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MICROCLIMATE AND THERMAL COMFORT OF PUBLIC ENCLOSED COURTYARDS IN HOT DRY REGIONS, WITH SPECIAL REFERENCE TO TRIPOLI, LIBYA

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ABSTRACT

With increasing concerns about the implications of climate change and urbanisation, there has been an increased public interest in the quality of urban open spaces in many countries because of its importance for daily people's lives and urban environment. Recent studies in this field have shown that the microclimatic conditions are very important for people's comfort in urban open spaces and, therefore, for the use of these spaces. Studying microclimate and thermal conditions in urban open spaces has been increased in the past years. The relationship between the microclimate, thermal comfort and the built urban form is still not understood very well. Further research in this aspect is needed.

The courtyard is one of the open space types widely used in the countries of North Africa, Middle East and South Europe. The courtyard is often referred to in literature as a microclimate modifier. Because of this, many studies have been conducted in order to investigate its thermal environment. The majority of these studies dealt with the courtyard as a private space as a part of a building that can contribute to improve the indoor thermal conditions of the surrounding covered areas (its main function is to provide daylight and ventilation into the covered spaces).

This study focuses on a particular type of courtyard. It deals with public enclosed courtyards which combine the features of the courtyards and public squares. This type of courtyard is not limited to provide only natural ventilation and natural daylight for the surrounding buildings, but it is mainly designed to offer a public place to perform a variety of activities for people such as social interactions, culture events, recreation, playing, business and many other activities. To the best of my knowledge, there have been no studies done on the microclimate and thermal comfort of courtyards with similar designs (function), particularly in hot dry regions. This study is conducted in Libya where the courtyard is the most common architectural pattern in its cities through all periods of the history. It is conducted in Libya where there is no published research on outdoor thermal comfort.

This study investigated the microclimate, thermal comfort and the relationship with the built urban form of public enclosed courtyards in Tripoli city. The general purpose of this study was to develop a database of the thermal environment and subjective responses of people in existing public open spaces in a hot dry climate.

The methodology used for this purpose was field studies. Two short-term field surveys were conducted in the two extreme seasons in Libya, one in the cool season day-time and the other one in the hot season day-time. A further field survey was performed during the hot season night-time, where no such study has been conducted in courtyards at this time in the past. In these field studies, extensive environmental measurements have been carried out in parallel to questionnaire surveys with the users of the selected case study sites. Six varied public enclosed courtyards representing three different architecture and urban-built forms of Tripoli city (old city, colonial city, and post-colonial city), were selected for the purpose of this study.

The results showed that during both seasons, the microclimatic conditions in the studied courtyards were varied depending mainly on the amount of solar radiation received by their surfaces. Spatial characteristics (architectural form, geometry and surface materials and colours) had important roles in shaping the microclimates of the studied sites during both seasons. The results also showed that the distribution of thermal sensation votes, overall comfort votes and thermal preference votes were different for both seasons, as well as for the sites. Air temperature and then wind speed were found to be the most important determinants of people comfort. The findings of the study also revealed that summer night-time is considered to be of concern for urban thermal comfort in outdoor environments in Tripoli. In general, the findings confirmed a strong relationship between the built urban form (spatial characteristics of the sites), the microclimatic conditions and people’s comfort.

In memory of my father

and to my family

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1 INTRODUCTION

This is the introductory chapter. It gives an insight into the proposed area of research, the aim, the objectives and the research questions. The scope and limitations of the study and thesis structure are outlined in this chapter as well.

1.1 Background

Over the past six decades, Libya has experienced the highest rates of urbanisation among the Mediterranean countries, from 18.6% in 1950 to 87.6% in 2000 (Brauch, 2003). Tripoli, the capital, is the biggest victim of this rapid urbanisation. It is the largest urban area in the country with a population of about 1.31 million inhabitants, i.e around 18.8% of the total population of Libya (2010 estimates, National Authority for Information and Documentation; NAID). Concomitant with the process of urbanisation, built-up areas in this city were expanding in the form of huge areas of concrete and asphalt. This came at the expense of urban open spaces within the city and the surrounding agricultural areas and forests. Rapid urbanisation often leads to negative environmental impacts, including changes to the urban microclimate.

More specifically, increasing ambient temperature is one of the environmental problems that Tripoli and other big cities in Libya are facing. This change in urban microclimate has effects on outdoor comfort conditions and consequently on people's lifestyle and usage of outdoor spaces. Poor urban microclimates have significant implications for the comfort and health of the inhabitants as well as energy use. In other words, poor urban microclimates particularly in the hot season, do not encourage people to use open spaces, it makes them spend more time indoors which leads to more energy consumption due to the increasing use of air conditioning for cooling. Therefore the quality of outdoor spaces is important as it contributes to the quality of life within cities. Recently, public interest in the quality of urban open spaces has increased, especially in the developed countries because of its importance for people living in urban areas. In Libya, public awareness about this issue is still very low.

In line with urban open spaces, there has been a growing interest in studying outdoor thermal comfort. Most previous studies of thermal comfort have been conducted in developed countries (European and North American cities). Thess focused on thermal comfort in indoor settings, while the thermal comfort outdoors, until recently, has received little research attention (Spagnolo and de Dear, 2003; Nicol, Wilson, Tritta, Nanayakkara and Kessler 2005). The reasons for that as highlighted by Spagnolo and de Dear are: the majority of people in these countries spend most of their time indoors, moreover, the outdoor thermal environment is more difficult to control than indoor. In additional to this, the ownership of, and responsibility for many of the outdoor spaces are not clearly defined as in indoor spaces.

The research in this area has been focused on aspects such as the relations between thermal comfort, microclimate, behaviour, use of place and spatial variation. Another direction of research has dealt with the psychological variables related to the thermal comfort of users in outdoor places. Recently, the research has been dealing with the association between culture and climatic characteristics that influence the use of outdoor spaces.

In recent years, outdoor thermal comfort has gained increased attention in Southern Europe, North Africa and Middle East. In Libya the situation is still far away, where there is no published research conducted on outdoor thermal comfort. Thus, the need to study the microclimate and thermal comfort in urban open spaces has become more urgent in Libya. In that sense, this study seeks to start filling some of these gaps by studying one of the most-used open space type and architectural pattern in Libyan cities in particular and in the surrounding regions in general. The study focuses on public enclosed courtyards which have not received any attention previously. The study seeks to add some empirical knowledge on the microclimate, thermal comfort in public enclosed courtyards and their relation with the built urban form. The study covers three periods which are cold season day-time, hot season day-time and hot season night-time. Thus, therefore, this study covers a new topic which is the microclimate and thermal comfort of public enclosed courtyards and covers a new area which is Libya and covers three time spans; one of them is night-time which has not received any attention in the previous studies. The results from this study may raise attention to the importance of public courtyards and contribute to the development of urban open spaces particularly in a hot dry climate.

1.2 Research Aim

This study is a first step towards outdoor thermal comfort research for the hot dry climate in Libya. The general purpose of this study is to develop a database of the thermal environments and subjective responses of people in existing public open spaces in a hot dry climate. More specifically, this study aims to contribute towards a deeper understanding of the relationship between built urban forms, the microclimate and outdoor thermal comfort in hot dry climates through a study conducted in public enclosed courtyards in the city of Tripoli during the hot and cool seasons.

1.3 Research Objectives

The main objective of this research is to investigate the microclimate, thermal comfort and their relationship with the built urban form in public enclosed courtyards in hot dry Tripoli. In order to achieve this, the following aspects are investigated:

- The spatial characteristics of the case study sites (studied courtyards)
- The microclimatic conditions of the case study sites during winter day-time and summer day/night-times
- The effects of the built urban form on the microclimatic environments of the case study sites
- The human response (thermal sensation, overall comfort and thermal preference) in the case study sites during both seasons
- Thermal acceptability in the studied sites during both seasons
- The relationship between the produced microclimatic conditions from the built form and the thermal comfort of courtyards' users
- Clothing and thermal comfort in the studied sites
- Thermal comfort adaptive behaviour

The results of this study could provide some general recommendations for the urban design in the Libyan coastal cities (and other cities with similar climates) under consideration of the microclimate and human comfort.

1.4 Research Questions

In order to achieve the aim of the study, the following questions should be answered:

- How do microclimate and outdoor thermal comfort vary spatially and temporally?
- How do the spatial characteristics of the built environment influence the microclimate in urban areas?
- Which are the main elements of the urban-built form influencing the urban microclimate of the case study sites?
- How does the microclimate affect subjects in terms of overall comfort, thermal sensation (perception) and thermal preference?
- Are the environments of the studied courtyards thermally acceptable (meet the ASHRAE Standard-55's 80% acceptability criteria) during both seasons?

1.5 Scope and Limitations

This study has been conducted to investigate the microclimate and thermal comfort in the public enclosed courtyards in hot dry Tripoli/Libya. The methodology used for this study was field studies. The techniques used for data collection were questionnaire surveys, environmental measurements and observations. The field study consisted of three parts, the first part was in the cold season day-time, the second one was during the hot season day-time and the final part was during the hot season night-times. The collected data was analysed using Microsoft Excel and SPSS software.

The study is limited to Tripoli, which is one of the cities that has a hot dry climate in Libya. This study only considers one type of public open space which is the courtyard, since courtyards are the most widely-used open space type and architectural pattern in the city throughout its history. Only fully-enclosed courtyards are considered in this research, whereas other types are not covered. The fieldwork was carried out during the cold winter day-time and the hot summer day/night-times (extreme months). Thus, spring and autumn were not included in the study due to the limited time, equipment and resources available.

The field measurements were not collected in courtyards C6 (Bab Bharr) during the winter day-time and summer day-time field surveys because this site was closed during these times. Moreover, the thermal comfort surveys were not carried out in some courtyards because of the lack of people available (e.g. courtyard C4 in the summer season due to student holidays, courtyard C5 because it was not accessible to the public and courtyard C5 because it was used as a connection area between rooms). The number of female participants in the study samples was relatively small compared to the number of males due to the nature of women in Libyan society.

1.6 Thesis Structure

The thesis consisted of two main parts: the theoretical and the empirical study. The first part covers the background study, and is divided into four chapters:

Chapter 1 : Gives insight into the proposed area of research, aims and objectives of the research and the scope and limitations of the study.

Chapter 2 : Presents a review of literature about thermal comfort including definitions, variables, scales, indices, conditions, standards and previous studies.

Chapter 3 : Deals with urban open spaces. It covers definitions, importance, and functions of open spaces, characteristics, needs, benefits and typology of open spaces, with a special focus on courtyards.

Chapter 4 : Provides background on case studies, it briefly gives an overview of the general picture of Libya and its capital Tripoli where this investigation is carried out, including information about location, population and climate. Climate elements, the urban form of Tripoli city and a general description of case study sites are discussed in detail in this chapter. The second part covers the research and empirical study. It includes four chapters:

Chapter 5 : Outlines the fieldwork research methodology employed in the present study, including the flow of the research and methods, main reasons behind the choice of Tripoli city as a study area, field surveys, and types of data collection, tools/equipment and samples.

Chapter 6 : Discusses the results of microclimate measurements obtained from the three field surveys in the case study sites. The microclimate of the studied sites is analysed, discussed and compared to each other in great detail. The effect of the elements of the built urban form on the courtyards' microclimates is discussed as well in this chapter.

Chapter 7 : Presents, analyses, discusses and compares the subjective thermal comfort data collected from the studied sites during the three field surveys. It contains analysis and discussions on thermal sensation votes, thermal comfort votes, thermal preference votes and comparisons between the results. The effect of clothing on people's thermal comfort and thermal comfort adaptive behaviour are included in this chapter.

Chapter 8 : Presents the findings through conclusions, recommendations and further research. Following this concluding chapter will be References and Appendices.

1.7 Conclusion

In conclusion, the aim of this research is to contribute towards a deeper understanding of the relationship between the built urban form, the microclimate and outdoor thermal comfort in a hot dry climate through a study conducted in the city of Tripoli, Libya. The work in this research can be classified as a first step towards outdoor thermal comfort research into the hot dry climate in Libya. This study may open the door in this field (outdoor thermal comfort) in Libya, and this research that has started is an ongoing work to be continued. The results from this study may also help to throw some light on the importance of thermal comfort and climate considerations in urban design in the new Libya.

2 THERMAL COMFORT

This chapter is about thermal comfort which is one of the main areas of this study. It begins with the definitions of thermal comfort, thermal sensation, neutral temperature and thermal acceptance and preferred temperature. This is followed by a detailed description of the factors determining thermal comfort. Heat balance, psychrometrics, ways of heat exchange between the human body and the surrounding environment are presented in this chapter. This chapter concludes with a review on existing studies and research regarding the thermal environments of courtyards.

2.1 Thermal Comfort

Several definitions of thermal comfort exist. As cited by Gagge, (1981), in the early 1920s, the heating and ventilating engineers (Houghton and Yaglou, 1923) were the first who recognised thermal comfort as a measurable entity. They defined a comfortable environment 'as one sensed by the occupant as neither warm nor cold'. Then later, human thermal comfort was clearly defined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) as 'the state of mind that expresses satisfaction with the surrounding thermal environment' (Standard, 2004). ASHRAE (552004) goes further to describe thermal comfort 'as the absence of thermal discomfort or the conditions in which 80% or 90% of people do not express dissatisfaction'. Thermal comfort is defined also by Givoni, (1998) as 'the range of climatic conditions considered comfortable and acceptable inside building'. He stated that 'thermal comfort could better be defined just as the absence of any sense of discomfort'. Thermal comfort is highly subjective and limits of comfort vary from person to person. This means that the conditions which are comfortable to one person might be uncomfortable for another. The feelings of thermal comfort or discomfort reported by humans are complex and are not completely understood. Thermal comfort is a function of many parameters and not just one, such as air temperature. In other words, thermal comfort is dependent on a range of environmental and personal factors which make up what is known as the 'human thermal environment'.

2.2 Thermal Sensation

Thermal sensation is an expression of the sensation of warmth or its lack. Thermal sensation is a rational experience that can be described as being directed towards an objective world in terms of cold and warm, but thermal comfort is an emotional experience (Hensel). In fact thermal sensation is related to how people feel and is, therefore, a sensory experience and a psychological phenomenon. As thermal sensation is related to how people "feel", it is not possible to define it in physical or psychological terms (Hensen, 1991). There are a number of subjective scales, which have been used in the assessment of thermal environments. One of them is the

ASHRAE 7-point scale. It is one way of expressing thermal sensation, and known as the thermal sensation scale as shown in **Error! Reference source not found.**.

2.3 Neutral Temperature

Humphreys in the UK (1978) and Auliciemes in Australia (1981& 1982) have investigated the thermal neutrality of the human body, (Zuhairy and Sayigh, 1993, Sala et al., 1999, Nikolopoulou et al., 2001, Rajapaksha et al., 2003, Nikolopoulou and Lykoudis, 2006, Rakoto-Joseph et al., 2009, Humphreys et al., 2010). The thermal neutrality was defined as the temperature at which the person feels thermally neutral (comfortable). Humphreys' and Auliciemes' researches were based on (laboratory and field) experimental studies in which people were thermally investigated under different conditions. Their experimental results were then statistically analysed by using regression analysis. Michael Humphreys derived a regression equation for free running building which uses a monthly mean outdoor temperature to determine an optimum temperature, referred to as Thermal Neutrality, and thus laid the foundation of the adaptability model (Sala et al., 1999, Parsons, 2003, Rakoto-Joseph et al., 2009).

A few years after Humphreys, Auliciemes followed by other scholars have suggested equations for Neutral temperature (T_n), (Szokolay, 2008b). The following table shows some of these equations.

Table 2-1: Thermal neutrality equations suggested by Humphreys and others

Author / Year	Equation
Humphreys (1978)	$T_n = 11.9 + 0.534 \times T_{o.av}$
Auliciemes (1981)	$T_n = 17.6 + 0.31 \times T_{o.av}$
Griffiths (1990)	$T_n = 12.1 + 0.534 \times T_{o.av}$
Nicol and Roaf (1996)	$T_n = 17 + 0.38 \times T_{o.av}$
Brager and de Dear (1997)	$T_n = 17.8 + 0.31 \times T_{o.av}$

Where: (T_n) is the neutral temperature and ($T_{o.av}$) is the month's mean outdoor temperature.

According to Fanger, the thermal neutrality is that the condition in which the subject would prefer neither warmer nor cooler surrounding. The neutral temperature is the temperature at which people experience a sensation which is neither slightly warm nor slightly cool. At this temperature, the mean votes of the subjects is at the central category (0), known as ‘neutral’ on the 7-point ASHRAE scale.

2.4 Thermal Acceptance and Preferred Temperature

The concept of thermal acceptability has been widely debated in the literature but in practice is difficult to determine (Nicol and Humphrey, 1995). In the UK, the Chartered Institution of Building Services Engineers (CIBSE) Guide A has stated that during the summer periods, 25°C is generally an acceptable indoor design operative temperature (OT) for non-air conditioned (free-running) office buildings, with few people feeling uncomfortable (Cibse, 2006). The operative temperature can be defined as the average of the mean radiant and ambient air temperatures. Table 2-2 shows acceptable values for general summer indoor temperatures for a range of free-running buildings.

Table 2-2: General summer indoor comfort temperatures for non-air conditioned buildings (Taken from Table 1.7 in CIBSE Guide A)

Building type		**Indoor summer comfort temperature / °C**	**Notes**
Offices		25 °C operative temperature	Assuming warm summer conditions in UK
Schools		25 °C operative temperature	Assuming warm summer conditions in UK
Dwellings	living areas	25 °C operative temperature	Assuming warm summer conditions in UK
	bedrooms	23 °C operative temperature	Sleep may be impaired above 24 °C
Retail		25 °C operative temperature	Assuming warm summer conditions in UK

The 2006 edition of CIBSE Guide A indicated that between indoor operative temperatures of 25 ºC - 28 ºC, number of people may feel hot and uncomfortable will be increased, but if the indoor operative temperature (OT) stays at or over 28 ºC for long periods of the day, this will increase the dissatisfaction for the majority of occupants, and were deemed to overheat. In the 2006 edition of CIBSE Guide A, the definition of an overheating building was one in which the OT exceeded 28°C for more than 1% of the annual occupied period (e.g. around 25–30 hours). In this context, the CIBSE guide A has recommended temperature benchmarks to identify building overheating. Table 2-2 shows these temperature benchmarks and overheating criteria for three non-air conditioned building types (offices, schools and dwellings) for use in design.

Table 2-3: Benchmark summer peak temperatures and overheating criteria (Taken from Table 1.8 in CIBSE Guide A)

<table>
<tr><th colspan="2">Building type</th><th>Benchmark summer peak temp. / °C</th><th>Overheating criterion</th></tr>
<tr><td colspan="2">Offices</td><td>28 °C</td><td>1% annual occupied hours over 28 °C operative temp.</td></tr>
<tr><td colspan="2">Schools</td><td>28 °C</td><td>1% annual occupied hours over 28 °C operative temp.</td></tr>
<tr><td rowspan="2">Dwellings</td><td>living areas</td><td>28 °C</td><td>1% annual occupied hours over 28 °C operative temp.</td></tr>
<tr><td>bedrooms</td><td>26 °C</td><td>1% annual occupied hours over 26 °C operative temp.</td></tr>
</table>

Note: the DfES Building Bulletin BB87 recommends an allowable overheating criterion of 80 occupied hours in a year over an air temperature of 28 °C.

In the US, the ASHRAE Standard 55-2004 has defined an acceptable thermal environment as ‘an environment that at least 80% of the occupants would find thermally acceptable’ (Olesen and Brager, 2004). In thermal comfort studies, several methods are used to measure thermal acceptability. According to (Brager et al., 1993), there is only one direct acceptability assessing method whereby people are asked ‘Do you find this environment thermally acceptable?’, but this question was rarely used in laboratory and field studies. They stated also that the most commonly-used methods for assessing thermal acceptability are the indirect measures; the 7-point ASHRAE thermal sensation scale, comfort scale and preference scale, (see Table 2-4). The first one considers the votes within the three middle categories of the thermal sensation scale as thermal acceptability conditions. This method was proposed by Fanger in developing the concept of Predicted Per cent Dissatisfied (PPD). The preference scale (3-point McIntyre scale) was also used as an indirect measure of thermal acceptability. This scale defines acceptability as a vote for ‘no change’. Thus this method considers the answer of ‘no change’ as an acceptable thermal condition for the subject. As for preferred temperature, it is the temperature at which a respondent requests no change in temperature or at which the greatest percentage of group of people request no change in temperature. Preferred temperature can be found by asking the direct question and using a present-time condition: would you like to be: Cooler or No Change or Warmer? (McIntyre scale).

In the present study, the three scales are used. Participants were asked to vote on these scales and analyses have been carried out for all sets of results.

Table 2-4: Three rating scales (thermal sensation, thermal comfort and thermal preference) used for this study

ASHRAE 7-point thermal sensation scale	3 Hot	Expanded thermal comfort scale	1 Very comfortable	McIntyre's 3-point preference scale	1 Warmer
	2 Warm		2 Comfortable		
	1 Slightly warm		3 Slightly comfortable		0 No change
	0 Neutral		4 Neutral		
	-1 Slightly cool		5 Slightly uncomfortable		
	-2 Cool		6 Uncomfortable		-1 Cooler
	-3 Cold		7 Very uncomfortable		

2.5 Factors Determining Thermal Comfort

The factors that have an influence on the thermal comfort can be classified into two categories, primary and secondary. The primary factors (six basic factors) consist of two groups, environmental and personal. The secondary factors (contributing factors) include other factors which are close to the psychological parameters.

2.5.1 The primary factors

Many researches were conducted in order to identify the factors that may affect thermal comfort. Fanger, P. O. in many of his publications (e.g., Fanger, 1972; Fanger, 1973; and (ASHRAE, 1997) have listed the main factors that have a direct effect on human thermal comfort. They are as follows:

2.5.1.1 Environmental variables

1) Air temperature (dry-bulb temperature) [DBT - °C].
2) Air velocity [V - m/s].
3) Relative humidity [RH - %].
4) Mean radiant temperature [MRT - °C].

These factors may be independent of each other, but together contribute to human thermal comfort. They can be described as follows.

2.5.1.1.1 Air temperature (dry-bulb temperature)

It is the most important factor in determining energy balance, comfort, discomfort, thermal sensation and perception of air quality. This factor has a direct effect on the rate at which the body loses or gains heat to or from the surroundings by convection. It can be measured by liquid-in-glass thermometers, thermocouples, and resistance temperature devices (Spengler J.D; Samet, 2001).

2.5.1.1.2 Mean radiant temperature

Mean radiant temperature is one of the main factors determining thermal comfort and governing human energy balance. MRT is defined as the ‘uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure’ (ASHRAE, 2001). In other words, MRT can be calculated as a function of three variables namely: air temperature, globe temperature and air velocity. Mean radiant temperature is the average of the temperature of the object or surface, which radiates heat to other objects (e.g. the human body can exchange heat with the surroundings by radiant transfer). Radiant heat transfer to and from the body is quite significant when sitting near a cold surface/area (e.g. cold window/low MRT) or a hot surface/area (e.g. fireplace/ high MRT). Mean radiant temperature is one of the most difficult parameters to be analysed, provided that it should take into account not only the thermal radiation coming from low-temperature surfaces (i.e. walls, windows,), but also the thermal radiation hitting the human body from high-intensity sources (La Gennusa et al., 2005). There are several methods for measuring and modelling MRT such as integral radiation measurements and the calculation of angular factors, measurements by globe thermometers and using Rayman1.2 software. Because of its simplicity, the instrument most commonly used to determine the mean radiant temperature is a black globe thermometer (Bedford and Warner, 1934). The globe thermometer was first developed for indoor measurements, but has later been applied outdoors (Nikolopoulou et al., 2001). In outdoor urban settings where thermal comfort researchers or urban planners and designers require an easy and reliable method of estimating mean radiant temperature, the 38mm flat grey globe thermometer provides a good and economical solution (Sofia et al., 2007).

The 38mm flat grey globe thermometer can successfully be used to estimate the MRT in an outdoor setting. Furthermore, the 38mm flat grey globe thermometer is a simple, mobile and economical instrument and is thus a valuable tool for thermal comfort researchers or urban planners and designers (Sofia et al., 2007).

2.5.1.1.3 Air velocity (Air movement)

Air velocity has an important influence on the human body and comfort in terms of its effect on skin temperature, skin wittedness, thermal sensation and convective and evaporative heat loss. In other words, as Rabah (2005) explained in his paper, the air movement can produce different thermal effects at different air temperatures, in two ways:

I. It increases convective heat loss, as long as the temperature of the moving air is less than the skin temperature. If this condition is not fulfilled, the air actually warms the skin.
II. It accelerates evaporation, providing a physiological cooling. Its effect is insignificant at humidities lower than 30%, when there is an unrestricted evaporation even with still air, and humidities above 85%, when even air movement cannot help adding vapour to the already highly saturated air. Pleasant ranges of air movements induce skin evaporation, more significantly in medium (40–50%) humidities. Air movement can be measured by several types of anemometers.

2.5.1.1.4 Relative humidity

Relative humidity may be defined as the ratio of the actual amount of water vapour in the air over the amount of the saturated water vapour in the air, usually expressed in percent.

$$Relative\ Humidity\ (RH) = \frac{(Actual\ Vapor\ Density)}{(Saturation\ Vapor\ Density)}\ X\ 100\%$$

RH has an influence on the heat balance of the human body by determining the amount of evaporation on the skin. In high humidity environments which have a lot of vapour in the air, the human body evaporates less sweat from the skin. In this case people may feel hotter (discomfort) even with the same air temperature. (Koch,

1960) concluded that between 20°C (68°F) and 34°C (93.2°F) and 20% and 90% relative humidity, humidity had only a small effect on comfort. Fountain et al. (1999) have studied many previous researches and tests on humidity and comfort have been conducted by some researchers such as Nevins et al. (1966); Fanger (1970); Tanabe et al. (1987); de Dear et al. (1991) and others. They concluded that humidity has only a modest effect on thermal sensation at temperatures within the comfort zone.

Fountain et al. (1999) performed climate chamber experiments to investigate thermal comfort at high humidities. One hundred and eleven subjects (sixty five subjects equipped with instrumentation for recording wittedness and skin temperature) were exposed for three hours to air temperatures and relative humidities ranged from 20°C (68°F)/60% RH to 26°C (78.8°F)/90% RH with two clothing levels, 0.5 and 0.9 clo, and three levels of metabolic activity, 1.2, 1.6, and 4 met. The investigators concluded their results as follows:

I. The 90% RH condition was typically the least favourably rated.
II. The 80% RH condition was not apparently worse than the 60% or 70% condition.
III. The 70% condition was frequently more favourably rated than the 60% condition.
IV. Finally, for metabolic rates 1.6 met and above, they conclude that no practical limit on humidity will be likely to lower the percentage dissatisfied below 25%.

2.5.1.2 Personal variables

1. Metabolic rate (activity) [1Met= 58 W/m2].
2. Clothing insulation value [1Clo= 0.155 m2ºC/W].

2.5.1.2.1 Metabolic rate (activity level)

The human body continuously generates its own heat through the metabolism processes (biological processes within the body). The produced heat must be emitted from the body to the surrounding environment by means of transferring sensible heat (radiation, convection and conduction) or by evaporating body fluids. This occurs to allow the body to keep its internal temperature fairly constant around 37ºC, and skin temperature comfortable. If the produced heat is too much then the body will sweat which will cause discomfort, but if the produced heat is too little then the blood will be withdrawn from the hands and feet, leading to a fall in skin temperature, in this case the person will feel cold and uncomfortable.

The metabolic rate is a rate of heat discharged from the human body by physical activities. The metabolic rate can vary depending on many factors such as the activity, the person, and the conditions under which the activity is performed. The body produces heat at a minimum rate during sleeping, and a maximum rate during sporting activities. The produced metabolic heat increases when the activity increases from sitting to walking to running Figure 2-1.

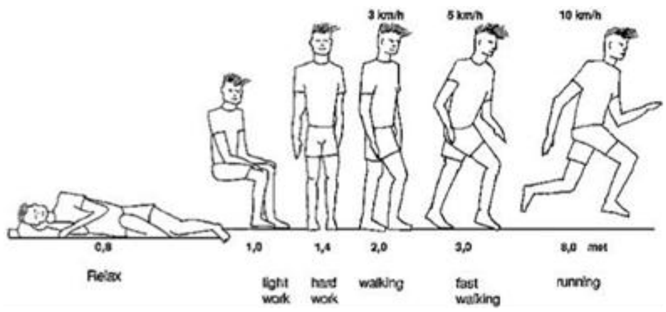


Figure 2-1: Metabolic rate of different activities by P.O. Fanger (Gut and Ackerknecht, 1993)

Activity level is measured in terms of metabolic rate, or met (Gagge et al, 1941). One met is the metabolic rate for a person who is seated and at rest. (1 met = 58.15 W/m2 of body surface). Frequently, values of 1.8 m^2 are assumed for the surface area and 70 kg for the mass of a man, and 60 kg and 1.6 m^2 for a woman. Some examples of metabolic rates for different activities are shown in Table 2-5.

Table 2-5: metabolic rates for different activities (Szokolay, 1997, 2007)

Activity	Met	W/m²	W(av)
Sleeping	0.7	40	70
Reclining, lying in bed	0.8	46	80
Seated, at rest	1.0	58	100
Standing, sedentary work	1.2	70	120
Very light work (shopping, cooking, light industry)	1.6	93	160
Medium light work (house~, machine tool ~)	2.0	116	200
Steady medium work (jackhammer, social dancing)	3.0	175	300
Heavy work (sawing, planning by hand, tennis) up to	6.0	350	600
Very heavy work (squash, furnace work) up to	7.0	410	700

2.5.1.2.2 Clothing insulation

Clothing is one of six important factors which affect heat exchange between the human body and its environment. It is an important modifier of body heat loss and comfort. This means clothing acts as body insulation. In other words, clothing provides a considerable degree of control over most forms of heat exchanges between the human body surface and the environment. Clothing insulation varies between people in a space due to differences in clothing preferences, season, company dress code, etc. (see Figure 2-2). Gagge, Bazett and Burton (1941) introduced the term 'clo' as a unit to measure clothing insulation (Welford, 1977, Parsons, 1993,2003, Huang and Xu, 2006). Clo value is determined by the weight of clothes, therefore clo ~ 0.15 x weight of clothes in lbs. For example, 10 lbs of clothing ~ 1.5 clo (Hedge, 2008).

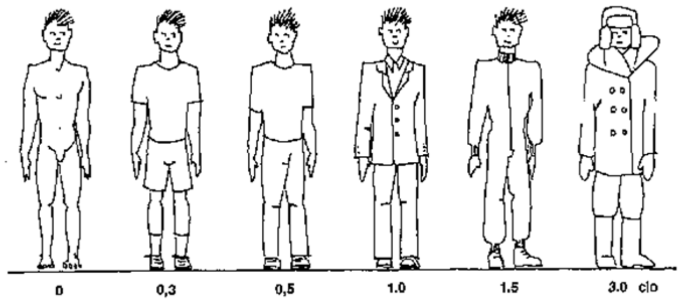


Figure 2-2: Thermal insulation values of different kind of clothing by P.O. Fanger (Gut and Ackerknecht, 1993), 1 clo = 0.155 m² K/W

Clo unit has been widely used by researchers to express the insulation of clothing systems, and to estimate its value, most researchers use tables that have been developed from clothing insulation studies. An example of these tables is shown below.

Table 2-6: Garment insulation values (Szokolay, 1997, 2007) based on ASHRAE 1985

Man		clo	Women		clo
Underwear	singlets	0.06	Underwear	bra + panties	0.05
	T-shirt	0.09		half slip	0.13
	briefs	0.05		full slip	0.19
	long, upper	0.35		long, upper	0.35
	long, lower	0.35		long, lower	0.35
Shirt	light, short sleeve	0.14	Blouse	light	0.20
	light, long sleeve	0.22		heavy	0.29
	heavy, short sleeve	0.25	Dress	light	0.22
	heavy, long sleeve +5% for tie or turtle neck)	0.29		heavy	0.70
Vest	light	0.15	Skirt	light	0.10
	heavy	0.29		heavy	0.22
Trousers	light	0.26	Slacks	light	0.26
	Heavy	0.32		heavy	0.44
Pullover	light	0.20	Pullover	light	0.17
	Heavy	0.37		heavy	0.37
Jacket	light	0.22	Jacket	light	0.17
	heavy	0.49		heavy	0.37
Socks	ankle length	0.04	Stockings	any length	0.01
	knee length	0.10		panty hose	0.01
Footwear	sandals	0.02	Footwear	sandals	0.02
	shoes	0.04		shoes	0.04
	boots	0.08		boots	0.08

2.5.2 The secondary Factors

The secondary factors (contributing factors) include other factors which are close to the psychological parameters such as age, gender, adaptation, seasonal and circadian rhythms, body build and weight, menstrual cycle, ethnic differences, food consumption. These may have an influence on determining thermal comfort. Their impacts, however, are not as significant as the primary factors (Parsons, K. C. 2003; ASHRAE 1997).The secondary factors can be described as follows:

2.5.2.1 Age

Many comfort studies have been conducted by Nevins et al (1966), Fanger (1970), Rohles et al (1972) and Tech. Uni. Of Denmark (1972) in Denmark and the United States on different age groups (mean age: 21-84years). The results showed that older people do not appear to prefer different thermal environments to younger people. The lower metabolism in elderly people seems to be compensated for by a lower evaporative loss (Symposium, 1973). Collins and Hoinville (1980) confirmed these results (ASHRAE, 2009). For the above result, if older and younger people prefer the same thermal environments, this does not necessarily mean that the sensitivity of them to the heat/cold is the same. As for why the ambient temperature level of elderly people's houses is often higher than for younger people, it is because of their lower activity level (lower metabolism).

2.5.2.2 Gender (sex)

Gender is similar to age, according to Fanger in his review paper published in the book (Symposium, 1973) in which he has cited several experiments performed by Nevins et al (1966), Fanger (1967, 1970) and Tech. Uni. of Denmark (1972) on groups of people which consisted of an equal number of male and female subjects to compare the comfort conditions for the two sexes. The results showed that women and men prefer almost the same thermal environments. Women's skin temperature and evaporative loss is slightly lower than that for men because women have a lower metabolism (ASHRAE, 2009). The lighter clothing that women usually wear is the main reason for their demand for higher temperatures.

2.5.2.3 Adaptation (acclimatisation)

It is widely believed that by exposure to hot or cold surroundings for a certain period, people can acclimatise themselves to this new thermal environment. Several experiments have been performed by Nevins et al (1966), Fanger (1967, 1970), Olesen et al (1971), Rohles et al (1972) and Tech. Uni. of Denmark (1972) on groups of people (from different nations and geographical regions) from Denmark, the United States and tropical countries to investigate thermal conditions for them. The findings showed that there were only slight differences in the preferred ambient temperature and physiological parameters in the comfort conditions were reported for the various groups. The results indicate that people cannot adapt to preferring warmer or colder environments, and therefore the same comfort conditions can likely be applied throughout the world (Symposium, 1973, ASHRAE, 2009). (Nikolopoulou and Steemers, 2003) have thrown some light on the psychological adaptation which seems to become increasingly important for the thermal evaluation of outdoor spaces.

2.5.2.4 Seasonal and circadian rhythms

As it has been observed above, people cannot become adapted to prefer warmer or colder environments. This means that there is no difference between comfort conditions in summer and winter**.** This was confirmed by an experimental investigation conducted at Kansas State University, where the results showed there was no different result of thermal comfort votes between summer and winter (ASHRAE, 2009, Symposium, 1973)

Fanger has carried out an experimental study to determine the preferred ambient temperature for 16 subjects both in the morning and evening hours (FANGER, 1973,, Symposium, 1973, ASHRAE, 2009). The results stated that there was no difference observed**.** Moreover, Fanger found only small fluctuations in the preferred ambient temperature during a simulated eight hour workday (sedentary work). There is a slightly preference for warmer conditions before having lunch, but none of the fluctuations are significant.

2.5.3 Other factors

Fanger tried to investigate the effect of body build and weight, menstrual cycle, ethnic differences and food consumption on the thermal comfort. He stated that these factors were not significantly related to thermal comfort (Fanger, P. O, 1970).

2.6 Condition of Thermal Comfort: Heat Balance

The human body continuously generates its own heat. This metabolic heat can be categorised into two types: basal metabolism and muscular metabolism, the first one is continuous and non-conscious, the second is consciously controllable (except in shivering) (Szokolay, 1997, 2007).The deep temperature of the human body (core-temperature) is about 37°C, and is not influenced even by large variations in ambient temperature. However, the human body can only cope with temperatures between 35°C and 40°C (see Table 2-7).

Table 2-7: Summarises the critical body temperatures (Szokolay, 1997, 2007)

Skin temperature	**Deep body temperature**	**Regulatory zone**
Pain: 45°C	42°C	Death
	40°C	Hyperthermia
		evaporative zone
		Vasodilation
31-34°C	37°C	Comfort
		Vasoconstriction
		Thermogenesis
	35°C	Hypothermia
Pain: 10°C	25°C	Death

The produced heat by metabolic processes normally has to leave the body to the environment in forms of mechanical work and heat. The mechanical work may be external such as physical activities or intake such as heart beats, respiration, digestion, and brain activities. The human body temperature is a result of the balance between heat production and heat loss (Figure 2-3).

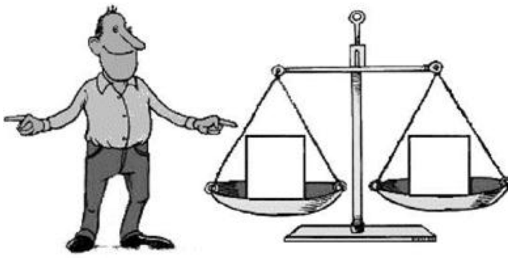


Figure 2-3: Heat produced in body = Heat lost from body

The body is continuously attempting to maintain a heat balance with its environment in spite of wide variations in the environmental condition. The body attempts to achieve thermal equilibrium with its surrounding environment through the following ways of heat exchange:

2.7 Ways of Heat Exchange between Human Body and Surrounding Environment

Thermal comfort is affected by heat conduction, convection, radiation, and evaporative heat loss.

2.7.1 Radiation

It is the method of heat exchange between the body and other objects through space without direct contact (e.g. the sun, heaters, buildings...etc). The heat energy transfers in the form of electromagnetic waves, or heat waves from warmer objects to cooler objects. People lose nearly half of their heat energy through radiation.

2.7.2 Conduction

It is the method of heat exchange (through solid material from molecule to molecule) by direct contact between the body and other objects when they are at different temperatures (e.g. heat passing through a metal bar). Heat transfers by conduction from the warmer to the cooler object. Only a small percentage of total heat exchange between the body skin and the environment takes place by conduction alone.

2.7.3 Convection

It is the method of body heat exchange with air. In other words, convection is the transfer of heat energy in a gas or liquid by the movement of currents. When the skin temperature is higher than the air temperature, the body transmits heat to the air (heat loss). But if the air temperature is higher than the skin temperature, the heat transmission is reversed (heat gain).

2.7.4 Evaporation

It is the method of body heat transmission to the environment by the evaporation of perspiration and by respiration. That means the heat loss from converting water from a liquid to a gaseous state. In more detail, the heat required to transform water to gas is absorbed from the body skin. The relative humidity of the surrounding air is the most significant factor in determining the extent of the evaporation of sweat. As stated above, the human body can gain or lose heat by one of the first three ways (radiation, conduction and convection) while evaporation is a way for heat loss only.

According to Robinson (1949),Gagge has presented his equation to express the process of heat exchange between the body and its environment as follows (H. R. Parsaei, 1993):

$$\pm S = M \pm CV \pm CD + R - E$$

Where:

S = heat storage (positive sign indicates heat gain, while negative indicates heat loss. If the heat balance is achieved, S = 0),
M = metabolic heat (always positive),
CV = convective heat (positive sign indicates air temperature is higher than skin temperature, and negative indicates the reverse case),
CD = conductive heat (positive when the contacting objects are warmer than the skin, and negative when the skin is warmer),
R = radiant heat (positive when surrounding objects are warmer than the skin, and negative when the skin is warmer), and
E = evaporative heat (always negative).

(Szokolay, 2008a) has provided the following graphic and equation to express the human body's thermal balance (Figure 2-4):

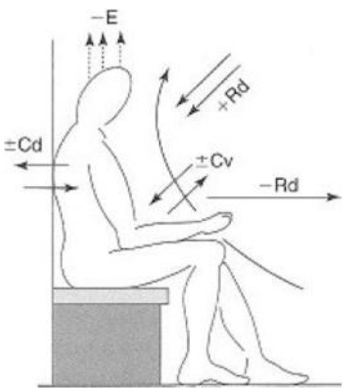


Figure 2-4: Heat exchange between the human body and its environment. Source (Szokolay, 2008)

$$M \pm Rd \pm Cv \pm Cd - Ev = \Delta S$$

Rd = net radiation exchange

Cv = convection (including respiration)

Cd = conduction

Ev = evaporation (including respiration)

ΔS = change in heat stored.

A condition of equilibrium is that the sum (i.e. the ΔS) is zero, but if ΔS is positive, the body temperature increases, if negative, it decreases.

2.8 Psychrometrics

Psychrometrics is the science of air/water vapor mixtures and the study of their thermodynamic properties. In other words, it is the science which investigates the thermal properties of moist air, considers the measurement and control of the moisture content of air, and studies the effect of atmospheric moisture on material and human comfort (Rajput, 2005). Psychrometrics is very important in many respects. It is very essential and fundamental for the analysis and design of heating, ventilating and air conditioning (HVAC) systems. It is also important to understand comfort zone and identify appropriate passive design strategies. Thus, understanding the main concepts and principles of psychrometrics is very important for mechanical engineers, architects and for all who are interested in these fields.

2.8.1 Psychrometric chart

The psychrometric chart is used to represent physical and thermal properties of moist air in a graphical form. It describes the different relationships possible between the various properties of moist air (variables). At present, several forms of the psychrometric charts are in use such as ASHRAE, CIBSE, Carrier and Mr. S K Wang. They differ with respect to range of temperature, barometric pressure, thermodynamic properties included and choice of coordinates. Mollier (enthalpy-humidity) type and Grosvenor (temperature-humidity) type were the most popular charts. The first diagram has always been used in Europe, while the second one has until recently been the most popular in the USA (Brooker et al., 1992). One of the widely used psychrometric charts is that of CIBSE (Hazlehurst, 2010). Figure 2-5, is a basic sketch of this chart that shows lines representing the chart properties.

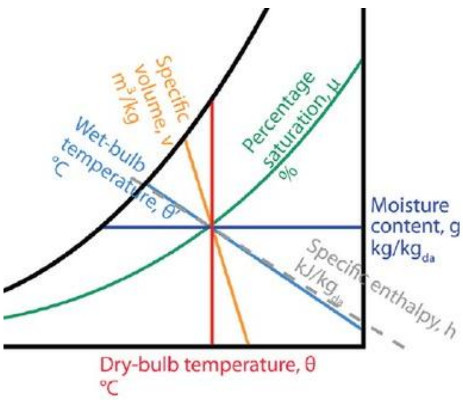


Figure 2-5: Properties lines of moist air on the sketch of the chart (Online: CIBSE Journal, October 2009).

As mentioned earlier, there are several types of psychrometric charts have been devised to show the graphical relationship between the various properties of moist air. Looking at CIBSE Psychrometric Chart as an example, it is produced on the basis of the relationship between vapour pressure and temperature, but the published chart shows moisture content against temperature as this is more useful to the user. This chart shows many moist air properties namely: dry-bulb and wet-bulb temperatures, moisture content, relative humidity (percentage saturation), specific volume and enthalpy (total heat), see Figure 2-6 . All these properties are regarded as independent properties. Only two of them must be known in order to use the chart.

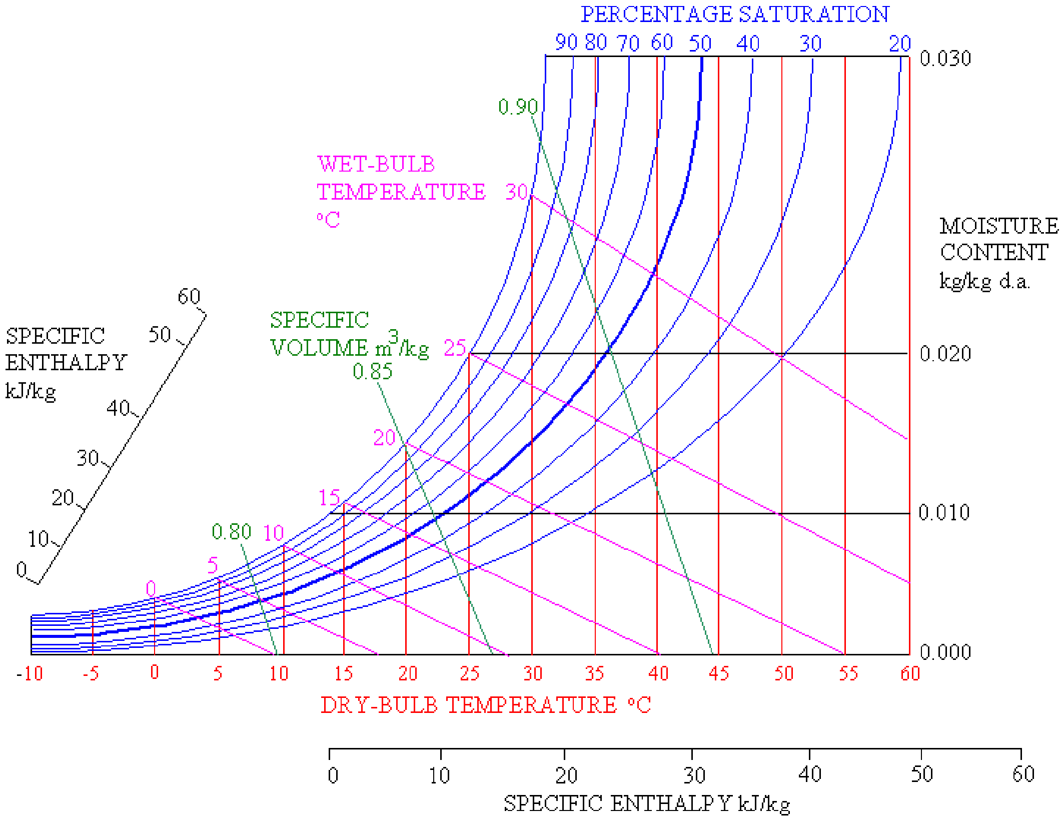


Figure 2-6: CIBSE psychrometric diagram (Source: Internet).

2.8.2 Properties on the Chart

The psychrometric chart describes the properties of the moist air through the following parameters, each of which is explained in more detail below:

2.8.2.1 Dry Bulb Temperature (DBT)

The dry bulb temperature (air temperature) is the basic temperature of the air-vapor mixture and is easily measured by a thermometer with a dry bulb in °C. Dry-bulb temperature is located on the horizontal, or X-axis, of the psychrometric chart and lines of constant temperature are represented by vertical chart lines (Figure 2-7). In general, the temperature range of these lines is from -10°C to 60°C.

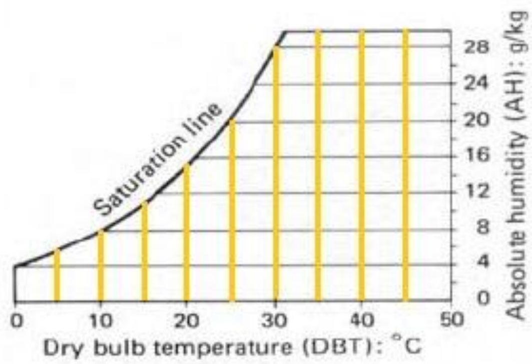


Figure 2-7: Dry-bulb temperature lines are plotted vertically at 5°C intervals (Source: Internet).

2.8.2.2 Percentage Saturation and Relative Humidity (RH)

Relative Humidity is the ratio of partial vapor pressure of an air-water vapor mixture to the pressure of saturated steam at the same dry bulb temperature, and is usually expressed as a percentage (Gupton Jr, 2001). The measurement of humidity can be done directly by an electric sensing hygrometer or a mechanical system. By using the psychrometric chart, the relative humidity can be determined from two readings of dry bulb temperature (DBT) and wet bulb temperature (WBT). The curved lines running from the lower left to the upper right of the psychrometric chart represent lines of constant relative humidity (Figure 2-8). They begin at the bottom at (10%) and end at the top with the saturation curve (100%).

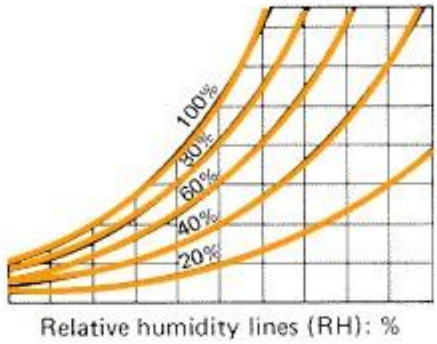


Figure 2-8: Relative humidity lines curve across the chart from left to right at intervals of 10% (Source: Internet).

2.8.2.3 Wet Bulb Temperature (WBT)

The wet bulb temperature (WBT) is a temperature measured by a thermometer whose bulb is covered by a wetted wick and blown by an air stream of sufficient velocity. This temperature represents how much moisture the air can evaporate. When the air is fully saturated, the DBT and WBT readings are identical and there is no evaporation. The wet bulb temperature scale is found along the curved upper left portion of the chart (the saturation curve). This temperature is indicated by lines are drawn diagonally from upper left to lower right at an angle of 30° from the horizontal axis as shown in the Figure 2-9 .

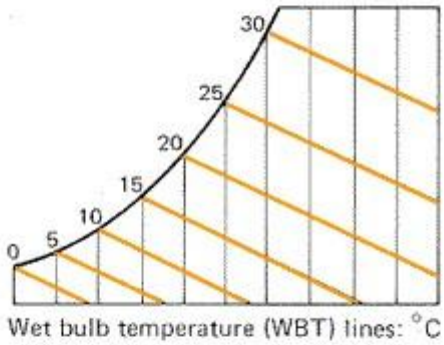


Figure 2-9: Wet-bulb temperature lines are indicated obliquely and fall almost parallel to enthalpy lines. They are shown at 5°C intervals (Source: Internet).

2.8.2.4 Moisture content (or humidity ratio, absolute humidity)

This is also known as the humidity ratio or absolute humidity. It is the amount of moisture in air given in grams (g) of moisture per kilogram (kg) of dry air or as a percentage. The moisture content (or humidity ratio, absolute humidity) is found on the vertical, Y-axis of the psychrometric chart, with lines of constant humidity running horizontally across the chart (Figure 2-10). Generally, moisture content range of these lines on psychrometric chart is from 0 to 30 g/kg of dry air (or from 0.000 to 0.030 kg/kg).

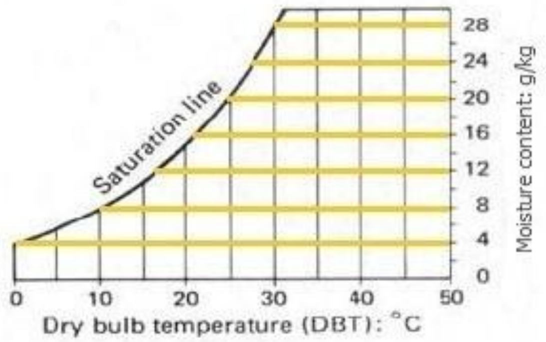


Figure 2-10: Moisture content values are plotted vertically along the right-hand margin, beginning with 0 at the bottom and extending to .03 at the top. They are shown at 1g (or 0.001kg) intervals (Source: Internet).

2.8.2.5 Enthalpy (total heat)

Enthalpy (H) is the heat energy content of moist air. This total air energy is the sum of both the dry bulb temperature of the air (sensible heat) and the vaporised moisture content in the air (latent heat) (Gupton Jr, 2001). Enthalpy is expressed in kilojoules per kilogram of dry air (kJ/kg) or Btu per pound of dry air (Btu/lb). Graphically, the lines of constant air enthalpy are nearly parallel to the wet bulb temperature lines, but values are read off separate scales. Lines of constant enthalpy run diagonally from the lower right to the upper left. The enthalpy scales are shown outside the body of the diagram. In general, enthalpy is widely used for making air conditioning assessments and calculations (e.g., heating, refrigeration and air conditioning design), and is rarely used in architectural context. For describing human comfort, wet bulb temperature is usually used to represent the energy content.

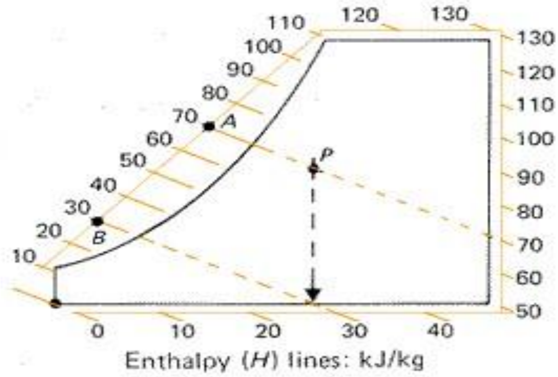


Figure 2-11: Constant enthalpy lines are plotted in oblique, at intervals of 5 kJ/kg of dry air (Source: Internet).

2.8.2.6 Specific volume (SV)

The specific volume (sv) is the volume of unit mass of dry air at a given temperature, normally measured in m^3/kg or ft^3/lb. This is the inverse of density (density is weight per unit volume: kg/m^3). The specific volume of air is affected by temperature, humidity levels and overall atmospheric pressure. It increases with increasing temperature. The more the moisture vapour present in the air, the greater shall be the specific volume. With increased atmospheric pressure, the greater the density of the air, so the lower its specific volume. Graphically, constant specific volume is represented on the psychrometric diagram by lines run at a steep angle from top left to bottom right (lines of constant specific volume have steeper slopes than those of wet bulb temperature and enthalpy), see Figure 2-12.

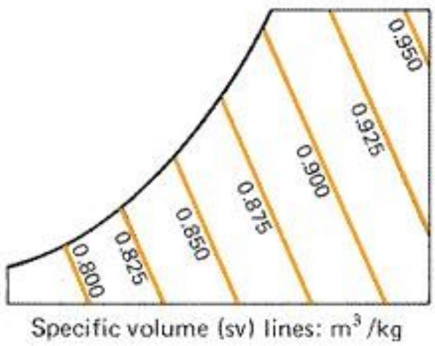


Figure 2-12: Constant specific volume lines (Source: Internet).

2.8.3 Measuring Psychrometric Variables (properties)

All psychrometric properties of air may be determined by knowing just two properties of moist air (three if barometric pressure is considered). The points of intersection of any two-property lines define the state -point of air. Once this point is located on the chart, the other air properties can be read directly. Usually the dry bulb temperature (DBT) and wet bulb temperature (WBT) are measured (by a hygrometer) and the others can then be read from the chart. For example, if the dry- and wet-bulb temperatures of air in a room at a specified pressure are given (20.0°C, 13.9°C, and 101.325kPa respectively). The other properties of this moist air may then be read directly from the chart. How?

Step1: find the intersection of the two known properties, dry-bulb and wet-bulb temperatures, on the psychrometric chart.

Step2: the dry-bulb temperature is located along the bottom horizontal axis. Find the line for 20.0°C, which runs vertically through the chart. Wet-bulb temperature is located along diagonal dotted lines leading to scale readings at the upper, curved boundary marked "saturation temperature".

Step3: the intersection of the vertical 20.0°C dry-bulb line and the diagonal 13.9°C wet-bulb line has now established a "state point" for the measured air.

Step4: from this state point determine read all of the other values as shown in :

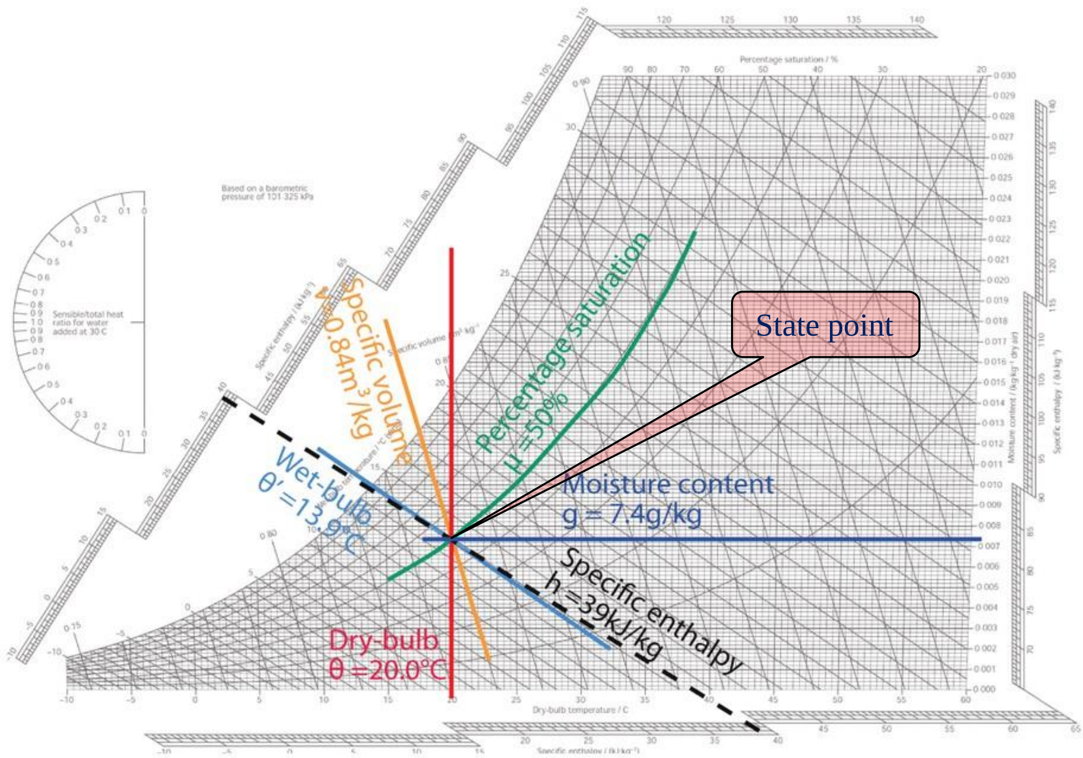


Figure 2-13: the state point is used to illustrate how to read other psychrometric properties (CIBSE Journal / online)

2.8.4 Using the psychrometric chart in thermal comfort

2.8.4.1 Comfort Zone

2.9 Review of Some of the Existing Studies and Research on Thermal Environments of Courtyards

Most of the human thermal comfort research done to date was about indoor conditions (Spagnolo and de Dear, 2003; Givoni et al., 2003). In recent years the research on thermal comfort in outdoor environments has received increased attention (Thorsson et al., 2007). Previous studies on outdoor thermal comfort were carried out in several regions with different climates around the world (Yahia, 2007). Many of these studies have been conducted in countries with a temperate climates, such as (Humphreys, 1977; Mayer and Hoppe, 1987; Gadilhe et al., 1993; Nikolopoulou et al., 2001; Nikolopoulou and Steemers, 2003; Picot, 2004; Gaitanis et al., 2005; Chatzidimitriou et al., 2006; Nicol et al., 2006; Nikolopoulou and Lykoudis, 2006; Nikolopoulou and Lykoudis, 2007; Gaitani et al., 2007; Bruse, 2009; Tseliou et al., 2010; Gulyás et al., 2006). Several studies also have been conducted in countries with a cold climate like (Nagara et al., 1996; Zacharias et al., 2001; Thorsson, 2003; Thorsson et al., 2004; Stathopoulos et al., 2004; Eliasson et al., 2007). Some of these studies were carried out in countries with a tropical climate like (Barradas, 1991; Lin et al., 2010; Krüger et al., 2011). Other studies have been done in countries with a hot dry climate such as (Meir et al., 1995; Fahmy and Sharples, 2009; Mayer, 2005; Toudert, 2005; Johansson, 2006; Yahia, 2007; Swaid et al., 1993).

Most of the previous studies on outdoor thermal environments were concentrated in temperate and cold climates in European and North American cities (Thorsson et al., 2007). In hot dry climates, the number of urban microclimate and thermal comfort studies into outdoor urban spaces is still small. It is mainly focused on urban canyons, (Pearlmutter et al., 1999, Al-Hemaidi, 2001, Bourbia and Awbi, 2004, Toudert, 2005, Johansson, 2006, Yahia, 2007), parks (Potchter et al., 2006, Mahmoud, 2011) and courtyards (Meir et al., 1995, Berkovic et al., 2012). In the Middle East and North Africa region, most of the studies in this field were conducted in Algeria, Morocco, Israel, Egypt and Syria. In Libya, the situation is different, all the published studies in thermal comfort field were about indoor environments (Ahmad et al., 1985, Ealiwa, 2000).

As it is explained in chapters four and five, this study has chosen public enclosed courtyards as case study sites. This is because the enclosed courtyard is the most-used open space type and architectural pattern in Libyan cities throughout all periods of the history. Therefore, this section presents a review of literature which focuses on urban microclimate and thermal comfort studies concerned with courtyards, and this includes number of previous experimental studies that have been conducted in wind tunnels, in-situ measurements and by using numerical modelling.

In the past most of the studies about courtyard building were mostly descriptive of the architectural features (Macintosh, 1973). With regard to thermal research on courtyards, most of the existing studies may be classified under three categories: field measurement, numerical simulations and laboratory tests. The following is a brief review of the work conducted in these directions:

(Meir et al., 1995) performed temperature monitoring inside two semi-enclosed courtyards with different orientations in the Negev desert in Israel during four representative days of summer, winter and autumn. They have found that their study results agree with some previous studies on enclosed courtyards on some points, including: first, improving microclimatic conditions in courtyards depends on controlled ventilation, as well as on controlled, dynamic shading. Second, the geometry of open spaces plays a crucial role in their thermal behaviour. Third, the correct orientation of semi-enclosed open spaces can improve their thermal behaviour, while orienting them irrespective of solar angles and wind direction may create thermal discomfort in them. In general, conditions may often be less comfortable within the courtyard than in the open surroundings.

(Al-Hemiddi and Megren Al-Saud, 2001a) studied experimentally the effect of a ventilated interior courtyard on the thermal performance of a village house located in an area around Riyadh, Saudi Arabia. The experiment was conducted in six phases during the summer of 1997. Each phase represented a different ventilation strategy (opening of an inner or outer window during the day or night, removing the courtyard's cover at night, a swimming pool with or without water). The results of this study showed that in the first phase, when the courtyard was not ventilated with open windows, the average courtyard temperature reached 34°C while the outdoor temperature was 33°C. This indicates that there was no significant cooling found during both day and night. In the second phase, when the courtyard was linked with the surrounding rooms, the average courtyard temperature reached 34°C while the outdoor temperature was 34°C, and this implies that there was no significant cooling effect of the ventilation in this phase. In the third phase, when the courtyard was ventilated during the night and not ventilated during the day, its daily average temperatures reached 34°C while the daily average outdoor temperature was 34°C. Thus, the ventilation at night has improved the performance of the courtyard by 2°C. This shows a better condition than the first and second phases. In the fourth phase, when the courtyard was ventilated 24 h a day, the average courtyard temperature was higher than the average outdoor air temperature by 1°C and same the average indoor temperature results. This means that there was a significant cooling effect of the nocturnal courtyard ventilation in this phase. In the fifth phase, when the courtyard was not covered and ventilation was provided during the night, the average daily courtyard temperature was almost the same as the average daily outdoor and indoor temperatures, about 32°C, and this shows there was a significant cooling effect of the nocturnal courtyard ventilation in this phase. In the sixth phase, when the courtyard was not vented and the swimming pool was eliminated, the average daily courtyard temperature was higher than the average daily outdoor temperature. This indicates that there was no significant cooling effect of the nocturnal courtyard ventilation in this phase. They concluded that the internal courtyard with a pool, tent and water spray during sunny hours provide a significant cooling effect for the internal spaces surrounding the courtyard. They also found that covering the courtyard by the tent during the day and opening it during the night provided significant lowering of the average courtyard temperature.

(Sharples and Bensalem, 2001) carried out a wind-tunnel study to investigate the airflow through courtyard and atrium building models. He found that an open courtyard in an urban area had a poor ventilation performance while an atrium roof with many openings operating under a negative pressure regime was the most effective. Changing the wind direction from perpendicular to the building façades to a 45º incidence angle had the effect of making the differences in the observed flows between all the models much smaller.

(Chatzidimitriou and Yannas, 2004) studied theoretically and experimentally the comfort in four urban blocks (courtyards) in the city of Thessaloniki, northern Greece. In this study, the measured data was used for the calibration of microclimate simulation software ENVI-met. They found that the microclimatic conditions are varied in and around urban blocks due to their spatial characteristics. They also found that the addition of vegetation and trees as well as the substitution of concrete pavement with soil and grass proved to have a warming effect in the winter and a cooling effect in the summer. Water pools have similar but milder effects on their immediate surroundings. Moreover, openings on ground level were found to increase airflow and temperature variation in summer, but revealed a negative effect in winter. Therefore all openings, even those not exposed to direct flow, need to be blocked in winter in order to prevent heat loss and incoming airflow.

(Shashua-Bar and Hoffman, 2004b) studied the cooling effect of shade trees in four green sites: two streets planted with trees and two canyon-type courtyards with some difference in planting density in Tel-Aviv, Israel. Two approaches were used in this study: one is empirical, using standard statistical tools (averages, regressions) applied to measurements in-situ, and the other analytical, using the "Green CTTC model". The cooling effect of trees (in both measurements and simulations) was defined as the difference between the air temperature at the site (with shade trees) and a reference point nearby (without trees). The cooling effect of trees in the two courtyards measured at 15:00 in July 1996 ranged between -2.47°C in the first courtyard and -3.26°C in the second. The cooling effect of trees was found to depend on the tree shade coverage and on the cluster geometry. The effect is reduced by deepening the cluster and by lowering the albedo of the surrounding walls.

(Muhaisen and B Gadi, 2006) studied numerically the influence of solar heat gain on the energy demand of courtyard building form with different proportions. They used a computer tool (IES) for the investigation and took Rome as an empirical background. They found that the solar radiation received by the surfaces of the courtyard is the major factor affecting its thermal performance. Moreover, the shading effect on increasing the required heating load in winter can be more significant than reducing the cooling load in summer. They concluded that the most efficient design for both winter and summer is to have a deep form to decrease solar radiation during the summer and to ensure minimum heat loss during the winter.

(Muhaisen and B Gadi, 2006) studied numerically the shading performance of polygonal courtyard forms (pentagonal, hexagonal, heptagonal and octagonal). The study revealed that the courtyard geometrical shape has a very small effect on the generated sunlit area in winter whilst in summer the influence is more remarkable.

(Muhaisen, 2006) has carried out a modelling study for assessing the shading performance of courtyard forms with different proportions in four different locations representing the climatic regions of hot humid, hot dry, temperate and cold climates. In this study, the results revealed that the deep and elongated courtyard forms achieve maximum internal shading area in summer, and this leads to less energy consumption. On the other hand, shallower courtyard forms allow a large amount of solar radiation to penetrate inside the courtyard and this, in turn, leads to less heating loads in winter. He concluded that the shading conditions of the courtyard's internal envelope are significantly dependent on the form's proportions, location latitude and available climatic conditions.

(Robitu et al., 2006) studied numerically and experimentally the comfort in summer in a real town square in Nantes, France. The model used in this study was to estimate the influence of trees and water ponds in the studied square. The comparison of the results between two situations, with and without vegetation and water pond, indicated that surface temperatures are reduced in the presence of trees and comfort is improved. Based on the results, trees and water ponds should be considered as real means for the improvement of microclimatic conditions in outdoor spaces.

(Biller, 2007a) studied experimentally (monitoring the microclimate of the courtyards) the overall performance of several existing courtyards in the old city of Beer-Sheva in Israel, during the hot and cold periods. From the comparison between the case study courtyards, she found a strong relation between the thermal behaviour of the courtyard and its treatment. She concluded that courtyard orientation plays a significant role in winter (e.g. a courtyard with northeast-southwest long axis and low southeast wall was much warmer compared to the rest of the courtyards) while in summer no effect was observed. In the hot season shading is essential in the courtyards (e.g. it is observed that the courtyards with more horizontal shade showed lower temperatures during the hot season. In the hot season also, it is observed that the monitored temperatures were significantly affected by courtyard surface treatment and materials.

(Aldawoud, 2008) studied numerically (by using a computer energy simulation programme DOE2.1E) the energy performance of a courtyard in buildings under the conditions of different factors. He used in his study weather data for four cities representing four different climatic regions of cold, temperate, hot humid, and hot dry climates. He concluded that the courtyard building was relevant in all climates, but it was more energy efficient in hot dry and hot humid climates than temperate and cold climates.

(Tablada et al., 2009a) have conducted field measurements and a limited comfort survey in three different types of residential courtyard buildings located in a compact urban area in the historical centre of old Havana, Cuba during the summer. The purpose of the study was to provide some preliminary design recommendations for residential buildings in old Havana. The results confirmed the importance of cross ventilation between a wide courtyard and the street, as opposed to single-sided ventilation through a narrow courtyard. The clear way to achieve cross ventilation is with a courtyard that is open to the exterior environment from both the top and the ground floor. This type of courtyard allows higher indoor ventilation rates in the buildings than the single narrow courtyard with only one opening from the top. An additional solar protection in wide courtyards is recommended. It concluded with the obtained comfort zone for summer conditions for the hot humid old Havana residential buildings which ranges from 24.7 to 30.7 ºC ET*.

