INDOOR THERMAL COMFORT OF THREE GARMENT FACTORIES IN DHAKA, BANGLADESH

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To:

My Beloved Father, Mother

and

My Wife, Son and Daughter.

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In the name of Allah, the most Gracious, the most Merciful, for giving me the determination and will to complete this study.

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ABSTRACT

Bangladesh is a developing country with lots of factories of different types of products for export and local consumption. Garments are one of the top items for export. Around four million workers are working in the garment factories which are not well designed in the sense of the indoor thermal environment. Appropriate use of building materials and design contributes to reducing the consumption of energy and indoor heat. Each month workers are having sickness related to frequent temperature difference in work place. As a result, the production of factories is being affected due to the employeesô health. The aim of this research is to measure the indoor environment quality and building related illness (BRI) within selected garment factories. The research was done using two methods. The empirical data collection by thermal data logger was done to measure the indoor temperature and the questionnaire survey at the work places were for BRI. The field study was conducted for one year. The collected data were recorded in different months for the whole year. Data collection was carried out for duration of seven days in winter and three months in summer. Thermal behavior evaluation was done by comparative analysis between indoor and outdoor temperature of factory buildings. In selected factory buildings, indoor air temperature from 12pm to 2pm was 1.58°C to 4.63°C above the normal 32°C. The comfort evaluation of indoor thermal environment indicated that indoor becomes uncomfortable for 1-8 hours from 11pm to 6pm when workers working inside the factory at work place. The findings of this research are that the indoor environment of factory building is uncomfortable for work at day time during both winter and summer. The existing condition does not help the factory workers as it is not comfortable and also contributes to BRI. The uncomfortable indoor thermal environment needs to be improved by employers or factory owners to provide a better healthy environment for workers.

ABSTRA

Bangladesh adalah sebuah negara membangun dengan pelbagai kilang dan jenis produk untuk penggunaan eksport dan tempatan. Pakaian adalah salah satu produk yang paling utama bagi barangan eksport. Sekitar empat juta pekerja yang bekerja di kilang-kilang pakaian. Pembangunan mampan adalah salah satu isu utama hari ini di seluruh dunia. Kilang-kilang tidak direka dengan baik dalam erti kata persekitaran dan haba dalaman. Kesesuaian penggunaan bahan binaan dan strategi reka bentuk semaga proses pembinaan menyumbang kepada mengurangkan penggunaan tenaga dan haba dalaman. Pekerja setiap bulan kerap mempunyai penyakit yang berkaitan dengan perbezaan suhu di tempat kerja. Hasilnya, pengeluaran kilang-kilang sering terjejas kerana kesihatan pekerja. Tujuan kajian ini adalah untuk mengukur kualiti persekitaran dalaman dan penyakit berkaitan bangunan (BRI) dalam kilang-kilang yang dipilih. Penyelidikan telah dilakukan dengan menggunakan dua kaedah. Pengumpulan data imperialis menggunakan haba data logger telah dilakukan untuk mengukur suhu dalaman dan soal selidik di tempat kerja adalah untuk BRI. Kajian medan telah dijalankan selama satu tahun. Data yang dikumpul telah direkodkan pada bulan-bulan yang berbeza bagi keseluruhan tahun. Pengumpulan data telah dijalankan untuk tempoh satu hari di musim sejuk dan tiga bulan di musim panas. Penilaian tingkah laku prestasi thermal telah dilakukan melalui analisis perbandingan antara suhu dalaman dan luaran bangunan kilang. Dalam bangunan kilang terpilih, suhu udara dalaman adalah lebih tinggi iaitu 1.58°C hingga 4.63°C di atas 32°C pada waktu siang antara 12:00 tengahari hingga 2:00 petang. Penilaian keselesaan persekitaran haba dalaman menunjukkan bahawa ruang dalaman menjadi tidak selesa untuk 1-8 jam antara jam 11:00-6:00 petang iaitu waktu apabila pekerja bekerja di dalam kilang di tempat kerja. Dapatan kajian ini adalah bahawa persekitaran dalaman bangunan kilang tidak selesa untuk kerja-kerja pada waktu siang semasa musim sejuk dan musim panas. Keadaan yang sedia ada tidak membantu pekerja kilang kerana ia tidak selesa dan menyumbang kepada BRI. Persekitaran yang tidak selesa dengan haba dalaman mungkin perlu diperbaiki oleh majikan atau pemilik kilang untuk meningkatkan margin pengeluaran mereka.

