1973), the value of thermal conductivity varies between 0.03 W/mdegC for insulating materials and up to 400 W/mdegC for metals. As a result, the heat transfer rate is lower in brick wall than metal walls.

According to Kabre (2010), it is necessary to reduce the heat transmitted through the sunlit walls. The east and west walls receive a good deal of radiation, while the north and south walls receive comparatively little radiation. Wonorahardjo (2004) argued that solar radiation in overheated period influences indoor thermal condition significantly, and consequently building envelope has to response this condition. He added that a thick brick wall seems to ensure better thermal performance than any lightweight building material in an overheated period.

- **Openings**

Openings are provided for the purposes of heat gain, day lighting and ventilation. Their pattern and configuration form an important aspect of building design. Appropriate design of openings helps to keep out sun and wind or allows them into the building (Nayak et al, 2006). Gut and Ackerknecht (1993) recommend that windows should be large and fully operable, with inlets of a similar size on opposite walls for proper cross-ventilation in tropical climates.

Ahmed (1987) in her study on the effects of climate on the design and location of windows for buildings in Bangladesh states that the orientation of windows should aim at excluding solar penetration. She has also claimed that windows should be avoided on western walls as it is almost impossible to shade it in all seasons. Gut and Ackerknecht

(1993) noted that openings in hot and humid regions should be placed according to the prevailing breeze so that air can flow through the internal space.

Liping et al. (2007) claim that ventilation and indoor air quality can be improved by increasing the window to wall ratios (WWR), but it would also increase solar heat gain. They claimed that the optimum window to wall ratio is equal to 0.24 and horizontal shading devices are needed for the four orientations, especially for large windows for further improvement in indoor thermal comfort.

4.7.3. Ventilation System

An indoor air speed of 1.5-2.0 m/s can cause comfort in warm and humid regions where the outdoor maximum air temperature does not exceed 28-32°C (Givoni, 1994). The available wind velocity in a room with a single window on the windward side is about 10% of the outdoor velocity at points up to a distance of one-sixth of room width from the window. Beyond this, the velocity decreases rapidly and hardly any air movement is produced in the leeward end of the room. Therefore, it is better to provide two windows on adjacent or opposite walls to improve ventilation. The window area and the direction of wind affect the performance of this cross ventilation (Nayak et al, 2006).

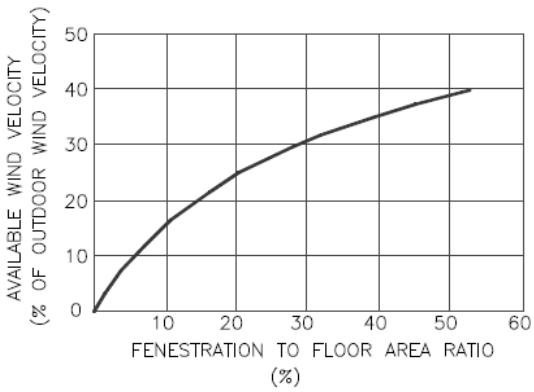

Figure 4.12: Effect of window area on indoor air speed (BIS, 1987)

Figure 4.12 shows how the window area affects the average indoor air velocity. The plot corresponds to the case where there are two windows of identical size on opposite walls; the wind direction is perpendicular or normal to the window. For windows that are 20% of floor area, the average indoor wind velocity is about 25% of outdoor velocity.

4.8. THERMAL COMFORT AND WORKPLACE PERFORMANCE

The concept of 'workplace performance' means workspace whose explicit objective is to support the performance of work. In other words, a performing workplace designed to optimise worker productivity. The indoor environment is a dynamic interaction of spatial, social and physical factors, which affects Productivity, health and comfort of the workers (Croome, 2002). There are many studies that have identified factors influencing workers productivity and attempted to measure their individual effects. One of these effects is thermal environment by which the efficiency of workers and their productivity is affected.

Work performance can be understood at two levels: group tasks and individual task. Spatial configuration makes work groups more or less effective whereas individual task-performance is affected by ambient environmental conditions such as lighting and visual conditions, acoustics, variations in temperature and humidity. Positive individual productivity outcomes mean improved speed and accuracy of the tasks performed, whereas negative outcomes might include a higher error rate, slower time for task completion, or adverse health effects on workers (Vischer, 2008). According to ASHRAE Workshop on Indoor Quality (1992) the recommended individual productivity measures are: Absenteeism rates, sickness records, discontinued work flow, speed and accuracy of work, number of error etc (Croome, 2002)

4.8.1. Effect of Temperature

That there is a direct effect of the thermal environment on mental work is supported by experimental results and extensively reviewed by Wyon (2000) and Fisk (2000). The results of multiple studies on the effect of temperature are relatively consistent and show an average relationship of 2% decrement in work performance per degree C but when the temperature is above 25°C (Seppänen et al, 2004). But these can be different at workplace area of RMG factories in Bangladesh context. However, when temperatures are either too high or too low, error rates and accident rates increase. While most people maintain high productivity for a short time under adverse environmental conditions, there is a temperature threshold beyond which productivity rapidly decreases (Lorsch and Abdou, 1993).

Link and Pepler (1970) measured productivity in an apparel factory and found a reduction of 8% in productivity in sewing work as the temperature increased from 23.9 to 32.2ºC. Mackworth found that overall the average number of errors made per subject per hour increased at higher temperature and that the average number of mistakes per subject per hour under the various conditions of heat and high humidity was increased at high temperatures, especially above 32°C (Mackworth, 1946). Schweisheimer attempts to demonstrate the increase in performance which occurs when the optimum microclimate is provided for workers. He found that the average performance of workers drops by 10% at an internal room temperature of 29°C, by 22% at 32°C and by 38% at 35°C (Croome, 2002).

Productivity is reduced when many individuals have to occupy the same indoor volume with no individual means of adjusting the temperature they experience. Thermal effects progressively reduce the performance of those whose neutral temperature is not exactly equal to the group average (Wyon, 2000). Berglund used physiological thermal model to relate performance to Effective Temperature (ET*). Roelofsen (2001) used this model further and converted Berglund's ET*-values to two commonly used thermal comfort parameters, Predicted Mean Vote (PMV) and Predicted Percent of Dissatisfied (PPD) which enables the model to be used for various combinations of thermal factors. A change from 18 ºC and dry to 28 °C and humid can increase the proportion of dissatisfied from 10% to 90% (Wyon, 2000).

According to Pepler and Warner (1968) people work best when they are slightly cool, but perhaps not sufficiently cool for it to be termed discomfort, and should not be too cool for too long. Lorsch and Abdou (1994) conclude that temperatures which provide optimum comfort may not necessarily give rise to maximum efficiency in terms of work output. The difficulty here is that this may be true for relatively short periods of time, but if a person is feeling uncomfortable over a long period of time it may lead to a decrement in work performance. So, to get maximum efficiency in terms of work output from the garments workers, a comfort temperature must be recommended.

4.8.2. Effect of Humidity

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).

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, 1978).

4.8.3. Effect of Ventilation

The studies of Seppänen et al (2006) indicated that typically a 1-3 % improvement in average performance occurs per 10 L/s-person increase in outdoor air ventilation rate. The performance increase, per unit increase in ventilation was bigger with ventilation rates below 20 L/s-person and almost negligible with ventilation rates over 45 L/s-person.

To obtain some evidence for pointing out ventilation as the factor that was probably responsible for some difference in sickness rates, Vernon et al. (1926) conducted a study on ‘the effects of ventilation on building occupant performance’. In two separate rooms in the same factory, female workers were employed on the same kind of light work. Over a period of two years, on account of sickness, the average time lost of the possible working time in one room was 2.44%, and in second room, it was 3.73%. The temperatures in the two rooms were very similar, but the air movement in second room was distinctly less (0.08 m/s in winter and 0.14 m/s in summer) than in first one (In winter months 0.17 m/s and 0.20 m/s in summer). The study showed that doubling the ventilation rate cut the time lost due to sickness to half (cited by Abdou et al, 2006).

However, most of the studies show an improvement in performance with increasing ventilation rate. But, a few exceptions are also found. Wargocki et al. (2004) report a 7.8% decrease in performance with increase of ventilation rate from 2.5 to 25 L/s-person. Improvements in performance with increased ventilation rate were most clearly seen with

initial ventilation rates below 20 L/s-person. (Note: these may be not corresponding for very colder and very hot climate, as the air temperature may be much higher or lower than the skin temperature).

4.9. CONCLUSION

The primary concern of this chapter has been to develop an understanding on indoor comfort and issues related to human comfort, focused on indoor environment. Findings of this chapter will help in later chapters to understand the issues of thermal environment for garment industries with respect to human comfort and their effect on workplace performance or productivity.

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5. RMG FACTORIES IN BANGLADESH

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5.1. INTRODUCTION

Readymade Garment (RMG) is a success story for Bangladesh. The industry started in the late 1970s, expanded heavily in the 1980s and boomed in the 1990s (Robbani, 2000). Moreover, approximately 2.5 million people are engaged in this sector as employee. And this large volume of people works within an estimated 4,000 factory buildings, mostly working in production areas (Majumder et al, 2006). Congestion, poor working condition, age-old structures and makeshift buildings are the common phenomena for this sector.

Garment workers are one of the hardest working segments of the labour force in Bangladesh and their working conditions must improve. In the long-run, this would be the best defence against labour agitation. Investing in worker training and in improved working environment would certainly enhance productivity (Quddus et al, 1999). Again, in most of the work environments in Bangladesh, thermal discomfort is a common feature and that certainly affects the efficiency and the workers' productivity. It also affects motivation of the workers (Rahman, 2000). Most of these complaints refer to discomfort due to heat. In Bangladesh, there are not available standards for thermal comfort evaluation adequate for the work conditions in the factories, and especially, for the activities which are performed in most industrial workplaces at RMG factories. All the standards are based on rules and procedures developed in foreign countries. Either the professionals or the academic researchers are thought to be responsible for workspaces' healthy environmental conditions, as the available technical information about thermal comfort evaluation for this sector is poor.

With most of the work sectors having health and safety problems associated with them, the garment industry in Bangladesh is no exception. Whether it be overcrowding because of the inadequate space in factory buildings and poor working condition (because of the age-old and makeshift buildings, obsolete machinery, high temperature levels in the production areas especially in sewing and ironing section), all represent health and safety issues that need to be addressed, often as a matter of grave urgency. For this, the following section aims to investigate health and safety issues of the workers along with

their productivity in production spaces along with the present condition of this sector and predict the temperature or combination of thermal variables (temperature, humidity, and air velocity) which will be found comfortable (Nicol and Humphreys, 2001) for the workers' health and wellbeing.

5.2. GROWTH OF RMG FACTORIES

Readymade Garments (RMG) sector has a venerable history of about 32 years. Starting as a non-traditional export in the late 1970s, RMG achieved this status within a short time. This sector evolved as the main export product of Bangladesh during the late 1980s (Ahmed, 2006). With the first garment exporting unit, Reaz Garments in 1978, and along with that initiative, Desh Garments, Bangladesh stepped into a new promised land of prosperity (Joynal, 2008). The period of 1970s was the 'Establishment Period' for the Garments sector. There were only 22 number of RMG units that existed with only 0.04 million US dollar ($) export earnings (Rahman, 2006). The garments' owners were not focused towards the working condition at that time.

Year	**Export of RMG** (in million USD)	**Total Export Earning** (percentage)	**No. of garment Unit**
1978-79	0.04	n. a.	22
1984-85	116.2	12.4	384
1985–86	131.5	16.1	594
1989–90	624.2	32.5	759
1994–95	2228.4	64.2	2182
1995–96	2547.1	65.6	2353
1999-00	4157.6	75.6	3200
2004-05	6417.7	74.2	4107
2005-06	7900.8	75.1	4135
2008-09	12347.8	79.3	n. a.

Table 5.1: Growth of RMG Industry (Majumder et al, 2006, Rahman, 2006, Uddin, 2006, BGMEA)

The period of 1980s was the 'Expansion Period' for this sector. In the Financial Year (FY) 1982-83, export earnings of RMG Sector was 245.83 million US dollar, which was earned by only 90 number of readymade garment units. In 1982 Bangladesh Garments Manufacturers and Exporters Association (BGMEA) was formed for the welfare of the manufacturers and exporters of RMG. In the late 1980s, the number of RMG units

increased to 759 with the export earnings of 624.16 million US dollar. The working condition in these factories is mostly neglected by the owners as they are not so conscious about this factor and to maximize the profits. Though, a few purpose built Garments were built in these period along with the makeshift factories.

The period of 1990s was the 'Rising Period' for this sector. During these period, exports increased by a factor of 4, with an annual growth rate in GDP about 5 percent, which was significantly due to the heavy growth of RMG industry (Uddin, 2006). In the late 1990s, the number of readymade garment units increased to 3200 with the export earnings of 4157.63 million US dollar (Majumder et al, 2006). In this period, a lot of purpose built Garments were built. After that, the 'Period of Development' for this sector started with the new millennium. In this period, the perception of what constitutes good working conditions has evolved among workers over time (Saxena, 2010). Moreover, in recent days, the social dimensions of the RMG industry are drawing more attention from consumers, social workers, welfare organizations and international buyers (Haider, 2007). So, now the RMG sector of Bangladesh needs to concentrate on improving the working environment in factories and address other social issues related to the garment industry.

5.3. WORK FLOW IN PRODUCTION SPACES AND WORKERS

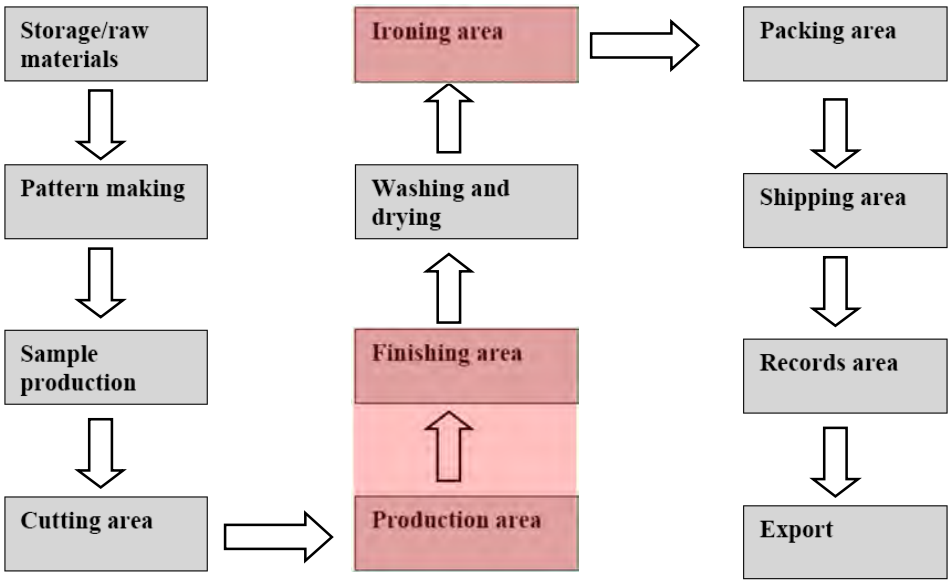
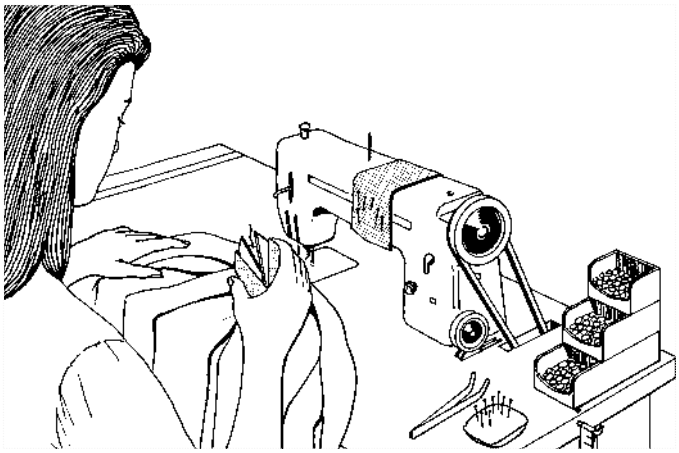


Figure 5.1: Process Flow Diagram Showing the Layout of a Garments Factory

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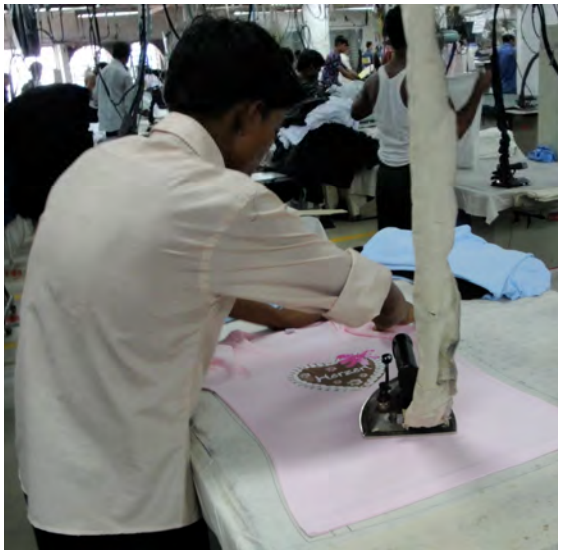

This study focused on the two main workspaces, sewing and finishing (ironing) which are the most critical. In the RMG sector, sewing section is the densely occupied zone by the workers (Table 5.2) and ironing area (Table 5.3) produces excessive heat in the finishing section. And most of the time, heat hazard is found, as these sections share same floor in the production area.

Work Category	**Survey 1990**		**Survey 1997**	
	% of Total workers		% of Total workers	
	Male	Female	Male	Female
Cutting Section	24.1	1.6	9.3	1
Sewing Section	**37.5**	**81**	**62**	**83.9**
Finishing Section	38.4	17.4	28.7	15.1

Table 5.2: Percentage of Workers according to Work Category (Majumder et al, 2000)

Cutting and finishing sections are less occupied and mostly male governed areas; whereas sewing section is highly occupied and female dominating area (Figure 5.4). This industry employs about 1.8 million women workers, though supervisors are largely male (Kabeer et al, 2004; cited by Khosla, 2009). Generally women workers start their job with two types of factory positions like helper and operator (Figure 5.4).

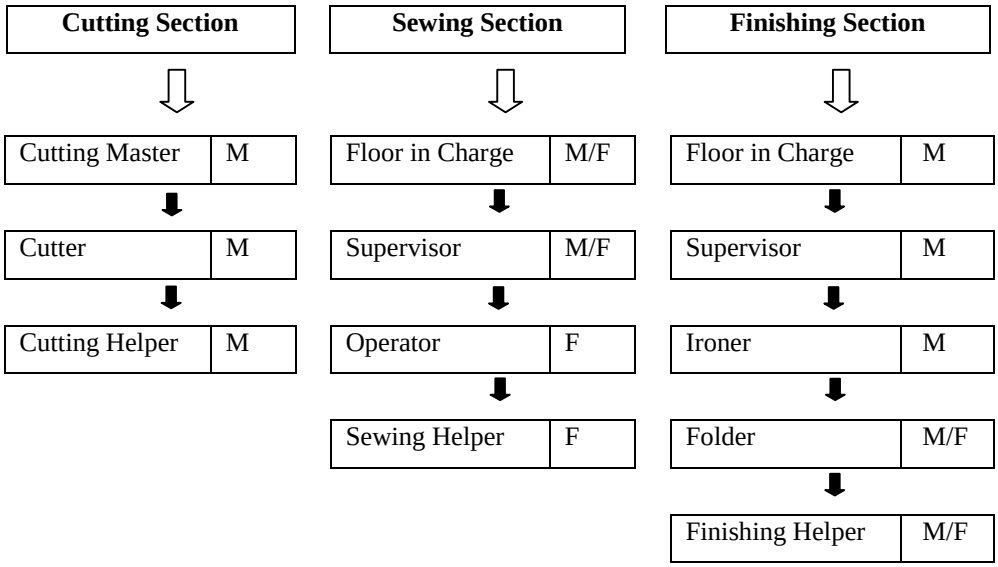

Figure 5.4: Job Category of the Workers according to Gender in RMG; M=Male, F=Female (Choudhury et al, 1991)

As this study focused on thermal comfort of the workers, the personal factors (clothing and metabolic rate) of the workers are to be discussed. The metabolic rate of the garment

of the workers thought that their factories have very good ventilation, while another 46% reported that their factories have moderately good ventilation. The rest 27% informed about either bad or very bad ventilation. 37% of the workers reported that their factories were very congested; while another 30% informed that their factories were moderately congested. The rest 33% thought that their factories were not congested (Majumder, 2003; Majumder et al, 2006).

It has already been mentioned earlier that as a tropical country, Bangladesh has hot and humid weather from March to November. In this condition, the temperature or heat hazard is certain to be high in garment factories. Many garment workers experience these hazards due to hot and humid conditions, especially those in the ironing section. Ironing results in tremendous heat hazard, since hot water flows through several pipes, which are hung just a few inches above the workers' heads (Majumder, 2003). Moreover, due to unplanned or makeshift factory buildings the garment workers are exposed to excessive heat and dampness. The situation becomes worse when the employers keep the door and windows closed. The available exhaust fans and blowers are not adequate. The workers work in this congested atmosphere under hundreds of powerful electrical bulbs for about 12 hours or even more than a day (Majumder, 2001). Again, responding to the *'Clean Cloth Campaign'*, some factories provided aprons to the workers. However, it was observed that in scorching summer days wearing aprons on saree or kamiz was quite impossible. This was also the case with masks and gloves (Majumder, 2003).

For the workers, hot working environment is very hazardous, as it can cause heat stroke and heat exhaustion. During the survey of 1997, a number of employers reported that the female workers faint during work, especially in the months of June and July (two warm adn most humid months of the year in Bangladesh; table 3.2) which may be the result of heat stroke and heat exhaustion suffered by the garment workers. During June-August, more than 3% of the workers reported that they fainted at least once (Majumder, 2003). General weakness and malnutrition of the Garments workers' may also be responsible, for this incidence. But prolonged exertion in hot environment is also partially responsible. Summer and rainy seasons are observed as two critical periods in the Garment sector for the employers, while the production performance is greatly disturbed by large-scale absenteeism of the workers. The employers informed that absenteeism rises along with

the temperature during very hot days (Majumder, 2003). A group of additional workers are hired to solve this problem of production loss by replacing the absent workers. From all these facts, the working environment of the production spaces in the garment factories is easily conceivable.

5.5. HEALTH CONDITION OF RMG WORKERS

From sewing section to ironing section, in Bangladesh, garments workers work in a wide variety of hot or warm and humid environments. Being uncomfortable is not only the major problem with working in high temperature and high humidity, but also workers who are working in a hot environment may face additional hazards to their health and safety. Excessive exposure to a hot work environment can bring about a variety of heat-related illness (HRI).

5.5.1. Heat-Related Illness (HRI) at RMG Factories

HRI is comprised of a continuum of disorders that occur when the body loses the ability to regulate body temperature due to loss of fluids. The disorders include: heat edema, heat cramps, heat syncope, heat exhaustion and heat stroke. According to industrial hygienists, Goetsch (1996), *'Hot and Humid working Environment is very dangerous which can lead to Heat Exhaustion, Headache, Fatigue, Nausea, Loss of Appetite, etc'*. For this, Environmental factors such as ambient temperature, humidity, wind, and sun exposure may alter the risk of HRI. Along with these, an individual's physical activity level, hydration level and amount or type of clothing may also increase the risk of HRI (FDH, 2011). So, the thermal comfort factors of working environment at RMG factories are responsible for heat-related illness of its workers.

5.5.2. Incidence of Illness

According to Zohir (2001), 'The working conditions of the factories are important factors for the health conditions of the workers (Chand, 2006). The working hours for the garment workers were about 12 hrs / day and it remained unchanged in 1997, with only half-hour to one hour lunch break. These long working hours with a short break are exhausting the work force'. The study showed that the incidence of illness was higher for female than male workers for almost all types of illness both in 1990 and 1997 (Table

5.3). The most frequent work related illness was physical weakness and headache. These are likely to result from the stifling conditions of most factories, lack of proper ventilation, frequent electricity failure, high humidity etc.

Incidence of illness	Non-EPZ				EPZ	
	1990		1997		1997	
	Male (%)	Female (%)	Male (%)	Female (%)	Male (%)	Female (%)
Headache	61.9	76.7	56.8	69.6	33.3	72.8
Weakness	65.9	75.0	52.6	63.2	37.0	65.2
Urine infection	18.1	28.1	18.4	15.1	18.5	19.6
Eye trouble	43.8	54.2	18.9	30.2	11.1	33.7

Table 5.3: Incidence of work related illness in the RMG factories at 1990 & 1997 (Zohir, 2001)

Weist et al (2002) found through their research that every worker claimed to suffer from both short term and long term health problems. Even a worker with less than a month experience as a garment worker came to suffer from headache - something she claimed had never bothered her before. The study respondents drew attention to temporary health problems, such as headache, fatigue and drowsiness, dizziness, allergic reactions, nausea and depression (Table 5.4) which are attributed to the stifling conditions of most factories, conditions related to closed doors and windows, frequent electricity failure, high humidity, inadequate numbers of fans, etc.