(Moonen et al., 2011) have numerically investigated the effect of the ambient wind direction on the ventilation performance of idealised courtyards, characterised by five different length-to-width ratios. They used two simulation methods, steady (RANS) and unsteady (LES) in this study. The results showed that the amount of exchange between the courtyard and the urban boundary-layer is maximal when the angle between the incident flow and the principal courtyard axis is between 15 - 30º, regardless of the courtyard length. The 90º-case presents the lowest exchange rate. The normalised exchange flux increases with the increasing courtyard length, and approaches the optimum for courtyards with a length-toheight ratio of ten.

(Sadafi et al., 2011) studied numerically (by using ECOTECT software) and experimentally the thermal performance of terrace housing by exploiting internal courtyards located in tropical climate, Malaysia. The study suggested that the internal courtyard of a terrace house can affect improvements in thermal conditions of the courtyard’s surrounding spaces, provided sufficient and efficient openings with shading devices are suitably incorporated.

(Al-Masri and Abu-Hijleh, 2012) used a computer simulation (IES-VR commercial package) to study the impact of integrating a courtyard in the design of midrise buildings on the year-round energy consumption in hot and humid weather conditions of Dubai, UAE. The results from the simulation analysis indicate that the courtyard model performed better in terms of daylight factor on both winter and summer days than the conventional form. They concluded that the courtyard form in midrise buildings has the potential to save significant amounts of energy when used in climates similar to Dubai, UAE.

(Berkovic et al., 2012) studied numerically the outdoor thermal comfort in an enclosed courtyard during summer conditions by using the 3-dimensional microclimate model (ENVI-Met 3.1). In this study, Predicted Mean Vote (PMV) index was used to evaluate thermal comfort and three possible shading strategies (galleries, trees and openings) were examined. The researchers concluded that the outdoor comfort is mainly dependent on solar radiation, and therefore shading contributes to improving comfort while wind contribution was limited and much smaller than that of shade. Orientation is the most important factor in determining the amount of shade within the courtyard. The elongated E–W rectangular courtyard showed the least shade during summer, and is therefore the most uncomfortable. Compared with the conditions obtained in a closed courtyard, the air temperature and the radiation temperature have increased in the courtyard with openings because of the penetration of hot air and radiation through them. The addition of trees or/and galleries to the closed courtyard significantly improves the outdoor comfort.

(Yang et al., 2012) have developed a temporal 3D air and surface temperature model to understand the energy exchanges in an ideal courtyard in Beijing, China. In order to determine the relationship between design parameters and the micro-scale thermal environment of the courtyard, some parameters such as the courtyard geometry, and thermal properties of building materials were studied. They found that the urban structures and the solar radiation are the most important factors in determining the courtyard thermal environment during the winter and summer seasons. In this context, the thermal properties of the building walls showed an important role as well. The results also showed that the height of the courtyard has the most significant impact on the courtyard thermal environment, while surface albedo has the least impact.

2.9.1 Summary

The existing studies in this field have used several methods for assessing the thermal environment of courtyards such as field measurements, airflow wind-tunnel experiments, comfort surveys and simulations, but the most widely-used technique is computer simulation. In the following are some of the aspects that have been studied in these studies:

By using field monitoring: some aspects have been studied such as microclimatic behaviour of courtyards (Meir et al., 1995), the effect of the interior courtyard on the thermal performance of the buildings (Biller, 2007a), and the effects of airflow patterns on the thermal behaviour of a ventilated courtyard building (Al-Hemiddi and Megren Al-Saud, 2001a).

By using wind-tunnel experiments: some aspects have been studied such as the influence of outside wind on the airflows inside the courtyard and airflow patterns inside the courtyard for a wide range of courtyard forms and orientations (Al-Bakri, 1997, Hall et al., 1999, Sharples and Bensalem, 2001).

By using computer simulations: many aspects have been studied such as the thermal comfort in courtyards (Robitu et al., 2006), energy consumption energy savings and daylight levels in the courtyard and surrounding covered areas (Aldawoud, 2008, Al-Masri and Abu-Hijleh, 2012), the effect of courtyard proportions on solar heat gain and energy requirement (Muhaisen and Gadi, 2006), the thermal performance of a building by exploiting the internal courtyard (Sadafi et al.), the ventilation potential of courtyards (Moonen et al., 2011), calculating the shaded and sunlit areas in a circular courtyard geometry (Muhaisen and Gadi, 2005), the passive cooling effects of courtyards (Safarzadeh and Bahadori, 2005), the relationship between design parameters and the micro-scale thermal environment of the courtyard (Yang et al., 2012), the shading performance of different courtyard forms (Muhaisen, 2006), the effect of geometrical parameters on the irradiation load in courtyard (Berkovic et al., 2012), the absorption of solar energy in courtyards (Wang and Liu, 2002), the influence of courtyard geometry on air flow and thermal comfort (Tablada et al., 2005), airflow patterns and the thermal performance of courtyard buildings (Rajapaksha et al., 2003).

By using a combination of methods: a few studies have used a combination of methods such as field measurements, comfort surveys and computer simulations to study some aspects in this field, the aspects included the thermal environment of some types of courtyards (Wang and Liu, 2002), the impact of urban geometry on outdoor thermal comfort and air quality of courtyards (Tablada et al., 2009a) and the cooling effects of some parameters (shade trees and albedo modification) on the microclimate of courtyards (Shashua-Bar and Hoffman, 2004a).

In conclusion, the majority of the existing studies on the thermal environment of courtyards were carried out in regions with climates of hot dry, hot humid and temperate, where courtyards were and still are extensively used. In general, most of the studies reviewed above indicate that the courtyard geometrical shape and solar radiation are the most important factors in determining the courtyard thermal environment during hot and cold seasons. Openings on ground level were found to increase airflow and temperature variation in summer, but revealed a negative effect in winter. In the hot season, ventilation, shading, vegetation and water are important for improving the microclimatic conditions in courtyards, and therefore for the internal spaces surrounding the courtyard. The main conclusions from this literature review are:

- Most of the previous studies were about courtyard buildings particularly courtyard houses. In other words, these studies dealt with the thermal environment of the courtyard as a space can contribute to improving the indoor thermal conditions of the surrounding covered areas or as a private familial space, it can be used at specific times.
- Most of the existing studies on the thermal environment of courtyards have used computer simulations as a method, while questionnaire surveys were rarely used.
- Air temperature and air flow patterns are the most climatic parameters to have received considerable attention in the existing studies.
- The relationship between the microclimate, thermal comfort and the built urban form in courtyards is rarely considered in the existing studies while in other types of open spaces such as streets, it has received some attention.
- To the best of my knowledge, there were no studies about the microclimate and thermal comfort in courtyards during night-times.
- There are no published studies in Libya on the microclimate and thermal comfort in outdoor open spaces in general and courtyards in particular.

In general, although these topics have gained increased attention in North Africa, Middle East and Mediterranean countries in recent years, the situation in Libya is still far away from these countries. Thus, there is a need to study all the aspects related to thermal comfort in outdoor urban spaces in Libya. In that sense, this study seeks to start filling some of the gaps mentioned above by studying a particular type of courtyard that has not received any attention previously. This type combines the features of the courtyards and the public squares. It is not mainly designed to provide daylight and natural ventilation for the surrounding covered areas as a traditional courtyard does. It is a public open space, widely used by people all year round. It provides space and facilities for leisure, social interaction, business, cultural and other activities. In general, the study seeks to achieve a better understanding of the relationship between the microclimate, thermal comfort and the urban-built form in public enclosed courtyards in hot dry Tripoli during the cold season day-time and the hot season day/night-times.

2.10 Conclusion

This chapter presented an overview on thermal comfort, comfort factors, heat exchange, psychrometrics and existing work on the thermal environments of courtyards. The existing studies provided some general recommendations to improve the thermal environment of courtyards. Computer simulations are the most-used method for assessing the thermal environments of courtyards, while questionnaire surveys were rarely used. Most of the existing research dealt with courtyards as a space which may contribute to improving indoor environments. This study has selected a particular type from the courtyards (public enclosed) as a case study in order to study its thermal environment. The case study sites, research method, results, discussion and conclusions are presented in the following chapters.

3 URBAN OPEN SPACES

This chapter is about urban open spaces which is one of the main areas of this research. The purpose of this chapter is to provide the background for the theoretical framework for the study. First it introduces the main functions, importance and definitions of urban open spaces. Next to this, it presents the characteristics of public spaces. This is followed by a description of the needs in public spaces. The chapter concludes with open space typology with some focus on courtyards and their thermal behaviour.

3.1 Introduction

'Public space has been an integral part of cities throughout history, so much so that without it, human settlements would be unimaginable' (Madanipour, 2010).

The importance of open spaces to our environment and quality of life is increasingly being recognised (De Groot, 1992; Naveh, 1997; Ward Thompson, 2002; Chiesura, 2004, cited in Maruani, 2007, p.1). This importance lies in many different benefits and opportunities that open spaces can provide to people's everyday urban lives. Understanding the role that open spaces play in people's lives and why spaces are used or ignored is fundamental to have well-designed and managed open spaces. In other words, understanding the needs of space users and the ways that public spaces can function to serve these needs is the key to have successful public spaces.

3.2 Definition of Urban Open Space

'The definition of open space is more complex, and can involve factors such as culture, interest, scale, and type of activity' (Madanipour, 2010).

In reality, there is no general agreement on one term or definition (common definition) for open spaces at present. A range of terms and definitions regarding open spaces have been used by a variety of different researchers, thinkers, authors and professionals in many fields including urban planning, landscape architecture, geography, economics, political science, sociology and history. This variety of terms and definitions of open spaces correlates to the way that they are valued and viewed. Open spaces are often defined in relation to the variety of the functions and services that they provide. Many terms including green space, open space, open areas, public space, urban space and urban public spaces are the most commonly-used terms to describe open spaces because open space systems include aspects of each of these terms.

As mentioned above**,** the definitions of open spaces are different and vary from state to state according to the approach that has been used to viewing these spaces. For example, Zevi (1957, cited in (Madanipour, 1996) has adopted in his definition of urban space the geographical approach, where he stated that urban space is all space that is ‘left over’ and not enclosed. In the same context, Krier (1979) defined urban space as , ‘all types of space between buildings in towns and other localities’. However, some definitions speak to the physicality of open space such as Gold (1980 as described in Woolley, 2003) who has defined open space as land and water in an urban area that is not covered by cars or buildings, or as any undeveloped land in an urban area. Nevertheless, Tankel (1964)has suggested that open space is not only the land, or the water on the land in and around urban areas, which is not covered by buildings, but is also the space and the light above the land.

Open spaces can be also defined by their legal boundaries, as Newman (1972 in (Madanipour, 1996) has suggested, that open spaces can be defined as public, semi-public (such as school playgrounds), semi-private (such as courtyards near houses) and private (such as gardens and homes). Spinks, (2001) cited in (Sutton, 2008) also emphasises that urban spaces can be personal, private, public or mixed, and thus cannot be seen as isolated geographically, but rather as changeable according to individual circumstances.

Other definitions take community and social relations into consideration such as Carr et al. (1992) who defined public space as the common ground where people carry out the functional and ritual activities that bind a community. Madanipour (1999) goes further and defines public space as those areas within towns, cities and the countryside that are physically accessible to everyone, where strangers and citizens can enter with few restrictions. Public spaces can also be defined in relation to their functions and services. For example, Kit Campbell Associates, (2001) has defined open space as a generic term covering all non-built-up spaces within the boundaries of a village, town or city which provide, or have the potential to provide environmental, social and/or economic benefits to communities, whether direct or indirect.

In summary, as these definitions indicate, urban open spaces include all outdoor spaces in the urban matrix (natural or manmade) such as squares, plazas, (courtyards, piazzas), playgrounds, school yards, streets, open markets, sports areas, waterfronts, gardens, parks, woodlands, green spaces, cemeteries etc. Recently, other elements of the built fabric have been classified as open spaces such as terraces, roofs, balconies. Urban open spaces generally have good landscape (physical and visual elements), adequate services, engaging activities where people can sit, walk, talk, and meet others. Whether planned or found, they are usually open and accessible to the public.

3.3 The Importance and Functions (Benefits) of Open Space

‘Open space is an essential part of the urban heritage, a strong element in the architectural and aesthetic form of a city, plays an important educational role, is ecologically significant, is important for social interaction and in fostering community development and is supportive of economic objectives and activities. In particular, it helps reduce the inherent tension and conflict in deprived parts of urban areas in Europe; it has an important role in providing for the recreational and leisure needs of a community and has an economic value in that environmental enhancement, in which the improvement of open space plays a major part, assists the economic revival of cities, not just through creating jobs but in increasing the attractiveness of a city as a place for business investment and sought-after residential areas’ (Council of Europe, 1986 cited in (Woolley, 2003).

The importance of open spaces to our environment and quality of life is increasingly being recognised (Thompson, 2002, Chiesura, 2004, Maruani and Amit-Cohen, 2007). Whyte (1980) has described public spaces as the physical and metaphysical heart of the cities for their functions as channels for movement, nodes of communication and common ground for cultural activities. Open space has also been mentioned as the lung of a city for its environmental and ecological functions. Besides these functions, open spaces provide social psychological services, which are critical for the liveability of the city and well-being of urbanites (Chiesura, 2004).

Open spaces are not limited to provide such benefits only, but they can also offer a place to perform a variety of activities for all sections of the community such as social interactions, culture and political events, ceremonies, employment and investment opportunities, recreation, sport, playing, wildlife habitats and tourism. According to Yusrafarah (2009), great public spaces act as the living room of the city. He also sees the combination of beautiful architecture with great public space creating the most beautiful places to live. It is clear from is what mentioned above, that open spaces are a vital part of urban environment with its own specific set of functions which play an important role in our quality of life. (Ewan, 1999) stated that open spaces (natural or manmade) contribute positively to the quality of life in many ways.

3.4 Functions (Benefits) of Open Spaces

Many attempts and ways have been carried out to classify these functions (benefits), but four main groups including social, health and education, environmental, and economic are the most commonly adopted. The following classification of open space functions is mainly summarised from previous studies conducted by

3.4.1 Environmental and ecological functions include

- Improving urban air quality and ameliorating the physical urban environment by reducing pollution, moderating the extremes of the urban climate.
- Urban vegetation, and particularly trees, within open spaces can act as sinks for carbon dioxide and can contribute to energy reduction by providing shelter for buildings.
- Helping to soften the impact of development and making green and civic spaces more appealing.
- Well-designed networks of spaces help to encourage people to travel safely by foot or bicycle.
- Green networks and corridors linking spaces also promote biodiversity and enable the movement of wildlife.
- Providing habitats for wild plants and animals plays an important part in wildlife and habitat conservation.
- Wildlife habitats – finding places where plants and animals can live alongside the rest of us.
- Noise screening: reducing noise levels.
- Influencing the hydrological cycle storm water management (green spaces can also act as sustainable urban drainage systems).

- Biodiversity – improving the range and quantity of wild plants and animals.

3.4.2 Social and societal functions include

- Providing space and facilities for leisure, sport, play and recreation.
- Well-designed spaces can reduce opportunities for crime and the fear of crime.
- Facilitating social contact and communication for all sections of the community (contributes significantly to social inclusion).
- Provides neutral ground available to all sectors of society and can become the focus of community spirit through the many and varied opportunities provided for social interaction.
- Access to and experience of nature.
- Helping to promote active and healthy lifestyles by providing opportunities for exercise and involvement in social, cultural and community activities which are beneficial to people's physical and mental health.
- Open spaces provide opportunities for environmental education for local groups, schools and individuals.

3.4.3 Structural and aesthetic functions include

- They form a city fabric and its character.
- Articulating, dividing and linking areas of the urban fabric.
- Improving the legibility of the city.
- Establishing a sense of place and be a source of community pride. Acting as a carrier of identity, meanings and values.
- Can define the landscape and townscape structure and the character and identity of settlements.
- Providing visual relief from concrete and pavement (built environment) while preserving and protecting the county's natural and historical resources.
- Some open spaces can become landmarks within the urban setting which in turn help people in identifying their locations.

3.4.4 Economic functions include

- The quality of open spaces undoubtedly helps define the identity of towns and cities, which can enhance their attraction for living, working, investment and tourism.
- Well-designed and managed open spaces can raise the quality of business, retail and leisure developments, making them more attractive to potential investors, users and customers.
- Open spaces provide on-site economic benefits, such as the direct employment that parks, play areas and other open spaces can provide for local people and the opportunities for commercial operations such as public open markets, community orchards and city farms, which generate revenue through the sale of produce to local people and visitors.
- Open spaces can also provide off-site or indirect benefits, such as helping to increase the value and marketability of nearby property (house-buyers are willing to pay to be near green space) and to support tourism and other forms of investment.

3.5 Characteristics (Criteria For) of Public Space

Walzer (1986) defined public space as a space where we share with strangers, people who aren't our relatives, friends or work associates. It is a space for politics, religion, commerce, sport; it is space for peaceful coexistence and impersonal encounter. Its character expresses and also conditions our public life, civic culture, and everyday discourse (Abdulkarim, 2004). As this definition indicates, public spaces in urban environments can take a variety of forms from big squares and parks to the open spaces within the buildings where different types of activities (social, cultural, political, commercial, religious, leisure and sport) can take place. Each site of these open spaces has its own identity (individual characteristics, features and facilities) such as size, location, accessibility, landscape design and facilities which are subsequently reflected in the kind and level of service they offer to their users.

Many attempts have been conducted to identify the main elements that urban spaces should provide to their users. Most of these studies have focused on the main physical characteristics of public space, to study the context in which it is located, and the different types of interaction between these places and their users. For instance, Lars Lerup (1972) has proposed four sets of criteria to measure the degree of goodness in two public spaces in Stockholm. The first set is related to territoriality, safety, structure, continuity, comprehensibility, and predictability. The second set concerns the degree of convenience of the setting such as issues of service, responsiveness, comfort, and convenience. The third set measures the degree of information and excitement of the place such as issues of exploration, instruction, awareness, information, self-expression, contrast, variety, interest, choice, identity and privacy. The fourth set pertains to the social interaction of the setting and its publicness (Abdulkarim, 2004).

Similarly, Carr, et al. (1992) identified three critical human dimensions (users' essential needs, their spatial rights, and the meanings they seek) as basic components in the interaction between people and places. In other words, they believed that public spaces should be responsive, democratic, and meaningful and the main criteria are classified according to these three types of spaces:

- **Responsive spaces -** are those that are designed and managed to serve the needs of their users including: comfort, relaxation, active and passive engagement and discovery (all these needs are discussed in detail below).
- **Democratic spaces -** are those that protect the rights of user groups, being accessible to all groups and provide for freedom of action but also for temporary claim and ownership.
- **Meaningful spaces -** are those that allow people to make strong connections between the place, their personal lives, and the larger world.

According to what Carr, Francis, Rivlin and Stone highlighted, these three dimensions should guide the process of design and management of public space.

3.5.1 Creating successful public spaces

'Successful public spaces are characterised by the presence of people, in an often self-reinforcing process. They typically have animation and vitality, an urban buzz' (Carmona, 2003).

In this context, W. Sarkissian and B. Stenberg (2003) outlined some general principles (guidelines) for public open spaces as ‘people places’. These guidelines were adapted from the criteria established by Marcus and Francis (1998) for successful people places. They see that the open spaces in order to be truly ‘people places’ have to have the following:

- Are located where they are easily accessible to and can be seen by potential users.
- Clearly convey the message that the place is available for use and is meant to be used.
- Are beautiful and engaging both on the outside and the inside.
- Are furnished to support the most likely and desirable activities.
- Provide a feeling of security and safety to potential users.
- Are designed for the user groups most likely to use the space.
- Encourage use by different subgroups of the resident population, without any one group disrupting another's use and enjoyment.
- Offer an environment which is physiologically comfortable at peak usage times.
- Are accessible to children, older people and people with a disability.
- Are consistent with and support the programmes or activities intended to occur in the space.
- Incorporate elements which the users can add to, change or personalise, as appropriate.
- Allow for the attachment to and maintenance of the space by users (especially residents), as appropriate.
- Are able to be easily and economically maintained.
- Incorporate principles of ecologically sustainable design (esd) and minimise the use of scarce or non-renewable resources.
- Allow for the incorporation of public art and participation in public art.
- Promote the safety of all groups of users at all times.
- Where appropriate, offer relief from urban stress and enhance the health and emotional well-being of its users.

3.6 Needs in Public Space

Understanding the role that public spaces play in people's lives and why spaces are used or ignored is very important to ensure an effective design and management for these spaces. In other words, understanding the needs of space users and the ways that public spaces can function to serve these needs is the key to have successful public spaces. Carr et al. (1992) have stated that the specific reasons people are drawn to public areas is reflected in many aspects of life, especially urban life. Based on their research and case study sites, there are five types of reasons that seem to account for people's needs in public space namely: comfort, relaxation, passive engagement with the environment, active engagement with the environment, and discovery. According to Carr and others, comfort is a prerequisite for other needs to be met. As such, it is a basic need, and plays a vital role in determining how long people stay in urban spaces.

3.6.1 Comfort

Comfort is a basic need for people and an essential prerequisite to have successful public spaces. It is difficult to perceive how other needs can be met without comfort. Comfort is also a function and an indicator of the length of time people stay in a public space. Comfort is subjective and varies from person to person and between cultures. A sense of comfort includes environmental factors (relief from sun, rain and wind and access to sun, etc.); physical comfort (comfortable and sufficient seating including the orientation of the seating, seating for individuals and groups, seating that enables reading, eating, talking, resting and privacy, etc,) and social and psychological comfort (the space's character and ambience) which is a deep and pervasive need that extends to people's experiences in public spaces, related to a sense of security and safety. Comfort may be enhanced by design features (for instance, providing visual access into or out of the public spaces may contribute toward psychological comfort) and space management policies (in some cases, they can be used to ensure the security of users).

3.6.2 Relaxation

A sense of psychological comfort may be a prerequisite of relaxation, but relaxation is a more developed state with body and mind at ease. Relaxation is a combination of physical and psychological needs. Relaxation occurs when people engage not only in passive areas, but also in active and noisy ones. Relaxation can be enhanced by two factors: elements of respite or contrast to the adjacent urban fabric (the places that contrast with the surrounding urban setting can offer a high degree of relaxation), and the presence of natural elements, such as greenery, trees and water can also offer opportunities for relaxation. Moreover, separation from vehicular traffic often makes it easier to be relaxed, however, during low use times, separation from traffic flow may increase user concern about safety and security. In addition, people look for public spaces which provide repose and relaxation and offer a brief pause from the routine and business of city life.

3.6.3 Passive engagement

The need for passive engagement is also important. As Carr and others (1992) noted passive engagement with the environment could lead to a sense of relaxation but it differs in that it involves the need for an encounter with the setting, although without becoming actively involved. Sometimes, people enjoy watching the passive scene rather than talking or doing. Passive engagement activities involve observation of people, activities, nature, landscape, public art, waterfronts etc. Watching people is the first form of passive engagement; it is also the most popular activity in public spaces. For instance, in most public spaces, people like to choose sitting in places near the pedestrian flow in order to watch other people for enjoyment. Another kind of passive engagement is observing (watching) games and sport events in the parks and sport areas. There are several attractions (physical and natural features) that make people enjoy coming to public spaces such as trees, fountains, flowers, water etc. Another important attraction of public spaces is the opportunity to observe performers and formal activities such as concerts. Passive engagement also concerns the physical and aesthetic qualities of a site involving viewing public arts or a compelling landscape (it is an important aspect of the enjoyment of the public scene).

3.6.4 Active engagement

Active engagement represents a more direct experience with a place and people within it. People-watching is very popular activity in public spaces, In spite of this, many people like direct interaction with others. Public spaces provide a setting for socialising not only with strangers, but also with relatives, neighbours, acquaintances, and friends. Unusual elements like sculptures in plazas can provide opportunities for people, including strangers to talk to each other. Small squares or piazzas are another type of public space which encourages social interaction between strangers. However, in large public spaces, direct contact between strangers may be less. Streets and sidewalks are the most prominent among the other types of open spaces as a space for interaction especially in traditional and poorer (low-income) neighbourhoods. Quality of public life of the streets can be affected by many factors like pavement width, traffic of people, attitude of shopkeepers and residents.

Parks, gardens and children's play areas provide spaces for children and parents to interact with others. People also look for festivals, ceremonies and celebrations in their public spaces. Such atmospheres are important for people to rejuvenate their lives. Public markets provide people with active engagement with vendors and shopkeepers. Some people visit these market areas for shopping, but others are looking for engagement with diversity of sights, sounds and smells of quintessential urban spaces within these public spaces. Monetary investment is necessary to create public spaces fitted with special features that provide personal challenges for individuals like climbing walls. For this reason, the personal challenge which is freely available to all is often neglected as an aspect of active engagement in public spaces.

3.6.5 Discovery

Discovery is the last reason for people's presence in public spaces in Carr and his associates list. It is closely associated with exploration. In urban open spaces, discovery can be understood as the opportunity to observe the different things that people are doing when moving through a site. This means that the public space user or visitor can move around and discover parts of the place. Exploration depends on the diversity (variety) in the physical design of the spaces and the changing vistas.

For example, (design effect) changes in perspective offer a succession of vistas to enjoy. Lynch (1963 cited in Carr et al,, 1992) suggests in regard of the effect of design on the sense of discovery, that contrast and juxtaposition of elements can provide a sense of pleasurable surprise that people enjoy. Travel and tourism often meet the desire for discovery. For instance, going to new locations can offer opportunities to discover their special qualities, meet new people, find new challenges from landscapes that are in contrast with familiar ones. Public spaces can be designed to create a sense of discovery. Discovery also can occur at home under conditions in which elements of known places change. For example, bringing toys by kids to playground areas can provide new opportunities for amusement. Some of these can be done with the participation of individual users but the role of space managers to support and extend these opportunities for discovery is more important.

In summary, it is very important to meet people’s needs in urban spaces. Meeting these needs is not only important for user satisfaction, but it is also a key factor in determining the success of urban open spaces. In other words they provide reasons for human engagement in urban open spaces. This research will try to investigate thermal comfort within the selected sites and levels of satisfaction of their users. The design and management of public spaces often needs to accommodate these needs, while also handling any conflict between them. Table 3-1 shows some of the activities that potentially occur based on the needs in public space.

Table 3-1: The needs in public open space (adopted from Carr et al, (1992)

Need	Activity
Comfort	- Relief/access to sun/shade (environmental factors) - Airy/sheltered places from wind - Comfortable and sufficient outdoor furniture (seats) - Sense of security
Relaxation	- Liveliness and engagement with the life of a place - Quiet relaxing atmosphere
Passive engagement	- People-watching - Visual contact with people - Opportunity to observe performers and formal activities - Observe various physical features
Active engagement	- Direct contact with people - Socialising with others - Exercise of body and competitive desire - Manipulation of the elements
Discovery	- Observe different things through moving - Sense discovery by design

3.7 Open Space Typology

Classifying urban open spaces into types or categories has been conducted from time to time as a planning tool. The purpose of the typology of urban spaces is to provide a basis to help identify and understand varieties of urban spaces and their functions. The sources investigated in this review categorise types of open space very differently. Two types of urban open spaces – single-minded space and open-minded space – are suggested by Michael Walzer as cited in Woolley (2003). Single-minded spaces fulfil single functions (i.e. houses and car parks), on the other hand, open-minded spaces are multi-functional and participative such as squares or plazas where a variety of buildings provide a context of mixed use and where the space itself is more likely to be used for activities of a less hurried nature, such as watching, walking and talking.

Another typology of urban open spaces is suggested by Kit Campbell Associates, (2001). This typology is based on the principal use of the space. In this typology, urban spaces are divided into two groups, civic and green, each one of them is sub-divided into sub-categories. Civic spaces (non-green) are predominantly paved areas, mainly in town and city centres, while green spaces are normally or predominantly vegetated spaces but places the whole of open spaces within urban boundaries. Table 3-2 shows a summary of this typology of urban open spaces.

Table 3-2: Typology of urban open spaces, Campbell Associates, (2001)

<table>
<tr><th colspan="2">OPEN SPACE</th></tr>
<tr><td colspan="2">Any unbuilt land within in the boundary of a village, town or city which provides, or has the potential to provide, environmental, social and/or economic benefits to communities, whether direct or indirect</td></tr>
<tr><th>GREEN SPACE</th><th>CIVIC SPACE</th></tr>
<tr><td>A subset of open space, consisting of any vegetated land or structure, water or geological feature within urban areas.</td><td>A subset of open space, consisting of urban squares, market places and other paved or hard landscaped areas with a civic function.</td></tr>
<tr><td>Parks and gardens
Amenity green space
Children’s play areas
Outdoor sports facilities
Green corridors
Natural/semi-natural green space
Other functional green spaces</td><td>Civic squares
Market places
Pedestrian pavements/streets
Promenades and sea fronts
Courtyards</td></tr>
</table>

3.7.1 Courtyards

'Enclosed and attached courtyards are common architectural patterns throughout many periods of history and in many regions. They are often referred to in the professional and scientific literature as microclimate modifiers, which may improve thermal comfort conditions in the enclosed as well as the attached built volume. This statement may be correct only under certain conditions, and is subject to a number of specific requirements: the relative dimensions of open space and built volume, the treatment of exposed surfaces, and the orientation of the open space'. (Meir et al., 1995)

Courtyards are another form of open spaces that are used in most of the climates in many parts of the world. They have been used since at least 3000BC. The earliest civilisations in China, the Middle East, and North Africa all had courtyards (Keister, 2005). A courtyard can be defined as an outdoor space that is (open to the sky and) partially or fully enclosed (surrounded) by walls or buildings, adjoining or within a building. If the definition of courtyard is expanded somewhat to take in other enclosed spaces, it can include deep light wells and relatively shallow piazzas, largely enclosed squares and the private spaces (usually gardens) formed by outward-facing buildings set in squares. On this basis the enclosed square, courtyard or light well must be one of the most common features of the built environment (Hall et al., 1999).

Courtyards were developed mainly in response to climatic requirements. They offer a great opportunity to provide environmental control and improve the microclimate of the surroundings. In addition they offer visual and comfortable thermal conditions in adjacent buildings and consequently help to reduce or even avoid the reliance on conventional energy (Muhaisen, 2005). A courtyard as an open space within a building is a design element in most vernacular buildings and was originally used in the Mediterranean, Middle Eastern and tropical regions. Agreement between building geometry, enclosure, orientation, density of the building context and access to wind flow can carry considerable architectural implications in modifying the microclimate of the courtyards.

3.7.1.1 Courtyard types

Courtyards can be classified according to their shapes (forms), size and functions. Hyde (2000) has identified courtyards based on their degree of enclosure (Figure 3-1). He has classified them into three types, which are summarised as follows**:**

3.7.1.1.1 Fully-enclosed courtyards

This is normally found in deep-plan buildings to provide light, ventilation and visual amenity.

3.7.1.1.2 Semi-enclosed courtyards

They are formed as residual spaces from the interlocking of buildings that provide privacy, shade, and semi-enclosure.

3.7.1.1.3 Semi-open courtyards

They are formed from a building with a minimum enclosure. The courtyard space is normally open on one side, providing access for ventilation and opportunities for view.

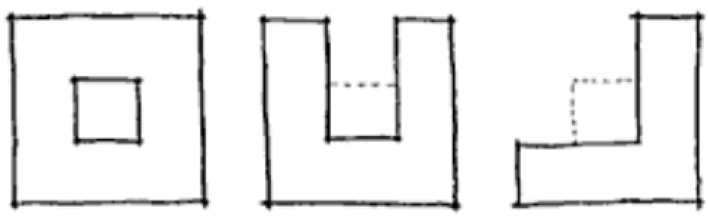


Figure 3-1: Types of courtyards: enclosed, semi-enclosed and semi-open (Hyde, 2000)

3.7.1.2 Orientation of the courtyard

The shape and orientation of courtyards can be determined by the surrounding streets and buildings and the sun path. Usually, one side of the courtyard at least is parallel with the street. This means the shape and orientation of the courtyard depends on the planning of the site in some cases. The orientation of the courtyard is different from region to region depending on the location and climate (e.g. in some regions, direct sunlight is favourable and in others is not). According to Reynolds, (2002) there is a huge variety of courtyard orientations in the old cities with no grid-pattern streets. Streets and courtyards in the newer gridded cities are often oriented to north-south, east-west or at about 45° of the cardinal points. The 45° orientation is considered as 'democratic' in terms of its sunlight distribution on the façades throughout the year. In short, it is difficult to determine which orientation is optimal for the courtyards. This depends on the case in which its functions inhabit the long or short sides, and whether winter heating or summer cooling is the greater problem.

3.7.1.3 Exposure of the courtyard (aspect ratio)

Studying the aspect ratio of a courtyard is used to measure its effectiveness in terms of environmental response. The aspect ratio of a courtyard is the degree of its openness to the sky. The greater aspect ratio would mean the courtyard is more exposed to the sky. This exposure permits the sun to warm the courtyard by day, the radiation to the sky to cool it at night-time and the entry of the wind (Reynolds, 2002).

$$Aspect\ ratio\ = \frac{area\ of\ the\ courtyard\ floor}{(average\ height\ of\ surrounding\ walls)^2}$$

Another aspect of comfort is the solar shadow index, which deals with winter sun exposure.

$$Solar\ shadow\ index = \frac{south\ wall\ height}{north - south\ floor\ width}$$

The greater the solar shadow index, the deeper the well formed by the courtyard, and the less winter sun reaches the floor, or even the north wall, of the courtyard.

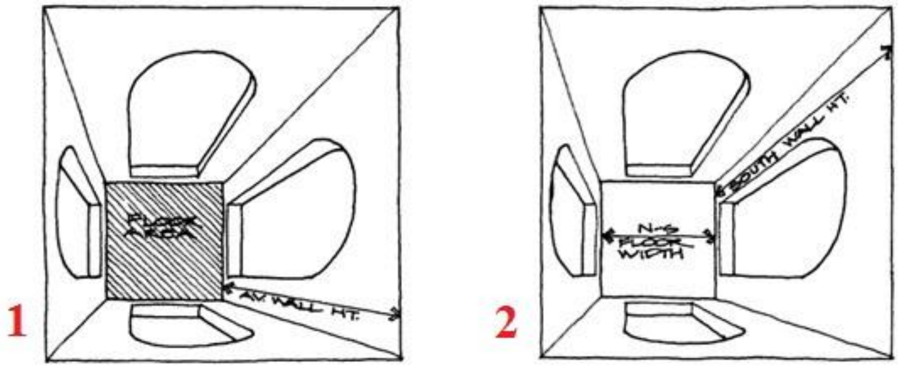


Figure 3-2: Bird's eye views of a square courtyard. 1) A high aspect ratio indicates greater courtyard exposure to the sky. 2) A high solar shadow index indicates more winter shadow on the courtyard's north face (Reynolds, 2002).

3.7.1.4 Thermal behaviour of the courtyard

The courtyard as a service space can potentially bring environmental benefits if this space and the surrounding servant spaces maintain favourable environmental conditions for thermal comfort. This depends on the appropriate control of heat transfer in the courtyard. The thermal performance of a courtyard comprises heat exchange processes that occur between the environments of three interconnected spaces: the indoor space (servant spaces), the courtyard and the external open space (outdoor microclimate) (R. Hyde, U. Rajapaksha, (2005). Figure 3-3 shows the heat exchange (heat transfer) between a courtyard and the outdoor microclimate and a courtyard and servant spaces.

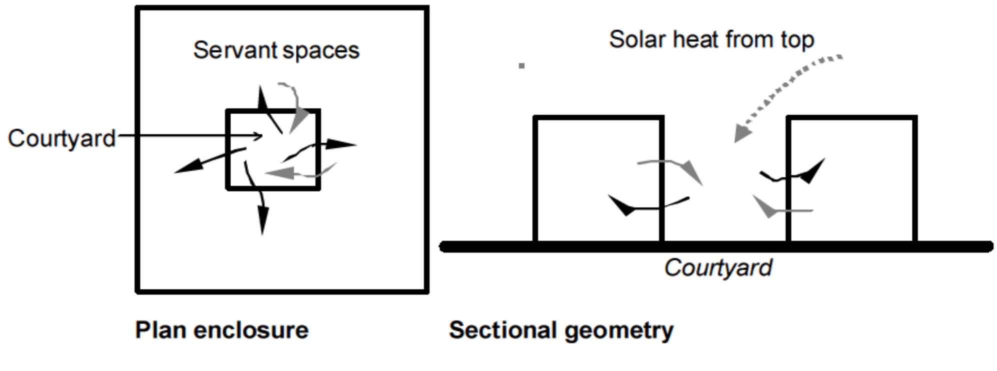


Figure 3-3: Heat transfer in a fully-enclosed courtyard building (HYDE, 2005)

Heat transfer processes between the courtyard, its adjacent servant spaces and the outdoor environment can be regulated between the effects of the airflow, thermal mass and passive solar (solar penetration). R. Hyde and U. Rajapaksha (2005) have also stated that airflow has an essential effect on the thermal environment of the courtyard. It promotes the comfortable cooling of users, structural cooling, controlling of overheating and the removal of solar heat out of the building interior. Airflow is caused to move through buildings by either a wind pressure effect or stack effect, which can be regulated by the wind permeability of the geometry and the wind permeability of the enclosure.

A semi-enclosed courtyard helps to increase the ventilation process within the courtyard and attached servant spaces. The movement of air through the building increases pressure fields around the building, creating high-pressure zones at the openings in the enclosing envelope. Thus, cross ventilation can take place from outside to the courtyard. Figure 3-4 explains how the wind permeability of the enclosure promotes upwind airflow.

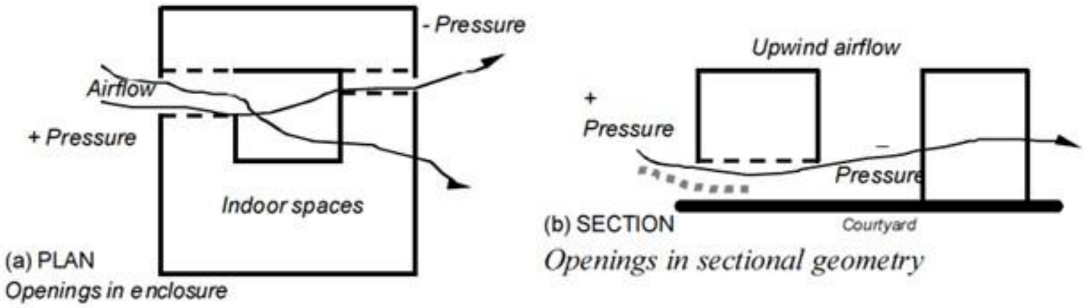


Figure 3-4: Semi-enclosed courtyard as an air funnel, wind permeability of plan enclosure and sectional geometry affecting upwind airflow (HYDE, 2005)

In the hot dry climates, the courtyard promotes the cooling of the surrounding spaces (servant spaces) in summer through the thermal process of convection and radiation (Figure 3-5). After sunset, the cool night air comes down into the courtyard and fills its area and seeps into the surrounding spaces, cooling them. The courtyard loses heat by irradiation to the night sky. This allows the courtyard to remain cool until the late afternoon. Around noon time, the sun shines directly into the courtyard floor. Some of the cool air begins to rise and also leaks out of the surrounding areas. The air in the courtyard begins to be gradually heated until the courtyard floor and the inside of the surrounding spaces get warmer and further convection currents are set up by the late afternoon. In the evening the warm air in the courtyard which was heated by the sun during the day, rises up and is gradually replaced by cool air above and so on.

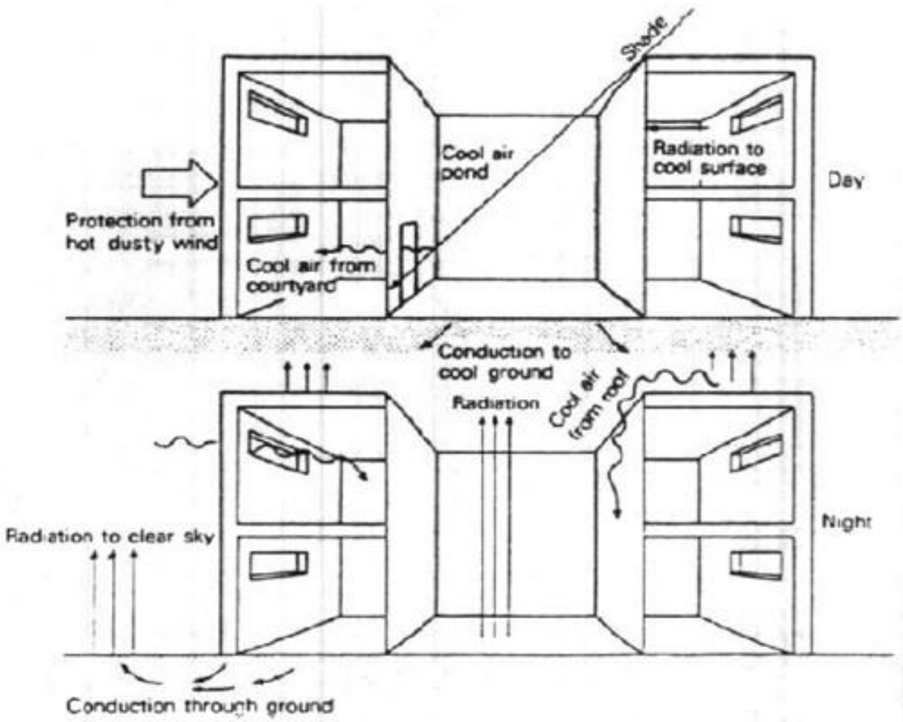


Figure 3-5: General scheme of the courtyard thermal behaviour (Scudo, 1988).

The courtyard has another function which is providing shade in summer through its physical form and the dimensional proportion of its length, width and height. A partly-shaded area of the courtyard floor can be achieved most of the day by using the appropriate proportion and orientation. As it has been mentioned above, a semi-enclosed courtyard or an enclosed courtyard with openings helps to increase the ventilation process within the courtyard and the surrounding spaces. The courtyard can also pull natural daylight into the building.

In short, the courtyard building moderates climatic conditions and creates its own microclimate. It is cool during the day when the outdoor temperature is high and warm at night when it is low. The thermal behaviour of the courtyard building can be further enhanced by calibrating the internal temperature, humidity and light towards a desired result. The calibration can be achieved by the form and proportion of the courtyard; by the size, type and colour of the garden plants; by the type, colour and extent of the paving; by the colour and treatment of walls; and by the degree of plant cover on walls (Muhaisen, 2005).

3.8 Conclusion

This chapter presented an overview of the definition, importance and functions of urban open spaces. It also discussed the criteria for public spaces and users' needs in these spaces. In addition, it gave a brief overview on the typology and types of open spaces in order to illustrate the differences between them. More focus was on the courtyard which is the open space type that is selected as a case study in this research. This is because it is the most widely-used open space type and architectural pattern in Libyan cities throughout many periods of the history. The main conclusions from this chapter are:

- The study highlights the importance of open spaces to the people and cities.
- Comfort is a basic need for people and an essential prerequisite to have successful public spaces.
- Courtyards were developed mainly in response to climatic requirements. They are generally referred to in scientific literature as microclimate modifiers.

The last statement may be correct under certain conditions. It is one of the main motivations of the present study, which seeks to contribute towards a deeper understanding of the thermal comfort and microclimatic behaviour of enclosed courtyards. The impacts of the elements of the urban-built form on courtyard microclimate are discussed in more detail in chapter 7.

4 CASE STUDY

This chapter gives a brief overview about Libya and its capital Tripoli which has been selected as a study area in terms of geography, climate, and types of climate, climate elements, location, population and main regions. It also discusses the background of the case study sites and concludes with a comparison between their general physical descriptions.

4.1 Libya (Study Area)

4.1.1 Location, area and population

Libya is situated in North Africa and approximately lies between latitudes 20°N and 34°N and longitudes 9°E and 25°E. It has a Mediterranean coast of about 1820 kilometres. Libya is bounded by the Mediterranean Sea to the north. Egypt lies to the east, Sudan to the southeast, Chad and Niger to the south, Algeria to the west and Tunisia to the northwest (Figure 4-1).

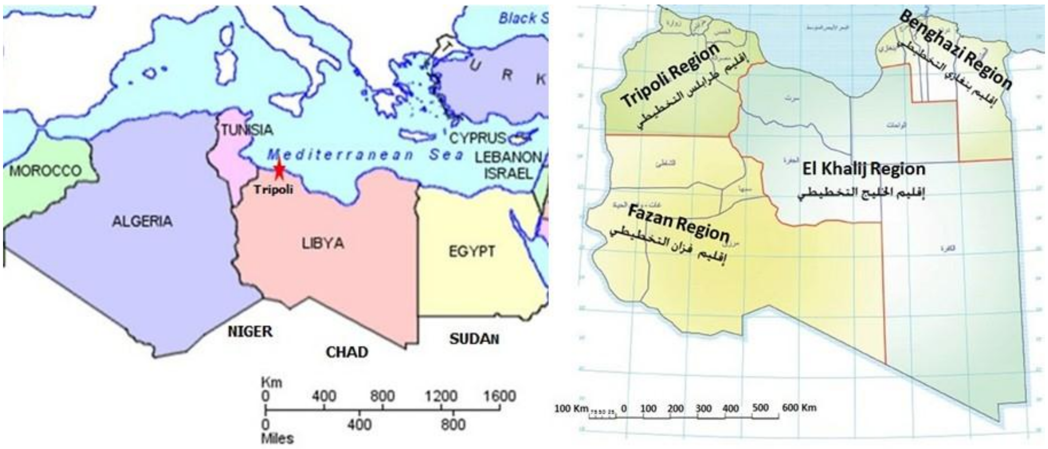


Figure 4-1: Libya; location and regions (Source: Internet)

Libya occupies an area of about 1,760,000 square kilometres and is fourth in size among the countries of Africa and seventeenth among the countries of the world. The population of Libya is about 6,971,000 inhabitants (2010 estimates, National Authority for Information and Documentation; NAID). About 85.2% of the total population is concentrated in the northern provinces. Libya is divided into four main planning regions, which in turn are divided into 18 sub-regional planning areas. The four main planning regions are: Tripoli region in the northwest of the country, Ben Ghazi region in the northeast, Fazan region in the southwest and EI Khalij region, located in the centre of the country and extending to the southeast (**Error! Reference ource not found.**).

4.1.2 Climate

Libya based on its location between 20° to 34° N lies in a sub-tropical climate. Five different climatic zones have been recognised in Libya, but the dominant climatic influences are the Mediterranean and Sahara (same-arid and arid).

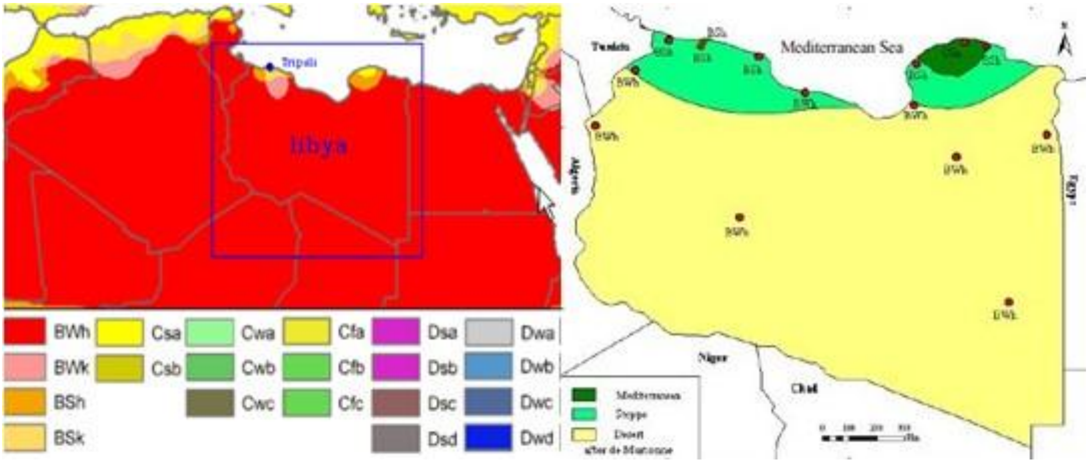


Figure 4-2: Climates of Libyan based on the Köppen classification (Source: Internet)

The most widely used climate classification is that of Köppen. The German botanist and climatologist Vladimir Köppen developed his classification system from 1918 to 1936. He used vegetation and temperature as a natural indication of the climate of the regions. According to this classification system, Libya has been classified into three main sub-categories (

Figure 4-2), namely:

- **Mediterranean climate** (Csa): This type of climate covers a part of Al-Jebal Al-Akhdar at the north-east of Libya and a tiny area around Tripoli city at the north-west of Libya. It is in general characterised by warm to hot, dry summers and mild to moderately cold winters with some modest rainfall ranges between 300 mm and 550 mm. In the north-east highlands (Al-Jebal Al-Akhdar mountain), the climate is characterised by moderate cold winters with snowfall in some years.

- **Sub-tropical steppe climate** (BSh): This type of climate covers most of the coastal and western highlands. It is characterised by a hot semi-arid climate with Mediterranean (Csa) influences. Annual rainfall usually ranges from 100 mm to 350 mm. The moderating influence of the Mediterranean Sea helps to keep temperature relatively low during summer in these areas.

- **Hot desert climate** (BWh): It is characterised by being hot and arid (very dry) year-round. This type of climate covers most of the mid and southern Libyan lands where the mean temperature is above 18°C all the year. It is also characterised by high temperature variations between the day and night during winter (night-time temperatures can drop to freezing or below).

4.1.3 Climate elements

4.1.3.1 Temperature

In general Libya has hot dry summers and mild winters with mean annual temperature ranges between 10.3 and 21.6°C (Ageena et al., 2012). Many geographical factors such as latitude, altitude, and distance from the sea can affect climatic conditions and their annual ranges. Table 4-1 shows the mean annual and seasonal temperatures (1946-2000) for a group of Libyan cities with different geographical features.

Table 4-1: Mean annual and seasonal temperatures for some Libyan cities (1946-2000) (Source: LNMC)

Station Site (City)	Latitude N.	Elevation (m)	Annual (°C)	Winter (Dec-Feb) (°C)	Summer (Jun-Aug) (°C)
Zuara	32.53	3	19.8	13.3	25.8
Tripoli	32.54	25	20.2	14.0	26.4
Sirt	31.12	13	20.5	13.4	25.5
Shahat	32.49	621	16.5	10.1	22.8
Ghadames	30.08	357	21.9	11.8	31.4
Jaghboub	29.45	-1	21.3	12.9	28.8
Sebha	27.01	432	23.4	12.8	30.6
Al Kufra	24.13	436	23.3	14.2	30.8

According to the data gathered from the Libyan National Meteorological Centre (LNMC), distribution of the average annual temperatures for the period 1946-2000 in Libya increases from the north towards the south (the lower temperatures toward the Mediterranean Sea in the north, whereas the higher temperatures toward the desert in the south). The above table shows that the mean annual temperatures in the coastal cities in the north are in Shahat 16.5°C and Zuara 19.8°C, while in the middle are 21.3°C in Jaghboub and 21.9°C in Ghadames, then in the south are 23.3 °C in El-Kufra and 23.4 °C in Sebha.

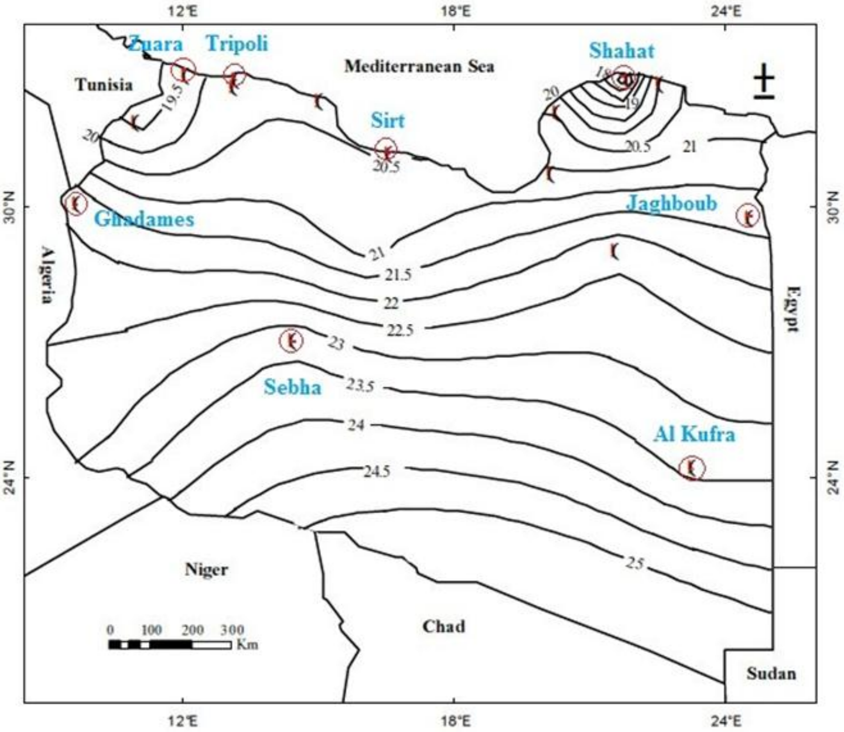


Figure 4-3: Distribution of the mean annual temperatures in Libya, 1946-200 (Source: LNMC)

Winter season in Libya is from December to February. During this season the weather is wet and mild to cold in the north and dry and warm to hot in the south (desert). The general pattern of the mean temperatures in this season is different from that of summer. As indicated in the Figure 4-4, the mean winter temperatures gradually decrease towards the north, but at the coastal cities, the temperatures rise again due to the influence of the Mediterranean Sea. This can be seen clearly through this example, in Sebha ain the south, the main winter temperature was 12.8°C, whereas in Ghadames in the middle was 11.8°C, then at the coast, was 13.4°C in Sirt, and 14.0°C in Tripoli.

As for the summer (June to August), the climate in Libya is usually dry with high temperatures. As shown in Figure 3-5, the mean summer temperatures in Libya (1946-2000) generally increase towards the south. The mean temperatures reach the

30s in the south (30.8°C in Al Kufra and 30.6°C in Sebha) and it reaches the high 20s in the middle (28.8°C in Jaghboub) whereas, it reaches the low and mid-twenties in the north (22.8°C in Shahat, 25.8°C in Zuara and 26.4°C in Tripoli).

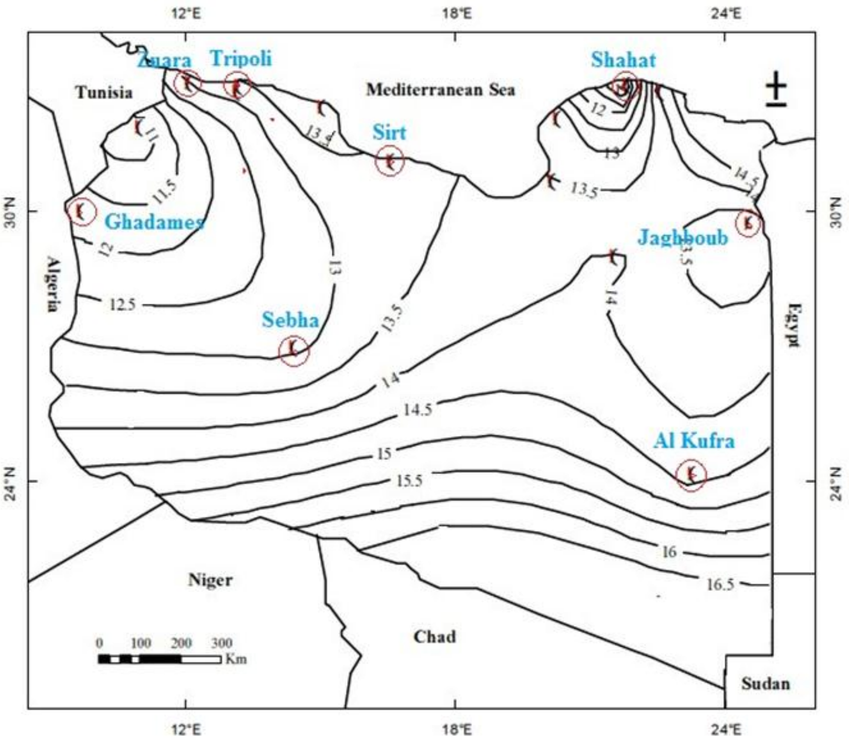


Figure 4-4: Distribution of the mean winter temperatures in Libya, 1946-2000 (Source: LNMC)

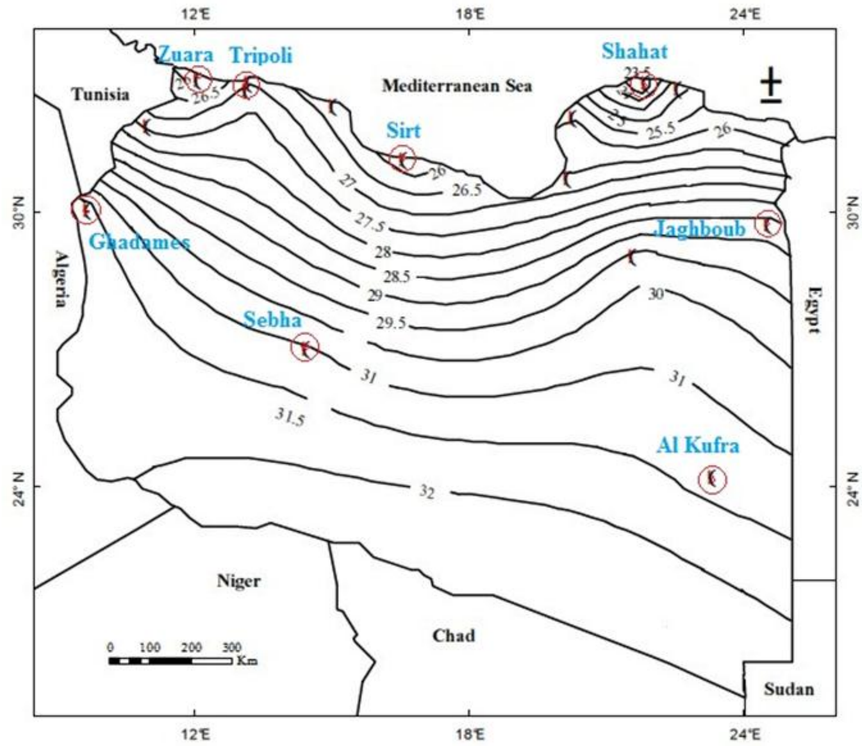


Figure 4-5: Distribution of the mean summer temperatures in Libya, 1946-2000(Source: LNMC)

Generally, as shown in the figures above, the general pattern of the mean temperatures increases towards the south. There's only a small difference in winter as the mean temperatures in the south and middle of Libya are lower than in the north, because of the great variation between day and night temperatures in the desert. Day-time is very hot and night-time is very cold and as well, the temperatures can drop to freezing or below. Moreover, the ranges of mean temperatures between summers and winters are high in the southern cities more than those in the north.

4.1.3.2 Precipitation

The precipitation in Libya varies from place to place and from season to season. As shown in Figure 4-6, the mean annual rainfall ranges from 0mm in the south of Libya to 500mm in the north. This distribution can be clearly seen through the mean annual rainfalls of some cities located in different regions: in the south it was 2.1mm in Al Kufra and 9.0mm in Sebha, while in the middle it was 15.8mm in Jaghboub and 31.9mm in Ghadames, whereas in the north it was 238.6mm in Zawara, 335.9mm in Tripoli and 559.3mm in Shahat. In general, most of the rain falls along the coastal area and it decreases towards the south, and falls mainly during the period from October to March, with December and January being the rainiest months of the year. In other words, about 95% of the area of the country receives less than 100mm per year (Ageena et al., 2012). The other feature of precipitation in Libya is snow which can fall sometimes on the mountains in the north-east and north-west.

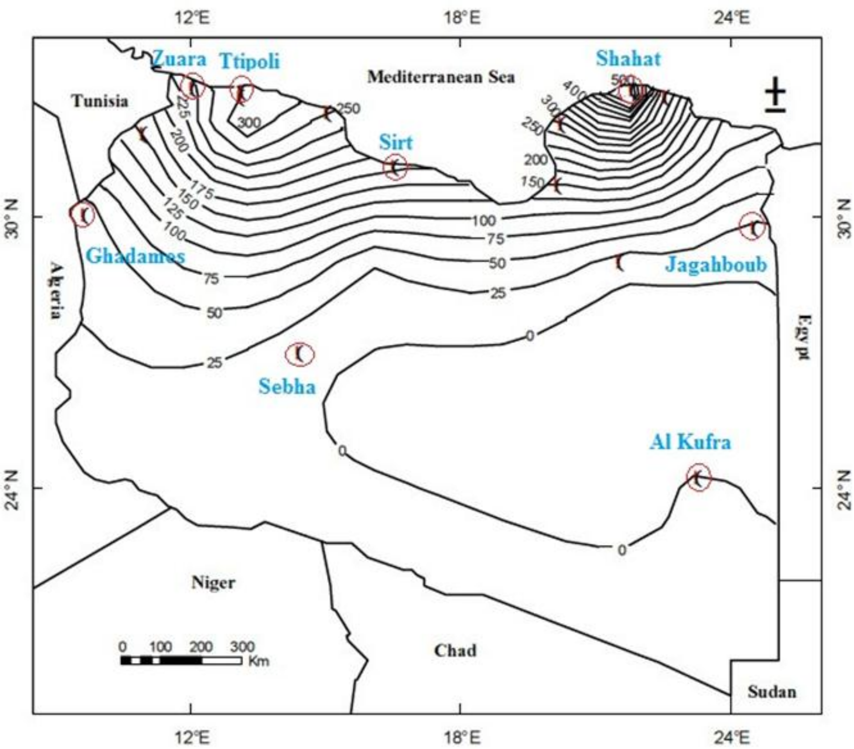


Figure 4-6: Distribution of the mean annual rainfall in Libya, 1946-2000 (Source: LNMC)

4.1.3.3 Relative humidity

As can be seen from the data in Table 4, the mean annual relative humidity along the coast is generally between 65-75% while in the middle between 40-50% whereas in the south below 35%. In most areas of the coastal zone, the relative humidity increases during the summer months and decreases during winter, while in the desert it is the opposite. Moreover, the variation in relative humidity between summer and winter in the desert is higher than that in the coastal zone. In general relative humidity increases towards the coast because of the effect of the Mediterranean Sea, Table 4 shows the mean annual and seasonal relative humidity (1946-2000) for a group of Libyan cities located in different regions.

Table 4-2: Mean annual and seasonal relative humidity for some Libyan cities (1946-2000) (Source: LNMC)

Station Site (City)	Location	Annual (%)	Winter (Dec-Feb) (%)	Summer (Jun-Aug) (%)
Zuara	on the coast	73.1	70.7	76.2
Tripoli	on the coast	64.8	62.5	63.5
Sirt	on the coast	70.4	68.3	74.7
Shahat	on the coast	68.9	76.1	63.8
Ghadames	in the middle	33.8	48.7	22.2
Jaghboub	in the middle	48.2	59.9	40.2
Jalo	in the middle	45.2	56.2	37.7
Sebha	in the desert	33.9	46.7	22.2
Al Kufra	in the desert	29.3	41.6	21.7

4.1.3.4 Wind

Wind is an unstable parameter but it is generally described by the direction from which it blows and the levels of speed. In Libya, the prevailing winds are the cold often from the west to the northwest between November and April. The hot dry dusty wind (Ghibli as known locally) usually blows across the desert from the south and southeast within the period late March to mid-May and may reach the coast during any season. From May to October almost all winds blow from the north and east.

4.1.3.5 Cloud cover

In general, Libya is not a cloudy area. Coastal areas in the western and eastern regions experience a high percentage of cloud cover in the country. Usually, the maximum cloudiness occurs during the winter months. As indicated on the Figure 4-7, the general distribution of the mean annual percentages of sky obscured by cloud cover during the period 1946-2000 varies from about 32% in the northwest of Libya to about less than 22% in the southwest. The local maximum of mean annual cloud cover (32%) is situated just around the city of Tripoli. The Libyan/Algerian border area of the Fezzan desert appears as an area of minimal cloud cover. In summary, there is a general pattern of decreased cloud cover towards the south and from east to west (El-Tantawi, 2005).

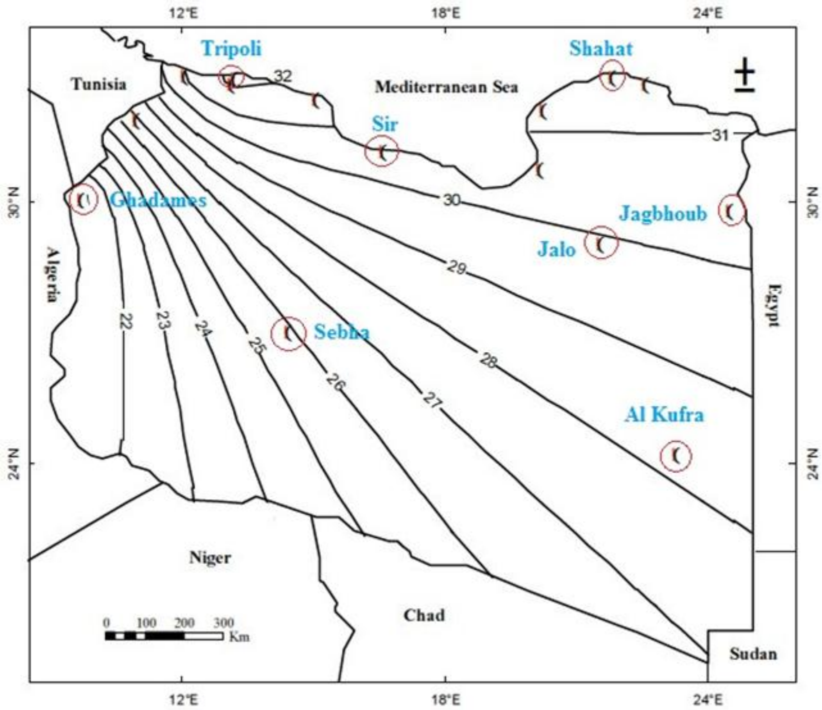


Figure 4-7: Distributions of the mean annual cloud cover in Libya, 1946-2000 (Source: LNMC). Units for cloud cover distributions are percent of sky obscured.

4.1.4 Other climatic considerations

4.1.4.1 Climate Change

Climate change has come to be recognised as one of the most critical challenges ever to face human-kind (UNFCCC, 2007). Climate change has now become a major global issue that affects not just the environment but all aspects such as economy, health, social system, national security, etc. The causes of climate change can be divided into two categories, human and natural causes (Climate Change online). One of these causes is human activity, which since the industrial revolution has increased the amount of greenhouse gases in the atmosphere, which in turn has led to more global warming. Other causes of climate change are natural ones such as volcanic eruptions, ocean currents, the earth's orbital changes and solar variations. As a result of these factors (natural and human), the world's climate has been (and is still) changing. Most of the observed changes in climate include increases in global temperatures and changes in rainfall patterns, snow and ice cover, and sea level.

Cities around the world contain over half of the world's population (Cohen, 2003). This number will continue to grow and the urban population is expected to reach 70% of the global population by 2050 (Butler, online). Cities are responsible for 80% of greenhouse gas emissions and consume 75% - 80% of the world's energy (Doytsher et al., Dodman, 2009). This significant contribution of urbanisation in climate change makes many cities around the world, particularly in the developing countries, on the front line of climate change impact.

4.1.4.2 Climate Change in Libya

As known, Libya is located in North Africa on the south coast of the Mediterranean region. This region as many other regions around the world is very vulnerable to the effects of climate change. During the 20th century, significant changes were observed in the Mediterranean climate such as an increase in temperature (warming) and a decrease in precipitation (Giorgi, 2002; Dunkeloh, 2003; Manalotte-Rizzoli, 2004; Giannakopoulos et al.; Medany, 2008; Brauch, 2010). Moreover, an increase in the rate of sea-level rise has been noted (observed) particularly in the east part of the Mediterranean basin (Cazenave et al., 2002). As for the future, Petit et al (2005) have highlighted that 'the Mediterranean basin is expected to be more strongly affected by ongoing global climate change than most other regions of the earth'. In this context, many studies, projects and climate models expect significant increases in temperature and a decrease in precipitation in this region by the end of the 21st century (Lionello et al., 2006).

As for Libya where about 95% of its population lives in urban areas along the coast, the country is potentially at risk from the effects of climate change (El-Tantawi, 2005). Many studies e.g. (El-Tantawi, 2005)have indicated that Libya over the last sixty years has experienced a significant increase in temperatures (warming trend) particularly in the minimum temperature. Moreover, (El-Tantawi, 2005) in his study on climate changes in Libya has identified important changes in precipitation, humidity and cloud amount. He found positive trends in winter precipitation and negative trends for the annual total, annual intensity, spring and autumn precipitation for the period 1976-2000. With regard to the relative humidity, an increase in the mean annual value of about 2% has been observed for the period 1951-2000. El-

Tantawi's study also has indicated that the annual cloud amount totals over all Libya decreased by about 2.77 Oktas from 1976 to 2000.