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LIST OF ABBREVIATIONS

ASHRAE	-	American Society of Heating, Refrigerating and Air
BMD	-	Bangladesh Meteorological Department
BRI		Building Related Illness
BST	-	Bangladesh Standard Time
BUET	-	Bangladesh University of Engineering and Technology
		Conditioning Engineers
CV	-	Comfort Vote
D.I	-	Discomfort Index
EPA		United States Environmental Protection Agency
GMT	-	Greenwich Mean Time
IAQ		Indoor Air Quality
LSB		Labour and Welfare
MRT		Mean Radiant Temperature
R.C.C.		Reinforce cement concrete
RC		Relative Compactness
RMG		Ready-Made Garment
SBS		Sick Building Syndrome
SHGC		Solar Heat Gain Coefficient
Tm		Mean Temperature
Tn		Neutral Temperature
TTC	-	Thermal Time Constant
WHO		World Health Organization
WWR		Window-to-wall ratio

LIST OF SYMBOLS

%	Percentage
°K	Degree Kelvin
Max	Maximum
Min	Minimum
ºC	Degree Centigrade
ºF	Degree Fahrenheit
Rh	Relative Humidity
T_d	Dry bulb temperature (^{0}C)
T_g	Globe Temperature
T_i	Indoor temperature (^{0}C)
T_n	Neutral Temperature
T_o	Outdoor temperature (^{0}C)
T_w	Wet bulb temperature (^{0}C)
hr	Hours
M	Metabolic rate
E	Rate of heat loss by evaporation, respiration, and elimination
R	Radiation rate
C	Conduction and convection rate
S	Body heat storage rate

CHAPTER

GENERAL INTRODUCTION

. I

Rapid urbanization is the main growth which is the proportional increase of the population living in the urban area. The world already experienced unprecedented urban growth in the last few centuries. In 1800, only 3 percent of world population was lived in urban areas. Population of each country left rural and suburban area and came to urban area for their work and income. The world population had been begun to increase rapidly after 1900. From that time period, the percentage of urban living population was increased upto 14 percent and 45 percent from 1900 to 2000. From previous study it was found that more than half of the world total population is started to live in urban areas in 2008 (Laski and Schellekens, 2007). It is also estimated by researchers that by 2030, up to 5 billion people will live in urban areas (Wong, 2009).

The urban population of a developing country increases rapidly from 286 million to 1,515 million from 1950 to1990. The population figure will reach up to 4 billion by 2025, with almost all developing countries within tropical and subtropical country (Wong, 2009). For this purpose, a significant attention to this matter should be paid for a sustainable urbanization in the tropical and subtropical areas of the world for a better living condition.

Bangladesh is a developing country. It is in the process of industrialization. Industries and factories as growing in number. In Bangladesh there are lots of factories of different products. Garments industries are one of the top most items of exported goods. A huge number of populations of the country are working in these industries. But these factories are not well designed in sense of the thermal environmental condition. The factories are not well located and also not in planned way in the city. The factories are grown in the city in scattered way. For this reason, the indoor environment of factory buildings is not up to standard. Each and every month workers are having sickness related to temperature difference. This research will find out and help the factory workers to provide a comfortable thermal environment and also help the employers to increase their production margins.