Incidence of illness	Percentage (%)
Fatigue	94.8
Headache	92.9
Drowsiness	76.4
Aggrieved feeling & depression	60.4
Nausea	57.1
Vomiting tendency	50.4
Nervous breakdown	10.8

Table 5.4: Incidence of work related illness in the RMG factories at 1999 & 2001(Weist et al, 2002)

The recent study by Majumder (2003) and Mridula et al (2009) also revealed that the more prevalent illnesses among the garment workers were headache, general anemia, weakness, fatigue, poor appetite, vomiting tendency etc (Table 5. 5).

Incidence of illness	According to Majumder (2003)	According to Mridula (2009)
Headache	57.0%	97%
Physical weakness / fatigue	42.4%	28%
Vomiting	24.8%	28%
Respiratory problem	11.3%	36%
Fainting	3.7%	18%

Table 5.5: Incidence of work related illness in the RMG factories at 2003 & 2009 (Majumder, 2003; Mridula et al, 2009)

5.6. COMPLIANCE IN RMG FACTORIES

Currently, many international buyers demand compliance before placing any garment import order (Haider, 2007). Those buyers are putting more emphasis on compliance standard, as consumers of developed countries are becoming increasingly concerned about work and social environment in the sourcing factories (Moazzem, 2000). Compliance is defined as a code of conduct, specification and standard that must be followed by business organizations (Morshed, 2007). Standard building-structure of factories, working condition, various rights of workers, workers' health and safety measures and environmental safety measures etc. can be ensured through compliances.

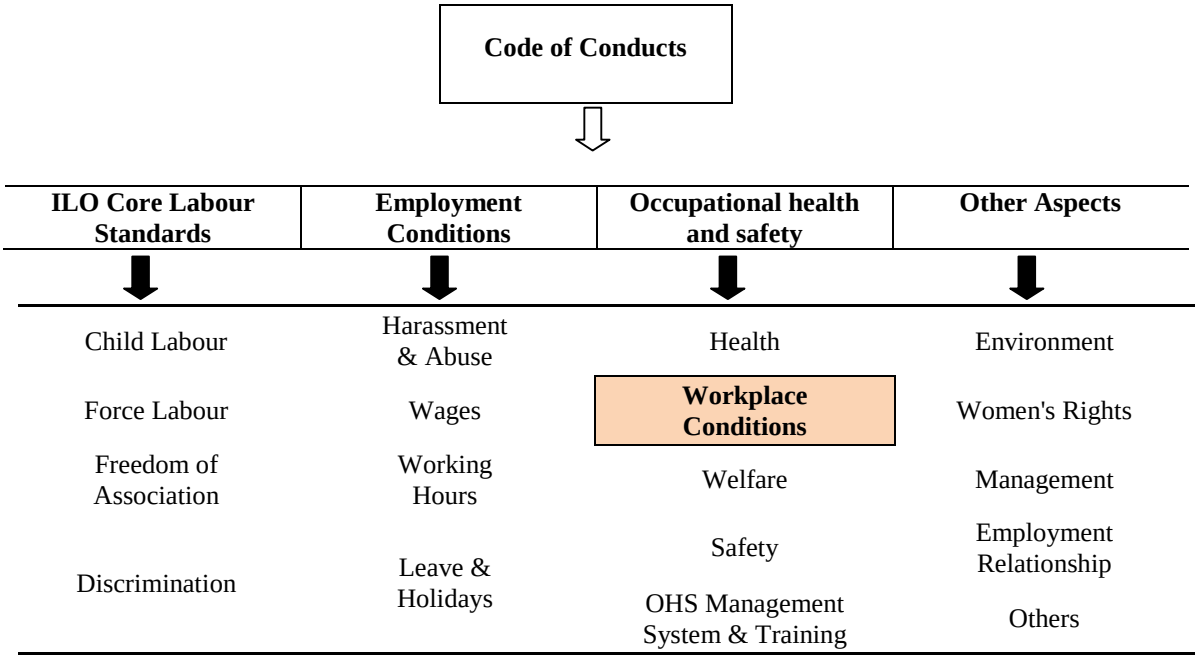

Figure 5.6: Subjects of Code of Conducts

Compliances are of two types: 'Technical Compliance' and 'Social Compliance'. Work Ergonomics, Work Organization, Material Storage and Handling, Housekeeping, Product Integrity, etc. are the part of Technical Compliance, whereas Social Compliance includes Working Conditions, Employment Conditions, Occupational Safety and Health, Welfare Facilities, Industrial Relations, ILO Conventions (i.e., Child Labour, Forced Labour, Discrimination), Building Code, Environmental Management System (EMS), Human Resources Management and so on (Figure 5.6).

In light of growing competition among RMG exporting countries and consumer preference for products which meet internationally recognized social standards, it is essential for Bangladesh's RMG sector to improve social compliance (Baral, 2010).

5.7. LEGISLATION RELATING TO FACTORIES

Presently, legislation is an essential part of the Practice. All the professionals related to building design industry along with the owner must have a clear understanding of the regulations and their interpretation. The primary concern of the legislation for factories (laid down by an official body such as Parliament, the Government or the Responsible Authorities) is to ensure safety, health and welfare of those employed in factories.

The legislation for Bangladesh factories preceded with *'The Indian Factories Act, 1881'*, followed by *'The Indian Factories Act, 1891'*, *'The Factories Act, 1911'*, *'The Indian Factories Act, 1922'*, *'The Factories Act, 1934'*, *'The Factories Act, 1965'*, *'The East Pakistan Factories Rules, 1969'* and *'The Bangladesh Factories Rules, 1979'*. Here, *'The Factories Act, 1965'* and *'The Bangladesh Factories Rules, 1979'* are discussed below, as *'The Factories Act, 1965'* repealed and re-enacted the previous *'The Factories Act, 1934'* for regulating the working conditions in factories and related matters. And, *'The Bangladesh Factories Rules, 1979'* attempt to further define the law to ensure safety, health and welfare of those employed in factories (Ahmed, 1992).

However, Violation of laws and factory rules provided by Factory Acts 1965 and Factory Rules 1979 of Bangladesh are widespread in the garment sector (Karmojibi Nari, 2003). In many cases, it is found that there is no proper ventilation in the factory buildings. According to the Survey of 1997, about 38% of the factories were found to have windows

on three sides, but windows on one side were always kept closed (either for complaints of excessive sound by the neighbourhood or to prevent pilferage i.e. dropping of cloths and other materials by the workers). 27% of the workers reported that their factories have either bad or very bad ventilation. Moreover, it was found that in 46% of the factories, ironing and sewing were done on the same floor (Majumder, 2003). These are some of the violation of laws and factory rules provided by Factory Acts 1965 and Factory Rules 1979, which is stated below at section 5.6.1.

Again, Bangladesh National Building Code (BNBC) is also been considered important to be discussed here for the reason that Bangladesh National Building Code (BNBC) was made to regulate the technical details of building construction and to maintain the standard of building construction for providing safety and healthy habitat by regulating all activities related to buildings such as planning, design and construction (Shafi, 2010).

5.7.1. The Factories Act, 1965 & The Factories Rules, 1979

With regards to temperature and ventilation, the Factories Act and Rules (Chowdhury, 2003) states that:

Effective and suitable provisions shall be made in every factory for securing and maintaining in every work-room -

a) *Adequate ventilation by the circulation of fresh air; and*
b) *Such temperatures as will secure to workers therein reasonable conditions of comfort and which will prevent injury to health and in particular-*
   i. *the walls and roof shall be of such material and so designed that such temperature shall not be exceeded but be kept as low as practicable;*
   ii. *where the nature of the work carried on in the factory involves, or is likely to involve, the production of excessively high temperature, such adequate measures as are practicable, shall be taken to protect the workers there from by separating the process which produces such temperature from the work-room by insulating the hot parts or by other effective means (Section 14).*

The Government may prescribe a standard of adequate ventilation and reasonable temperature for any factory or class or description of factories or parts thereof and direct

that a thermometer shall be provided and maintained in such place and position as may be specified (Section 14).

Thermometers shall be maintained at all factories in such manner as the Chief Inspector may, by instruction, direct in this behalf. If the Inspector gives notice in writing that a thermometer is not accurate it shall not be deemed to be accurate unless and until a fresh certificate is obtained declaring its fitness (Rule 20).

With regards to humidity, the Factories Act and Rules (Chowdhury, 2003) states that:

The Government may, in respect of all factories in which humidity of the air is artificially increased, make rules -

a) prescribing standards of humidification;

b) regulating the methods used for artificially increasing the humidity of the air;

c) directing prescribed tests determining the humidity of the air to be correctly carried out and recorded; and

d) prescribing methods to be adopted for securing adequate ventilation and cooling of the air in the work-rooms (Section 16)

The introduction of air directly from outside through moistened mats or screens placed in openings at a time when the temperature of the room is 80 ºF (26.6 °C) or more shall not be deemed to be artificial humidification (Rule 2).

No hygrometer shall be fixed at a height of more than 5 feet 6 inches from the floor to the top of the thermometer stem, or in the direct drafts coming from a fan, window or ventilation opening (Rule 21).

Therefore this study is essential to determine the standard of temperature range, humidity and ventilation rate especially for the garment factories that are stated to be prescribed by the Government in laws and factory rules provided by Factory Acts 1965 and Factory Rules 1979.

Indoor Environmental Attributes	Guidelines
Ventilation	Adequate ventilation will be ensured Standard of ventilation rate may prescribed by government
Temperature	Reasonable Condition of Comfort will be ensured Separation of excessive heat produced production process Standard of reasonable temperature range may prescribed by government Thermometer shall be introduced as record instrument for temperature
Humidity	Standard of humidity range may prescribed by government Hygrometer shall be introduced as record instrument for humidity Placement of the hygrometers is specified.

Table 5.6: Summarized Guidelines from the Factories Act, 1965 & the Factories Rules, 1979

5.7.2. Bangladesh Labour Act 2006

The Bangladesh Labour Act 2006 (GoB, 2006) makes suitable and effective provisions for adequate ventilation and temperature. The outlines of the ventilation and temperature provisions of Labour Act are given below:

a) *Effective measure shall be undertaken in every establishment for securing and maintaining in every work-room with adequate ventilation by the circulation of fresh air.*

b) *Temperature in every room shall be kept in such as will ensure to workers therein reasonable conditions of comfort and prevent injury to health.*

c) *Where the nature of the work carried on in an establishment involves, or is likely to involves, the production of excessively high temperature, such adequate measures as are practicable shall be taken to protect the workers there from by separating the process which produces such temperature from the work-room by insulating the hot parts or by other effective means.*

d) *If it appears to the government that in any establishment or class or description of establishment excessively high temperature can be reduced by such methods as*

white-washing, spraying or insulating and screening outside walls or roofs or windows or by raising the level of the roofs, or by insulating the roofs either by an air space and double or by the use of insulating roof materials, or by other methods, it may prescribed such of those or other methods to be adopted in the establishment.

5.7.3. Bangladesh National Building Code

The purpose of the Bangladesh National Building Code (HBRI and BSTI, 1993) is to establish minimum standards for design and construction, use and occupancy, location and maintenance of buildings within Bangladesh to safeguard, within achievable limits, life, health, property and public welfare (Shafi, 2010). The code also provide minimum standards for regulating and controlling the design, location, operation, maintenance and use of air conditioning, heating and ventilation systems to ensure public health, safety and welfare.

Guidance on Mechanical ventilation (*Air Conditioning*) is provided (Section 3.3.2).
For Comfort Air Conditioning, the inside design conditions shall be selected with an objective to reduce energy consumption in the operation of the air conditioning system. Acceptable values of inside design conditions for summer are provided in a Table 5.7.

Velocity of air in an air conditioned space, in the zone between the floor level and the 1.5m level, shall be within 0.12 m/s and 0.25 m/s for comfort applications for commercial buildings, and for other applications it shall not exceed 0.5 m/s (Section 3.3.2.1).

Type of application	Normal Practice		
	DBT(C°)	RH (%)	Temp. Swing(C°)
Air Conditioned Factory	25.5 ~26.5	50 ~ 60	1 ~ 2

Table 5.7: Indoor Conditions for Air Conditioned spaces in summer

Guidance on Mechanical ventilation (Low Energy Cooling) is provided (Section 3.7.3).
Mechanical ventilation shall be provided in all occupied rooms or spaces where the requirements for natural ventilation are not met; in all rooms or spaces, which because of the nature of their use or occupancy, involve the presence of dust, fumes, gases, vapours,

or other noxious or injurious impurities, or substances which create a fire hazard, where space temperature is more than 40 ºC, where relative humidity of inside air is more than 70%, where job conditions require ventilation, or where required as per provisions of this Code (Section 3.7.3.1).

Type of application	Normal Practice		
	DBT(C°)	RH (%)	Required ventilated air (l/s per person)
Mechanical Ventilated Factory	more than 40	70	17.5

Table 5.8: Indoor Conditions for Mechanical Ventilated Spaces in summer

The temperature differential between ventilation air and air in the conditioned space shall not exceed 5.5 °C (Section 3.7.3.5).

Guidance on natural ventilation is provided (Section 3.7.2)
Natural ventilation of an occupied space shall be through windows, doors, louvers, skylights or other openings to the outdoor (Section 3.7.2.1). *The minimum ventilating opening to the outdoors shall be 4% of the floor area being ventilated* (Section 3.7.2.2).

It can be observed in BNBC that for naturally ventilated building, the relationship between the opening area and floor area is stated. However, Temperature level, humidity and ventilation rate are not mentioned, whereas for mechanically (both low energy and high energy) ventilated buildings, temperature level, humidity and ventilation rate are prescribed. Therefore, the present study is essential to determine required temperature levels along with the other comfort factors (i.e. humidity and wind speed) to attain thermal comfort especially for the garment factories as previously a few research were conducted on thermal comfort of residential buildings.

5.7.4. Standards and Codes in Other Countries

It is essential to know the standards and codes of the countries which import the woven garments (like USA-49.05% and UK 8.69% in 2006-2007) from Bangladesh. Moreover, the standards and codes of the countries which compete with Bangladesh in exporting the

woven garments (like China, India) also need to be studied. In this regard, the codes of USA, UK, Malaysia, Singapore and India are reviewed.

- **Standards and Codes in USA**

Standards addressed directly to the thermal comfort and related thermal environment (Markov, 2002):

a) ASHRAE 55: Thermal environmental conditions for human occupancy, and
b) ISO 7730: Moderate thermal environments: Determination of the PMV and PPD indices and specification of the conditions for thermal comfort

ASHRAE 55: The purpose of ASHRAE Standard 55 is to specify the combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable to a majority of the occupants within the space (ASHRAE, 2004). The scope of the standard is to specify the environmental factors such as temperature, thermal radiation, humidity, and air speed along with the personal factors as activity and clothing.

It is intended that all of the criteria in the standard are applied together, since comfort in a particular environment within a space is complex and responds to the interaction of all the factors that are addressed. The standard gives definitions, makes a classification of the parameters and provides information for the conditions for an acceptable thermal environment.

Season	Operative Temperature Range(°C)	Humidity (%)	Mean Air Speed (ms^{-1})	Metabolic Rate (met)	Clothing Insulation (clo)
Summer	23 ~ 26	50	≤ 0.15	1.2	0.5
Winter	20 ~ 23.5				0.9

Table 5.9: Optimum and Acceptable Ranges for Thermal Comfort (ANSI/ASHRAE, 1992)

ISO 7730: The purpose of this standard is to introduce a process for predicting the thermal sensation and the degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments as well as to specify acceptable thermal

environmental conditions for comfort. The standard is applied to people exposed to indoor environments, where the aim is to attain thermal comfort. The standard has been prepared for working environments but can be applied to any kind of environment.

Cate-gory	Thermal state of the body as a whole		Operative temperature °C		Max. mean air velocity m/s	
	PPD %	PMV	Summer (0.5 clo) Cooling	Winter(1 clo) Heating	Summer(0.5 clo) Cooling	Winter(1 clo) Heating
A	< 6	-0.2 < PMV < + 0.2	23.5 – 25.5	21.0 – 23.0	0.18	0.15
B	< 10	-0.5 < PMV < + 0.5	23.0 – 26.0	20.0 – 24.0	0.22	0.18
C	< 15	0.7 < PMV < + 0.7	22.0 – 27.0	19.0 – 25.0	0.25	0.21

Table 5.10: 3 categories of thermal environment: Percentage of dissatisfied due to general comfort and local discomfort (Olesen, 2005)

LEED 2009: According to LEED 2009 for New Construction and Major Renovations Rating System, design for thermal comfort is one of the important issues to provide a comfortable thermal environment that promotes occupant productivity and well-being. Here, the potential technologies & strategies are (USGBC, 2008):

a) *To establish comfort criteria according to ASHRAE 55-2004 that supports the desired quality and occupant satisfaction with building performance.*
b) *To design the building envelope and systems with the capability to meet the comfort criteria under expected environmental and use conditions.*
c) *To evaluate air temperature, radiant temperature, air speed and relative humidity in an integrated fashion.*

- **Standards and Codes in UK**

HSE Guidance: The 'Workplace (Health, Safety and Welfare) Regulations (as amended) 1992' set down specific requirements for most aspects of the working environment. Regulation 7 deals specifically with the temperature in indoor workplaces and states that *'during working hours, the temperature in all workplaces inside buildings shall be reasonable'*. However, there is no maximum temperature stated in the Regulations or associated Approved Code of Practice (HSE, 1992).

The Health & Safety Executive's (HSE) guidance document, HSG194, 'Thermal Comfort in the Workplace' states that *'an acceptable zone of thermal comfort for most people in the UK lies roughly between 13°C (56°F) and 30°C (86°F), with acceptable temperatures for more strenuous work activities concentrated towards the bottom end of the range, and more sedentary activities towards the higher end'* (HSE, 2005).

CIBSE: The CIBSE (Chartered Institute of Building Services Engineers) in Section 1 (Environmental criteria for design) Guide A: Environmental Design suggests that the indoor environment should be designed and controlled so that occupants' comfort and health are assured. It also realizes the necessity to specify measurable limits or ranges for each of the environmental factors. The recommended ranges are:

Season	Operative Temperature Range(°C)	Humidity (%)	Metabolic Rate (met)	Clothing Insulation (clo)
Summer	23 ~ 26	40-70	1.4	0.65
Winter	19 ~ 21			1.0

Table 5.11: Recommended Thermal Comfort Criteria (CIBSE, 1999)

- **Standards and Codes in Malaysia**

The purposes of Malaysian Standard are to encourage the design, construction, operation and maintenance of new and existing buildings in a manner that reduces the use of energy without constraining creativity in design, building function and the comfort or productivity of the occupants. The indoor design conditions for comfort cooling should be as follows:

Operative Temperature Range (°C)	Humidity (%)	Mean Air Speed (ms^{-1})
23 ~ 26	55-70	0.15 ~0.5

Table 5.12: Recommended Thermal Comfort Criteria (DSM, 2007)

- **Standards and Codes in Singapore**

The intent of the Code for Environmental Sustainability of Buildings is to establish environmentally friendly practices for the planning, design and construction of buildings, which would help to mitigate the environmental impact of built structures and to maintain comfort, health and safety of the occupants.

Operative Temperature Range (°C)	Humidity (%)	Mean Air Speed (ms^{-1})
24 ~ 26	< 65	0.6

Table 5.13: Recommended Thermal Comfort Criteria (BCAS, 2010)

- **Standards and Codes in India**

With the advancement of green building movement in India, many companies have demonstrated keen interest in having a holistic green design and construction framework for upcoming factory buildings. With the national GDP expected to grow at about 7% and the contribution of the manufacturing sector to the national GDP being quite significant at 25%, more and more factories would be set up in the country. In this context the development and launch of a green rating programme for factories would have far reaching impacts on saving natural resources, betterment of working conditions and enhanced productivity, thereby leading to substantial national benefits. As regards Comfort Conditions, the Indian Green Building Council states in their Green Factory Rating system:

The goal is to achieve indoor conditions so as to provide good work environment and increase productivity of employees. The new factory building should be designed so as to achieve a minimum PMV (Predicted Mean Vote) value of 0 to 1.8. Points are awarded as follows:

PMV range	Points
0 – 1.8	2
0.2 – 1.6	3
0.4 – 1.4	4
0.6 – 1.2	5

Table 5.14: PMV range for unconditioned buildings

The air conditioning systems should be designed for keeping PMV within range of 0.4 and 1.4.

PMV range	Points
0.4 – 1.4	2

Table 5.15: PMV range for conditioned buildings

5.8. CONCLUSION

Basically, this whole chapter is aimed to build up the knowledge base for RMG Factories in Bangladesh. From the above discussion, the need to study on the production area of RMG factories has been established. The working condition of the Factories have been analysed to get some guidance for the survey of this study. The processes of production and workflow patterns in RMG factories have been investigated carefully to learn the workers' need. The compliance for the RMG factories is scrutinized to know the buyers demand on the working environment. The legislations, Codes and Standards are also reviewed in support of the study. Last of all, by studying the standard and codes of other countries, the necessity to determine the standard of temperature range, humidity and ventilation rate in the context of the garment factories in Bangladesh are proved.

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6. SURVEY AND ANALYSIS

6. SURVEY AND ANALYSIS

6.1. DATA COLLECTION AND FINDINGS

It is stated in a previous chapter (Chapter 2) that the selection of the case study buildings was based on the typical volume of the production space (either Multi-Storied or Single-Storied for RMG buildings in Dhaka), their location in two different industrial zones in Dhaka, their accessibility to collect data and information and cooperation of the Workers as well as the owners to conduct questionnaire and photographic survey.

A structured questionnaire was administered for the workers. The workers were helped in filling out the questionnaire to get a good feel of the problems faced by them. Each respondent took about 5-10 minutes to complete a questionnaire. The workers were randomly selected from mainly two occupation groups: sewing and ironing as they seemed the most critical among the all occupation groups working in the production spaces. As the interview was conducted within the factory premise, adequate care was taken to ensure confidentiality and none of the management personnel was around during the interview. This eliminated possible bias which could have been there if either the workers are selected by the management personnel or they are interviewed in presence of the management personnel.

6.1.1. Overview of the RMG buildings

The major concentration of the Readymade Garment (RMG) Factories in Dhaka is in two different industrial zones: (a) Tongi – Gazipur Industrial Developments and (b) Savar EPZ and Surrounding Industrial Developments. Four RMG Factories were selected among these two areas and among them one represents typical single-storied volume and the other three represents typical multi-storied volume of production spaces for RMG buildings in Dhaka.

240 respondents were randomly selected from these RMG Factories. Among them, half of the total respondents are randomly selected from the two RMG Factories of Tongi – Gazipur Industrial Developments and half of the total respondents were randomly selected from the two RMG Factories of Savar EPZ and Surrounding Industrial

Developments. Equal percentage of the workers was selected from sewing and ironing sections of the production spaces. In two factories these two sections are in the same floor while in rest two, these two sections are separated in different floor.

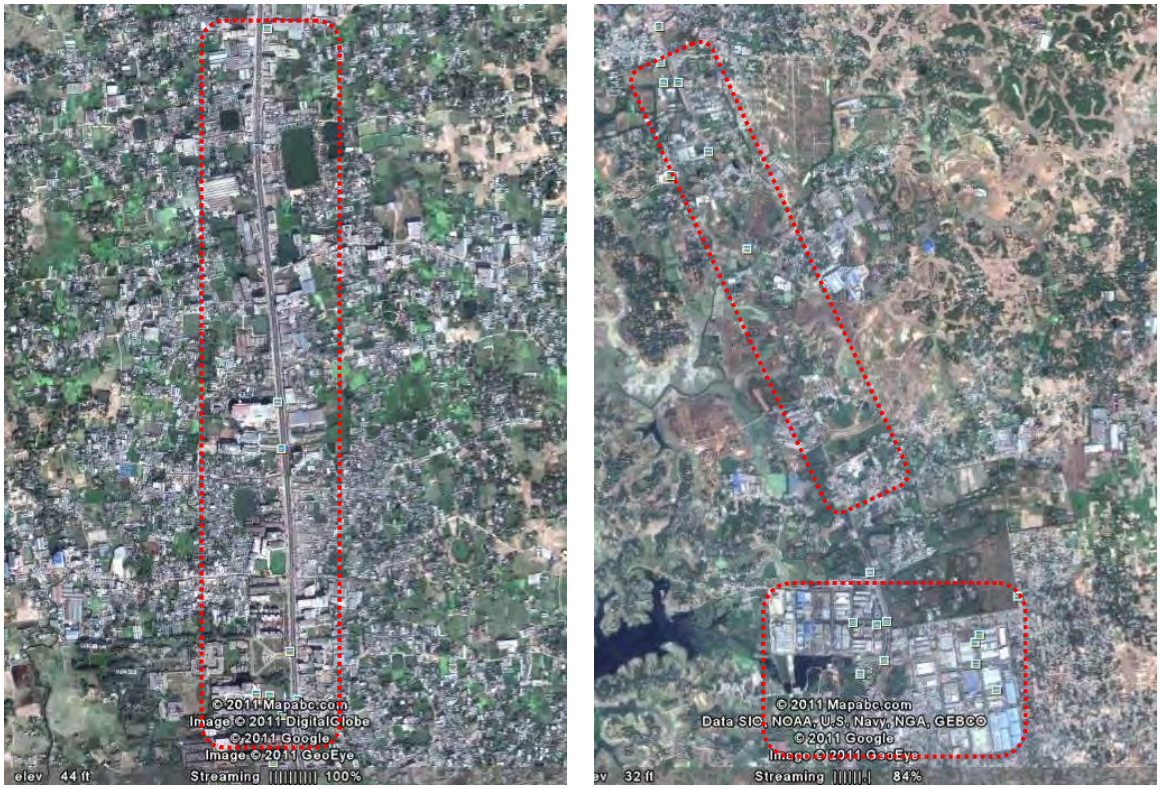


Figure 6.1: (a) Tongi – Gazipur Industrial Developments and (b) Savar EPZ and Surrounding Industrial Developments

For this research, a few factors are considered to define the typical factory building in Dhaka. To determine the comfort zone for the workers' who worked at the production area of the garments factories, the advantages and disadvantages of the following factors were explored:

- The position of the production area in the building (vertical level wise) for both single-storied and multi-storied buildings.
- The impact of orientation on the building indoor comfort factors for, both north-south orientation and east-west orientation.
- The impact of building form on the building indoor comfort factors for both rectangular shaped building and oblong shaped-square like building.