4.1.4.3 Urban Heat Island (UHI)

'The UHI increases both indoor and outdoor thermal discomfort and increases energy consumption for cooling purposes' (Givoni, 1998).

Urban heat island (UHI) is probably the most popular phenomenon related to the urban climate. It is a term used to describe the increased temperature of atmosphere and surfaces in cities (urban areas) compared to their rural surroundings (Voogt, 2004). Cities are usually warmer than nearby rural areas, (Figure 4-8). This difference in temperature is due to many factors including rapid urbanisation in the cities which has led to the huge replacement of natural surfaces like landscape and vegetation with artificial surfaces like buildings and pavements. These changes have contributed to drier and hotter environments within the cities because of increasing surface absorption and reflection of sunlight, surface radiation especially during night-time, lack of evapotranspiration (absence of vegetation), blocking wind flow (preventing cooling by convection) (McGregor and Nieuwolt, 1998). Many other human activities such as car use, industrial processes and household cooling contribute to the increase in the temperature and pollution in the cities. As a consequence of these factors, the urban area becomes warmer than the surrounding rural areas and the so-called urban heat island develops.

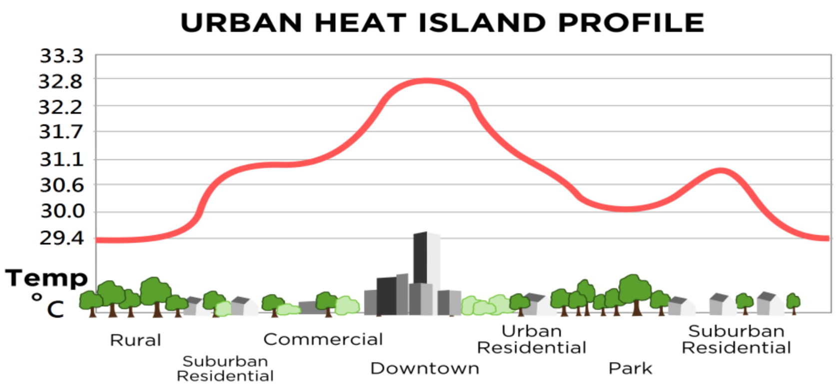


Figure 4-8: Typical urban heat island profile (Source: internet)

In general, the formation and intensity of urban heat islands (characteristics) are related to the city form, size and function, vegetation, geographic location, time of day and season and weather (cloud and wind) (Oke, 1982, Voogt, 2004). As for the types of Urban Heath Island, there are three main types including surface layer heat island, canopy-layer heat island, and boundary-layer heat island (Oke, 1982, Voogt, 2007), Figure 4-9.

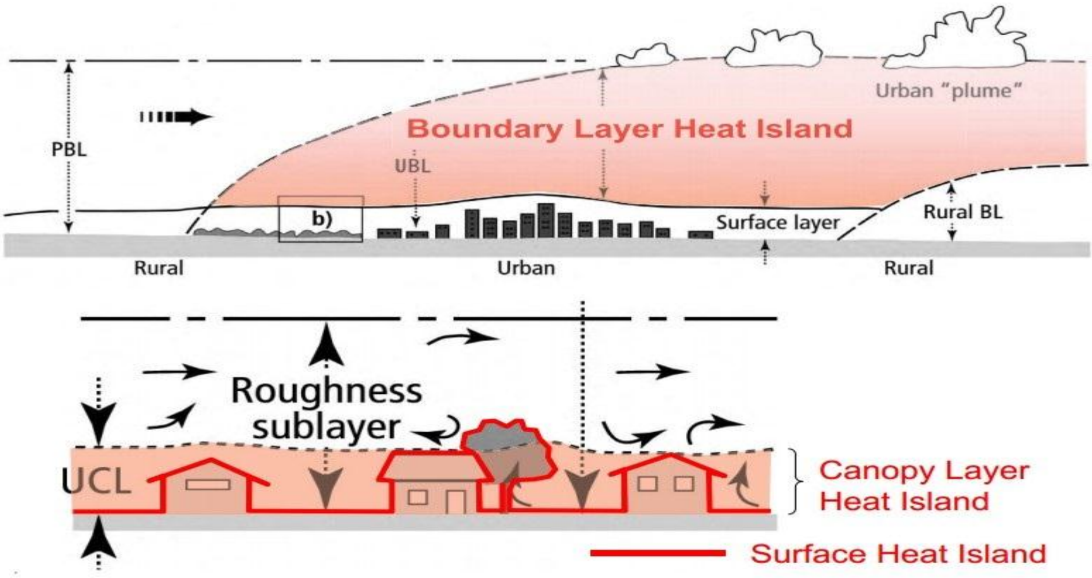


Figure 4-9: Urban Heat Islands: Three Main Types, Source: (Voogt, 2007)

According to the EPA, the UHI has many negative impacts on the community's environment and quality of life including contributing to human discomfort and health risks, increasing energy consumption for cooling particularly in hot regions, elevating emissions of air pollutants, smog and greenhouse gases due to the greater amounts of energy use and impairing air and water quality.

4.1.4.3.1 **Urban Heat Island in Libya**

Although, urbanisation is the main cause of the urban heat island (UHI), and Libya has experienced the most rapid increase in the urbanisation rate in the Mediterranean countries, and most of its population live in urban areas (Brauch, 2010), the UHI issue has not received the attention it requires from the government and the public. In this regard, no published studies were found concerning the UHI phenomenon in Libya. But there are many studies about climate change which have indicated that there is a general increase in temperatures (warming) in Libya e.g. (El-Tantawi, 2005, El Kenawy et al., 2009, Ageena et al., 2012).

According to these studies, the general trend of temperature in Libya is decreasing as you go further north, but this does not apply to the big cities where the increase in temperatures is higher than in the small towns regardless of the geographical location. Tripoli for instance, is located at the furthest northern point of Libya, but its mean annual and summer temperatures are higher than those of the rest of northern cities. The following table shows the difference in mean temperatures between the big and small coastal cities for the period (1946-2000).

Table 4-2: The difference in mean temperatures between the big and small coastal cities for the period 1946-2000, (Source: LNMC)

Station Site (City)	Latitude N.	Annual (°C)	Winter (Dec-Feb) (°C)	Summer (Jun-Aug) (°C)
Tripoli	32.54	20.2	14.0	26.4
Zuara	32.53	19.8	13.3	25.8
Shahat	32.49	16.5	10.1	22.8
Derna	32.47	20.0	14.8	25.1
Misurata	32.19	20.4	14.1	26.2
Benghazi airport	32.05	20.1	13.4	26.1

Figure 4-10: Location of some Libyan coastal cities

As it can be seen from Table 4-2 and Figure 4-10, the three big cities in Libya, Tripoli, Benghazi and Misurata have experienced the high mean values of annual and summer temperatures. This may indicate the effects of the urban heat island in these cities.

4.1.4.4 Urban wind flow and ventilation

Air movement plays an important role in improving outdoor comfort (de Schiller and Evans, 1998).

A lot of studies were done in this field, mostly concerning street canyons which have similar geometrical characteristics to the courtyards. The street canyon refers to a relatively narrow street in-between buildings that line up continuously along both sides and generally can be regarded as a semi-enclosed courtyard. The most important features of the street canyon microclimate are the wind-induced flow patterns such as air recirculation, which has a significant impact on the level of air pollution emitted from vehicles and also the thermal comfort of the inhabitants (Li et al., 2006). The most important factor that determines the air flow pattern inside street canyons is their geometries, in particular, the section aspect ratio: H/W (it has been discussed in the chapter of open spaces). Three different flow patterns were identified by Oke (1988) according to field measurements and mathematical modelling, as shown in Figure 4-11.

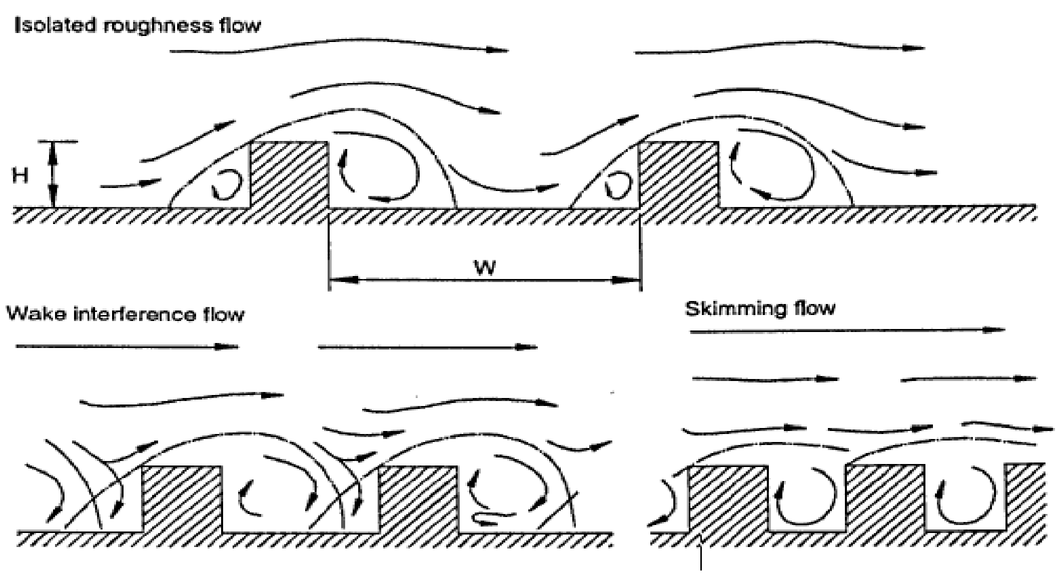


Figure 4-11: Three flow patterns associated with different section aspect ratio, Source: (Oke, 1988)

The three flow regimes between buildings are:

- **Isolated roughness flow:** spacing between buildings is larger than the sum of the upwind and downwind eddies; good for ventilation.
- **Wake interference flow:** spacing is larger than that required to create a stable vortex between buildings but smaller than the sum of the upwind and downwind eddies.
- **Skimming flow:** buildings are placed close to each other.

Some studies have also been carried out for courtyards. Walker et al (1993) and Shao et al (1993) performed CFD and wind-tunnel studies of courtyards and

Alvareze et al (1998) modelled airflow patterns in courtyards as a function of their depth and width ratios. Sharples and Bensalem (2001) compared several different opening scenarios (see fig.4-12) under various wind circumstances using a wind tunnel and found that mode A1 which is an enclosed courtyard (without openings) has a very weak ventilation performance, particularly when the wind is perpendicular to the courtyard without an inclined angle.

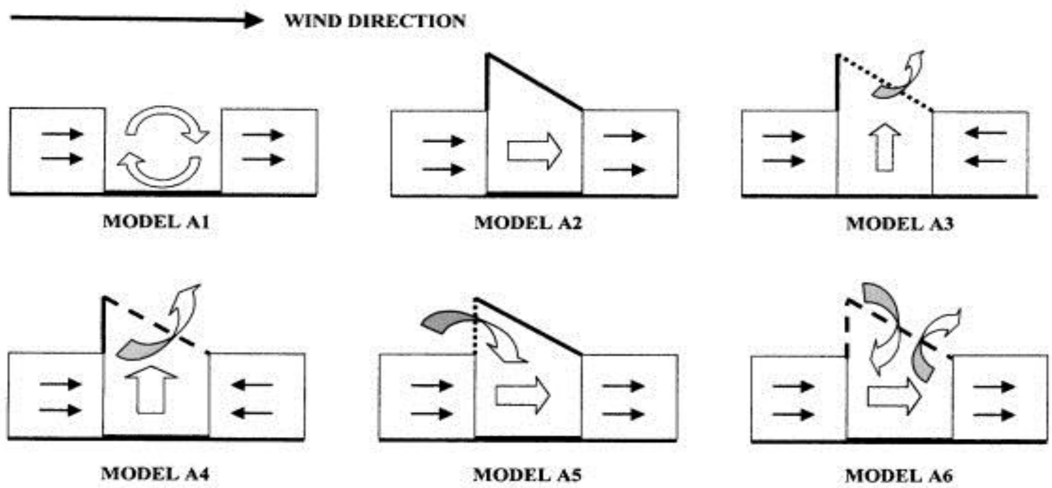


Figure 4-12: Showing different models with different openings for (courtyard & atrium) studied by Sharples et al (2001)

4.2 Tripoli (the Studied City)

4.2.1 Location and history

Tripoli city is the capital and largest urban area in the country with a population about 1.31 million inhabitants, or approximately 18.8% of the total population of Libya (2010 estimates, National Authority for Information and Documentation; NAID). Tripoli is located on the coast of Mediterranean Sea in the northwest of Libya (32° 54' 08" N and 13° 11' 09" E), Figure 4-13. It is the capital of the Tripoli region which extends from the boundary with Tunisia in the west to Gulf of Sidra in the east (about six hundred kilometres). The region is the most populated area in the country, with about 61% of the Libyan population, and is the centre of commercial and industrial activities in Libya.

Figure 4-13: Location of Tripoli (Source: internet & Google Earth)

Historically, Tripoli city is very ancient and was founded by the Phoenicians in the 7th century BC. The name Tripoli comes from Tri-Polis, which means three cities, the famous three cities that made up the region of Tripolitania in ancient times: Sabratha, Leptis Magna and Oea (Tripoli itself). Throughout its history, Tripoli has been dominated by many different nations; Phoenicians, Carthaginians, Romans, Muslims, Spanish, Ottomans and later on the Italians. During these periods the city of Tripoli was both positively and negatively affected by waves of destruction and development.

4.2.2 Climate

The climate of Tripoli is similar to that of nearby coastal cities. It has a sub-tropical steppe climate (BSh). In general its climate is characterised by hot and dry summers and mild, wet winters with a Mediterranean rainfall pattern. The warmest months are June, July and August, whereas the coldest are December, January and February. Most of the rainfall occurs from October to March. The average annual rainfall is less than 400 millimetres while snowfall has occurred in past years and most recently in 2011.

4.2.3 Climatic details of Tripoli and analysis of meteorological data

The meteorological data used in the analysis was obtained from Libyan National Meteorological Centre, Climatological Department. The available data covered the period 1971 to 2000, and included the average monthly mean, maximum, and minimum temperature (°C), average monthly relative humidity (%), average monthly wind velocity (m/s) and average monthly rainfall (mm). All the graphs presented here are generated from the data obtained from the Meteorological Centre, Table 4-3.

Table 4-3: Presents the 30-year average monthly records of temperatures, relative humidity, wind velocity and rain falls for the city, (Source: LNMC)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max. Temp. ºC	17.7	18.7	20.5	23.7	27.3	30.6	31.7	32.6	31.4	28.1	23.0	19.2
Min. Temp. ºC	9.1	9.7	11.5	14.0	17.4	21.0	22.5	23.5	22.4	18.8	13.9	10.3
Mean Temp. ºC	13.4	14.2	16.0	18.9	22.4	25.8	27.1	28.1	26.9	23.5	18.5	14.8
R. Humidity %	72.7	68.2	63.2	59.7	54.8	54.6	53.7	55.9	60	62.9	68	68.6
Wind Speed m/s	2.4	2.4	2.7	2.8	2.9	2.6	2.3	2.2	2.3	2.1	2.2	2.3
Rainfall Q. mm	70.3	38.8	34.6	14.6	5.6	1.2	0.7	0.2	14.1	43.2	66.1	74.1

4.2.3.1 Temperature

As shown in the Figure 4-14, the average annual mean temperature in Tripoli is 20.8ºC and ranges between 13.4ºC in January and 28.1ºC in August with a difference of 14.7ºC. The monthly average minimum temperatures occur in January (9.1ºC) while the monthly average maximum temperatures occur in August (32.6ºC). Only the months of June, July, August and September have displayed average maximum temperatures above 30ºC, while the average minimum temperatures were found below 10ºC in January and February and 10.3ºC in December. Therefore June, July, August and September could be considered the warmest months (summer) while, December, January and February are the coldest months (winter).

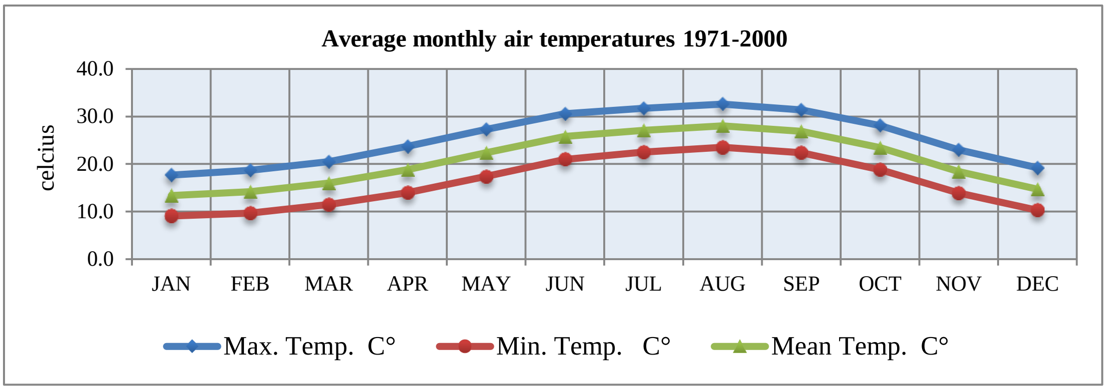


Figure 4-14: Average monthly air temperature for Tripoli 1971-2000, (Source: LNMC)

4.2.3.2 Precipitation

As seen in the figure below, the Tripoli climate has wet winter/dry summer precipitation. It is the typical pattern of rainfall in the Mediterranean region. It is characterised by unequal annual distribution of rainfall with about 50.4%

falling in winter (December to February), followed by 34% in autumn (September to November) and 15.1% in spring (March to May), while summer (June to August) is dry and receives very little rainfall, only 0.5%.

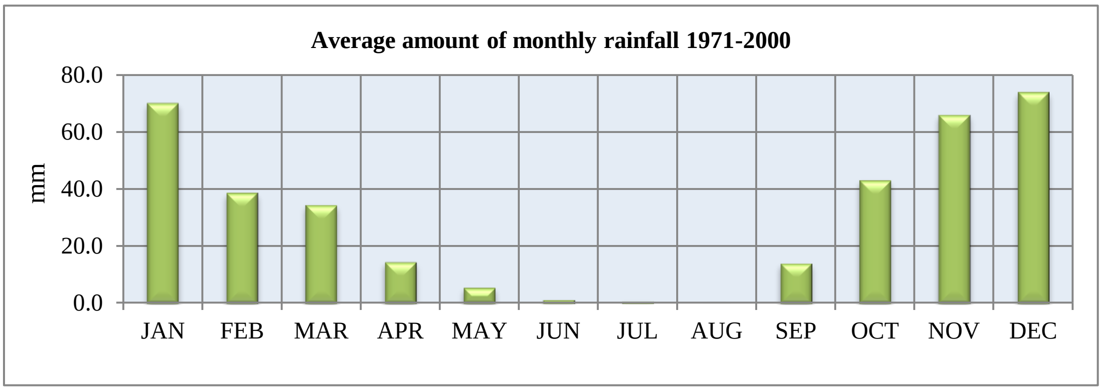


Figure 4-15: Average monthly annual rainfall for Tripoli 1971-2000, (Source: LNMC)

The 30-year (1971-2000) average annual rainfall for Tripoli city is about 360mm. More than 90% of the annual rainfall occurs in six months, from October to March. December and January are the rainiest months, with an average of 74.1 and 70.3mm respectively, whereas July and August are the driest months, with an average of less than 1.0mm of rain. In general, most of the precipitation in the city falls as showers, but intensive showers (rain storms) and snowfall have been observed in past years and most recently in 2011, (Figure 4-16).

Figure 4-16: Flooding and snowfall in Tripoli, 2011 (Source: Internet)

4.2.3.3 Relative Humidity (RH)

Based on the 30-year records from 1971 to 2000, the average annual mean relative humidity is 61.9% and ranges between 53.7% (mildly humid) and 72.7% (humid). As it is shown in Figure 4-17, there is a small variation in the seasonal averages. In more detail, winter (December to February) has the highest average of mean relative humidity with 69.8% followed by autumn (September to November) with 63.6% then spring (March to May) with 59.2% and finally summer (June to August) with the lowest average 54.7%.

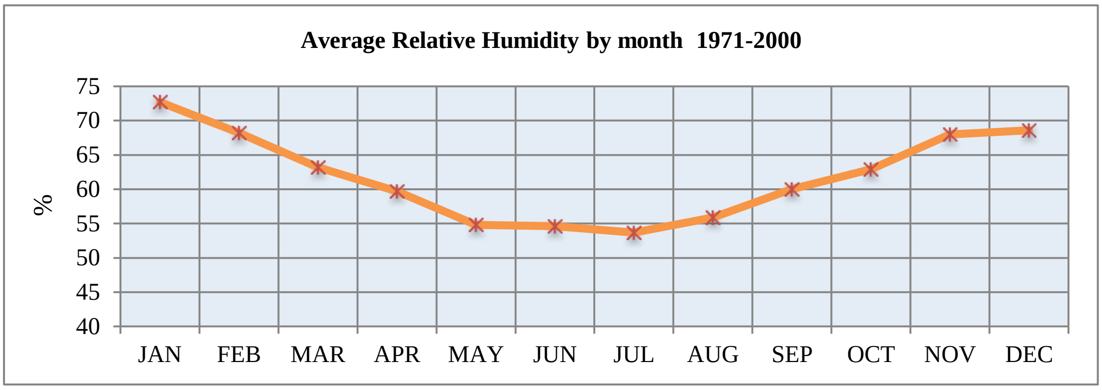


Figure 4-17: Average relative humidity by month for Tripoli from 1971-2000, (Source: LNMC)

As the figure shows, the monthly average of relative humidity reaches its peak in January (winter) with 72.7% and then drops gradually to reach the minimum percentage in July (summer) with 53.7%, and then goes back up again. Relative humidity increases with decreasing temperature. In general, the mean relative humidity in Tripoli averages between 60% and 70% during the rainy months (October – March) and between 50% and 60% during the remaining months of the year.

4.2.3.4 Wind

According to the 30-year (1971–2000) wind records, the mean monthly speed value ranges from 2.1 m/s (metres per second) in October to 2.9 m/s in May with an annual average wind speed of about 2.4 m/s. According to the Beaufort scale, this range of wind speeds is classified as a light breeze which is strong enough to be felt on the face and to rustle leaves. May was the windiest month of the year followed closely by April and March while October was the least windy (Figure 4-18).

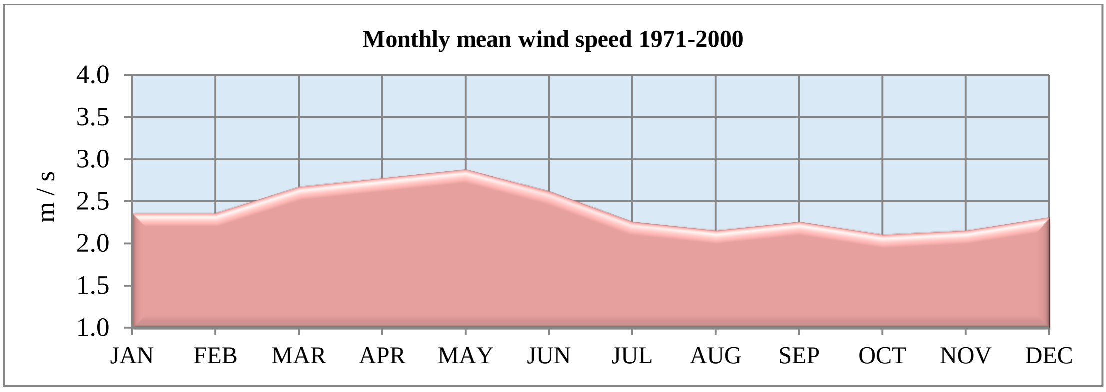


Figure 4-18: Monthly mean wind speed for Tripoli from 1971-2000, (Source: LNMC)

As for the prevailing wind directions, the northwest wind occurs between November and April usually bringing rain to the city, while from May to October, the prevailing wind comes from the north and east with occasional south winds from the desert. In general, as shown in the figure above, the average wind speed in the city is relatively light throughout the year. This could be due to the existing urban structures which may prevent the flow of moderate and high wind velocity and create an uncomfortable outdoor environment. Therefore, wind blow can be perceived as an environmental element that needs great attention and consideration in open space design due to its limitation.

4.2.3.5 Comparing weather data and conclusions

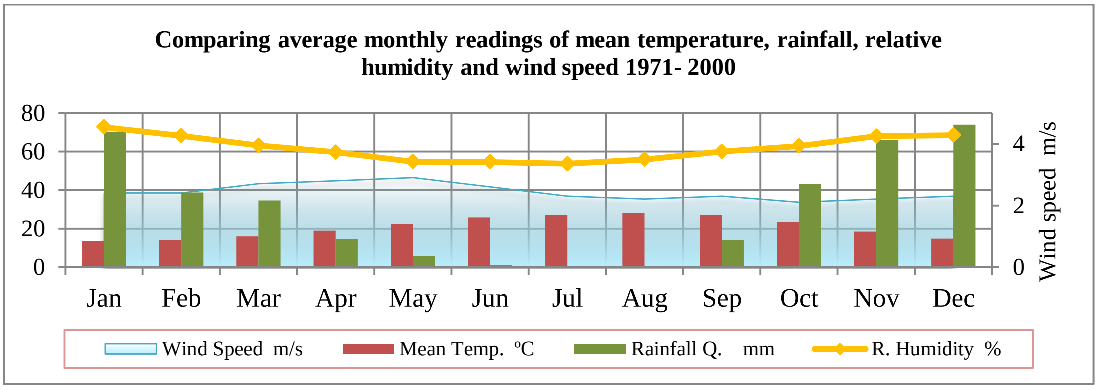


Figure 4-19: Comparing average monthly readings of mean temperature, rainfall, relative humidity and wind speed 1971- 2000, (Source: LNMC)

From Figure 4-19, it is apparent that the air temperature increases as the rainfall decreases. In contrast, relative humidity increases during rainy months. The statistical analyses provide evidence of a significant correlation between air temperature, relative humidity and rainfall. It shows a strong positive correlation between relative humidity and rainfall (+.944), and a strong negative correlation between relative humidity and rainfall with the air temperature with values -.849 and -.786 respectively. Based on the analysis conducted above, the main observations on Tripoli weather can be summarised in Table 4-4.

Table 4-4: Summary of the weather condition of Tripoli

	Highest readings	Lowest readings
Air Temperature	August then July	January then February
Relative Humidity	January then December	July then June
Rain Fall	December then January	August then July
Wind Speed	May then April	October

In general, it can be concluded that the city experiences a climate with dry and hot summers and mild and wet winters. From June to September, the weather is hot with fairly low relative humidity, while the weather from December to March is mild and humid. The wet season lasts from October to March and the dry season from June to August and often relative humidity is high during the rainy months. January followed by February is the coldest month, whereas August followed by July is the hottest month. In terms of rainfall, January and December are the wettest months while August and July are the driest months.

Based on these results, four months were selected for conducting winter and summer field studies in the city. For the winter survey, January and February were selected to represent the coldest and wettest period while for the summer survey July and August were chosen as the hardest months of the year in terms of high temperatures and aridity.

4.2.4 City built-up form

The existing (current) urban fabric of Tripoli city can be classified into three stages (zones): the old city, the colonial city and the post-colonial city (modern). Each of these cities has its own architecture and urban form and reflects a part of the city history (Figure 4-20: Three main areas of Tripoli city ((Source: author with Google Earth)

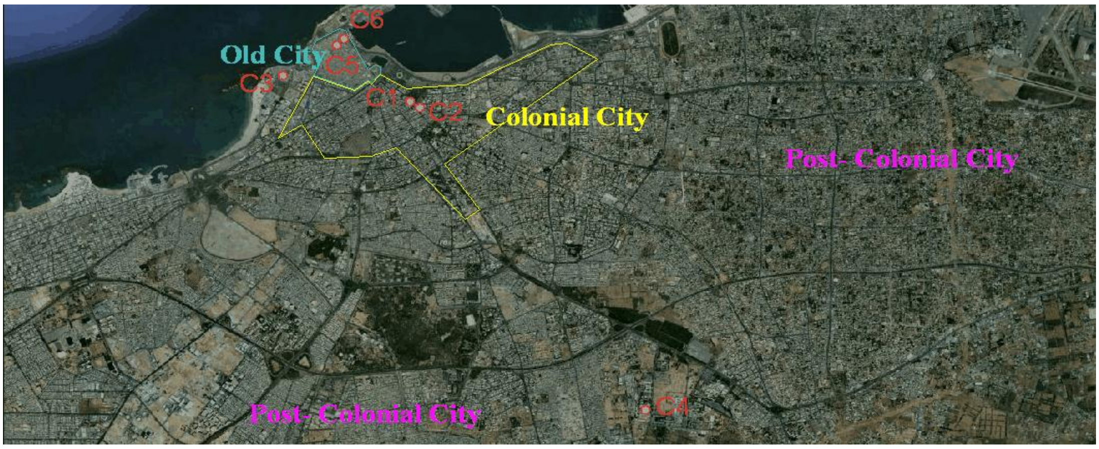


Figure 4-20: Three main areas of Tripoli city ((Source: author with Google Earth)

4.2.4.1 The old or traditional city (medina)

It is situated in the heart of Tripoli at the northern point of its geographical location with an area about 45 hectares. Most of the buildings are still visible today in the city such as mosques, schools, hotels, markets, baths, hospitals, palaces and distinctive houses were constructed during the periods from 1551 to 1911 where Tripoli was under the rule of the Karamanli dynasty and Ottoman Turks.

Figure 4-21: Old aerial view and new Google image for the old city (Source: internet)

The old city has a very compact built environment (Figure 4-21). Its urban fabric is characterised by its irregular narrow and partly covered alleyways with widths between two and three metres. It gives an obvious example of organic growth. The majority of the buildings in the city have courtyards and are characterised by one or two-storey buildings. Azzuz (2000) indicated that the consideration of climate, customs and traditions were major factors in shaping this city. In general, its urban structure is compact with narrow streets of various orientations and low aspect ratios.

4.2.4.2 The colonial city

It is a new European type of city was created by the Italian colonialism that is completely different from the old city. This city has been established outside the old city walls from the south and west sides during the period from 1911 to 1943, (Figure 4-22). The city was connected with other parts of the country by railways. First the master plan for the city was issued during this period which was divided into three urban zones: the first were new central business districts, the second new industrial areas, and the third new residential areas.

Figure 4-22: Old aerial view and new Google image for a part from the colonial city (Source: internet)

The urban fabric in the colonial city is distinguished by its planning system of the streets which was based on a radial layout with a focal point at the main square in the city which was named piazza Italia (now: Midan El Shohada). The built-up areas in the city are divided into regular blocks and separated by a grid pattern of wide and straight streets. The heights of buildings in this city range from two to four-storey buildings. The colonial city has particular architectural and planning values, such as its arcades and open spaces (courtyards, squares and parks)

4.2.4.3 The post-colonial city (new city)

The first master plan for Tripoli city after the colonialism period was in 1958. The second one was initiated in 1968. The third master plan (1988 – 2000) covers in addition to the old city (medina) and the colonial city all the extended areas from Janzur in the west to Tajura in the east. New types of buildings, roads and building materials were introduced during the post-colonial era. Some areas are characterised by high-rise buildings overlooking wide and straight streets, (Figure 4-23).

Figure 4-23: An aerial view and Google images for some parts from the post-colonial city where the studied courtyards are located (Source: internet)

4.3 The Case Study Sites

In order to assess microclimate and thermal comfort in public enclosed courtyards in hot dry Tripoli and to understand the relationship between the built urban form, the microclimate and the subjects' comfort within these environments, six public enclosed courtyard spaces with different microclimates, locations, orientations, functions, sizes, designs, geometric forms, ground covers (fully paved and grassed), building heights, urban fabric (urban geometry) were selected as case study sites.

4.3.1 Introduction to studied sites

The six selected enclosed courtyards are:

1. Courtyard (C1) / within the building of social security (Addamaan)
2. Courtyard (C2) / within the building of the municipality (Albaladia)
3. Courtyard (C3) / within Dath el-Imad complex towers
4. Courtyard (C4) / within the building of Faculty of Engineering
5. Courtyard (C5) / within the building of Noueiji cultural house
6. Courtyard (C6) / within the building of Bab Bharr club

4.3.1.1 **Courtyard (C1) / Building of Social Security (Addamaan)**

Figure 4-24: Google image and photographs showing location of courtyard C1 (Source: author & internet)

The courtyard is a part of Addamaan building which is situated in the central business district of the colonial city, one of the busiest pedestrian shopping areas in the city of Tripoli. It is an example of the architecture and urbanism of Italian colonialism in Libya during the 1920s and 1930s of the last century. The Addamaan building is one of the main buildings of Algeria square (Piazza Catedrali), one of the most beautiful squares of the city (see Fig).The building is located at the north side of the Algeria square and overlooks the south side of Al-Baladiaa Park. It is surrounded on four sides by streets with intense vehicle traffic. As seen from (Figure 4-24), the main mass of the Addamaan building consists of four storeys above ground level and one below ground level. The south facade of the building has two small corner towers with three high arched openings stand in the section located between these towers, each tower rising six storeys.

The building has two courtyards; the big one is fully enclosed and designed mainly to provide natural lighting and fresh air ventilation to the surrounded covered areas. The second courtyard which is one of the selected case study sites has a rectangular shape (approximately 16.92m x 16.92m), and is surrounded by four arcades, with 12 marble columns. On the ground floor, the studied courtyard is surrounded by some administrative offices and shops (barber and cafe shops), while the upper floors are surrounded by administrative offices, some of them with balconies. The courtyard is completely paved and contains a marble fountain (out of order) in its centre, where the pavement is placed two steps below the level of pavement of the surrounding arcades. The courtyard is greatly occupied in summer times especially during late afternoons and weekends. People utilise the space to eat, relax and socialise. The courtyard is open to the public seven days a week, at any time, and the access to the site is provided via two tall arched entrances/exits, one at the north side of the courtyard provided by seven steps and a ramp and the other one at the south side of the courtyard. In addition to their function as pedestrian access to the courtyard, the three tall arched entrances act as a wind tunnels to allow fresh air to pass from sea-shore and adjacent park to the inside of courtyard as well as to the Algeria square. Inside this courtyard, the north façade of this courtyard is named façade 1, while the Eastern one is named façade 2, the south facade is named façade 3, finally the west façade is named façade 4.

It can be concluded that this courtyard is a type of small sheltered courtyard with big openings that act as canals for ventilation. It was chosen as a case study site to represent the architecture and urban fabric of the colonial city and because of its location in one of the main shopping areas in the city. The site is surrounded by densely built areas and located about 500m from the coastline. Today, the courtyard mainly serves as an extension sitting space for coffee shops and attracts a high number of visitors every day.

4.3.1.2 Courtyard (C2) / Building of the Municipality (Al-Baladiaa):

Figure 4-25: Google image and photographs showing location of courtyard C2 (Source: author & internet)

The second case study site is Al-Baladiaa courtyard which is a part of a big building located at the east side of the Algeria square (Figure 4-25). This building is one of the important buildings in the colonial city. It houses the post and local government offices in the city from the colonial period until now. The building has four floors plus the underground floor (basement) and is surrounded on all sides by streets. The area where the building is located in is busy with cars and pedestrians. The building has two main entrances, one facing Algeria square and the other towards Al-Baladiaa Street. Al-Baladiaa courtyard has been chosen as another case study site representing the urban fabric of the colonial city, but it differs from the courtyard (C1) in the location, shape, orientation and function (use). This courtyard is one of three enclosed courtyards located inside the building. It is located at the east part of the building on the first floor which is surrounded by three storeys of administrative offices. The courtyard has a semi-triangle shape, and also is fully paved with a complete absence of water features and plants. It is fully enclosed and is not open for people to use. The courtyard has a floor area of about 304.4 m² and was designed mainly to provide shadow, natural lighting and fresh air ventilation to the surrounded covered areas.

4.3.1.3 Courtyard (C3) / Dath el-Imad complex towers: (a mixed-use complex)

Figure 4-26: Google image and photographs showing location of courtyard C3 (Source: author & internet)

Dath al-Imad administrative business complex is located on the seafront of Tripoli's financial and business district, the most modern part of the city, (Figure 4-26). The complex is situated overlooking the sea on three sides, from the north, northeast and northwest and is surrounded by roads from the east with heavy vehicular traffic, southeast, south and southwest. It also overlooks a multi-storey underground car park covered by a beautiful landscaped garden situated between groups of high-rise buildings. The complex consists of a wide enclosed courtyard (approximately 65m x 72m), surrounded by a two-storey building (complex body) plus the complex garage in the basement floor. It also has five towers of 16 storeys standing around the courtyard, each tower has two separate entrances; one external and one internal opens towards the courtyard. The courtyard's surface is partially paved with the presence of some grassed areas and a few plants distributed around its centre where a big fountain (out of order) is located. At the northeast and northwest sides of the courtyard, there are two gates (openings) acting as services access and maybe as wind tunnels (to allow fresh air to pass from the sea-shore to the courtyard). Many sitting places with benches are distributed inside the courtyard, but they are unprotected, and exposed to the sun and winds from almost any direction. The complex building is considered one of the main places for business and service activities in the city and therefore receives a large number of visitors each day.

Thus, this courtyard was selected as a case study site, as it represents the architecture and urban fabric of the post-colonial city (modern) (high-rise building down town), and also chosen to allow the interviewing of the large courtyard users (office workers and visitors), and because of its special location beside the waterfront.

4.3.1.4 Courtyard (C4) / the building of Faculty of Engineering

Figure 4-27: Google image and photographs showing location of courtyard C4 (Source: author)

The building of the faculty of engineering is situated in the main campus of the University of Tripoli which is located about 7km south-east of the city centre. The faculty is composed of a group of building blocks that is arranged around a group of beautifully landscaped courtyards. The studied courtyard is a large common space surrounded by a group of individual buildings, one-storey building on its west side and two-storey buildings on the other side, Figure 4-27). This courtyard has a rectangular shape (approximately 42.22m x 62.41m) with its longitudinal axis laying in an east-west direction. The courtyard surface is mostly covered with, grass and has a lot of vegetation (shrubs and trees) which offer shade for a big part of the courtyard and is also provided by paved footpaths to travel from one point to another. The courtyard acts to provide natural air and light to all the surrounding buildings and for commuting from one building to other. It is also used as a common seating place for the students. This courtyard is another example representing the architecture and urban fabric of the post-colonial city. The site is very quiet and surrounded by limited movement of vehicles. It can be accessed directly from all the sides via corridors and paths.

Thus, this courtyard was selected as a case study site as it represents large courtyards with intensive greenery (grass and shading trees) which are classified as a space surrounded by individual building blocks (not enclosed courtyard inside a building), also because such a place is popular with university students and therefore frequently visited throughout the academic year.

4.3.1.5 Courtyard (C5) / the building of Noueiji cultural house

Figure 4-28: Google image and photographs showing location of courtyard C5 (Source: author)

Noueiji cultural house is located at the northern part of the old city which is characterised by continuous compact building masses with inner small spaces (courtyards, squares, etc) and narrow streets (very densely built-up areas). The building is a two-storey building with a small fully-enclosed and landscaped courtyard, (Figure 4-28). This kind of enclosed courtyard is a space located inside a building and surrounded on all sides by various spaces (rooms). It is a typical example representing the scattered enclosed courtyards in the urban fabric of the old Arab-Muslim city (Medina). The courtyard area is paved (marble) with beautiful trees in its centre and some plants and flower beds on both sides of the steps which lead from the courtyard toward to the upper floor. On the ground floor, the courtyard which has a rectangle shape (approximately 11.57m x 10.79m) and is surrounded on three sides by spaces (rooms) that open directly to the courtyard through arched doors, while on the fourth side (southwest), the rooms (offices) open onto a beautiful arcade which in turn overlooks the courtyard. This attractive courtyard also has beautiful arcades with decorative banisters on the upper floor at the southwest, northwest and northeast sides. The building was used as a residence for the British Consul until 1870, but now is used as a library, which is open for the public five days a week from 9.00 a.m. to 3.00 p.m. The building has just one entrance located on the northern west elevation toward Al-Akwash Street and leads to the courtyard through an L-shaped passage (indirect access). The courtyard provides interconnection between rooms (offices) on the ground floor and has a set of steps leading to the top floor through a large arch. In addition to this function, the courtyard provides natural light and ventilation into the interior spaces.

Thus this courtyard is selected as a case study site, as an example representing a small fully-enclosed courtyard inside the buildings which is considered as one of the common architectural patterns in the urban fabric of the old city.

4.3.1.6 Courtyard (C6) / the building of Bab Bharr sport club

Figure 4-29: Google image and photographs showing location of courtyard C6 (Source: author)

This courtyard is another example representing the courtyards in the urban fabric of the old Arab-Muslim city (Figure 4-29). It has been selected as an additional case study site for conducting just night surveys during the summer season (exactly during Ramadan which is a special month in which people tend to spend most of their night-times outdoors),comparing it with the Addamaan courtyard (another site was used for night surveys). The Bab Bharr building is located in the north part of the old city, on a small hill overlooking the harbour. It is situated in an area rich in coffee shops and restaurants with many spectacular panoramic views. This area is considered as an attraction place for the tourists and local residents particularly, for who are looking for quiet and traditional resting-places. The site is provided by few car parks and surrounded by streets with low levels of vehicle traffic.

Bab Bharr is an administration building of a sport club, located on the north side of the square of the Marcus Aurelius arch (which was built around AD164), which is the most impressive ancient monument in Tripoli city. The Bab Bharr building is established on a rectangular plan with two floors consisting of a number of rooms arranged around an enclosed courtyard on three sides. The courtyard is fully paved by stones, and has a rectangular shape (approximately 16.59m x 7.64m), its long side on the northeast-southwest axis. This courtyard also has a small fountain in its centre, with two big palm trees and some plants distributed within the space. It is surrounded on all sides by arcades (riwaq) of slender columns except the south-western side (blocked) on the ground floor and south-eastern side (front façade) on the upper floor where, there is a terrace with decorative banisters overlooking the Arch square. The building is accessed through an entrance found in the middle of three arched openings located on the front elevation of the building that leads directly from the Marcus Square to the rooms and stairs via the courtyard. This means all the movement between rooms and between the internal spaces and outside is achieved via the courtyard. In addition to its function as a connecting (transition) space, the courtyard also provides natural light and ventilation to the interior spaces (covered spaces). The courtyard was closed during my winter field study, but in the summer (during the night-times of the Ramadan month) it was opened for the public as a sitting place, and provided temporally coffee-shop, chairs, tables, and TV screens. In that month, the courtyard was used extensively by the people who were looking for a place to smoke, relax, have fast food, drinks, meet friends and play games (cards, dominoes and chess).

4.3.2 Aspect ratio of the studied courtyards

Studying the aspect ratio of a courtyard is used to measure its effectiveness in terms of environmental response. The aspect ratio of a courtyard is the degree of its openness to the sky. The greater aspect ratio would mean the courtyard is more exposed to the sky. This exposure permits the sun to warm the courtyard by day, the radiation to the sky to cool it at night-time and the entry of the wind (Reynolds, 2002).

$$Aspect\ ratio\ = \frac{area\ of\ the\ courtyard\ floor}{(average\ height\ of\ surrounding\ walls)^{2}}$$

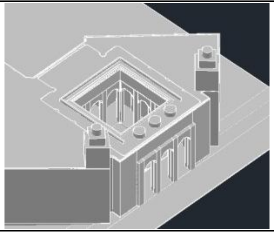
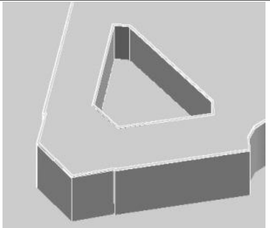
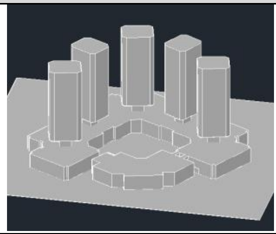
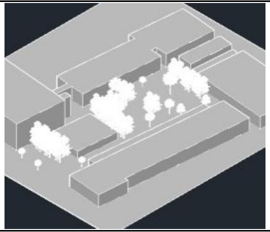
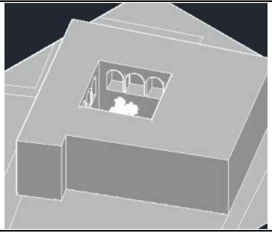
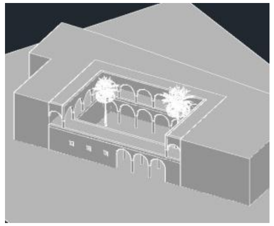
Table 4-5: The calculated Aspect ratio of the studied courtyards

Heights of facades	C1	C2	C3	C4	C5	C6
Fl	18.82	12.6	9.4	4.61	9.46	7.40
F2	18.82	12.6	12.6	8.56	9.46	7.40
F3	18.82	12.6	12.6	6.69	9.46	3.95
F4	18.82	12.6	9.4	6	9.46	7.40
F5	-	12.6	-	-	-	-
F6	-	12.6	-	-	-	-
Total height (m)	75.28	75.6	44	25.86	38.56	26.16
(Average height) ^{2}	354.2	158.8	121	42.25	89.49	42.76
Area of courtyard (m) ^{2}	292.4	304.4	3476.6	2634.6	124.6	126.75
Aspect ratio	0.82	1.92	28.73	62.36	1.39	2.96

Based on the results shown in (Table 4-5), courtyard C4 has the highest value of the aspect ratio followed by C3 then C2 after that C5 and C1. This means that C4 is more open to the sky, and more exposed to the sun and solar radiation followed by C3, C2, C5 and lastly C1. More details about the physical and microclimatic characteristics of these courtyards are shown in the following tables.

4.3.3 Microclimatic characteristics of the studied courtyards

Table 4-6: 3D models for the six study courtyards and the characteristics of the microclimate at each site (Source: author)

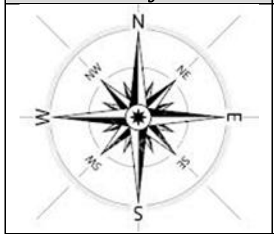
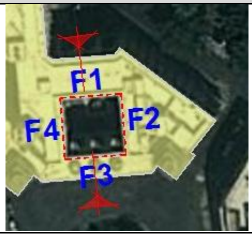
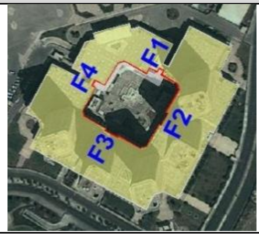
Courtyard	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
3D models						
Microclimate	It seems to be shaded during winter and partly shaded in summer. An airy place during both seasons where it is provided with big openings that act as canals for ventilation.	It seems to be a sheltered place from wind in all direction during both seasons. Partly shaded in winter.	It seems to be sunny during both seasons and exposed to wind in winter and sea breeze in summer. It is provided with towers which provide some shade particularly in winter. Towers may contribute to increased wind speed at pedestrian level.	It seems to be partly sunny place and partly shaded during both seasons where it is provided with groups of trees. Sheltered place from wind during both seasons. In general more humid, and seems to have moderate climate during both seasons.	It seems to be a very sheltered place from wind during both seasons (poor ventilation). Fairly shaded in winter and partly shaded in summer	It seems to be fairly airy place where it is provided with external openings on only one side (front side). It is exposed to sun during both seasons that because its sunny side has only single-storey height. Therefore the solar radiation can reach inside the courtyard even in winter when sun angle is low.

4.3.4 General description of studied courtyards

Table 4-7: General description of courtyards C1, C2, C3, C4, C5 and C6 (Source: author with Google Earth map)

Courtyard	C1	C2	C3	C4	C5	C6
						
Location	Colonial city	Colonial city	Post-colonial city	Post-colonial city	Old city	Old city
Type	Fully-enclosed courtyard inside a building	Fully-enclosed courtyard inside a building	An enclosed courtyard inside a building	An enclosed courtyard surrounded by individual building blocks	Fully-enclosed courtyard inside a building	Fully-enclosed courtyard inside a building
Use	Commercial	Administrative	Business	Educational	Cultural	Administrative
Orientation (long side)	E-W (fairly square)	E-W	SE-NW	E-W	NE-SW (fairly square)	NE-SW
Area (m²)	292.4	304.4	3476.6	2634.6	124.6	126.75
Aspect ratio	0.82	1.92	28.73	62.36	1.39	2.96
Vegetation + Water	Some plants and flower beds One fountain is out of order	Complete absence	Some grassed areas and plants Group of fountains are out of order	Intensive presence of vegetation (shrubs & trees)	One medium tree, in the middle and some plants and flower beds on the side	Two palm trees, some plants and flower beds A small fountain

Table 4-8: General description of courtyards C1, C2, C3, C4, C5 and C6 (Source: author with Google Earth map)

Courtyard	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
						
Ground area	Completely paved by red brick and some marble	Completely paved by concrete	Mostly paved by concrete pavers with some grassed areas	Mostly covered with, grass with some concrete footpaths	Completely paved by light grey marble	Completely paved by black stone
Height (internal facades)	All facades = 4-storey 18.82 m	All facades = 3-storey 12.6 m	F1& F4 = 1-storey F2 & F3 = 2-storey 9.4 m & 12.6 m	F1& F4 = 1-storey F2 & F3 = 2-storey 4.61 m, 6 m & 8.56 m, 6.69 m	All facades = 2-storey 9.46 m	All = 2-storey except F3 = 1-storey 7.40 m & 3.95 m
Finishing	Plaster	Textured plaster	Plaster / Glass	Textured plaster	Plaster	Plaster
Colour	Cream	Cream	White	White / Beige	White / Maroon	Cream
Shading devices	4 arcades around courtyard	None	Veranda along four sides with some plants	Groups of trees	1 arcade at F4 & 1 tree in the middle	3 arcades at F1, F2, & F3 with 2 palm trees
Openings	3 high arched openings at F1 & F3	None	2 gates at F1 & F4	5 gaps between the buildings	None	3 arched openings at F3

4.4 Conclusion

This chapter presented an overview on the location, population and climate of Libya. Then it discussed the metrological data (climate elements) of Libya in general and Tripoli (study area) in particular. These elements form the important aspects, to be considered in future development plan design. This chapter also gave an overview on the built urban form of the study area. The case study sites were introduced and described in detail in this chapter. This chapter also discussed general characteristics of the case study sites (studied courtyards). These aspects have been discussed in order to give a clear picture about the study area and case study sites. The main conclusions from this chapter are:

- Libya has experienced significant climate change over the last sixty years.
- January and February are the coldest months, whereas August and July are the hottest months according to the meteorological data of the study area.
- The courtyard is the most widely-used open space through the history of Tripoli city.

The chapter is concluded with a comparison between the studied courtyards in terms of their spatial characteristics (location, size, geometry, use, design, built and natural elements etc.). The obtained data will be linked with the results in chapters 7 and 8 (microclimate measurements and thermal comfort surveys) in order to identify the relationship between the urban-built form, microclimate and thermal comfort in the studied courtyards (effects of the elements of the urban-built form on the microclimate and therefore on thermal comfort conditions).

5 METHODOLOGY

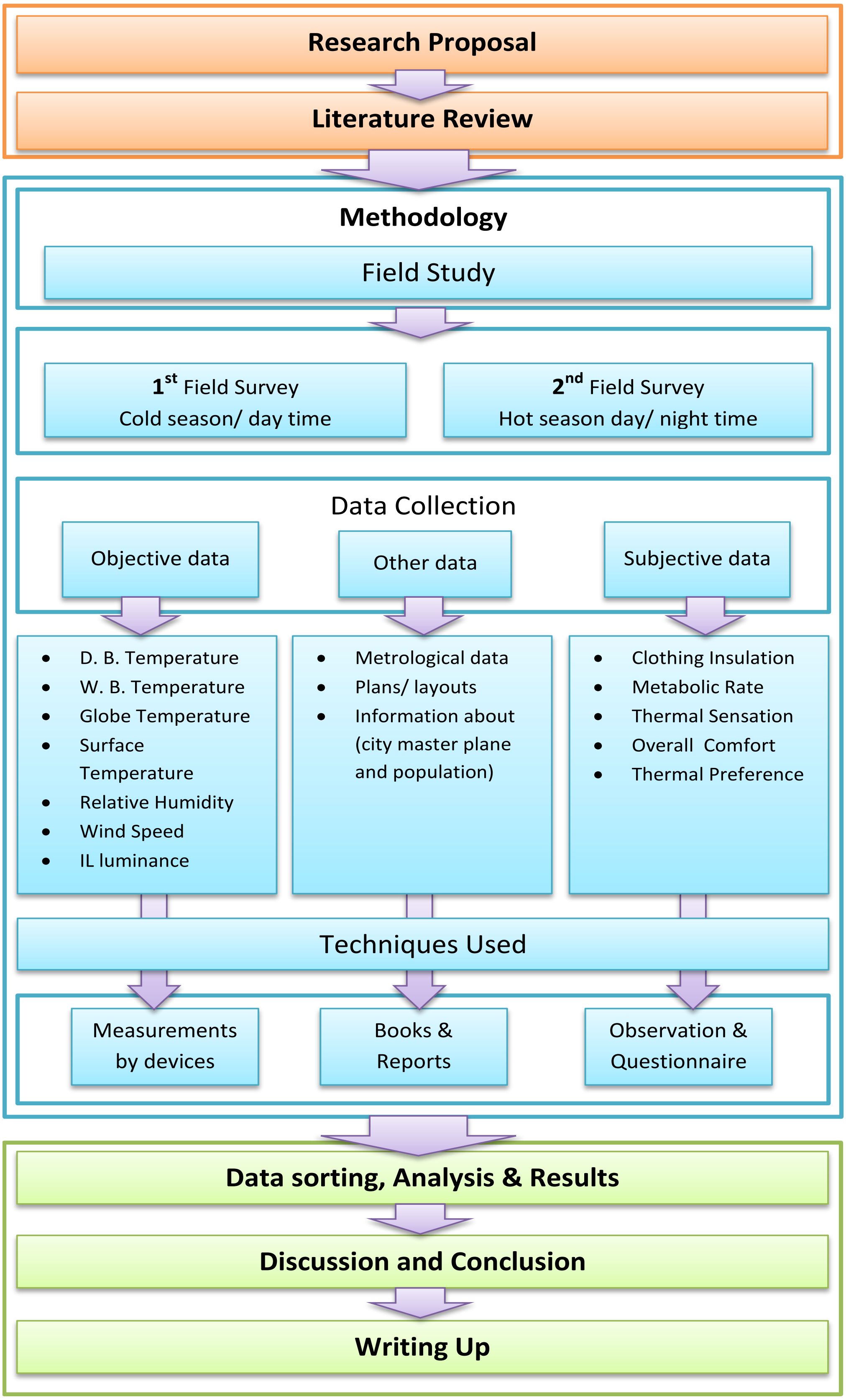
In this chapter, the details of the method used in the study are discussed. The chapter begins with a brief introduction about the method used in the study. Next to this, the chapter presents the flow diagram of research. Then, it provides the reasons for case study selection. This is followed by a description of the methods used for collecting objective and subjective data. Details about techniques, equipment and sample are included.

5.1 Introduction

This study is multidisciplinary in character including the fields of urban design, architecture, urban climatology, and thermal comfort. Its main objective is to understand the relationship between the microclimate, the built urban form and thermal comfort in urban outdoor environments in hot dry Tripoli. In order to accomplish this purpose, a set of techniques were applied. The literature review is one of the main stages, through which the theoretical framework is established. It included a review of the main aspects that related to this study (thermal comfort, urban open spaces and the microclimate and morphology of the case study). The field study of the microclimate and thermal comfort is the methodology used for the present study, which is based on the collection of environmental parameters, observations and structured interviews with people in their real environments. One advantage of this method is that it is an in-situ experiment, which means that the obtained results can be directly applied to similar thermal environments.

In this field study, a classic field survey of thermal comfort was used in which a number of subjects provided subjective responses whilst at the same time the environment was measured. The purpose of the survey was to use a number of respondents (as many as possible) and make only one assessment at a particular time and space. This type of survey indicates the extent of variation among individuals' responses and gives good estimates for the population (Humphreys; 1976 as cited by (Heidari, 2000). In this context, two short-term field surveys have been conducted in six case study sites within the urban areas of hot dry Tripoli during winter day-time and summer day/night-time, 2010.

5.2 Flow of Research



5.3 Main Reasons for Selecting Tripoli As a Case Study

Tripoli was selected as a case study based on three general considerations. First, it is the largest Libyan city, and this makes it one of the cities most affected by the implications of rapid urbanisation and climate change in Libya as well as in North Africa. Second, it is located on the coast of the Mediterranean Sea, where the majority of the Libyan population live, and this could help to generalise the results to a large number of the cities that have the same climate. Third, the urban fabric of the city is varied and composed of three different urban areas (old city, colonel city and post-colonial city), and each one of them has its own architecture and urban form. This diversity would provide a scope to have a good comparison between the studied sites which have been chosen to represent these areas. In addition to the above considerations, there are other reasons contributing to the selection of the city of Tripoli as a place to study:

- Libya as a country has been chosen for this research where no data is presently known about thermal comfort conditions in outdoor spaces.
- To date, urban open spaces in Libyan cities have not received any attention for studying their thermal comfort conditions.
- Tripoli city is the largest metropolitan area in the country that contains about 18.8% of the total population of the country.
- Tripoli is still undergoing the rapidest urban growth as well population growth in Libya because of its importance as the most important administrative, business and commercial centre in the country. This makes it one of the most urban areas in Libya suffer from the impact of urbanisation and climate change.
- Tripoli is a Libyan city that has conserved its urban fabric which is composed of a variety of different architectural and urban planning forms that represent different periods of its history.
- In addition to its environmental conditions, Tripoli’s location, climate and physical form are similar to many Libyan cities (climatically and architecturally typical for Libyan coastal cities).

- Enclosed courtyards have been chosen for this study because they are the most commonly-used architectural patterns as open spaces throughout different periods of the history of the city.

All of these were the main reasons for choosing Tripoli city to be a good example of Libyan coastal cities (that have same or similar climate) for studying the microclimate and thermal comfort in its urban open spaces.

5.3.1 Site selection

Six different enclosed courtyards were selected for this study as examples representing the three main areas that compose the city of Tripoli. The selected sites are namely: the courtyard of Addamaan (C1) and courtyard of Al-Baladiaa (C2) from the colonial city, the courtyard of Dat al-Imad (C3) and the courtyard of F. Engineering (C4) from the post-colonial city and the courtyard of Noueiji cultural house (C5) and the courtyard of Bab Bharr (C6) from the old city (more details are found in chapters 5, 6 & 7), Figure 5-1. These sites were chosen as case study sites based on the following criteria:

- Must be located within the urban areas of Tripoli (hot dry climate)
- Must be public enclosed courtyards
- Varies in terms of location, design, geometry, material, use and microclimate as far as possible (two cites from each area)

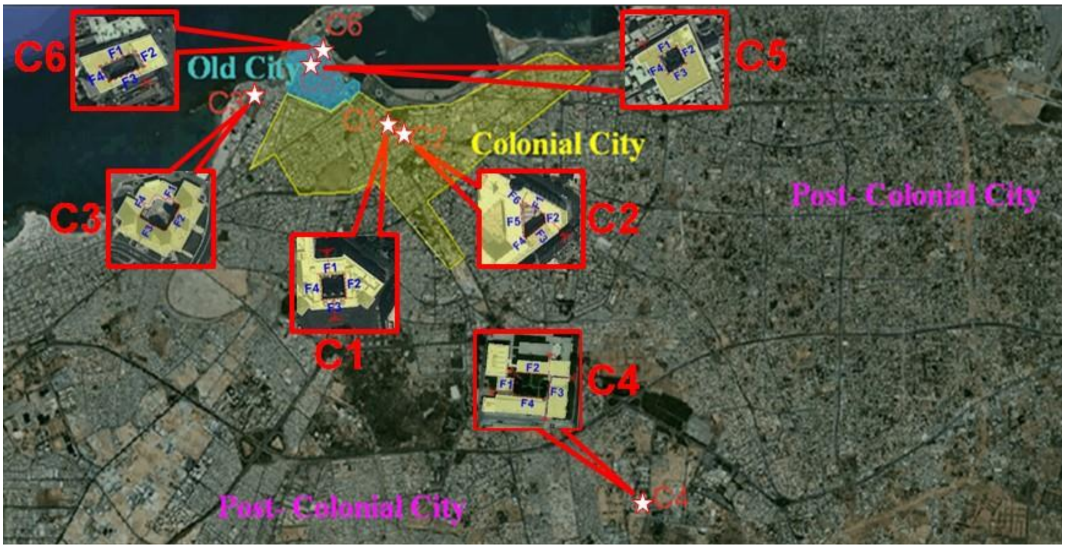


Figure 5-1: Aerial view showing location of the studied courtyards (adapted from Google Earth)

5.4 Meteorological Data As a First Step

The collection of the Meteorological data from the Libyan National Meteorological Centre, Climatological Department (LNMC) was in 2009. It included data regarding temperature, humidity, rainfall, wind and cloud cover for Libya for the period 1946-2000 and for Tripoli, 1971-2000. Some of this data was analysed using the Excel-Microsoft Office Package. The analysed meteorological data helped to give clear and detailed information on the climate of Libya in general and Tripoli in particular. One of the main points of this analysis was to determine the extreme months (the most extreme weather conditions) in both seasons (cool and hot), and therefore determine the proper time for conducting the field surveys.

5.5 Preparation for Fieldwork

It was decided to conduct this survey in public enclosed courtyards in hot dry Tripoli as a case study for this research to represent a type of urban outdoor space which are very common in North Africa and Middle East. According to Nicol (1993) as cited by Heidari, (2000), the first thing in order to conduct a field survey to any researcher is that he/she should have a clear idea of what it is he/she wants to measure, and how he/she intends to measure it. Based on the background analysis of the study area, together with the literature review of the thermal comfort field survey studies, all the requirements to conduct the field study and achieve its objective were identified and prepared/provided including a general plan, selection of case study sites, budget, programme, tools/equipment, data collection forms. In general, the study aimed to collect as much information and data as possible in order to develop a database of the thermal environments and subjective responses of people in urban outdoors in a hot dry climate.

5.6 Administration

Before starting the field surveys in both seasons, formal letters were sent to ask for permission from relevant bodies to conduct fieldwork within their premises, copies of which are attached in the Appendix.

5.7 Field Study (Field Surveys) As a Main Step

A field survey is a key part of understanding the true nature of people's interaction with their environment. The main aim of this field study was to map variations in the microclimate and outdoor thermal comfort in urban outdoor environments (public enclosed courtyards) in hot dry Tripoli, and to find the relationship between the microclimate, the urban-built form and thermal comfort. As it was mentioned above, the field surveys have been taken place at the selected case study sites during winter and summer 2010, (all the details will be found in chapter 6 and chapter 7). The winter survey was conducted during the period from 15 Jan to 15 Feb on weekdays and weekends. As for the summer survey, it was carried out during the period from 15 Jul to 15 Aug on weekdays and weekends as well. The time period that the surveys were carried out varied according to the season, also aiming to obtain the daily, as well as the seasonal picture of the microclimate and thermal comfort in the studied sites. In winter (cool season), the surveys were running from 09:00h until 18:30h, whereas in summer day-time (hot season), the surveys were running from 09:00h to 20:00h, but in summer night-time, the surveys were running from 22:30h until 01:30h, and the reason for this was because of the Ramadan month where the people are available outdoors during the period between Isha prayer and Suhoor time.

The data collection included objective measurements (environmental measurements), subjective measurements and other data related to the research. The data collection was focused on questionnaire surveys, environmental measurements (detailed microclimatic monitoring) and observation as the main tools to gather the required information. Microsoft Excel and SPSS software were used to analyse the data collected and to obtain results.

5.7.1 Environmental measurements (objective measurements)

The environmental measurements aimed to collect the microclimatic data including dry-bulb temperature (DBT), Wet-bulb Temperature (WBT), Globe Temperature (TG), Floor-Surface temperature (ST-F), Wall-Surface temperature (ST-W), illuminance (ILL), relative humidity (RH) (calculated from the table) and Wind Speed (WS), which were necessary for further microclimate and thermal comfort analysis. All these parameters were continuously measured and logged in data collection every ten minutes from 09:00 am until 06:30 pm in the winter field surveys and from 09:00 am until 08:00 pm in the summer day-time field surveys and from 10:30 pm until 01:30 am in the summer night-time field surveys. In winter and summer day-time, the measurements were taking place in five courtyards (C1, C2, C3, C4 & C5), whereas in the summer night-time the measurements were taking place in only two courtyards (C1 & C6) (all the details are found in chapter 6).

In general, the measurements were taken at a height of between 1.50-2.10m above the floor, which represents the height of the subjects at seating and standing positions (except the measurements of the surface temperatures which were at different positions and levels). The measured parameters were averaged for each half-hour in order to minimise error in the data gathered and therefore use it in the analysis. These parameters were measured by a set of appropriate equipment (see Figure 5-3) which was portable and easily transported around the site. With the help of the assistants, the equipment was all prepared at least twenty minutes before the start of the measurements. Figure 5-2 shows a part of the measurements within the studied sites. Measurements were recorded in forms such as the one is shown in Appendix 4.

Figure 5-2: photographs taken while the measurements were taking place (Source: author's survey)

5.7.1.1 Measurement equipment

In order to measure the outdoor environmental variables within the studied sites during the hot and cool seasons, this study used a combination of the commercially available equipment.

5.7.1.1.1 Whirling hygrometer

A whirling hygrometer is a manual technique and also called a Sling Psychrometer. (Figure 5-3/1). In this study, it was used to measure Dry and Wet-bulb temperatures and to calculate relative humidity (RH) levels. This device consisted of two thermometers. One thermometer is called the dry bulb and the other is the wet-bulb. The wet-bulb thermometer has a cotton sleeve wrapped around its base. Distilled water from a small reservoir is used to keep the sleeve wet. The hygrometer should be held above the head and whirled around in the air for a set period of time. While this happens, water from the sleeve of the wet-bulb thermometer evaporates, and the wet-bulb temperature shown by the thermometer goes down. The process is repeated until the readings are consistent. RH and dew-point are then calculated from the wet and dry-bulb temperature readings using the guide. All the readings for each site will be recorded in an environmental data form.

5.7.1.1.2 Professional digital anemometer

It is a portable instrument used to measure the air velocity in the case study sites. This device consisted of the unit which has a large LCD display, and a data hold function for storing the desired values connected with a vane sensor by a cable. It is a small, lightweight design and simple to use (Figure 5-3/2). This anemometer provides fast, reliable and accurate measurements in four different scales m/s, ft/min, km/h, knots. To use this instrument, the vane sensor is held slightly higher than the level of head in front of a source of air flow. All the readings were recorded in appropriate form according the measurements time table of each site.

5.7.1.1.3 Globe thermometer

It was used to measure globe temperature. It consisted of a 6-inch-diameter hollow copper sphere painted with a matt black paint to absorb the radiant heat from surrounding objects and containing a thermometer with its bulb or sensor located at the centre of the sphere (Figure 5-3/3). The globe must be kept a dull black at all times, free of dust or rain streaks, by dusting, washing, or repainting if necessary. The instrument needs to be left for at least 15 minutes before it gives a reliable reading (time to reach equilibrium). All the readings were recorded in the appropriate data form.

5.7.1.1.4 Professional digital light meter

Digital light meter is an accurate hand held instrument, also called an illuminance meter. It was used to measure the quantity of light or light level in lux units. One lux (or foot candle) is equal to the total intensity of light that falls on a one square meter (or square foot) surface. This device consisted of a body with a display connected with a separate photo cell or light sensor by a thin cable (Figure 5-3/4).To use this instrument, the sensor is placed in the horizontal position in the selected point under the sun away from the display unit. This allows the auditor to read the meter without casting a shadow on the sensor. Each cycle will need about ten minutes to measure and calculate the minimum, maximum and average of illuminance in lux or foot candle. All the readings were recorded in the data collection form.

5.7.1.1.5 Professional high temperature infrared thermometer

This thermometer was used to measure the surface temperature of walls and floor areas of case study sites. This device is lightweight, compact, and easy-to-use

(Figure 5-3/5). It can measure the surface temperature of objects from a distance without contact with them and can provide several readings per second. The surface temperatures were taken in several positions in each case study. All the measurements were recorded in a prepared data form, see Appendix 4.