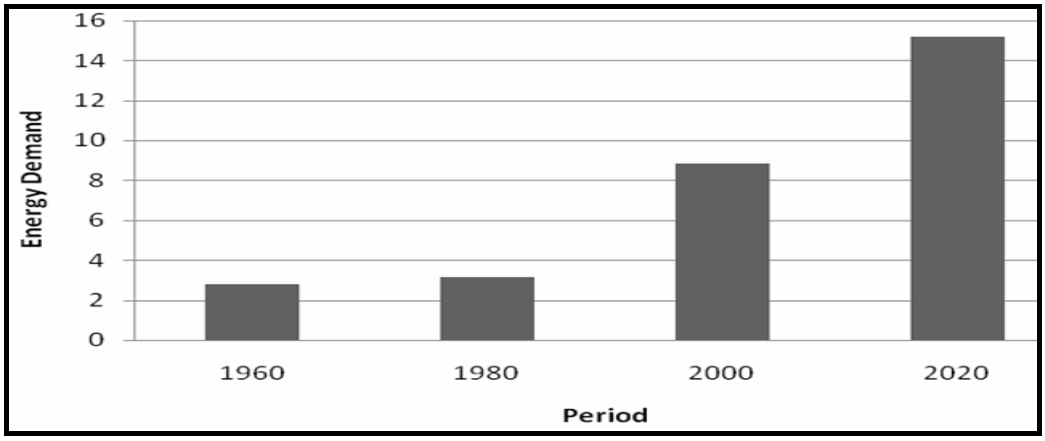
F . Exterior and interior of current condition for factory buildings in urban area. (source: internet)

. S : G B

This factory building has been expanding rapidly since the late 1970s. Bangladesh factory buildings have been criticized over the last 30 years for the working environmental conditions in where employees spend most of their day time. Internal heat gains from artificial lighting, equipment and machineries and human metabolic rate. The produced heat causes an intolerably hot work environment and high energy consumption work place in the most of the factories. In Bangladesh, previously the normal commercial buildings were refurnished as the factories for

production. There were no rules and regulation for converting the commercial buildings in the city. It was easy to get workers in the city as rural and sub-urban people came to the city for work.

Among the all environmental compliances which are recommended illumination conditions, thermal comfort and reduce the energy consumption of factory are important factors that must be ensured. The extra energy consumption (28.18 MTOE) in industry sector came from structural change (S-effect) and intensity change (I-effect) with the amount of 16.39 and 11.79 MTOE, respectively. In figure 1.2, it is shown that the energy demand is changing rapidly in industrial sectors of Bangladesh (Rabiul, 2011).



**F . ** Graph profile of energy demand in Bangladesh (Power development authority, Bangladesh, 2009)

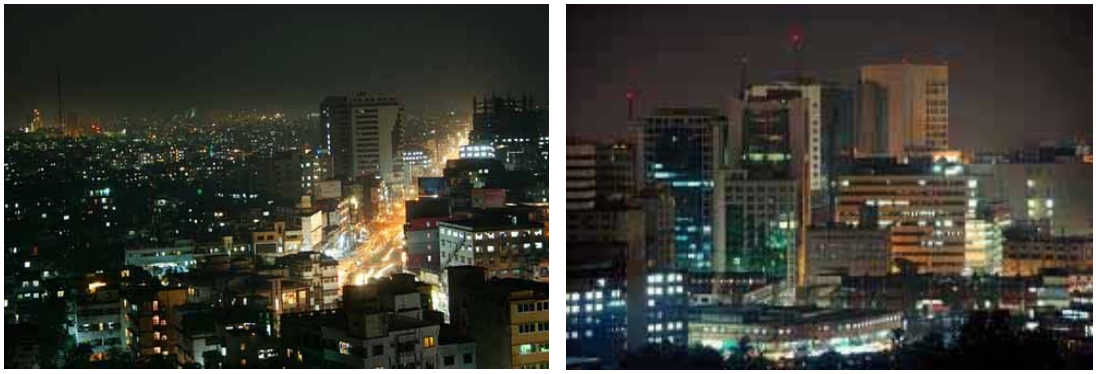
From the graph profile (figure 1.2) it was found that from 1960 to 2020 the energy consumption in industrial sector was increased almost 10 times. But still the indoor environment it not comfortable for the workers who are working in that.

The context of this research and project is situated in suburban area in Bangladesh. The industry is the economic lifeline of the country which is employing 10% of the total population in these sectors. Bangladesh is the 12th largest apparel exporter in the world (fifth largest in EU), with a turnover of US$9.52 billion annually (Rabiul, 2010). Currently there are 8000 factories in Bangladesh and the British Bangladesh Chamber of Commerce (BBCC) had reported that 1000 more will be built by the end of 2008 (Rabiul, 2010).