- The impact of microclimate on the building indoor comfort factors for factories in different area.

- **CASE STUDY- A**

Location

The building is in Savar Export Processing Zone (EPZ) area. EPZs in Bangladesh basically offer a package of services like on-site support facilities and services for producers.

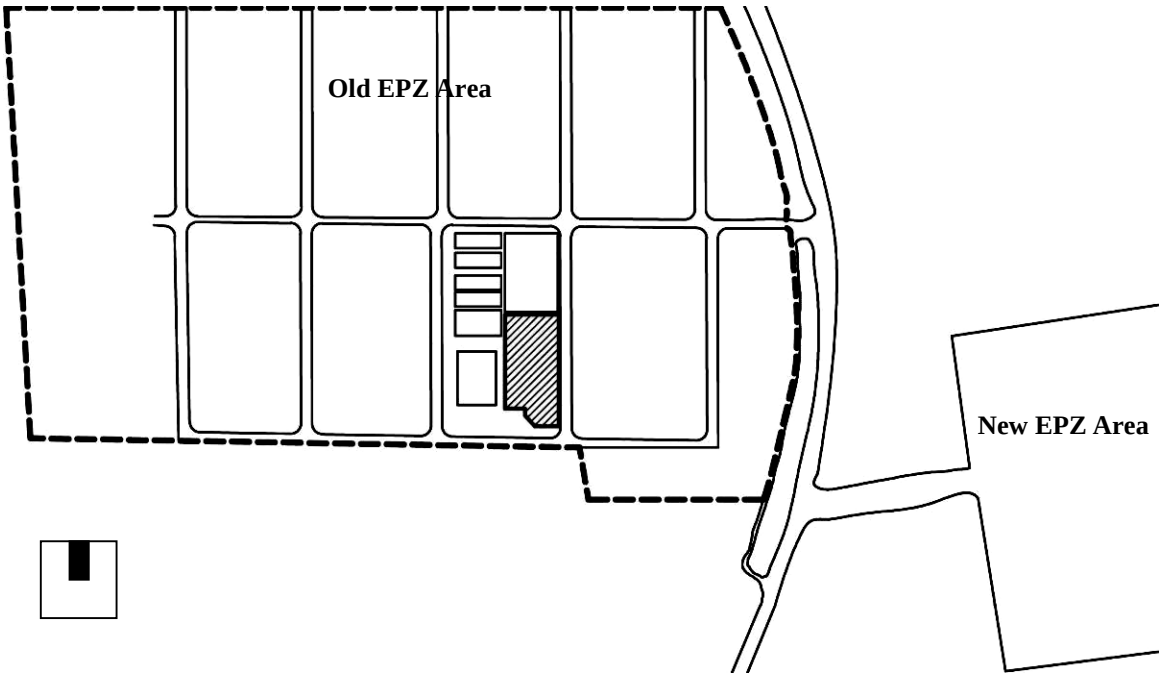
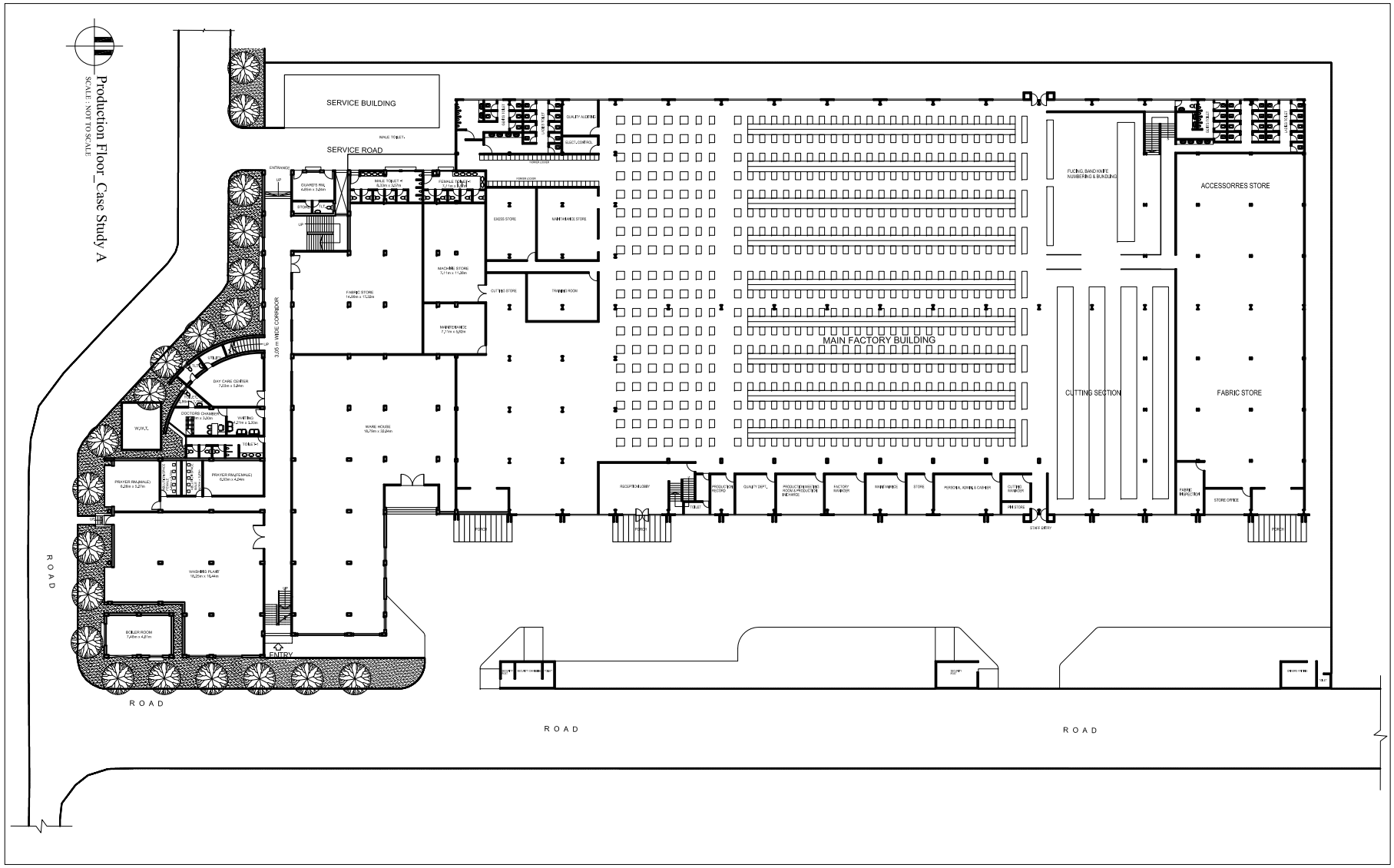
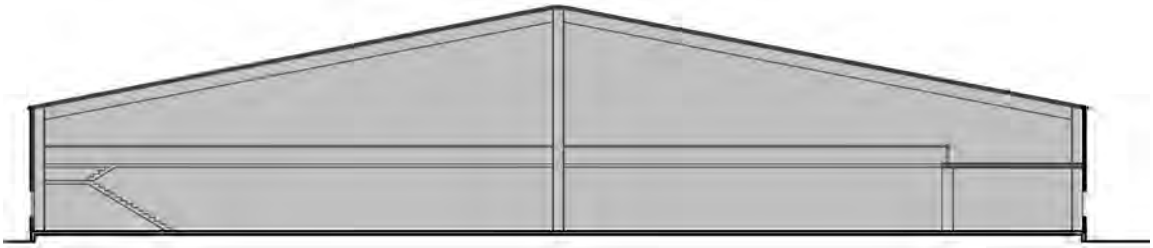


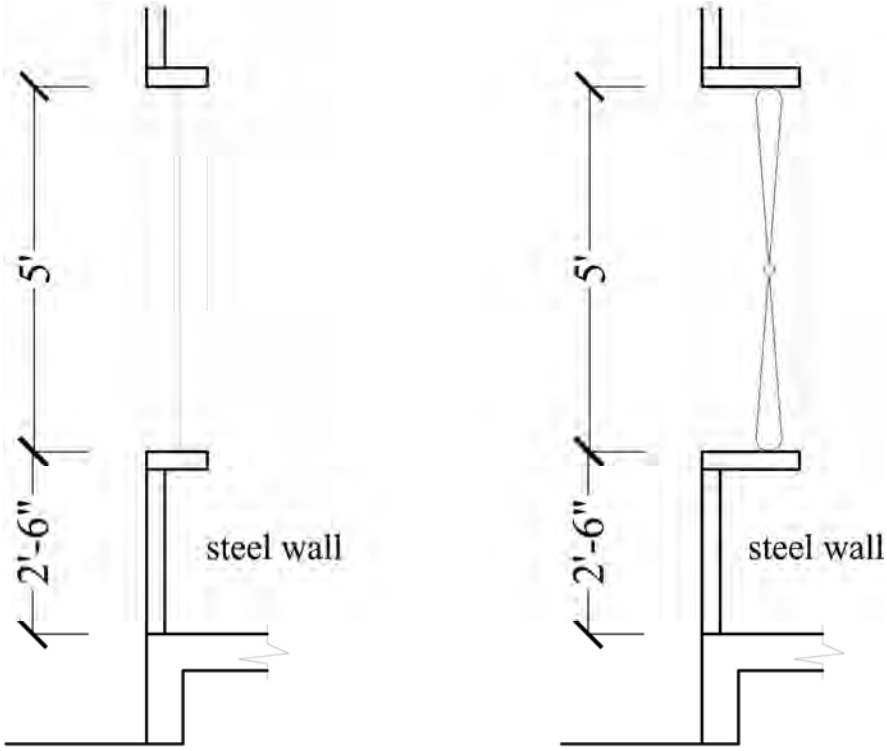
Figure 6.2: Location of Case Study A

The zone is a fenced area where the movement of goods is policed by customs officials, but more importantly, it is equipped with infrastructural facilities such as roads, electricity, water and gas, telecommunications, as well as ready industrial plots - the quality of which is normally superior to those available outside (Bhattacharya, 1998).


Production Floor_Case Study A
SCALE: NOT TO SCALE
SERVICE BUILDING
SERVICE ROAD
ENTRANCE
GUARDS HAL
MALE TOILET
FEMALE TOILET
STORE
3.05 m WIDE CORRIDOR
FABRIC STORE
MACHINE STORE
MAINTENANCE
EXESS STORE
MAINTENANCE STORE
CUTTING STORE
TRAINING ROOM
QUALITY AUDITING
SUPERVISOR
DAY CARE CENTER
DOCTORS CHAMBER
WAITING
TOILETS
WARE HOUSE
PRAYER RM.(MALE)
PRAYER RM.(FEMALE)
WASHING PLANT
BOILER ROOM
ENTRY
ROAD
MAIN FACTORY BUILDING
RECEPTION/LOBBY
PRODUCTION RECORD
QUALITY DEPT.
PRODUCTION DIRECTOR HEAD & PRODUCTION INCHARGE
FACTORY MANAGER
MAINTANANCE
STORE
PERSONAL ADMIN & CASHIER
CUTTING MANAGER
FM STORE
STAFF ENTRY
FUSING, BAND KNIFE NUMBERING & BUNDLING
CUTTING SECTION
ACCESSORRES STORE
FABRIC STORE
FABRIC INSPECTION
STORE OFFICE
PORCH



Schematic Section: Case Study A



Section through West Wall: Case Study A

Planning Aspects

- Building Orientation

In many climates, the optimum orientation would be a north-south orientation with the long facade facing towards the equator minimizing the facade areas facing east and west (Haase et al, 2009). This is also valid for the climates of Bangladesh.

Figure 6.3: Orientation of Case Study A

In this study, the long axis of the building runs north-south, i.e. the facades on the west and east are bigger than the north and south elevations. The orientation of the building is contrary to the recommendation of Nayak and Prajapati (2006), Gut and Ackerknecht (1993), and Ahmed (2002). They state that the best orientation for buildings in tropical climates is for the longer axis of the building to lie along east-west direction to avoid solar heat gain. The building is orientated in the way (facing east and west) that all external facades of it allow to be irradiated by sun rays throughout the year. Thus, the indoor temperatures are high and consequently, the thermal comfort is affected.

- Building configuration

The building contains a single volume production space that represents the typical volume of the production area for RMG building with such facilities. The northern part of the building contains a mezzanine floor. The main building is rectangular in shape and the total height of the main production space is approximately 11 m. Here, the building has

an elongated shape and the production space is not so much compact in character like the form suggested by Gut and Ackerknecht (1993). They suggested buildings with spread-out forms for warm-humid climates like Bangladesh.

Building Envelope

- Roof

The roof is pitched roof about 60 mm thick (sheet with corrugation top to bottom: 50 mm plus the thickness of insulation material: 10 mm is added). It is made of steel sheet. In this study, the orientation of the building is towards the direction of sun. Therefore, a huge portion of roof is heat up by the sun at daytime and increases the indoor temperature. To mitigate the excessive heat transmitted from the roof, a layer of insulation is integrated with the roof material.

- External Wall

All the external walls are made of steel (fig. 6.5) and it is approximately 50 mm thick (sheet with corrugation). The external wall of this building permits a good amount of heat transmission like Nayak and Prajapati (2006) claimed. They stated that for a given temperature difference, the higher the thermal conductivity of a material of fixed thickness and cross-sectional area, the greater is the quantity of heat transferred.

- Openings

The windows are sliding with aluminium frame (Fig. 58) and have 5 mm thickness clear glass. The opening of these sliding windows is limited to 50% of the window size and so is not good for providing airflow in particular. The Window to floor area ratio (WFR) and Window to wall area ratio (WWR) are calculated (Table 6.1). The value is below the recommended value as suggested by Liping et al. (2007).

Window orientation	Floor area, sqm	Window size, sqm	Wall area, sqm	Window to floor area ratio (WFR)	Window to wall area ratio (WWR)
West wall	2742	73	1312	0.03	0.06

Table 6.1: Window to floor area ratio (WFR) and window to wall area ratio (WWR) of Case Study A

Figure 6.4: Pitched Roof of Case Study A

Figure 6.5: Steel Wall of Case Study A

Figure 6.6: Openings at West Facade of Case Study A

Figure 6.7: Ceiling Fans & Air Vent From Evaporative Cooler at Production Area of Case Study A

In the factory building, initially the openings are designed with the provisions for natural ventilation. But, the orientation of the openings of the building is not in accordance with prevailing wind direction. Moreover, at the development phase, a layer of functions are

added at the east side which separate the production area from the exterior of the building. Hence, the production area is exposed from west side which add the ill effect of temperature and heat along with the ill effect sun. To increase the air circulation for cooling the indoor environment of the production area, 10 number of exhaust fans are incorporated at the western wall of the building (fig. 6.6).

Ventilation System

To ensure proper ventilation and to cool the indoor environment, mechanical ventilation is applied. As mechanical devices, ceiling fans and evaporative coolers are incorporated (fig. 6.7). In addition, exhaust fans (1500 mm diameter) are added to remove the hot air of the indoor production area (fig. 6.6).

Case Study A: in Summary

Location	:	Savar Export Processing Zone (EPZ) Developments.
Planning Aspects		
Building Orientation	:	East West Oriented (opposite the prevailing wind direction & towards sun direction)
Building Configuration	:	Rectangular in shape & Single-storied building with approximately 11m height
Building Envelope		
Roof	:	Pitch roof (roof material is steel with insulation material); Thickness 60mm.
External Wall	:	Steel walls (Chance of High rate of heat flow during overheated period); Thickness 50 mm
Openings	:	East West oriented, Large Exhaust fans (1500 mm diameter) are added for force ventilation
Ventilation System	:	Mechanical ventilation by evaporative coolers and ceiling fans

Table 6.2: Case Study A- in Summary

- **CASE STUDY-B**

Location

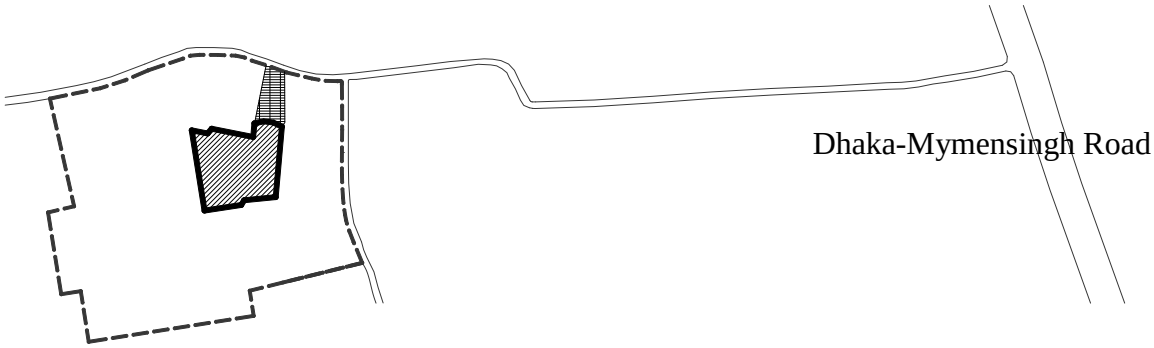


Figure 6.8: Location of Case Study B

The building is in Tongi – Gazipur Industrial Developments. This area is at fringe area of Dhaka and offers all packages of services for producers, though act as private enterprise. The zone is developed by the entrepreneurs as the area is equipped with infrastructural facilities such as roads, electricity, water and gas, telecommunications, as well as ready industrial plots - the quality of which is normally superior to those available at the fringe of Dhaka.

Planning Aspects

- Building Orientation

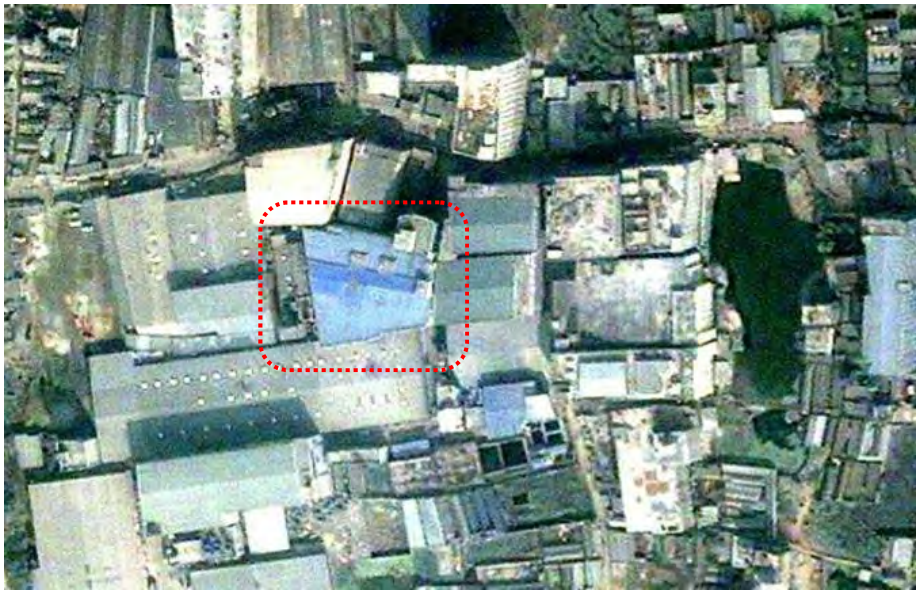


Figure 6.9: Orientation of Case Study B

Here the building is oblong shaped and square-like. The advantages of long axis towards East and West are lessening for this building though the openings are arranged along South direction to capture the prevailing wind. But A few openings at the west reduce the benefit and add the ill effect of temperature and heat along with the ill effect sun. Thus, the indoor temperatures are high and consequently, the thermal comfort is affected.

- Building Configuration

The building contains a multi-storied volume production space that also represents the typical volume of the production area for RMG building with such facilities. The main building is oblong in shape and the surveyed production space is at level 4. The total height of this production space is approximately 3.66m. Here, the building has a compact shape, unlike the form suggested by Gut and Ackerknecht (1993) for warm and humid climatic zone.

Building Envelope

- Roof

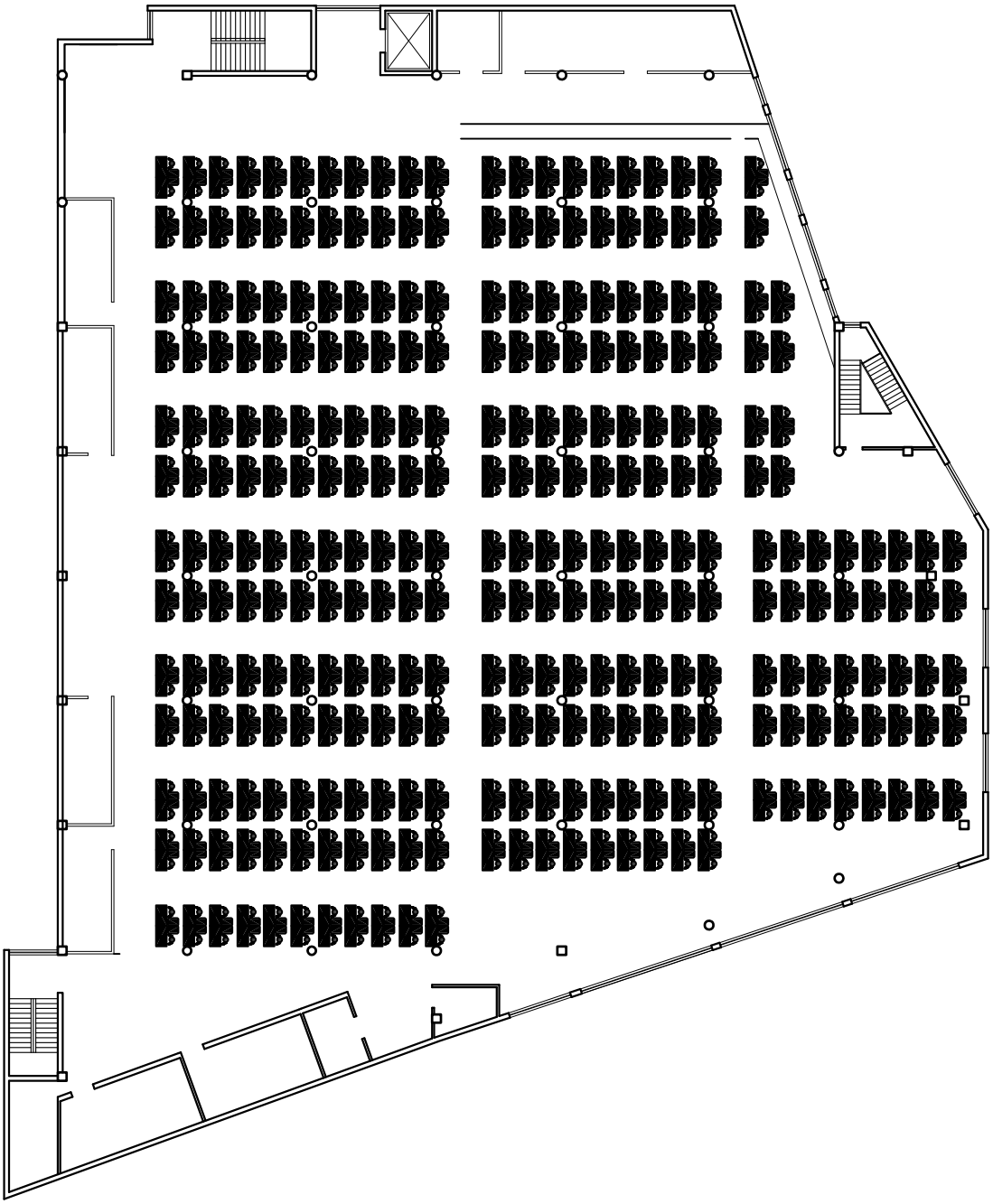
The roof is flat, about 150 mm thick. It is made of reinforced concrete slab as it is in midlevel floor of a multi-storied building. As a midlevel floor, it is free from ill effect of sun that comes from roof. The upper floors act as barrier of excessive heat from roof at day time.