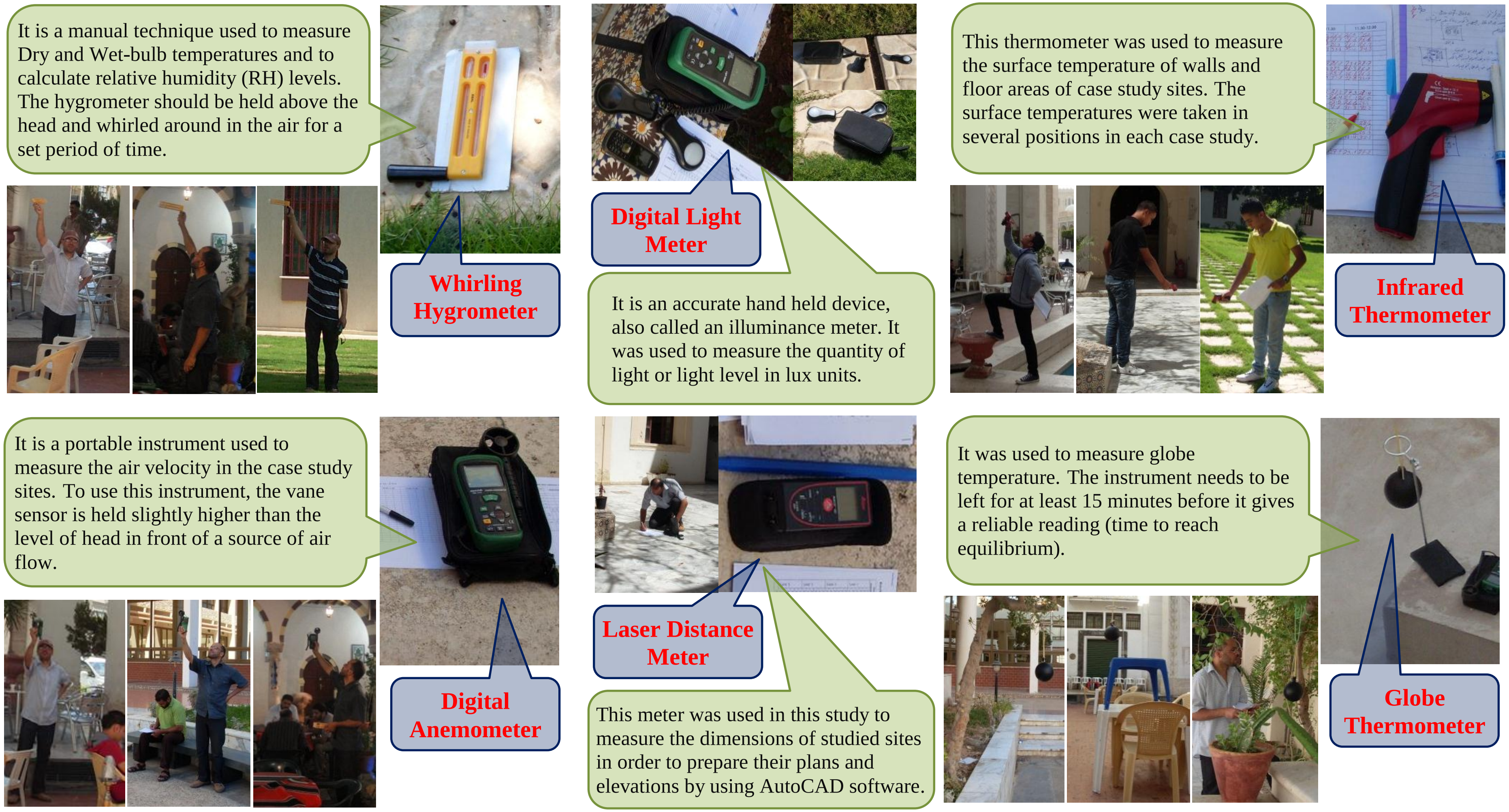
5.7.1.1.6 Laser distance meter

This meter was used in this study to measure the dimensions of studied sites in order to prepare their plans and elevations by using AutoCAD software (Figure 5-3/6).

Figure 5-3: Images showing the equipment used in the field study (Source: author’s survey)

Figure 5-4: Real photographs and brief descriptions for the equipment used in this study.

The equipment used in the field study



In general, the measurements were taken at a height of between 1.50-2.10m above the floor, which represents the height of the subjects at seating and standing positions (except the measurements of the surface temperatures which were at different positions and levels). All the parameters were continuously measured and logged in data collection every ten minutes

5.7.2 Subjective measurements

In this study, the subjective assessments were based on the votes of the courtyards' users on a questionnaire survey on thermal comfort, which was administrated simultaneously with the environmental measurements in each site. More specifically, the assessment of thermal environments in the studied sites was based on the subjects' votes on the thermal sensation scale, thermal comfort scale and thermal preference scale. In this study, the questionnaire surveys were conducted in four enclosed courtyards within the city of Tripoli during winter day-time and summer day/night-times, 2010. In winter, the surveys were carried out in courtyards (C1, C3 & C4) whereas in summer day-time they were conducted in courtyards (C1 & C3), while in summer night-time they were performed in courtyards (C1 & C6), all the details are shown in chapter 7.

5.7.2.1 Questionnaire based survey

The questionnaire technique was used in this study because it is a quick and an inexpensive way (a set of questions) to gather data from individuals. The questionnaire is one of the most commonly-used instruments in field surveys. It has been used in a large number of published field studies in several parts of the world. For this study, the questionnaire form was designed using simple and clear language to be easily understood by the respondents. It was first developed in English and then translated into Arabic (see Appendix 1 and Appendix). In general its design was drawn and developed from some models used in previous studies prepared by Fergus Nicol, Jennifer Spagnolo, Richard de Dear, Valentina Dessì, Aniza and M. Alsousi. Its questions are short and closed while the answers are placed in the form of multiple choice. There is no need to write the answer just select the appropriate ones, to encourage the respondents to understand the questions and answer them very easily. In other words, it was a self-completion questionnaire type, so the respondents can fill the answers themselves.

The questionnaire form has been divided into two parts. The first part begins with an introduction covering details about the site and interviewee (respondents) such as: site location, date, day, and time, survey number, health state, gender and age. After that there is a group of questions concerning weather condition, clothing, activity levels, food consumed, and duration of stay in the site, thermal sensation and thermal comfort. As for the second part, it is composed of a set of questions about the thermal preference and the perception of individual weather parameters

Figure 5-5: photographs taken while the respondents were filling in the questionnaire form (Source: author's survey)

5.7.2.1.1 Subjective scales

The three main scales used were thermal sensation, overall comfort and thermal preference. The thermal sensation scale was the traditional ASHRAE seven-point scale (−3, cold; −2, cool; −1, slightly cool; 0, neutral; 1, slightly warm; 2, warm; and 3, hot). The overall comfort scale was (1, very comfortable; 2, comfortable; 3, slightly comfortable; 4, neutral; 5, slightly uncomfortable; 6, uncomfortable; and 7, very uncomfortable). The thermal preference was the McIntyre scale (right now I want to be "-1, cooler" or ''0, no change" or ''1, warmer"). In general all these scales were used as indirect measures of the thermal acceptability of the studied environments.

5.7.2.1.2 Personal factors

The subjective data included also clothing insulation (clo) and Metabolic Rate (met) for every respondent in every survey. These factors were recorded during the interviews through the questionnaire form and unobtrusive observation. Clothing is an important factor contributing to human response. It gives insight into the way people have adjusted to the prevailing temperatures. For this study, the value of clothing insulation was derived from the Appendix. On the other side, most of the studies in this field have given only a general description of the activity of their respondents. According to Nicol (1993) as cited by (Heidari, 2000), the measurement of metabolic rate is not really necessary in field studies. Based on this and because all the respondents were in sitting or standing position, the analysis of the subjective data is only focused on data concerning clothing insulation.

5.7.2.2 Observations

This method can be used for a variety of purposes during different stages of the study. In this study, a digital camera and observation form were used to record sky condition, physical features of the studied sites (natural and built elements), and the behaviour of the people within the studied courtyards. A large amount of photos/videos was collected during the field surveys in both seasons. The sky condition and attendance of people within the sites were recorded every hour along the time of the survey days. The form designed to use for observation purposes is attached as Appendix 3.

5.7.3 Other data collection

Site location and layout plans for the case study sites were requested from the relevant authorities. Moreover, initial field visits were carried out for every site before starting the experimental work in order to collect data concerning site dimensions, location, orientation, area, urban form, site features and heights of surrounded buildings. Additional data and maps about the city master plan and its physical built forms were requested from Department of Urban Planning.

5.7.4 The samples

The background survey was administrated to everyone using public enclosed courtyards. Participation in the surveys was the same way in all the phases of the field study, any person sat or stood or laid within three metres of the meteorological instruments, he/she was invited to complete a questionnaire (normally there were some rejections), and in general, the questionnaire took from five to ten minutes. This means that all the users of the studied courtyards (who were available at the time when the survey was carried out) had an equal chance of being included in the sample. The subjects involved in the surveys were female and male and their age range was between 17 and 71. The only considerations which were taken into account in choosing any participant were that his/her duration of stay in the studied courtyard should be no less than 30 minutes before the start of the interview, his/her health state should be normal and it was preferable if he/she was familiar with the space (site). The samples are described in detail in chapter 7.

5.8 Conclusion

Conducting fieldwork involving a large number of urban variables and environmental readings by using a few set of equipment was very challenging for the researcher (e.g. more than 120 readings per hour x 11 hours in summer day-time, x 9.5 hours in winter day-time and x 3 hours in summer night-time for every studied site). This complexity seems to be the main reason for the very limited number of field studies on outdoor thermal comfort (Toudert, 2005). Another challenge was that huge amounts of data were gathered from the three field surveys, and therefore it became difficult to analyse all this data. It is therefore suggested using this data in future research in this field.

This chapter dealt with the methods and procedures employed in this study. It described types of data collected from the surveys and the tools/equipment used for this purpose. Details about city case studies and the studied sites are found in chapter 5. Chapter 6 discusses the results regarding the microclimate surveys, whereas chapter 7 discusses the results related to thermal comfort surveys. General conclusions and recommendations are found in chapter 8.

6 MICROCLIMATE MEASUREMENTS

One of the main aims of this chapter is to add some empirical knowledge about the microclimatic behaviour of the enclosed courtyards in hot dry climates. This chapter provides analysis, discussion and conclusion on the microclimate of the studied courtyards during the cold and hot seasons in the city of Tripoli. It starts with a brief introduction on the strategy which was implemented in the analysis process followed by three parts that cover three phases of field study (winter day-time, summer day-time and summer night-time). Each part is sub-divided into three sections. The first one presents, analyses, and discusses the environmental data collected from the field works (microclimate of the studied courtyards). The second section deals with the ranking of studied courtyards based on the changes in the environmental variables. The third contains conclusions regarding the effects of the urban-built form on the courtyards' microclimates. Finally, this chapter ends with a summary of microclimatic variation, and general conclusion.

6.1 Strategy of Analysing the Microclimate of the Studied Courtyards

For the purpose of this study, and in order to investigate how the microclimate varies temporally and spatially and how the built urban form (geometry, architectural form and built and natural elements) influences the microclimate, the analysis and discussion of the environmental data of the three periods (winter day-time, summer day-time and summer night-time) are made in the following way:

1. Studying the microclimate of the studied courtyards by:
    - Comparing and contrasting the pattern of each variable of the microclimate of the studied courtyards during the observation hours and relating the results to the site's built form conditions and sky/weather conditions.
    - Identifying the difference between the highest and lowest reading (range) of each environmental variable and comparing between the studied sites.
2. Ranking the studied sites based on the highest and lowest recorded reading of each environmental variable.
3. Summarising the main effects of the built urban form on the microclimate of the studied courtyards (built urban form and microclimate).

6.2 Part I: Winter Day-time

This study was done over a period of five days covering five case study sites (one day at each site). The study was conducted during January – February 2010, since these months are the coldest according to the meteorological data from the Libyan Meteorological Department, Tripoli. Thus, this study was performed to study day-time courtyards' microclimates during the cold period. All the environmental variables mentioned below were recorded every ten minutes from 09:00 to 18:30h (local time), and then averaged every half an hour. The measured environmental variables include dry-bulb temperature (DBT), Wet-bulb temperature (WBT), Globe temperature (GT), Floor-surface temperature (ST-F), Wall-surface temperature (ST-W), illuminance (ILL), relative humidity (RH) and wind speed (WS), whereas the used measurement units were (ºC, lux, % and m/s).

6.2.1 The studied courtyards

Five different enclosed courtyards were selected for the winter field study to represent three different built-up areas within the city of Tripoli: courtyard C1 (Addamaan) from the colonial city, and courtyard C2 (Al-Baladiaa) from the colonial city as well, courtyard C3 (Dat al-Imad) & Courtyard C4 (F. Engineering) from the post-colonial city, and finally courtyard C5 (Noueiji) from the old city, see Figure 6-1.

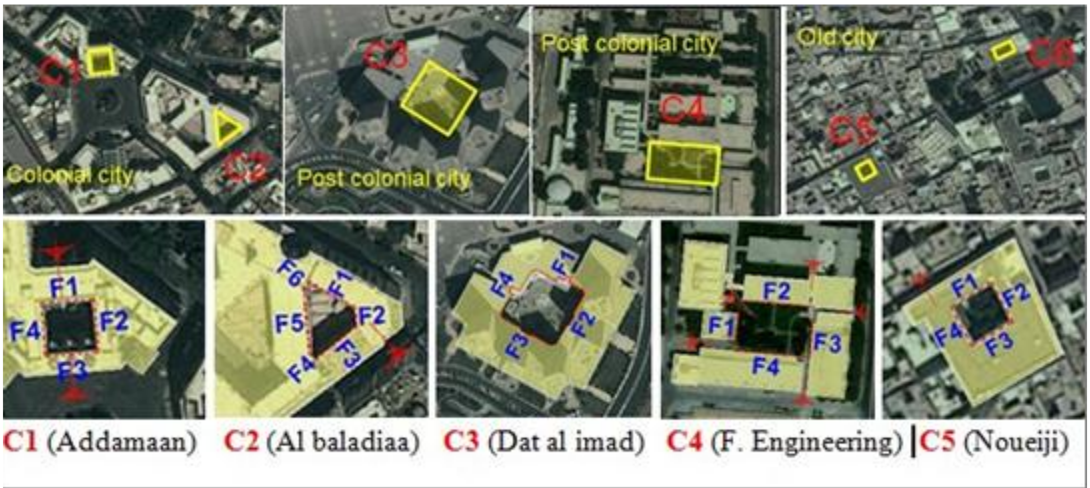


Figure 6-1: Aerial view showing location, orientation and size of studied courtyards (Source: adapted from Google Earth)

6.2.2 Weather and sky conditions

The weather and sky conditions varied from one day to another when the field work was conducted at the studied courtyards. As shown in Figure 6-2, the weather was cold and rainy in the morning and dry after that in the courtyard C1 (Addamaan), whereas the sky was cloudy to partly cloudy. In courtyard C2 (Al-Baladiaa), the weather and sky condition was dry, cloudy to clear. For courtyard C3 (Dat al-Imad), the weather was cold and dry, while the sky condition was cloudy to partly cloudy. The weather in Courtyard C4 (F. Engineering) was slightly warm winter day, whereas the sky condition was partly cloudy in the afternoon. In courtyard C5 (Noueiji), the weather and sky were sunny and clear.

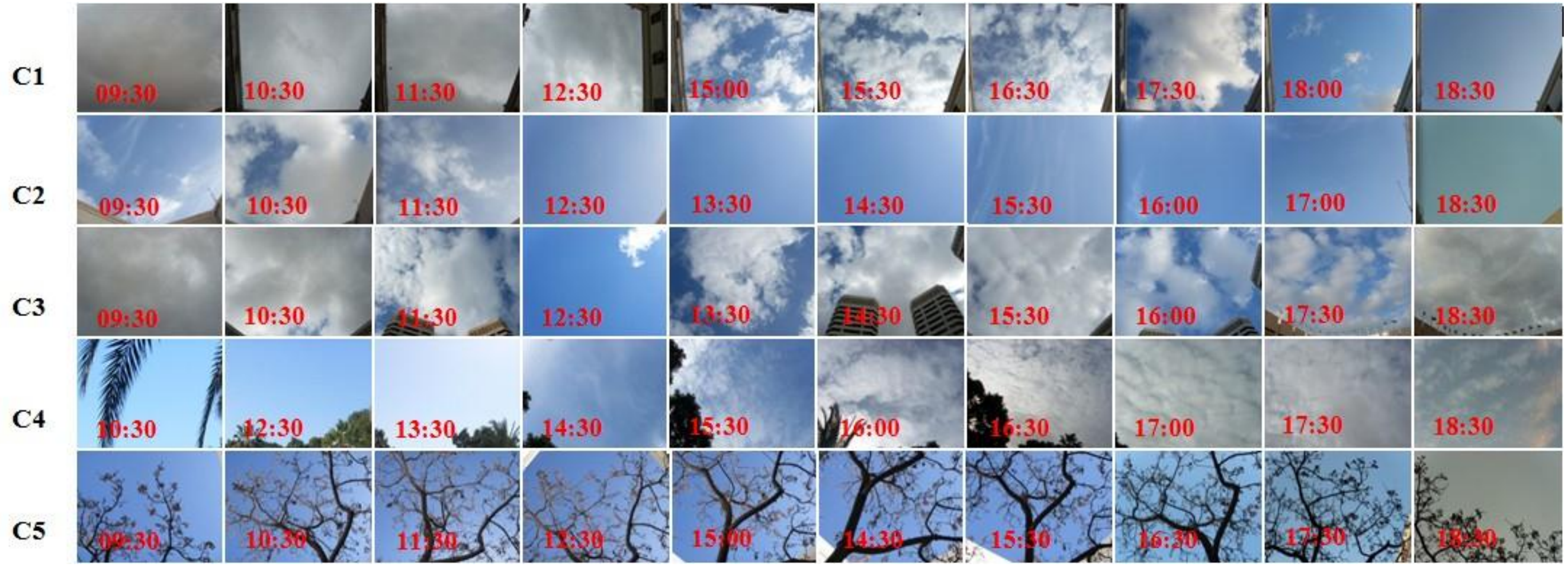
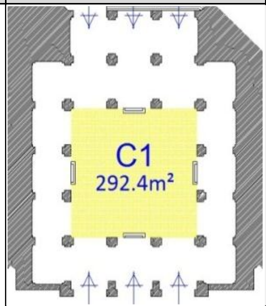
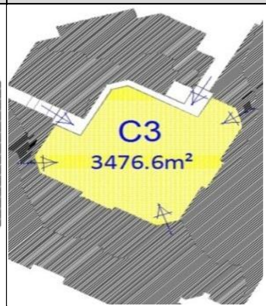
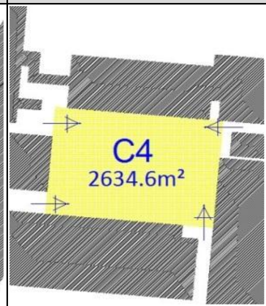
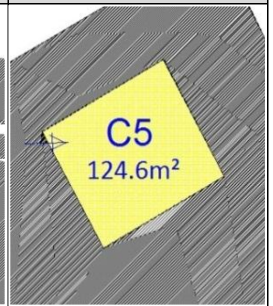


Figure 6-2: Photographs showing sky condition of the studied sites during survey hours/winter day-time (Source: author's survey)

6.2.3 6.2.3 Analysis and discussion of the courtyards' microclimate variables

This section studies and compares the patterns of the environmental variables during the monitoring hours in order to find the variation in daily and seasonal microclimate conditions of the studied courtyards and to understand the relationship between the built urban form parameters (such as location, geometry, architectural form and natural and built elements) and weather/sky conditions and microclimate. The difference between the highest and lowest readings of each environmental variable is also analysed, discussed and compared among the studied sites in order to identify which courtyard is the most dynamic (extreme) or undynamic (stable) site in terms of its environmental changes. Table 6-1 gives an overview about site plan, aspect ratio and minimum and maximum of temperatures which were recorded in the studied sites during winter study.

Table 6-1: Site plan and aspect ratio of the studied courtyards with min and max of (DBT, WBT, GT, ST-F and ST-W) at the sites / winter day-time

Courtyard	C1	C2	C3	C4	C5
 Site plan					
Aspect ratio	0.82	1.92	28.73	62.36	1.39
min DBT (C°)	11.8	13.5	13.0	15.6	13.7
max DBT (C°)	15.5	17.2	14.7	22.7	18.0
min WBT (C°)	10.7	10.8	9.3	9.4	8.2
max WBT (C°)	12.3	13.5	10.4	12	11.2
min GT (C°)	13.8	16	15.1	18.8	15.8
max GT (C°)	18.3	21.5	18	26.5	25.4
min ST-F (C°)	10	12.3	13	7.8	10.7
max ST-F (C°)	12.5	16.8	18.6	14.1	15.7
min ST-W (C°)	11.2	12.6	14.4	12.4	11.4
max ST-W (C°)	14	16.6	16.3	18.4	15.1

6.2.3.1 Dry-bulb temperature and Globe temperature / DBT & GT (ºC)

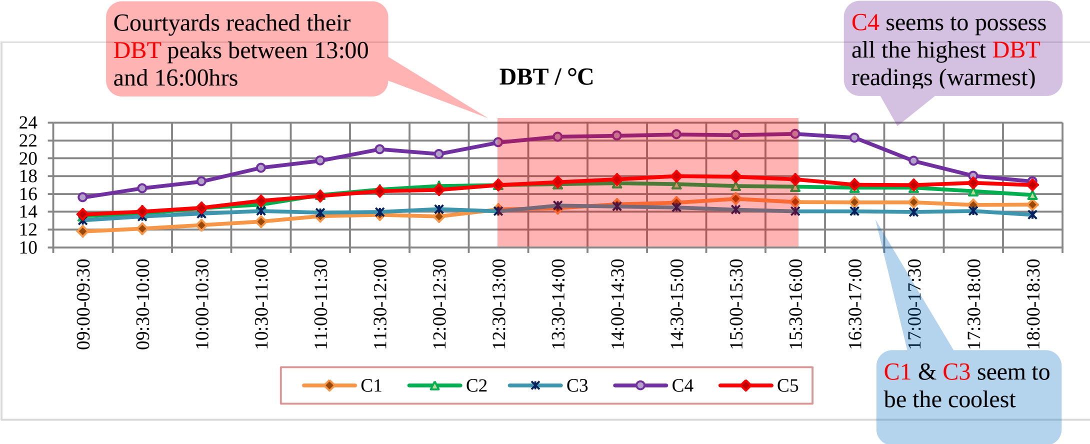


Figure 6-3: Dry-bulb temperature (DBT) at studied courtyards / winter day-time

As illustrated from Figure 6-3, the dry-bulb temperature (DBT) curves of the studied courtyards followed varied paths. The DBT curves of all the sites were very similar and close to each other except for that of C4. Comparing with C4, courtyards C1, C2, C3 and C5 showed low temperatures ranging in general between 11.8 and 18°C. As for courtyard C4, its DBT curve showed relatively high temperatures ranging between 15.6 and 22.7°C. Generally all the courtyards recorded their lowest DBT at 09:30h (morning), while the highest readings (peaks) were observed between 14:00 and 16:00 hrs. The highest reading of dry-bulb temperature (DBT) (22.7ºC) was recorded at 16:00h, at courtyard C4 while the lowest value of DBT (11.8ºC) was observed at 09:30 h, at courtyard C1. In general, courtyard C4 seems to have most of the highest DBT readings followed by C5, C2, C3 and finally C1.

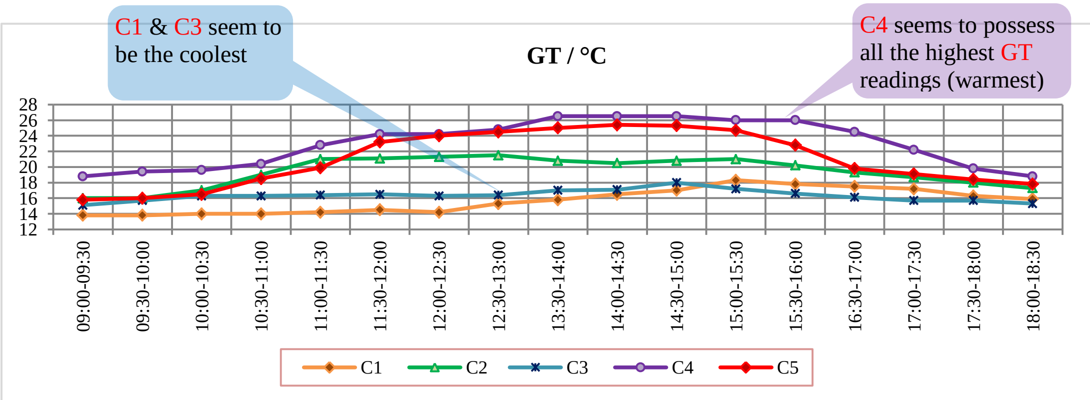


Figure 6-4: Globe temperature (GT) at studied courtyards / winter day-time

As regards the globe temperature (GT), it's clear from Figure 6-4 that the GT curves of the studied courtyards followed to some degree different paths from those of the DBT. Courtyard C4 seems to record the highest reading of GT of 26.5°C at 14:00-15:00hrs, whereas the lowest reading (13.8°C) was observed at 09:30 and 10:00hrs in courtyard C1. In general low globe temperature (GT) readings in all the studied sites were observed in the morning (09:30 and 10:00hrs), and the high readings were found between 13:00 -15:30hrs. Courtyard C4 tended to possess most of the GT highest readings, whilst courtyard C1 seemed to have most of the lowest readings followed by C3. From the results, it’s obvious that the studied courtyards reached their peaks of dry-bulb temperature (DBT) and globe temperature (GT) at different times between 13:00 and 16:00hrs depending on the time and duration of their exposure to the direct solar radiation which in turn affects the thermal environment of the courtyard as a whole.

Courtyard C4 with large size shallower form seems to possess higher DBT & GT readings, and this could be due to its geometry as the site has the biggest aspect ratio among all the studied courtyards which allowed it to receive a large amount of solar radiation.

Courtyard C1 which has the deepest form among all the studied courtyards seems to have lower readings of dry-bulb temperature (DBT) and globe temperature (GT). Courtyard C1 shows a tendency to be cooler that probably because of its geometry has a small aspect ratio (<1) and this seems to play an important role in keeping the site cold by providing shadow. In other words, due to its deep form, only a small part of the C1 surfaces can be directly exposed to the sunlight even at noontime because the solar incident angle in winter is so small. This agrees well with Muhaisen and B Gadi, (2006) who have found that the shading has significant effect on the courtyards with deep form because obtaining solar radiation inside this kind of courtyard in winter is more critical than avoiding it in summer.

6.2.3.2 Floor and Wall surface temperatures / ST-F & ST-W (ºC)

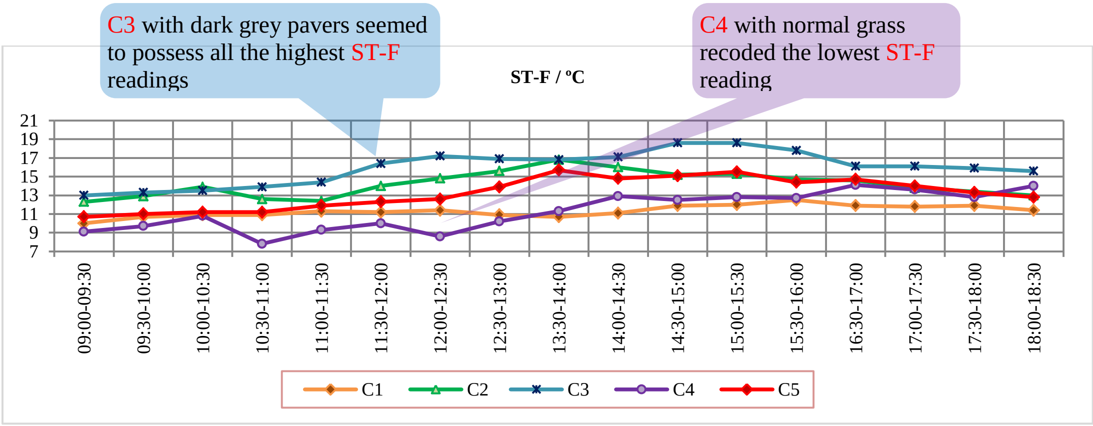


Figure 6-5: Floor-surface temperature (ST-F) at studied courtyards / winter day-time

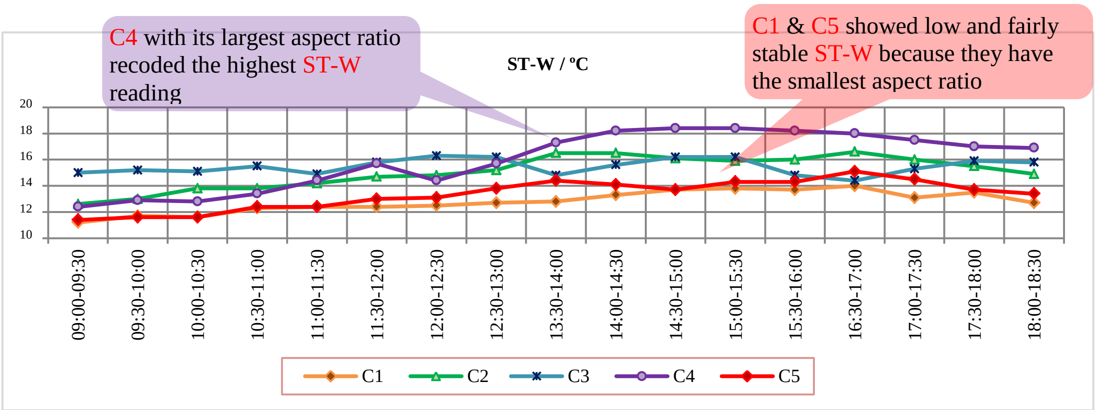


Figure 6-6: Wall-surface temperature (ST-W) at studied courtyards / winter day-time

As it appears from **Error! Reference source not found.**and Figure 6-6, the studied courtyards showed a clear variation in their floor and wall-surface temperatures (TS-F & TS-W) because of the differences in their orientation, geometry and surface colour and material etc. The studied courtyards show floor surfaces temperatures (TS-F) ranging from a minimum of 7.8°C to a maximum of 18.6°C. The highest reading was recorded at C3 at 15:00 and 15:30hrs, while the lowest was observed at C4 at 11:00h. Based on the measured data, the studied sites tended to reach their TS-F peaks between 14:00 and 17:00hrs. Courtyards with small aspect ratio such as C2 and C5 seemed to record their maximum ST-F readings in the early afternoon (14:00h) because of their short duration of exposure to solar radiation. Courtyards with a large aspect ratio like C3 and C4 tended to have their ST-F peaks in the afternoon (15:00-17:00hrs) due to their long duration of exposure to direct solar radiation. In general the highest readings (peaks) always occur when the surface receives intensive solar radiation. In addition to what is mentioned above, the link between the courtyards geometry and their floor-surface temperatures (TS-F) was clearly observed at courtyard C1. Due to its smaller aspect ratio among all the studied sites, C1 shows fairly stable floor-surface temperatures along the hours of the survey day that because its floor area was in complete shade.

The following table compares between the floor-surface temperatures (ST-F) of the studied courtyards based on the colour and material of their surfaces (dark grey concrete, red brick, light grey marble and grass, see Figure 6-7).

Table 6-2: Minimum and maximum readings of ST-F by sites' pavement type and colour

Site	Pavement type	Colour	ST-F (ºC)		Sky condition	Thermal condition
			Lowest reading (min)	Highest reading (max)		
C1	Brick	Red	10	12.5	Cloudy – partly cloudy	Coldest
C2	Concrete	Dark grey	12.3	16.8	Partly cloudy – clear	Second warmest
C3	Concrete P.	Dark grey	13	18.6	Cloudy – partly cloudy	Warmest
C4	Grass	N. green	7.8	14.1	Clear – partly cloudy	Coldest
C5	Marble	Light grey	10.7	15.7	Clear	Second coldest

As it is shown in Table 6-2, under cloudy to partly cloudy sky, dark grey concrete pavers (C3) recorded the highest maximum reading of the ST-F (18.6°C) and tended to possess all the highest readings compared to the rest of the studied courtyards. Dark grey normal concrete (C2) comes second with a maximum ST-F reading of 16.8°C that occurred under partly cloudy to clear sky conditions. After that, the light grey marble (C5), its maximum ST-F value (15.7°C) was recorded under clear sky. As for the minimum readings of ST-F, normal grass (C4) recorded the lowest reading (7.8°C) and had most of the lowest readings among all the studied sites followed by red brick (C1) with a reading of 10°C, then light grey marble (C5) with a reading of 10.7°C.

Figure 6-7: Photographs showing the pavements type and colour of the five studied courtyards / winter day-time

From this comparison it can be clearly seen that courtyards' grounds (floors) paved with dark coloured surfaces (concrete) such as C2 and C3 have a tendency to be the warmest regardless of the sky condition (cloudy, partly cloudy or clear), and this may be due to the high heat capacity and low albedo of the concrete. Although the red brick pavement as C1 has a fairly dark colour, it seems to record low and stable temperatures (10 - 12.5ºC), and this as mentioned above is probably because of the shading effect provided by courtyard geometry (the ground was always in complete shadow). The courtyard ground covered by grass (C4) shows a tendency to be cooler than other ground surfaces during late morning and noontime and slightly warmer than red brick and light grey marble during the afternoon. This might be because of its low albedo and low conductivity, the first enables the grass to absorb large amounts of solar heat during peak sunny hours, most of which is used for evaporating water from the grass, the second enables the grass to release its stored heat slowly and remain warmer during the afternoon and night-time than other pavements with high heat conductivity.

As regards wall-surface temperatures (TS-W), the influence of the courtyards geometry was significant on ST-W during the winter. Courtyards C1 and C5 for instance, show low and fairly stable floor-surface temperatures compared to the other courtyards because of the effect of the complete shade provided by their geometries (as they have the smallest aspect ratio among the studied sites: 0.82 & 1.39 respectively). Another example of the effects of geometry on ST-W, courtyard C3 displayed clear fluctuations in its wall (façade) surface temperatures that are probably because of the effect of the shade provided by its surrounding towers. Despite the solar incident angle in winter being small, the role of orientation can also be seen in determining wall-surface temperatures (ST-W) particularly in the big sized courtyards. Courtyard C4 for example showed obvious variations in wall-surface temperatures, its west-facing wall showed general low surface temperatures in the morning (12.4 – 14.4°C), and high surface temperatures during the afternoon time (16.9 – 18.4°C).

6.2.3.3 The difference between the max and min of DBT, WBT, GT, ST-F & ST-W (range)

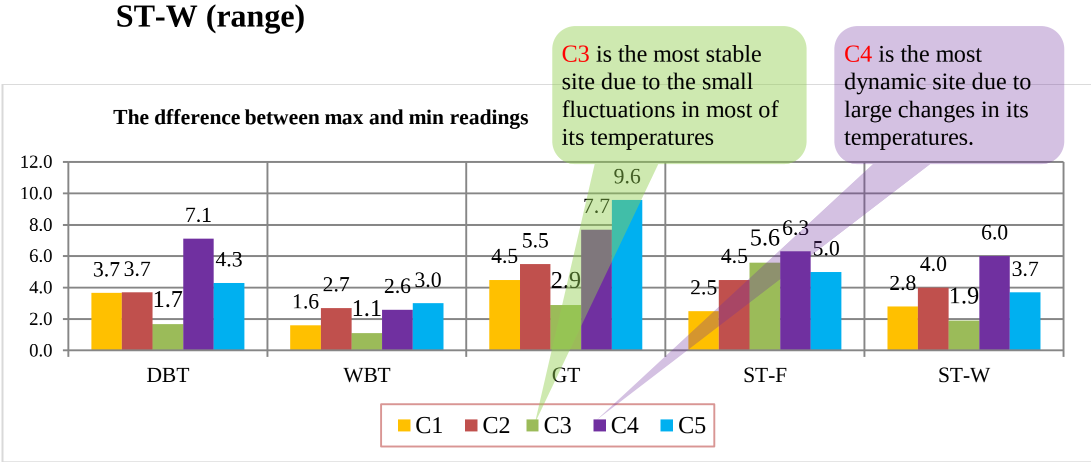


Figure 6-8: The difference between the max and min recorded readings of DBT, WBT, GT, ST-F & ST-W in the studied courtyards / winter day-time

The above chart is produced to study the differences between the highest and lowest values of each environmental parameter and make comparisons between the studied sites in order to identify which courtyard is the most dynamic (extreme) or undynamic (stable) site in terms of its environmental changes. Any parameter has the widest range that means it is the most dynamic while the narrowest would be the most stable. Based on Figure 6-8, the dry-bulb temperature (DBT) range for C4 seems to be wider than others, followed by that for C5, then C1 & C2, and lastly C3. As for wet-bulb temperature (WBT) range, courtyard C5 possesses the widest range followed by C2, C4, C1 and C3 respectively. The globe temperature (GT) range in courtyard C5 is the widest, followed by C4, after that C2, then C1, and finally courtyard C3. For the floor-surface temperature (ST-F), courtyard C4 shows the widest range followed by C3 then C5, whereas courtyard C1 displays the narrowest range followed by C2. The range of wall-surface temperature (ST-W) in courtyard C4 is wider than those in other courtyards followed by C2, C5, C1 and C3 respectively.

Therefore, courtyard C4 is suggested as having the most dynamic site due to large changes in its temperatures (DBT, ST-F and ST-W) compared to other courtyards, and this may be because of the effects of solar radiation and shade provided by trees on these environmental parameters. In other words, this courtyard has the biggest area and aspect ratio among all the studied courtyards, and this allowed it to receive a large amount of solar radiation. At the same time, this courtyard has lots of shade trees, which provide shade for some parts of courtyard. Thus this courtyard has some shaded areas and some sun-exposed areas, and this explains why this courtyard shows large changes in its temperatures. Therefore, it is suggested also that courtyard C3 is the most stable site due to the smaller fluctuations in most of its environmental variables (DBT, WBT, GT and ST-W) compared to all the sites.

6.2.3.4 Illuminance / ILL (lux)

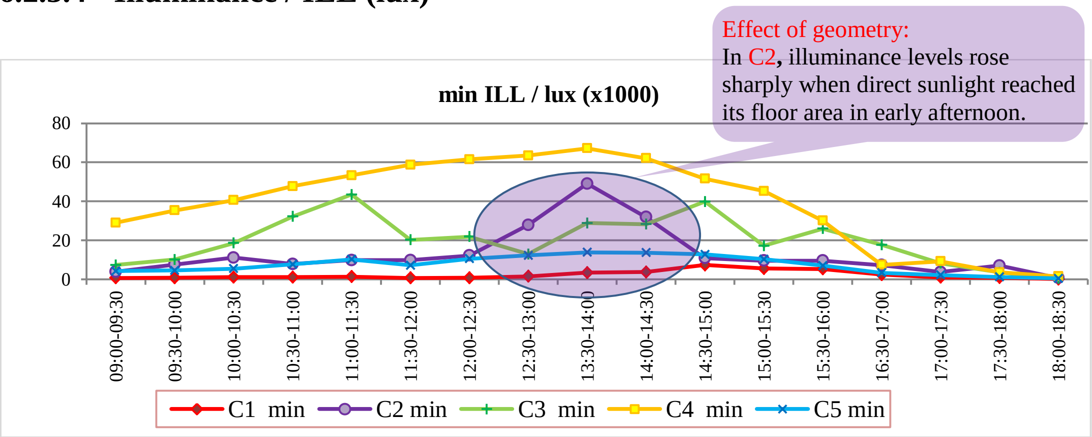


Figure 6-9: Minimum illuminance readings of the studied courtyards / winter day-time

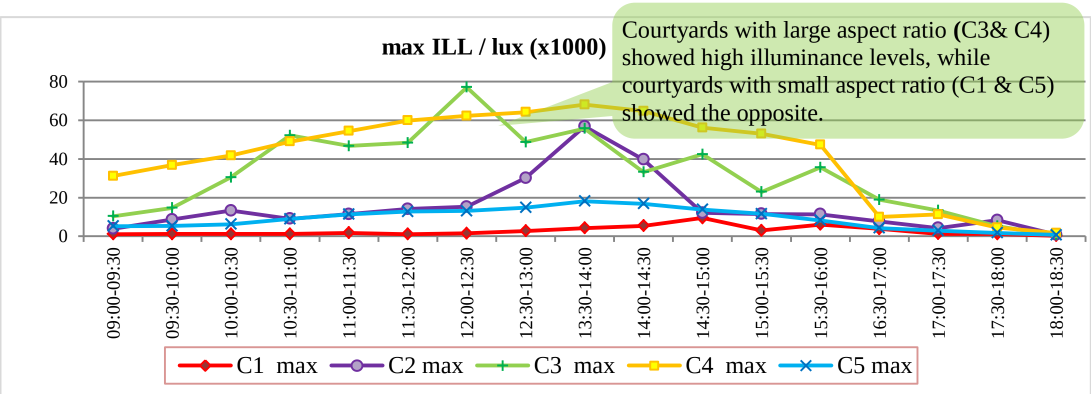


Figure 6-10: Maximum illuminance readings of the studied courtyards / winter day-time

Table 6-3: Minimum, maximum illuminance readings and aspect ratio of the studied courtyards / winter day-time

Courtyard	C1	C2	C3	C4	C5
Aspect ratio	0.82	1.92	28.73	62.36	1.39
min ILL x 1000 (lux)	0.16	0.76	0.41	1.51	0.45
max ILL x 1000 (lux)	9.45	56.80	77.00	68.00	18.17

As is seen in Figure 6-9 and Figure 6-10, the studied courtyards showed varied patterns of illuminance (ILL) under different sky conditions (clear, partly cloudy and cloudy). The courtyards with large aspect ratio (C3 and C4) generally seemed to have high illuminance levels compared to the courtyards with medium and small aspect ratios such as C2, C1 and C5. Courtyards C3 and C4 displayed maximum ILL readings between 30500 to 77000 lux for many hours, from 10:30-16:00h, whereas courtyards C1 and C5 did not exceed 18500 lux throughout the day-time. Concerning courtyard C2, due to its medium aspect ratio compared to other sites, the direct sunlight reached its floor area only at the early afternoon (13:00-14:30h) during which its illuminance rose sharply to record maximum readings between 30000 to 57000 lux.

In general, all the studied courtyards reached their illuminance peaks at 14:00h (early afternoon) except for C3 and C1 which recorded their highest readings at 12:30h and 15:00h respectively. As shown in Table 6-3, the highest illuminance reading was about 77000 lux, whereas the lowest was 160 lux. The first was observed under fairly clear sky at 12:30h in the courtyard C3 (shallow form), while the second was found in C1 (deep form) at 18:30h under clear sky at sunset time.

When comparing between the sites, it’s clear that courtyard C4 tends to have most of the highest readings of illuminance with no clear effect from the sky condition which was partly covered with light clouds. Moreover, this courtyard is the only site which has started its ILL curve with a reading above 30000 lux at 09:30h in the morning and this may be because it has elongated form with large aspect ratio. Under a cloudy sky day condition, courtyard C3 has recorded the highest ILL reading among them all, but its daylight levels were unstable regularly and frequently fluctuated by the shadow of the surrounding towers. From the graphs above, it’s very clear that the geometry has great influence not only on the daylight levels in C3 and C4 but also on those of the rest of the studied sites. Courtyard C2 for instance, as it was mentioned above, has experienced a significant rise in its daylight levels only when the direct sunlight reached its floor area due to the effect of its geometry. Although the sky was clear when the survey was conducted in courtyard C5, its daylight levels were low below 20000 lux because the effect of its small aspect ratio. Due to its small aspect ratio and the sky condition which was completely covered with thick clouds particularly in the morning, courtyard C1 showed a tendency to record the lowest illuminance levels less than 10000 lux (poor daylight levels) throughout the day-time.

Therefore, in general, the geometry seemed to have great influence on the intensity of illuminance inside the courtyards but at the same time, there are also many other factors that can play a role in determining the daylight levels such as season, time of day and sky condition.

6.2.3.5 The difference between the max and min of illuminance (range):

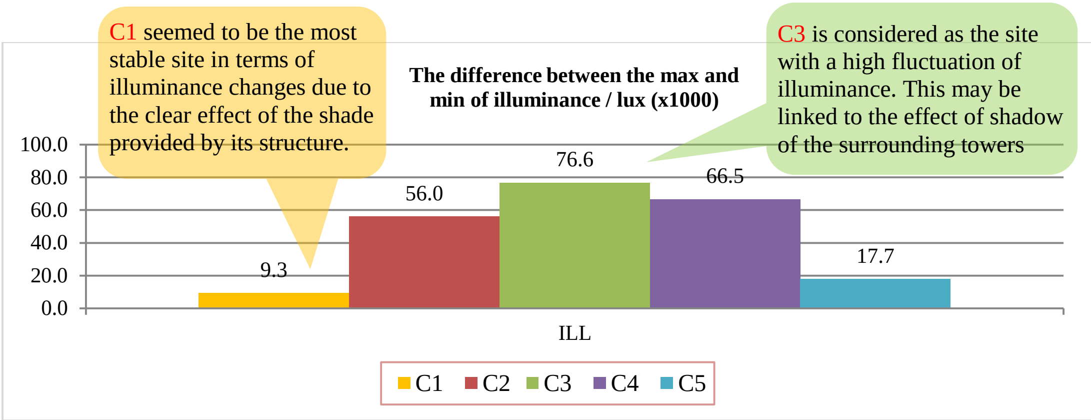


Figure 6-11: The difference between the max and min of illiminance levels in the studied courtyards / winter day-time

Table 6-4: Minimum and maximum illuminance readings and the difference between them in the studied courtyards / winter day-time

Courtyard	C1	C2	C3	C4	C5
min ILL x 1000 (lux)	0.16	0.76	0.41	1.51	0.45
max ILL x 1000 (lux)	9.45	56.80	77.00	68.00	18.17
The difference between min and max	9.3	56.0	76.6	66.5	17.7

Regardless of the sky conditions, the difference between min and max illuminance readings in the courtyards with large and medium aspect ratio tends to be wide, while the range in the courtyards with small aspect ratios seems to be narrow due to the clear effect of the shade provided by their structures (geometry). As it appears from Table 6-4 and Figure 6-11, the wide range of illuminance (ILL) seems to be found in courtyard C3 and followed by that of C4, then C2, whereas the narrowest range of ILL was for courtyard C1 followed by C5. Thus, it suggests C3 (large sized shallow courtyard) as the site with a high fluctuation of illuminance, whereas C1 (small sized deep courtyard) is the more stable site in terms of illuminance changes.

6.2.3.6 Relative Humidity / RH (%)

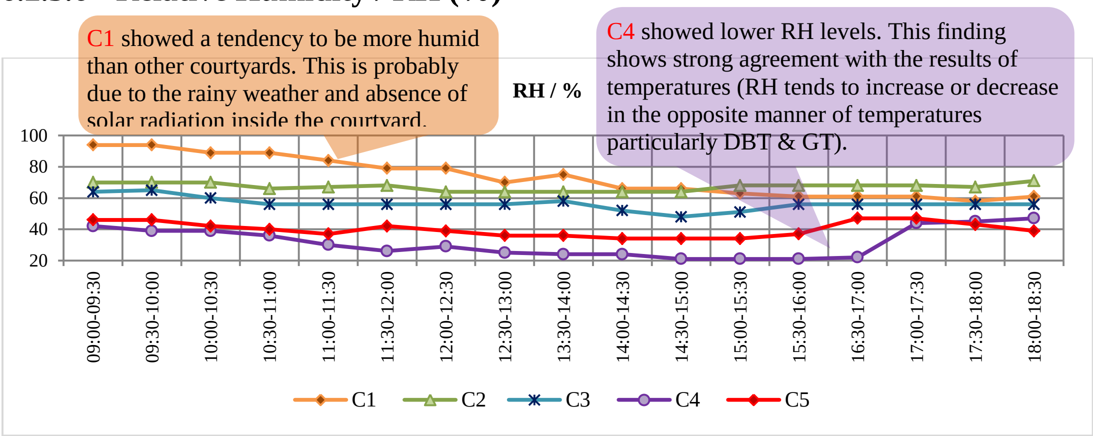


Figure 6-12: Relative humidity (RH) at studied courtyards / winter day-time

Based on Figure 6-12, it seems clear that the relative humidity (RH) patterns in the studied sites were varied. Overall, RH was on average around 58.7% between 09:00-12:00hrs, 49.9% between 12:00-15:00hrs and 51.2% between 15:00-18:30hrs. The highest reading (94%) was observed in the courtyard C1 in the morning under a rainy and dark sky, while the lowest reading (21%) was found in courtyard C4 during the afternoon time in a dry and slightly warm day (unusual in the winter season). When comparing between the sites, it was found that courtyards C1, C2 and C3 (cool sites) have a tendency to be more humid than courtyards C4 and C5 (warm sites). This finding shows a strong agreement with the results of DBT and GT. In general it seems that the relative humidity has a relation with the temperatures (RH tends to increase or decrease in the opposite manner of DBT and GT in particular), therefore the factors which may affect temperatures may affect relative humidity as well such as solar radiation.

6.2.3.7 The difference between the max and min of relative humidity (RH) (range):

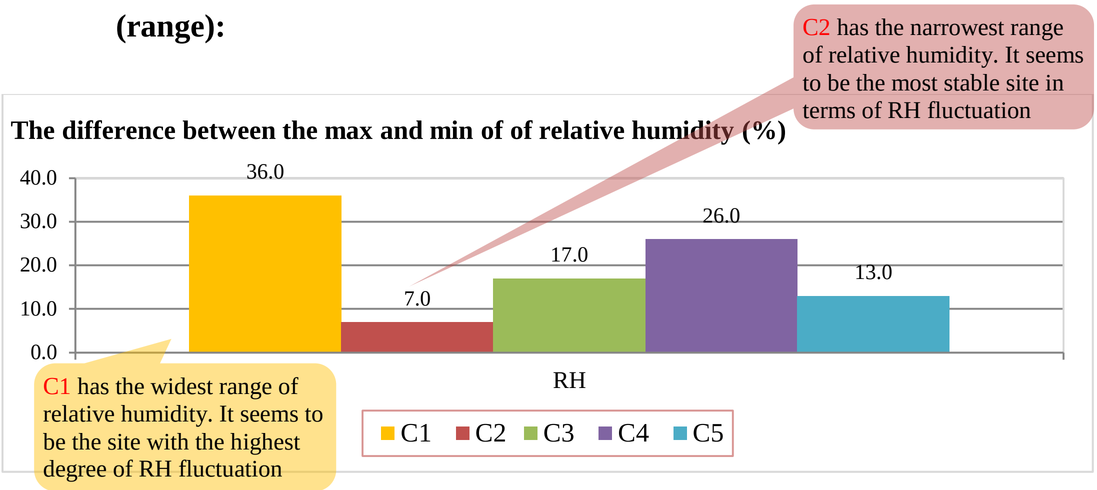


Figure 6-13: The difference between the max and min of RH in the studied courtyards / winter day-time

Table 6-5: Minimum, maximum readings of relative humidity and the difference between them in the studied courtyards / winter day-time

Courtyard	C1	C2	C3	C4	C5
min RH (%)	58	64	48	21	34
max RH (%)	94	71	65	47	47
The difference between min and max	36	7	17	26	13

From Figure 6-13 and Table 6-5, it’s clear that the difference between the maximum and minimum relative humidity (RH) readings was large in courtyard C1 (36%) and courtyard C4 (26%) compared to the other studied courtyards. This is probably related to the weather conditions when the fieldwork was taking place in C1, where it was heavy rain particularly in the early morning and during which the RH reached its highest reading of 94%. As for courtyard C4, the likely reasons behind the high fluctuation in its RH readings are; firstly the large amount of vegetation inside it, which contributed to increased RH levels particularly at the morning and afternoon, whereas the second was the weather condition on the survey day which was an unusual warm winter day, that means the courtyard received a large amount of solar radiation especially during noon and early afternoon which led to lower RH levels and record low readings. Based on the graph, it can be seen that courtyard C1 has the widest range of relative humidity, followed by C4, C3, C5 and lastly C2. It suggests, therefore, that courtyard C1 seems to be the site with the highest degree of RH fluctuation, while the courtyard C2 is the opposite.

6.2.3.8 Wind Speed / WS (m/s)

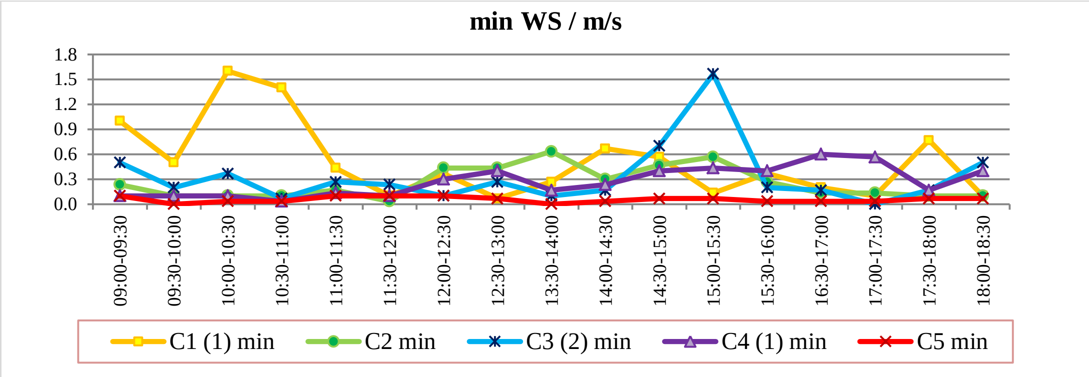


Figure 6-14: Minimum wind speed readings of in the studied courtyards / winter day-time

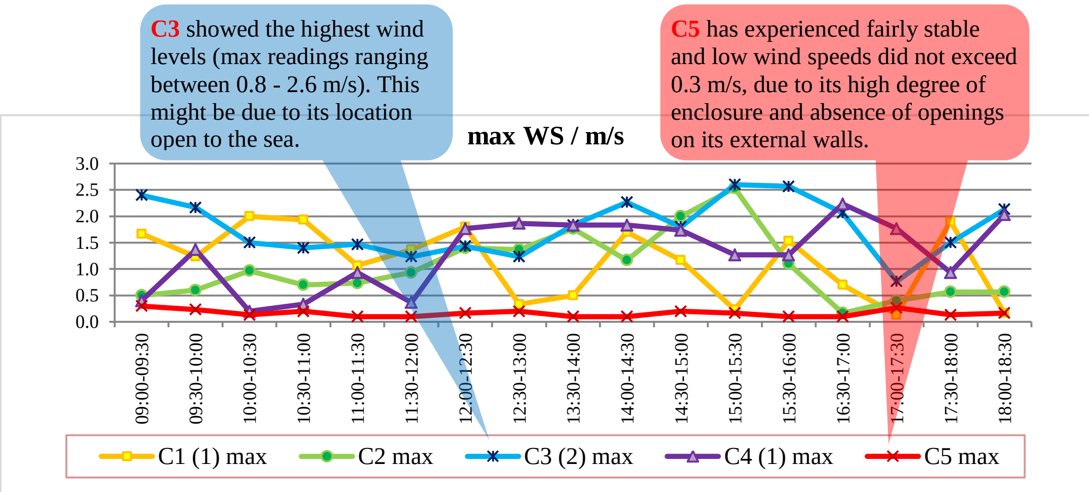


Figure 6-15: Maximum wind speed readings of the studied courtyards / winter day-time

As it can be seen from Figure 6-14 and Figure 6-15, during the survey days, the wind in the studied sites was fairly blowing most of time with different speeds. In general, it ranged between 0.0 - 2.6 m/s with an overall average of 0.7 m/s. The highest wind speed reading was 2.6 m/s recorded in courtyard C3, while the lowest wind speed reading was 0.0 m/s (stagnant) observed in courtyard: C2, C3, C4 and C5. When comparing between the studied courtyards, the results clearly show that the highest average of wind speeds (1.1 m/s) was found in courtyard C3, followed by an average of 0.8 m/s in C1 & C4, then 0.6 m/s in C2 and finally an average of 0.2 m/s in courtyard C5. There are two possible and likely reasons why C3 (max readings ranging between 0.8 - 2.6 m/s) showed high wind levels compared with other sites. As is shown on Figure 6-16, the first reason is due to its location open to the sea (toward the prevailing winter wind), whereas the second is because of its geometry as it has a large size and a shallow form provided with two big gates (openings) through which the wind can reach the courtyard, and surrounded by five towers from east, south and west which act to force the air to flow down therefore increasing the wind speed at the courtyard level.

Figure 6-16: Photographs showing location and openings provided in courtyard C3/winter day-time

Figure 6-17: Photographs showing location and enclosure degree of courtyard C5/winter day-time

As for the reason why courtyard C5 experienced fairly stable and low wind speeds not exceeding 0.3 m/s, that is because of its geometry as it is a fully-enclosed small and shallow courtyard with no openings in the external walls, and located in a very densely built-up area with similar building heights and narrow streets with lack of air circulation, see Figure 6-17.

6.2.3.9 The difference between the max and min of wind speed (WS) (range)

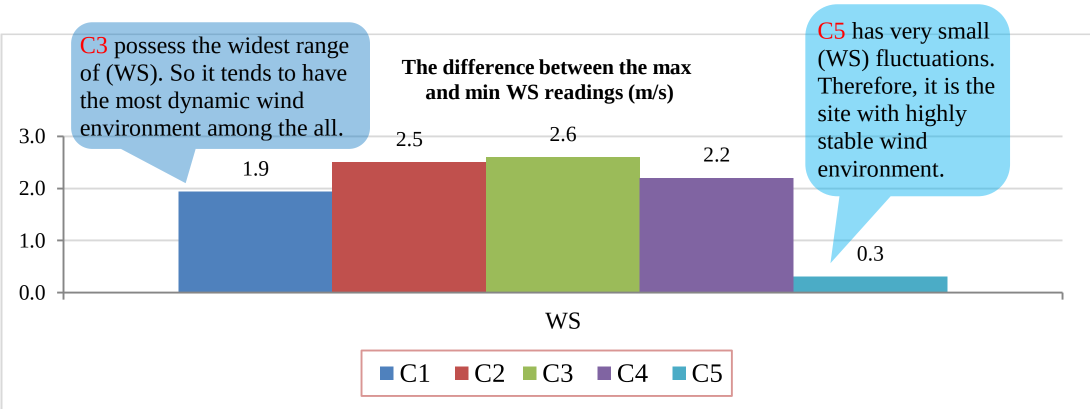


Figure 6-18: The difference between the max and min WS readings in the studied courtyards / winter day-time

Table 6-6: Minimum, maximum readings of wind speed and the difference between them in the studied courtyards / winter day-time

Courtyard	C1	C2	C3	C4	C5
min WS (m/s)	0.1	0.0	0.0	0.0	0.0
max WS (m/s)	2.0	2.5	2.6	2.2	0.3
The difference between min and max	1.9	2.5	2.6	2.2	0.3

Firstly, it is important to note that wind speed (WS) is characterised by giving fluctuated readings even within seconds. From Figure 6-18, it appears that courtyard C3 tends to possess the widest range of wind speed among all the sites, followed by C2 which has WS range slightly lower than that of C3, and slightly higher than that of C4, and then C1. On the other hand, the wind speed fluctuation in courtyard C5 was very small compared to the rest of the sites. Thus, it suggests that courtyard C3 tends to have the most dynamic wind environment among all the studied sites, and this probably due to its location open to the sea and its geometry as it was mentioned (discussed) above. It is suggested also that C5 is the site with a highly stable wind environment, that's likely because of its geometry as it is a small fully-enclosed courtyard with no openings on the external walls, and is located in very densely built-up area (a sheltered place).

6.2.4 Ranking of the studied courtyards based on the highest and lowest recorded readings of their environmental parameters: DBT, WBT, GT, ST-F, ST-W, ILL, RH and WS

Ranking the studied sites based on the highest and lowest recorded readings of each environmental variable is done in two categories. The first is concerning the highest (maximum) readings and the order is from the highest (red) to the lowest one (blue). The second category regarding the lowest (minimum) readings and the order is from the lowest (blue) to the highest (red).

Table 6-7: Courtyards ranking based on highest and lowest readings of their environmental variables

	Parameter	Rank of studied courtyards
Highest reading	Dry bulb temperature (DBT)	**C4**, C5, C2, C1, **C3**
	Wet bulb temperature (WBT)	**C2**, C1, C4, C5, **C3**
	Globe temperature (GT)	**C4**, C5, C2, C1, **C3**
	Floor-surface temperature (ST-F)	**C3**, C2, C5, C4, **C1**
	Wall-surface temperature (ST-W)	**C4**, C3, C2, C5, **C1**
	Illuminance (ILL)	**C3**, C4, C2, C5, **C1**
	Relative humidity (RH)	**C1**, C2, C3, **C4 & C5**
	Wind speed (WS)	**C3,** C2, C4, C1, **C5**
Lowest reading	Dry bulb temperature (DBT)	**C1**, C3, C2, C5, **C4**
	Wet bulb temperature (WBT)	**C5**, C3, C4, C1, **C2**
	Globe temperature (GT)	**C1**, C3, C5, C2, **C4**
	Floor-surface temperature (ST-F)	**C4**, C1, C5, C2, **C3**
	Wall-surface temperature (ST-W)	**C1**, C5, C4, C2, **C3**
	Illuminance (ILL)	**C1**, C3, C5, C2, **C4**
	Relative humidity (RH)	**C4**, C5, C3, C1, **C2**
	Wind speed (WS)	**C5 & C3**, C2 & C4, **C1**

According to Table 6-7, the courtyard C4 shows the highest reading of dry-bulb temperature (DBT) among them all, while the lowest reading is in courtyard C1. In looking at the wet-bulb temperature (WBT), courtyard C2 has the highest reading and courtyard C5 the lowest. As for the globe temperature (GT), courtyard C4 seems to have the highest reading, whereas C1 possesses the lowest reading. For the floor-surface temperature (ST-F), courtyard C3 appears to record the highest reading, whilst courtyard C4 tends to record the lowest. Courtyard C4 records also the highest reading of wall-surface temperature (ST-W) and courtyard C1 seems to have the lowest. The highest reading of illuminance is found in courtyard C3, whereas the lowest is recorded in courtyard C1. As for the relative humidity (RH), courtyard C1 has a tendency to have the highest reading, and courtyard C4 has the lowest reading. The highest reading of wind speed (WS) is observed in courtyard C3, whereas the lowest reading is found in courtyards C3 and C5.

Based on the table above, which ranks the studied courtyards in terms of the highest and lowest recorded reading of each environmental parameter, it may suggest that courtyard C4 possesses the highest readings of dry-bulb temperature (DBT), globe temperature (GT), and wall-surface temperature (ST-W), but at the same time it has the lowest readings of floor-surface temperature (ST-F) and relative humidity (RH). Courtyard C3 is suggested as the site with the highest readings of floor-surface temperature (ST-F), illuminance (ILL) and wind speed (WS) and lowest reading of wind speed as well. The results also suggest that courtyard C1 has a tendency to have the lowest readings of dry-bulb temperature (DBT), globe temperature (GT), wall-surface temperature (ST-W) & illuminance (ILL), as well as the highest reading of relative humidity (RH). Courtyard C2 appears to record the highest reading of wet-bulb temperature (WBT), while courtyard C5 seems to possess the lowest readings of WBT and WS.

When looking at the overall ranking of the studied sites in terms of the highest and lowest recorded readings of each environmental parameter, it appears that the variation in the weather and built urban form (physical conditions) of the studied courtyards have played key roles in this result. If we look at C4 for instance, due to its wider area, greater aspect ratio and moderate weather condition during its fieldwork day, it is logical for this courtyard to have the highest readings in dry-bulb temperature, globe temperature and wall-surface temperature as well as the lowest reading in relative humidity. In contrast, C1 has the highest reading of relative humidity that may be because of the cloudy and rainy weather and the lowest readings of dry-bulb temperature, globe temperature, wall-surface temperature and illuminance, and this is probably due to its deeper form and smaller aspect ratio (high shaded area). As for C3, it is expected to record the highest wind speed among them all, that's due to its location and geometry, as it has a wide area, shallow form and is located in an open area close to the sea. C3 also seems to have the highest readings of floor-surface temperature and illuminance despite the sky condition which varied from sunny to cloudy, and this might be because of its large aspect ratio, which allowed a large amount of solar radiation to reach the horizontal surface of the courtyard as well as floor-surface colour and material. Due to its geometry as a small sized courtyard with high degree of enclosure and no openings on the external walls, it is also logical for C5 to record the lowest wind speeds (low airflow). C4 seems to record the lowest reading of floor-surface temperature due to the material of its floor area (full grass).

Thus, it is suggested that courtyard C1 has to some degree an extreme reading for its environmental parameters (low temperatures, low day light levels and high relative humidity levels), followed by courtyard C4 which shows unusually winter warm temperatures, and lastly courtyard C5 which has tendency to have low day light levels and weak air circulation. On the other hand, courtyard C3 then C2 seem to have fairly moderate microclimates.

6.2.5 Built urban form and microclimate

Under varying winter weather and sky conditions (wet, dry, sunny, cloudy, cold and relatively warm), the comparison between the studied courtyards shows that variations in their microclimates is almost due to the difference in their built urban form (physical conditions). Based on the analysis, it is observed that, solar radiation, the proximity to the sea, built form, (architectural form, geometry, surfaces colour and material) and sky conditions are the most factors that seem to have clear effects on the microclimates of the studied courtyards. The most important effects seem to be related to the following factors:

6.2.5.1 Effect of the proximity to the sea (location)

The measurements show that the proximity to the sea may affect the pattern of some elements of the courtyards' microclimates such as airflow and air temperature, particularly where there is no barrier between them. Courtyard C3, due to its location open to the sea records the highest wind speed reading and the highest wind speed average among all the studied sites. The proximity to the sea probably also has some influence on the air temperature pattern inside the courtyards. Under a similar weather condition of other courtyards, courtyard C3 shows a tendency to have the lowest maximum dry-bulb temperature and globe temperature among them all, and that's likely because of its proximity to the sea.

6.2.5.2 Effect of the vegetation

It seems there is no clear evidence of any significant effect of the vegetation on the pattern of any of the microclimate variables of the studied courtyards during the winter study.

6.2.5.3 Effect of geometry (H/W/L) and architectural form

Courtyard geometry (H/W/L) and the architectural form of the studied courtyards (openings, degree of enclosure, shading devices) were identified as the built form parameters influencing courtyard microclimate. In winter where the sun angle is low, the geometry appears to have significant impact on all the environmental parameters particularly in the courtyards with a small aspect ratio. Regardless of the sky conditions during the field work, it was observed that illuminance levels increase with the increasing aspect ratio of the studied sites. Courtyards with a large aspect ratio such as C3 and C4 have recorded high illuminance levels despite their skies being partly cloudy to cloudy most of the time, whereas the low aspect ratio courtyards such as C1 with cloudy to partly cloudy skies and C2 with a clear sky showed low illuminance levels below 20000 lux, and this may be more linked to their limited sky view factors than sky conditions.

Although the ventilation performance of the courtyards generally is weak (Sharples and Bensalem, 2001), in this study it is found that the geometry and architectural form of the courtyard building (shape, openings, height of surrounding walls) have a clear effect on the airflow pattern inside the courtyards. Courtyard C5 which is located in very compact built-up area, has experienced very low air velocity compared with other sites, and this is likely due to its small size form, high degree of enclosure and absence of external openings.

Clearly the weather condition has played some role in shaping the microclimates of the studied courtyards. However from the comparison between the sites it appears that the effect of the shade generated by the courtyards' geometry was greater especially in the deep courtyards, as it was observed in courtyard C1, a similar result was indicated by Muhaisen and B Gadi, (2006). In this courtyard (C1), the effect of the high intensity of shade reached all the environmental parameters as it recorded the lowest averages of dry-bulb temperature, globe temperature, floor-surface temperature, wall-surface temperature and illuminance, and the highest humidity average among all the sites.

6.2.5.4 Effect of surface reflectivity and thermal properties of surface materials

Surface colours and materials in the studied sites showed a clear effect on the recorded surfaces' temperatures. According to the measurements, generally higher surface temperatures are observed on floors with dark colours except for the cases of the grass and red brick. The latter recorded low and stable temperatures, that's because of the continuous full shade. Among all types of the courtyards' pavements, concrete pavers and tiles in C2 and C3 showed the highest temperatures, followed by grey marble in C5, whereas grass in C4 had the lowest temperatures. Surprisingly, low temperature was also observed on the red coloured bricks in C1, but as mentioned above it is likely due to the complete absence of direct solar radiation inside the courtyard. As for wall-surface temperatures, it is important to note that the recorded temperatures were mostly dependent on the orientation of the façades and size and aspect ratio of the courtyards, that’s because all the studied sites have light coloured façades with similar finishes. In general, from the results of the winter study, high fluctuations in wall-surface temperatures were observed in courtyards with a large aspect ratio, whereas low and stable wall-surface temperatures were found in the courtyards with a small aspect ratio.

In summary, the microclimatic conditions in the studied courtyards are varied depending mainly on the amount of solar radiation received by their surfaces. The courtyards’ geometry and architectural form seemed to have the key role in shaping the microclimates of the studied sites during the winter. The proximity of the site to the sea and the properties of the surfaces appeared to have some influence on some of the microclimate elements of the studied sites.

6.3 Part II: Summer day-time

For the summer field study, the aim was to study day-time courtyards' microclimates during the hot period and the relationship with the urban-built form. July and August 2010 were selected for this study as they are the hottest months of the year. This study was performed in five days (one day per site) during which the environmental variables were measured every ten minutes throughout the day-time from 09:00 to 20:00h (local time), and then averaged every half an hour. The measured variables are related to dry-bulb temperature (DBT), Wet-bulb temperature (WBT), Globe temperature (GT), Floor-surface temperature (ST-F), Wall-surface temperature (ST-W), illuminance (ILL), relative humidity (RH) and wind speed (WS), whereas the used measurement units are (ºC, lux, % and m/s).

6.3.1 The studied courtyards

The study was performed in the same five studied sites where the winter field study had taken place. The sites include: courtyard C1 (Addamaan), courtyard C2 (Al-Baladiaa), courtyard C3 (Dat al-Imad), Courtyard C4 (F. Engineering), and courtyard C5 (Noueiji) see Figure 6-19.