The selected company has been always, and still remains, to produce quality products for meeting complete customer satisfaction. At every stage of production, stringent quality control measures are adopted to ensure delivery of only quality products. The company unyielding quality control policy has further consolidated the reputation of the company both at home and abroad. The company has a vertically integrated production system starting from polymer extrusion to weaving, coating, printing and sewing. This system provides the needed flexibility to meet varied requirements of the customers. The daily production capacity is about 15 tons of various types of bags. The daily workers per shift 350 nos. are working at a time in these three industries. There are two shifts in these factories. The indoor environmental conditions of these factories are also very important to keep the work place under comfortable environment.

F . Products of the company (left)and sewing section (right)(source: Author)

Most of factories are facing for their overheated working conditions, causing a health hazard for the workers who are working in these factories for 10 to 12 hours. The high density of workers, equipment and artificial lighting are the main source for high internal temperatures. The sewing section is the main workspace which is extensively using of artificial lighting and that is the major cause for high internal temperatures. The cooling solutions of these spaces for such factories usually use ceiling fan and industrial exhaust fans. It is not possible natural ventilation of the factories as those are with deep floor plans and with high ceiling heights which are made of steel sheets. The resulting lack of heat dissipation leads to an oven-like working place for the workers at the middle of the day. For this reason, the area of field study of this research was selected for subtropical country Bangladesh.



**F . ** Dense Dhaka city skylines during day and night skyline view

At the 19th to 20th century, many countries of Asia had experienced high economical growth which accompanied by rapid urbanization in the cities. Due to rapid urbanization there has been a tremendous population growth in cities(figure 1.4). This population growth affect people's aesthetic sense and it influenced the architecture of the world (kubuta, 2006). However, in present the architectural design had paid very little amount of attention to the extreme local climatic conditions in the region. Architect, town planer, designer, landscape designer have the great influence for sustainable development of a country. There are three major groups of problem such as population growth, depletion of resource and atmospheric pollutions. Reduce energy demands of buildings use and substitute of renewable sources for energy as far as possible (S.V. Szokolay, 2008). Most of the case of factory indoor environment is not comfortable for the workers. Every month workers are facing illness which is caused from heat. The workers bear own responsibility to their health and safety while working in factories. This is the main issue to start this research on indoor thermal behavior of factory buildings.

This research examined the indoor thermal behavior of factory building in hot warm-humid tropical climate of Bangladesh. The physical measurements for all three factories were carried out using air temperature, humidity data loggers and surface temperature data loggers. Internal and external air temperature and relative humidity were measured to evaluate the indoor thermal behavior of factory building. This research finding can provide further improvements, advancement of knowledge and appropriate design strategy of factory buildings within subtropical countries and provide an assessment for a good environment of work place.

. S P

Among, the major problems of factory buildings development are the overheating by roof materials, deep planning and cross ventilations. For factory buildings in equatorial regions with warm-humid climatic condition such as Bangladesh, the exposed roof is the major source of heat gain for indoor environment. Beside this factor, in factory buildings other heat sources like human metabolisms, machineries, overcrowded of workers and less ventilation scope. Due to geographical location of Bangladesh, receives the sunlight directly most of the day throughout the whole year. Therefore, major heat gain of factory buildings comes from the roof as it is most of the time made by steel sheets. When the heat enters into the indoor through roof, the hot air heats up the indoor work environment and the heat is then remain there. The excessive heat was gained from the direct sun will be radiated from the roof to the occupants in the factory through long wave radiation (Koenigsberger et al., 1980). From previous studies, heat transfer around 87% from the roof to occupant is through radiation process. Thereby around 13% of heat is transferred from outdoor to indoor through conduction and convection (Cowan, 1973). It is also founded from previous research that insulation could be used to replace the mass insulation materials due to higher thermal performance (Allen, 2008). Air temperature is the main criteria of human comfort. So this research work will provide a preliminary guideline or idea for indoor thermal behavior of factory building on the basis of thermal condition of workers workplace with their vote for comfort temperature.