- External Wall

All external walls are of 125 mm solid brick (fig. 6.11). Both external and internal walls have a cement plaster over the brick and white wall finishes.

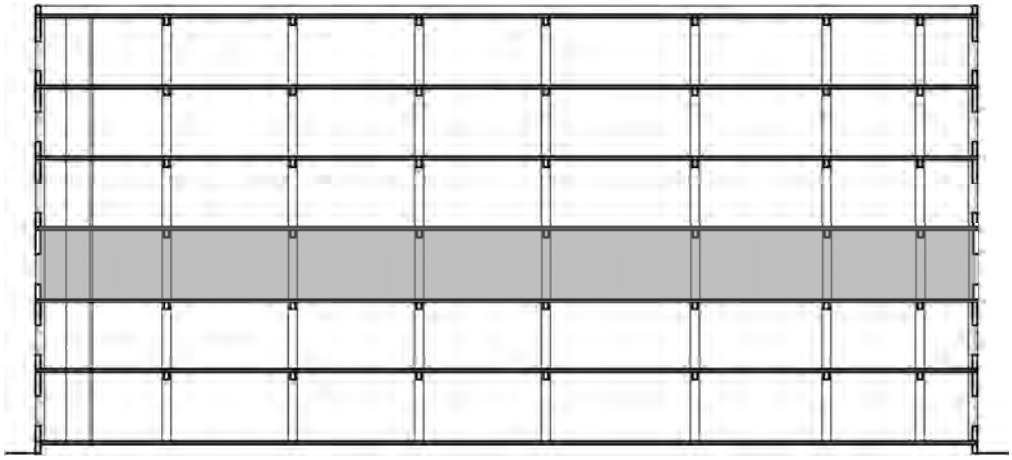
- Openings

The windows are sliding with aluminium frame (Fig. 58) and have 5 mm thickness tinted glass. The opening of these sliding windows is limited to 50% of the window size and so is not good for providing airflow in particular. The Window to floor area ratio (WFR) and Window to wall area ratio (WWR) are calculated (Table 6.3).

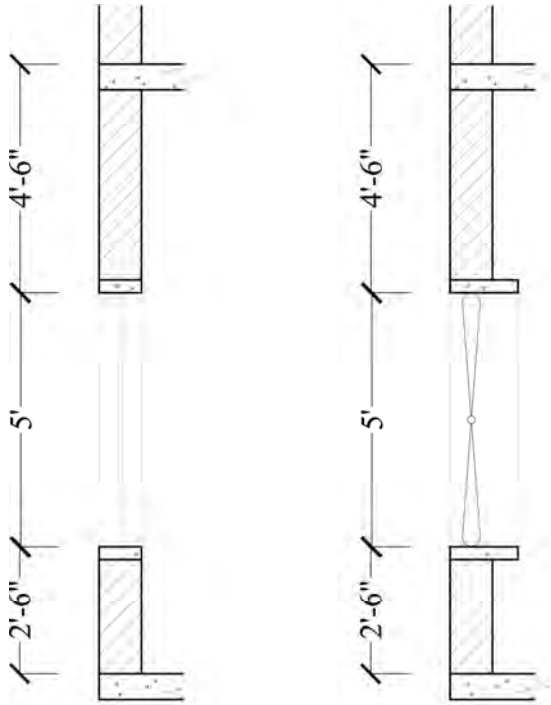


Production Floor_Case Study B

SCALE : NOT TO SCALE



Schematic Section: Case Study B



Section through South Wall: Case Study B

Figure 6.10: Concrete Ceiling of Case Study B

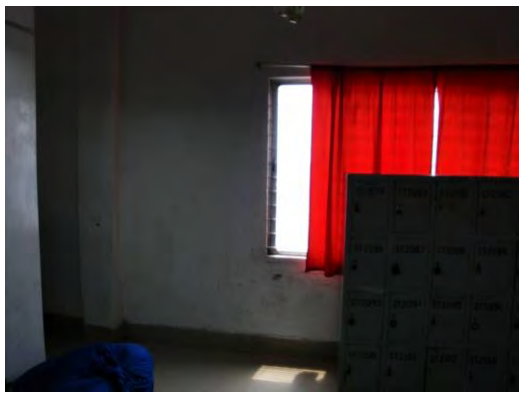


Figure 6.11: Brick Wall of Case Study B

Figure 6.12: Openings of Case Study B

Figure 6.13: Cooling Systems of Case Study B

Here in the factory building, the openings are designed with the provisions of natural ventilation. But, at the development phase, a layer of functions are added at the north and east side which obstruct the natural flow of the prevailing wind in the production area. To

bring in natural light, openings are introduced at west side which is very critical in respect of heat gain. Moreover, as cross ventilation is obstructed, force ventilation is the only choice to ensure the indoor thermal comfort for the workers. Therefore, large exhaust fans are incorporated at south side which also wrong decision as this side is the high pressure zone for prevailing wind.

Window orientation	Floor area, sqm	Window size, sqm	Wall area, sqm	Window to floor area ratio (WFR)	Window to wall area ratio (WWR)
South & West wall	2360	63	735	0.03	0.09

Table 6.3: Window to floor area ratio (WFR) and window to wall area ratio (WWR) of Case Study B

Ventilation System

To ensure proper ventilation and indoor thermal comfort for the workers, mechanical ventilation is applied. As mechanical devices, evaporative coolers are more emphasised (fig. 6.13). In addition, exhaust fans (1375 mm diameter) are added to incorporate force ventilation at the indoor production area (fig. 6.12). Moreover, to remove the added heat gain at ironing section pedestal fans (650-750 mm diameter) are introduced (fig. 6.13).

Case Study B: in Summary

Location	:	Tongi – Gazipur Industrial Area
Planning Aspects		
Building Orientation	:	Non-directional (lack of the benefit of orientation)
Building Configuration	:	oblong shaped-square-like & Multi-storied building with approximately 3.66 m floor to floor distance
Building Envelope		
Roof	:	Flat roof of 150 mm (heat gain is absent for multi-storey)
External Wall	:	Brick walls; thickness 125 mm
Openings	:	Wrongly organized (at west), Large Exhaust fans (1375 mm dia.) added at south is also wrong.
Ventilation System	:	Mechanical ventilation mostly by evaporative coolers and a few pedestal fans (650-750 mm dia.) at ironing section.

Table 6.4: Case Study B- in Summary

- **CASE STUDY C**

Location

The building is in Savar EPZ and Surrounding Industrial Developments. This area is at fringe area of Dhaka and offers all packages of services for producers, though act as private enterprise. The zone is developed by the entrepreneurs as the area is equipped with infrastructural facilities such as roads, electricity, water and gas, telecommunications, as well as ready industrial plots - the quality of which is normally superior to those available at the fringe of Dhaka.

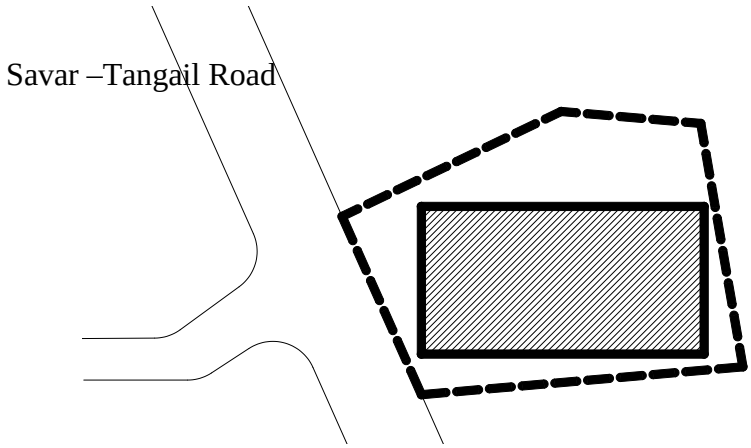


Figure 6.14: Location of Case Study C

Planning Aspects

- Building Orientation

Figure 6.15: Orientation of Case Study C

For the climates of Bangladesh, the proper orientation is north-south orientation with the long facade minimizing the facade areas facing east and west. In this study, the long axis of the building runs West-East, i.e. the facades on the North and South are bigger than the East and West elevations. The orientation of building is according to the recommendation of Nayak and Prajapati (2006), Gut and Ackerknecht (1993), and Ahmed (2002).

- Building Configuration

The building contains a multi-storied volume production space that also represents the typical volume of the production area for RMG building with such facilities. The main building is rectangular in shape and the total height of the main production space is approximately 3.66m. In this study, the building has an elongated shape and the production space is not so much compact in character like the form suggested by Gut and Ackerknecht (1993).

Building Envelope

- Roof

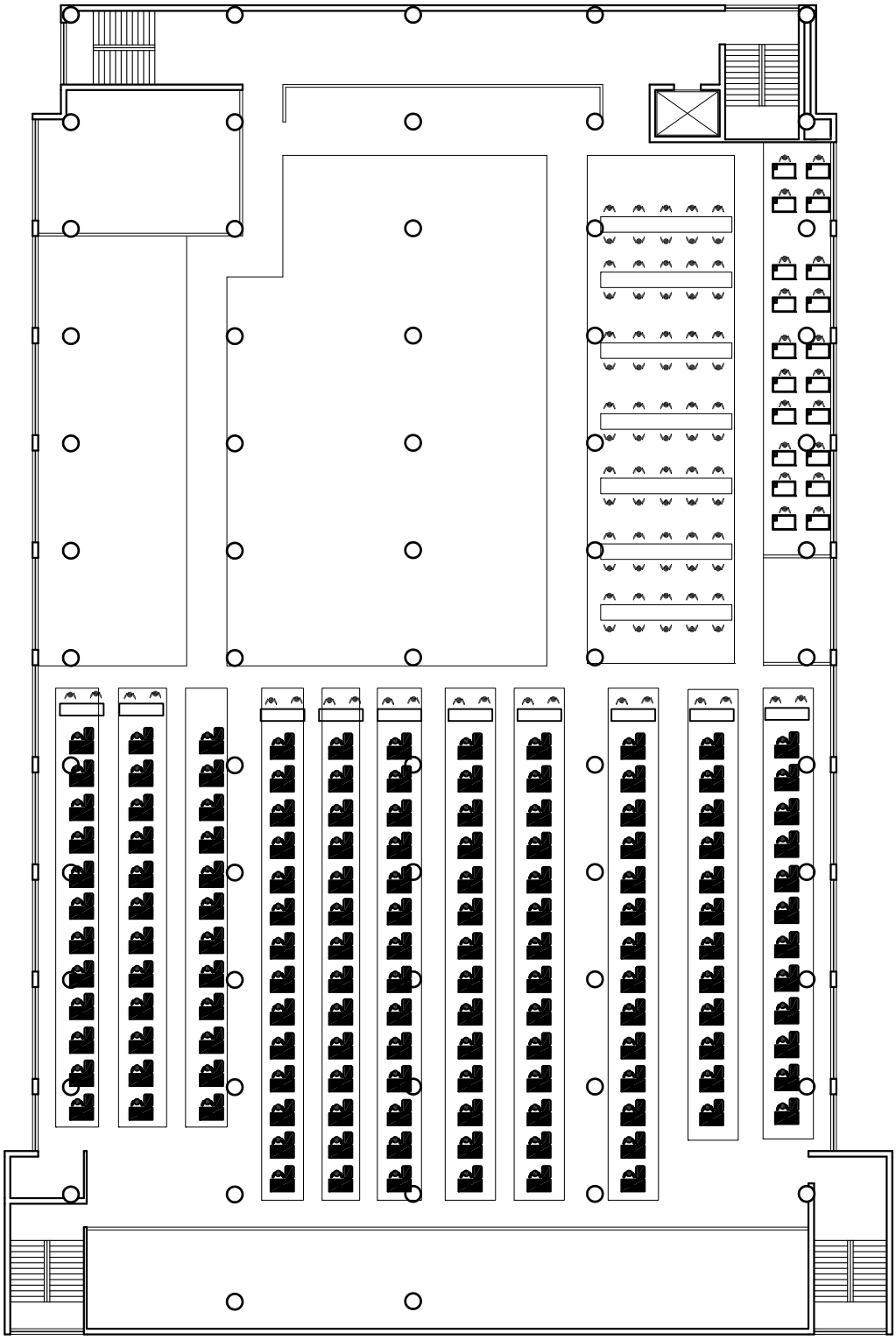
The roof is flat, about 150 mm thick. It is made of reinforced concrete slab as it is in midlevel floor of a multi-storied building. As a midlevel floor, it is free from ill effect of sun that comes from roof. The upper floors act as barrier of excessive heat from roof at day time.

- External Wall

All external walls are of 125 mm solid brick (fig. 6.17). Both external and internal walls have a cement plaster over the brick and white wall finishes. As the large facade is north south oriented and the brick as a building material is better as heat gain barrier, very little heat is transmitted through the walls.

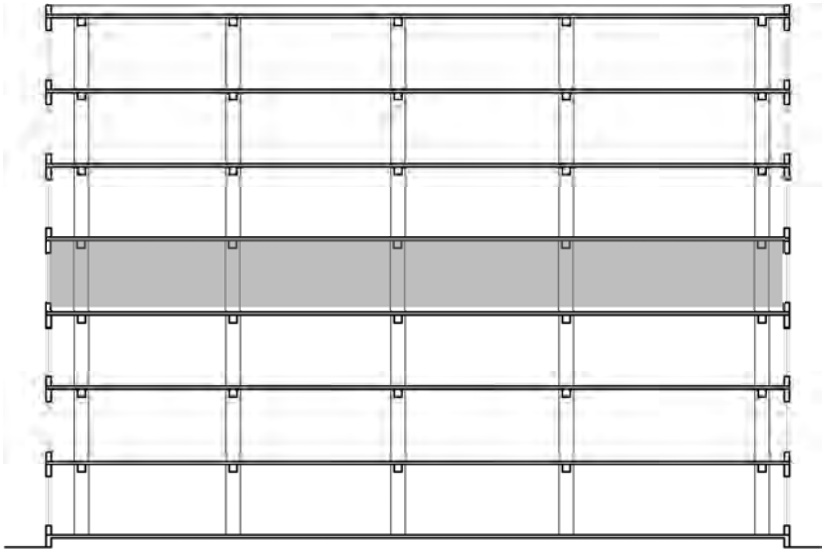
- Openings

The windows are sliding with aluminium frame (Fig. 58) and have 5 mm thickness clear glass. The opening of these sliding windows is limited to 50% of the window size and so

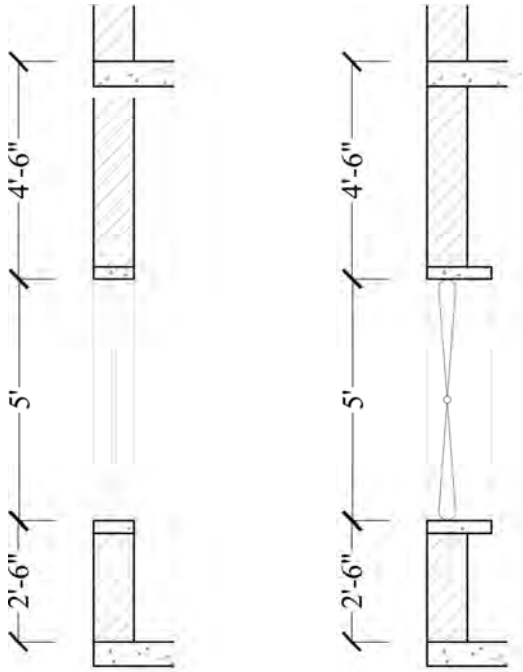


Production Floor_Case Study C

SCALE : NOT TO SCALE



Schematic Section: Case Study C



Section through North Wall: Case Study C

is not good for providing airflow in particular. The Window to floor area ratio (WFR) and Window to wall area ratio (WWR) are calculated (Table 6.5).

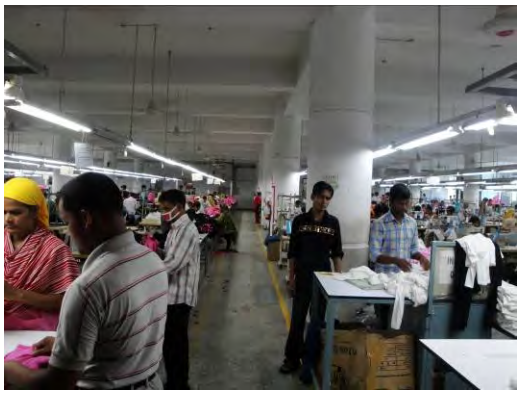


Figure 6.16: Concrete Ceiling of Case Study C

Figure 6.17: Brick Wall of Case Study C

Figure 6.18: Openings of Case Study C

Figure 6.19: Cooling Systems of Case Study C

Here the openings are at north and south side. Openings are large. Cross ventilation is introduced along with force ventilation as the building is too deep to ensure the same air speed. Therefore, large exhaust fans are incorporated at north side which is the low pressure zone for prevailing wind.

Window orientation	Floor area, sqm	Window size, sqm	Wall area, sqm	Window to floor area ratio (WFR)	Window to wall area ratio (WWR)
South-North Wall	1865	189	642	0.1	0.29

Table 6.5: Window to floor area ratio (WFR) and window to wall area ratio (WWR) of Case Study C

Ventilation System

To ensure proper ventilation and indoor thermal comfort for the workers, both natural and mechanical ventilation is applied. As mechanical devices, ceiling fans are incorporated. In addition, exhaust fans (1500 mm diameter) are added to incorporate force ventilation at the indoor production area (fig. 6.18). Moreover, to remove the added heat gain at upper floor evaporative coolers are introduced (fig. 6.19).

Case Study C: in Summary

Location	:	Savar EPZ and Surrounding Industrial Area
Planning Aspects		
Building Orientation	:	North South Oriented
Building Configuration	:	Rectangular in shape & Multi-storied building with approximately 3.66m floor to floor distance
Building Envelope		
Roof	:	Flat roof of 150 mm (heat gain is absent for multi-storey)
External Wall	:	Brick walls; thickness 125 mm
Openings	:	Well organized (at north and south side), Large Exhaust fans (1500 mm diameter) added at north.
Ventilation System	:	Mechanical ventilation mostly by evaporative coolers and ceiling fans.

Table 6.6: Case Study C- in Summary

- **CASE STUDY D**

Location

The building is in Tongi – Gazipur Industrial Area. This area is at fringe area of Dhaka and offers all packages of services for producers, though act as private enterprise.

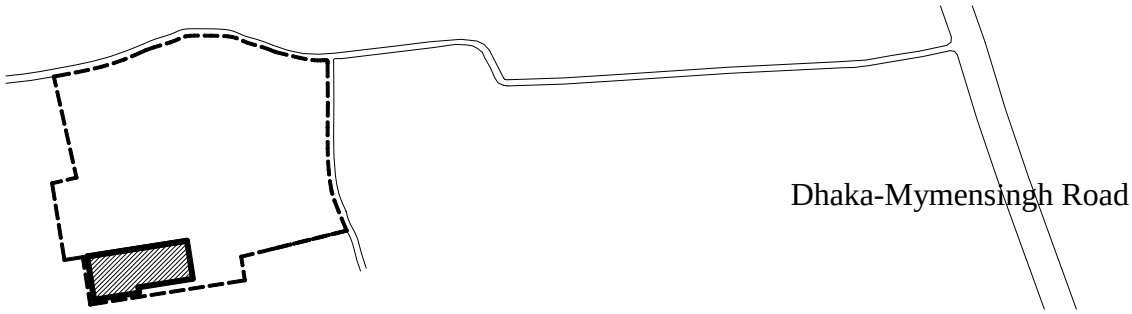


Figure 6.20: Location of Case Study D

The zone is developed by the entrepreneurs as the area is equipped with infrastructural facilities such as roads, electricity, water and gas, telecommunications, as well as ready industrial plots - the quality of which is normally superior to those available at the fringe of Dhaka.

Planning Aspects

- Building Orientation

Figure 6.21: Orientation of Case Study D

Here the building is north south oriented (slightly inclined towards south-east). In this study, the long axis of the building runs West-East, i.e. the facades on the North and South are bigger than the East and West elevations. The orientation of building is according to the recommendation of Nayak and Prajapati (2006), Gut and Ackerknecht (1993), and Ahmed (2002).

- Building Configuration

The building contains a multi-storied volume production space that also represents the typical volume of the production area for RMG building with such facilities. The main building is rectangular in shape and the total height of the main production space is approximately 3.66m. In this study, the building has an elongated shape and the production space is not so much compact in character like the form suggested by Gut and Ackerknecht (1993).

Building Envelope

- Roof

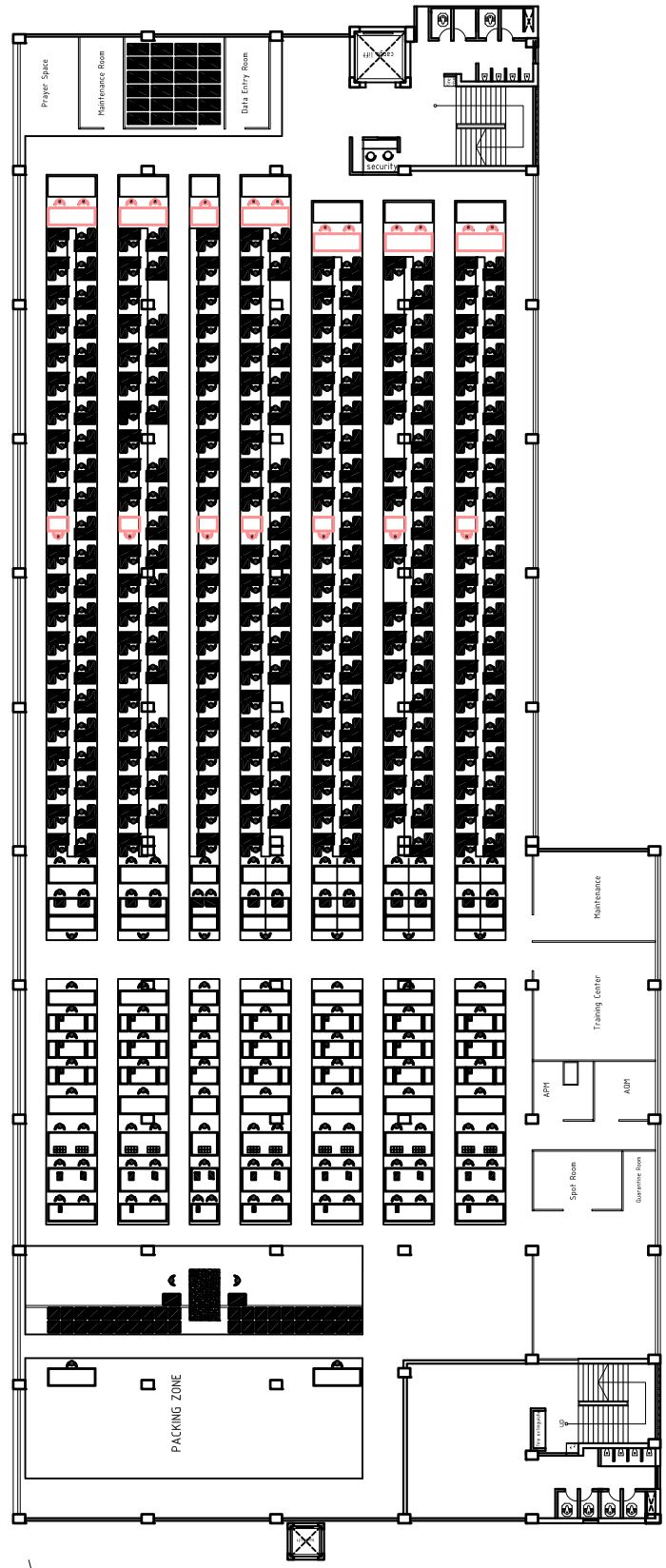
The roof is flat, about 150 mm thick. It is made of reinforced concrete slab as it is in midlevel floor of a multi-storied building. As a midlevel floor, it is free from ill effect of sun that comes from roof. The upper floors act as barrier of excessive heat from roof at day time.

- External Wall

All external walls are of 125 mm solid brick (fig. 6.23). Both external and internal walls have a cement plaster over the brick and white wall finishes. As the large facade is north south oriented and the brick as a building material is better as heat gain barrier, very little heat is transmitted through the walls.