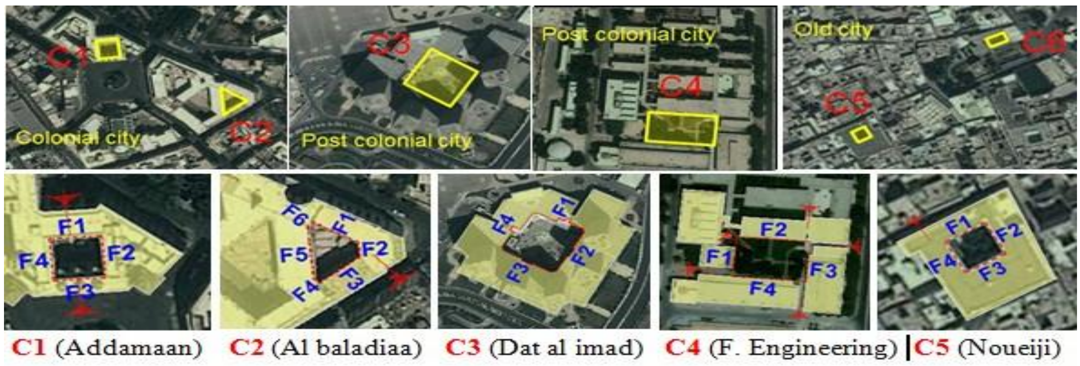


Figure 6-19: Aerial view showing location, orientation and size of studied courtyards/summer day-time (Google Earth)

6.3.2 Weather and sky conditions

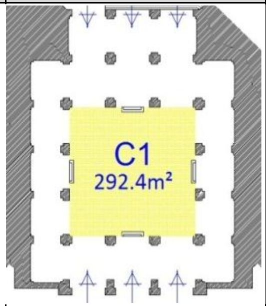
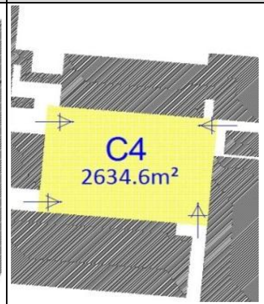
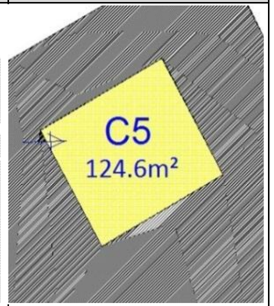
In general the weather and sky conditions during the field works were sunny and clear. The average of dry-bulb temperature of the five studied sites for the period of record was about 28ºC, whereas according the Libyan Meteorological Department, the monthly average mean temperatures in the city was about 28.1ºC in August and

27.1ºC in July, and this means that the field works were conducted within the range of the average temperatures of the normal summer days.

6.3.3 Analysis and discussion of the courtyards' microclimate variables

As in Part I, this section studies and compares the patterns of the environmental variables during the monitoring hours in the studied sites as well as the difference between the highest and lowest readings of each environmental variable. Table 6-8 gives an overview about site plan, aspect ratio and minimum and maximum of temperatures which were recorded in the studied sites during summer day-time.

Table 6-8: Site plan and aspect ratio of the studied courtyards with min and max of (DBT, WBT, GT, ST-F and ST-W) at the sites / summer day-time

Courtyard	**C1**	**C2**	**C3**	**C4**	**C5**
 Site plan					
Aspect ratio	0.82	1.92	28.73	62.36	1.39
min DBT (C°)	27.1	26.9	25.4	26.6	27.7
max DBT (C°)	28.9	29.2	27.7	29.4	29.6
min WBT (C°)	22.4	21.9	21.0	21.5	19.5
max WBT (C°)	24.1	22.7	21.9	24.1	23.4
min GT (C°)	28.8	29.3	27.1	27.8	29.5
max GT (C°)	32.7	32.7	30.4	33.0	34.5
min ST-F (C°)	27.2	26.3	25.0	27.2	26.4
max ST-F (C°)	48.7	49.5	48.5	40.2	42.7
min ST-W (C°)	25.2	29	27	26.3	24.5
max ST-W (C°)	32.4	40	32.4	32.4	29.2

6.3.3.1 Dry-bulb temperature and Globe temperature / DBT & GT (ºC)

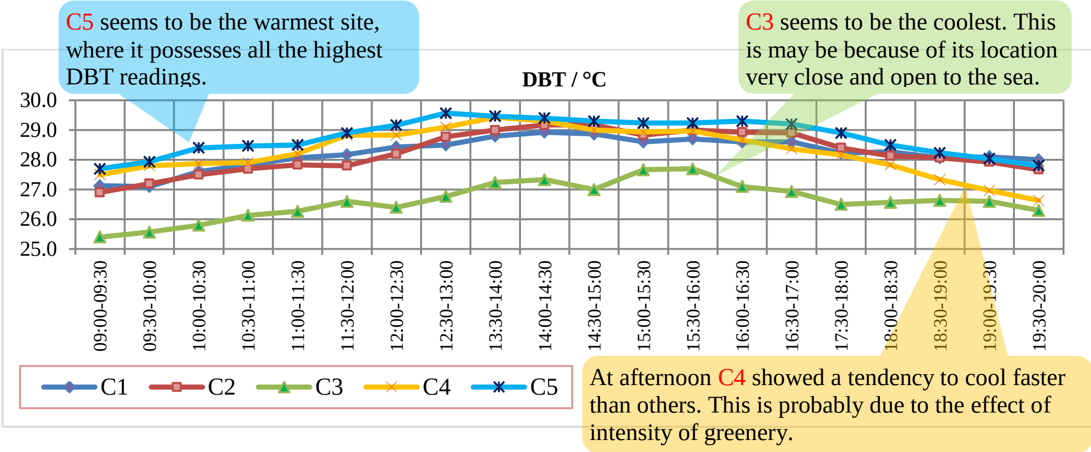


Figure 6-20: Dry-bulb temperature (DBT) at studied courtyards summer day-time

From Figure 6-20 it can be seen that in general, the dry-bulb temperature (DBT) curves of all the studied courtyards followed very similar paths. They started with their lowest readings in the morning, and then increased gradually till they reached their peak in the early afternoon and afternoon, then gradually decreased toward the late afternoon.

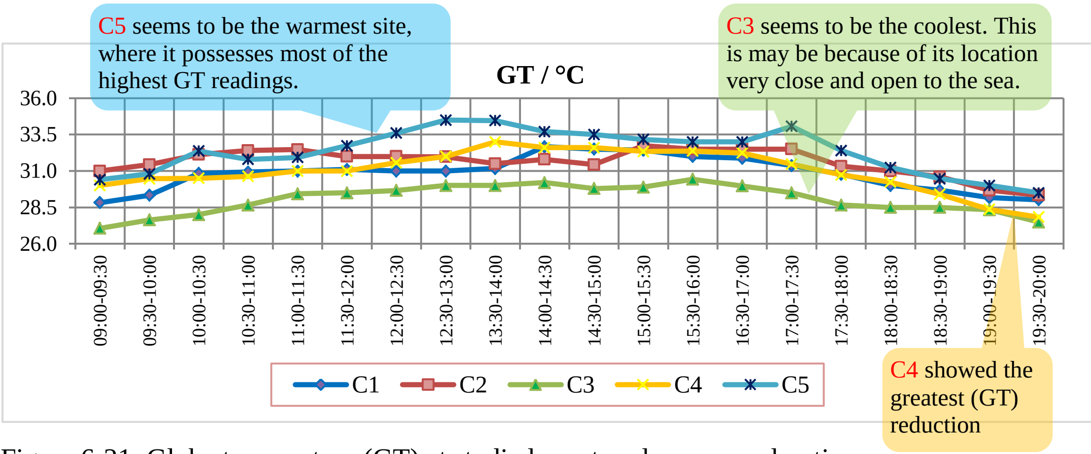


Figure 6-21: Globe temperature (GT) at studied courtyards summer day-time

As for the Globe temperature (GT), in general, the curves followed almost the same paths as those of the DBT with temperature differences of 0.7-5.7°C, see Figure 6-21.

All the courtyards reached their DBT & GT peaks between 13:00 and 16:00h (during peak sunny hours), and this may show the direct effect of solar radiation on the microclimates of the studied courtyards. The small courtyards C1, C2 and C5 ended their DBT and GT curves in late afternoon with readings higher than those of the large courtyards C3 and C4. This indicates that in the afternoon large courtyards have a tendency to cool faster than small courtyards. The highest values of DBT and GT (29.6 & 34.5ºC respectively) were recorded around 13:00h, in courtyard C5, while the lowest values of DBT and GT (25.5 & 27.1ºC respectively) were recorded around 09:30h, in courtyard C3.

Courtyard C5 seemed to record most of the highest DBT and GT readings, whereas courtyard C3 seemed to possess all the lowest DBT and GT readings. Courtyard C5 showed a tendency to be slightly warmer than the others, that may be because of its form, size and surfaces materials. The courtyard has a shallower form (more exposure to the direct sun), small size (its walls are very close to each other) and its floor area was paved with marble (with high reflectivity). This means that the amount of solar radiation inside the courtyard is affected by the diffused and reflected radiation as well as the direct solar radiation. In other words, the overall solar absorption within the courtyard increases by internal reflection and in turn, air temperature increases. As for courtyard C3 which clearly tends to be cooler than the others, that is probably because of its location very close to the sea. So the sea breeze can be expected to lower air temperature inside the courtyard during the summer

In the afternoon between 16:00 and 20:00h, courtyard C4 showed among all the courtyards the greatest GT and DBT reduction of 4.6 & 2.4 °C respectively, which is probably due to the intensity of greenery in the site (providing more shadow and releasing less heat to the environment). This supports the fact that landscape design may help to improve the microclimate in courtyards.

6.3.3.2 Floor and Wall surface temperatures / ST-F & ST-W (ºC)

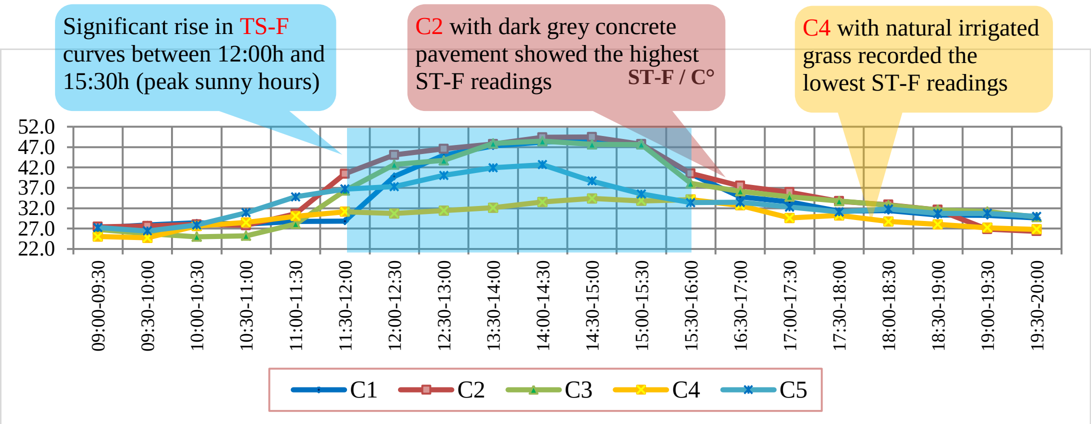


Figure 6-22: Floor-surface temperature (ST-F) at studied courtyards / summer day-time

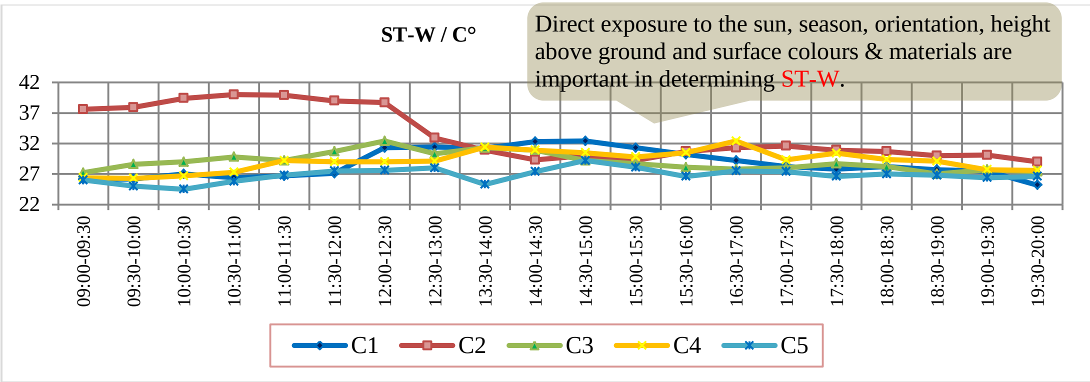


Figure 6-23: Wall-surface temperature (ST-W) at studied courtyards / summer day-time

The surface temperatures of façades and floors varied considerably depending on their exposure to direct solar radiation (surfaces were shaded or sunlit), orientation, height above ground for façades and surfaces colours and materials. As shown on Figure 6-22 the floor surfaces temperatures (TS-F) of the courtyards showed a significant rise in their curves between 12:00h and 15:30h. This clear increase in floor temperatures occurred during the noon and early afternoon time, when the courtyards' horizontal surfaces were exposed intensely to direct solar radiation. From Figure 6-23, wall-surface temperatures (ST-W) were cooler than floor-surface temperatures (ST-F) especially around noon and early afternoon when the differences reached 2–16.3°C. The reason was mainly because the intensity of the solar radiation on the horizontal surfaces is much more than on the vertical surfaces particularly during noon and early afternoon, due to different angles of incidence of the solar radiation. At the same time, it should also be noted that the courtyards' façades (walls) have lighter colours (high reflectivity) than the floor areas, which is probably one of the important factors made a deference between them.

When comparing between the studied courtyards in terms of floor-surface temperatures, C2 which is paved with concrete has a tendency to be the warmest site followed by C3 (paved with concrete pavers) then C1 (paved with red bricks) then C5 (paved with marble) and lastly C4 (full of grass). This is clearly linked to the material (thermal properties) and colour of the floor-surface of each courtyard as shown in Figure 6-24.

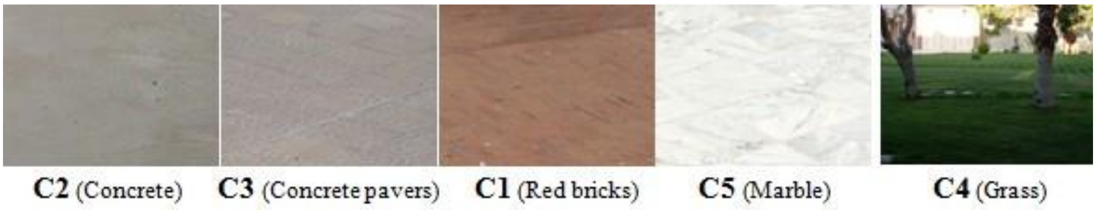


Figure 6-24: Photographs showing the pavements type and colour of the five studied courtyards / summer day time

Under the same sky conditions (clear sunny), the highest floor-surface temperature was observed on concrete (C2), with up to 49.5°C, followed by concrete pavers (C3) with 48.7°C, then red bricks (C1) with 48.5°C and then marble (C5) with 42.7°C, while the coolest surface was grass (C4) with temperatures up to 34.4°C. In general, floor surfaces with fairly dark colours such as concrete pavers and red bricks (with low reflectivity), displayed higher temperatures than floor surfaces with light colours such as grey marble (with high solar reflectivity), whereas grass despite its small value of reflectivity, seems to be cooler than all the pavements; that may be because a large portion of the received solar radiation by grass was used for the evaporation of the liquid water stored in the grass and soil.

From the recorded measurements, it can be concluded that courtyard C5 seems to be the warmest than the other courtyards, followed by C2, C4, C1 and lastly C3.

6.3.3.3 The difference between the max and min of DBT, WBT, GT, ST-F &ST-W (range)

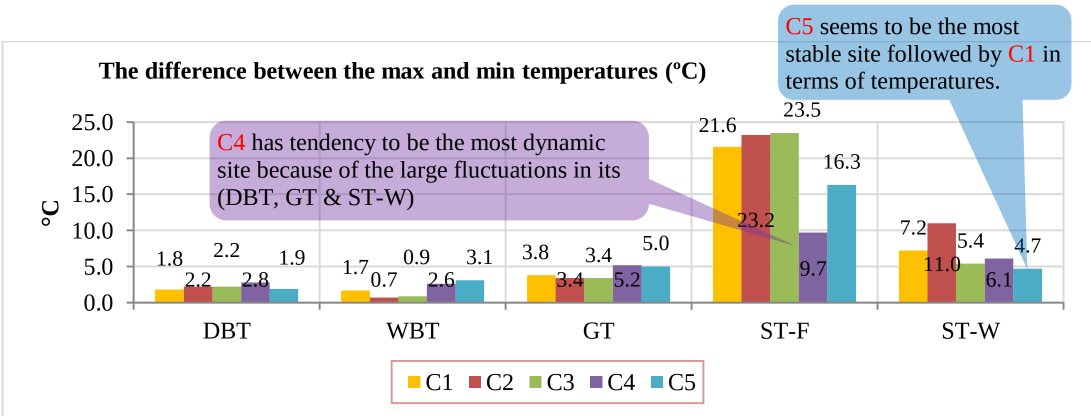


Figure 6-25: The difference between the max and min of DBT, WBT, GT, ST-F and ST-W in the studied courtyards / summer day-time

The above chart is produced to study the differences between the highest and lowest values of each environmental parameter and make a comparison between the studied sites in order to identify which courtyard is the most dynamic (extreme) or undynamic (stable) site in terms of its environmental changes. Any parameter has the widest range that means it is the most dynamic while the narrowest would be the most stable. Based on Figure 6-25, the dry-bulb temperature (DBT) range for C4 is slightly wider than others, followed by C2 and C3, then C5, and lastly C1. For the wet-bulb temperature (WBT) range, C5 possesses the widest range followed by C4, C1, C3 and C2 respectively. The Globe temperature (GT) range in C4 is wide, followed by C5 after that C1 and finally C2 and C3. As for floor-surface temperature (ST-F), courtyard C3 shows the widest range followed by C2 then C1, whereas C4 displays the narrowest range followed by C5. The range of wall-surface temperature (ST-W) in the courtyard C2 is much wider than the other courtyards followed by C1, C4, C3 and C5 respectively. Thus, it is suggested that courtyard C4 has the tendency to be the most dynamic site because of the large fluctuations in its environmental parameters compared to other courtyards, while courtyard C5 seems to be the most stable site. Surfaces temperatures (ST-F & ST-W) possess the widest ranges among all the temperatures due to the greater effect of direct solar radiation.

6.3.3.4 Illuminance / ILL (lux)

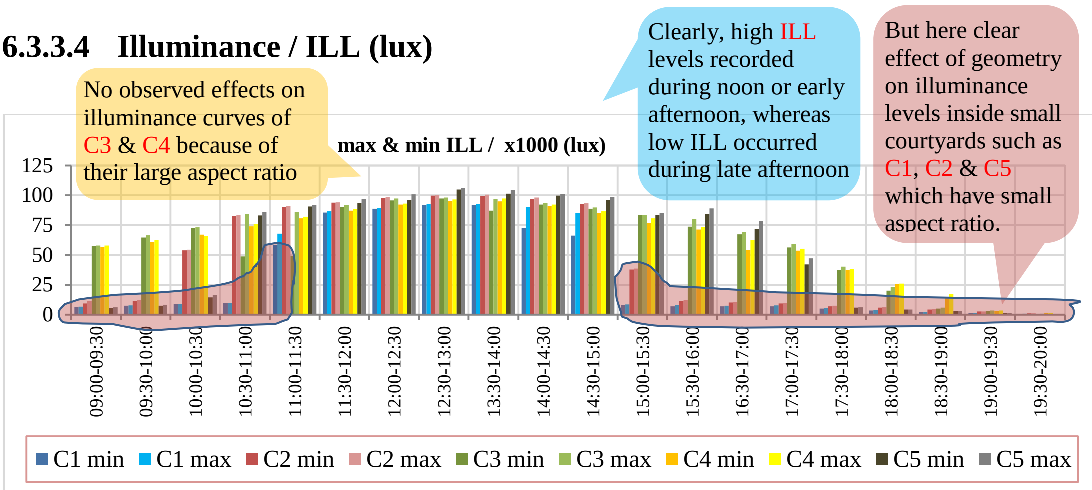


Figure 6-26: Minimum and maximum illuminance readings of the studied courtyards / summer day-time

Table 6-9: Minimum, maximum illuminance readings and aspect ratio of the studied courtyards / summer day-time

Courtyard	C1	C2	C3	C4	C5
Aspect ratio	0.82	1.92	28.73	62.36	1.39
min ILL x 1000 (lux)	0.50	1.05	0.53	1.60	0.39
max ILL x 1000 (lux)	92.77	100.63	98.20	97.30	105.83

Under clear sunny sky conditions, the courtyards' geometries (H/W/L) showed significant effects on the daylight levels (illuminance) inside some of the studied courtyards. It appears from Figure 6-26 that all the courtyards reached their peaks at 13:00h or 14:00h (early afternoon). The highest reading was about 105830 lux, whereas the lowest was 390 lux. Both readings were recorded in courtyard C5, the first was found at 13:00h (early afternoon), while the second was found at 20:00h (late afternoon).

From Figure 6-26 and Table 6-9, it can be seen that there are three different curves (patterns) of illuminance (ILL) levels. The first one is concerning large size courtyards surrounded by two-storey buildings (C3 and C4). In these courtyards which have shallow and wide forms, the ILL levels tend to follow the normal curve without any observed effect from the courtyards' geometers. They started at 09:30h (morning) with values around 60000 lux, and then gradually increased until they reached their highest values of about 98000 lux, at 13:00 & 14:00h (early afternoon), and then decreased gradually toward the late afternoon during which they recorded their minimum levels. The only noticed difference is that at 19:00h, max ILL reading in C4 was 17510 lux, while in C3 it was lower at about 5800 lux, and this indicates the probable effect of the orientation factor in determining the amount and duration of the sunlight entering the courtyards particularly on elongated courtyards (C4).

The second one is regarding small and shallow courtyard C5 (surrounded by a two-storey building). The daylight levels inside this courtyard were slightly influenced by the courtyard proportions (L/W, H/W). The low ILL intensity below 20000 lux was observed before 11:00h and after 17:30h. This is probably when the floor area was almost completely shaded.

The last one is related to the small and deep courtyards C1 and C2; ILL levels inside them were influenced significantly by the courtyards' geometry (L/H/W). In this regard, it was observed that, as the height of the surrounding walls of the courtyard increases, the intensity of solar radiation inside the courtyard decreases. For instance, C2 which is a small courtyard surrounded by three-storey building displayed low ILL levels below 20000 lux before 10:30h and after 15:30h, whereas C1 which is also a small courtyard but is surrounded by four-storey building showed low ILL levels below 20000 lux before 11:00h and after 15:00h. In other words, by looking at the averages of the maximum ILL of the courtyards and their aspect ratios, it was found that as the aspect ratio decreases, the duration of exposure to direct solar radiation decreases and the average of maximum ILL of the courtyard decreases as well. This indicates that a strong relationship was found between the aspect ratio of the courtyards, and the intensity of solar radiation inside the courtyard.

6.3.3.5 The difference between the max and min of illuminance (range)

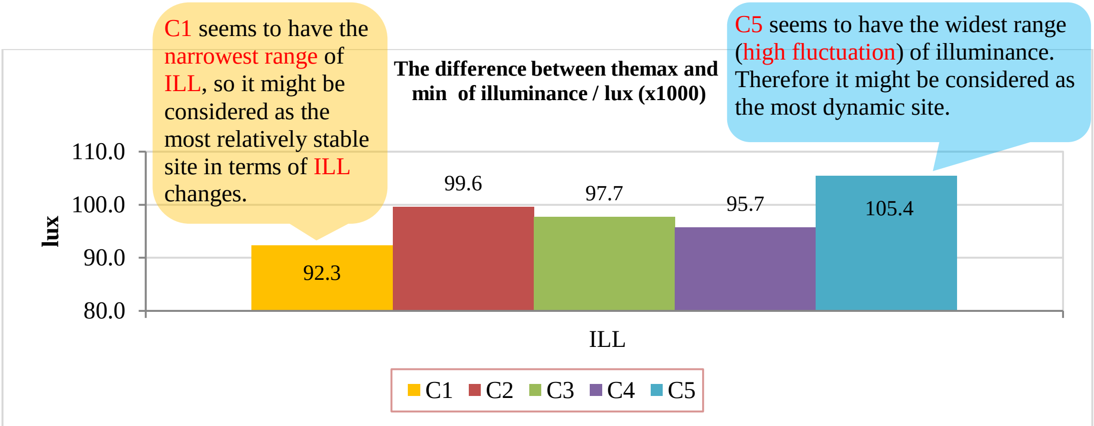


Figure 6-27: The difference between the max and min illiminance levels in the studied courtyards / summer day-time

Table 6-10: Minimum, maximum readings of relative illiminance and the difference between them in the studied courtyards / summer day-time

Courtyard	C1	C2	C3	C4	C5
min ILL x 1000 (lux)	0.50	1.05	0.53	1.60	0.39
max ILL x 1000 (lux)	92.77	100.63	98.20	97.30	105.83
The difference between min and max	92.27	99.58	97.67	95.70	105.44

As is clear from Figure 6-27 and Table 6-10, the difference between the min and max illiminance (ILL) readings (range) in all the courtyards tends to be large, that is because of the direct effect of the intensity of solar radiation (depending on the time when the data was recorded). High ILL values for instance normally occurred during noon or early afternoon during peak sunny hours whereas low ILL values normally occurred during late afternoon when the sun *was* near or below the horizon. Based on the graph above, the courtyard C5 seems to have the widest range (high fluctuation) of illuminance and followed by C2, then C3, then C4 and lastly C1. Under the same weather conditions (a clear sunny sky), the differences of ranges between the studied courtyards are relatively small (they do not exceed 13000 lux). But in general C5 might be considered as the most dynamic site, while C1 is the opposite. As mentioned earlier, this is probably because of geometry of C5 and its light coloured surfaces (with high solar reflectivity), whereas the geometry of C1 (deep form) has a clear effect on the amount and duration of the sunlight entering the courtyard (reducing the time for solar radiation to penetrate into the courtyard). In looking to the courtyards which have recorded the highest values of air and surface temperatures (C1 and C2), we find that the same courtyards have recorded the highest values of illuminance. These results are in complete agreement with the fact that higher illuminance readings suggest the possibility of higher readings for ambient air and surface temperatures.

6.3.3.6 Relative Humidity / RH (%)

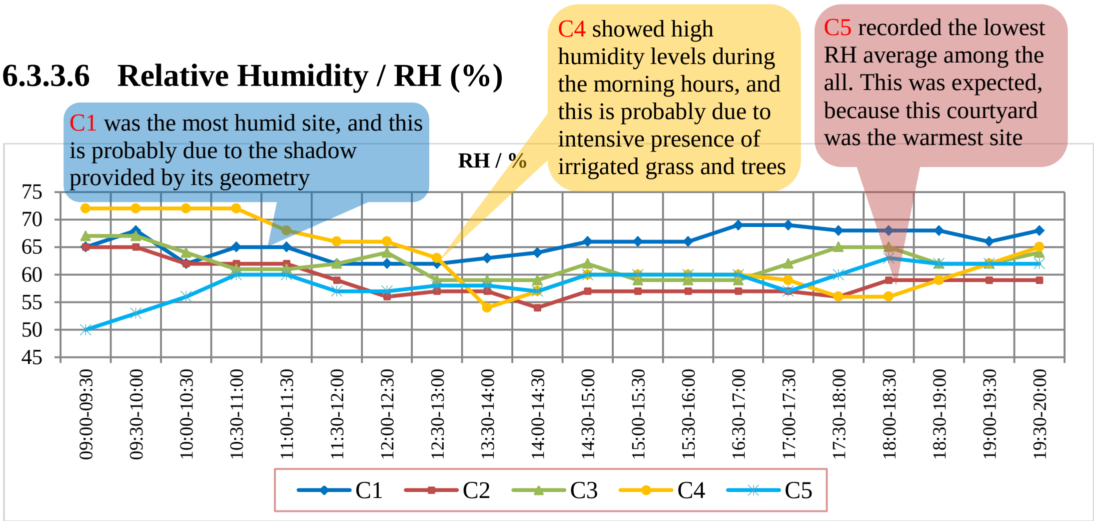


Figure 6-28: Relative humidity (RH) at studied courtyards / summer day-time

From Figure 6-28, it can be seen that the relative humidity (RH) was slightly varied between sites; it was on average around 61.6%. The highest reading (72%) was recorded in courtyard C4, while the lowest reading (50%) was found in courtyard C5. This result was as expected, because courtyard C4 is full of irrigated grass that often requires irrigation particularly during the summer, and this directly affects its humidity values. As for courtyard C5, which was slightly less humid than the other courtyards and had the lowest RH value, that's probably because, as mentioned earlier, this courtyard tended to be the warmest, and had the highest illuminance levels among all the courtyards. This was because of the intensity of the exposure to direct solar radiation as well as the diffused and reflected radiation from the courtyard surfaces. This finding indicates that a clear relationship was found between temperatures, relative humidity, illuminance and solar radiation. RH seems to increase or decrease in the opposite manner to the temperatures and ILL.

6.3.3.7 The difference between the max and min of relative humidity (RH) (range)

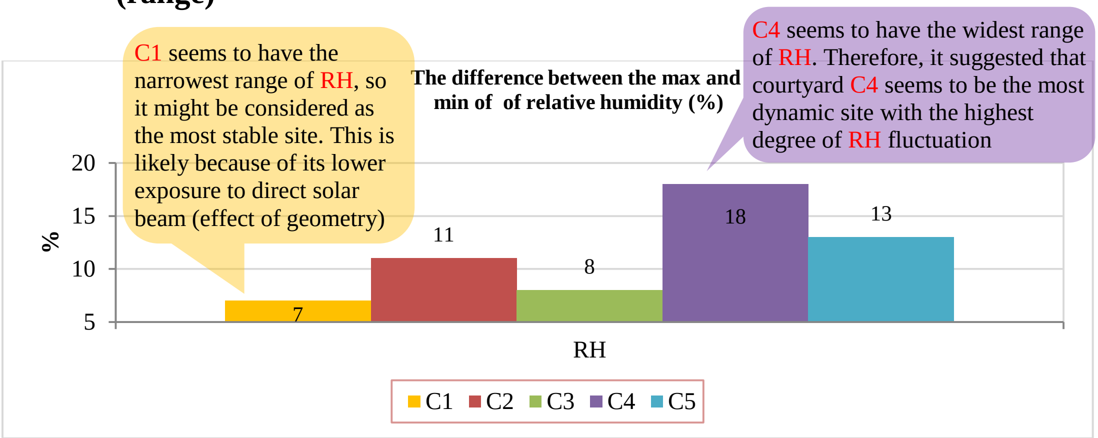


Figure 6-29: The difference between the max and min of relative humidity (RH) in the studied courtyards / summer day-time

Table 6-11: Minimum, maximum readings of relative humidity and the difference between them in the studied courtyards / summer day-time

Courtyard	C1	C2	C3	C4	C5
min RH (%)	62	54	59	54	50
max RH (%)	69	65	67	72	63
The difference between min and max	7	11	8	18	13

As it shown on Figure 6-29 and Table 6-11, the difference between the relative humidity (RH) ranges of all the studied courtyards does not exceed 11% (small). This is probably due to the small sizes of the studied sites which do not exceed 3500 m². Courtyard C4, which recorded the highest RH level (in the morning) among all the courtyards, seems to have the widest range of RH followed by C5 then C2, while C1 tends to have the narrowest average followed by C3. Therefore, it is suggested that courtyard C4 seems to be the most dynamic site with the highest degree of RH fluctuation. The reason behind this is likely to be a combination of a large amount of vegetation inside the courtyard (more greenery with fully grassed floor area), and its great aspect ratio. The first may contribute to the increase in RH levels particularly in the morning, and the second enables the courtyard to receive a large amount of solar radiation especially at noon and the early afternoon, which in turn leads to a decrease in RH levels. The courtyard C1 seems to be the most undynamic site (fairly stable compared with other courtyards); that's likely because of its lower exposure to direct solar beam. This courtyard has the smallest aspect ratio among all the studied sites (effect of geometry) which allows a longer time of protection from direct solar radiation, and this makes the courtyard more stable.

6.3.3.8 Wind Speed /WS (m/s):

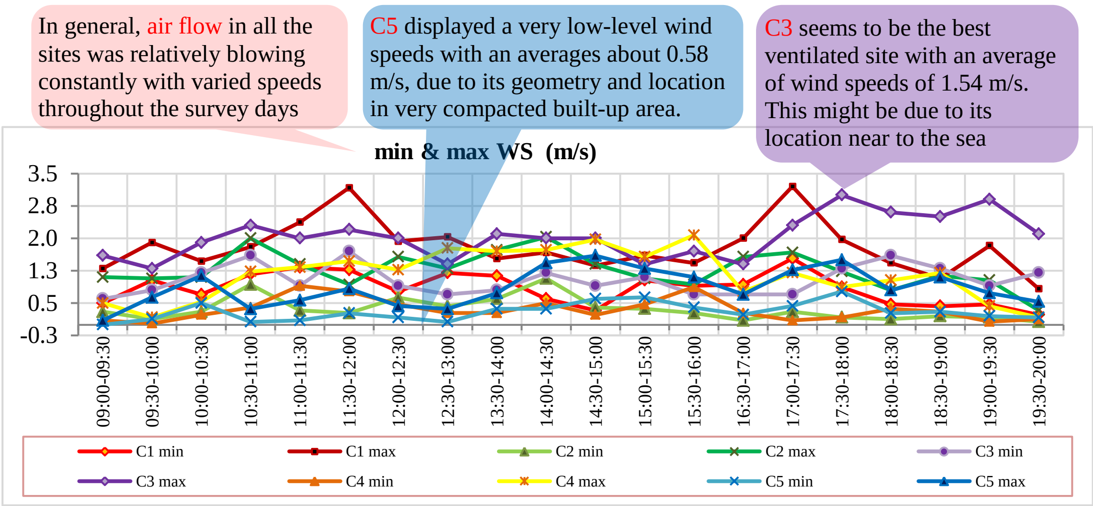


Figure 6-30: Minimum and maximum wind speed readings of the studied courtyards / summer day-time

As seen in Figure 6-30, the air flow (wind) in all the studied courtyards was relatively blowing constantly with varied speeds throughout the survey days. Generally, the courtyards have experienced low wind levels with averages almost below 2 m/s. The maximum wind speed reading (3.2 m/s) was recorded in courtyard C1, while the minimum wind speed reading (0.0 m/s) was recorded in courtyard C5.

When comparing between the studied courtyards, courtyard C3 seems to be the best ventilated site with an average wind speed of 1.54 m/s. This is probably because of its location open to the sea breeze (it’s clear from the chart that the courtyard display wind levels exceed 2 m/s during the late afternoon hours (17:30 - 20:00h) which seems to be the most active time for the sea breeze speed and penetration to reach its maximum). It should be also noted that, the courtyard is provided with two big gates (openings) through which the wind can reach the courtyard at the ground level, so its architectural form and layout may also play an important role in improving the ventilation performance, see Figure 6-31 .

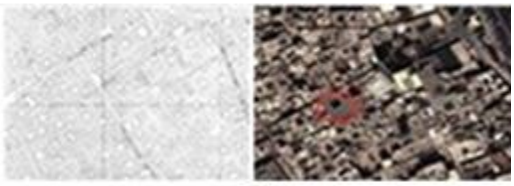
C3

C1

Figure 6-31: Photographs showing location and openings provided in courtyard C3/summer day-time
Figure 6-32: Photographs showing location and enclosure degree of courtyard C5/summer day-time

Although the average wind speed for courtyard C1 was about 1.3 m/s, maximum readings were almost between 1.5 and 3.2 m/s. This indicates that the courtyard has a tendency to be a good ventilated space due to its orientation and physical form and layout (it is provided with three tall openings at the back and front sides to allow the sea breeze to reach the site), see Figure 6-32. It should be noted that the density of trees in the area in between the sea and the courtyard might contribute to slowing down the incoming sea breeze sometimes.

C2 C4



C5

Figure 6-33: Photographs showing location and openings provided in courtyard C3/summer day-time
Figure 6-34: Photographs showing location and enclosure degree of courtyard C5/summer day-time

As for the rest of the courtyards; C2, C4 and C5, generally displayed very low-level wind speeds with averages below 0.9 m/s. This may be linked to many different reasons such as the courtyard's architectural form and layout, geometry, location, built-up area characteristics, presence of greenery etc. C2 for instance has only one small opening that probably is not enough for the air to flow to inside, and because is surrounded by four-storey buildings from the outside that may have an impact to some extent on the incoming wind, see Figure 6-33. The intensity of vegetation landscape in and around courtyard C4, and its location about 7km away from the sea are some of the factors that may lower its wind speed, see Figure 6-33. The geometry and characteristics of the built-up area may have some effect on the wind speed inside courtyard C5, see Figure 6-34. Although C5 has shallow form, it showed a clear lack of ventilation which may be due to its geometry (small enclosed courtyard without ventilation openings), and its location in an area with similar building heights, uniform density and narrow streets.

6.3.3.9 The difference between the max and min of wind speed (WS) (range)

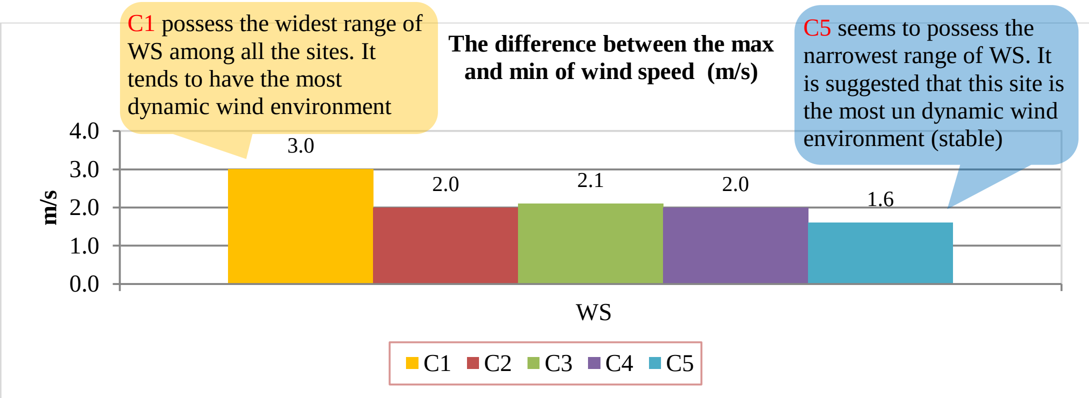


Figure 6-35: The difference between the max and min of wind speed readings in the studied courtyards / summer day-time

Table 6-12: Minimum, maximum readings of wind speed and the difference between them in the studied courtyards / summer day-time

Courtyard	C1	C2	C3	C4	C5
min WS (m/s)	0.23	0.07	0.10	0.03	0
max WS (m/s)	3.20	2.03	2.20	2.07	1.60
The difference between min and max	2.97	1.96	2.10	2.04	1.60

From Figure 6-35 and Table 6-12, it can be seen that courtyard C1 seems to have the highest wind fluctuation, followed by C3 which is slightly higher than C2 and C4. In contrast, C5 seems to possess the narrowest range of WS. It suggests, therefore, that courtyard C1 tends to have the most dynamic wind environment with fairly high wind speed and consistent wind blow among all the studied sites because of its physical form and layout. It is provided with three tall openings at the back and front sides which act as an air tunnel (cross ventilation) to allow for good air circulation within the courtyard. Courtyard C5 is suggested to be the most undynamic wind environment due to its geometry and enclosure and urban form of the surrounding area. This courtyard showed a small fluctuation in its wind speed which may because of its small size with a higher degree of enclosure (fully enclosed). The only way for ventilation in such courtyard is through its sky roof opening, which seems to be influenced by the characteristics of the surrounding area, which has a very compact urban form with similar building heights, big number of courtyards, uniform density and narrow streets.

6.3.4 Ranking of the studied courtyards based on the highest and lowest recorded readings of their environmental parameters: DBT, WBT, GT, ST-F, ST-W, ILL, RH & WS

As in Part I, the studied sites are ranked here in two categories based on the highest and lowest recorded readings of their environmental variables. The first is about the maximum readings and the order is from the highest (red) to the lowest one (blue). The second category concerns the minimum readings and the order is from the lowest (blue) to the highest (red).

Table 6-13: Courtyards ranking based on highest and lowest readings of their environmental variables / summer day-time

	Parameter	Rank of studied courtyards
Highest reading	Dry bulb temperature (DBT)	**C5**, C4, C2, C1, **C3**
	Wet bulb temperature (WBT)	**C1**, C4, C5, C2, **C3**
	Globe temperature (GT)	**C5**, C4, C2, C1, **C3**
	Floor-surface temperature (ST-F)	**C2**, C1, C3, C5, **C4**
	Wall-surface temperature (ST-W)	**C2**, C1 & C3 & C4, **C5**
	Illuminance (ILL)	**C5**, C2, C3, C4, **C1**
	Relative humidity (RH)	**C4,** C1, C3, C2, **C5**
	Wind speed (WS)	**C1,** C3, C4, C2, **C5**
Lowest reading	Dry bulb temperature (DBT)	**C3**, C4, C2, C1, **C5**
	Wet bulb temperature (WBT)	**C5**, C3, C4, C2, **C1**
	Globe temperature (GT)	**C3**, C4, C1, C2, **C5**
	Floor-surface temperature (ST-F)	**C4**, C3, C2, C5, **C1**
	Wall-surface temperature (ST-W)	**C5**, C1, C4, C3, **C2**
	Illuminance (ILL)	**C5**, C1, C3, C2, **C4**
	Relative humidity (RH)	**C5**, C2 & C4, C3, **C1**
	Wind speed (WS)	**C5**, C4, C2, C1, **C3**

From As in Part I, the studied sites are ranked here in two categories based on the highest and lowest recorded readings of their environmental variables. The first is about the maximum readings and the order is from the highest (red) to the lowest one (blue). The second category concerns the minimum readings and the order is from the lowest (blue) to the highest (red).

Table 6-13, courtyard C5 seems to record the highest dry-bulb temperature (DBT) reading, while C3 has the lowest reading. As for wet-bulb temperature (WBT), courtyard C1 appears to have the highest reading, whereas C5 possesses the lowest reading. With regard to globe temperature (GT), C5 appears to record the highest reading, whilst C3 records the lowest. In looking to the floor and wall surfaces temperatures (ST-F & ST-W), it appears that C2 records the highest reading of both ST-F and ST-W. However, courtyard C4 seems to have the lowest reading of ST-F, and C5 possesses the lowest reading of ST-W. For the illuminance, courtyard C5 seems to record the highest and lowest readings among all the sites. As for the relative humidity (RH), courtyard C4 appears to have the highest reading while C5 has the lowest reading. Lastly wind speed (WS), courtyard C1 appears to have the highest reading, whereas courtyard C5 possesses the lowest reading.

According to these results, it suggests that courtyard C5 possesses the highest readings of dry-bulb temperature, globe temperature and illuminance, and on the other hand the same courtyard seems to have the lowest readings of wet-bulb temperature, floor-surface temperature, illuminance, relative humidity and wind speed. It is logical as discussed earlier, that C5 possess the highest readings on DBT, GT and ILL. This is due to, in addition to the direct effect of solar radiation, the courtyard having a small sized shallow form (its walls are very close to each other with very light coloured surfaces) which leads to much potential of internal reflection of radiation, which in turn contributes to a rise in the readings of the mentioned parameters. This might also explain why C5 records the lowest reading on relative humidity and wall-surface temperatures. Due to its geometry and architectural form (small fully-enclosed courtyard) and its uniformity area (similar building heights, density, courtyards etc.), it's also logical for C5 to have the lowest readings of wind speed. C1 appears to record the highest readings of wind speed due to its architectural form and layout. As for C2, it seems to have the highest readings of floor and wall-surface temperatures because of the thermal properties of its floor area as it has a concrete floor. As expected, courtyard C4 records the highest level of relative humidity and the lowest reading of floor-surface temperature among all the sites, that's strongly related to the large amount of greenery inside the courtyard (trees and fully grassed floor area). As for C3, it appears to have the lowest readings of dry-bulb temperature and globe temperature, and this is to some extent expected, probably because of its proximity to the sea (cooling by sea breezes).

In general, therefore, it is suggested that courtyard C5 has to some degree an extreme environmental parameters readings, followed by C2 then C4. On the other hand, courtyard C3 seems to possess a good ventilated environment and moderate air and globe temperatures followed by C1.

6.3.5 Built urban form and microclimate

In summer day-time where the weather was sunny and dry in all the studied sites, the analysis shows variations in the microclimates of the studied courtyards due to the difference in their spatial characteristics. Built urban form (geometry, architectural form and urban fabric), built and natural elements (vegetation & surfaces colour and material) and the proximity to the sea were identified as the most important factors affecting the courtyards' microclimates. The most important effects on the courtyards' microclimate can be summarised as follows:

6.3.5.1 Effect proximity to the sea (location)

The sea breeze seems to have a positive effect on the thermal behaviour of the courtyards located close to the sea during the summer season. This is due to its lower air temperature and higher wind speeds. Courtyard C3 for instance, which is situated in an area open to the sea, was much cooler than the rest of the studied courtyards and has a good ventilated environment. This agrees well with the results reported by Saaroni et al (2000), who found that the sea-shore area in Tel-Aviv, Israel in general appears to be comparatively colder than the rest of the city because of the moderating effect of the sea. The effect of sea breeze on urban climate was also noted by Emmanuel and Johansson (2006) in Colombo, Sri Lanka, where they found a clear difference between three sites located close to the sea. Two of them were much warmer than the third one that is because the sea breeze was blocked by buildings, and cannot reach these sites.

6.3.5.2 Effect of the vegetation

Vegetation seems to have some effect on some elements of the courtyard microclimate. For example, courtyard C3 seemed to record the highest relative humidity level and the lowest floor-surface temperature among all the studied courtyards due to a large amount of greenery on the site (trees and fully grassed floor area). C3 also showed a tendency to cool faster towards the late afternoon than the rest of studied courtyards, which is most likely due to the thermal properties of its floor area (grass), whereas other courtyards with paved floor areas showed slow reduction in their ambient temperature. This is therefore in good agreement with Dimoudi, et al (2003), Ali-Toudert, et al., (2004), Picot, (2004), Attia, (2006) and Biller, (2007b) who have stated that vegetation may help to improve the microclimate in urban spaces.

6.3.5.3 Effect of geometry (H/W/L) and architectural form & layout

Courtyard proportions (deepness and aspect ratio), size (plan ratio) and elements of built form (openings and enclosure) were identified as the most important factors influencing courtyard microclimate. Based on the analysis (under clear sunny sky conditions), a strong relationship was found between the aspect ratio of the studied courtyards and solar radiation gain. In general, as the aspect ratio of the courtyards decreases, the duration of exposure to direct solar radiation decreases (the intensity of solar radiation inside the courtyard decreases), and this in turn affects daylight levels and the ambient temperature (air and surfaces) of the courtyard. However, this effect probably will be more significant in winter (low sun angles). This is in good agreement with Muhaisen and B Gadi, (2006) who have shown that the courtyard proportions and geometry have a considerable influence on the shading performance of courtyard forms.

From the recorded measurements, it was found that courtyard architectural form appears to have significant influence on the ventilation performance of the courtyards. Courtyard C5 for instance, showed a clear lack of ventilation (recorded the lowest wind speed levels) despite it having a shallow form (surrounded by two-storey buildings) and located about only 270m from the sea, but that’s likely because of its small size and fully-enclosed walls. However, courtyard C1 recorded the highest wind speeds among all the studied sites, although it has the deepest form (surrounded by four-storey building) and located about 470m from the sea, and this is probably because it is provided by openings designed to allow air to circulate and cross through the courtyard. No link was found between the courtyards’ geometry and levels of humidity, and this is probably because of the small sizes of the studied sites which do not exceed 3500 m². Relative humidity is likely more sensitive to the presence and intensity of greenery than to any other factor.

6.3.5.4 Effect of surface reflectivity and thermal properties of surface materials

Comparison between floor surfaces temperatures of studied courtyards shows a strong relationship between surface temperatures and surface colours. Floor surfaces with light colours (high reflectivity) recorded lower temperatures than surfaces with dark colours (low reflectivity) except for the case of grass which has special thermal properties and because of the evapotranspiration effect, and this is in strong agreement with the results obtained by Chatzidimitriou et al., (2006) in their study conducted in Thessaloniki city, Greece. Based on the pavement materials, the results reveal that concrete seemed to record the highest temperatures followed by red brick then marble and lastly grass due to their thermal properties (heat conductivity).

A possible correlation between high temperatures and illuminance readings, courtyard size, and surface colour (albedo) was found. From the measurements, it was observed that small sized, fully-enclosed courtyards (C5 then C2) have recorded the highest levels of daylight and the highest averages of air and globe temperatures. This is obviously due to a large amount of solar radiation inside these courtyards, which is affected by the direct, diffuse, and reflected radiation from the surrounding walls, which are very close to each other and have high (bright) albedo. This may explain why these courtyards displayed high daylight levels and high ambient temperatures. In this regard, Toudert, (2005) in her study in Ghardaia city in Algeria has noted that increasing the aspect ratio of streets obviously leads to less potential of solar irradiation of the façades.

In general it can be concluded from the analysis results that direct solar radiation and geometry, the architectural form and layout of the courtyard are found to be the most important factors in shaping the courtyard microclimate during the summer. The thermal properties and colours of the courtyards' surfaces particularly floors also play a significant role in determining the courtyards' thermal environment. It is also important to note that the sea breeze appears to have a clear effect on the thermal performance of the sites that are more open to the sea.

6.4 Part III: Summer Night-time

This study was conducted during the night-time in the hot period. The purpose of the study was to study night-time courtyards' microclimate and relationship with the built urban form during the hot period. This study was conducted in July and August 2010 as they are the hottest months of the year. It was performed in two nights (one night per site) during which the environmental variables were measured every ten minutes along the monitoring time from 22:30 to 01:30h (local time), and then averaged every half an hour. The measured variables were dry / wet-bulb temperature (DBT / WBT), globe temperature (GT), floor / wall-surface temperatures (ST-F / ST-W), relative humidity (RH) and wind speed (WS), whereas the used measurement units are (ºC, % and m/s).

6.4.1 The studied courtyards

Two courtyards used in this study. The first is C1 (Addamaan from the Colonial city) which has a deep and square form, whereas the second is C6 (Bab Bharr from the Old city) which has a shallow and rectangular form Figure 6-36.

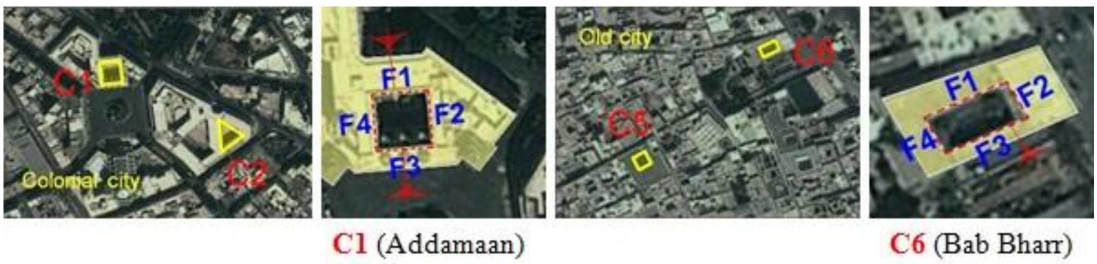


Figure 6-36: Aerial view showing location, orientation and size of studied courtyards/summer night-time (Google Earth)

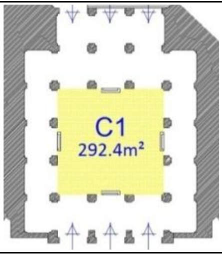
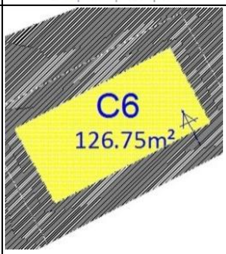
6.4.2 Weather and sky conditions

It was slightly hot with clear skies during the survey nights.

6.4.3 Analysis and discussion of the courtyards' microclimate variables

As explained in Part I and II, the section studies and compares the patterns of the environmental variables during the monitoring hours in the studied sites as well as the difference between the highest and lowest readings of each environmental variable. Table 6-14 gives an overview about site plan, aspect ratio and minimum and maximum of temperatures which were recorded in the studied sites during summer night-time.

Table 6-14: Site plan and aspect ratio of the studied courtyards with min and max of (DBT, WBT, GT, ST-F and ST-W) at the sites / summer night-time

Courtyard		Aspect ratio	min DBT (C°)	max DBT (C°)	min WBT (C°)	max WBT (C°)	min GT (C°)	max GT (C°)	min ST-F (C°)	max ST-F (C°)	min ST-W (C°)	max ST-W (C°)
C1		0.82	32.0	32.5	19.5	21.9	32.4	33.2	26.8	27.7	31.2	31.8
C6		2.96	32.3	34.3	19.2	20.8	33.0	34.1	31.5	32.2	32.4	33.4

6.4.3.1 Dry-bulb temperature and Globe temperature / DBT & GT (°C)

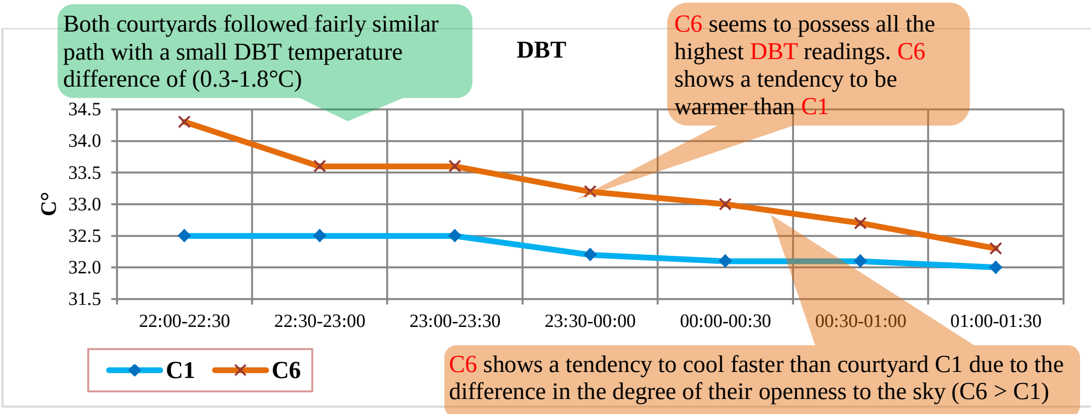


Figure 6-37: Dry-bulb temperature (DBT) at studied courtyards / summer night-time

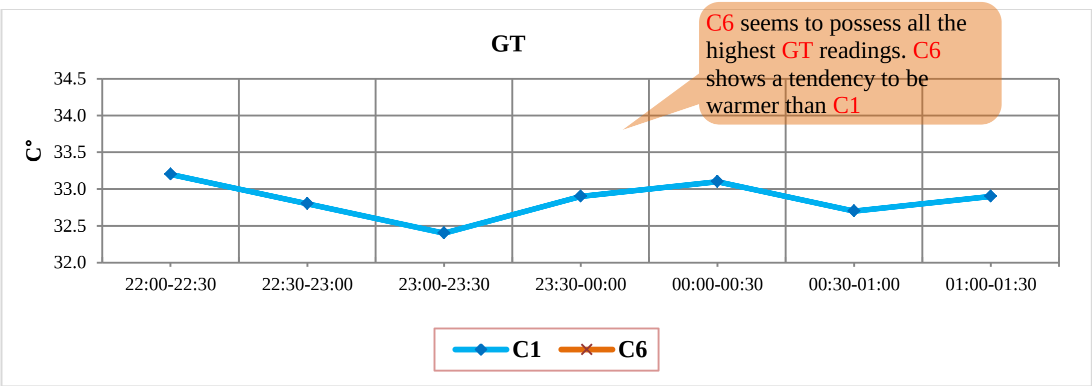


Figure 6-38: Globe temperature (GT) at studied courtyards / summer night-time

As it can be seen in Figure 6-37, the dry-bulb temperature (DBT) curve of courtyard C1 follows fairly the same path as that of courtyard C6 with a small temperature difference of (0.3-1.8°C). Both courtyards started their curves with their highest readings at 22:30h, and then decreased gradually towards 01:30h where they reached their lowest readings. As for globe temperature (GT), generally, the curves followed almost the same paths as those of the DBT with some fluctuations in the GT curve of C1, see

Figure 6-38. Courtyard C6 seems to record the highest readings of DBT and GT (34.3 & 34.1ºC respectively), both were recorded at 22:30h, while courtyard C1 seems to possess all the lowest DBT and GT readings (32 and 32.4ºC respectively), the first was recorded at 01:30h whereas the second was observed at 23:30h.

When comparing between the general trend of DBT and GT distribution in the two courtyards, it appears that they are almost similar. Both the sites show a steady decrease (reduction) in their temperatures towards the late night, particularly courtyard C6 which shows a tendency to cool faster than courtyard C1, and this is likely linked to the degree of the courtyard's openness to the sky. C6 (shallow form) with an aspect ratio of 2.96 is more exposed to the sky than C1 (deep form) with an aspect ratio of 0.82. Therefore, because of its large sky view factor, C6 seems to cool faster in the evening and night-time, whereas C1 with its limited sky view factor, cools more slowly due to its restricted long-wave radiation potential.

In general, due to the clear effect of the geometry and architectural form, courtyard C6 seems to be slightly warmer than courtyard C1. As it was described earlier, C6 has a small size shallower form (rectangular courtyard surrounded by two-storey building on three sides, and a single storey on the fourth side), whereas C1 has a square deep form (slightly bigger than C5 and surrounded by a four-storey building on all sides). In other words, C6 has aspect ratio of 2.96, which is bigger than that of C1 (0.82), that means the duration of exposure to direct solar radiation and the amount of solar heat gain by the surfaces during day-time is more in C6 than in C1. Therefore, the amount of transferred heat to the atmosphere at night is also larger in C6 than in C1. (It's clear that, as the aspect ratio of the courtyard increases, the amount of direct solar radiation inside the courtyard increases, thus the impact on the general thermal performance of the space will be more significant).

6.4.3.2 Floor and Wall surface temperatures / ST-F & ST-W (ºC)

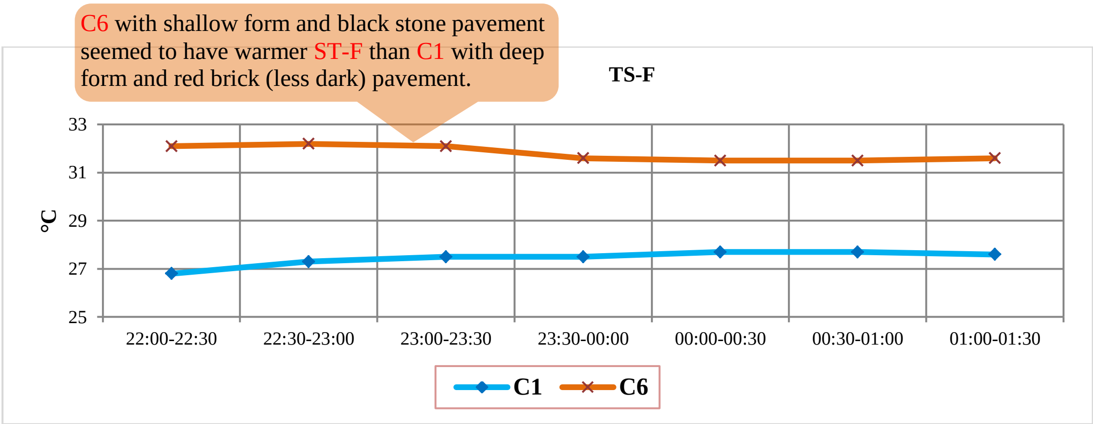


Figure 6-39: Floor-surface temperature (ST-F) at studied courtyards / summer night-time

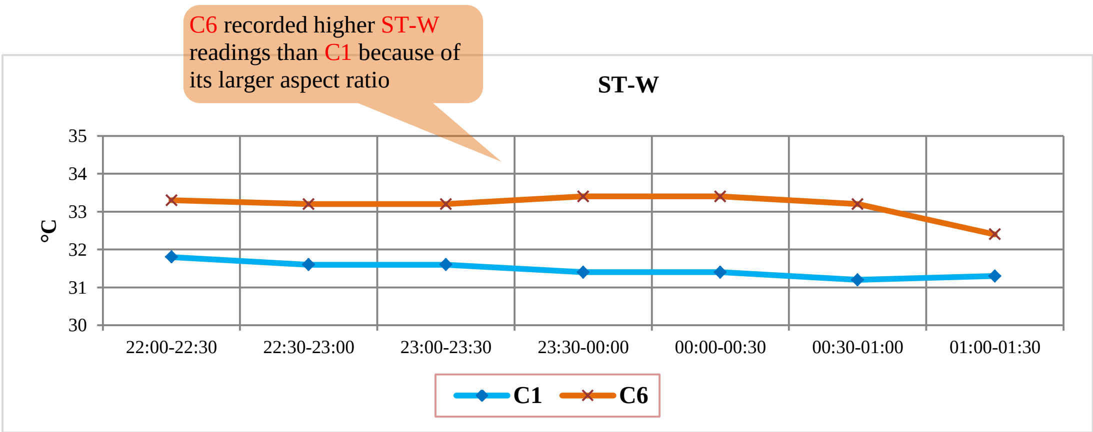


Figure 6-40: Wall-surface temperature (ST-F) ST-W in the studied courtyards / summer night-time

From Figure 6-39 and Figure 6-40, it can be seen that the floor and wall surfaces temperatures (TS-F) and (ST-W) in both courtyards C1 and C6 seemed to be fairly stable over the survey hours due to complete shade (absence of solar radiation). In other words, the general trend of the readings of ST-F and ST-W in both courtyards displayed very small variations (not exceeding 1°C) over the survey time. When comparing TS-W (façades) with ST-F (floors) in both sites, it appears that the TS-W is warmer than the ST-F in both courtyards (however, during the day-time the situation is opposite). The reason for this might be because the floor surfaces of the courtyards can be directly illuminated by sunlight only around noon and early afternoon (short exposure to direct solar radiation), while façade surfaces could be kept exposed to sunlight for even the late afternoon (before sunset). The surface temperatures of façades (walls) and floors varied considerably depending on the duration and time of exposure to direct solar radiation, orientation, geometry (aspect ratio, height above ground for façades, shadow devices, etc.), and surface colours and materials.

When comparing between the courtyards in terms of floor and façade surface temperatures, it's clear that courtyard C6 (shallow form) seems to have warmer ST-F and ST-W than C1 (deep form). Several reasons might contribute to this including geometry, orientation and surface colours and materials. With respect to the effect of geometry factor, it's clear that due to the difference in the aspect ratio values of the two courtyards, C6 with a larger aspect ratio receives and absorbs a larger amount of solar radiation than C1, which in turn acts to raise the surfaces' temperatures and consequently the temperature of the adjacent air layers. Another point related to the geometry is that the front side of C6 which is most exposed to the sunlight is only one-storey in height, and that in turn increases the amount of solar radiation entering the courtyard during day-time.

As for orientation, it also may play some role here, C6 is an elongated rectangle that runs along the NE-SW axis, and this may contribute in increasing the duration of the surface's exposure to direct solar radiation and therefore increasing amounts of heat gain. In looking at the colours and materials of courtyard surfaces, it appears that the floor area of C6 which is fully paved with black stone (dark colour) is warmer than the floor area of C1 which is paved with red brick (less dark), with a temperature difference of 4-5.3°C, see Figure 6-41. This might be linked to the surface colour (reflectivity) and thermal properties of the surface material as well. Pavements with high heat capacity usually retain their high surface temperature and continue to heat the lower atmosphere at night. With regard to wall-surface temperatures (ST-W), as is shown in Figure 6-40 and Figure 6-41, the wall surface of C1 with a slight light colour seems to have a lower temperature than that of C6 with a slight dark colour.

Figure 6-41: Photographs showing floor and wall types and colours of the two studied courtyards / summer night-time

6.4.3.3 The difference between the max and min of DBT, WBT, GT, ST-F &ST-W (range)

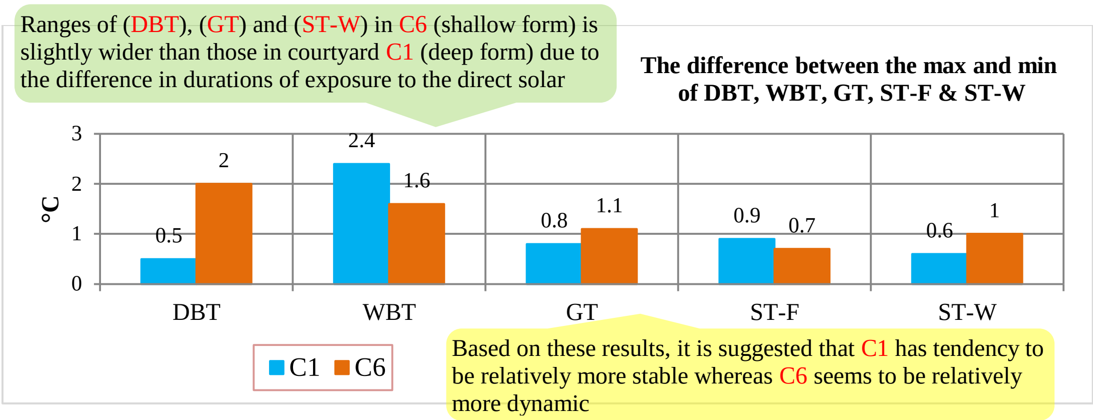


Figure 6-42: The difference between the max and min of DBT, WBT, GT, ST-F and ST-W in the two studied courtyards / summer night-time

The above chart is produced to study the differences between the highest and lowest readings of each environmental parameter (range). Any parameter has the widest range that means it is the most dynamic while the narrowest would be the most stable. It is generally observed that the differences between the highest and lowest readings of all the temperatures (DBT, WBT, GT, ST-F & ST-W) in both courtyards were small and did not exceed 2.4°C because of complete shade (absence of sun/night study).

Based on Figure 6-42, it is clear that the range of dry-bulb temperature (DBT), globe temperature (GT) and wall-surface temperature (ST-W) in courtyard C6 (shallow form) is slightly wider than those in courtyard C1 (deep form) due to the difference in durations of exposure to direct solar radiation and amount of heat gain during the day-time (effect of geometry). For floor-surface temperature (ST-F), both courtyards C1 and C6 have ranges with very close values (but not equal). Therefore, it is suggested that courtyard C1 has a tendency to be relatively more stable whereas C6 seems to be relatively more dynamic (compared to each other).

6.4.3.4 Relative Humidity / RH (%)

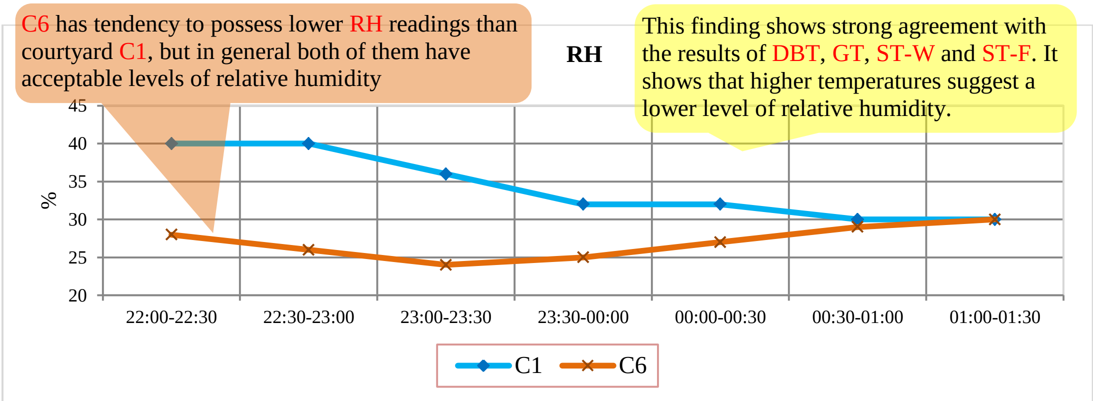


Figure 6-43: Relative Humidity (RH) at studied courtyards / summer night-time

As for relative humidity (RH), from Figure 6-43, it can be seen that RH was slightly varied between the courtyards. C1 seems to have higher relative humidity reading at 22:30h than C6, while at 01:30h, both of them record the same RH reading. The highest reading (40%) was recorded in courtyard C1, while the lowest reading (24%) was found in courtyard C6. The difference in relative humidity between both courtyards seems to be not significant (does not exceed 14%), that is probably because of the similarity in their sizes. Courtyard C6 has a tendency to possess lower RH readings than courtyard C1, but in general both of them have acceptable levels of relative humidity. So this result was entirely expected, because, as mentioned above, both sites were slightly hot during the night-time particularly courtyard C6. This finding shows strong agreement with the results of DBT, GT, ST-

W and ST-F. It shows that higher temperatures suggest a lower level of relative humidity.