**F . ** Workers working in the factory building (Source: Author)

The workers feel uncomfortable when they are working in the factory as the indoor start getting heat at day time. For this reason workers suffer heat related sickness around the whole year. This condition of workers effects the productions of the factories. Most of factories do not consider the building depth, building height, indoor volume, equipments and number of stories which factors are very important to make factory an energy efficient building. Workers is used to describe the situations in which occupants experience acute health and comfort effects that was appeared to be linked to time they spent in a factory building. This is the main issue to start this research on thermal evaluation of indoor for factory building as an indoor thermal comfortable strategy and finding the comfort temperature for workers in Bangladesh.

. R G

There is some previous study which was done on thermal performance of factory building. Previous all thermal studies have identified that roofs have a huge impact on the indoor thermal performance of the whole building (Badrul et al., 2006; Nor, 2005). Solar protections of the roofs are the important concerns to all researchers (W. Puangsombut et al., 2007: Francois et al., 2004: Olgyay, 1992. Koenigsberger et al., 1980; Cowan, 1973). Inappropriate roofing materials might cause overheating of roof and therefore excessive heat would be radiated to the indoor (Allen, 2008). Unfortunately, there is a lack of concern of the effect of roofing materials and sustainable design to achieve workers comfort level in local factory buildings. This is the main issue of the problem of indoor thermal behavior of factory buildings. Therefore, this study was aimed to record the thermal data at indoor of factory building in Bangladesh for a better understanding on the thermal effect to provide better indoor thermal environment for workers in Bangladesh.

Very few studies were done about thermal performance and thermal comfort in respect to urban and sub-urban in Bangladesh. Previous study was done for new industry or factory building design which considered the energy efficiency of building in Bangladesh (Rabiul, 2010) and finding state that modeling could raise

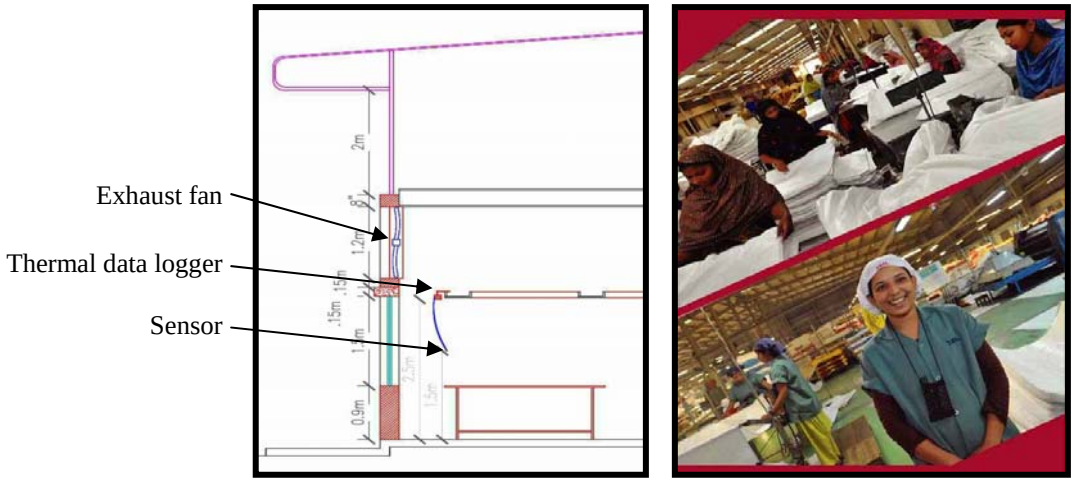
awareness for energy and environmental issues and could give an adequate status in design decision making. In a previous study, it had been observed that increased daylight, color, building height and depth, window openings performance had often resulted in reduced thermal performance in production areas (Rabiul, 2010). One methodology was developed for both thermal comfort and human (worker) comfort of ready-made garments factory buildings and applied it to the existing factories with support of design guidelines in Bangladesh under the same consideration of local climatic.

Workers of factory buildings suffer from various diseases which are occurred from heat stress and working in uncomfortable work place. Some previous study was done on employees' health who is working in office building (Hiroko, 2004). Other research was done on the thermal performance of office building (Christian, 2009) and found that some improvements to the building fabric and controls can bring about better performance. From the study it was observed that a certain combinations of improvement in better windows, natural ventilation, and efficient electrical lighting have the potential to significantly reduce the buildings' cooling loads in the local climatic condition.