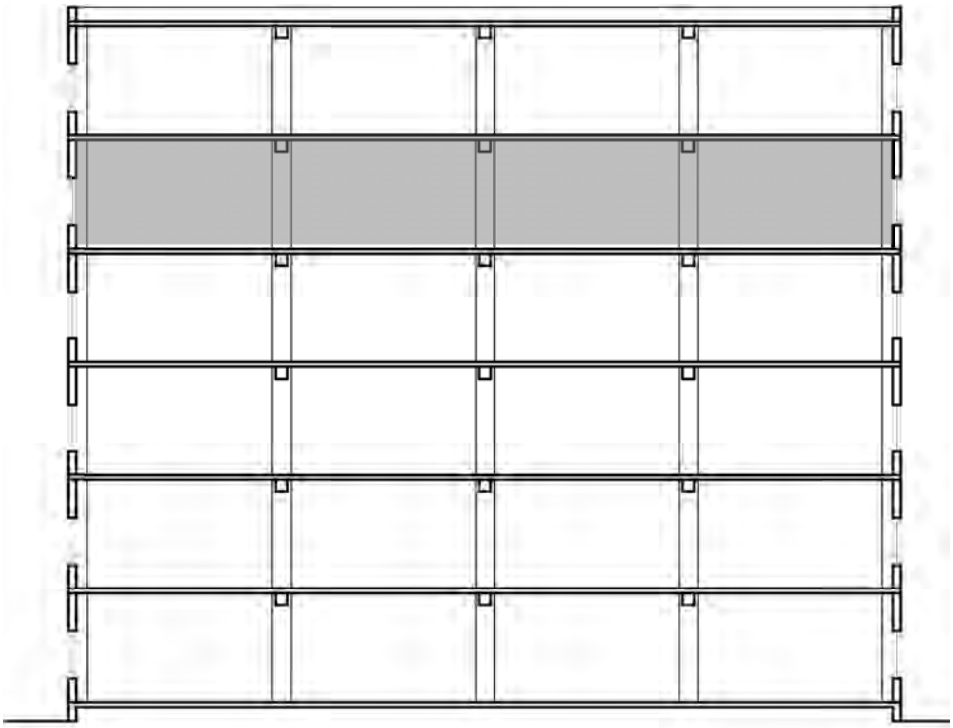
- Openings

The windows are sliding with aluminium frame (Fig. 58) and have 5 mm thickness clear glass. The opening of these sliding windows is limited to 50% of the window size and so

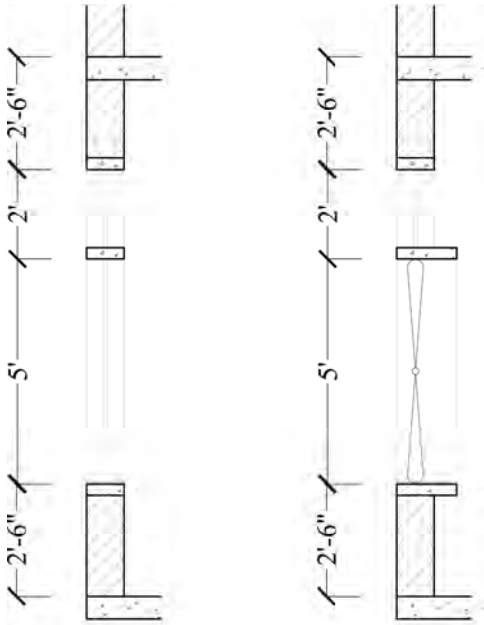


Production Floor_Case Study D

SCALE : NOT TO SCALE



Schematic Section: Case Study D



Section through North Wall: Case Study D

is not good for providing airflow in particular. The Window to floor area ratio (WFR) and Window to wall area ratio (WWR) are calculated (Table 6.7).

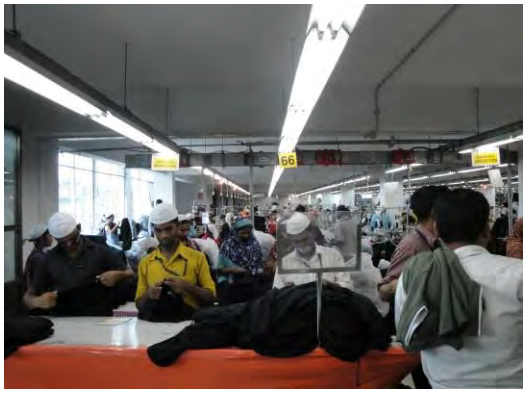


Figure 6.22: Concrete Ceiling of Case Study D

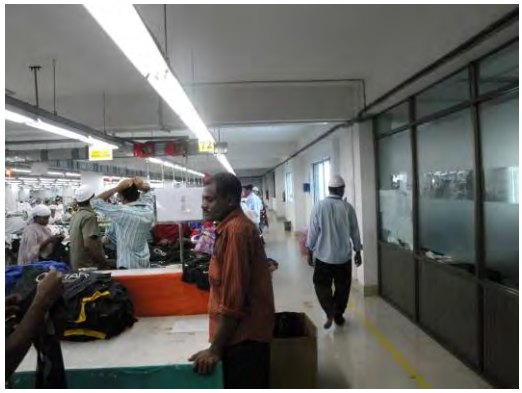


Figure 6.23: Brick Wall of Case Study D

Figure 6.24: Openings of Case Study D

Figure 6.25: Cooling Systems of Case Study D

Here the openings are at north and south side. Openings are large. Cross ventilation is introduced along with force ventilation as the building is too deep to ensure the same air speed. Therefore, large exhaust fans are incorporated at north side which is the low pressure zone for prevailing wind.

Window orientation	Floor area, sqm	Window size, sqm	Wall area, sqm	Window to floor area ratio (WFR)	Window to wall area ratio (WWR)
South-North Wall	1660	167	649	0.1	0.26

Table 6.7: Window to floor area ratio (WFR) and window to wall area ratio (WWR) of Case Study D

Ventilation System

To ensure proper ventilation and indoor thermal comfort for the workers, both natural and mechanical ventilation is applied. As mechanical devices, ceiling fans are incorporated. In addition, exhaust fans (1375 mm diameter) are added to incorporate force ventilation at the indoor production area (fig. 6.24). Moreover, to remove the added heat gain at upper floor evaporative coolers are introduced (fig. 6.25).

Case Study D: in Summary

Location	:	Tongi – Gazipur Industrial Area
Planning Aspects		
Building Orientation	:	North South Oriented (towards the prevailing wind direction & opposite sun direction)
Building Configuration	:	Rectangular in shape & Multi-storied building with approximately 3.66m floor to floor distance
Building Envelope		
Roof	:	Flat roof of 150 mm (heat gain is absent for multi-storey)
External Wall	:	Brick walls; thickness 125 mm
Openings	:	Well organized (at north and south side), Large Exhaust fans (1375 mm diameter) added at north.
Ventilation System	:	Mechanical ventilation only by evaporative coolers.

Table 6.8: Case Study D- in Summary

6.1.2. Subjective Parameters Assessments

Questionnaire surveys were conducted during the period of the environmental parameter measurements. The subjective assessments were based on the occupants' vote on the thermal sensation, thermal preference, thermal acceptance, air velocity and humidity in the production spaces of the garments factories. The selection process of the workers as respondents is random. The whole production area divided into 9 different segments and maximum 6-7 workers were randomly selected from each segment (fig. 26). Minimum 60 respondents were selected from each RMG Factory. Equal percentage of the workers was selected from sewing and ironing section of the production spaces.

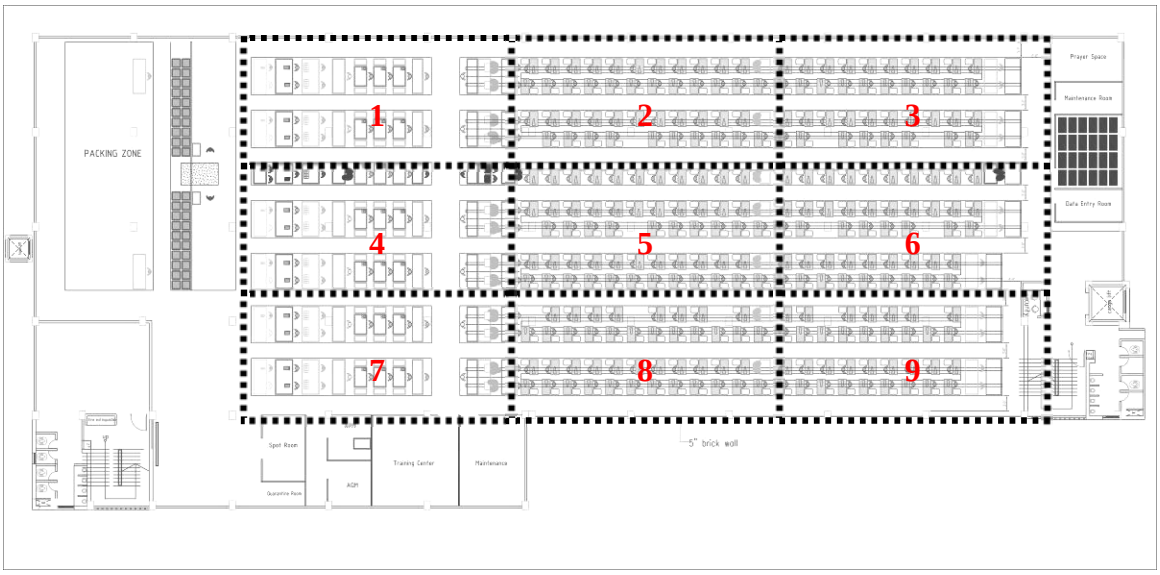


Figure 6.26: Typical Division of Production Area into 9 Segments for Random Selection

It was observed that sewing sections housed female workers mostly, while ironing sections housed male workers mostly. As a result, 65%-70% of the respondents were female and 30% -35% were male.

Factory	Female	Male	Total
Case Study A	42 (70%)	18 (30%)	60
Case Study B	40 (67%)	20 (33%)	60
Case Study C	41 (68%)	19 (32%)	60
Case Study D	39 (65%)	21 (35%)	60

Table 6.9: Number of Respondents

The respondents were selected in such a way that the pertinent analyses concerning thermal comfort were accomplished on a population considerably homogeneous, because all production areas adopt work processes composed by the same equipments and activities. The tasks accomplished by the workers are practically the same for a working day, which reduced the uncertainties in the establishment of metabolic rates. Collected data were measurements of environmental variables and a survey about the workers' thermal sensation and gathering of information to estimate personal variables.

Figure 6.27: Survey Conducted in Production Spaces of Garment Factories in Dhaka Region

6.1.3. Personal Parameters Assessments

Personal parameters were also observed and recorded on the survey forms. Enquiries of subjective responses in the questionnaire included thermal sensation, comfort, preference, acceptability, humidity and air movement. Values for metabolic rate and thermal insulation of the garment, necessary to the calculation of PMV, were estimated. These parameters (section 4.4.1) were as follows:

Maximum Metabolic Rate : 1.65 met
Minimum Metabolic Rate : 1.4 met
Maximum Clo Value : 0.5
Minimum Clo Value : 0.4

The necessary information for the estimation of those variables was obtained simultaneously to the measurement of the environmental variables. Questionnaires were applied, as well as observations of all the other factors that could influence in the measurements or in the answers of the workers' tested group. In the questionnaires there were included some personal information such as age, sex and the garment used by the individual. The activities, as well as the work cycle performed by the worker were also annotated.

6.1.4. Environmental Parameters Assessments

Environmental parameters that had been measured and recorded were air temperature (T), relative humidity (RH) and air velocity (V). These factors were taken the measurement by HOBO U30 and Kestrel 3000 Pocket Weather Meter. All measurements were carried out following the recommendations of the Standard ISO 7726 (1998). HOBO U30 was the basic monitoring system to collect the continuous data for overall indoor environmental condition and Kestrel 3000 Pocket Weather Meter was the handheld weather-monitoring device for the spot measurement to calculate local environmental condition. The measurement parameters are presented in tables 6.10-6.13 for the four case studies:

Case study A

Variables	Z-1	Z-2	Z-3	Z-4	Z-5	Z-6	Z-7	Z-8	Z-9
Air Temperature (ºC)	35.8	36.2	36.8	36.6	36.5	35.2	34.8	34.5	34.6
Relative Humidity (%)	62	60	56	58	56	60	64	60	55
Wind Speed (ms^{-1})	0.1	0.1	0.1	0.2	0.5	0.1	0.5	0.3	0.2

Table 6.10: Survey Data from Case Study A (here, Z=Zone)

Maximum Temperature : 36.8 ºC
Minimum Temperature : 34.5 ºC
Average : 35.7 ºC
Maximum RH : 54%
Minimum RH : 55%
Average : 59%
Maximum Wind Speed : 0.5 ms^{-1}
Minimum Wind Speed : 0.1 ms^{-1}
Average : 0.2 ms^{-1}

Case study B

Variables	Z-1	Z-2	Z-3	Z-4	Z-5	Z-6	Z-7	Z-8	Z-9
Air Temperature (ºC)	36.5	36.8	37.3	36.5	36.4	34.0	34.2	34.5	34.3
Relative Humidity (%)	66	62	60	61	60	70	68	69	67
Wind Speed (ms^{-1})	0.3	0.4	0.1	0.2	0.3	0.1	0.5	0.7	0.2

Table 6.11: Survey Data from Case Study B (here, Z=Zone)

Maximum Temperature : 37.3 ºC
Minimum Temperature : 34.0 ºC
Average : 35.6 ºC
Maximum RH : 70%
Minimum RH : 60%
Average : 65%
Maximum Wind Speed : 0.7 ms^{-1}
Minimum Wind Speed : 0.1 ms^{-1}
Average : 0.3 ms^{-1}

Case study C

Variables	Z-1	Z-2	Z-3	Z-4	Z-5	Z-6	Z-7	Z-8	Z-9
Air Temperature (ºC)	32.7	32.3	32.9	33.3	33.2	33.4	34.0	34.0	34.0
Relative Humidity (%)	74	74	74	77	75	78	72	72	75
Wind Speed (ms^{-1})	0.4	0.6	1.2	0.4	0.4	1.0	1.2	0.2	0.4

Table 6.12: Survey Data from Case Study C (here, Z=Zone)

Maximum Temperature : 34.0 ºC
Minimum Temperature : 32.3 ºC
Average : 33.3 ºC
Maximum RH : 78%
Minimum RH : 72%
Average : 75%
Maximum Wind Speed : 1.2 ms^{-1}
Minimum Wind Speed : 0.2 ms^{-1}
Average : 0.6 ms^{-1}

Case study D

Variables	Z-1	Z-2	Z-3	Z-4	Z-5	Z-6	Z-7	Z-8	Z-9
Air Temperature (ºC)	28.7	29.4	29.8	29.9	29.7	30.3	30.5	30.1	30.2
Relative Humidity (%)	63	56	54	55	58	62	60	56	56
Wind Speed (ms^{-1})	0.5	1.6	1.2	1.0	0.6	0.5	1.5	0.1	0.5

Table 6.13: Survey Data from Case Study D (here, Z=Zone)

Maximum Temperature	:	28.7 ºC
Minimum Temperature	:	30.5 ºC
Average	:	30.0 ºC
Maximum RH	:	63%
Minimum RH	:	54%
Average	:	58%
Maximum Wind Speed	:	1.6 ms^{-1}
Minimum Wind Speed	:	0.1 ms^{-1}
Average	:	0.8 ms^{-1}

6.1.5. Comparative Analysis of Environmental Parameters

- **Air Temperature (°C)**

Based on Air Temperature survey, the case study B is higher in temperature and case study A is near to case study B while the other two buildings are relatively lower in temperature.

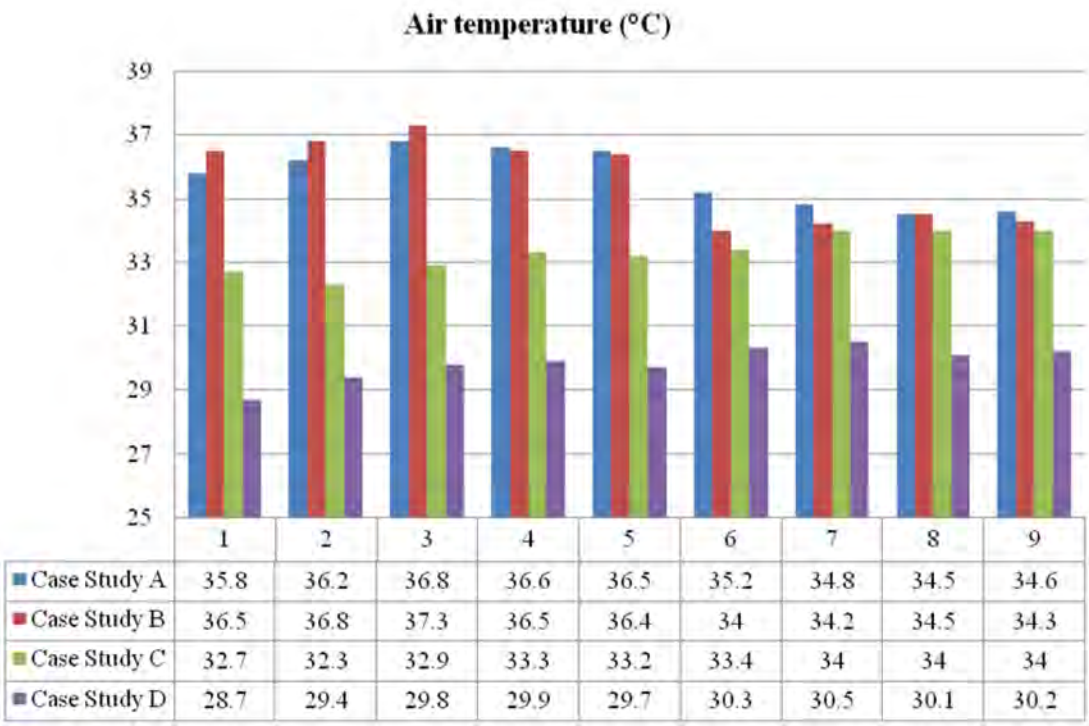
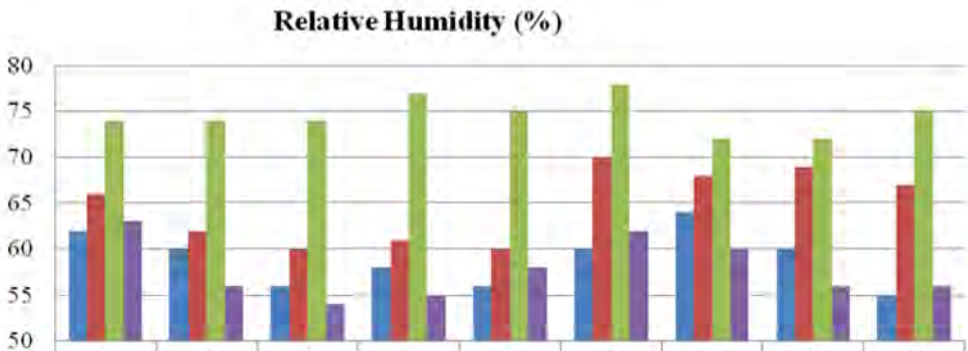


Figure 6.28: Comparative Analysis of Air Temperature (°C)

- **Relative Humidity (%)**



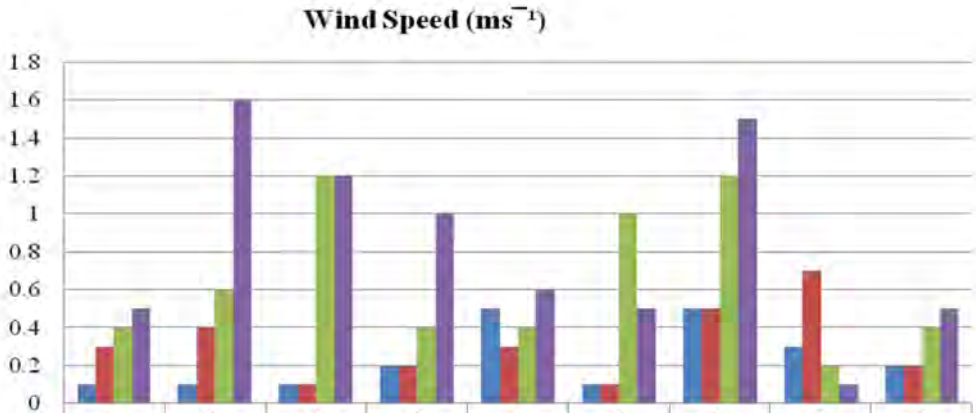
	1	2	3	4	5	6	7	8	9
Case Study A	62	60	56	58	56	60	64	60	55
Case Study B	66	62	60	61	60	70	68	69	67
Case Study C	74	74	74	77	75	78	72	72	75
Case Study D	63	56	54	55	58	62	60	56	56

Figure 6.29: Comparative Analysis of Relative Humidity (%)

Based on Relative Humidity survey, the case study C is higher in percentage and according to position the other three are respectively case study B, case study A and case study D.

- **Wind Speed (ms^{-1})**

Based on Wind Speed survey, the case study d is higher in speed and according to position; the other three are respectively case study C, case study B and case study A.



	1	2	3	4	5	6	7	8	9
Case Study A	0.1	0.1	0.1	0.2	0.5	0.1	0.5	0.3	0.2
Case Study B	0.3	0.4	0.1	0.2	0.3	0.1	0.5	0.7	0.2
Case Study C	0.4	0.6	1.2	0.4	0.4	1	1.2	0.2	0.4
Case Study D	0.5	1.6	1.2	1	0.6	0.5	1.5	0.1	0.5

Figure 6.30: Comparative Analysis of Wind Speed (ms^{-1})

- **Overall Matrix regarding Thermal Performance**

Month	Case Study A	Case Study B	Case Study C	Case Study D
Building Orientation				
Building Configuration				
External Wall				
Openings				
Air Temperature				
Humidity				
Airflow				
Overall Perform.				

Table 6.14: Overall Matrix regarding Thermal Performance

Scale (of impact):

4 3 2 1

Best

6.1.6. Response of the Workers

The thermal comfort research for the garment workers at production area herein applies the methodology of 'field studies', using field surveys for assessing subjective thermal responses of people in actual environments. Questionnaires used in this research consist of five enquiries of subjective responses, including thermal sensation (seven-point ASHRAE and Bedford Scales), comfort level (six-point Comfort Scale), thermal preference (three- point and seven-point Preference Scales), acceptability (two-point Acceptability Scale) and last of all, humidity and air movement (five-point Humidity and Air Movement Scales) (Appendix 01).

- **Thermal Sensation: ASHRAE vs. Bedford Scale**

The equation that relates thermal conditions to seven point ASHRAE thermal sensation scale of: -3 (cold), -2 (cool), -1 (slightly cool), 0 (neutral), 1 (slightly warm), 2 (warm) and 3 (hot), is known as the PMV (Predicted Mean Votes) index and a related index called the Predicted Percentage Dissatisfied (PPD) is calculated (Charles, 2003). The

equation that relates thermal conditions to seven point Bedford Scales of: -3 (much too cool), -2 (too cool), -1 (comfortably cool), 0 (comfortable), 1 (comfortably warm), 2 (too warm) and 3 (much too warm), is also considered as the PMV (Predicted Mean Votes) index in this kind of research work.

According to ASHRAE Standard 55-92 (1992; cited by Tablada et al. 2005) the three central categories of the thermal scale between -1 and +1 express that at least 70% of people feel their thermal sensation acceptable. In this study, the Bedford scale reflects that 68% voted inside these three central categories, while in the ASHRAE thermal scale 65% voted in this range of points.

But, here subjective thermal responses using ASHRAE and Bedford Scales revealed that the distribution of votes was biased toward a warm side of the scale. The number of votes at '0' or 'neutral and comfortable' was approximately 24-33%. The number of votes at '+1' or 'slightly warm and comfortably warm' was approximately 32-44%, while the number of votes at '+2' or "warm and too warm' was approximately 23% and the number of votes at '+3' or 'hot' was approximately 9-12%, shown in fig 6.31.

In this study, it is observed that the worker's at ironing section felt warmer than the worker's at sewing section. And if the ironing section was at same floor with sewing section, then the workers' at sewing section felt warmer, where as workers' at sewing section felt less warmer in same temperature if the ironing section was in separate floor.

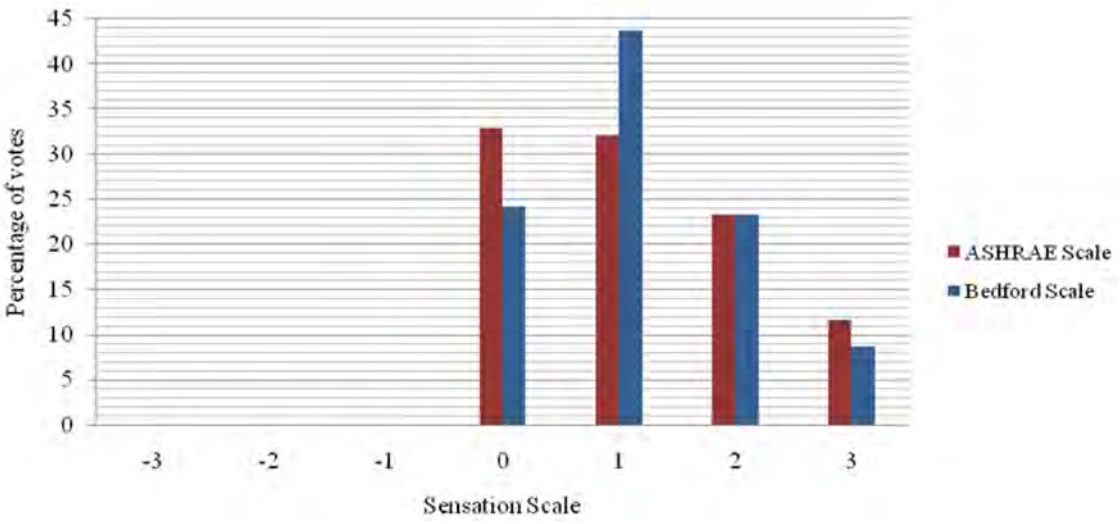


Figure 6.31: Frequency Distribution of Thermal Sensation

However, when using Comfort Scale, majority of votes were at '-2' or 'moderately comfortable', shown in fig 6.32. This can be explained by both the acclimatisation of the local people to the warm-humid climate of Dhaka. Adding all involved in comfortable criteria responses, the number of subjects were about 68%.