6.4.3.5 The difference between the max and min of relative humidity (RH) (range)

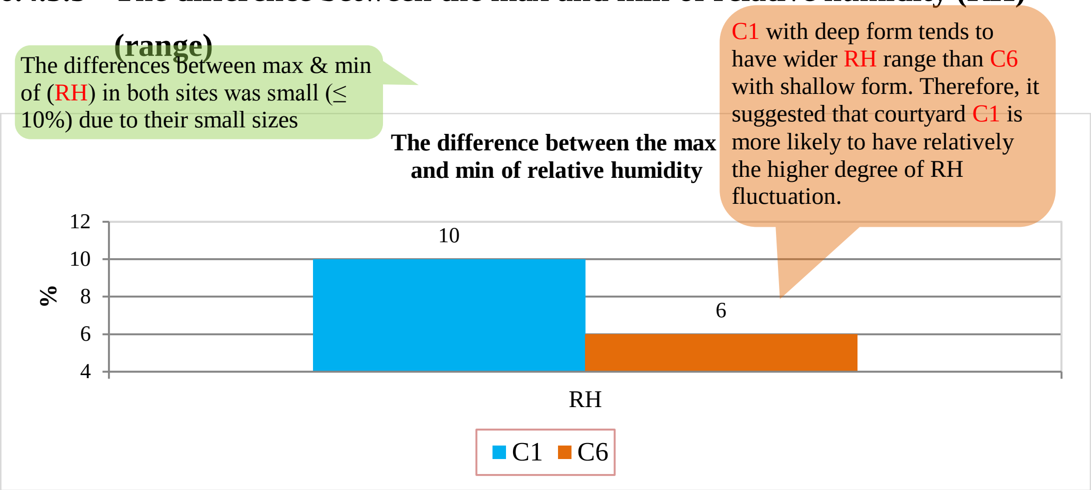


Figure 6-44: The difference between the max and min of relative humidity (RH) in the two studied courtyards / summer night-time

As it appears from Figure 6-44, the relative humidity (RH) range in both studied sites was small, and did not exceed 10% and this might be because of their small sizes. Courtyard C1 (deep form) tends to have a wider RH range than C6 (shallow form). Therefore, it suggested that courtyard C1 is more likely to have relatively the higher degree of RH fluctuation.

6.4.3.6 Wind Speed / WS (m/s)

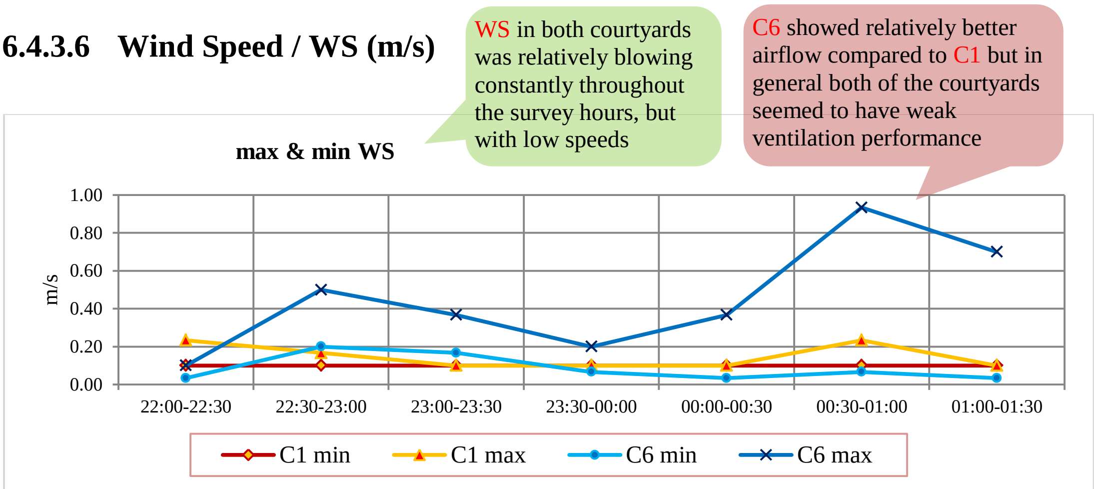


Figure 6-45: Minimum and maximum wind speed readings of the two studied courtyards / summer night-time

Concerning wind speed (WS), it has been observed that the wind (air flow) in both courtyards C1 and C6 was relatively blowing constantly throughout the survey hours, but with low speeds (Figure 6-45). WS in C1 ranges between 0.10 m/s and 0.23 m/s with an average of 0.12 m/s, whereas in C6, it ranges between 0.03 m/s and 0.93 m/s with an average of 0.27 m/s. Courtyard C6 (shallow form) has a tendency to be a relatively good ventilated space compared to courtyard C1 (deep form), but in general both of the courtyards seemed to have weak ventilation performance during the night-time. This was unexpected because both of the courtyards have adequate potentials in terms of design (architectural form) for being good ventilated spaces, see Figure 6-46. They are provided with openings to allow the air flow to reach their internal spaces. So there is no clear reason behind this strange situation particularly C1, which showed good ventilation performance during the summer day-time through which it recorded the highest wind speed reading (3.2 m/s) among all the studied courtyards.

Figure 6-46: Photographs showing size and place of the openings of the two courtyards/summer night-time

6.4.3.7 The difference between the max and min of wind speed (WS) (range)

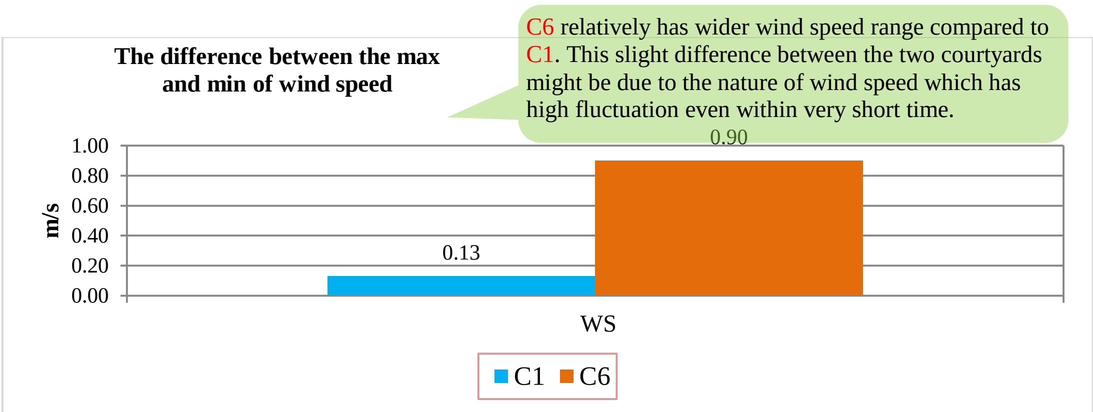


Figure 6-47: The difference between the max and min of WS in the two studied courtyards / summer night-time

According to Figure 6-47, it is clear that courtyard C6 relatively has a wider wind speed (WS) range compared to C1, and this as mentioned earlier, is probably due to the effect of its geometry. Courtyard C6 is more open, and has a shallower form with a bigger aspect ratio than that of C1. Both the courtyards have big openings towards the outside, but the main difference between them was the height of the surrounding buildings. C6 is surrounded by two-storey buildings on three sides and a single storey on the fourth side, while C1 is surrounded by four-storey buildings on all sides. This may explain why there is a slight difference between the two courtyards in addition to the nature of wind speed which has a high fluctuation even within a very short time.

6.4.4 Ranking of the studied sites based on the highest and lowest recorded readings of their environmental parameters: DBT, WBT, GT, ST-F, ST-W, ILL, RH & WS

As in Part I and II, ranking the studied sites based on the highest and lowest recorded readings of each environmental variable is done in two categories. The first concerns the maximum readings and the order is from the highest reading (red) to the lowest one (blue). The second category regarding the minimum readings and the order is from the lowest (blue) to the highest reading (red).

Table 6-15: Courtyards ranking based on highest and lowest readings of their environmental variables / summer night-time

	Parameter	Rank of studied courtyards
Highest reading and **Lowest reading**	Dry bulb temperature (DBT)	**C6**, **C1**
	Wet bulb temperature (WBT)	**C1**, **C6**
	Globe temperature (GT)	**C6**, **C1**
	Floor-surface temperature (ST-F)	**C6**, **C1**
	Wall-surface temperature (ST-W)	**C6**, **C1**
	Relative humidity (RH)	**C1**, **C6**
	Wind speed (WS)	**C6**, **C6**

According to Table 6-15, courtyard C6 appears to have the highest reading of dry-bulb temperature (DBT), globe temperature (GT), floor-surface temperature (ST-F) and wall-surface temperature (ST-W), while C1 possesses the lowest. As for wind speed (WS), courtyard C6 seems to record the highest and lowest readings. For wet-bulb temperature (WBT) and relative humidity (RH), courtyard C1 seems to have the highest reading, whilst courtyard C6 has the lowest. Most of these findings are expected, that is probably because of the clear roles played by the courtyards' geometries.

Based on the results discussed above, it is suggested that both of the courtyards have slightly higher temperatures (warm environments), acceptable relative humidity levels and low air velocity (weak ventilation). In particular, courtyard C6 has to some degree extreme environmental parameter readings, due to the grate effect of its geometry which allowed the courtyard's surfaces to receive large amounts of solar radiation during day-time. Finally, it can be concluded that the courtyard with shallow form (C6) seems to be in general, a warm site due to large amounts of solar radiation received during day-time, whereas the courtyard with the deep form (C1) tends to be less warm due to the protection it afforded against solar radiation.

6.4.5 Built urban form and microclimate

Under clear summer night sky conditions (usually warm summer nights), a comparison between the two studied courtyards indicates slight variations in their microclimates that are probably related to the difference in their spatial characteristics (physical conditions). Based on the analysis, it is found that the geometry and surfaces' colours and materials have significant direct and indirect effects on the courtyard's microclimates. The following points summarise the most important effects:

6.4.5.1 Effect of geometry and architectural form

The aspect ratio of the courtyards was identified as the most important factor that influenced most of the environmental parameters, particularly temperatures (DBT, WBT, GT, ST-F and ST-W). It is clear from the results that there was a strong link between the aspect ratio of courtyards and solar radiation gain during the day-time, and consequently the thermal performance of the courtyard as a whole (during day- and night-time). In other words, it is found that as the aspect ratio of the courtyard increases the courtyard temperatures increases. This is in good agreement with Muhaisen and B Gadi, (2006) who have shown that the courtyard proportions and geometry have a considerable influence on the shading performance of courtyard forms. The effect of the geometry on the environmental parameters is also noted by Johansson, (2006) in Fez, Morocco, where he found that the maximum air temperature was found to decrease with an increasing H/W ratio. It is clear from the obtained results that there is also evidence of the importance of the courtyards' aspect ratio for the improvement of night-time microclimates. It is found that a courtyard with a large aspect ratio (large openness to the sky) tends to cool faster than a courtyard with limited openness to the sky at night-time, that is because of its large potential to lose more heat by long-wave radiation emission towards the cold sky. This is in agreement with what Al-Hemiddi and Megren Al-Saud, (2001b) have found that covering the courtyard during day-time and opening it during the night provides significant lowering of the average courtyard temperature.

6.4.5.2 Effect of surface reflectivity and thermal properties of surface materials

A clear link was found between surface temperatures and surface colours of the courtyards. Surfaces with light colours (high albedo or high solar reflectance) recorded low temperatures than surfaces with dark colours (low solar reflectance). Similar results have been observed by other studies conducted during the day-time on different urban open spaces in different climatic regions such as (Yilmaz et al., 2007, Yang et al., 2012, Chatzidimitriou et al., 2006, Biller, 2007b). Surface materials also may have a role in increasing surface temperatures. For instance, black stone pavers tend to be warmer than the surface temperature of red brick pavers, and this may be related to in addition to the surface colour, the thermal properties of the pavement material. A possible link also seems to be found between surface material, surface temperatures and air temperature. Courtyards paved with black stone (C6) have recorded in addition to the highest surface temperatures, the highest DBT and GT readings. This likely agrees with the fact that the material of high thermal mass usually has a high specific heat capacity to retain the heat absorbed during the daylight hours, and radiate it slowly into the atmosphere at night.

From the comparison between day- and night-time temperatures of courtyard C1, it is apparent that the courtyard tends to be warmer during night-time than in the day-time. For instance, averages of dry-bulb temperature (DBT) and globe temperatures (GT) in this courtyard were 4°C and 2.1°C lower respectively during day-time than at night-time. This clearly indicates the effect of micro-scale urban heat island, which is responsible for rising night-time temperatures more than day-time temperatures, Folland et al (2002). As mentioned above, materials with a higher heat capacity store heat longer and gradually release heat at night. In this regard Ferguson et al., (2008) have presented that thermal emittance has an important role in determining a material's contribution to urban heat islands. They further stated that research in 2007 has suggested that albedo (solar reflectance) and thermal emittance are the most important factors to have the biggest influence on determining how a conventional pavement cools down or heats up. Estimation by researchers at Lawrence Berkeley National Laboratory (LBNL) pointed that every 10% increase in solar reflectance could decrease surface temperatures by 4ºC (7ºF). Further, they predicted that if pavement reflectance throughout a city was increased from 10% to 35%, the air temperature could potentially be reduced by 0.6 ºC (1 ºF) which would result in significant benefits in terms of lower energy use and reduced ozone levels (Lionel Lemay, 2011).

As it has been concluded in Part II, generally courtyards' geometry and the thermal properties of courtyard surfaces are the most important factors affecting the courtyard thermal environment. The first one can influence how much solar radiation enters inside the courtyard and heat escapes to the sky in the form of long-wave radiation. The second can influence the way courtyard surfaces absorb, store, and transfer heat. This strongly agrees with Yang et al. (2012) who concluded in their study under the title A simple temporal 3D air and surface temperature model for an ideal courtyard, that the solar radiation, urban structures and the thermal properties of the walls are found to be the most important factors in determining the courtyards' thermal environment during both summer and winter.

6.5 Summary of Microclimatic Variations

Based on the results, as shown in Table 6-16 , there was a considerable variation in the measured DBT, WBT, GT, ST-F, ST-W, ILL, RH and WS between winter and summer for all the studied courtyards. In the hot season (summer), the variation in the measured environmental variables was clear as well as between day-time and night-time for the studied courtyards. Significant microclimatic differences were found between the studied courtyards during the same season (period), due to the difference in their urban-built form (physical conditions) such as building geometry, architectural form and layout, built and natural elements and aspect ratio.

Table 6-16: Average readings of measured dry-bulb temperature (DBT), wet-bulb temperature (DBT), globe temperature (GT), floor-surface temperature (ST-F), wall-surface temperature (ST-W), illuminance (ILL), relative humidity (RH) and wind speed (WS) in summer and winter in the five studied courtyards as well as average readings of measured environmental variables for the courtyards which studied in summer night-time

Variable	C6	C1			C2		C3		C4		C5		All		
	Summer night-time	Summer night - time	Winter day-time	Summer day-time	Winter day-time	Summer day-time	Winter day-time	Summer day-time	Winter day-time	Summer day-time	Winter day-time	Summer day-time	Winter day-time	Summer day-time	Summer night-time
DBT (ºC)	33.2	32.3	14.0	28.3	16.1	28.3	14.0	26.6	20.1	28.3	16.5	28.8	16.1	28.0	32.8
WBT (ºC)	19.7	20.6	11.6	23.5	12.7	22.3	9.8	21.4	11.2	23.0	9.8	22.7	11.0	22.6	20.2
GT (ºC)	33.6	32.9	15.7	30.8	19.4	31.6	16.3	29.1	23.0	31.0	21.0	32.3	19.1	31.0	33.2
ST-F (ºC)	31.8	27.4	11.3	35.4	14.2	36.7	16.0	35.7	11.3	30.0	13.2	33.7	13.2	34.3	29.6
ST-W (ºC)	33.2	31.5	12.8	28.7	15.1	33.5	15.5	29.0	16.0	29.1	13.3	26.8	14.5	29.4	32.3
ILL (1000 x lux)	-	-	2.6	32.8	14.1	46.3	26.3	62.4	40.7	62.1	8.3	55.6	18.4	51.8	-
RH %	27.0	34.3	73.5	65.6	67.1	58.8	56.4	62.1	31.5	63.0	39.9	58.6	53.7	61.6	30.6
WS (m/s)	0.3	0.1	0.8	1.3	0.6	0.9	1.1	1.5	0.8	0.7	0.1	0.6	0.7	1.0	0.2

As mentioned above the environmental data varied from season to season and from one site to another. The dry-bulb temperature (DBT) averaged about 28ºC for all sites in the hot season with 12ºC between the cold season and the hot season (around 16.1ºC in the cold season), whereas the difference between day and night in the hot season is approximately 5ºC (about 32.8ºC, at night-time).

A difference of about 12ºC was also found between general averages of globe temperature (GT) in both seasons (19.1ºC in the cold season and 31ºC in the hot season), and a small difference of about 2ºC was observed between day and night-times during the hot season (about 33.2ºC, at night-time). In looking at the studied sites, courtyards with deeper form (small aspect ratio) showed a tendency to be cooler than other sites during the winter. In summer night-time, the courtyard, which has an elongated and shallow form, was slightly warmer than other ones with a deeper form. It is also important to note that courtyards located close to the sea showed low temperatures in both cold and hot seasons, and this may be due to the effect of wind and breeze coming from the sea.

An extensive variation in surface temperatures (floors and walls) was found between the hot and cold seasons. According to the results, the higher surface temperatures were observed in the summer day-time with averages of 34.3ºC for ST-F and 29.4 ºC for ST-W due to the large amount of solar radiation received by the surfaces. The general averages of floor-surface temperatures (ST-F) and wall-surface temperatures (ST-W) of the studied sites during summer night-time were 29.6ºC and 32.3ºC respectively. In winter day-time, the general averages of ST-F and ST-W of the studied sites were lower (up to 21.1ºC and 14.9ºC respectively) than those of summer day-time, and this was because of the short duration of surface exposure to direct solar radiation which in some cases (sites with small aspect ratio) was because the direct sun could not reach the ground even at noontime. A clear variation was observed between the surface temperatures of the studied sites even during the same season due to different surface materials and colours. Surfaces with dark colours (pavements) showed higher temperatures than those with light colours (albedo) in both seasons except for the case of grass. In both seasons (cold and hot), the surface temperature of concrete pavements was warmer than others, while the grass was the coolest compared to them all.

The levels of illuminance (ILL) were varied from season to season and from site to site. A great difference was observed between the general averages of illuminance levels in winter and summer (up to 33400 lux) because of the effects of several factors including sky condition (sky cover), building geometry and solar incident angle (season). It has found that courtyards with a small aspect ratio recorded lower illuminance levels than courtyards with a large aspect ratio in both seasons, particularly in winter where the illuminance levels were very low in these sites (avg. below 10000 lux).

As for relative humidity, the difference between general averages of RH of all sites during the day-time in the cold and hot seasons was small, below 8%. It is somewhat surprising that the general average of relative humidity (RH) in summer day-time (hot season) slightly higher than that of winter day-time (cold season), and this may have occurred as a result of low humidity levels recorded during unusually warm winter days in some sites. It is notable that the relative humidity during summer night-time was largely lower than those during winter and summer day-time which was probably an effect of high temperatures recorded during summer night-times. The variation in relative humidity between the studied sites for each season (period) was fairly small except that for the case of courtyard C1 which recorded very high RH levels in winter due to one rainy day.

The variation in wind speed between the two seasons (winter and summer day-times) was small, where the difference between the averages was only about 0.3 m/s. In general, averages of wind speeds in the three periods (case studies) were 1.0 m/s or below, which may appear to be low levels. For the summer night-time study, the wind speeds were very low and more stable compared with the other two periods. The results showed that the averages of wind speeds at the courtyard located close to the sea were higher than other sites in both seasons (cold and hot), while the small courtyard with a high degree of enclosure located in very a compact built-up area recorded the lowest wind speeds in both seasons (poor ventilation environment).

6.6 Conclusion

The results of two short-term field studies conducted in six different public enclosed courtyards in the city of Tripoli are presented in this chapter. The first was carried out in five days in the winter of 2010 (January & February), whereas, the second one was conducted over five days and two nights in the summer of 2010 (July and August). The general objective was to obtain a complete picture of the daily and seasonal microclimate of the enclosed courtyards during the extreme seasons in the hot dry region, as well as on the relationship between these microclimates and the urban-built form (geometry, architectural form, location and natural and built elements of studied sites). In order to investigate how the microclimate of the enclosed courtyards varies temporally and spatially and how the built urban form influences the microclimate, the analyses of the environmental data of the studied courtyards during the three periods (winter day-time, summer day-time and summer night-time) were performed with different approaches.

From the comparison between the results in the three periods, it is concluded that the microclimate of the enclosed courtyards was varied from one site (place) to another and from one season to another. It is also found that there was some variation between the day and night microclimates of the studied courtyards during the hot season. Quantitatively, the results showed that the average of dry-bulb temperature (DBT) was higher in summer night-time (32.8ºC) than those of summer day-time (28ºC) and winter day-time (16.1ºC). The temperature differences during winter were higher than those during summer day and night time. In winter day-time, it ranged from 1.7ºC in courtyard C3 to 7.1ºC in courtyard C4, while in summer day-time, it ranged from 1.8ºC in courtyard C1 to 2.8ºC in courtyard C4. During summer night-time, the temperature differences were small, did not exceed 1.3ºC in both studied courtyards.

An extensive variation in surface temperatures (floors and walls) was found between winter and summer seasons. The higher floor surface temperatures (TS-F) were recorded during summer day-time with an average of 34.3ºC; however, the higher wall surface temperatures (TS-W) were recorded during summer night-time with an average of 32.3ºC. The corresponding values for winter day-time were 13.2ºC and 14.5ºC respectively. As for relative humidity, it was on average, about 54% during winter day-time, 62% during summer day-time and around 31% at summer night-time. It is notable that the RH during the summer night-time was considerably lower than during the winter and summer day-time.

A great difference in illuminance levels (ILL) was observed between winter and summer. The average of ILL levels in summer was higher up to 33400 lux than that in winter, and this may because of the effects of several factors including sky condition (sky cover), building geometry and solar incident angle (season). The variation in wind speeds (WS) between winter and summer day-times was a small. In summer day-time, the average of WS was about 1.0 m/s, whereas in winter it was 0.7 m/s. For the summer night-time, the wind speeds were very low and more stable compared with the other two periods, with an average of 0.2 m/s.

Based on the analysis and discussion, it appears that the microclimatic conditions in the studied courtyards are varied depending mainly on the amount of solar radiation received by their surfaces. It is also found that the built urban form including architectural form, geometry (size, aspect ratio and height of walls), built and natural elements (surface materials and colours, openings and vegetation) has a key role in shaping the microclimates of the studied sites during both seasons. Sky cover and weather conditions also have somewhat of an effect on some elements of the microclimate such as illuminance levels. The following points summarise the main effects of these factors on the microclimate of the enclosed courtyards.

- Courtyards provided with large external openings tended to have better ventilated environments than others in both seasons regardless of the change in heights of external walls.
- Courtyards with a small size form, no external openings and a high degree of enclosure showed a tendency to have a poor ventilated environment in both seasons.
- Courtyards located close to the sea showed relatively low temperatures in both seasons compared to the others; moreover these courtyards recorded the highest average of wind speeds in both seasons among all the sites.
- Courtyards with large amount of vegetation and grassed floor area showed the lowest floor-surface temperatures in both seasons and also showed a tendency to cool faster towards the afternoon than the rest of sites during the summer.
- Courtyards with a deep form and a very small aspect ratio (less than 1) showed low air temperature, low daylight levels (illuminance), low floor-surface temperature during the winter and showed slow reduction in the temperatures at summer night-time.
- Courtyards with a small aspect ratio generally showed lower illuminance levels than courtyards with a large aspect ratio particularly in winter where the difference is large regardless of the sky conditions.
- Courtyards with a large aspect ratio generally showed higher temperatures than courtyards with a small aspect ratio in particular those located away from the sea.
- Courtyards whose surfaces have high albedo (light grey marble floor area and white plaster walls) showed high readings of dry-bulb temperature and illuminance during the summer despite their size and aspect ratio being small (below 1.5).
- Courtyards with dark coloured surfaces showed higher surface temperatures than courtyards with light coloured surfaces in both seasons.

7 THERMAL COMFORT SURVEYS

This chapter presents an analysis, discussion and conclusion on the subjective thermal comfort data that collected from the selected case study sites during the cold and hot seasons in the city of Tripoli. This chapter begins with the field survey programme. Next to this, the chapter provides descriptions of the studied sites, followed by a description of the samples. Section four is about correlation analysis. The fifth section deals with the analysis and discussion of the thermal comfort data. It contains analysis and discussions on thermal sensation votes, thermal comfort votes, thermal preference votes and comparisons between the results. The sixth section includes effect of clothing on people's thermal comfort and thermal comfort adaptive behaviour. Finally, this chapter ends with a conclusion.

7.1 The Field Survey Programme

The programme of work included three phases of field survey study in the city of Tripoli. In all the field survey phases, the questionnaire surveys and unobtrusive observations were performed simultaneously with the environmental measurements within each selected sites. The three phases of field surveys are the following.

7.1.1 Winter (cold season)

For the winter field survey, the aim was to study thermal comfort conditions within public enclosed courtyards in the city during the cold period. January and February 2010 were selected for the survey as they are the coolest months of the year. The surveys took place in three courtyards over three days (one day per site) between 09:00 and 18:30h on weekdays and weekends.

7.1.2 Summer day-time (hot season)

The main purpose of this survey was to investigate thermal comfort conditions within public enclosed courtyards during the day-time in the hot period (summer). July and August 2010 were selected for the survey as they are the warmest months of the year in Tripoli city. The surveys took place in two courtyards over two days (one day per site) between 09:00 and 20:00h on weekdays and weekends.

7.1.3 Summer night-time (nocturnal)

This survey was conducted during the summer night-time (hot season) in order to study thermal comfort conditions within public enclosed courtyards at night-time. July and August 2010 were selected for the survey as they are the warmest months of the year in the city. The surveys took place in two courtyards over two nights (one night per site) between 22:30 and 01:30h.

7.2 Description of the Studies Sites

7.2.1 Winter

The three courtyards considered in this survey study were namely courtyard C1 from the colonial city (Figure 7-1) and courtyard C3 (Figure 7-2) and courtyard C4

(Figure 7-3) from the post-colonial city. The three selected courtyards typically represent examples of two different urban fabrics within Tripoli city. They are also having different intended use, sizes, designs and varying microclimates. The first (C1) is a small deep sheltered courtyard located in the centre of the colonial city (one of the main shopping areas in the city), and therefore frequently has a large number of users (especially by people who have a deep passion of smoking shisha). The second (C3), is a big sized courtyard located close to the sea in central business district (high-rise building area) and is widely used by office workers and visitors. The third one is C4 which is a large beautiful landscaped courtyard with fully grassed floor area and groups of shading trees. It is located in the main campus of Tripoli University, about 7km away from the sea-shore, and therefore is widely used by university students during the study periods.

Figure 7-1: Photographs for courtyard C1 (Addamaan)

Figure 7-2: Photographs for courtyard C3 (Dat al-Imad)

Figure 7-3: Photographs for courtyard C4 (F. Engineering)

7.2.2 Summer day-time

This field survey was conducted in the same courtyards where the winter field survey was performed in C1 and C3 (Figure 7-4 and Figure 7-5), the only difference is that courtyard C4 was excluded from this survey that because its users (students) were on summer holiday (July – September).

Figure 7-4: Photographs for courtyard C1 (Addamaan)

Figure 7-5: Photographs for courtyard C3 (Dat al-Imad)

7.2.3 Summer night-time

Two courtyards with different spatial characteristics and varied microclimates were selected for this survey. The first is C1 (no photographs/lost), as described in the two previous phases, whereas the second courtyard C6 (Figure 7-6) is from the old city. The latter can be described as a small enclosed courtyard that has a rectangle shape and is located in very active touristic area. Both courtyards attract a large number of visitors (very busy spaces) during the summer night-time.

Figure 7-6: Photographs for courtyard C6 (Bab Bharr)

7.3 Description of Participants (Sample)

The samples were selected in the same way as the three phases of the field survey study, any person sat or stood or laid (no less than 20 minutes) within three metres of the meteorological instruments, he/she was invited to complete a questionnaire (normally there were some rejections), and in general, the questionnaire took from five to ten minutes.

7.3.1 Winter

A total of 130 people participated in this survey study, 53 at courtyard C1, 32 at courtyard C3 and 45 at courtyard C4. About 22 participants were female (17%), and they were distributed between the two courtyards C3 and C4 (11 in each site). All the participants were Libyan and in good and normal health condition. Table 7-1 shows a statistical summary of the participants in winter field survey study.

Table 7-1: Statistical summary of the participants in winter study

	Participants (respondents)				
	Male	Female	Combined (M & F)		
			Number	Age range	Average age
Courtyard **C1**	53	0	53	18-70	34
Courtyard **C3**	21	11	32	18-53	31
Courtyard **C4**	34	11	45	18-28	22
All	108	22	130	18-70	29

7.3.2 Summer day-time

The total number of people who participated in this survey was 72, of these 9 (12.5%) were female. The sample in C1 included 37 participants; all of them were male, whereas the sample in C3 included 35 participants. All the participants were Libyan and in good and normal health condition. Table 7-2 presents a statistical summary of the participants in summer field survey study.

Table 7-2: Statistical summary of the participants in summer day-time

	Participants (respondents)				
	Male	Female	Combined (M & F)		
			Number	Age range	Average age
Courtyard **C1**	37	0	37	18-64	41
Courtyard **C3**	26	9	35	17-58	31
All	63	9	72	17-64	36

7.3.3 Summer night-time

A bout 54 people participated in this survey study, 28 at courtyard C1 and 26 at courtyard C6. Only two participants were female, they were in courtyard C6. About 94% of the participants (49 persons) were Libyan and all of the participants were in good and normal health condition. Table 7-3 shows a statistical summary of the participants in summer field survey study.

Table 7-3: Statistical summary of the participants in summer night-time

	Participants (respondents)				
	Male	Female	Combined (M & F)		
			Number	Age range	Average age
Courtyard **C1**	28	0	28	17-51	33
Courtyard **C6**	24	2	26	17-47	32
All	52	2	54	17-51	32.5

7.4 Analysis and Discussion of the Studied Sites' Thermal Comfort Data

This section analyses and evaluates the subjective thermal comfort data that has been collected from the studied sites during the three phase of the survey. As mentioned earlier, this data was collected by using photographic observation and by a questionnaire survey, which was administered simultaneously with the physical measurements in each site. The questionnaire was mainly concerned with thermal sensation, thermal comfort and thermal preference. The main purpose of the survey was to assess thermal comfort perception and preferences of the people in their natural environments (public enclosed courtyards) at winter day-time and summer day/night-times, as well as relating the results from the study to ASHRAE Standard 55.

A thermal acceptability assessment will be performed to find out whether the environments of the studied courtyards meet the ASHRAE Standard-55's 80% acceptability criteria. Thermal acceptability can be defined with reference to different scales (Han et al., 2009). The direct measure of acceptability 'Do you find this environment thermally acceptable?' has been asked rarely in either laboratory or field studies (Brager et al., 1993). For this study, three methods (ASHRAE sensation scale, comfort scale and preference scale) are used as indirect measures of thermal acceptability, see Table 7-4.

The definition of thermal acceptability in this study is associated with voting within the three central categories of the thermal sensation scale, with voting within the neutral-comfortable categories of thermal comfort scale, and with voting for ‘no change’ of the thermal preference scale, and this will be explained in more detail in the subsections to follow.

The analysis will be performed in three steps. Firstly, it starts with the correlation analysis in order to determine the relationship between the studied variables (thermal sensation, thermal comfort and thermal preference and environmental variables). The next step is analysing people’s simultaneous responses to the three scales in order to determine the levels of thermal acceptability in the studied sits at both seasons. Finally, we compare the results obtained at different seasons.

Table 7-4: Three rating scales used for this study (green shaded portions represent indirect measures of acceptability)

<table>
<tr><td rowspan="7">ASHRAE 7-point thermal sensation scale</td><td>3 Hot</td><td rowspan="7">Thermal comfort scale</td><td>1 Very comfortable</td><td rowspan="7">McIntyre’s 3-point preference scales</td><td rowspan="2">1 Warmer</td></tr>
<tr><td>2 Warm</td><td>2 Comfortable</td></tr>
<tr><td>1 Slightly warm</td><td>3 Slightly comfortable</td><td rowspan="3">0 No change</td></tr>
<tr><td>0 Neutral</td><td>4 Neutral</td></tr>
<tr><td>-1 Slightly cool</td><td>5 Slightly uncomfortable</td></tr>
<tr><td>-2 Cool</td><td>6Uncomfortable</td><td rowspan="2">-1 Cooler</td></tr>
<tr><td>-3 Cold</td><td>7 Very uncomfortable</td></tr>
</table>

7.4.1 Correlation between sensation votes and comfort votes

In general the thermal comfort level is related to the thermal sensation. In this study the relationship between thermal comfort votes and thermal sensation votes is examined by an appropriate statistical technique called measure of association. It is used for determining the strength of the relationship between two or more variables and its direction (positive or negative). As mentioned above, the two studied variables are thermal comfort (TC), and thermal sensation (TS), the first is considered as the dependent variable whereas the second is the independent variable, therefore the comfort level of the users of the studied sites will be determined by the thermal sensation variable.

Gamma as a measure of association is used in this analysis because the two studied variables are categorised as ordinal scaled data (7-point ordinal scaled data as mentioned above). Gamma as a symmetrical measure of association that can vary from -1.0 to +1.0, see Table 7-5.

Table 7-5: Measure of association – value of measures and definitions (Babbie et al., 2007)

Strength of association	Value of MoA for Gamma
None	0.00
Weak / uninteresting association	± 0.01 to 0.09
Moderate / worth noting	± 0.10 to 0.29
Moderate of strong association / extremely interesting	± 0.30 to 0.99
Perfect / strongest possible association	± 1.0

As shown in the table above, the correlation ranges from 1.0 to -1.0, and it can be positive (when the variables change in the same direction), or zero, or negative (when they change in opposite directions).

7.4.1.1 Winter

The results of the measure of association (symmetric measures) between the thermal comfort (TC) and thermal sensation (TS) votes of the samples within the studied sites during the winter season are presented in Table 7-6.

Table 7-6: Results on measure association between TC and TS / winter survey

	C1	C3	C4	All sites
Gamma value	.644	.733	-.328	.403

Based on the results, the gamma values for the three studied courtyards (C1, C3 and C4) are found within the range of ± 0.30 to 0.99, and this means there is a strong relationship between the thermal comfort and thermal sensation votes in all the studied sites. In other words, this means that the cooler the environment, the more uncomfortable the subjects (respondents) are going to be. As for the negative sign, it is found in courtyard C4 where the weather was moderate to slightly warm (unusual in winter) when the survey was taking a place in this courtyard, see Figure 7-7. This might be reflected in the participant's votes which showed that the number of participants who voted on the warm part of the scale (1 to 3) was higher than the number of participants who voted on the cool part of the scale (-1 to -3). This means that the general direction of the votes was, the warmer the environment, the more uncomfortable the subjects and this may be opposite to what it was supposed to be in such a season (TC and TS change in opposite directions).

Figure 7-7: Photographs showing the adaptive actions were taken by people on a slightly warm winter day in courtyard C4, e.g. looking for shaded places (1,2 & 3) and wearing light clothing (4,5 & 6)

Based on the results it can be concluded that a strong relationship is found between the thermal comfort votes and thermal sensation votes in all the studied courtyards in the winter survey. Positive correlations between TS and TC in C1 and C3 suggest that the cooler conditions in these courtyards were more uncomfortable than warmer conditions, whereas negative ones in C4 suggest that the warm conditions in this courtyard were more uncomfortable.

7.4.1.2 Summer day-time

The results of the measure of association between the thermal comfort votes (TC), and thermal sensation votes (TS) of respondents in the studied sites during summer day-time are presented in Table 7-7.

Table 7-7: Results on measure association between TC and TS / summer day-time survey

	C1	C3	All sites
Gamma value	-.759	-.990	-.880

The results shown in Table 7-7 show that the gamma values for both courtyards (C1 and C3) are found within the range of ± 0.30 to 0.99, and this indicates there is a strong correlation between the thermal comfort and thermal sensation votes in both sites. For the negative sign, it shows that the TS and TC change in opposite directions, and this means that the direction of the relationship between the two variables was the hotter the environment, the more uncomfortable it become.

7.4.1.3 Summer night-time

Table 7-8 shows the results obtained from the correlation analysis between the TC & TS votes of the subjects within the studied courtyards during the summer night-time.

Table 7-8: Results on measure association between TC and TS / summer night-time survey

	C1	C6	All sites
Gamma value	-.944	-.640	-.509

From Table 7-8 it is clear that all gamma values are found within the range of ± 0.30 to 0.99. These results provide clear evidence of a strong relationship existing between the thermal comfort votes and thermal sensation votes of the respondents in both sites. For the negative sign, as previously explained, TS and TC change in opposite directions (the hotter the environment, the more uncomfortable the subjects are).

7.4.2 Thermal sensation (TS)

The first method used in this study for assessing thermal acceptability in the studied sites is by using the 7-point thermal sensation scale as an indirect measure. The scale is as follows; -3 (cold), -2 (cool), -1 (slightly cool), 0 (neutral), +1 (slightly warm), +2 (warm) and +3 (hot), see Table 4-4. The most commonly-used method for assessing acceptability is to assume a relationship between thermal sensation and satisfaction (Brager et al., 1993). A common assumption in thermal comfort research is that a vote outside the three central categories (-1, 0, 1) of the ASHRAE scale is an expression of dissatisfaction (unacceptability) (Schiller et al., 1988, Brager et al., 1993, de Dear and Fountain, 1994). Based on this assumption, the acceptability in this analysis will be associated with the voting inside the three central categories (slightly cool, neutral, and slightly warm) of the thermal sensation scale. Thus, this analysis will look at the subjects' votes on this scale to determine whether a minimum of 80% of the votes in each site is within the definition of acceptability. A comparison between the case studies and seasons (winter, summer day-time and summer nigh-time) will be done as well.

7.4.2.1 In winter (cold season)

Figure 7-8 shows the percentage frequency distribution of the thermal sensation votes of the participants in the three studied courtyards (C1, C3 and C4) in the winter season, whereas Table 7-9 gives the mean and standard deviation of sensation votes during the same season.

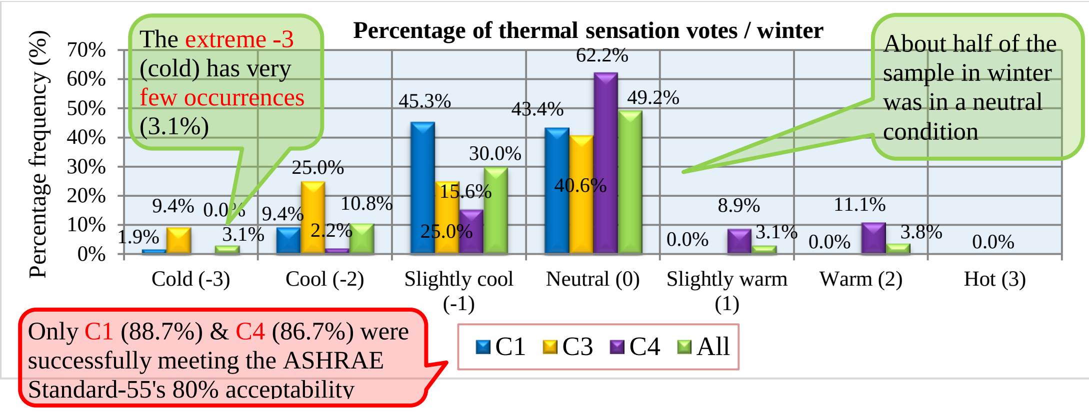


Figure 7-8: Percentage frequency distribution of thermal sensation votes of participants in the studied courtyards for winter

As shown in the figure above, there is a slight discrepancy in the percentage frequency distribution of the thermal sensation (TS) votes between the three courtyards. The (TS) votes in the courtyards C1 and C3 range from neutral (0) to cold (-3), whereas in courtyard C4 it ranges from cool (-2) to warm (+2). In courtyard C1, about 45.3% of the respondents (subjects) voted for slightly cool; this is slightly higher than the percentage of those who voted for neutral (43.4%), whereas the rest of them voted for cool (9.4%) and cold (1.9%). The corresponding distribution in courtyard C3 is 25% for slightly cool, 40.6% for neutral, 25% for cool and 9.4% for cold. As for courtyard C4, the majority (62.2%) of respondents voted for neutral, 15.6% for slightly cool, 11.1% for warm, 8.9% for slightly warm and 2.2% for cool.

In looking at all samples combined, it is clear that the largest percentage of votes (90%) varied from neutral to cool (0 to -2). It is interesting to notice that about 49.2% of the respondents voted for neutral (0). This seems to suggest that around half of the sample were in a neutral condition during the cold season. It is also shown that about 43.8% of the participants voted for the cool part of the scale and 6.9% for the warm. The extreme -3 (cold) has very few occurrences (3.1%) in general, whereas the extreme +3 (hot) votes were not found which is understandable, since the season is winter (cold season). In general, it is interesting to note that some extreme votes (+2) ‘warm’ were observed in courtyard C4 during the cold season, and this agrees well with the environmental variables measured in this courtyard which in turn showed that the weather on the day of the interview was moderate to slightly warm in this site.

Table 7-9: Mean and standard deviation of sensation votes during the cold season

	Courtyard C1	Courtyard C3	Courtyard C4	All
Mean	-.70	-1.03	.11	-.50
Std. Deviation	.723	1.031	.885	.974
Min.	-3	-3	-2	-3
Max.	0	0	2	2

As for the means of sensation votes, the mean of subjects' thermal sensation votes in the cold season (all samples combined) was -.50 in the interval between neutral (0) and slightly cool (-1), on the cold side of neutral. When comparing between the studied sites, the distribution of sensation votes is different from one site to another. As shown in Table 7-9, the mean sensation vote in courtyard C4 is .11 which is considered as the highest among the studied sites followed by the mean sensation vote in courtyard C1 (-.7) and lastly courtyard C3 with -1.03. This means that the condition of the subjects in courtyard C3 were in the interval between slightly cool (-1) and cool (-2), whereas subjects in courtyard C1 were in a slightly cool condition. It is surprising to some extent that subjects in C3 had slightly cooler sensations than those in C1. The reason for this might be because of the effect of the wind speed, where C3 was experiencing higher average wind speeds than courtyard C3.

For courtyard C4, the thermal sensation votes as a mean are in the interval between neutral (0) and slightly warm (+1), on the warm side of neutral. It is approximately around neutral, and this indicates that the subjects in this courtyard are marginally warmer than those in other courtyards. This might be related to the microclimate of this courtyard as it was ranked as the warmest among the studied sites based on the environmental measurements. Figure 7-7 shows students wearing light clothing and sitting in shade as result of the weather which was slightly warm, and this might have affected the voting levels of subjects.

When looking at the percentage of the subjects who voted within the central three categories of the thermal sensation scale (-1, 0, 1), there is a noticeable difference in the comfort sensation votes between the three studied courtyards in the cold season. 88.7% and 86.7% of the subjects in the courtyards (C1 and C4 respectively) are satisfied with their thermal condition, indicating that these courtyards were successfully meeting the ASHRAE Standard-55's 80% acceptability criteria. On the other hand, only 65.6% of the subjects in courtyard C3 are pleased by their thermal environment, which means that this courtyard did not meet the 80% acceptability criterion. The percentage of acceptable votes in C3 is lower than in C1 and C4 despite the first two courtyards having the same mean air temperature, 4.1ºC lower than that in courtyard C4, but the difference in wind speed might have an influence over the subjects' comfort sensation where the average was higher in C3 than in C1 and C4. This can be clearly observed when looking at the percentage of the subjects who felt acceptably cold in both courtyards (C1 and C3). For instance, in courtyard C1, among the 56.6% of subjects who voted for the cold part of the scale, 80% voted for slightly cool (acceptably cool), which explains the high acceptability with the thermal condition in C1. However, in courtyard C3, among the 59% of subjects who voted for the cold part of the scale, only 42.1% voted for slightly cool (acceptably cool), and this explains the lower thermal acceptability level in C3.

In summer day-time

Figure 7-9 shows the percentage frequency distribution of thermal sensation votes of the participants in the two studied courtyards (C1 and C3) in summer day-time (hot season), whereas the mean and standard deviation of sensation votes are given in Figure 7-10.

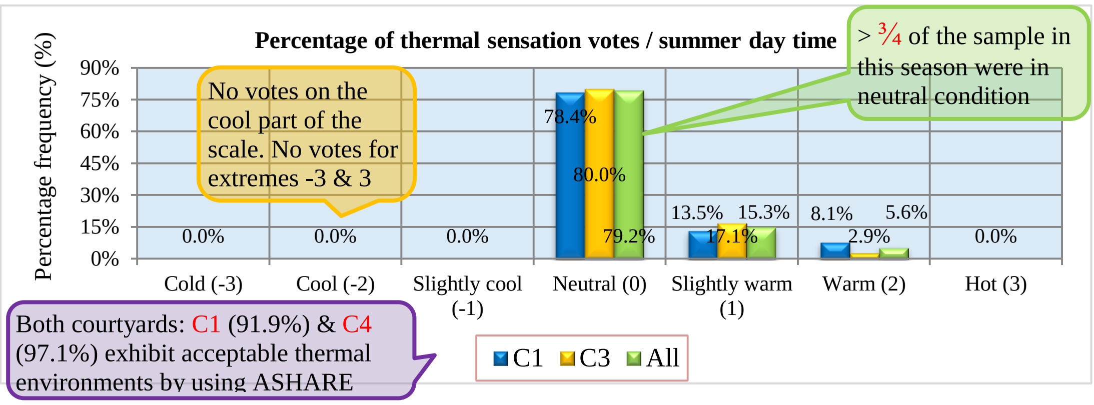


Figure 7-9: Percentage frequency distribution of thermal sensation votes of participants in the studied courtyards for summer day-time
According to

Figure 7-9, the distribution of thermal sensation (TS) votes in the two studied courtyards (C1 & C3) is very similar. The TS votes in both courtyards range from neutral (0) to warm (+2). About 78.4% of the subjects in courtyard C1 and 80% in courtyard C3 were in a neutral condition. Only 13.5% of the subjects in courtyard C1 selected slightly warm conditions whereas about 17.1% of courtyard C3 did so. Less than 3% of respondents in courtyard C3 voted for warm, and about 8.1% in courtyard C1 voted for the same category.

As for them all (two samples combined), it is interesting to notice that all the votes (100%) of the participants in the summer day-time field survey indicated one of these categories (neutral - slightly warm - warm), but the peak vote was for neutral (79.2%).This seems to suggest that more than three-quarters of the sample were in a neutral condition during the day-time in the hot season. It is also apparent that only 20.9% of the votes fall on the warm part of the scale and no votes on the cool one.

Table 7-10: Mean and standard deviation of sensation votes during day-time in hot season

	Courtyard C1	Courtyard C3	All
Mean	.30	.23	.26
Std. Deviation	.618	.490	.556
Min.	0	0	0
Max.	2	2	2

The mean sensation votes for all samples combined during the day-time in the hot season was .26 in the interval between neutral (0) and slightly warm (+1). Based on Table 7-10, the mean sensation vote in courtyard C1 (.30) is slightly higher than that of courtyard C3 (.23). In other words, the subjects in both courtyards are around neutral conditions, but respondents in C1 tended to have a slightly warmer sensation than those in C3. The reason for this might be that the mean bulb-dry temperature and mean globe temperature in C1 were higher than those in C3. Wind speed (sea breezes) which on average was higher in C3 than in C1, may have had some impact on the sensation votes as well, see Table 6-16.

When looking at the voting of subjects within the central three categories of the thermal sensation scale (-1, 0, 1) in summer day-time, the results show that the percentages of thermal acceptability in the two studied courtyards C1 and C3 were 91.9% and 97.1% respectively. This level was higher than that obtained in the winter season. Thus, both courtyards in summer day-time exhibit acceptable thermal environments using the ASHARE scale.

7.4.2.2 In summer night-time

Figure 7-10 and Table 7-11 show the percentage frequency distribution and mean and standard deviation of the sensation votes of the participants in the two studied courtyards C1 and C6 during summer night-time.

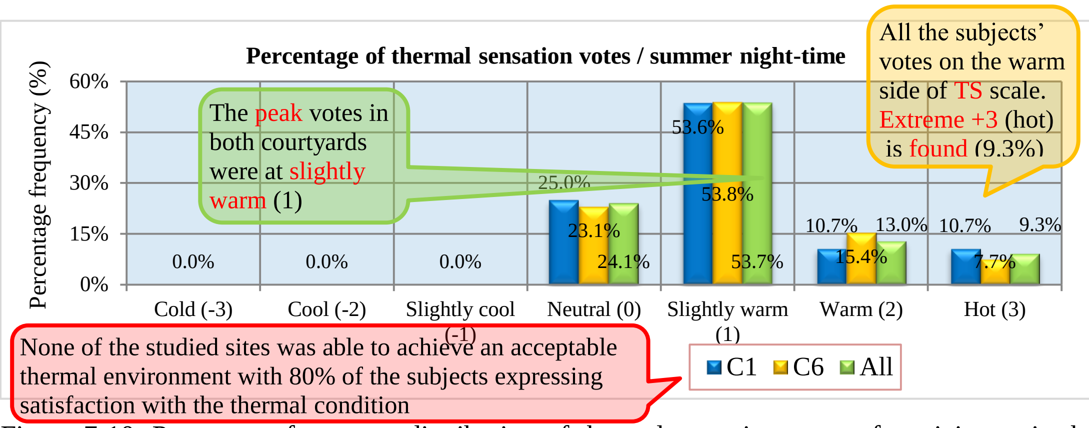


Figure 7-10: Percentage frequency distribution of thermal sensation votes of participants in the studied courtyards for summer night-time

As seen in Figure 7-10, the distribution of the thermal sensation (TS) votes in the two studied courtyards (C1 & C6) is very similar. The TS votes in both courtyards range from neutral (0) to hot (+3). In courtyard C1, about 25% of the respondents voted for neutral, 53.6% for slightly warm, 10.7% for warm and a similar percentage for the hot category. The corresponding distribution in courtyard C6 is 23.1%, 53.8%, 15.4% and 7.7%. The peak votes in both courtyards were at slightly warm.

In looking at both samples combined, it is clear that all the votes of the respondents (100%) fall in the interval between neutral to hot (0 to +3). It is interesting to notice that less than 25% of the subjects voted for neutral (0), whereas the rest of the subjects voted for the warm part of the scale. The extreme +3 (hot) has few occurrences (9.3%).

Table 7-11: Mean and standard deviation of sensation votes during night-time in hot season

	Courtyard C1	Courtyard C3	All
Mean	1.07	1.08	1.07
Std. Deviation	.900	.845	.866
Min.	0	0	0
Max.	3	3	3

Based on Table 7-11, the mean sensation votes for all samples combined during the night-time in the hot season was +1.07 in the interval between slightly warm (+1) and warm (+2) on the warm side of neutral. When looking at the sites separately, the means of sensation votes within them are very similar. From Table 7-11, the mean sensation vote in courtyard C1 was +1.07 and in courtyard C6 it was +1.08, both were around slightly warm. The difference between them is very small, and this was expected that because their recorded environmental data (temperatures, wind speed and relative humidity) were very close to each other.

When looking at the voting of subjects within the central three categories of thermal sensation scale (-1, 0, 1) in summer night-time, the results show that the percentages of thermal acceptability in the two studied courtyards (C1 and C6) were 78.6% and 76.9% respectively. Thus by using ASHARE scale, none of the studied sites was able to achieve an acceptable thermal environment with 80% of the subjects expressing satisfaction with the thermal condition.

7.4.2.3 Comparison between seasons

Figure 7-11 shows the percentage distribution of the thermal sensation votes for all the samples combined at different seasons.

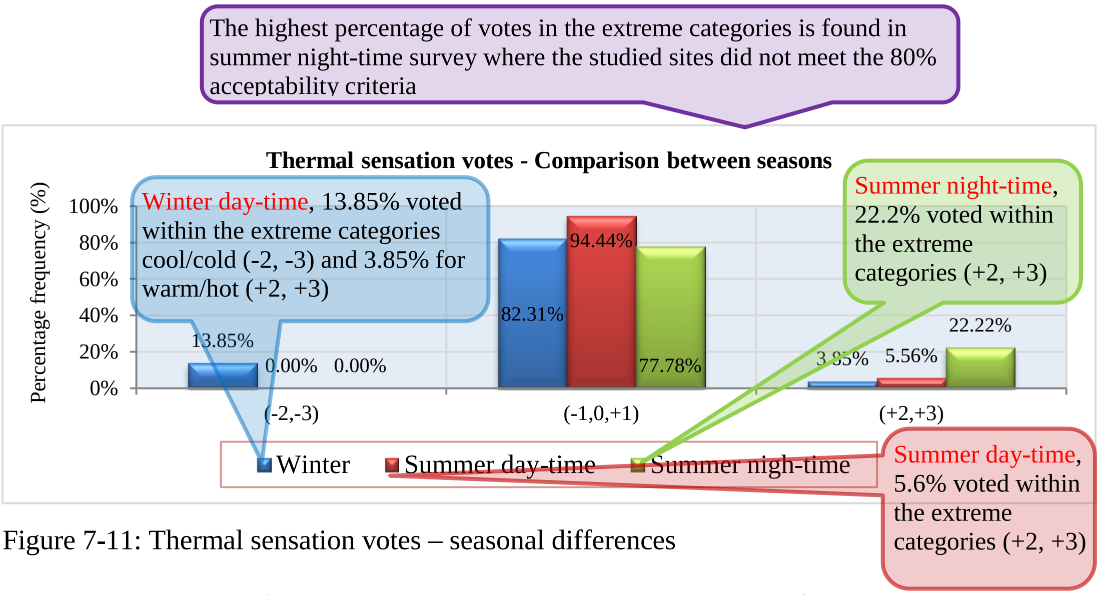


Figure 7-11: Thermal sensation votes – seasonal differences

From the above figure, the thermal sensation votes were fairly distributed in the same way in both seasons. It is clear from the figure that the majority of TS voted in the three survey times were within -1, 0, +1 with slight warm/hot (+2, +3) votes in the hot season and slight cool/cold (-2, -3) in the cold season. More specifically, in the winter and summer day-time surveys, about 82.3% and 94.4% (respectively) of the subjects voted within the three central categories, which indicates that the majority of people were satisfied with their thermal environment. As for the summer night-time survey, the results are slightly different where the majority of the subjects (77.8%) voted within the three central categories as well, but this percentage was not enough to consider the studied sites thermally acceptable. When looking at the subjects who voted outside of the three central categories, in winter (cold season) 13.85% voted within the extreme categories cool/cold (-2, -3) and 3.85% voted for the extreme categories warm/hot (+2, +3), whereas in the hot season, all these votes were within warm/hot categories, where 22.2% was in summer night-time and 5.6% was in summer day-time. These results indicate that the high percentage of votes in the extreme categories of the thermal sensation scale is found in the summer night-time survey where the air temperature (DBT) has recorded its highest readings compared to other surveys (winter and summer day-time). This explains why the studied sites during summer night-time showed the lowest acceptability levels and did not meet the 80% acceptability criteria prescribed by ASHRAE Standard 55.

7.4.3 Thermal comfort (TC)

The second method used in this study for assessing the thermal acceptability of the studied sites is by using the thermal comfort scale as an indirect measure. The subjective scale used for thermal comfort is as follows; 1 (very comfortable), 2 (comfortable), 3 (slightly comfortable), 4 (neutral), 5 (slightly uncomfortable), 6 (uncomfortable) and 7 (very uncomfortable), see Table 7-4. Level four is neutral when one does not feel any thermal discomfort. (Givoni et al., 2003, Gaitani et al., 2007) stated that thermal comfort could better be defined just as the absence of any sense of discomfort. As far as just the absence of discomfort is concerned, thermal acceptability could be expanded to include, in addition to the three categories of comfort (1, 2 and 3), the category of neutral (4). Based on this, the acceptability in this analysis will be associated with the voting inside the four categories (very comfortable, comfortable, slightly comfortable and neutral) (1, 2, 3, 4) of the thermal comfort scale. Thus, this analysis will look at the subjects' votes on this scale to determine whether a minimum of 80% of the votes in each site are within the definition of acceptability. A comparison between the case studies and seasons (winter, summer day-time and summer night-time) will be done as well.

7.4.3.1 In winter (cold season)

The frequency distribution of thermal comfort votes of the three studied courtyards (C1, C3 and C4) for the cold season is given in Figure 7-12.

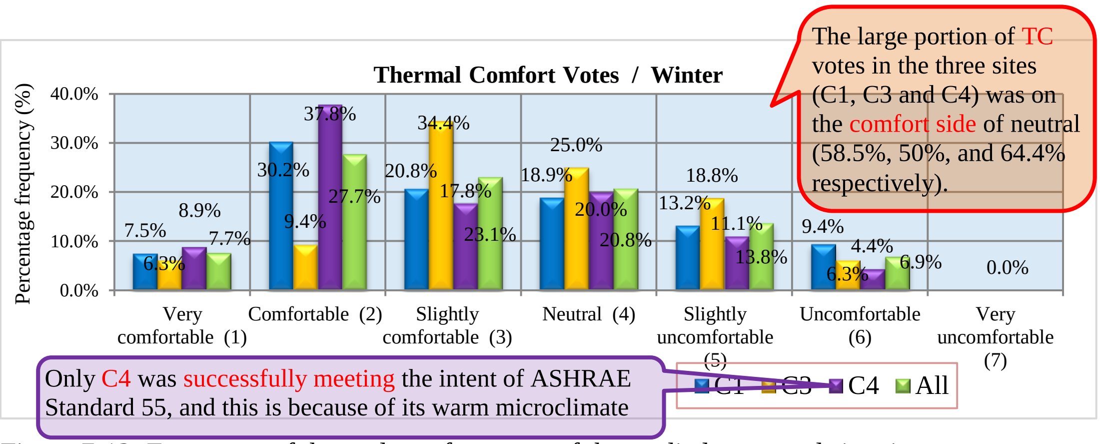


Figure 7-12: Frequency of thermal comfort votes of the studied courtyards in winter

From the data in the above graph, it is apparent that the large portion of thermal comfort votes of the subjects in the three studied courtyards (C1, C3 and C4) was on the comfort side of neutral (58.5%, 50%, 64.4% respectively). Using four categories (neutral and three categories of comfort) as the criterion for acceptability, the results indicate that the percentages of subjects who were comfortable in their sites increased to 77.4% in courtyard C1, 75% in courtyard C3 and 84.4% in courtyard C4. This means that among the three studied sites only courtyard C4 (F. Engineering) was successfully meeting the intent of ASHRAE Standard 55. One reason may be that mean air temperatures were higher in C4 than in C1 and C3 during the field survey, and this may be consistent with the hypothesis that during the cold season generally people prefer warm conditions than cold ones. In other words, a higher percentage of acceptability votes in courtyard C4 was due to the weather on the day of the interview which was slightly warm, dry, less air movement and this was probably suitable for an outdoor stay.

7.4.3.2 In summer day-time

The frequency distribution of thermal comfort votes of the subjects in the two studied courtyards (C1, and C3) for the hot season (summer day-time) is presented in Figure 7-13.

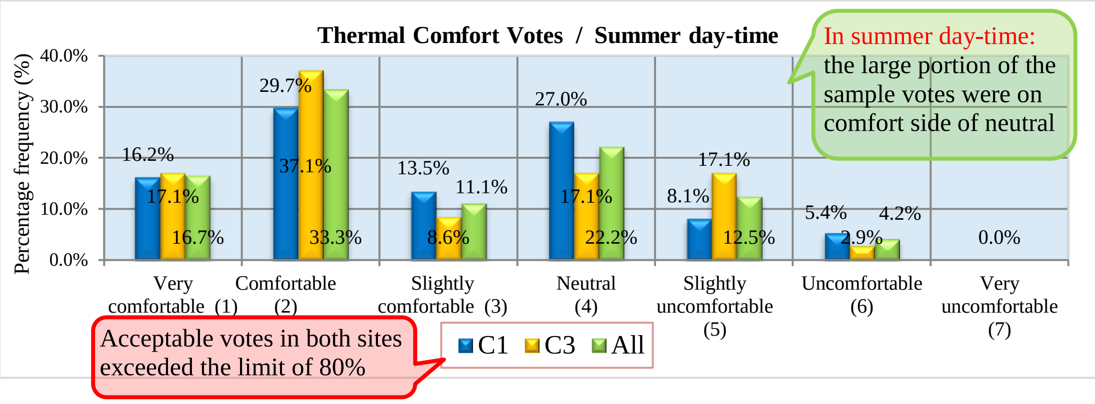


Figure 7-13: Frequency of thermal comfort votes of the studied courtyards in summer day-time

It is shown in Figure 7-13 that most of the thermal comfort votes in courtyard C1 (59.5%) and C3 (62.9%) were on the comfort side of neutral. When looking at the voting on comfortable-neutral categories (neutral and three categories of comfort), the percentage of acceptable votes in both courtyards exceeded the limit of 80%. Surprisingly, the percentage of subjects who found the condition to be satisfactory and acceptable in C1 (86.5%) is slightly higher than in C3 (80%) despite the latter courtyard having a lower air temperature and higher wind speeds, and this is probably related to the clothing insulation values which were higher in C3 than in C1. The mean clothing insulation value was 0.53 clo in C1 and 0.60 clo in C3, see Figure 7-14 and Figure 7-15 which give a clear picture about the clothes people were wearing in both courtyards. Thus, it can be concluded that 80% or more of the people in both courtyards found the environments thermally acceptable during summer day-time.

Figure 7-14: Photographs showing people wear formal clothes in courtyard C3 (work place)

Figure 7-15: Photographs showing people wear casual clothes in courtyard C1 (leisure place)

7.4.3.3 In summer night-time

The frequency distribution of thermal comfort votes of the subjects in the two studied courtyards (C1, and C6) for the hot season (summer night-time) is presented in Figure 7-16.

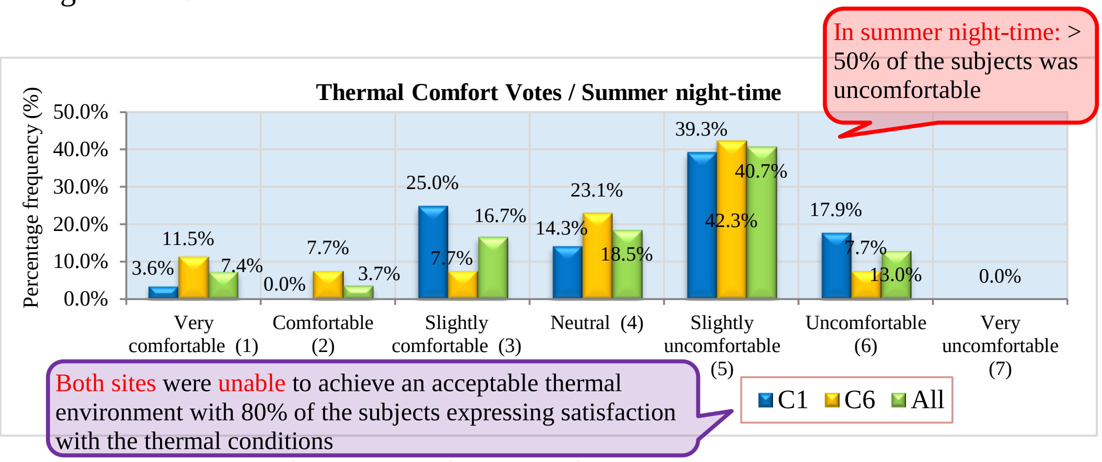


Figure 7-16: Frequency of thermal comfort votes of the studied courtyards in summer night-time

Figure 7-16 reveals that the large portion of the subjects in both courtyards (C1 and C6) voted outside the comfort range on the thermal comfort scale (57.1% and 50% respectively). Looking back at the percentage of votes within comfortable-neutral categories (neutral and three categories of comfort), the results indicate that only 42.9% of the subjects in C1 and 50% in C6 have expressed satisfaction with their thermal environment. This means that none of the studied courtyards was able to achieve an acceptable thermal environment with 80% of the subjects expressing satisfaction with the thermal conditions. The results seem to show that a large portion of the summer night-time subjects were uncomfortable in both courtyards across an air temperature range of 32 – 34.3ºC.

7.4.3.4 Comparison between seasons

Figure 7-17 shows the percentage distribution of thermal comfort votes for all the samples combined at different seasons.

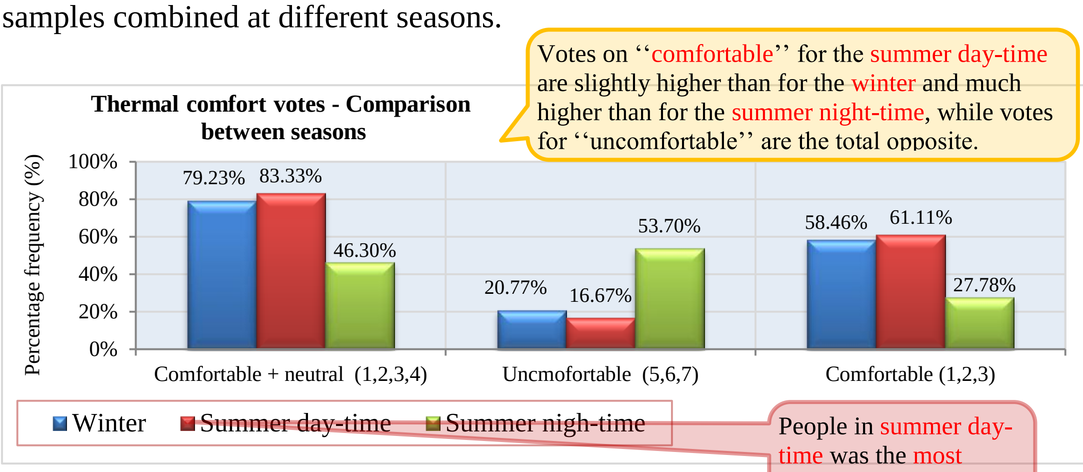


Figure 7-17: Thermal comfort votes – seasonal differences

As it is shown in the figure above, the thermal comfort scale reveals some similarities and some differences between peoples' comfort votes in the three survey phases (cold and hot season). Votes on 'comfortable' for the summer day-time are slightly higher than for the winter and much higher than for the summer night-time, while votes for 'uncomfortable' are the total opposite. Based on these results in general, the studied environments in winter day-time and summer night-time did not reach the limit of thermal acceptability of 80% as proposed by ASHRAE. When the definition of thermal acceptability was expanded to include neutral in addition to the comfort categories within the acceptable range (neutral-comfortable), the thermal acceptability levels increased in both seasons (winter and summer day and night-time), particularly in summer day-time where the percentage exceeded the 80% acceptability criteria and in winter where the level was close to this percentage. Therefore, it is suggested that people during summer day-time were the most comfortable with their thermal environment.

7.4.4 Thermal preference (TP)

The third method for assessing thermal acceptability in the studied environments is by using the McIntyre preference scale as an indirect measure despite the fact that it was not commonly used for this purpose in thermal research as stated (Brager et al., 1993). The scale is as follows; -1 (cooler), 0 (no change), +1 (warmer), see

Table 7-4. According to this scale, the subjects were asked in their natural environment whether they wanted to accept or change their thermal state. For this analysis, acceptability will be defined by subjects' votes on category 'no change' which indicates that they accept their thermal environment. Based on this, the analysis will look at the subjects' votes on this scale to determine whether a minimum of 80% of the votes in each site are within the definition of acceptability. A comparison between the case studies and seasons (winter, summer day-time and summer night-time) will be done as well.

7.4.4.1 In winter

The distribution of thermal preference votes of subjects in the three studied courtyards (C1, C3 and C4) for the cold season is shown in Figure 7-18.

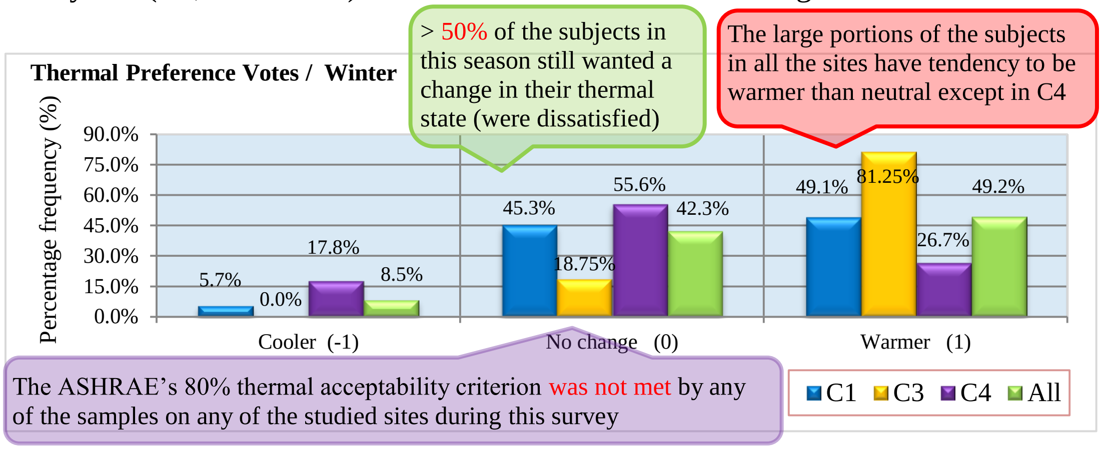


Figure 7-18: Percentage frequency distribution of thermal preference votes of participants in the studied courtyards for winter

As seen from the above graph, responses to the thermal preference question revealed different results in the three studied courtyards (C1, C3 and C4) in the cold season (winter). Looking first at all the votes in the three sites (samples combined), the graph shows that 49.2% of the votes in cold season wanted to be warmer, 42.3% wanted no change and only 8.5% of the votes wanted to be cooler. This is to be expected since the survey was conducted in the cold season.