All of these studies suggested some isolated studies have been done in Bangladesh factory buildings. There is no specific research was done to study the thermal behavior of factory buildings in Bangladesh. However, it is important to find out the comfort vote of workers in which workers feel more comfortable then present condition and improve their performance. Therefore, this thesis attempts to focus on the performance and thermal behavior of factory building in the context of Bangladesh.

. R H

The hypothesis of this study states that indoor thermal condition of a factory building is currently in substandard condition and therefore is significantly responsible for the thermal discomfort of workers, thus affecting their work rate.



F . Section of factory and workers working in a comfortable environment (Source: Author)

. R A O

The aim of this research is to improve the indoor thermal environment for better quality of work place and to make guidelines for maintaining indoor air temperature under indoor comfort temperature range for worker in the factory buildings in order to improve work rate. To evaluate the thermal behavior of factory buildings in Bangladesh with the following objectives:

- To study the daily and seasonal indoor and outdoor temperature in three garments factories indoor.
- To evaluate the thermal comfort of three garments factories at Dhaka in Bangladesh.

. R

In order to achieve the objectives three corresponding research questions are developed and those are:

1. Is there any significant influence of climate on indoor thermal environment?

2. Is there any significant relationship between the perceptual comfort zone with work rate?
3. Is there any significance relationship between thermal comfort and workers health?

. S

1. The scope of this research is to investigate the thermal condition of workers work place and find out the comfort condition in factory building
2. This study also considers the sub-tropical climatic condition for indoor thermal behavior for factory building.

. L

There are some limitations in this study such as

1. The main limitation was to convince the factory owners for the permission and run the field survey and questionnaire survey during working hours.
2. In this study only thermal performance and thermal comfort zone is considered as a variable.
3. Another limitation was the site selection, as it did not select cases from all over the country.
4. In this study the air movement was not measured for the equipment limitations.

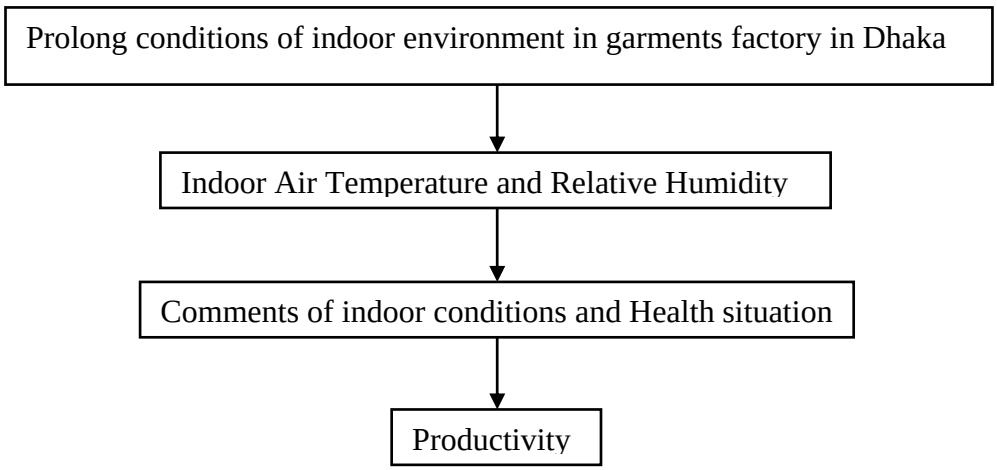
Above these opportunities and obligations, research on the thermal behavior of the factory building in Bangladesh was carried out and described briefly in the following chapters.

. S R

The significance of this research lies on understanding the thermal behavior of factory buildings in the context of sub-urban areas in sub tropical climate and its relationship with thermal comfort that includes factors such as human well being, health, and perceptual .