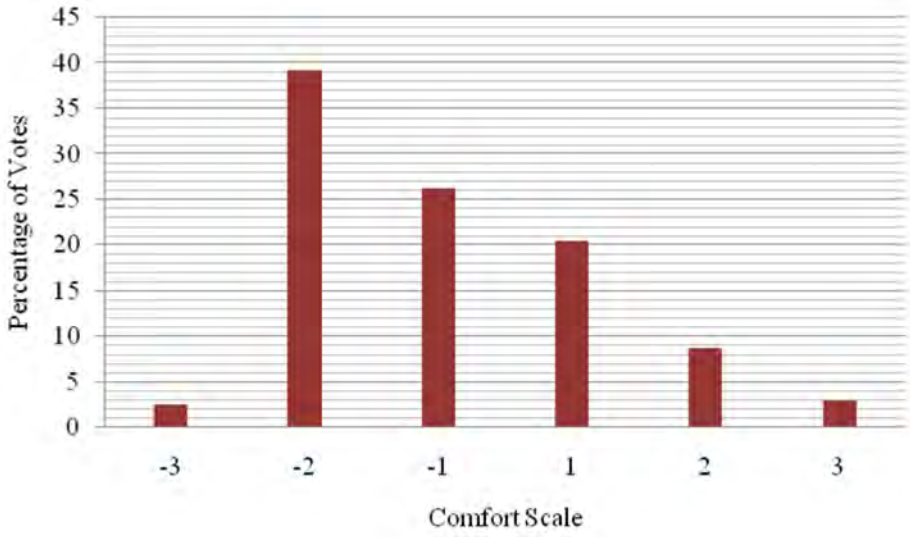


Figure 6.32: Frequency Distribution of Comfort Vote

- **Thermal Preferences and Acceptability**

On exploring the acceptability, 42% of the respondents (100 numbers of respondents) 'accepted' their immediate environments to be comfortable, shown in fig 6.33. This means that although some sample felt comfortable, they did not accept their environments.

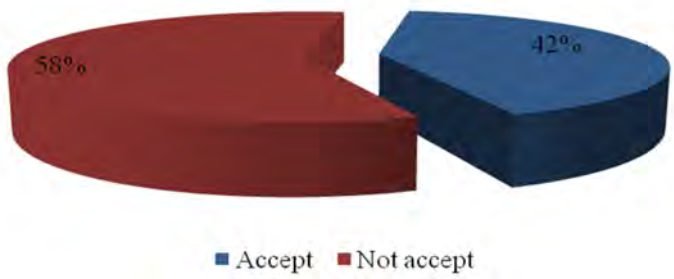


Figure 6.33: Frequency Distribution of Acceptability Vote

It can be explained from The Preference Scale that they would like to change their environments to be 'cooler', as shown in fig 6.34. As reported by other researchers many respondents responding in the neutral zone, thus having thermal comfort, also voted that they prefer to be cooler (Busch, 1992). But, here the Preference Scale contained 76% of

votes at '-1' or 'slightly cooler', '-2' or 'cooler' and '-3' or 'much cooler', which indicates that the comfort zone may be shifted from the classic defined by Olgyay.

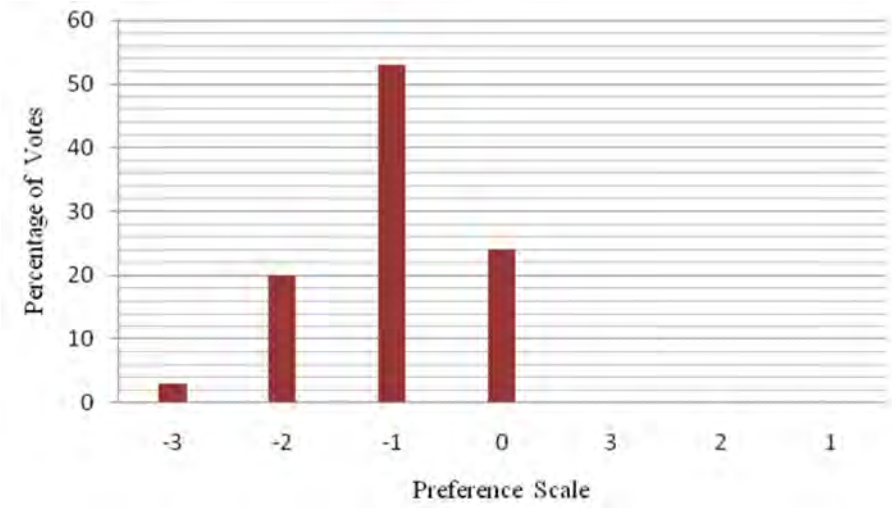


Figure 6.34: Frequency Distribution of Preference Vote

- **Humidity Sensation and Preference**

Humidity had been investigated in a number of reported surveys carried out in hot climate, and these surveys found that humidity can have a significant effect on the thermal comfort (Nicol, 2004). The effect of relative humidity on thermal comfort should not be ignored at high and low temperatures since the high relative humidity would reduce the latent heat loss of the human body by sweat evaporation in warm conditions and would also decrease the insulation of clothing due to it being damp in cold and humid conditions (Parsons, 1993; McIntyre, 1980; cited by Li et al. 2010).

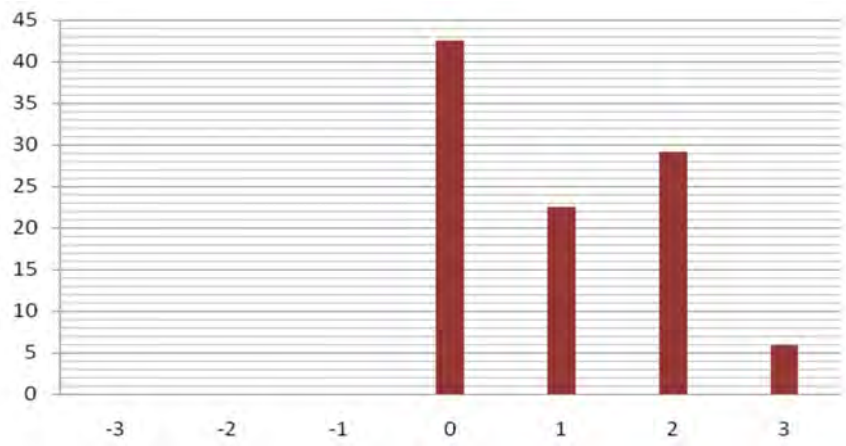


Figure 6.35: Frequency Distribution on Relative Humidity of Preference Vote

In this study, the relative humidity varied from 54% to 78 %. The relationship between humidity preference and its corresponding thermal sensation were also analysed and the result is shown in Fig. 6.35, indicating that the major distribution of votes (58%) was bias towards the humid side of the scale, that means the humidity is from 'slightly humid' (-1) to 'much too humid' (-3). Only 42% of people who wanted no change in humidity also voted for no change in their general thermal sensation.

In this regard, Isaksson & Karlsson (2006) reported that the majority of respondents voted in the 'central band' on the Humidity Scale, when comfortable (-1<TS<+1), even when the humidity was high. But we know that the high level of humidity (above 60%) in the air increases temperature perception of human from the actual air temperature (Table 4.3).

- **Air Movement Sensation and Preference**

Air velocity has an effect on thermal comfort. It is ensured by de Dear et al. (1991; cited by Li et al. 2010) that people would prefer breezy air movement in warmer conditions and less so in cooler environment. In a free-running building, people would often open doors or windows for cooling when they feel the air temperature is uncomfortably high. But, for the garments factories, there are restrictions regarding opening the doors or windows for security reasons. As a result, workers have to depend on mechanical ventilation or extraction ventilation by evaporative coolers.

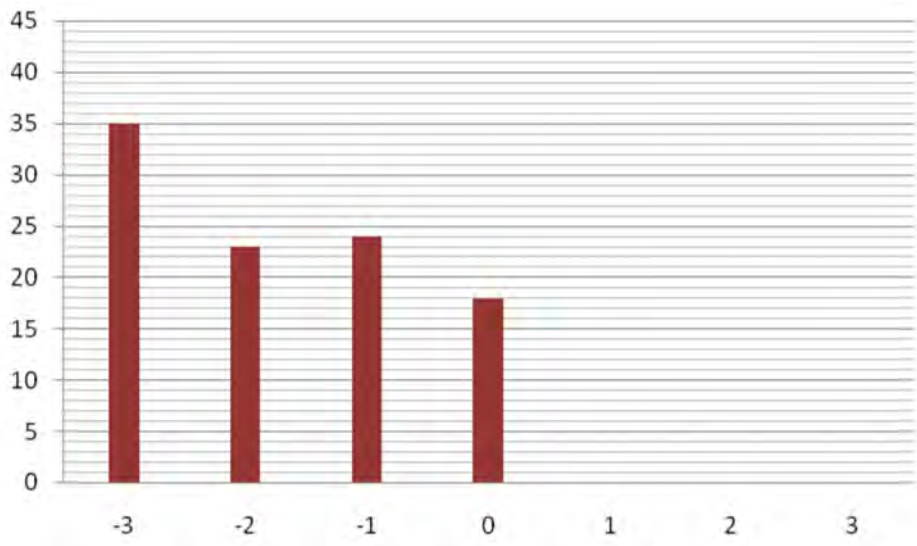


Figure 6.36: Frequency Distribution on Air Movement of Preference Vote

In the study, the indoor air velocity varied from 0.1 to 1.6 ms^{-1}. The distribution of air movement sensation (AMS) vote is shown in Fig. 6.36, indicating that 18% of respondents felt the air velocity was just right and the majority of people (82%) voted in the left part of the scale, indicates that the air is from 'slightly still' (-1) to 'much too still' (-3). 76% of people who voted in this range also voted that they prefer to be cooler in the preference scale. Li et al. (2010) confirmed that people's preferences for higher air movement when there was an increase in thermal sensation and added that even without a cooling requirement related to thermal comfort; people would appear to welcome the feeling of air movement to still air. Here, those 18% of respondents who wanted no change in air movement also voted for no change in their general thermal sensation.

- **Comfort Zone**

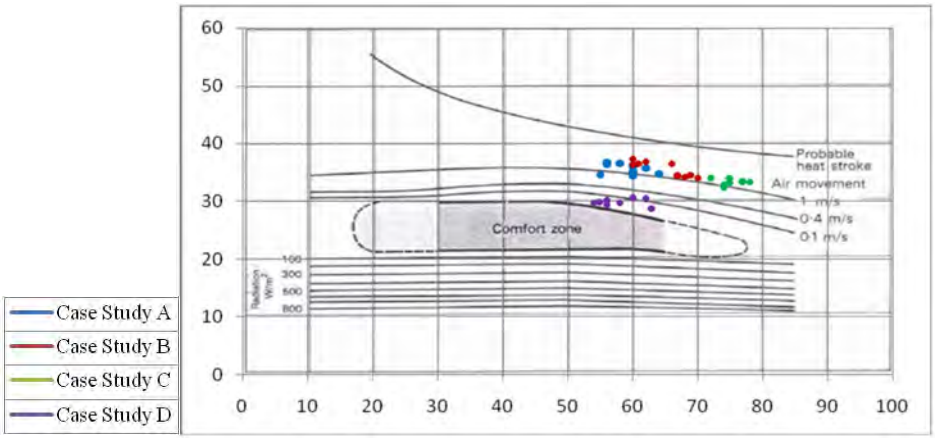


Figure 6.37: Comparative Analysis of Comfort Zone

Through this research in production spaces of several garments factories in Dhaka, it was found that there was none of votes in the Olgyay's comfort zone. The nearest position towards the Olgyay's comfort zone is hold by the Case study D (fig. 6.37). And it is observed that this unit is more comfortable to the highest percentage of workers. Though they are acclimatized on higher range, for this a new range has to be proposed for them.

Workers wanted to sit near the evaporative cooler (the source of cooler breeze) rather than near the exhaust fan. 58% of the surveyed population (fig. 6.33) wanted to change their seat as they are far from the evaporative cooler. For this, job rotation, workstation rotation, etc. should be introduced.

6.1.7. Workers' Performance Assessments

Recently, a strong relationship between thermal comfort and occupant productivity are observed through some researches. Here, most researchers would agree that a link exists; but it is difficult to prove scientifically or statistically as productivity is difficult to measure and quantify (McCartney et al, 2002). In practice, two main approaches are practised in assessment of productivity and the link to thermal comfort: Perceived Productivity and Specific Task Performance. For this research, to link the assessment of productivity and thermal comfort, the data were collected from the case study A.

- **Perceived Productivity**

Self-assessment questionnaires are developed as an alternative approach for the assessment of productivity and the link to thermal comfort. During the course of their normal work, occupants are asked to assess their own 'perceived' productivity on a subjective rating scale. The results from these votes are then compared to measurements of the indoor environmental conditions to establish a link to thermal comfort (McCartney et al, 2002). This method is the one most commonly used by thermal comfort researchers today (Bordass, Leaman and Ruyssevelt 2001). Here, in this research, the perceived productivity approach lost its effectiveness as the workers failed to assess themselves due to their confusion about the conception of productivity.

- **Specific Task Performance**

There are many studies that have identified temperature as the influencing factor on the performance of certain carefully designed tasks under strictly controlled conditions. The performance of some tasks improves with rising room temperature, while that of the others deteriorates (Wyon, 1986; cited by McCartney et al, 2002). As modern working process is becoming more multi-faceted, it is difficult to measure productivity of the workers. According to ASHRAE Workshop on Indoor Quality, 1992 the recommended individual productivity measures are: Absenteeism rates, sickness records, discontinued work flow, speed and accuracy of work, number of error etc (Croome, 2002). Here, in this research, Absenteeism rates, number of error and task performance percentage is collected from the factory archive and records (Table 6.15).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean indoor temperature	**21**	**27**	**32**	**34**	**35**	**34**	**34**	**33**	**33**	**32**	**31**	**22**
Absenteeism rates (%)	**9**	**16**	**14**	**13**	**17**	**13**	**12**	**7**	**10**	**11**	**10**	**16**
Number of error (%)	**0.82**	**1.52**	**1.58**	**1.67**	**2.05**	**1.70**	**1.82**	**0.58**	**2.50**	**3.22**	**0.98**	**1.41**
Task Performance	**78**	**87**	**74**	**82**	**81**	**80**	**74**	**78**	**76**	**78**	**72**	**81**

Table 6.15: The Assessment of Productivity (based on factory record)

Moreover, sickness records are collected from the factory medical centre to identify any relationship between thermal comfort and occupant productivity.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Headache	**120**	**144**	**156**	**155**	**145**	**110**	**118**	**130**	**125**	**121**	**94**	**65**
Fever	**132**	**175**	**150**	**150**	**150**	**40**	**110**	**120**	**150**	**180**	**125**	**114**
Allergy	**13**	**6**	**10**	**14**	**12**	**12**	**11**	**14**	**10**	**12**	**7**	**7**
General weakness	**24**	**56**	**105**	**87**	**57**	**60**	**58**	**55**	**20**	**17**	**26**	**14**
Acidity	**93**	**109**	**130**	**186**	**140**	**176**	**150**	**115**	**105**	**96**	**61**	**54**
Loose motion	**76**	**103**	**160**	**85**	**79**	**58**	**55**	**43**	**50**	**58**	**53**	**59**
Chest pain	**10**	**20**	**8**	**58**	**58**	**1**	**5**	**11**	**17**	**6**	**5**	**9**
Abdominal pain	**64**	**49**	**74**	**36**	**39**	**50**	**45**	**30**	**59**	**50**	**33**	**41**
Body ache	**70**	**70**	**100**	**98**	**64**	**85**	**76**	**67**	**77**	**70**	**49**	**47**
Back pain	**15**	**8**	**19**	**3**	**15**	**10**	**12**	**15**	**9**	**14**	**9**	**3**
Vomiting	**19**	**39**	**54**	**22**	**17**	**6**	**8**	**15**	**18**	**25**	**18**	**9**
Toothache	**9**	**11**	**9**	**18**	**18**	**15**	**12**	**10**	**14**	**11**	**7**	**12**
Redness of eye	**1**	**4**	**2**	**2**	**2**	**12**	**8**	**5**	**7**	**3**	**2**	**4**
Abscess	**1**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**1**	**1**
Tonsillitis	**10**	**10**	**17**	**6**	**4**	**4**	**8**	**12**	**16**	**15**	**15**	**10**
Total	**657**	**804**	**996**	**920**	**800**	**639**	**676**	**642**	**678**	**679**	**505**	**449**

Table 6.16: The Sickness Reports (the grey coloured tables are correlated with thermal environment) (based on factory record)

6.2. RESULTS AND DISCUSSION

One recognised method to predict the subjective comfort which results from a given temperature, or combination of environmental variable, is regression analysis (Nicol et al., 1994). The present study used simple linear regression for the calculation of neutral temperature T_n and acceptable conditions. Neutral temperature is that temperature at which people have a neutral thermal sensation to their environment i.e. they do not feel warm or cool. According to ISO, 7730 (2005) the range of PMV between (-1 to +1) sensation vote on the ASHRAE scale would result in 75% of subjects feeling satisfaction with their thermal environment. For 90% satisfaction the range would be between (-0.5 to +0.5).

6.2.1. Analysis of Votes

Here, simple linear regression analysis was performed on subjective thermal responses of Sensation Scales (both ASHRAE and Bedford Scales) and Comfort Scale as a function of air temperatures; and that of Humidity Scale as a function of relative humidity as well as that of Air Movement Scale as a Function of air movement, to predict comfort conditions.

Scales	T_n	Slope	Intercept	R^2	Acceptability (75%)	Acceptability (90%)
ASHRAE	30.4°C	0.36	-11.02	0.83	27.7 -33.2°C	29.0 -31.8°C
Bedford	30.0°C	0.33	-9.88	0.89	27.0 -33.1°C	28.5 -31.6°C
Comfort	31.0°C	0.53	-18.54	0.75	29.1 -32.8°C	30.0 -31.9°C

Table 6.17: Results of Temperature from Linear Regression Analysis

Scales	Comfort Conditions	Slope	Intercept	R^2	Acceptability (75%)	Acceptability (90%)
Relative Humidity	56%	0.13	-6.95	0.91	48 -64%	52 -60%
Air movement	1.3 ms^{-1}	2.04	-2.68	0.82	0.8 -1.8 ms^{-1}	1.1 -1.5 ms^{-1}

Table 6.18: Results of Relative Humidity and Air Velocity from Linear Regression Analysis

The results from the analysis were statistically significant. The goodness of fit (R^2) of regression lines to data of air temperatures was comparatively high, and that is also statistically acceptable. This proves that the workers are related their comfort with temperature as the main parameter along with humidity. Regression coefficient (slope) of the predicted comfort temperatures from ASHRAE and Bedford Scales were steep at the level of 0.36 and 0.33. These slopes in the field studies were quite similar to that found in climate chamber of 0.32 (Fanger, 1970).

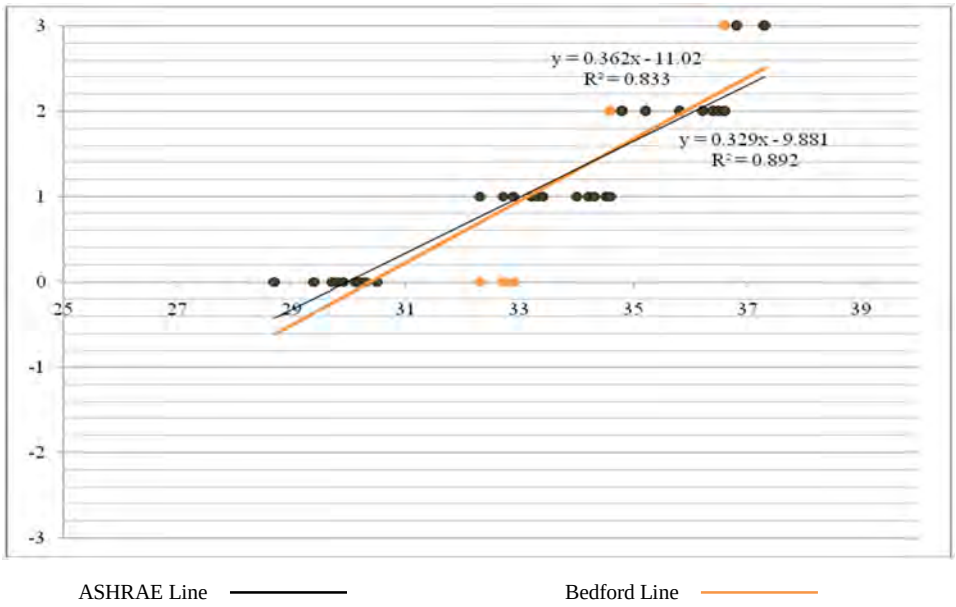


Figure 6.38: Scatter Diagram and Linear Regression Lines of both ASHRAE and Bedford Scales as a Function of Air Temperatures.

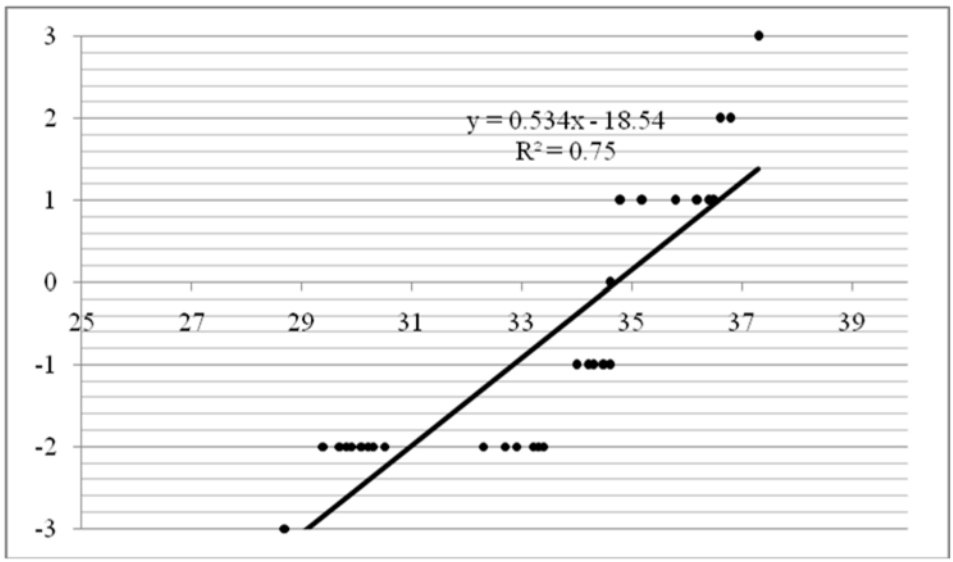


Figure 6.39: Scatter Diagram and Linear Regression Lines of Comfort Scale as a Function of Air Temperatures

Yet again, the regression coefficient of the Comfort Scales more steep at the level of 0.53 and the regression coefficient of the Humidity Scales were far less steep, only at 0.13. These values of regression coefficient suggest that the respondents are able to adapt to their thermal variation (temperature and humidity), but the comfort variation are non-adaptive by the respondents.

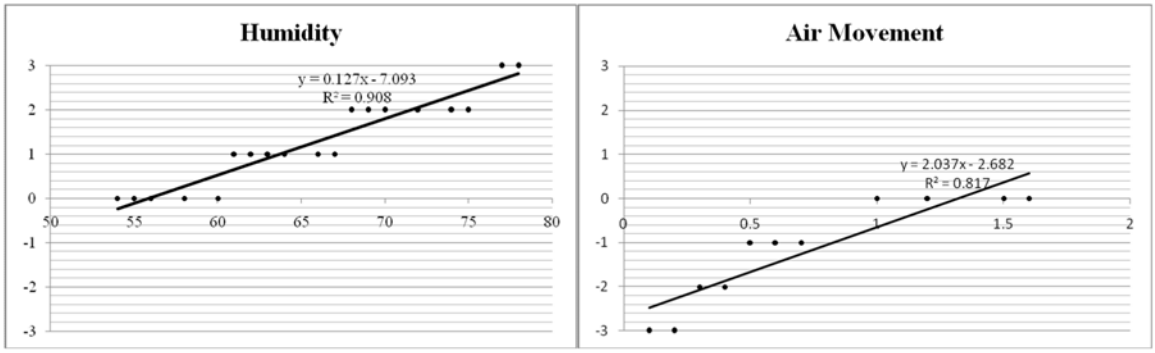


Figure 6.40: Scatter Diagram and Linear Regression Lines of Humidity Scale as a Function of Relative Humidity and that of Air Movement Scale as a Function of Air Movement

6.2.2. Neutral Temperature and Indoor Temperature

The calculation of the neutral temperature T_n and acceptable conditions with a preliminary definition of the comfort zone was one of the objectives of the climatic measurements and survey. These parameters are used in a next phase to evaluate and compare different geometries of production spaces of garments factories in Dhaka region.