When looking into the preference votes of the subjects in the three studied sites, about 81.25% of the subjects in courtyard C3, 54.7% in courtyard C1 and 44.4% in courtyard C4 still wanted a change in their thermal state (preferring to feel warmer or cooler). This means that more than 50% of the subjects as a whole in the winter survey were dissatisfied. More specifically, the results show that the large portion of the subjects in C3 (81.25%) and in C1 (49.1%) still wanted to be warmer, and this suggests that a warm condition is the most desirable for the samples in these courtyards during the cold season. These results agree with the idea that people in regions with cold winters have a tendency to be warmer than neutral.

Looking back into the subjects who considered their sites to be thermally acceptable, it's clear from the results that the highest percentage of votes on 'no change' (55.6%) was in C4, followed by 45.3% in C1, and lastly 18.75% in C3. It may, thus, be concluded that the ASHRAE's 80% thermal acceptability criterion was not met by any of the samples on any of the studied sites (C1, C3 and C4) during the cold season (winter).

7.4.4.2 In summer day-time

The distribution of thermal preference votes of subjects in the two studied courtyards (C1 and C3) for the hot season (day-time) is shown in Figure 7-19.

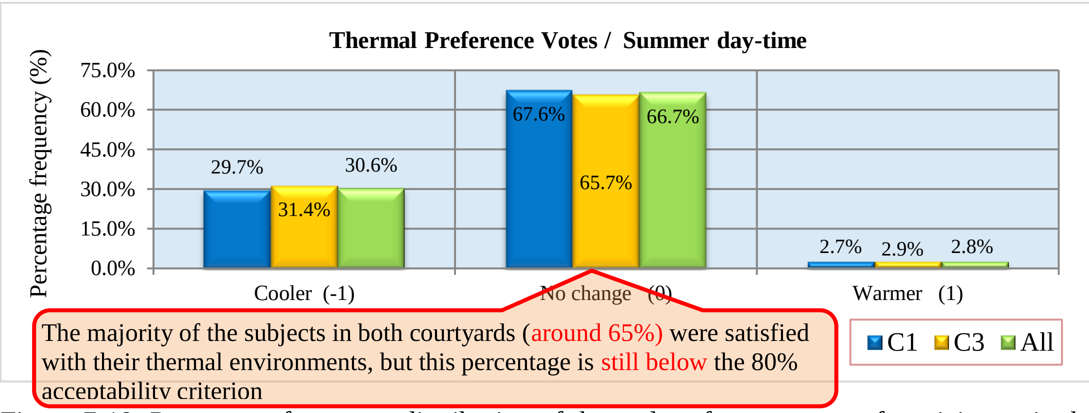


Figure 7-19: Percentage frequency distribution of thermal preference votes of participants in the studied courtyards for summer day-time

From the figure above, responses to the thermal preference question revealed very similar results in both courtyards (C1, and C3) in the hot season (summer day-time). In general, a large portion of total subjects, more than ⅔ of the samples (66.7%) voted for no change, whereas only about ⅓ of the subjects still wanted a change in their thermal state (30.6% preferred to feel cooler and 2.8% preferred to feel warmer). More specifically, 67.6% of subjects in courtyard C1 were satisfied with an air temperature (DBT) average of 27.1- 28.9ºC. About 65.7% of the subjects in courtyard C3 were satisfied with an air temperature (DBT) average of 25.5- 27.7ºC. Although the results showed that the majority of subjects in both courtyards (around 65% of the sample) were satisfied with their thermal environments, the percentages are still below the 80% acceptability criterion. Thus, the results indicate that ASHRAE's 80% thermal acceptability criterion was not met by both studied courtyards during summer day-time (hot season).

7.4.4.3 In summer night-time

The distribution of thermal preference votes of subjects in the two studied courtyards (C1 and C6) for the hot season (night-time) is shown in Figure 7-20.

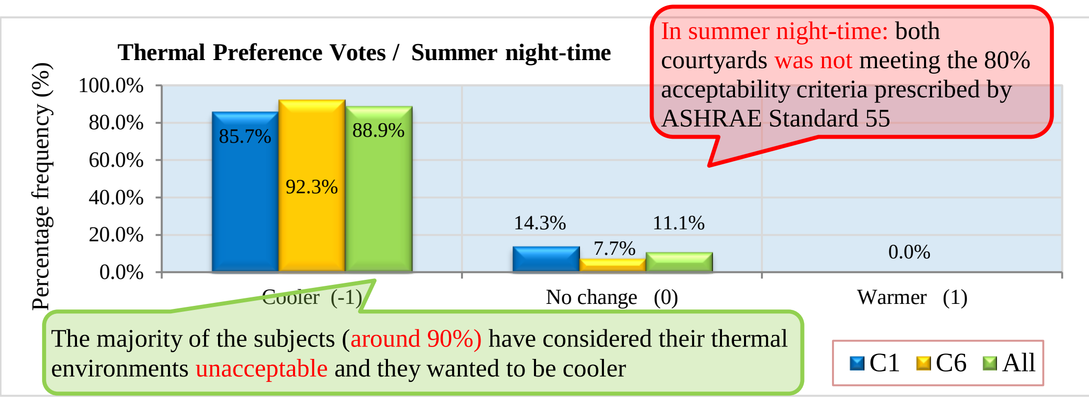


Figure 7-20: Percentage frequency distribution of thermal preference votes of participants in the studied courtyards for summer night-time

Based on the graph above, the results show very similar responses to the thermal preference question in both courtyards (C1 and C6) in the hot season (summer nigh-time). This is probably due to the similarity in their microclimates (environmental measurements in both courtyards were very close to each other).When looking into the subjects who voted for no change in both courtyards, the results indicate that only a small portion of the subjects (not exceeding 15%) were satisfied with their thermal environment, whereas the majority of the subjects (around 90%) considered their thermal environments unacceptable and they wanted to be cooler. Therefore, these results indicate that both courtyards were not meeting the 80% acceptability criteria prescribed by ASHRAE Standard 55.

7.4.4.4 Comparison between seasons

Figure 7-11 shows percentage distribution of thermal preference votes for all the samples combined at different seasons.

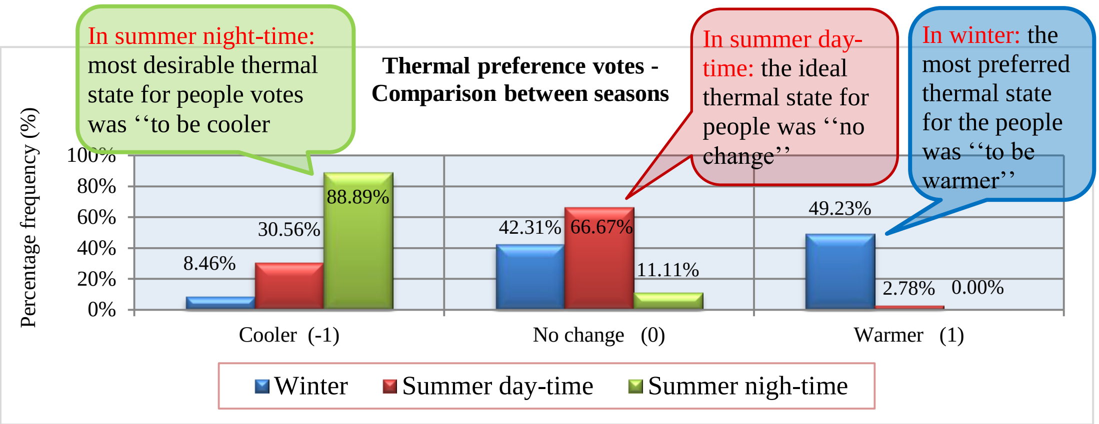


Figure 7-21: Thermal preference votes – seasonal differences

From the figure above, it is clear that there were some seasonal differences in people's preferences. The results show that the large portion of thermal preference (TP) votes in winter was for 'to be warmer', in summer day-night it was for 'no change' and in summer night-time it was for 'to be cooler'. More specifically, when looking at the people who prefer a change in their thermal state, the results show that in winter about 49.2% of them want to be warmer and 17.8% want to be cooler, while in summer day-time, 30.6% want to be cooler and only 2.8% prefer to be warmer. In summer night-time, all the people who want to change their thermal condition prefer to be cooler (88.9%). This indicates that the majority of the subjects who want change their thermal state in winter concentrated on a warmer category, while in summer they concentrated in cooler category.

Thus, in the cold season (winter), 85.2% of the people who wanted to change their thermal state preferred to be warmer, while in the hot season (summer day-time), 91.6% of who wanted to change their thermal state preferred to be cooler, and this pattern was stronger in summer night-time where this percentage increased to100%. These results suggest that 'be warmer' is the most preferred thermal state for the people in winter, while in summer day-time 'no change' is the ideal one, but in summer night-time, the most desirable thermal state for people is to be cooler.

7.4.5 Comparison between results of thermal sensation (TS) and thermal comfort (TC)

7.4.5.1 In winter season

A cross-comparison of simultaneous votes on both the thermal sensation scale and thermal comfort scale for the subjects in the winter survey is shown in Table 7-13 and Table 7-13.

Table 7-12: Cross tabulation of sensation votes and comfort votes for C1 and C3 / winter

Comfort Votes (%)	Courtyard C1								Courtyard C3							
	Sensation Votes (%)								Sensation Votes (%)							
	3	2	1	0	-1	-2	-3	Total	3	2	1	0	-1	-2	-3	Total
1	-	-	-	7.5	-	-	-	**7.5**	-	-	-	6.3	-	-	-	**6.3**
2	-	-	-	22.6	7.5	-	-	**30.2**	-	-	-	9.4	-	-	-	**9.4**
3	-	-	-	-	18.9	1.9	-	**20.8**	-	-	-	21.9	6.3	6.3	-	**34.4**
4	-	-	-	13.2	5.7	-	-	**18.9**	-	-	-	3.1	12.5	-	9.4	**25**
5	-	-	-	-	5.7	5.7	1.9	13.2	-	-	-	-	6.3	12.5	-	18.8
6	-	-	-	-	7.5	1.9	-	9.4	-	-	-	-	-	6.3	-	6.3
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	-	-	**-**	**43.4**	**45.3**	9.4	1.9	100	-	-	**-**	**40.6**	**25**	25	9.4	100

Table 7-13: Cross tabulation of sensation votes and comfort votes for C4 and for the All / winter

Comfort Votes (%)	Courtyard C4								All (combined)							
	Sensation Votes (%)								Sensation Votes (%)							
	3	2	1	0	-1	-2	-3	Total	3	2	1	0	-1	-2	-3	Total
1	-	-	-	8.9	-	-	-	**8.9**	-	-	-	7.7	-	-	-	**7.7**
2	-	2.2	-	31.1	2.2	2.2	-	**37.8**	-	0.8	-	22.3	3.8	0.8	-	**27.7**
3	-	2.2	2.2	2.2	11.1	-	-	**17.8**	-	0.8	0.8	6.2	13.1	2.3	-	**23.1**
4	-	-	2.2	15.6	2.2	-	-	**20**	-	-	0.8	11.5	6.2	-	2.3	**20.8**
5	-	4.4	2.2	4.4	-	-	-	11.1	-	1.5	0.8	1.5	3.8	5.4	0.8	13.8
6	-	2.2	2.2	-	-	-	-	4.4	-	0.8	0.8	-	3.1	2.3	-	6.9
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	-	11.1	**8.9**	**62.2**	**15.6**	2.2	-	100	-	3.8	**3.1**	**49.2**	**30**	10.8	3.1	100

The above tables show that the percentages of thermal acceptability by using the thermal sensation scale were 88.7% in courtyard C1, 65.6% in courtyard C3 and 86.7% in courtyard C4. This level was clearly higher than that obtained from using the thermal comfort scale where the percentages were 77.4%, 75% and 84% respectively. Thus, C4 was the only courtyard who showed a higher than 80% acceptability obtained from the two scales (TS & TC), whereas courtyard C1 met this creation from only the votes of the thermal sensation scale.

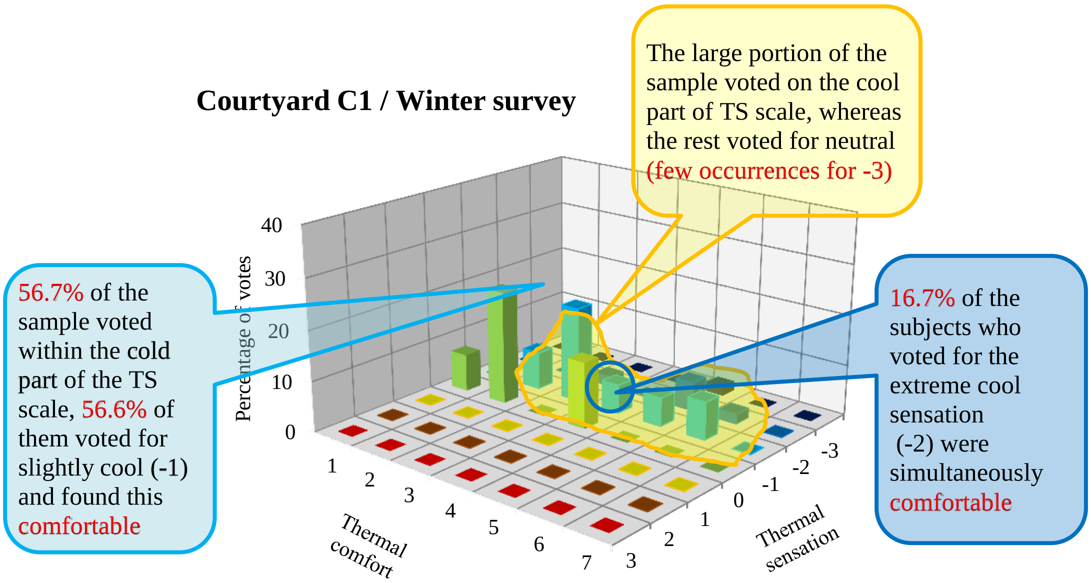


Figure 7-22: A cross-comparison of simultaneous votes on both TS & TC scales for the subjects in courtyard C1 during winter survey

Looking at the cross-comparison of simultaneous votes on both scales (TS & TC), the results show that about 56.7% of the sample in courtyard C1 voted within the cold part of the TS scale, 56.6% of them voted for slightly cool (-1) and found this comfortable (Figure 7-22).

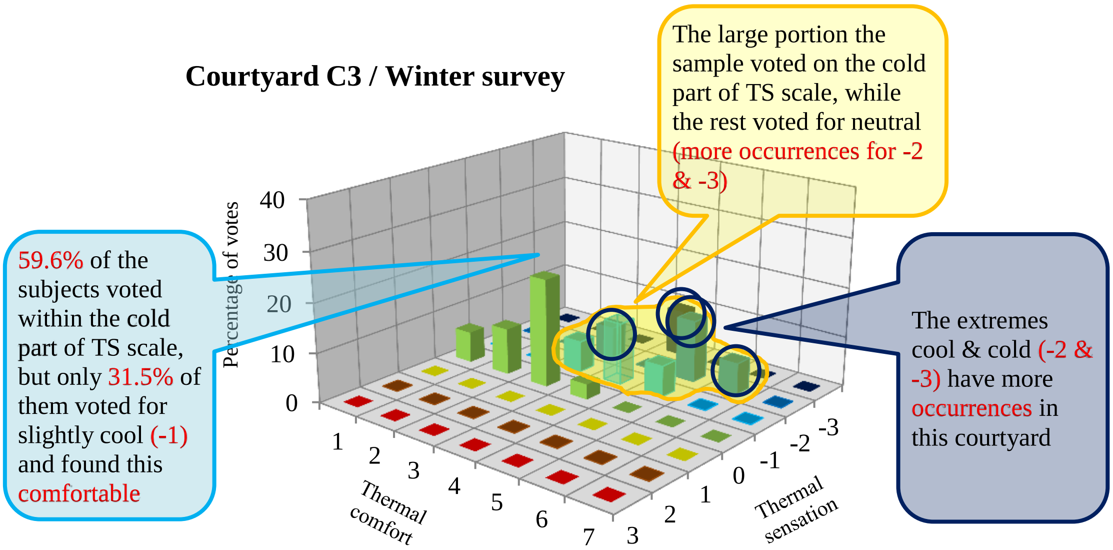


Figure 7-23: A cross-comparison of simultaneous votes on both TS & TC scales for the subjects in courtyard C3 during winter survey

In C3, 59.6% of the subjects voted within the cold part of the TS scale, but only 31.5% of them voted for slightly cool (-1) and found this comfortable (Figure 7-23). The situation is different in courtyard C4 where 17.7% and 19.8% of the subjects voted within the cold and warm parts respectively, 87.6% of the first voted for slightly cool (-1) and found this comfortable and 22.2% of the second voted for slightly warm (+1) and found this comfortable. These notable higher percentages of votes for comfortably cold (-1) and comfortably warm (+1) in some courtyards, may explain why these sites showed high levels of acceptability than the others, and this is strongly related to the microclimatic conditions of these sites. For instance C4 showed the highest level of acceptability in winter because its environment was warmer than the other two courtyards, whereas C1 came second despite its air temperature being the same as that of C3, but the difference in wind speeds might make the difference in acceptability levels between the two sites.

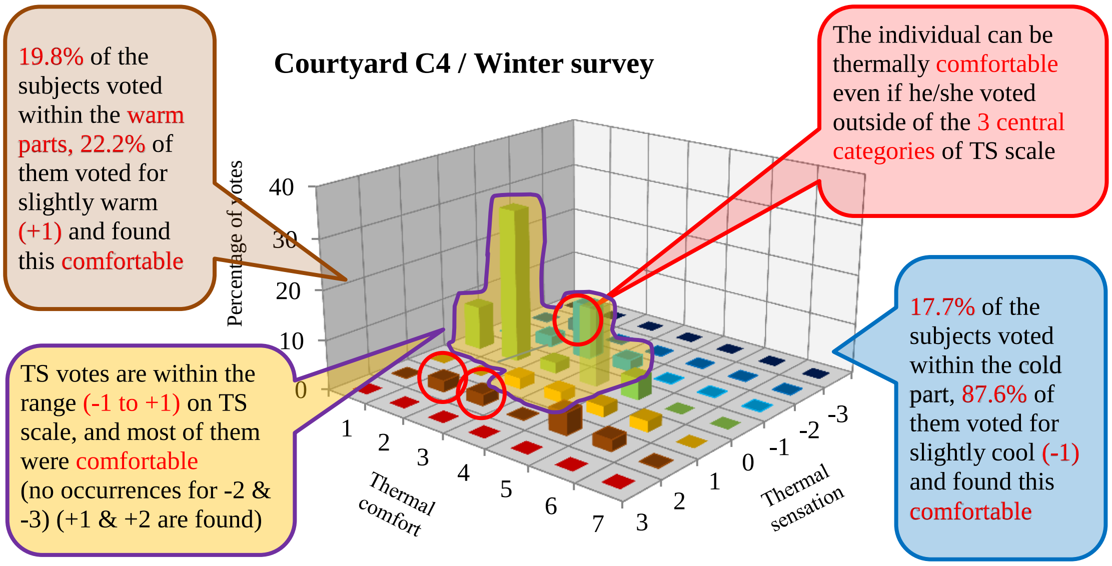


Figure 7-24: A cross-comparison of simultaneous votes on both TS & TC scales for the subjects in courtyard C4 during winter survey

On the other hand, it appears from the results that there were subjects voted within the extremes (-2, -3) & (+2, +3) of the thermal sensation scale and simultaneously were comfortable with their thermal environments. In C1, 16.7% of the subjects who voted within the extremes (cool sensation) were simultaneously comfortable, whereas about 45.5% in C3 did so. As shown in Figure 7-24, the corresponding percentage in C4 was 50% (16.7% voted for cool sensation and 33.3% for warm sensation). These results suggest that the individual can be thermally comfortable even if he/she voted outside of the three central categories of the thermal sensation scale.

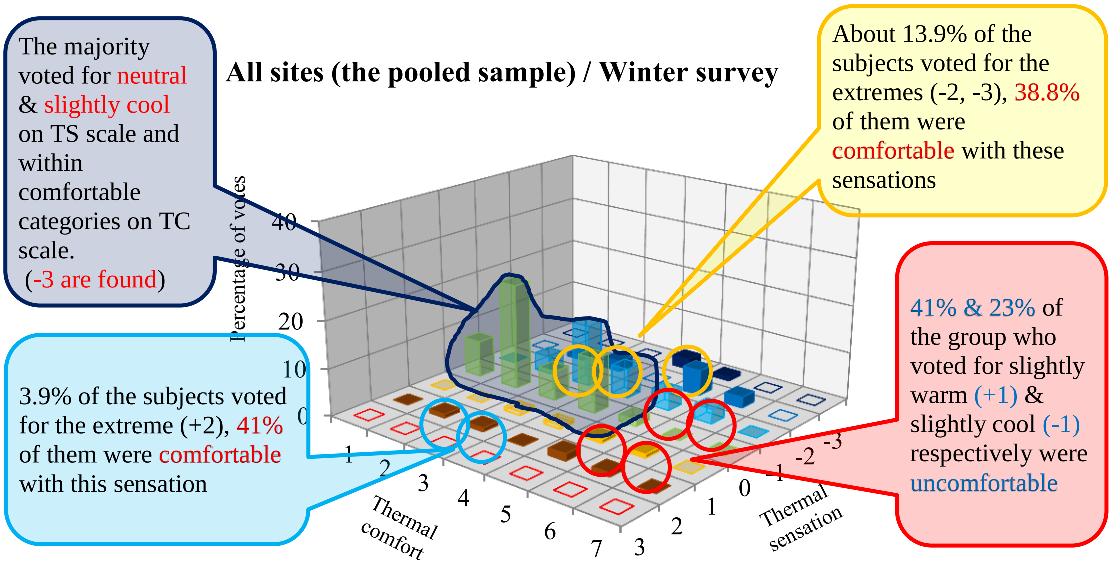


Figure 7-25: A cross-comparison of simultaneous votes on both TS & TC scales for the pooled sample (All sites) during winter survey

As for the sample as a whole (the pooled sample) in the winter survey, Table 7-13 and Figure 7-25 indicate that about 13.9% and 3.9% of the subjects voted for the extremes (-2, -3) and (+2) respectively, 38.8% of the first and 41% of the second were comfortable with these sensations. The results also show that about 23% of the group who voted for slightly cold (-1) were uncomfortable, and 41% of the group who voted for slightly warm (+1) were uncomfortable as well. This diversity of subjects' votes might be the result of differences in microclimatic parameters as well as the clothing values of the subjects in the three studied courtyards in winter season.

7.4.5.2 In summer day-time

A cross-comparison of simultaneous votes on both the thermal sensation scale and thermal comfort scale is shown in Table 7-14 and Table 7-15.

Table 7-14: Cross tabulation of sensation votes and comfort votes for C1 and C3 / summer day-time

Comfort Votes (%)	**Courtyard C1**								**Courtyard C3**							
	Sensation Votes (%)								Sensation Votes (%)							
	3	2	1	0	-1	-2	-3	Total	3	2	1	0	-1	-2	-3	Total
1	-	-	-	16.2	-	-	-	**16.2**	-		-	17.1	-	-	-	**17.1**
2	-	2.7	-	27	-	-	-	**29.7**	-	-	-	37.1	-	-	-	**37.1**
3	-	-	2.7	10.8	-	-	-	**13.5**	-	-	-	8.6	-	-	-	**8.6**
4	-	-	2.7	24.3	-	-	-	**27**	-	-	2.9	14.3	-	-	-	**17.1**
5	-	-	8.1	-	-	-	-	8.1	-	-	14.3	2.9	-	-	-	17.1
6	-	5.4	-	-	-	-	-	5.4	-	2.9	-	-	-	-	-	2.9
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	-	8.1	**13.5**	**78.4**	-	-	-	100	-	2.9	**17.1**	**80**	-	-	-	100

Table 7-15: Cross tabulation of sensation votes and comfort votes for the entire sample in summer day-time

Comfort Votes (%)	**All** the sample in summer day time survey							
	Sensation Votes (%)							
	3	2	1	0	-1	-2	-3	Total
1	-	-	-	16.7	-	-	-	**16.7**
2	-	1.4	-	31.9	-	-	-	**33.3**
3	-	-	1.4	9.7	-	-	-	**11.1**
4	-	-	2.8	19.4	-	-	-	**22.2**
5	-	-	11.1	1.4	-	-	-	12.5
6	-	4.2	-	-	-	-	-	4.2
7	-		-	-	-	-	-	-
Total	-	5.6	**15.3**	**79.1**	-	-	-	100

The distribution of sensation votes and comfort votes in the summer day-time survey have shown that the percentages of thermal acceptability from the thermal sensation votes were 91.9% in courtyard C1 and 97.1% in courtyard C3. This level was higher compared to that obtained from the thermal comfort votes where the percentages were 86.5% and 80% respectively. Thus, both scales in both courtyards in summer day-time were able to achieve an acceptable thermal environment, with a minimum of 80% of the subjects expressing satisfaction with the thermal conditions.

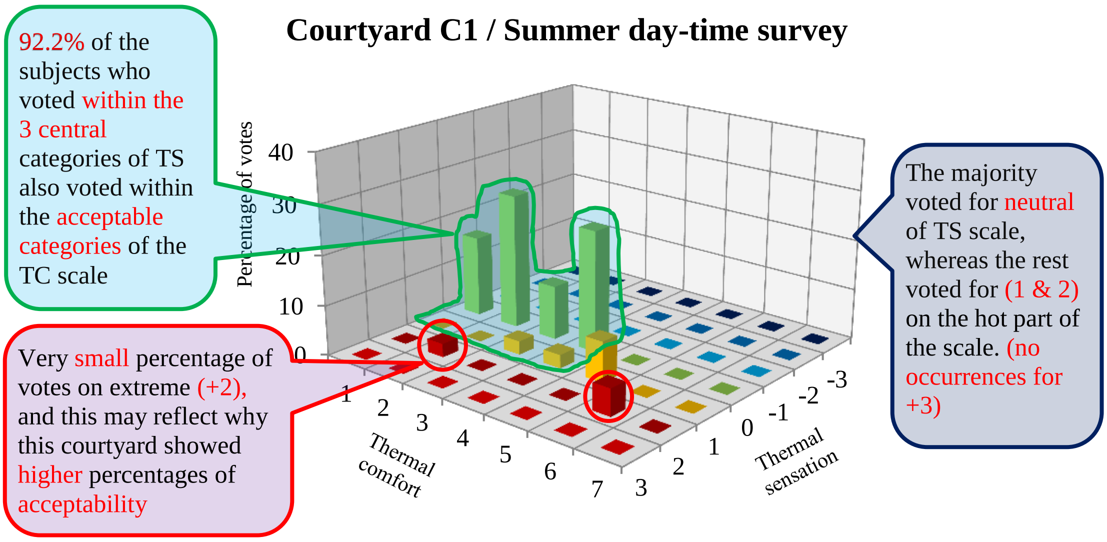


Figure 7-26: A cross-comparison of simultaneous votes on both TS & TC scales for the subjects in courtyard C1 during summer day-time survey

Figure 7-26 shows that about 92.2% of the subjects who voted within the three central categories in C1, also voted within the acceptable categories of the thermal comfort scale, whereas the corresponding percentage in courtyard C3 was 82.3% as shown in Figure 7-27.

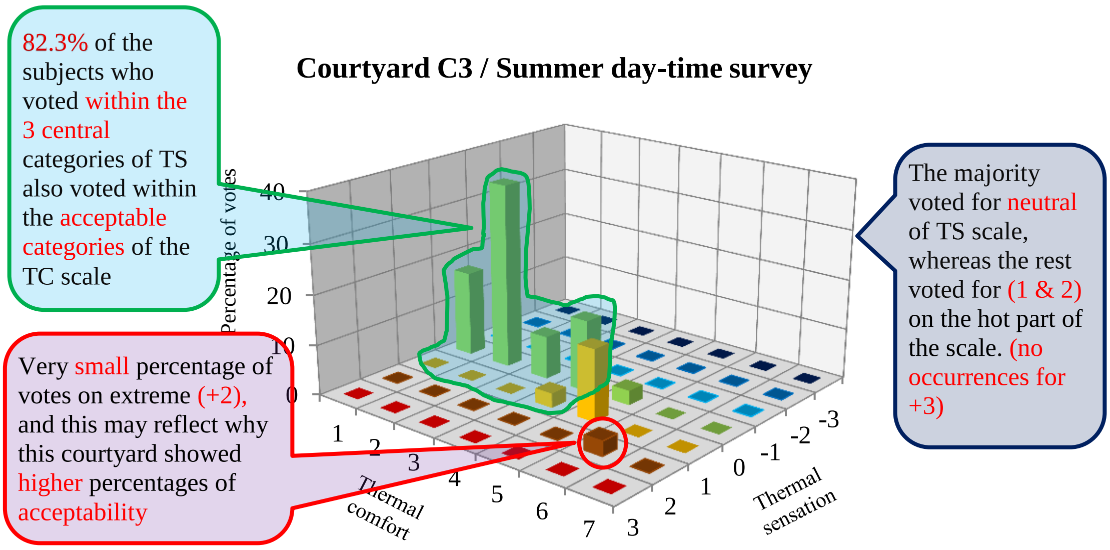


Figure 7-27: A cross-comparison of simultaneous votes on both TS & TC scales for the subjects in courtyard C3 during summer day-time survey

This shows that there is high correlation between the results obtained from the TC scale (comfortable-neutral) and results obtained from the TS scale (three central categories) in both courtyards.

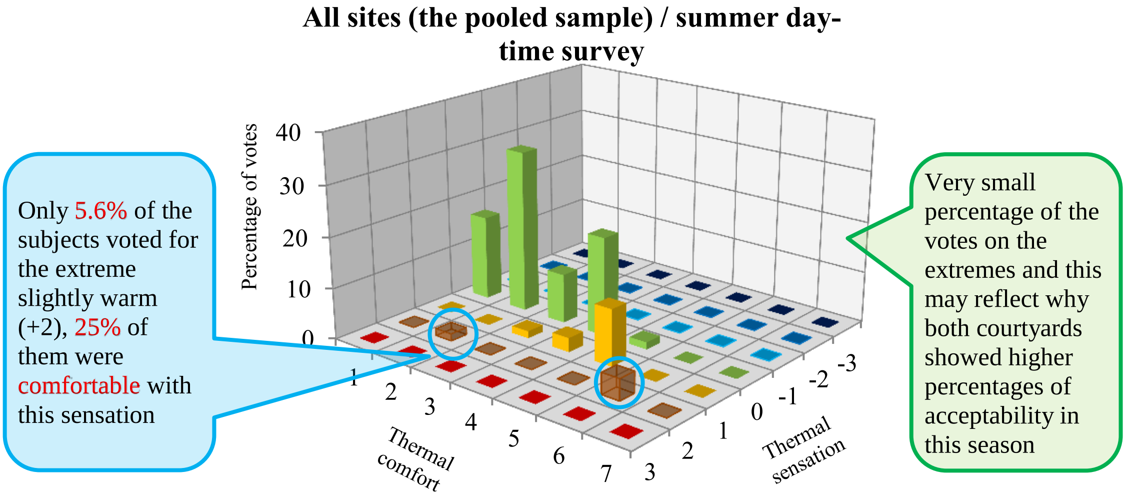


Figure 7-28: A cross-comparison of simultaneous votes on both TS & TC scales for the pooled sample (All sites) during summer day-time survey

When looking at the sample as a whole in the summer day-time survey, the results indicate that only 5.6% of the subjects voted for the extreme slightly warm (+2) on the thermal sensation scale and 25% of them were comfortable with this sensation (Figure 7-28). This may reflect why both of the studied courtyards showed higher percentages of acceptability in this season.

7.4.5.3 In summer nocturnal

A cross-comparison of simultaneous votes on both thermal sensation scale and thermal comfort scale is shown in Table 7-16 and Table 7-17.

Table 7-16: Cross tabulation of sensation votes and comfort votes for C1 and C6 / summer night-time

Comfort Votes (%)	**Courtyard C1**								**Courtyard C6**							
	Sensation Votes (%)								Sensation Votes (%)							
	3	2	1	0	-1	-2	-3	Total	3	2	1	0	-1	-2	-3	Total
1	-	-	-	3.6	-	-	-	**3.6**	-	-	-	11.5	-	-	-	**11.5**
2	-	-	-	-	-	-	-	-	-	3.8	-	3.8	-	-	-	**7.7**
3	-	-	10.7	14.3	-	-	-	**25**	-	-	7.7	-	-	-	-	**7.7**
4	-	-	7.1	7.1	-	-	-	**14.3**	-	3.8	11.5	7.7	-	-	-	**23.1**
5	-	3.6	35.7	-	-	-	-	39.3	3.8	3.8	34.6	-	-	-	-	42.3
6	10.7	7.1	-	-	-	-	-	17.9	3.8	3.8	-	-	-	-	-	7.7
7	-	-	-	-	-	-	-	-	-	-	--	-	-	-	-	-
Total	10.7	10.7	**53.6**	**25**	-	-	-	100	7.7	15.4	**53.8**	**23.1**	-	-	-	100

Table 7-17: Cross tabulation of sensation votes and comfort votes for the entire sample in summer day-time

Comfort Votes (%)	All the sample in summer night-time survey							
	Sensation Votes (%)							
	3	2	1	0	-1	-2	-3	Total
1	-	-	-	7.4	-	-	-	**7.4**
2	-	1.9	-	1.9	-	-	-	**3.7**
3	-	-	9.3	7.4	-	-	-	**16.7**
4	-	1.9	9.3	7.4	-	-	-	**18.5**
5	1.9	3.7	35.2	-	-	-	-	40.7
6	7.4	5.6	-	-	-	-	-	13
7	-	-	-	-	-	-	-	-
Total	9.3	13	**53.7**	**24.1**	-	-	-	100

Looking first at the distribution of sensation votes and comfort votes in the summer night-time survey, the results show that none of the studied sites met the ASHRAE Standard-55's 80% acceptability criteria. Using the thermal sensation scale gave the highest level of acceptability of 78.6% and 76.9% for courtyard C1 and courtyard C6 respectively, but when using the thermal comfort scale, these percentages drop to 42.9% in C1 and 50.0% in C6.

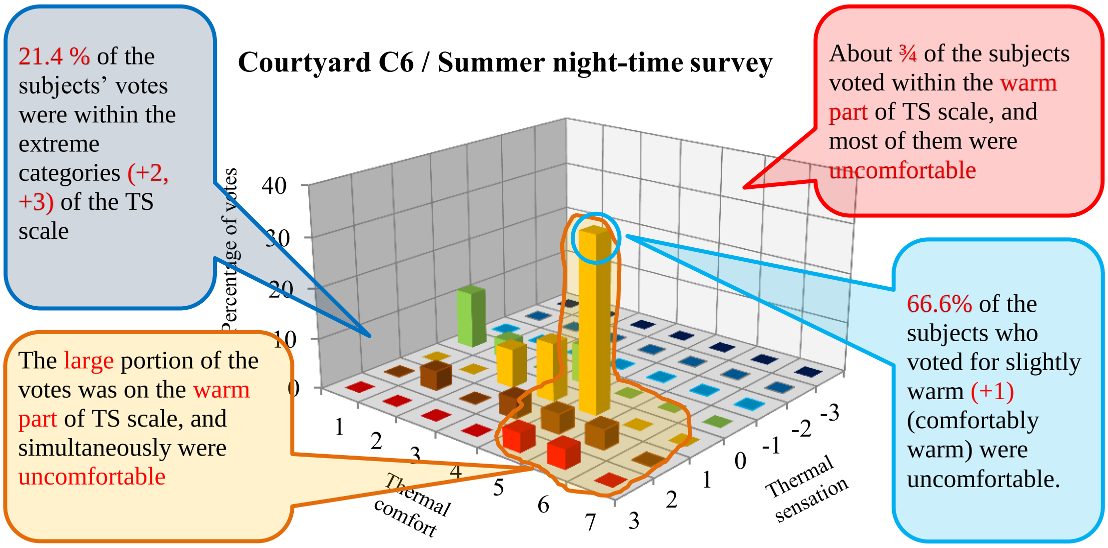


Figure 7-29: A cross-comparison of simultaneous votes on both TS & TC scales for the subjects in courtyard C6 during summer night-time survey

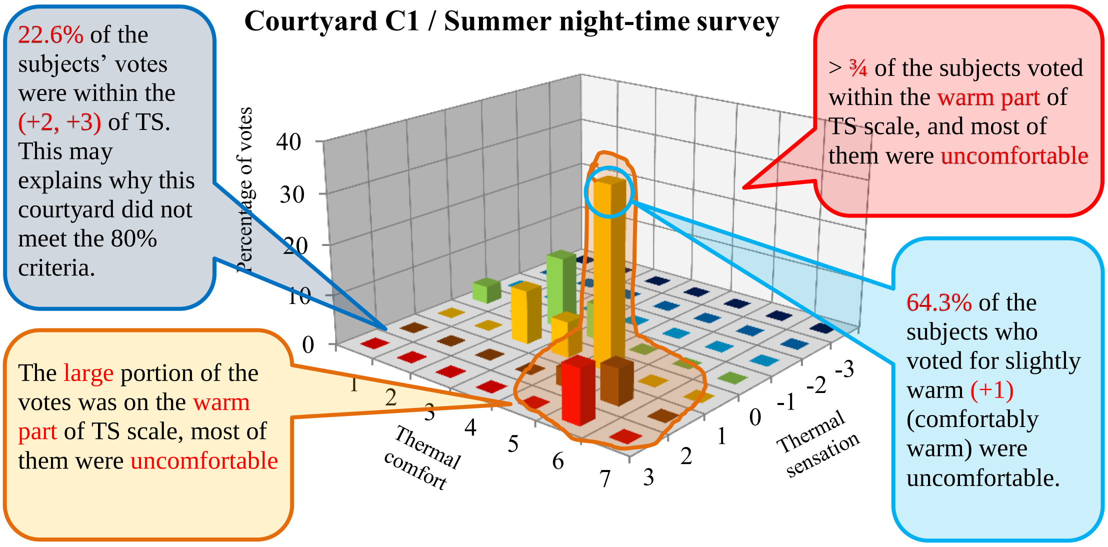


Figure 7-30: A cross-comparison of simultaneous votes on both TS & TC scales for the subjects in courtyard C1 during summer night-time survey

Looking at the subjects' votes on TS scale and TC scale in more detail as shown in Figure 7-29 and Figure 7-30, the results reveal that about 21.4 % and 22.6% of the subjects' votes in C1 and C6 respectively were within the extreme categories (+2, +3) of the thermal sensation scale, and this probably explains why both courtyards did not meet the 80% acceptability criteria. Moreover, the results indicate that in courtyard C1, 66.6% of the subjects who voted for slightly warm (+1) were uncomfortable. Similarly, in courtyard C6, 64.3% of the subjects who voted for slightly warm (+1) also were uncomfortable. Based on the definition of acceptability using the thermal comfort scale, these results indicate that voting for +1 on the thermal sensation scale is not necessarily always associated with thermal satisfaction (comfort).

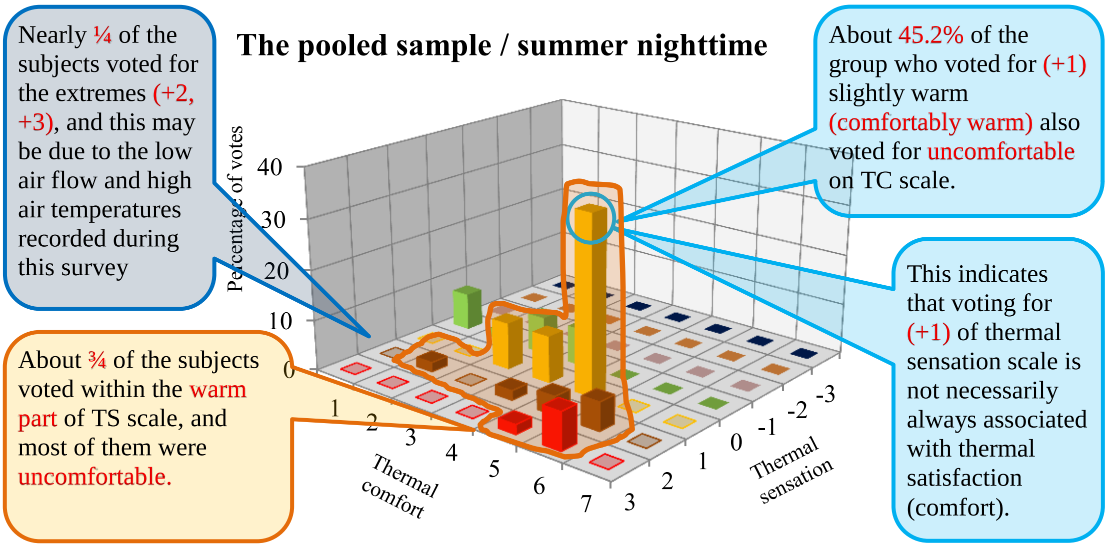


Figure 7-31: A cross-comparison of simultaneous votes on both TS & TC scales for the pooled sample (All sites) during summer night-time survey

When looking at the sample as a whole in the summer night-time survey as seen in Table 7-17 and Figure 7-31, as expected nearly a quarter of the subjects (22.3%) voted for the extremes (+2, +3) due to the high temperatures and low wind speeds recorded in the studied sites in this survey. Moreover, about 45.2% of the group who voted for +1 comfortably warm, also voted for uncomfortable on the thermal comfort scale. This strongly reflects the influence of microclimatic parameters on the subjects' responses and this resulted in a decrease in the level of the thermal acceptability in the studied sites in summer night-time.

7.4.6 Comparison between the results of thermal sensation (TS) and thermal preference (TP),

7.4.6.1 In winter season

A cross-comparison of simultaneous votes on both the thermal sensation scale and thermal preference scale is shown in Table 7-18 and Table 7-19.

Table 7-18: Cross tabulation of sensation votes and preference votes for C1 and C3 / winter

Preference Votes (%)	Courtyard C1								Courtyard C3							
	Sensation Votes (%)								Sensation Votes (%)							
	3	2	1	0	-1	-2	-3	Total	3	2	1	0	-1	-2	-3	Total
-1	-	-	-	5.7	-	-	-	5.7	-	-	-	-	-	-	-	-
0	-	-	-	20.8	20.8	3.8	-	**45.3**	-	-	-	9.4	9.4	-	-	**18.8**
1	-	-	-	17	24.5	5.7	1.9	49.1	-	-	-	31.3	15.6	25	9.4	81.3
Total	-	-	-	**43.4**	**45.3**	9.4	1.9	100	-	-	-	**40.6**	**25**	25	9.4	100

Table 7-19: Cross tabulation of sensation votes and preference votes for C4 and for all the samples combined / winter

Preference Votes (%)	Courtyard C4								All							
	Sensation Votes (%)								Sensation Votes (%)							
	3	2	1	0	-1	-2	-3	Total	3	2	1	0	-1	-2	-3	Total
-1	-	4.4	4.4	8.9	-	-	-	17.8	-	1.5	1.5	5.4	-	-	-	8.5
0	-	4.4	4.4	35.6	8.9	2.2	-	**55.6**	-	1.5	1.5	23.1	13.8	2.3	-	**42.3**
1	-	2.2	-	17.8	6.7	-	-	26.7	-	0.8	-	20.8	16.2	8.5	3.1	49.2
Total	-	11.1	**8.9**	**62.2**	**15.6**	2.2	-	100	-	3.8	**3.1**	**49.2**	**30**	10.8	3.1	100

A comparison of thermal sensation and preference votes reveal that the percentages of votes in the three central categories of the thermal sensation scale is much higher compared to that for ‘no change’ on the preference scale in all the studied courtyards in the winter survey. Based on the thermal sensation scale, the percentages of thermal acceptability in the studied courtyards; C1, C3 and C4 were 88.7%, 65.6% and 86.7% respectively, however the percentages obtained by using the preference scale were 45.3% in C1, 18.75% in C3, and 55.6% in C4.

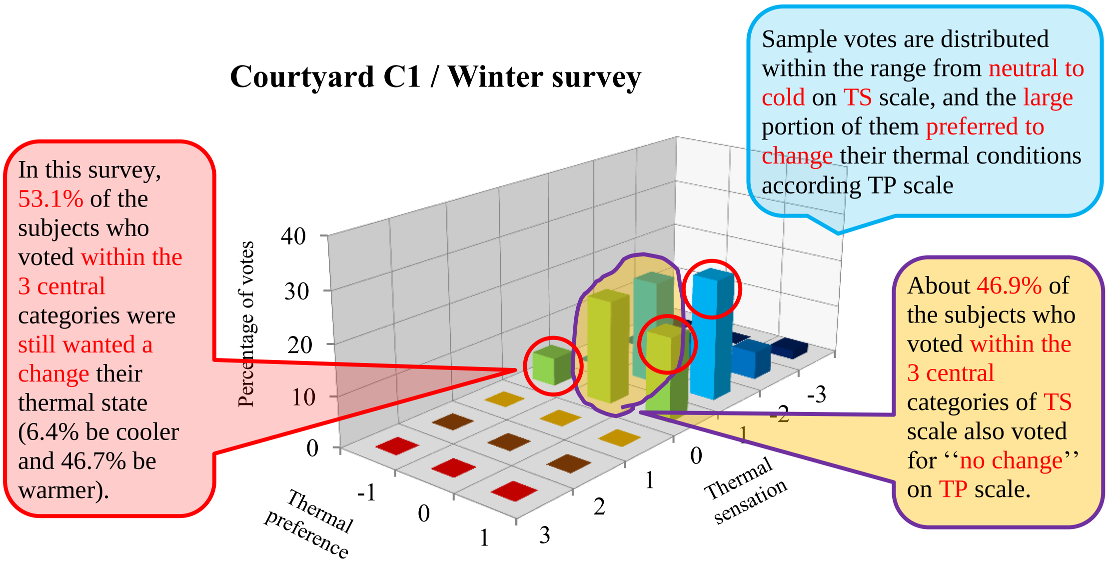


Figure 7-32: A cross-comparison of simultaneous votes on both TS & TP scales for the subjects in courtyard C1 during winter day-time survey

Looking back at the distribution of the subjects' votes on both scales the results indicate that, in courtyard C1, only 46.8% of the subjects who voted within the three central categories of thermal sensation scale also voted for 'no change' on the thermal preference scale (Figure 7-32).

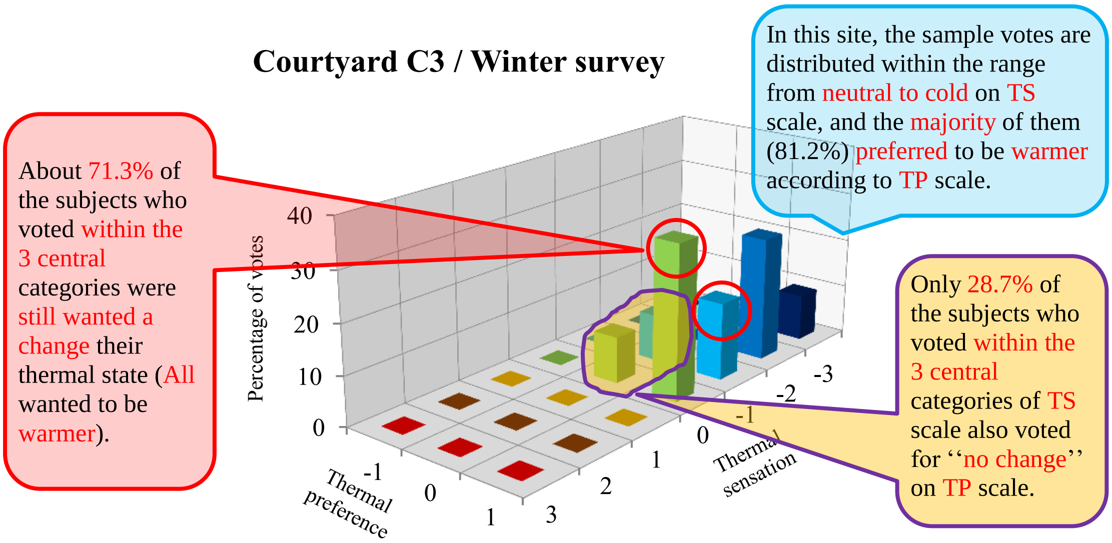


Figure 7-33: A cross-comparison of simultaneous votes on both TS & TP scales for the subjects in courtyard C3 during winter day-time survey

As are shown in Figure 7-33 and Figure 7-34, the corresponding percentages in courtyard C3, and courtyard C4 were 28.6% and 56.4% respectively. In addition, the above tables show that there were subjects who voted within the three central categories who were dissatisfied and wanted a change in their thermal state.

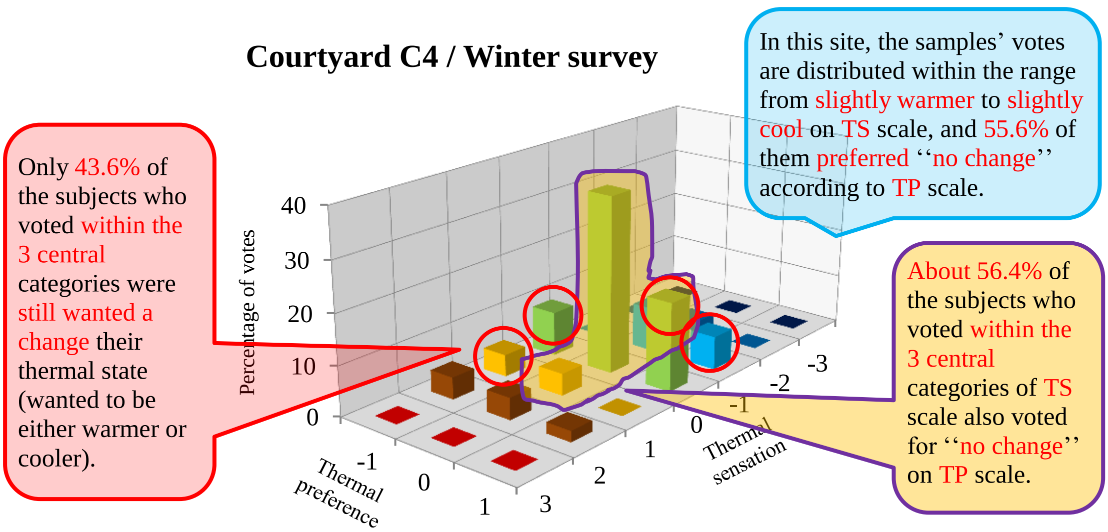


Figure 7-34: A cross-comparison of simultaneous votes on both TS & TP scales for the subjects in courtyard C4 during winter day-time survey

In courtyard C1, about 53.2% of the subjects who voted in the three central categories were simultaneously dissatisfied (6.4% wanted to be cooler and 46.7% wanted to be warmer). For courtyard C3, about 71.4% of the people who voted in the three central categories wanted to be warmer (change their state). As for C4, 43.6% of the subjects who voted in the three central categories wanted to be either warmer or cooler, and therefore indicated their unsatisfied thermal state.

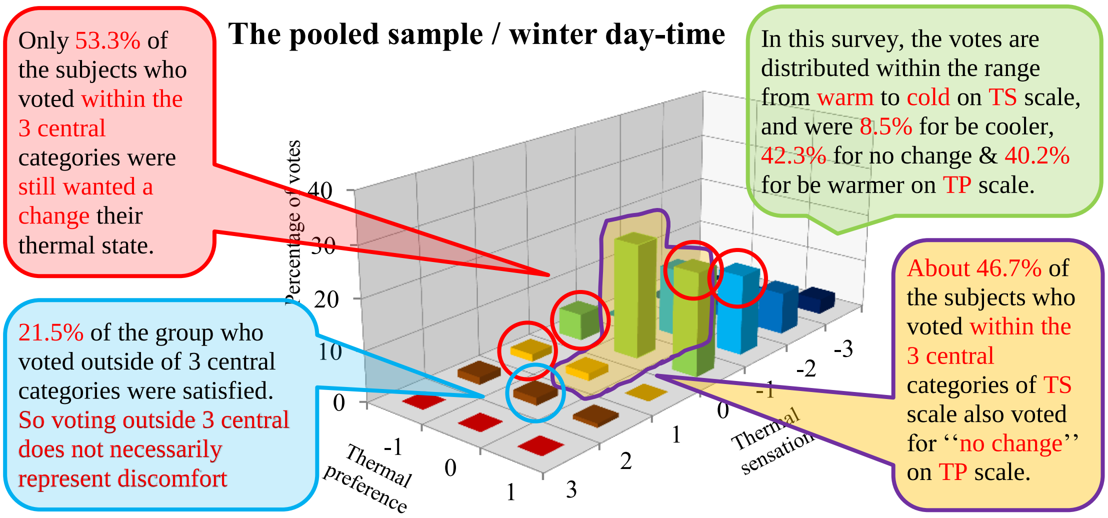


Figure 7-35: A cross-comparison of simultaneous votes on both TS & TP scales for the pooled sample (All sites) during winter night-time survey

As shown in Figure 7-35, when looking at the sample as a whole in the winter survey (sites combined), the findings show that about 42.9% of the group who voted within the three central categories still wanted to change their thermal state (37% preferred to be warmer and 6.9% preferred to be cooler). These results suggest that not all people who voted within the three central categories of the thermal sensation scale were satisfied with their thermal state. On the other hand, 21.5% of the group who voted outside of the three central categories (within the extremes -2, -3, 2, 3) were satisfied with their thermal condition and wanted 'no change'. This agrees with the idea that the voting outside of the three central categories of thermal sensation scale did not necessarily represent discomfort.

7.4.6.2 In summer day-time

A cross-comparison of simultaneous votes on both thermal sensation scale and thermal preference scale is shown in Table 7-20 and Table 7-21.

Table 7-20: Cross tabulation of sensation votes and preference votes for C1 and C3 / summer day-time

Preference Votes (%)	Courtyard C1								Courtyard C3							
	Sensation Votes (%)								Sensation Votes (%)							
	3	2	1	0	-1	-2	-3	Total	3	2	1	0	-1	-2	-3	Total
-1	-	8.1	10.8	10.8	-	-	-	29.7	-	2.9	14.3	14.3	-	-	-	31.4
0	-	-	2.7	64.9	-	-	-	**67.6**	-	-	-	65.7	-	-	-	**65.7**
1	-	-	-	2.7	-	-	-	2.7	-	-	2.9	-	-	-	-	2.9
Total	-	8.1	**13.5**	**78.4**	-	-	-	100	-	2.9	**17.1**	**80**	-	-	-	100

Table 7-21: Cross tabulation of sensation and preference votes for the All / summer day-time

Preference Votes (%)	All							
	Sensation Votes (%)							
	3	2	1	0	-1	-2	-3	Total
-1	-	5.6	12.5	12.5	-	-	-	30.6
0	-	-	1.4	65.3	-	-	-	**66.7**
1	-	-	1.4	1.4	-	-	-	2.8
Total	-	6.6	**15.3**	**79.2**	-	-	-	100

The distribution of sensation votes and preference votes in the summer day-time survey shows that the percentages of thermal acceptability from the thermal preference votes in both courtyards were 67.6% in courtyard C1 and 65.7% in courtyard C3. This level is much less than that obtained from the thermal sensation votes where the percentages were 91.9% and 97.1% respectively. This obvious difference in the results may be due to the range of acceptability which is wider in the thermal sensation scale (three categories) than in the thermal preference scale (one category).

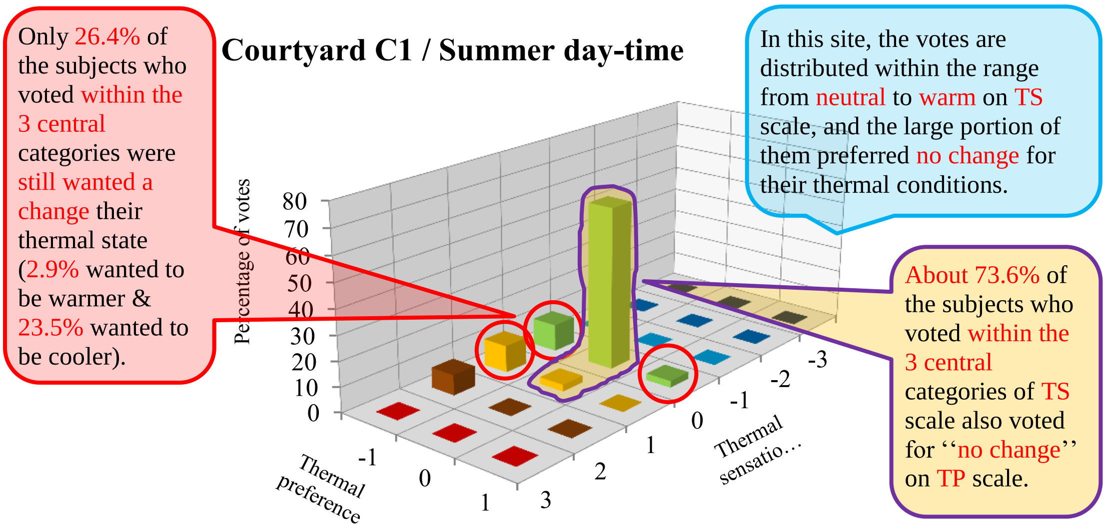


Figure 7-36: A cross-comparison of simultaneous votes on both TS & TP scales for the subjects in courtyard C1 during summer day-time survey

As can be seen from Figure 7-36, the group of people voting within the three central categories of the thermal sensation, 73.6% of this group in courtyard C1 preferred no change in their condition and the rest was distributed between 2.9% who wanted to be warmer and 23.5% who wanted to be cooler.

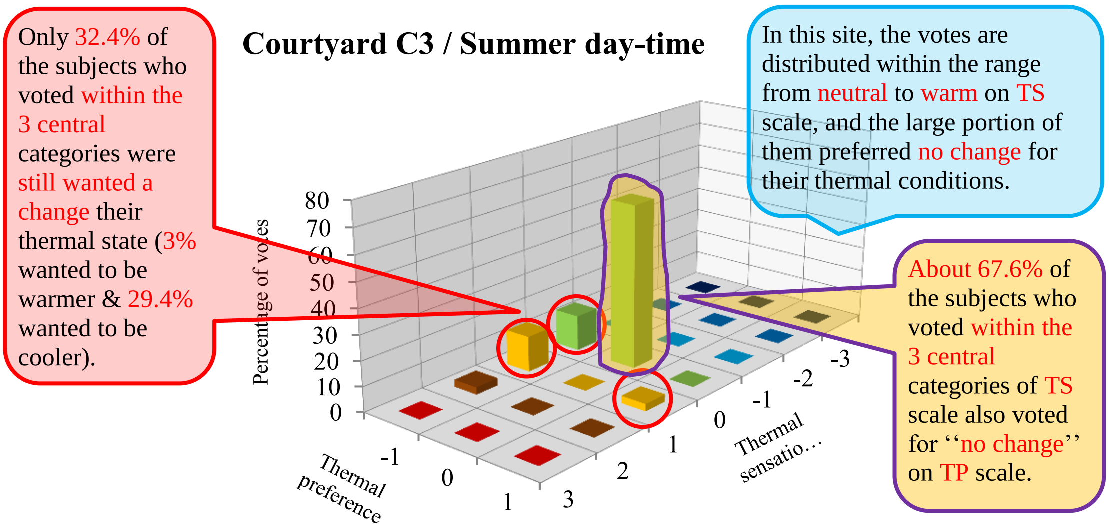


Figure 7-37: A cross-comparison of simultaneous votes on both TS & TP scales for the subjects in courtyard C3 during summer day-time survey

As for courtyard C3, 67.6% of the group preferred no change in their condition and the rest was distributed between 3.0% who wanted to be warmer and 29.4% who wanted to be cooler (Figure 7-38).

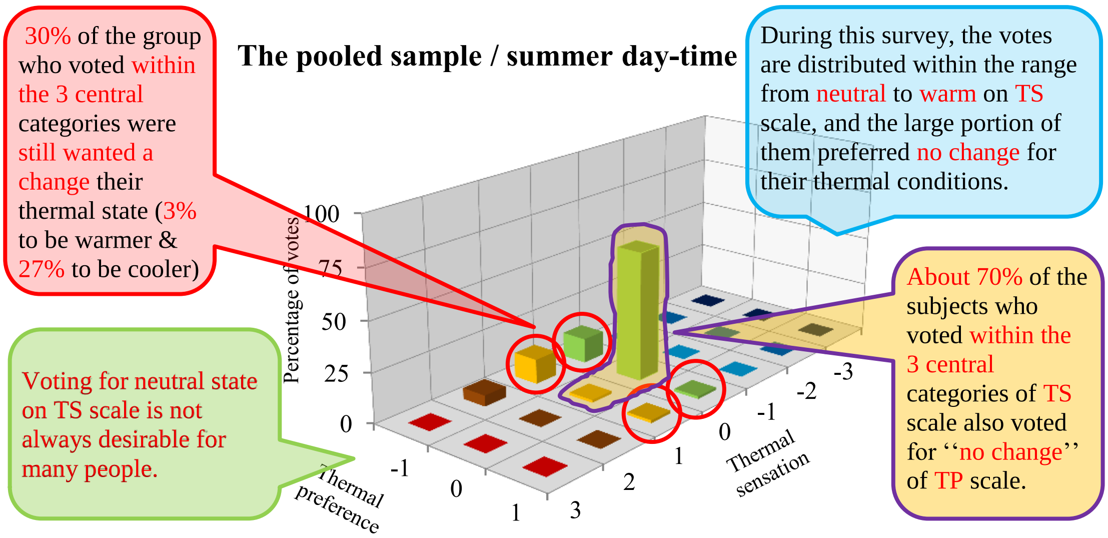


Figure 7-38: A cross-comparison of simultaneous votes on both TS & TP scales for the pooled sample (All sites) during summer day-time survey

For the sample as a whole, it can be seen from Figure 7-38 that only 29.4% of the group who voted within the three central categories still wanted a change in their thermal state (be cooler, warmer). This result suggests that the neutral state on the thermal sensation scale is not always desirable for many people.

7.4.6.3 In summer nocturnal

A cross-comparison of simultaneous votes on both the thermal sensation scale and thermal preference scale is shown in Table 7-22 and Table 7-23.

Table 7-22: Cross tabulation of sensation votes and preference votes for C1 and C6 / summer night-time

Preference Votes (%)	**Courtyard C1**								**Courtyard C6**							
	Sensation Votes (%)								Sensation Votes (%)							
	3	2	1	0	-1	-2	-3	Total	3	2	1	0	-1	-2	-3	Total
-1	10.7	10.7	46.4	17.9	-	-	-	85.7	7.7	15.4	53.8	15.4	-	-	-	92.3
0	-	-	7.1	7.1	-	-	-	**14.3**	-	-	-	7.7	-	-	-	**7.7**
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	10.7	10.7	**53.6**	**25**	-	-	-	100	7.7	15.4	**53.8**	**23.1**	-	-	-	100

Table 7-23: Cross tabulation of sensation votes and preference votes for the All / summer night-time

Preference Votes (%)	**All**							
	Sensation Votes (%)							
	3	2	1	0	-1	-2	-3	Total
-1	9.3	13.0	50	16.7	-	-	-	88.9
0	-	-	3.7	7.4	-	-	-	**11.1**
1	-	-	-	-	-	-	-	-
Total	9.3	13.0	**53.7**	**24.1**	-	-	-	100

Looking first at the percentages of acceptability obtained from using the thermal sensation scale (TS) and the thermal preference scale (TP), the first scale gave the highest level of acceptability (78.6% for C1 and 76.9% for C6), whereas the second scale gave much less percentages, 14.3% for C1 and 7.7% for C6. Thus, the acceptability levels obtained from both scales (TS and TP) for both courtyards do not meet the 80% acceptability goal in this survey. Another interesting point is that a significant difference was observed between the results obtained by using the TS scale and TP scale. In all the studied sites during all the phases of the survey (winter, summer day-time and summer night-time), acceptability levels obtained from thermal sensation votes were much higher than those obtained from the thermal preference votes. This suggests that neutral 'no change' is not the most ideal or preferred thermal state for the people in public enclosed courtyards.

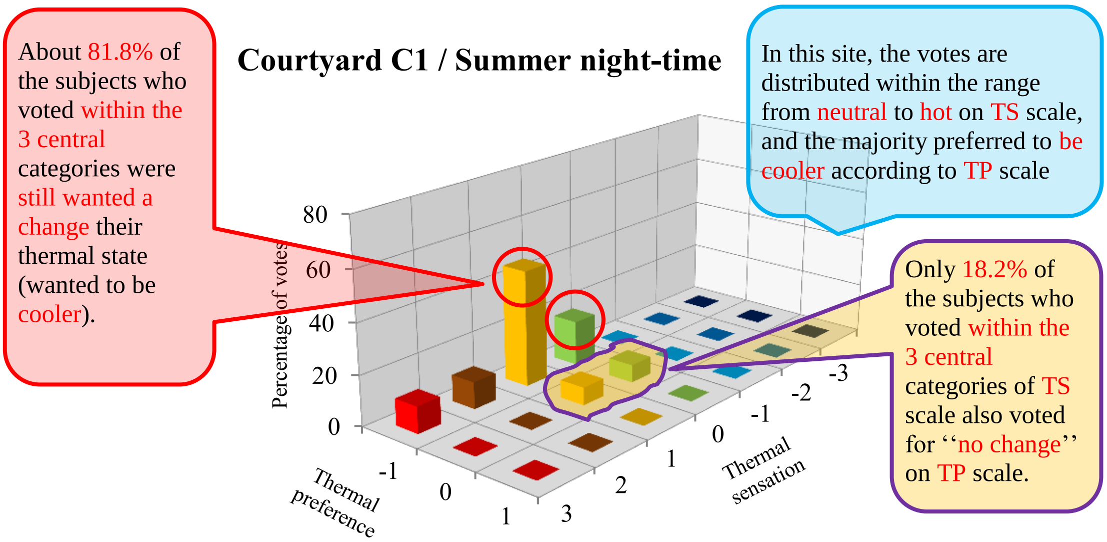


Figure 7-39: A cross-comparison of simultaneous votes on both TS & TP scales for the subjects in courtyard C1during summer night survey

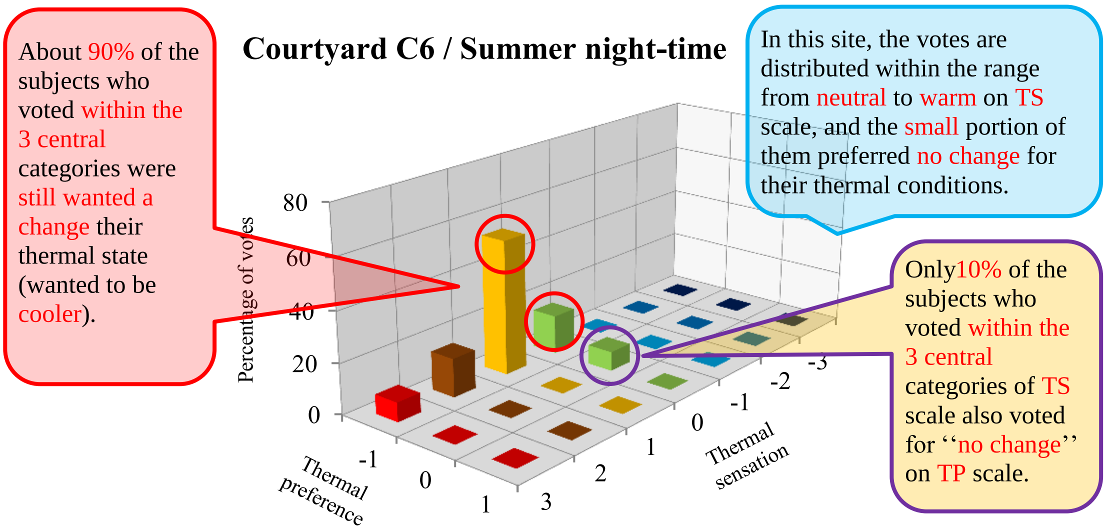


Figure 7-40: A cross-comparison of simultaneous votes on both TS & TP scales for the subjects in courtyard C6during summer night-time survey

As seen from Figure 7-39 and Figure 7-40, when look at the group of subjects voting within the three central categories of the thermal sensation, 81.9%, 90.0% and 85.7% of the group in courtyard C1, courtyard C6 and the sample combined, respectively still wanted to be cooler, and therefore indicated their unsatisfied thermal state. This was probably due to the high air temperatures and low wind speeds recorded in both sites, and this indicates the strong relationship between the microclimate and thermal comfort conditions.