This research study can find a significant relationship between thermal comfort of factory building and work rate and health of worker then administration can try to maintain comfort temperature all around the year to produce maximum work output from workers

. R P

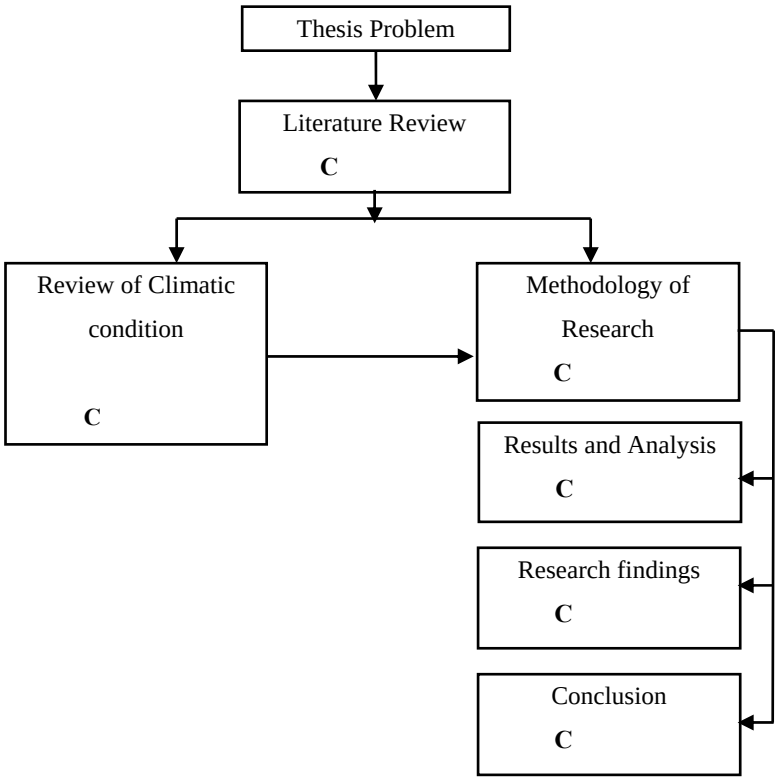


**F . ** Diagram of research position.

Good thermal performance of a building means it can positively respond to the changing of outdoor temperature. So whatever the outdoor temperature outside, the indoor will remain inside comfort zone. The tolerance level is the cut-off point beyond which may cause poor work rate by workers. The tolerance level in the factory building will be measured in these two following ways.

1. Workers discomfort
2. Workers health problems, both of which are subjective to human perception.

. T S



F . The flow of research process and thesis structure.

The thesis is organized into six chapters and those are summarized below.

C presents the main issue of the research. This chapter also introduces the problem statement of this research, objectives of this study, scope and limitation of the study and significance of this research. In this chapter also discussed about the research gap, research questions, research hypothesis and the thesis structure.

C explains the previous studies which are related to this research. Workers health, heat stress and comfort vote applications are also discussed here in details.

C introduces the climatic classification of Bangladesh. This chapter explains the urban climatic components such as air temperature, rain fall, relative humidity, wind speed etc. The chapter also introduces the present conditions of the Dhaka City and surroundings conditions. The previous research of climate, climatic comfort, indoor comfort, summer comfort zone, summer comfort zone will also be explained here. Environmental criteria, comfort vote are also described briefly in this chapter.

C explains the methodology of this study. It describes the objective of the methodology and description of the selected factory buildings in Bangladesh. Instrumentation, installation of thermal data logger and location of loggers and methodology of data collection are also described briefly here. The procedure of questionnaire survey is also mentioned in this chapter.

C presents the results of findings and results analysis of this research. It describes the air temperature difference of indoor and outdoor of factory buildings with diurnal variation and also with the change of seasons. Air temperature difference between BMD and field study data are also explained here. Here also explained comfort vote of workers and health conditions of workers.

C concludes the overall review of the thesis objectives and research questions. Here also concludes remarkable of the major findings of the field experiment.

C concludes this research conclusion and presents the guideline which is developed for comfort environment and it also suggests for further works after the thesis findings.

. C

In this chapter, a brief introduction of the subjects that might be necessary for this research explained here. It included briefly about the hypothesis and the objective of the study, background information on Bangladesh, the context regarding factory buildings, research scope and limitation, past investigations on thermal comfort of factory building etc. Finally, a brief discussion of the research structure and position for this study has also been introduced in this chapter.

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