A comparative analysis of Adaptive models and equations for Neutral and Comfort temperature is better for the triangulation of the proposed comfort zone, the neutral temperature T_n and acceptable conditions.

- Humphreys (1976; cited by Heidari et al., 2002) showed a strong relationship between the mean indoor temperature T_i and neutral temperature T_n. The simple regression equation is:

$$T_n = 0.831T_i + 2.6 \quad [1]$$

- Very similar correlations have been found subsequently by Auliciems (1981; cited by Auliciems, et al., 2007) using an enlarged data base, including all buildings (both free running and conditioned) and this simple regression equation is:

$$T_n = 0.31\ T_i + 17.6 \qquad [2]$$

- Auliciems and de Dear (1986; cited by Heidari et al., 2002) developed another equation that expressed comfort as a function of mean indoor air temperature. The related equation is:

$$T_n = 0.73\ T_i + 5.41 \qquad [3]$$

- Based on the study of Griffiths (1990, cited by Auliciems, et al., 2007) the regression becomes practically the same as Humphreys:

$$T_n = 0.534\ T_i + 12.1 \qquad [4]$$

- In a more recent study in Pakistan Nicol and Roaf (1996) found:

$$T_n = 0.38\ T_i + 17 \qquad [5]$$

Adaptive models and equations for Neutral and Comfort temperature		T_n (ºC)
ASHRAE Scale	From field study	30.4
Bedford Scale	From field study	30.0
Humphreys [eqn. 1]	$T_n = 0.831T_i + 2.6$	30.2
Auliciems [eqn. 2]	$T_n = 0.31\ T_i + 17.6$	27.9
Auliciems and de Dear [eqn. 3]	$T_n = 0.73\ T_i + 5.41$	29.6
Griffiths [eqn. 4]	$T_n = 0.534\ T_i + 12.1$	29.8
Nicol and Roaf [eqn. 5]	$T_n = 0.38\ T_i + 17$	29.6

Here, in the survey, the mean indoor temperature T_i was 33.2 ºC

Table 6.19: Obtained Comfort and Neutral Temperature according to Various Adaptive Models

The neutral temperature calculated from the simple regression analysis from this research is higher than that of Auliciems' equation but is quite similar as the neutral temperature calculated from the equations of Humphreys.

6.2.3. Comparison of PMV and Actual Mean Vote

The PMV values from the survey were also determined using the WWW thermal comfort index calculator. The calculator was programmed in JavaScript from the original source

code supplied in the ISO7730 Standard and also the software by Fountain and Huizenga, 1997 (the computer thermal comfort prediction tool: WinComf©).

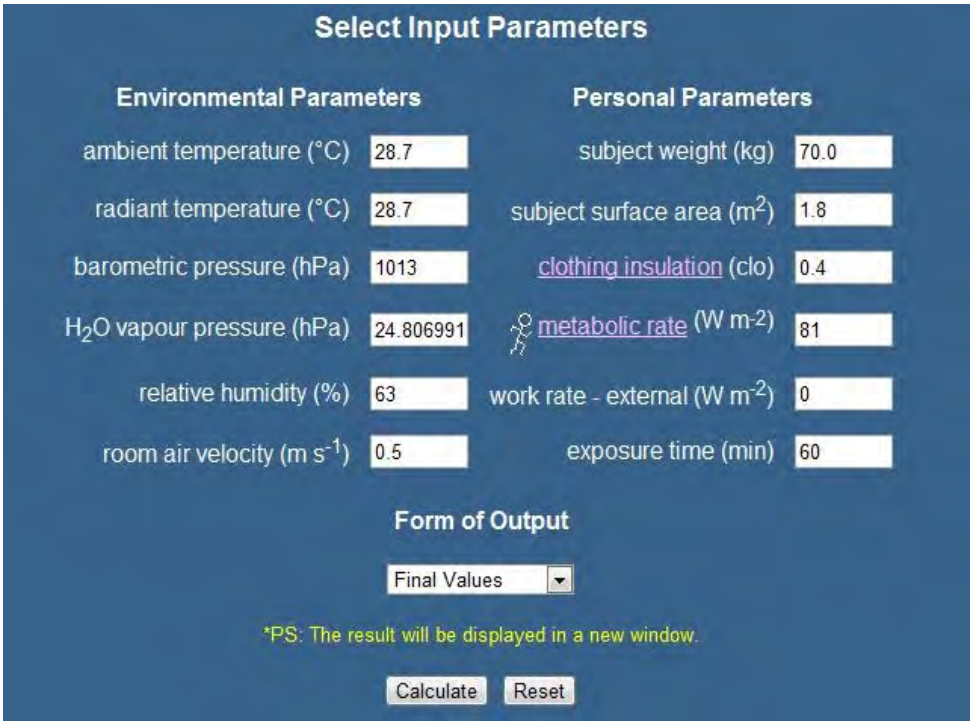


Figure 6.41: The WWW Thermal Comfort Index Calculator

Comfort Model STDOUT		
Effective Temperature (ET*)	29.48	
Standard Effective Temperature (SET*)	26.89	
Discomfort (DISC)	1.03	Slightly Uncomfortable
Thermal Sensation (TSENS)	0.74	Slightly Warm
Predicted Mean Vote (PMV)	0.88	Slightly Warm
Predicted Percentage Dissatisfied (PPD)	21.25	
Heat Stress Index (HSI)	35.34	

Figure 6.42: Thermal Comfort Calculation in the WWW Thermal Comfort Index Calculator

Actual data from the respondents (data of 240 persons) were put into computer program. All the physical, clothing and activity parameters were derived directly from observations, with the proviso that mean radiant temperature was assumed to be equal to the measured indoor air temperature. The actual and predicted sensation votes for PMV is

0.356/°C and is lower than that of the actual mean vote (AMV) of 0.363/°C. The neutral temperature from the actual mean vote is 30.4°C while the predicted temperature from PMV is 26.4°C. This difference of around 4K is in line with findings from Humphreys (1994; cited by Heidari et al., 2002).

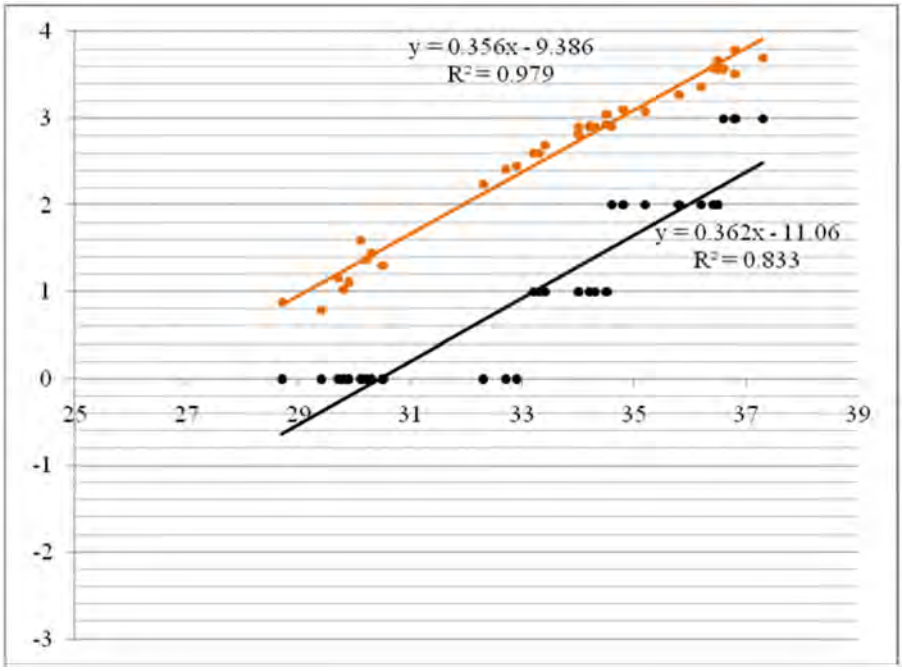


Figure 6.43: Scatter Diagrams of Predicted Mean Votes (PMV) and Actual Mean Votes (AMV) with Air Temperatures

Equation for PMV is: (y= 0.356x –9.386; R^2=0.98) and

Equation for AMV is: (y=0.362x –11.06; R^2=0.83)

6.2.4. Optimum Comfort Parameters and Proposed Comfort Zone

The predicted thermal comfort conditions were defined at air temperatures of 28.5-33°C and relative humidity of 56-75%. When matched comfort temperatures and comfort humidity from the same scale, it was possible to draw and establish a proposed comfort zone, shown in Fig.6.44. The new comfort zone will be suitable for the workers in production spaces of garments factories in Dhaka region, where both air temperatures and relative humidity are comparatively high due in hot and humid seasons.

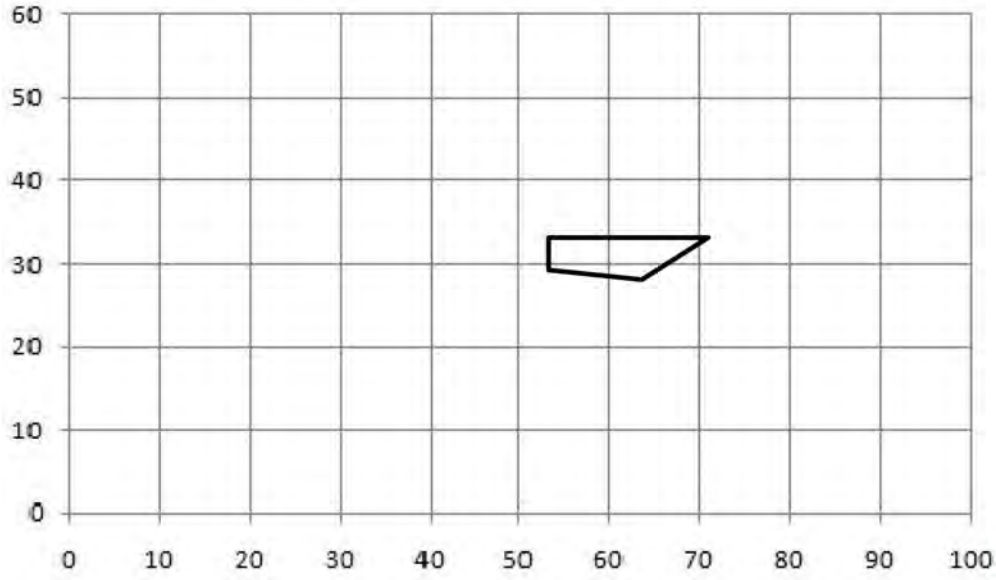


Figure 6.44: Establishment of Proposed Comfort Zone for the workers in production spaces of garments factories in Dhaka region

A comparative study in applying the new comfort zone had been investigated against the central-three-category (-1, 0, +1) of ASHRAE Scale. Previously, it was found that there was none of votes in the Olgyay's comfort zone, while there were a large number of votes in the proposed comfort zone, shown in Fig.3.45.

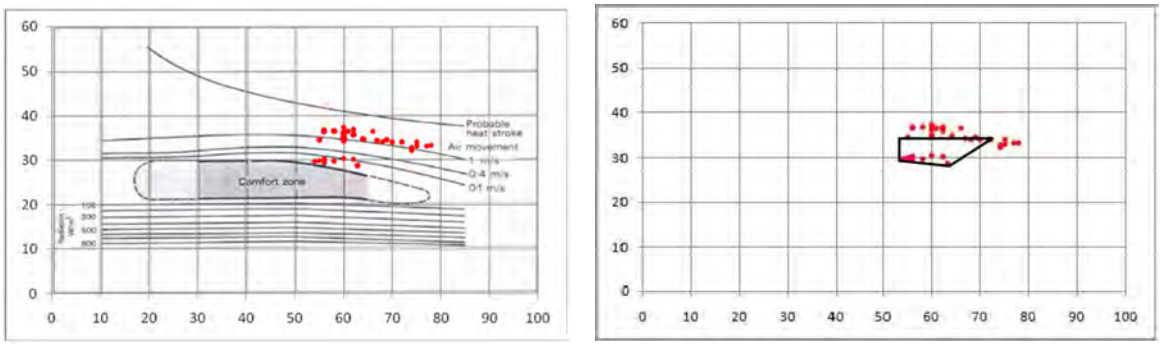


Figure 6.45: Central-Three-Category of ASHRAE Votes Applying on Olgyay's Comfort Zone and Proposed Comfort Zone

Therefore, the classic Olgyay's comfort zone (air temperatures of 21-30°C and relative humidity of 35-65%) can be shifted into a new comfort zone (air temperatures of 28.5-33°C and 56-72%).

Thermal Comfort and Productivity Analysis

Here, simple linear regression analysis and correlation analysis was performed on the productivity factors: Absenteeism rates, number of error, task performance percentage and sickness records with the mean indoor temperature of case study A, to predict the relationship between productivity and thermal comfort.

Factors	Slope	Intercept	R^2	r	Correlation
Absenteeism Rates	0.03	13.27	0.002	0	No
Number Of Error	0.06	-0.12	0.144	0.4	Weak
Task Performance	-0.21	84.74	0.056	-0.2	No
Sickness Records	12.90	308.1	0.154	0.4	Weak

Table 6.20: Results of Thermal Comfort and Productivity from Linear Regression Analysis

According to Moore (1996), if correlation coefficient (r) is close towards '0: Zero', there is no linear correlation or a very weak linear correlation. A correlation coefficient > 0.8 is generally described as strong, whereas a correlation coefficient < 0.5 is generally described as weak.

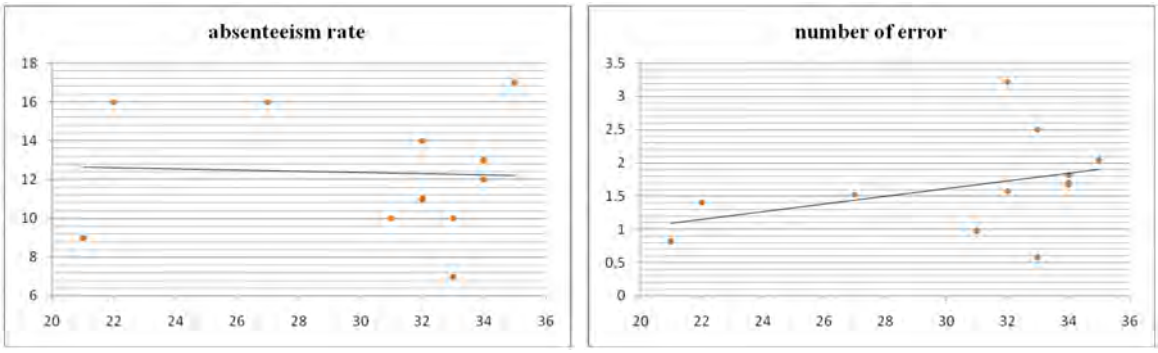


Figure 6.46: Simple Linear Regression Analysis on Absenteeism Rate and Number of Error

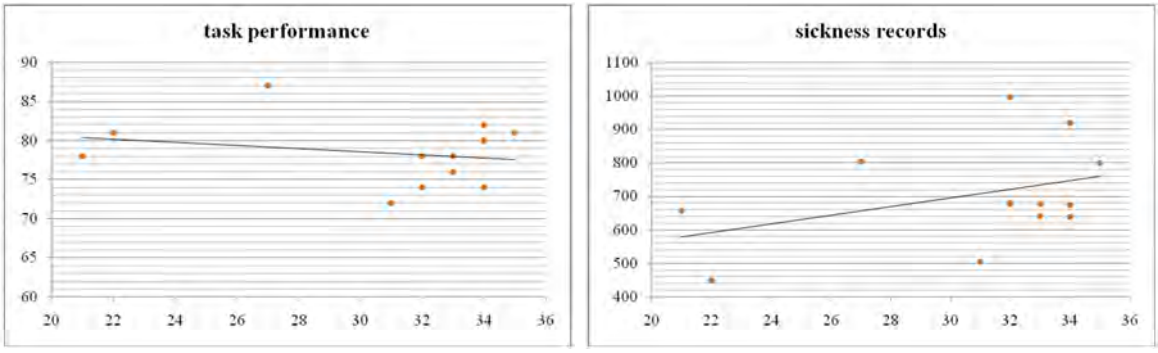


Figure 6.47: Simple Linear Regression Analysis on Task Performance and Sickness Records

From the correlation analysis, it can be said that the number of error and sickness records are correlated with the mean indoor temperature (though the correlation coefficient is weak). And if the proposed comfort temperature range (28.5-33°C) is applied, then the error and sickness percentage can be reduced and thus the productivity increased.

Existing Condition at Overheated Period			**Proposed Condition at Overheated Period**		
Indoor Temp. (°C)	Number Of Error (%)	Sickness Records (nos.)	Indoor Temp. (°C)	Number Of Error (%)	Sickness Records (nos.)
34 - 35	**1.82-1.88**	**747-760**	28.5 - 33	**1.51-1.76**	**676-734**

Table 6.21: Comparison of Thermal Comfort and Productivity of Existing and Proposed Condition

Equation for Number of Error (%) is: ($y = 0.057 x - 0.118$; R^2=0.144) and
Equation for Sickness Records is: ($y= 12.9x + 308.1$; R^2=0.154)

6.3. Conclusion

In this research, the comfort conditions can be established through simple linear regression analysis. Firstly, the ranges of optimum comfort parameters are calculated from the Scatter Diagram and Linear Regression Lines. The relationship between neutral temperature and the mean indoor temperature established through the comparative analysis of different adaptive models and equations for neutral temperature. To enhance the validity of research findings, data triangulation method is applied on Predicted Mean Votes as subjective responses. A comparative analysis of Actual Mean Votes and software generated Predicted Mean Votes are applied, which proves the significance of the field survey. Last of all, a new comfort zone is proposed, where the range of air temperatures was 28.5-33°C and of relative humidity was 56-72%. This proposal had been proved that it is fitted with the central-three-category of ASHRAE votes. Moreover, from productivity analysis, it is also proved that the proposed range of air temperatures (28.5-33°C) can reduce the number of error from 1.88% to 1.51% which is quite significant in terms of group productivity. And again the proposed range of air temperatures can reduce the total number of sickness from 760 to 676, which is quite significant in terms of individual productivity.

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7. CONCLUSION AND RECOMMENDATION

7. CONCLUSION AND RECOMMENDATION

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

7.1. REVIEW OF RESEARCH OBJECTIVES AND QUESTIONS

As stated in Chapter 1, the main aim of this study was to suggest a required level of thermal variables (temperature, humidity and air velocity) to attain thermal comfort and thereby improve work efficiency of the workers in ready-made garments factories in Dhaka. Other specific objectives of the study are as follows:

- To identify the environmental conditions those are perceived as comfortable by the workers in the production spaces and their effect on their work efficiency.
- To determine required temperature levels along with the other comfort factors (i.e. humidity and wind speed) to attain thermal comfort.

The following questions were addressed in this study:

- What is the thermal condition in respect of human comfort of the production spaces at Ready Made Garments factories in Dhaka?
- How do the Thermal Comfort Factors influence the work efficiency or productivity of workers in production spaces?

7.2. RECOMMENDATION FOR THERMAL COMFORT

This section attempts to conclude the research by summarizing the major findings of the study and answering the research questions as stated. They are as follows:

- The findings revealed that the workers of garments factories in Dhaka region could achieve comfort at higher indoor air temperatures than would be recommended by international standards like ISO 7730. As a result, the new comfort zone (Fig. 7.1), proposed through this research of field studies on indoor thermal comfort has been shifted from the classic comfort zone of Olgyay's Bioclimatic chart. 240 workers in their production spaces of garments factories gave their thermal responses during the overheated period from April to June in 2010.

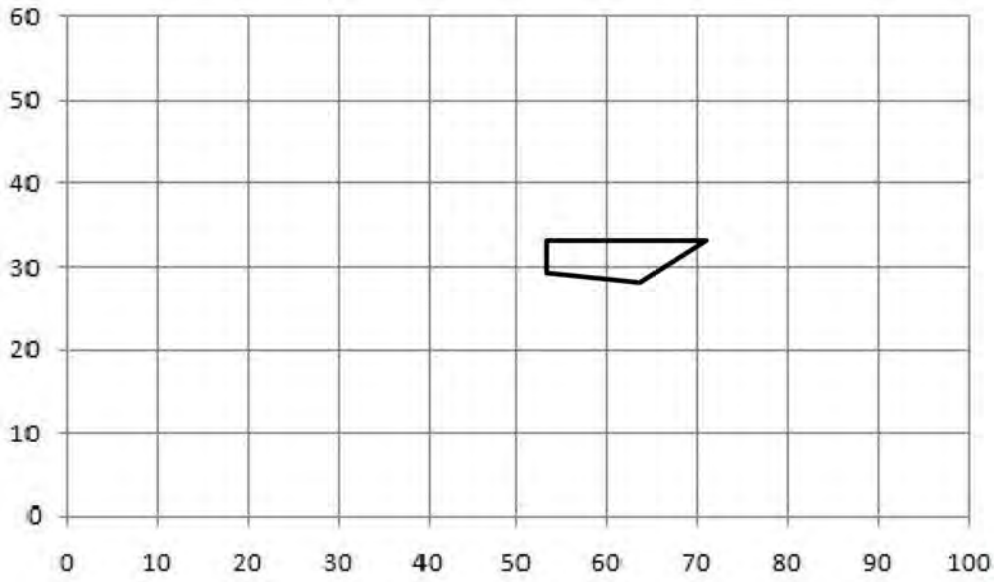

Figure 7.1: Proposed Comfort Zone for the workers in production spaces of garments factories in Dhaka region

- According to the research, comfortable conditions at the overheated period (from April to June) for people working at readymade garments factories and doing work at production area are as follows:

Air Temperature	28.5°C-33°C depending on the season
Relative Humidity	56-72%;
Air Movement	0.8-1.5 ms-1

The results showed that, according to their behavioural pattern, clothing insulation values had a mean of 0.4 clo, and metabolic rates had a mean of 1.40 met.

- Although thermal environments in the surveys were relatively extreme, approximately 65-68% of sample group voted at responses involved in comfortable criteria on ASHRAE, Bedford and Comfort Scales. Among these, only 58% accepted their immediate environments to be comfortable on Acceptability Scale. Therefore, 76% of votes on Preference Scale stated that: they would like to change their environments to be cooler. 58% of the surveyed population (fig. 6.33) wanted to change their seat as they are far from the evaporative cooler. Because, workers wanted to sit near the evaporative cooler (the source of cooler breeze) rather than near the exhaust fan.

- Simple linear regression analysis is used in this study. And, the regression coefficient of the Comfort Scales more steep (at the level of 0.53) and the regression coefficient of the Humidity Scales were far less steep (only at 0.13). These values of regression coefficient suggest that the respondents are able to adapt to their thermal variation (temperature and humidity), but the comfort variation are non-adaptive by the respondents.

- From the correlation analysis, it can be said that the number of error and sickness records are correlated with the mean indoor temperature (though the correlation coefficient is weak). And if the proposed comfort temperature range (28.5-33°C) is applied, then the error and sickness percentage can be reduced and thus the productivity increased. It is also proved that the proposed range of air temperatures can reduce the number of error from 1.88% to 1.51% which is quite significant in terms of group productivity and can reduce the total number of sickness from 760 to 676, which is also significant in terms of individual productivity.

- Last of all, a few general guidelines are developed from the observations of case studies to enhance the thermal performance of the production space along with the workers' performance.

7.3. GENERAL GUIDELINES

7.3.1. Control Measures

The hierarchy of controls should be used to reduce the discomfort of working in hot and humid environments to an acceptable level. The hierarchy of controls includes techniques to minimise discomfort in the following order:

a. The Source Control

- From the case studies, it is observed that thermal insulation or heat barrier was necessary in roofs and walls to control the heat gain and to minimize the radiation effects on occupants. Temperature in working zone should be maintained within the optimal range as recommended by this study to ensure workers comfort conditions.

b. The Environment Control

- From the case studies, it is studied that hot air was replaced with cold, or by extraction ventilation. For this, evaporative coolers were introduced to cool the hot air. These coolers produce a moderate reduction in air temperature. If the production spaces are deep in nature, then evaporative coolers are recommended to use to cool the hot air and to increase the air movement.

- It is also observed that local cooling was provided; where a reasonably comfortable temperature cannot be achieved throughout a working area i.e. small ‘personal’ (pedestal) fans were provided for this purpose to increase the air movement. These types of mechanical device are recommended if the air temperature is below the skin temperature.

- Sliding windows were installed in those buildings as openings to promote natural air flow. The opening of these sliding windows was limited to 50% of the window size and so was not good for providing airflow in particular. For these, fully operable windows are recommended, i.e. swing windows, pivoting windows etc.

c. The Source Separation

In this study, it is observed that the worker's at ironing section (40%) felt warmer than the worker's at sewing section (27%). And if the ironing section was at same floor with sewing section, then the workers' at sewing section felt warmer, where as workers' at sewing section felt less warmer in same temperature if the ironing section was in separate floor. For this, the recommendation is -

- To identify and isolate the equipments giving off radiant heat i.e. steam iron.
- To introduce barriers or to separate the source of heat i.e. ironing section is recommended to shield or to introduce in separate floor.

d. The Worker Protection

The following rest breaks are recommended to working in hot and humid environments:

34 – 35°C	:	15 minutes per hour
35 – 36°C	:	30 minutes per hour
37°C or higher	:	Cease work until conditions improve.

e. The Worker Monitoring

58% of the surveyed population (fig. 6.33) wanted to change their seat as they are far from the evaporative cooler. For this, job rotation, workstation rotation, etc. are recommended. Rotation of tasks within workplaces and between employees is to be needed, so that work that is designated as 'hot' is rotated with 'cooler' tasks.

7.3.2. Heat Related Illness Control

From the correlation analysis, it can be said that t sickness records are correlated with the mean indoor temperature. And if the proposed comfort temperature range (28.5-33°C) is applied, then the sickness percentage can be reduced and thus the productivity increased. It is also proved that the proposed range of air temperatures can reduce the total number of sickness from 760 to 676, which is also significant in terms of individual productivity. For this, it is recommended that the workers' should wear light coloured, loose fitting clothing; they should take time to adjust to the environment and they should drink plenty of fluids during hot weather.

7.4. SUGGESTIONS FOR FURTHER RESEARCH

This research has revealed two significant findings. Firstly, the workers of garments factories in Dhaka region could achieve comfort at higher indoor air temperatures than would be recommended by international standards like ISO 7730 (2005). As a result, the classic comfort zone of Olgyay's Bioclimatic chart has been challenged by the new comfort zone, proposed through this research of field studies on indoor thermal comfort.
And secondly, it is also proved that the proposed comfort criteria can reduce the number of error which is highly needed to enhance group productivity and also reduce the total number of sickness which is also an influencing factor for enhancing individual productivity. However, there were some limitations within the scope of this research. Those loopholes can be addressed in the future research and therefore, it is recommended that future research could look further into this area in order to strengthen and compliment this research. The suggestions for the future research are as follows:

- An intensive research on productivity and overall indoor environment at the production spaces of the readymade garment factories is required to give a better indication on the relationship between indoor environment and work performance. Because, apart from thermal comfort, there are other influencing factors which play significant role in reducing or enhancing productivity.

- Investigation on the effectiveness of the material to ensure indoor thermal comfort at the production spaces of the readymade garment factories. Apart from higher U value of material, the other material related factors need to be investigated for this purpose.

- Further investigations are required to determine the effects of building orientation on indoor thermal comfort for the readymade garment factories.

- Further study and analysis on building form and volume and its impact on indoor thermal comfort should be carried out to give a better indication on the indoor thermal comfort performance. Hence, a better comparison on the performance can be carried out.

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APPENDICES

APPENDIX 01: QUESTIONNAIRE FORMAT

Field Data Sheet: **Comfort Survey** [sheet no._____]

Personal Data

Time :

Age/Sex :

Activity Name :

Experience of the worker :

Clothing :

Color of Clothing :

Work Efficiency Data

Total work hour :

Effective production per hr :

Number of Errors per hr :

Physical Data of factory

Location of the work station :

Production line (Rating) :

Ventilation measures :

Outdoor Climatic Condition

Air Temp. (DBT) :

RH :

Air flow :

Thermal Comfort Data

How do you feel the immediate environment at this moment?

ASHRAE Scale	Value	Bedford Scale	Response
cold	-3	much too cool	
cool	-2	too cool	
slightly cool	-1	comfortably cool	
neutral	0	comfortable	
slightly warm	+1	comfortably warm	
warm	+2	too warm	
hot	+3	much too warm	

How do you feel the immediate environment at this moment?

Comfort Scale	Value	Response
very comfortable	-3	
moderately comfortable	-2	
slightly comfortable	-1	
just right	0	
slightly uncomfortable	+1	
moderately uncomfortable	+2	
very uncomfortable	+3	

Would you like to be …

3-point Preference Scale	Value	7-point Preference Scale	Response
	-3	much cooler	
	-2	cooler	
cooler	-1	slightly cooler	
no change	0	no change	
warmer	+1	slightly warmer	
	+2	warmer	
	+3	much warmer	

Do you accept that the immediate environment at this moment is comfortable?

Acceptability Scale		Response
accept	+1	
not accept	0	

Does the temperature vary with different time of the day?

a. Highly varies b. Moderately varies c. Varies d. Negligible e. not at all

Answer :

Does the temperature of the place change a lot with seasonal variation?

a. Highly varies b. Moderately varies c. varies d. negligible e. not at all

Answer :

Is there a heat source in the environment?

a. yes b. no Answer :

How do you feel the immediate environment at this moment?

Comfort Scale	Value	Response
much too dry	-3	
too dry	-2	
slightly dry	-1	
just right	0	
slightly humid	+1	
too humid	+2	
much too humid	+3	

How do you feel the immediate environment at this moment?

Comfort Scale	Value	Response
much too still	-3	
too still	-2	
slightly still	-1	
just right	0	
slightly breezy	+1	
too breezy	+2	
much too breezy	+3	

APPENDIX 02: EXAMPLE OF QUESTIONNAIRE SURVEY

কারখানা কর্মীদের উপাত্ত সংগ্রহঃ

ব্যাক্তিগত তথ্যঃ

সময়ঃ	:	সকাল ০৭:৩০- সন্ধ্যা ০৬:৩০
বয়স/লিঙ্গ	:	২১ বছর, মহিলা
কাজের প্রকারঃ	:	সেলাই
কাজের অভিজ্ঞতাঃ	:	৫ বছর
পোষাক-পরিচ্ছদঃ	:	সেলোয়ার কামিজ
পোষাকের রঙঃ	:	কালো

কর্মক্ষমতা সংক্রান্ত তথ্যঃ

মোট কাজের সময়ঃ	:	১০ ঘন্টা
প্রকৃত উৎপাদন/ ঘন্টাঃ	:	৪৫ পিস
ভুলের পরিমান/ঘন্টাঃ	:	০৪%

কারখানা সংক্রান্ত তথ্যঃ

কাজের জায়গার অবস্থানঃ	:	৫ম তলা
সারিঃ	:	৩১
বায়ুচলাচল পদ্ধতি	:	ফ্যান

আবহাওয়া সংক্রান্ত তথ্যঃ

তাপমাত্রা	:	৩৬.৪°C
আর্দ্রতা	:	৬০%
বায়ুচলাচলের পরিমান	:	0.8 ms^{-1}

মূল উপাত্ত সংগ্রহঃ

এই পরিবেশে আপনার গরম বা ঠান্ডার অনুভূতি কি বলুন?

খুব ঠান্ডা	-৩	
বেশ ঠান্ডা	-২	
কিছুটা ঠান্ডা	-১	
সঠিক	০	
কিছুটা গরম	+১	
বেশ গরম	+২	✓
খুব গরম	+৩	

এই পরিবেশে গরম বা ঠান্ডার অনুভূতিতে আপনার কেমন লাগছে?

খুব আরাম লাগছে	-৩	
বেশ আরাম লাগছে	-২	
অল্প আরাম লাগছে	-১	
কোনোটাই লাগছে না	০	
অল্প খারাপ লাগছে	+১	
বেশ খারাপ লাগছে	+২	✓
খুব খারাপ লাগছে	+৩	

এই পরিবেশে আপনার চাহিদা.....

	-৩	খুব ঠান্ডা	
	-২	বেশ ঠান্ডা	✓
ঠান্ডা	-১	কিছুটা ঠান্ডা	
পরিবর্তন নয়	০	পরিবর্তন নয়	
গরম	+১	কিছুটা গরম	
	+২	বেশ গরম	
	+৩	খুব গরম	

এই পরিবেশে আপনি যেমন আছেন আপনি কি তেমনি পরিবেশে কাজ করতে চান?

হ্যাঁ	+১	
না	০	✓

দিনের বিভিন্ন সময়ে ভেতরের তাপমাত্রার কোন পরিবর্তন হয় কি?

ক. অনেক খ. বেশ গ. অল্প ঘ. খুব অল্প ঙ. হয় না

উত্তর: ঙ

বছরের বিভিন্ন সময়ে ভেতরের তাপমাত্রার কোন পরিবর্তন হয় কি?

ক. অনেক খ. বেশ গ. অল্প ঘ. খুব অল্প ঙ. হয় না

উত্তর: খ

এখানে গরমের কোন উৎস আছে কি?

ক. হ্যাঁ খ. না উত্তর: খ

এই পরিবেশে আপনার আর্দ্রতার অনুভূতি কি বলুন?

খুব শুষ্ক	-৩	
বেশ শুষ্ক	-২	
কিছুটা শুষ্ক	-১	
সঠিক	০	
কিছুটা ভ্যাপ্সা	+১	✓
বেশ ভ্যাপ্সা	+২	
খুব ভ্যাপ্সা	+৩	

এই পরিবেশে বাতাসের পরিমানের ব্যাপারে অনুভূতি কি বলুন?

স্থির	-৩	
বেশ স্থির	-২	
কিছুটা স্থির	-১	✓
সঠিক	০	
কিছুটা উপস্থিত	+১	
বেশ উপস্থিত	+২	
উপস্থিত	+৩	

APPENDIX 03: DATA FROM FIELD WORK

Recorded Air temperature Relative Humidity and Air Velocity:

Temperature	RH	Air Velocity
28.7	63	0.5
29.4	56	1.6
29.7	58	0.6
29.8	54	1.2
29.9	55	1
30.1	56	0.1
30.2	56	0.5
30.3	62	0.5
30.5	60	1.5
32.3	74	0.6
32.7	74	0.4
32.9	74	1.2
33.2	75	0.4
33.3	77	0.4
33.4	78	1
34	70	0.1
34	72	1.2
34	72	0.2

Temperature	RH	Air Velocity
34	75	0.4
34.2	68	0.5
34.3	67	0.2
34.5	69	0.7
34.5	60	0.3
34.6	55	0.2
34.8	64	0.5
35.2	60	0.1
35.8	62	0.1
36.2	60	0.1
36.4	60	0.3
36.5	56	0.5
36.5	66	0.3
36.5	61	0.2
36.6	58	0.2
36.8	56	0.1
36.8	62	0.4
37.3	60	0.1

Air temperature and Comfort Votes in Different Scale:

Recorded Temperature	Ashrae Scale	Bedford Scale	De dear
28.7	0	0	1.2
29.4	0	0	1.4
29.7	0	0	1.5
29.8	0	0	1.5
29.9	0	0	1.6
30.1	0	0	1.6
30.2	0	0	1.7
30.3	0	0	1.7
30.5	0	0	1.7
32.3	0	1	2.3
32.7	0	1	2.4
32.9	0	1	2.4
33.2	1	1	2.5
33.3	1	1	2.6
33.4	1	1	2.6

Recorded Temperature	Ashrae Scale	Bedford Scale	De dear
34	1	1	2.8
34.2	1	1	2.9
34.3	1	1	2.9
34.5	1	1	3.0
34.6	2	1	3.0
34.8	2	2	3.0
35.2	2	2	3.1
35.8	2	2	3.3
36.2	2	2	3.5
36.4	2	2	3.5
36.5	2	2	3.5
36.6	3	2	3.6
36.8	3	3	3.6
37.3	7	3	3

Relative Humidity and Votes:

Recorded RH	Votes
54	0
55	0
56	0
58	0
60	0
61	1
62	1
63	1
64	1
66	1

Recorded RH	Votes
67	1
68	2
69	2
70	2
72	2
74	2
75	2
77	3
78	3

Air Velocity and Votes:

Recorded Air Velocity	Votes
0.1	-3
0.2	-3
0.3	-2
0.4	-2
0.5	-1
0.6	-1
0.7	-1
1	0
1.2	0
1.5	0
1.6	0

APPENDIX 04: INSTRUMENT

Kestrel 3000 Pocket Weather Meter

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

The Kestrel 3000 Pocket Weather Meter is the handheld weather-monitoring device that provides a wide range of functions, plus accurate relative humidity measurements. Before the Kestrel 3000 came along, the technology required to gather this information would require masses of equipment – but not anymore. The Kestrel 3000 Weather Meter measures essential environmental parameters like temperature and wind speeds, and has added advantages for professionals that need access to humidity and heat stress readings. Because of its compact size and high durability, the Kestrel 3000 and Kestrel 3500 have become the pocket weather meters of choice for Wildland fire-fighters, concrete professionals, even professional coaches – all of whom need accurate weather info to properly access environmental conditions and make crucial decisions.

The Kestrel 3000's sensitive and user-replaceable impeller technology provides accurate wind speed info. Additionally, an external temperature sensor and waterproof casing allow you to gauge the temperature of water (it even floats) and snow, as well as the open air. A hard slide-on case, lanyard, and battery are included. The Kestrel 3000 accurately measures: Wind Chill; Air, Water, and Snow Temperature; Displayed in Fahrenheit or Celsius w/ accuracy of +/-1°; Current, Average, and Maximum Wind Speed; Wind Speeds displayed in: Beaufort Wind Scale, Knots, MPH, KPH, or Feet per Minute; Relative Humidity; Dew point and Heat Stress Index

Certificate of Conformity

Kestrel® 3000 Pocket Weather® Meter
Certificate of Conformity

This certifies that the enclosed Kestrel 3000 Pocket Weather Meter was manufactured by

Nielsen-Kellerman Co.

at its facilities located at

21 Creek Circle, Boothwyn, PA 19061 USA

This instrument was produced under rigorous factory production control and documented standard procedures. It was individually inspected and tested for display, backlight, button and software functionality and its measurement performance was individually calibrated and tested against standards traceable to the National Institute of Standards and Technology ("NIST") or calibrated intermediary standards. This unit is certified to have performed at the time of manufacture in compliance with the specifications printed on the reverse.

Methods Used in Calibration and Testing

Wind Speed /Air Velocity:

The Kestrel impeller installed in this unit was individually tested in a subsonic wind tunnel operating at approximately 1200 fpm (6.1 m/s) monitored by a Gill Instruments Model 1350 ultrasonic time-of-flight anemometer. The low-speed functionality of this impeller was further verified following wind tunnel testing. The Gill 1350 is calibrated at low and high speeds by NIST with a maximum relative expanded uncertainty of ±0.60% within the airspeed range 591 to 7874 fpm (3.0 to 40.0 m/s) and further verified on a regular schedule by NK's internal measurement assurance program.

Temperature:

The temperature response of this unit was verified in comparison with a Eutechnics 4600 Precision Thermometer or a standard Kestrel 4000 Pocket Weather Tracker calibrated weekly with the Eutechnics 4600. The Eutechnics 4600 is calibrated annually and is traceable to NIST with a maximum relative expanded uncertainty of ±0.020°C.

Relative Humidity:

This unit received a two-point RH calibration in humidity and temperature controlled chambers at 75.3% RH and 32.8% RH at 25° C. The calibration chambers were monitored with an Edgetech Model 2002 DewPrime II Standard Chilled Mirror Hygrometer. Following calibration, the performance of this instrument was further verified at an RH of approximately 43.2% against the Edgetech Hygrometer. The Edgetech Hygrometer is calibrated annually and is traceable to NIST with a maximum relative expanded uncertainty of +/- 0.5 %RH.

Inspected By: _____

Kestrel® 3000 Pocket Weather Meter Specifications

Measurement *Response Time*	Units	Maximum Range	Resolution	Accuracy (+/-)	Specification Range
Wind Speed (Air Velocity) *1 second*	**m/s**	0.4 to 60.0 m/s	0.1	Larger of 3% of reading or least significant digit	0.4 to 40.0 m/s
	ft/min	59 to 11,948 ft/min	1		59 to 7877 ft/min
	km/h	1.0 to 218.0 km/h	0.1		1.0 to 144.0 km/h
	mph	0.8 to 135.0 mph	0.1		0.8 to 89.0 mph
	knots	0.6 to 118.3 kt	0.1		0.6 to 78.0 kt
	Beaufort	0 to 12 B	1		0 to 12 B

1 inch diameter impeller with precision axle and sapphire bearings. Off-axis accuracy -1% @ 5° off-axis; -2% @ 10°; -3% @ 15°. Calibration drift < 1% after 100 hours use at 16 MPH / 7 m/s. Sustained operation above 60 MPH / 27 m/s will wear impeller rapidly and may cause destruction of impeller. Replacement impeller (NK PN-0801) may be field-installed without tools (US Patent 5,783,753).

Temperature *1 second*	°F	-49.0 to 257.0 °F	0.1	1.8 °F	-20.0 to 158.0 °F
	°C	-45.0 to 125.0 °C	0.1	1.0 °C	-29.0 to 70.0 °C

Measures air, water and snow temperature. Thermally isolated, hermetically sealed, precision thermistor mounted externally (US Patent 5,939,645). Calibration drift negligible.**NOTE: See "Functional Temperature Limits" below for further temperature range information.**

Relative Humidity *1 minute*	**%RH**	0.0 to 100.0 %	0.1	3.0 %RH	5.0 to 95.0 % non-condensing

Polymer capacitive humidity sensor mounted in thin-walled chamber external to case for rapid, accurate response (US Patent 6,257,074). (To achieve stated relative humidity accuracy, unit must be permitted to equilibrate to external temperature when exposed to large, rapid temperature changes and must be shielded from direct sunlight.) Calibration drift +/- 2% over 24 months. Relative humidity may be recalibrated at factory or in field using Kestrel Humidity Calibration Kit (NK PN-0824)

Wind Chill *1 second*	°F	0.7 to 135.0 MPH, -49.0 to 257.0 °F	0.1	1.8 °F	1.8 to 89.0 mph, -50.0 to 50.0 °F
	°C	0.4 to 60.0 m/s, -45.0 to 125.0 °C	0.1	1.0 °C	0.4 to 40 m/s, -45.6 to 10.0 °C

Calculated from the primary measurements of wind speed and temperature. Utilizes the NWS Wind Chill Temperature (WCT) Index, revised 2001, with wind speed adjusted by a factor of 1.5 to yield equivalent results to wind speed measured at 10 m above ground. (Specification temperature limits established by WCT Tables.)

Heat Index *1 minute*	°F	0.0 to 100.0 %RH, -49.0 to 257.0 °F	0.1	3.6 °F	70.0 to 130.0 °F, 0 to 100% RH
	°C	0.0 to 100.0 %RH, -45.0 to 125.0 °C	0.1	2.0 °C	21.1 to 54.4 °C, 0 to 100 %RH

Calculated from the primary measurements of temperature and relative humidity. Utilizes the NWS Heat Index (HI) tables. (Specification temperature limits established by HI tables.)

Dewpoint *1 minute*	°F	0.0 to 100.0 %RH, -49.0 to 257.0 °F	0.1	3.6 °F	-20.0 to 158.0 °F, 20.0 to 95.0% RH
	°C	0.0 to 100.0 %RH, -45.0 to 125.0 °C	0.1	2.0 °C	-29.0 to 70.0 °C, 20.0 to 95.0 %RH

Calculated from the primary measurements of temperature and relative humidity. Temperature to which the air would need to be cooled at a constant pressure to become saturatec

Max / Average Wind Speed (Air Velocity)	One-button clear and restart of Max Wind Gust and Average Wind measurement.
Display	Reflective 3 1/2 digit LCD. Digit height 0.36 in / 9 mm.
Display Update	1 second.
Display Backlight	Aviation green electroluminescent backlight.
Functional Temperature Limits	The liquid crystal display and batteries will not function below 14 °F / -10 °C, and**damage to both may result if the unit temperature exceeds 131 °F / 55 °C**. Readings may be taken beyond these functional limits, to the limits of the maximum ranges listed above, by maintaining the unit within these functional limits and exposing it to temperature extremes for the minimum time necessary to take a reading (30 seconds to 1 minute).
Storage Temperature	-22 °F to 140 °F / -30 °C to 60 °C.
Auto Shutdown	After 45 minutes of no key presses.
Certifications	CE certified. Individually tested to NIST-traceable standards. Certificates of conformity to specifications provided at no charge. Certificates of Calibration with data available at additional charge.
Batteries	CR2032, one, included. Average life, 300 hours of use, +/-depending on backlight use.
Sealing	Waterproof (IP67 standard).
Dimensions	Unit 4.8 x 1.7 x 0.7 in / 122 x 42 x 18 mm. Case 4.8 x 1.9 x 1.1 in / 122 x 48 x 28 mm.
Weight	Unit 2.3 oz / 65 g. Case 1.3 oz / 37 g.

HOBO U30 Remote Monitoring System

HOBO U30 systems provide real-time access to data from any web browser. Whether you're tracking climate conditions for field research, or measuring energy usage in a commercial building, HOBO U30 monitoring systems deliver accurate, dependable data right to your desktop.

Key Advantages:

- Web-based energy and environmental monitoring
- All electronics are housed within an industrial-grade, tamperproof enclosure
- Setup is quick and easy with plug-and-play sensors
- Measures a wide range of energy and environmental parameters
- GSM Cellular, Wi-Fi, Ethernet, direct USB options available

Data Logging Systems

Industrial-grade dependability

HOBO U30 Remote Monitoring Systems deliver high accuracy measurements you can count on — in even the harshest environmental conditions. All at a fraction of the cost of competitive solutions.

Incorporating patented technology, all of the systems' electronics are housed within a rugged double-weatherproof, tamperproof enclosure. This provides twice the protection and ensures years of reliable monitoring performance.

Fast, easy deployment

The systems' plug-and-play architecture enables any combination of Smart Sensors to be plugged in without extensive user programming, wiring, or calibration. Plug in your sensors, connect the battery, and you're streaming real time data!

Learn More:
See specifications on page 45
See pricing on pages 46-47

See page 55 to learn more about HOBOlink, a web-based software platform that provides access to the HOBO U30 Remote Monitoring Systems.

Wide range of measurements

HOBO U30 systems measure and record a wide range of parameters including:

ENERGY

- AC Voltage
- AC Amps
- DC Amps
- kW
- kWh
- Gauge Pressure
- Differential Air Pressure
- CO_2
- Pulse Inputs from electric, or flow meters
- DC voltage
- 4-20mA

ENVIRONMENTAL

- Temperature
- Temp/RH
- Rainfall
- Soil Moisture
- Wind Speed & Direction
- Leaf Wetness
- PAR
- Solar Radiation
- Pulse Input
- Barometric Pressure

An optional analog sensor port provides sensor power with user-selectable warm-up time.

Available models include:

HOBO U30/GSM

- Buit-in GSM cellular means no IT road-blocks
- Double weather proof, tamperproof enclosure

Starts at $850

HOBO U30/Wi-Fi

- Ruggedized hard-ware, with integrated Wi-Fi
- Get notified of problems via cell phone or e-mail

Starts at $770

HOBO U30/ETH

- Remote access to real-time data over Ethernet
- Simplifies facility-wide monitoring

Satrts at $675

HOBO U30/NRC

- Fast data offload via direct USB
- Optional analog inputs with sensor excitation

Starts at $399

Specifications	
GSM Wireless Communications	Quad-Band GSM/GPRS 850/900/1800/1900 MHz
Wi-Fi Wireless Communications	2.412 - 2.484 GHz IEEE 802.11 b/g
Ethernet	IEEE 802.11 b/g
Alarm Relay	Can be activated, deactivated or pulsed on user-defined sensor alarms. The relay can be configured as normally open or normally closed, (30V, 1A Max)
Alarm Notification Latency	Logging interval plus 2 to 4 minutes (typical)
Certifications	FCC Certified. Check www.onsetcomp.com for the latest certifications. CE
Smart-Sensor Inputs	5 or 10
Data Channels	Maximum of 15 (some sensors use more than one data channel)
Sensor Network Cable Length	100 m (328 ft) maximum
Normal Operating Range	-20 to 40ºC (-4 to 140ºF)
Extended Operating Range	-40 to 60ºC (-40 to 140ºF) see battery life, Note: the GSM module will not communicate below -30ºC (-22ºF)
Local Communication	USB
Data Storage Memory	512K bytes local storage in non-volatile flash memory
Operational Indicators	LEDs show
Logging Interval	1 minute to 18 hours, user-specified
Station-to-Internet Upload Interval	10 minutes minimum, user-specified (depends on HOBOlink data service plan)
Power	An Onset solar panel (1.2w, 3w, 6w) or AC adapter is required
Battery Type	4 Volt, 10 AHr, or 4.5 AHR Rechargeable Sealed Lead Acid
Battery Life	Typical 3-5 years depending upon conditions of use. Regular operation outside of the normal operating range will reduce battery life to 1-2 years.
Environmental Rating	Weatherproof; tested to NEMA 6
Dimensions	17.8 H x 11.7 D x 19.3 W cm (7.0 H x 4.6 D x 7.6 W inches)
Weight	2 kg (4.30 lbs.)
Mounting	Up to 1.63 in (4.1 cm) mast or wall mount
Enclosure Access	Hinged door secured by two latches, which can be further secured with user-supplied padlocks
Optional Analog Sensor Port	
Inputs	2 channels - User-configured as either 0-20 mA or 0-20 VDC
Sensor Power	Switched 12 VDC, up to 50 mA: user-selectable warm-up from 5 milliseconds to 2 minutes
Scaling	Linear scaling to user units
Accuracy	±0.25% full scale

Note: Some HOBO U30 models require high-speed internet access and a data plan with HOBOlink.com, an Onset-hosted and managed web server.

Data Logging Systems