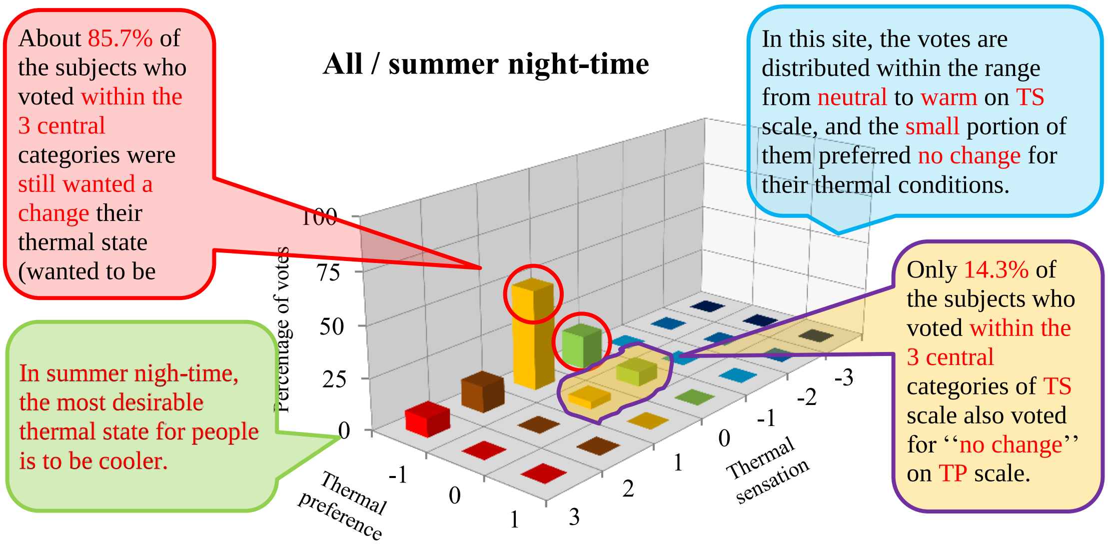


Figure 7-41: A cross-comparison of simultaneous votes on both TS & TP scales for the pooled sample (All sites) during summer night-time survey

For the sample as a whole, it can be seen from Figure 7-41 that about 85.7% of the group who voted within the three central categories were still wanted a change their thermal state (be cooler). This result suggests that summer night-time is considered to be of concern for urban thermal comfort in outdoor environments in Tripoli.

7.4.7 A comparison between results obtained from the three methods of acceptability for summer and winter

As mentioned earlier in this chapter, thermal acceptability has been analysed by three indirect scales measures (methods). Table 7-24 gives the comparison of the results obtained from the three assessing thermal acceptability methods in both seasons. The table also shows summaries of the measured physical data of the studied courtyards in both seasons.

Table 7-24: Thermal acceptability - percentage of people finding their courtyard environments thermally acceptable and the corresponding physical data

				Studied courtyards				
				C1	C3	C4	C6	All
Indirect measures of thermal acceptability	Thermal sensation	Winter		88.7%	65.6%	86.7%	-	82.3%
		Summer day-time		91.9%	97.1%	-	-	94.4%
		Summer night-time		78.6%	-	-	76.9%	77.8%
	Thermal comfort	Winter		77.4%	75.0%	84.4%	-	79.2%
		Summer day-time		86.5%	80.0%	-	-	83.3%
		Summer night-time		42.9%	-	-	50.0%	46.3%
	Thermal preference	Winter		45.3%	18.75%	55.6%	-	42.3%
		Summer day-time		67.6%	65.7%	-	-	66.7%
		Summer night-time		14.3%	-	-	7.7%	11.1%
Distribution of physical data	Winter	DBT (ºC)	Average	14.0	14.0	20.1	-	16.03
			Range	11.8-15.5	13.0-14.7	15.6-22.7	-	11.8-22.7
		ST-F (ºC)	Average	11.3	16.0	11.3	-	12.86
			Range	10.0-12.5	13.0-18.6	7.8-14.1	-	7.8-18.6
		RH (%)	Average	73.5	56.4	31.5	-	53.8
			Range	58.0-94.0	48.0-65.0	21.0-47.0	-	21-94
		WS (m/s)	Average	0.8	1.1	0.8	-	0.9
			Range	0.1-2.0	0.0-2.6	0.0-2.2	-	0.0-2.6
		Clothing (clo)	Mean	1.08	1.09	1.0	-	1.05
			Range	0.96-1.30	0.96-1.30	0.61-120	-	0.61-1.30
	Summer day-time	DBT (ºC)	Average	28.3	26.6	-	-	27.4
			Range	27.1-28.9	25.5-27.7	-	-	25.5-28.9
		ST-F (ºC)	Average	35.4	35.7	-	-	35.55
			Range	27.2-48.7	25.0-48.5	-	-	25-48.7
		RH (%)	Average	65.6	62.1	-	-	63.85
			Range	62.0-69.0	59.0-67.0	-	-	59-69
		WS (m/s)	Average	1.3	1.5	-	-	1.4
			Range	0.23-3.2	0.6-3.0	-	-	0.23-3.0
		Clothing (clo)	Mean	0.52	0.60	-	-	0.56
			Range	0.32-0.61	0.53-0.74	-	-	0.32-0.74
	Summer night-time	DBT (ºC)	Average	32.3	-	-	33.2	32.8
			Range	32.0-32.5	-	-	32.3-34.3	32-34.3
		ST-F (ºC)	Average	27.4	-	-	31.8	29.6
			Range	26.8-27.7	-	-	31.5-32.2	26.8-32.2
		RH (%)	Average	34.3	-	-	27.0	30.6
			Range	30.0-40.0	-	-	24.0-30.0	24-40
		WS (m/s)	Average	0.1	-	-	0.3	0.2
			Range	0.1-0.23	-	-	0.1-0.93	0.1-0.93
		Clothing (clo)	Mean	0.53	0.52	-	-	0.525
			Range	0.32-0.61	0.32-0.66	-	-	0.32-0.66

A comparison of the three various methods of assessing thermal acceptability reveal that, the three scales (TS, TC and TP) used in the assessment gave different results and showed different patterns at different seasons.

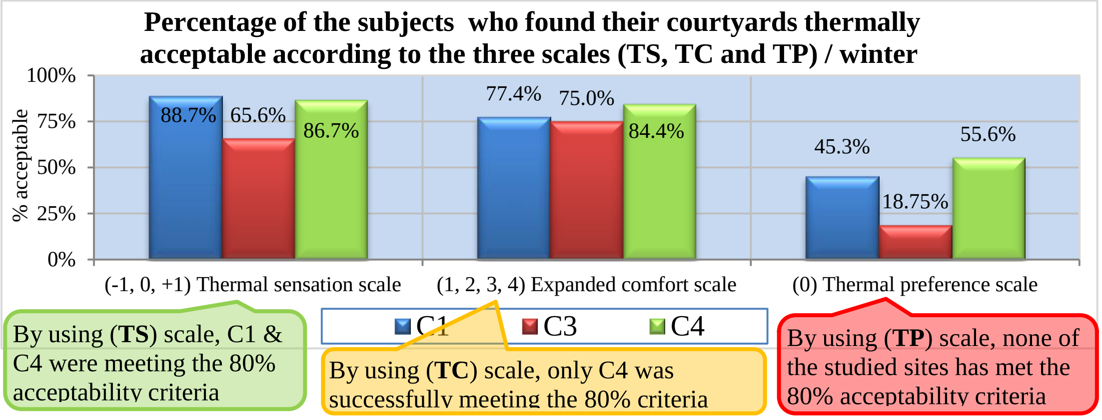


Figure 7-42: Percentage of the subjects who found their courtyards thermally acceptable according to the three scales (TS, TC and TP) / winter

In winter (cold season), as it can see from Figure 7-42, the thermal sensation scale gave the highest level of acceptability of 88.7%, 86.7% and 65.6% for courtyards C1, C4 and C3 respectively, whereas the corresponding percentages of the acceptability obtained by using the thermal comfort scale were 77.4%, 84.4% and 75.0%. This level is lower than that obtained from the first method (TS scale). Percentages of acceptability obtained from the responses on the thermal preference scale (TP) were 55.6% for C4, 45.3% for C1 and 18.75% for C3, clearly these percentages are much less than those obtained from the other two scales.

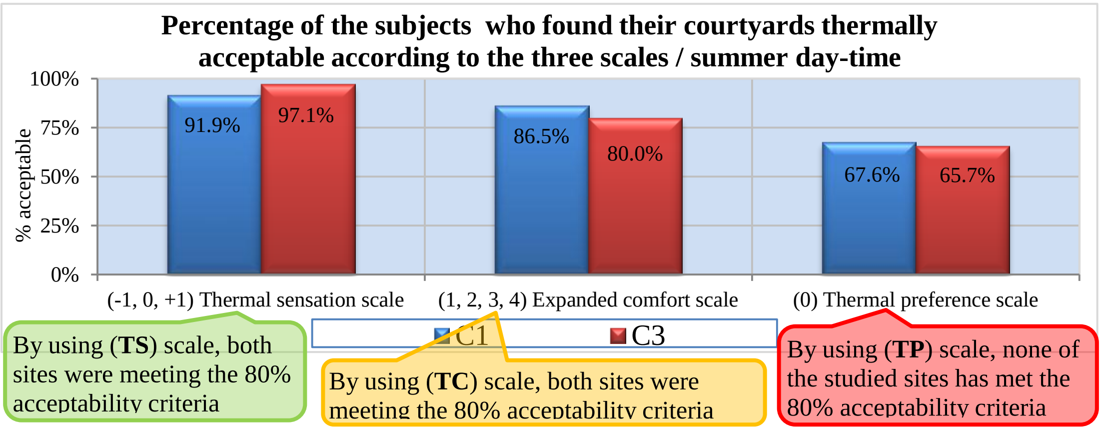


Figure 7-43: Percentage of the subjects who found their courtyards thermally acceptable according to the three scales / summer day-time

For the summer day-time (hot season), as shown on Figure 7-43, very high percentages of the acceptability obtained from using the thermal sensation scale, the percentages were 97.1% for C3 and 91.9% for C1. The corresponding percentages of acceptability obtained from using the thermal comfort scale were 80.0% for C3 and 86.5% for C1. As expected, the thermal preference scale gave the lowest percentages of the acceptability of 67.6% and 65.7% for both courtyards (C1 and C3 respectively).

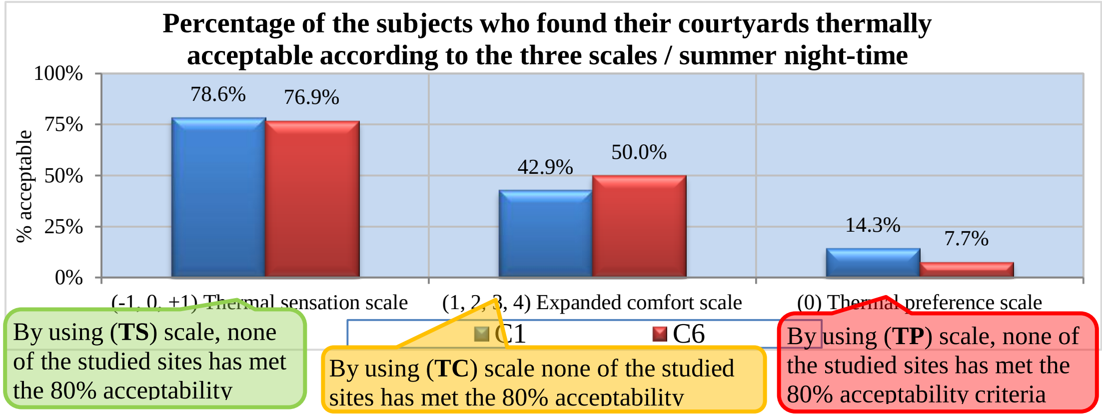


Figure 7-44: Percentage of the subjects who found their courtyards thermally acceptable according to the three scales / summer night-time

In summer night-time (hot season), As it can see from Figure 7-44, the results indicate that the highest level of acceptability was obtained from using the thermal sensation scale (78.6% for C1 and 76.9% for C6) followed by that obtained from the thermal comfort scale (42.9% for C1 and 50.0% for C6), and lastly the very low level of acceptability was obtained from using the thermal preference scale of 14.3% and 7.7% for C1 and C6 respectively.

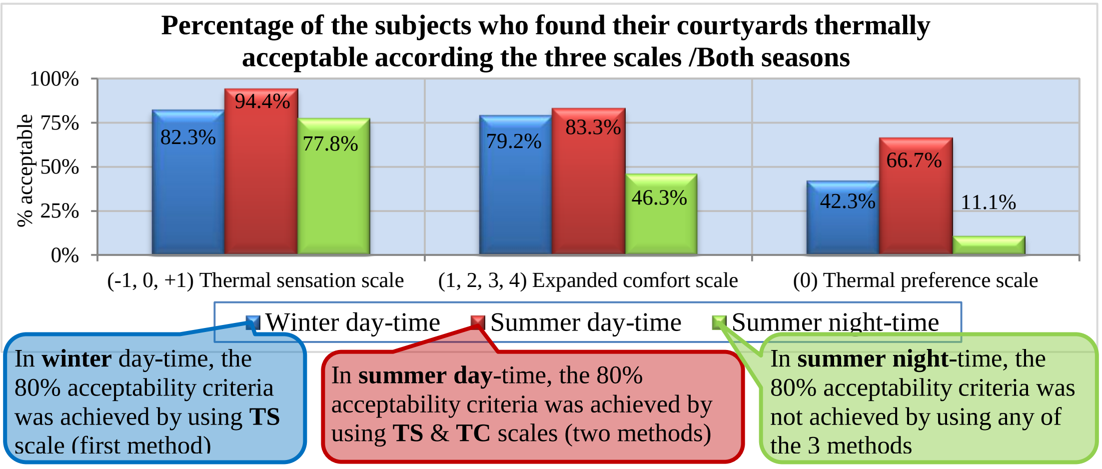


Figure 7-45: Percentage of the subjects who found their courtyards thermally acceptable according the three scales /both seasons

Looking to the sample as whole in each season (combined sites), as illustrated in Figure 7-45, the results show that the highest percentage of acceptability was obtained from the thermal sensation votes in summer day-time (94.4%), followed by 83.3% which was obtained in summer day-time as well but from the thermal comfort votes, 82.3% in winter from the thermal sensation votes, 79.2% in winter from the thermal comfort votes, 77.8% in summer night-time from the thermal sensation votes, 66.7% in summer day-time from the thermal preference votes, 42.3% in winter from the thermal preference votes, 11.1% in summer night-time from the thermal preference votes. The above results clearly indicate that people in summer day-time were more satisfied with the thermal conditions in their environments with an air temperature range from 25.5 to 28.9ºC. However, the results obtained from the three scales (TS, TC and TP) demonstrate that the percentage of all the subjects' votes in summer night-time was always below the 80% acceptability criterion, and this might be associated to high air temperatures and low wind speeds recorded in the studied courtyards, see Table 7-24.

Looking at the subjects' responses to the three scales in more detail, it appears that people in courtyard C4 tended to feel more comfortable than other courtyards in winter, with air temperature ranges between 15.6 and 22.7 ºC. In summer day-time, both courtyards (C1 & C3) were strongly meeting the ASHRAE Standard-55's 80% acceptability criteria. As for summer night-time, none of the three methods (scales) in the two studied courtyards (C1 & C6) was able to achieve an acceptable thermal environment with 80% of the people expressing satisfaction with the thermal conditions. This may, as mentioned above, be due to high air temperatures (32-34.3ºC) and low wind speeds (0.1-0.93 m/s) recorded in both courtyards.

7.5 Clothing and Thermal Comfort

Clothing value has a substantial impact on thermal comfort. It is individual and has a difference from one person to another. In this study, clothing insulation values were determined (estimated) from the data collected in the field surveys. The data was converted into numerical values by using values set by ASHRA 2001. The unit normally used for measuring clothing's insulation is the clo unit, where 1 clo = 0.155 m² ºC/W. Table 7-25 shows a summary of clothing information of participants (men and women) at the studied courtyards during the cold and hot seasons.

Table 7-25: Mean, Minimum, Maximum and Standard deviation of clothing value of participants

	Winter day-time						**Summer day-time**					**Summer nigh-times**				
	Both (M+F)						Both (M+F)					Both (M+F)				
	C1	C3	C4	Male (all sites)	Female (all sites)	All	C1	C3	Male (all sites)	Female (all sites)	All	C1	C6	Male (all sites)	Female (all sites)	All
Mean Clo	1.08	1.09	1.00	1.03	1.15	1.06	0.52	0.60	0.54	0.71	0.56	0.53	0.52	0.52	0.61	0.53
SD	0.11	0.12	0.17	0.14	0.05	0.13	0.07	0.07	0.06	0.02	0.08	0.08	0.08	0.08	0.06	0.08
Min	0.96	0.96	0.61	0.61	1.04	0.61	0.32	0.53	0.32	0.67	0.32	0.32	0.32	0.32	0.57	0.32
Max	1.30	1.30	1.20	1.30	1.20	1.30	0.61	0.74	0.61	0.74	0.74	0.61	0.65	0.61	0.65	0.65

From the data in Table 7-25, it is apparent that the calculated clo values of the subjects in all the groups averaged around 1.06 clo during the cold season, whereas in warm season it was 0.56 clo during the day-time and 0.53 clo during the night-time. In general, therefor it seems that the outdoor condition (climate) had an effect on clothing.

In the warm season night-time, the mean clothing insulation values of the subjects were 0.53 clo in courtyard C1and 0.52 clo in courtyard C6. This means there was no difference in clothing value between the two courtyards. On the other hand during the day-time, courtyard C1 is different from courtyard C3 in the average clo value of the subjects, where in the first it was 0.53, in the second it was 0.60. This difference between the two courtyards occurred because the range of clothing insulation values in courtyard C3 (administrative and business space) was high between 0.53 and 0.74 clo because most of its users were employees, business owners and company directors and their clothes were formal, whereas in courtyard C1 (public space) it was between 0.32 and 0.61 clo and its users were wearing casual clothing (typically jeans, shorts and T-shirts). Moreover the study sample of courtyard C3 included a number of female participants that affected the average clo value of the sample because of their high clo value in comparison with the males, while in courtyard C1the sample was 100% males.

In the cool season, the amount of clothing in all groups had been increased with some differences between some of them. In C1, and C3 the mean clothing values were similar (1.08 clo and 1.09 clo, respectively), but in courtyard C4, it was slightly lower (1.00 clo), that probably happened because the weather was moderate to slightly warm on the survey day in this courtyard.

7.5.1 Males and females

In general, western clothing is the most used by the male participants in all the courtyards in both the cold and warm seasons. Whereas, the majority of female participants were wearing western clothing in Islamic style as a hijab (shoes, long sleeves, long skirts or trousers and head scarfs). In other words, they were wearing clothing that covers the whole body except the face and the hands in both seasons with different layers of thickness. Comparing male and female clothing values showed that the mean clo value of female's clothing was higher than those of males in both seasons due to the impact of religion, culture and tradition. It should also be noted that the male participants registered greater variability in their daily mean clo values than the females. Their clothing levels were widely varied from a minimum of 0.61 clo up to a maximum of 1.30 clo in the cold season and between 0.32 clo and 0.61 clo in the warm season, whereas female's clothing levels were between 1.04 clo and 1.20 clo in the cold season while in summer (warm season) it was between 0.67 clo and 0.74 clo during the day-time and between 0.57 clo and 0.65 clo during the night-time. This does not necessarily mean that males were more weather responsive in their clothing choices than the females, but that perhaps because females are more restricted than males in their clothing choices due to the factors such as religion, tradition and culture.

7.5.2 Correlation between clothing values and microclimatic variables

The main focus for the analysis has been on the air temperature and the wind speed. The Pearson's Correlation coefficients suggest that there is a strong correlation (-0.96) between mean clo values and the average of air temperatures in all the sites during the warm and cold seasons. They are negatively correlated because when one variable of them increases the other one decreases (opposite direction). As was to be expected the clothing value, which is an indication of how much insulation a person is wearing, reduces with increasing temperature and increases with increasing wind speed. The link between clothing values and the microclimate was investigated by (Humphreys, 1977) who also found strong relationships between the clothing values and air temperature. Thus, the results suggest that air temperature is the most dominant parameter in relation to the subjects' clothing levels as respective correlations with wind speed is very weak.

7.6 Thermal Comfort Adaptive Behaviour

The term 'adaptation' in the thermal comfort field ''may involve all the processes which people go through to improve the fit between the environment and their requirements' (Nikolopoulou and Steemers, 2003). In this study, it is observed that several thermal comfort adaptive actions have been taken by people to achieve comfort. The observations provided clear evidence that people used different behavioural actions to adjust themselves to the environment during the cool and hot seasons. Most of these actions were in the form of personal adjustments such as altering clothing levels, consumption of hot or cold drinks, changing position etc. Figure 7-47, Figure 7-48, Figure 7-49 and Figure 7-50 show some examples of the behavioural adaptations undertaken by the people in the studied sites during both seasons. Some environmental adjustments were observed as well including some actions (special structural adaptation measures) to control the environment during the extreme seasons. Figure 7-46 shows an example of the behavioural control actions that people made in order to alter the environment to their needs.

Figure 7-46: Photographs showing special structural adaptation measures (covering the courtyard during the winter season (1 &2) and removing the cover during the summer season (3 &4)

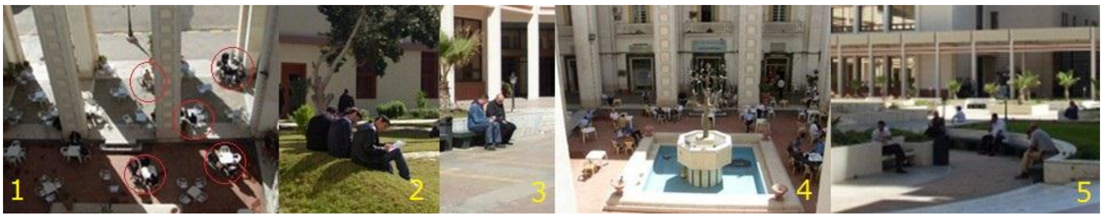


Figure 7-47: Photographs showing people staying under direct sun in winter (1, 2 & 3) and staying in shaded places in summer ‘avoiding direct sun’ (4 & 5)

Figure 7-48: Photographs showing people choosing airy places during hot season (1 & 2), and wind-sheltered places (corners) during cold season (3 & 4)

Figure 7-49: Photographs showing people staying in standing position instead sitting on cold seats (marble)

Figure 7-50: Photographs showing people wear dark and thick clothing in cold season (1 & 2) while in hot season they use light clothing (3 & 4)

7.7 Conclusion

From the above analysis and discussion, the following conclusions can be drawn:

- Thermal sensation votes are highly correlated with thermal comfort votes in all the studied sites in both seasons.

- The mean thermal sensation on the ASHRAE scale was marginally cooler than neutral (-.50) for winter day-time (cold season), whereas for the summer day-time (hot season) it was around neutral (+.26) on the warm side of the scale and finally, it was slightly warm (+1.07) for the summer night-time (hot season).

- In winter, extreme -3 (cold) has very few occurrences (3.1%), and surprisingly votes for +2 (warm) were observed in the cool season. In summer day-time extreme +3 (hot) votes were not observed, while in summer night-time they were found.

- In relation to thermal comfort votes, clear seasonal differences were observed where, votes of ‘comfortable’ for the summer day-time were slightly higher than for the winter and much higher than for the summer night-time, while votes for ‘uncomfortable’ were the total opposite.

- In relation to the thermal preference votes, the results suggest that the most preferred thermal state for people in winter is to be warmer, while in summer day-time ‘no change’ is the ideal one, but in summer night-time, the most desirable thermal state for people is to be cooler.

- A comparison of the three different methods: thermal sensation scale (TS), thermal comfort scale (TC) and thermal preference scale (TP) of assessing thermal acceptability reveals that they gave different results for both seasons as well as for sites. Using the three central categories of the 7-point ASHRAE thermal sensation scale gave the highest levels of thermal acceptability for all the sites in both seasons. However, using the central category of the 3-point McIntyre scale of thermal preference gave the lowest levels.

- A comparison between the case study sites reveals that in winter (cool season), courtyard C4 was the only site that successfully met the ASHRAE Standard-55's 80% acceptability criteria by using two measures (86.7% from TS and 84.4% from TC), with a range of air temperature from 15.6 to 22.7 ºC and air speeds average of 0.8m/s. In this season, courtyard C1 also met this creation but only from the votes of the thermal sensation scale. In summer day-time, the percentages of thermal acceptability in both studied courtyards (C1 and C3) exceed 90% (obtained from TS) and higher than 80% (obtained from TC scale), this strongly indicates that both courtyards in the hot season day-time exhibit acceptable thermal environments by using two measures. In summer night-time, none of the studied courtyards (C1 and C6) was able to meet ASHRAE Standard 55's 80% acceptability in the three scales, and that is likely due to the high air temperatures and low air velocity recorded in these sites (air temperature ranges between 32-34.3ºC and air speeds average of 0.19m/s).

- The results confirm that there is a strong relationship between microclimatic variables and comfort conditions, especially with air temperature (indirectly with solar radiation) and wind speeds. Regarding wind speeds, there is increasing discomfort as wind speed increases in the cool season and the opposite happens in the hot season.

- A comparison of votes on the three scales in this study showed that the voting outside of the three central categories of the thermal sensation scale for some people does not necessarily reflect discomfort. Moreover, the voting for neutral on the ASHRAE scale is not necessarily ideal for a proportion of people.

- In relation to the clothing, it was observed that an individual chooses the type of clothes to wear mainly depending on the temperature and not on the wind speed. In this context, the results show a high relationship (negative) between air temperature and clothing insulation during both seasons, whereas wind speeds do not show such a strong relationship. This confirms that there is a strong relationship between microclimatic variables (air temperature) and the clothing subjects were wearing, and also a difference in people’s sensitivity to them.

- In this study, the subjects' clothing values were widely varied from a minimum of 0.61 clo up to a maximum of 1.30 clo in the cold season and between 0.32 clo and 0.61 clo in the warm season, whereas female’s clothing levels were between 1.04 clo and 1.20 clo in the cold season while in summer (warm season) it was between 0.67 clo and 0.74 clo during the day-time and between 0.57 clo and 0.65 clo during the night-time.

- In this study, there was some evidence of adaptation taking place such as seasonal variation in clothing, consumption of cool/hot drinks, staying in shaded/sunny places and in wind-sheltered/airy places.

8 CONCLUSIONS

This chapter presents a general conclusion of this study and gives some suggestions for future research. It is divided into three sections. In addition to the recommendations and future research, the first section provides a discussion of conclusions. The second one contains a graphical presentation of the main research findings with data is presented in 3D graphical format. The last section presents a summary of research findings in a tabulated format that can be used as a design or research guide depending on the readers' background.

8.1 Conclusions, Recommendations, and Future Research

8.1.1 Discussion of conclusions

This study has looked at the microclimate and thermal comfort in some examples of public enclosed courtyards that represent the three main types (old city, colonial city and post-colonial city) of the urban fabric of hot dry Tripoli. The methodology used for this study was a field study in the real world including questionnaire survey, observation and environmental measurements during the two extreme seasons, winter day-time (cool) and summer day/night-times (hot). Since no other research works have been conducted into such studies in Libya, this present work will complement the existing knowledge on urban microclimate and thermal comfort in outdoor spaces in general and courtyards in particular. In addition to this, the results obtained from this study may be used as input data in further works.

In this study it is found that the microclimate and thermal comfort in public enclosed courtyards (outdoor environments) in hot dry Tripoli are varied from one site to another and from one season to another. Solar radiation and spatial characteristics of the studied courtyards (architectural form, geometry and built and natural elements) are found to have the key role in shaping the microclimates of the case study sites during both seasons. It is also found that air temperature then wind speed and surface temperatures are the most important determinants of comfort. In general, the findings confirm a strong relationship between the built urban form or the spatial characteristics of the enclosed courtyards, the microclimatic conditions and people's comfort. The main conclusions can be summarized and presented as the following:

8.1.1.1 Microclimate conditions

In winter day-time:

- The courtyard with deeper form was in general, cooler than other courtyards due to its geometry, where it has the smallest aspect ratio among all the studied sites which seemed to play an important role in keeping the site cold because of the shade from the surrounding walls. In other words, due to its deeper form, only a small part of the courtyard surfaces can be directly exposed to the sunlight even at noontime especially in winter where solar incident angle is so small. Regardless of what the geometry is, the courtyard located close to the sea showed a tendency to have cold environment as well, and this likely was because of the effect of the sea breezes. However, the courtyard with the largest aspect ratio and located 7km away from the sea shore, tended to be slightly warmer (less cold) than other sites.

- The study also found that floor and wall surface temperatures of the courtyards were mainly affected by the mount of solar radiation received by their surfaces. Courtyards with shallower form and large aspect ratio showed high floor and wall surface temperatures, while courtyards with deeper form and small aspect ratio recorded low surface temperatures even if their surfaces have lower albedo (e.g. red brick in C1). A colour and material of surfaces seemed to play an important role in determining the temperatures of the courtyards surfaces. Courtyards surfaces with dark colours tended to be warmer than those with light colours (with high albedo). Courtyards with concrete pavements showed higher surface temperatures than those with other types of pavements. However, the courtyard with a ground covered by grass showed a tendency to be cooler than other types of ground surfaces.

- Great influence of geometry on the intensity of illuminance inside the courtyards was found. Courtyards with a small aspect ratio particularly those with deeper form showed very low averages of illuminance levels (below 10000 lux), and this was probably because of the shading effect provided by their geometries (their ground areas almost were in complete shadow). On the other hand, courtyards with large aspect ratio showed considerable averages of illiminance levels even in cloudy weather.

- The higher relative humidity level observed in the deeper form courtyard compared with the shallower one was probably linked to the weather conditions (heavy rain in C1). No link could found between urban geometry and humidity level. In general, it seemed that the relative humidity had a relation with the temperatures (RH tended to increase or decrease in the opposite manner of DBT & GT in particular).

- Location and architectural design of the studied sites showed obvious effects on pattern of wind speed inside the courtyards. The highest wind speed readings were recorded in the courtyard located close to the sea. Courtyards with big external openings towards the surrounding outdoor environments showed good air movements. The poor ventilation condition was observed in the courtyard with high degree of enclosure and located in very compacted urban built-up area.

In summer day-time:

- Despite its large size and large aspects ratio, the courtyard which is located near to the sea showed a tendency to be less warmer than the others and this might be because of the role of sea breeze in lowering air temperature inside the courtyard during the summer. However, courtyard with small size, shallower form and located in very densely built-up area seemed to have a tendency to be slightly warmer than the others.

- As in winter season, in general, floor and wall surfaces with fairly dark colours (low reflectivity), displayed higher temperatures than those with light colours (with high solar reflectivity). Concrete pavers showed a tendency to be warmer than other types of pavements, whereas grass despite its small value of reflectivity, but it seemed to be cooler than all other pavements, and this may be because a large portion of the received solar radiation by grass was used for the evaporation of the liquid water stored in the grass and soil. During this season where the sun angle is high, the geometry appeared to have a less pronounced role in determining surface temperatures of the courtyards compared with the winter season.

- As in winter season, no evidence of a link between relative humidity and geometry of the studied courtyards was found. The highest reading of relative humidity was recorded in the morning hours in courtyard with large amount of greenery, whereas the lowest one recorded in the courtyard with the warmest environment. This indicates that a clear relationship was found between temperatures, relative humidity, illuminance and solar radiation. In general, as temperatures increases in courtyards, relative humidity decreases.

- A clear influence of geometry on illuminance levels inside the courtyards was observed particularly during the morning and late afternoon hours. Courtyards with small aspect ratio tended to have lower daylight levels than those with large aspect ratio. In general, it was observed that, as the height of the surrounding walls of the courtyard increases the intensity of sunlight inside the courtyard decreases. It is also important to note that some role of surface colour & material in increasing illuminance levels was observed. Courtyard C5 for instance, it recorded the highest reading of illuminance despite it's a small size and aspect ratio. This is probably because it has surfaces with high albedo (marble) and its walls are very close to each other, and this leads to much potential of internal reflection of radiations, which in turn contributes in raising the illuminance levels particularly during the noon hours.

- Courtyard located near to the sea seemed to be the best ventilated site with an average of wind speeds of 1.54 m/s. As mentioned above, this is probably because of the effect of sea breeze. However, courtyard with a high degree of spatial enclosure showed a clear lack of ventilation. In addition to the proximity to the sea and orientation, the architectural form and layout of the studied sites also showed clear effects on ventilation performance of the courtyards. In other words, good air movement circulation was recorded in the courtyards with big openings at their external walls.

In summer night-time:

- During summer night-time, both courtyards (shallower & deeper one) recorded similar environmental measurements. Both courtyards showed a tendency to have slightly hotter environments than those during the day-time and this may indicate to the existence of micro-scale urban heat island in these sites. In general, because of the difference in their aspect ratio, the courtyard with shallower form seemed to have slightly higher air & surface temperatures and lower relative humidity levels than the other one with deeper form. In addition to this, the shallow courtyard (with rectangular form surrounded by 2-storey building on three sides, and single storey on the forth side) showed a tendency to cool faster towards the late night than the deep courtyard (with square form surrounded by 4-storey building on all sides), and this likely linked to the degree of the courtyard's openness to the sky (exposure to the sky). In other words, due to its restricted long-wave radiation potential, the courtyard with limited sky view factor seemed to cool more slowly in the evening and night time compared to the courtyard with large sky view factor.

8.1.1.2 Thermal comfort conditions

- In relation to the thermal sensation votes, the general findings demonstrate that in winter the largest percentage of votes (90%) varied from neutral to cool (0 to -2), whereas in summer day-time, more than ¾ of the sample (79.2%) was in a neutral condition, but in summer night-time, all the votes of the respondents (100%) fall in the interval between neutral to hot (0 to +3).

- The mean thermal sensation vote on the ASHRAE scale was marginally cooler than neutral (-.50) for the cool season day-time (winter), whereas in the hot season (summer), it was around neutral (+.26) at day-time, and slightly warm (+1.07) at night-time.

- Based on the survey findings, it is found that votes of 'comfortable' for the summer day-time were higher than for the winter and much higher than for the summer night-time, while votes for 'uncomfortable' were the total opposite. Therefore, summer night-time is considered to be of concern for urban thermal comfort in outdoor environments in Tripoli.

- In relation to the thermal preference votes, the results suggest that the most preferred thermal state for people in winter is to be warmer, while in summer day-time ‘no change’ is the ideal one, but in summer night-time, the most desirable thermal state for people is to be cooler.

- In relation to the thermal acceptability assessment, a comparison of the three methods used for this purpose; thermal sensation scale (TS), thermal comfort scale (TC) and thermal preference scale (TP) reveals that, they gave different results for both seasons (winter day-time and summer day/night-times) as well as for sites. Moreover, for each assessing method, the levels of thermal acceptability were different for seasons as well as for the studied courtyards (places).

- In general, using the thermal sensation scale (acceptable = -1, 0, +1) gave the highest levels of acceptability for all the sites in both seasons, while using the thermal preference scale (acceptable = 0) gave the lowest. The latter scale appears to be the most stringent measure of thermal acceptability as stated by Yang and Zhang, (2008). This result is similar to results of previous studies in thermal comfort such as Brager et al., (1993); Heidari, (2000); Hwang et al. (2006); Yang and Zhang, (2008).

- Based on the results obtained from the three scales (TS, TC and TP), the findings reveal that in winter, courtyard C4 was the only site that successfully met the ASHRAE Standard-55's 80% acceptability criteria by using two measures (TS & TC), and that was with a range of air temperatures of 15.6 - 22.7 ºC and an air speed average of 0.8m/s. In summer day-time, at a range of air temperatures between 25.5-28.9 ºC and an air speed average of 1.4m/s, both case study sites (C1 & C3) exhibit acceptable thermal environments (higher than 80%) obtained from using two scales (TS & TC). In summer night-time, none of the studied courtyards (C1 & C6) was able to meet ASHRAE Standard 55's 80% acceptability in the three scales, and that was with a range of air temperatures between 32-34.3ºC and an air speed average of 0.19m/s.

- Based on the results obtained from the three scales (TS, TC and TP), the majority of the sample in summer day-time was satisfied with the thermal environment, whereas in winter a large proportion of the sample did so. By contrast in summer night-time, the majority of the sample was uncomfortable with the thermal condition.

- A cross-comparison of votes on the thermal sensation and thermal comfort scale reveals that the individual can be thermally comfortable even if he/she voted outside of the three central categories of the thermal sensation scale, and therefore, voting outside of the three central categories does not necessarily reflect discomfort.

- A cross-comparison of votes on the thermal sensation and thermal comfort scale demonstrates that voting within the three central categories of thermal sensation scale (particularly voting for -1 and +1) is not necessarily always associated with thermal satisfaction (comfort).

- A cross-comparison of votes on the thermal sensation and thermal preference scale shows that the ‘neutral’ on the ASHRAE scale does not necessarily mean the preferred thermal state.

- The mean clothing value was around 1.06 clo during the cool season, whereas in the hot season, it was 0.56 clo during the day-time and 0.53 clo during the night-time. The mean clothing value for males was lower than that for females in both seasons. In general, clothing levels were widely varied for males than for females, but this does not necessarily mean that males were more weather responsive in their clothing choices than the females, but that may be because females are more restricted than males in their clothing choices due to factors such as religion, tradition and culture. A strong relationship between the clothing values and air temperature was found, and therefore, the results suggest that air temperature is the most dominant parameter in relation to the subjects’ clothing levels as respective correlations with wind speed is very weak.

- This study identified several thermal comfort adaptive actions (personal and environmental adjustments) undertaken by people in the studied courtyards to achieve comfort during both seasons such as seasonal variation in clothing, consumption of cool/hot drinks, staying in the shaded/sunny places and staying in wind-sheltered/airy places. It is also interesting to note that people in small courtyards tried to alter the environment to their needs throughout covering the courtyard during the winter and opening it during the summer.

- This study demonstrated that people in the winter have a high potential of adaptation to the climate, whereas in the summer they are successfully able to adapt to moderate outdoor conditions, but in summer night-time where the weather was hot, people did not achieve complete adaptation, the majority were dissatisfied with their thermal state.

In general, the courtyard with a largest aspect ratio (more open to the solar access) and sheltered from the wind was identified as the most comfortable site during the cool season (courtyard C4 which was ranked as the less cold site in winter). On the other hand, the highest level of discomfort was found in the courtyard most exposed to the wind due to its location open to the sea (courtyard C3 which was ranked as the coldest site in winter). This indicates that increasing wind speeds in the cool season increases discomfort levels (as observed in courtyard C3). While in the hot season, the positive effect of the sea breeze on the microclimate therefore on the thermal comfort level of people in the courtyard located close to the sea was clearly observed. It is also found that during the hot season, air temperature at night-time was higher than that in day-time in the sites located in more densely built-up areas (C1 & C6), and this indicates the existence of a micro-scale urban heat island in these sites. This, in addition to the total lack of ventilation (low wind speeds) may explain the high levels of discomfort reported in these courtyards during the hot season night-time.

8.1.2 Recommendations

In light of this study and the literature review presented, some general guidelines in designing public courtyard in Tripoli and other cities that have similar climates are suggested. In general, courtyards should be designed to provide adaptive opportunities for the users.

- In summer (hot season), the main issue is to avoid solar radiation as much as possible, and this can be achieved by providing the shade by using removable shading elements. More importance should be given to designing the openings on external walls that can create the preferred higher air movement and therefore increase the comfort levels. Avoiding dark and dry surfaces is very important for horizontal surfaces particularly those who are exposed directly to solar radiation. Light colours are recommended for walls. Using water elements is recommended during hot season as indicated in other studies.

- In winter (cool season), the main issue is to receive as much solar radiation as possible and to avoid incoming airflow as much as possible. Courtyard external walls should be designed (especially the south-facing side) to allow maximum winter sun penetration inside the courtyard. Providing wind-sheltered spaces for people in open spaces is important.

8.1.3 Future Research

In general, this study is a first step towards outdoor thermal comfort research for the hot dry climate in Libya. It is an initial exploration rather than a comprehensive investigation, and it is hoped that the results will be found sufficiently interesting to provoke further research in this hitherto neglected area. This study has provided the framework and the basis to support further experimental and numerical analysis of microclimate and thermal conditions and the development of more specific open space (courtyard) design recommendations in the hot dry cities. In order to pursue the research in this field further, more studies are needed. In future, the studies should be extended to cover other forms of open spaces such as parks, squares and streets and to cover other cities that have the same climate.

Due to the complexity of the urban environment and interactive relationship between physical and environmental parameters, the field study alone seemed to be not sufficient to understand how the urban-built form affects urban microclimates in a hot dry climate. Future simulation models should preferably be conducted to develop more detailed knowledge on the effect of the built urban form on the microclimates of courtyards. Analysing the existing urban design regulations in Libya from a climatic point of view is very important and urgent. This will help to develop urban design regulations and guidelines for the development of urban spaces in new Libya according to the human comfort and climatic requirements (in order to achieve comfortable outdoor environments).

8.2 A Graphical Presentation of the Main Research Findings

The following figures are graphic presentations of the main results revealed in the study.

They include:

8.2.1 Graphical presentation: The distribution of averages of the measured microclimatic parameters of the studied courtyards during both seasons.

8.2.2 Graphical presentation: A cross-comparison of simultaneous votes on both TS & TC scales for the pooled sample (All sites) in each survey time

8.2.3 Graphical presentation: A cross-comparison of simultaneous votes on both TS & TP scales for the pooled sample (All sites) in each survey time

8.2.4 Graphical presentation: The three methods used for assessing thermal acceptability of the studied courtyards: A comparison between sites and seasons

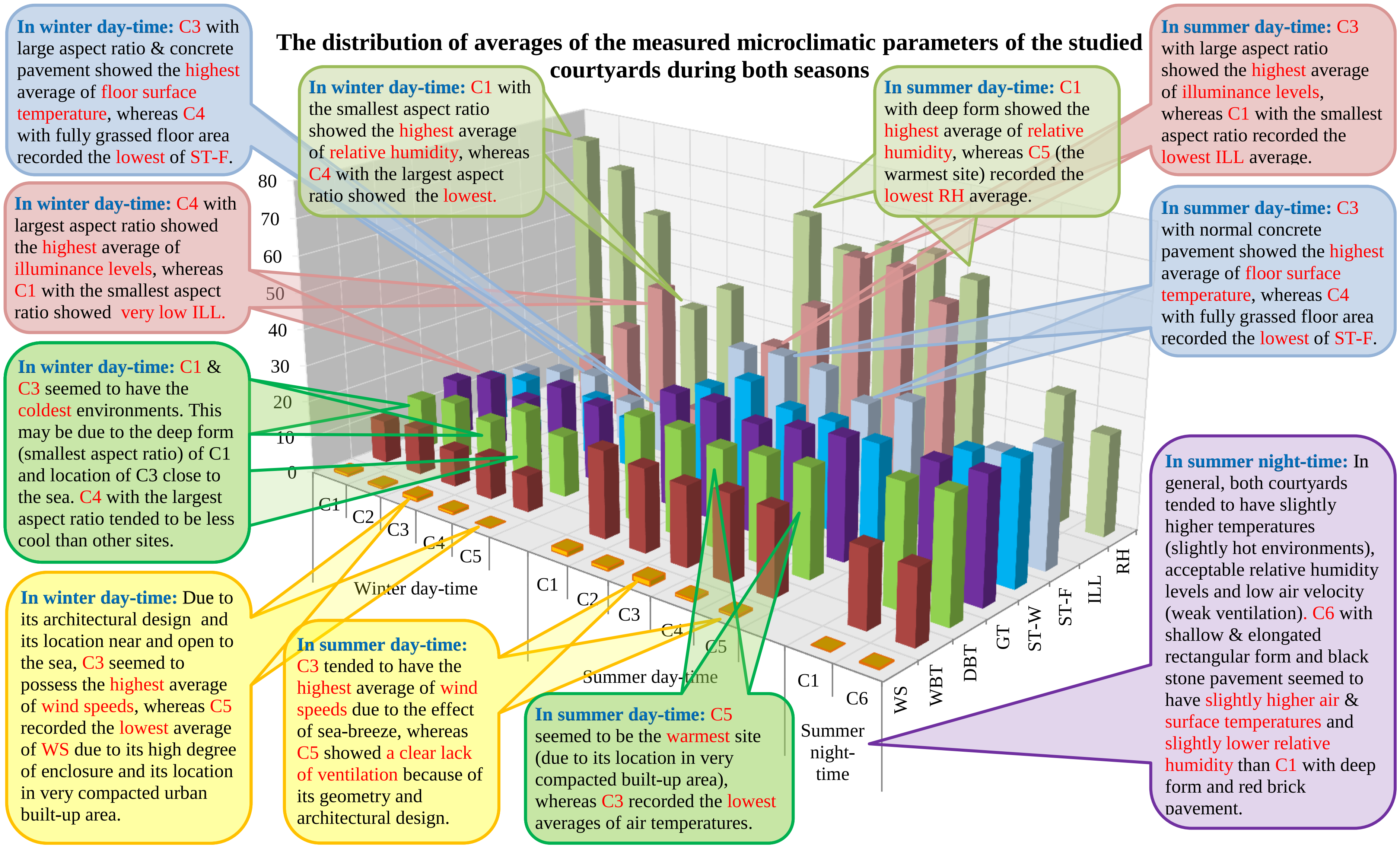


Figure 8-1: The distribution of averages of the measured microclimatic parameters of the studied courtyards during both seasons

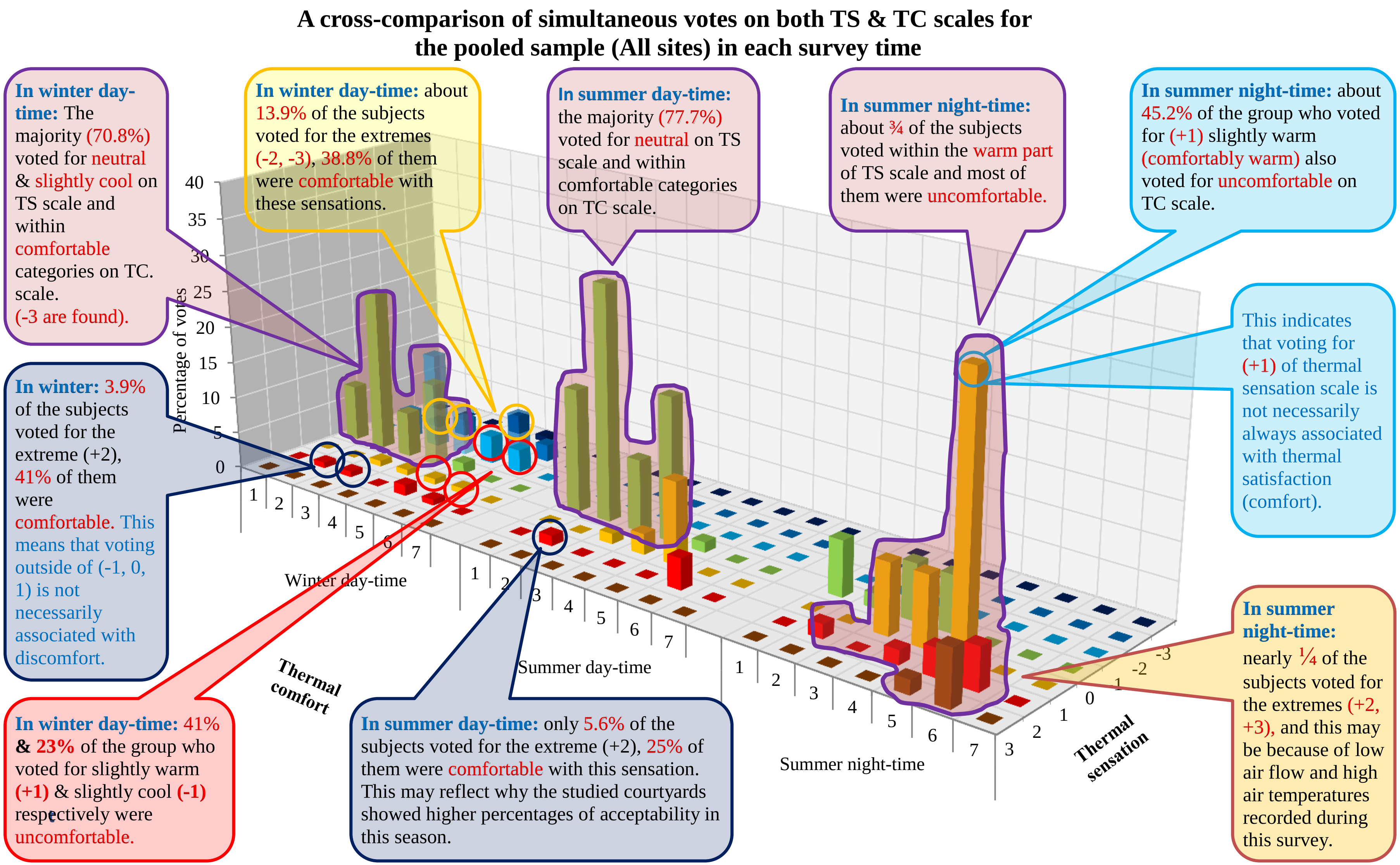


Figure 8-2: A cross-comparison of simultaneous votes on both TS & TC scales for the pooled sample (All sites) in each survey time

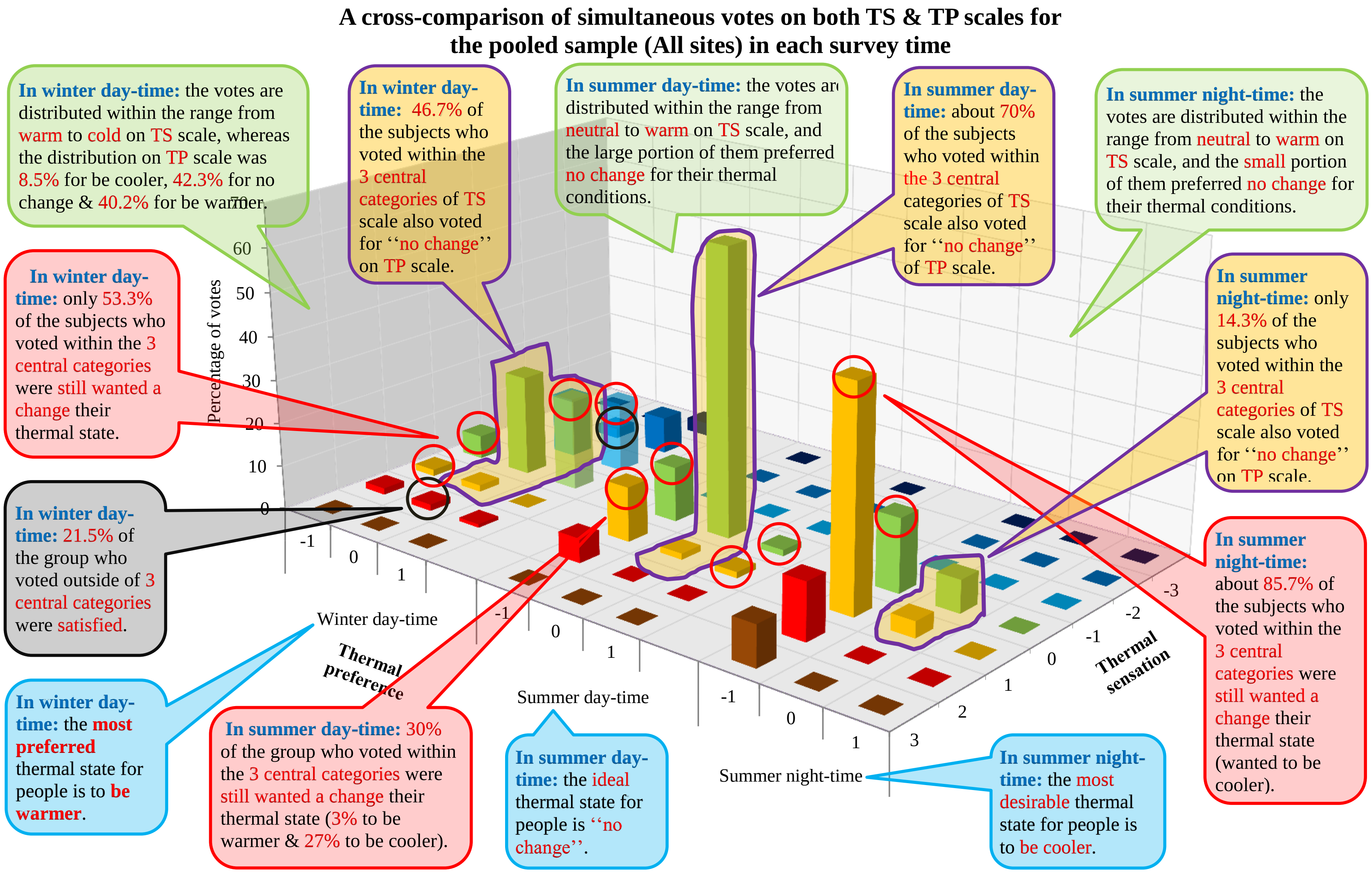


Figure 8-3: A cross-comparison of simultaneous votes on both TS & TP scales for the pooled sample (All sites) in each survey time

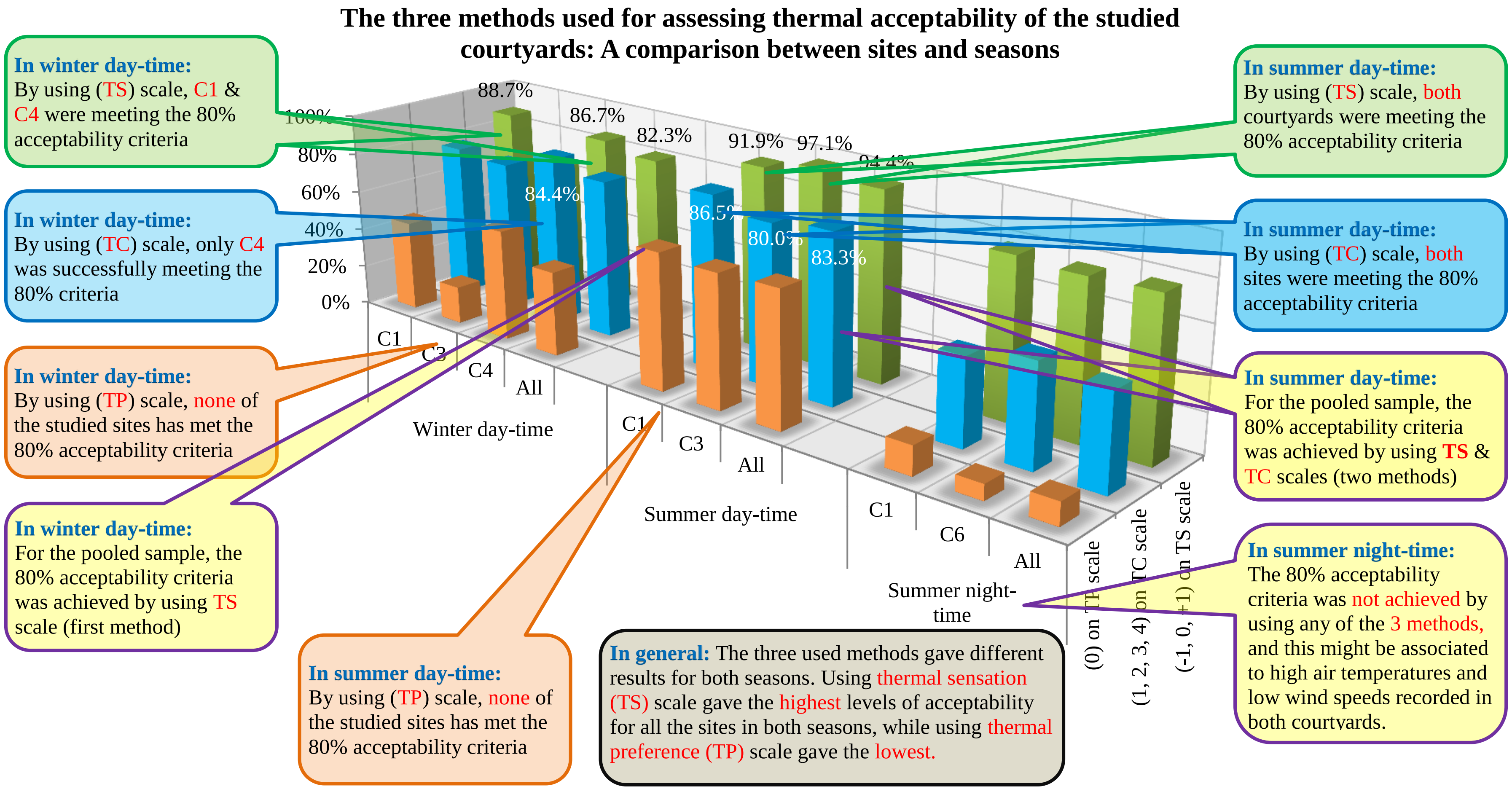


Figure 8-4: The three methods used for assessing thermal acceptability of the studied courtyards: A comparison between sites and seasons

8.3 A Tabulated Summary of the Research Findings

The following tables summarise the study results.

They include:

8.3.1 General description of the studied courtyards (Table 1)

8.3.2 Microclimatic conditions of the studied sites during winter day-time (Table 2 & 3)

8.3.3 Microclimatic conditions of the studied sites during summer day-time (Table 4 & 5)

8.3.4 Microclimatic conditions of the studied sites during summer night-time (Table 6 & 7)

8.3.5 Summary of microclimatic variations (Table 8)

8.3.6 The influence of urban geometry on microclimate of studied sites (Table 9)

8.3.7 Thermal comfort conditions in the studied sites during winter day-time (Table 10 & 11)

8.3.8 Thermal comfort conditions in the studied sites during summer day-time (Table 12 & 13)

8.3.9 Thermal comfort conditions in the studied sites during summer night-time (Table 14 & 15)

Table 8-1: Summary of the Research Findings

General description of the studied courtyards

Courtyard	C1	C2	C3	C4	C5	C6
						
						
General description	It is located in the colonial city, and has the deepest form and smallest aspect ratio among the studied sites. It is provided with 3 tall and big arched openings at the front and back sides. It is fully paved with red brick & some marble.	It is located in the colonial city, and has a semi triangle shape with high degree of enclosure. It was mainly designed to provide the surrounding covered areas with natural lighting and ventilation. It is fully paved with concrete.	It has the second biggest size and aspect ratio among the studied sites, and located on the seafront of Tripoli's financial and business district. It is paved with concrete pavers and partly with grassed small areas. It is surrounded by five towers of 16-storey.	It has the biggest size and aspect ratio among the studied sites, and located about 7km from the sea-shore. It is beautiful landscaped courtyard with full of dense greenery (grass and shading trees) & and surrounded by a group of individual buildings.	It has the smallest size and second smallest aspect ratio among the studied sites. It is fully enclosed courtyard, paved with light grey marble and located in the old city in very densely built up area. It provides natural light, ventilation and interconnection between rooms.	It is located in the old city, and has the second small size form among the studied sites. It has a rectangular shape with two big palm trees. It is fully paved by black stones. Its front side has only one-storey height and provided with 3 arched openings.

Microclimatic conditions of the studied sites during winter day-time

Courtyard			C1	C2	C3	C4	C5	C6
Microclimatic conditions	Winter day-time	DBT	Recorded the lowest DBT average (14ºC), and the lowest minimum reading of DBT (11.8°C)	Its DBT average was about (16.1ºC)	Recorded the lowest DBT average (14.0 ºC)	Recorded the highest DBT average (21.1 ºC), and the highest maximum reading of DBT (22.7ºC)	Its DBT average was about (16.5ºC)	-
			The dry-bulb temperature (DBT) averaging in general about 16.1ºC in this season. The courtyard with deepest form (smallest aspect ratio) and the courtyard which located close to the sea showed a tendency to be cooler than other sites.					
		GT	Recorded the lowest GT average (15.7 ºC), and the lowest minimum reading of GT (13.8°C)	Its GT average was about (19.4ºC)	Its GT average was about (16.3ºC)	Recorded the highest GT average (23.0ºC), and the highest maximum reading of GT (26.5°C)	Its GT average was about (21.0 ºC)	-
			The glob temperature (GT) averaging in general about 19.1ºC in this season. Courtyard with smallest aspect ratio showed a tendency to be cooler than other sites, while the courtyard with the largest aspect ratio showed a tendency to be warmer than the others.					
		ST-F	Recorded the lowest ST-F average (11.3 ºC),	Its ST-F average was about (14.2 ºC)	Recorded the highest ST-F average (16ºC), and the highest maximum reading of ST-F (18.6°C)	Recorded the lowest ST-F average (11.3 ºC), and the lowest minimum reading of ST-F (7.8°C)	Its ST-F average was about (13.2 ºC)	-
			The average of floor surface temperature (ST-F) in winter season was about 13.2ºC.					
		ST-W	Recorded the lowest ST-W average (12.8ºC),	Its ST-W average was about (15.1ºC)	Its ST-W average was about (15.5ºC)	Recorded the highest ST-W average (16ºC), and the highest maximum reading of ST-W (18.4°C)	Recoded the lowest minimum reading of ST-W (11.4ºC). Its ST-W average was about (13.3ºC)	-
			In this season, the general average of wall surface temperature (ST-W) was about 14.5 ºC. The courtyard with deep form (smallest aspect ratio) showed the lowest average of ST-W, whereas the courtyard with shallower form and largest aspect ratio showed the highest average of ST-W.					

Microclimatic conditions of the studied sites during winter day-time

<table>
<tr><th colspan="3">Courtyard</th><th>C1</th><th>C2</th><th>C3</th><th>C4</th><th>C5</th><th>C6</th></tr>
<tr><td rowspan="6">Microclimatic conditions</td><td rowspan="6">Winter day-time</td><td rowspan="2">RH</td><td>Recorded the highest RH average (73.5%), and the highest maximum reading of RH (94%)</td><td>Its RH average was about (67.1%)</td><td>Its RH average was about (56.4%)</td><td>Recorded the lowest RH average (31.5%), and the lowest minimum reading of RH (21%)</td><td>Its RH average was about (53.7%)</td><td>_</td></tr>
<tr><td colspan="6">In winter season, the general average of relative humidity (RH) was 53.7%. As for the variation in relative humidity between the studied sites in winter season was fairly small except that for the case of courtyard C1 which recorded very high RH due to one rainy day.</td></tr>
<tr><td rowspan="2">WS</td><td>Its WS average was about (0.8 m/s)</td><td>Recorded the lowest minimum reading of WS (0.0 m/s). Its WS average was about (0.6 m/s).</td><td>Recorded the highest WS average (1.1 m/s), and the highest maximum reading of WS (2.6 m/s)</td><td>Recorded the lowest minimum reading of WS (0.0 m/s). Its WS average was about (0.8 m/s)</td><td>Recorded the lowest WS average (0.1 m/s), and the lowest minimum reading of WS (0.0 m/s)</td><td>_</td></tr>
<tr><td colspan="6">The average of wind speed in winter was about 0.7 m/s. The highest WS readings were recorded in the courtyard which is located close and open to the sea, whereas the poor ventilation condition was observed in the courtyard with high degree of enclosure and located in very compacted urban built-up area.</td></tr>
<tr><td rowspan="2">ILL</td><td>Recorded the lowest ILL average (2600 lux), and the lowest minimum reading of ILL (160 lux)</td><td>Its ILL average was about (14100 lux)</td><td>Recorded the highest maximum reading of ILL (77000 lux). Its ILL average was about (26300 lux)</td><td>Recorded the highest ILL average (40700lux)</td><td>Its ILL average was (8300 lux)</td><td>_</td></tr>
<tr><td colspan="6">The average of illuminance levels in winter was about (18400 lux). In this season, the courtyards with small aspect ratio showed very low averages of illuminance levels (below 10000 lux), while courtyard with large aspect ratio showed considerable averages of ILL levels.</td></tr>
<tr><td colspan="3">Conclusion</td><td colspan="6">Based on what is described above, it is suggested that courtyard C1 has to some degree an extreme readings for its environmental parameters (low temperatures, low day light levels and high relative humidity levels), followed by courtyard C4 which shows (unusual winter warm temperatures, low floor surface temperatures, low relative humidity levels, and low wind speeds), and lastly courtyard C5 which has tendency to have low day light levels and weak of air circulation. On the other hand, courtyard C3 then C2 seems to have fairly moderate microclimates.</td></tr>
</table>

Microclimatic conditions of the studied sites during summer day-time

Courtyard			C1	C2	C3	C4	C5	C6
Microclimatic conditions	Summer day-time	DBT	Its DBT average was about (28.3ºC)	Its DBT average was about (28.3ºC)	Recorded the lowest DBT average (26.6ºC), and the lowest minimum reading (25.5°C)	Its DBT average was about (28.3ºC)	Recorded the highest DBT average (28.8ºC), and the highest maximum reading (29.6ºC)	-
		DBT	The dry-bulb temperature (DBT) averaging in general about 28ºC in this season.					
		GT	Its GT average was about (30.8ºC)	Its GT average was about (31.6ºC)	Recorded the lowest GT average (29.1ºC), and the lowest minimum reading of GT (27.1°C)	Its GT average was about (31ºC)	Recorded the highest GT average (32.3ºC) and the highest maximum reading of GT (34.5ºC)	-
		GT	The globe temperature (GT) averaging in general about 32.3ºC in this season. The lowest temperatures were recorded in the courtyard which located close to the sea, while the highest one were recorded in the courtyards which is located in very compacted built-up area (in the old city).					
		ST-F	Its ST-F average was about (35.4ºC),	Recorded the highest ST-F average (36.7ºC) and the highest maximum reading of ST-F (49.5°C).	Its ST-F average was about (35.7ºC),	Recorded the lowest ST-F average (30ºC), and the lowest minimum reading of ST-F (24.7°C)	Its ST-F average was about (33.7 ºC)	-
		ST-F	The average of floor surface temperature (ST-F) in summer day-time was about 34.3ºC. The highest floor surface temperatures were recorded in the sites which are paved with concrete, while the lowest one was recorded in the courtyard which has full grassed floor area.					
		ST-W	Its ST-W average was about (28.7ºC),	Recorded the highest ST-W average (33.5ºC), and the highest maximum reading (40ºC)	Its ST-W average was about (29ºC)	Its ST-W average was about (29.1ºC),	Recorded the lowest ST-W average (26.8ºC), and the lowest minimum reading (24.5°C)	-
		ST-W	The average of wall surface temperature (ST-W) in summer day-time was about 29.4 ºC. The lowest wall surface temperatures were recorded in the courtyard which has the smallest size (area) among the all.					

Microclimatic conditions of the studied sites during summer day-time

Courtyard			C1	C2	C3	C4	C5	C6
Microclimatic conditions	Summer day-time	RH	Recorded the highest RH average (65.6%)	Its RH average was about (58.8%)	Its RH average was about (62.1%)	Recorded the highest maximum reading of RH (72%). Its RH average was about (63%)	Recorded the lowest RH average (58.6%), and the lowest minimum reading of RH (50%)	-
			In this season, the general average of relative humidity (RH) was 61.6%. The highest RH reading recorded in the courtyard with large amount of greenery, whereas the lowest one recorded in the warmest courtyard.					
		WS	Recorded the highest maximum reading of WS (3.2 m/s). Its WS average was about (1.3 m/s).	Its WS average was about (0.9 m/s)	Recorded the highest WS average (1.5 m/s)	Its WS average was about (0.7 m/s)	Recorded the lowest WS average (0.6 m/s), and the lowest minimum reading of WS (0.0 m/s)	-
			The average of wind speed (WS) in this season was about 1.0 m/s. The courtyard with higher degree of enclosure and located in very compacted built up area showed very low air flows, while the courtyard which is located close to the sea showed the highest wind speed average. Moreover, the courtyard with tall and big arched openings at its front and back sides has recorded the highest WS reading.					
		ILL	Recorded the lowest ILL average (32800 lux)	Its ILL average was about (46300 lux)	Recorded the highest ILL average (62400 lux)	Its ILL average was about (62100 lux)	Recorded the highest maximum & lowest minimum (105830 & 930 lux). Its ILL average (5560 lux)	–
			Courtyard C5 possesses the highest reading of illuminance (ILL). This is because it has surfaces with high albedo (e.g. marble) which contributes in increasing illuminance levels inside the courtyard. In other words, in addition to the direct sunlight, the courtyard is very small with walls are very close to each other, and this leads to much potential of internal reflection of radiations, which in turn contributes in raising the illuminance levels particularly during the noontime. This courtyard also recorded the lowest reading of ILL because of its small aspect ratio.					
Conclusion			Based on the results discussed above, it is suggested that courtyard C5 has to some degree an extreme environmental parameters readings, followed by C2 then C4. On the other hand, courtyard C3 followed by C1 seems to possess a good ventilated environment and moderate air and globe temperatures.					

Microclimatic conditions of the studied sites during summer night-time

Courtyard			C1	C2	C3	C4	C5	C6
Microclimatic conditions	**Summer night-time**	DBT	Recorded the lowest DBT average (32.3ºC), and the lowest minimum reading of DBT (32ºC)	-	-	-	-	Recorded the highest DBT average (33.2ºC), and the highest maximum reading of DBT (34.3ºC)
			In summer night-time, the dry-bulb temperature (DBT) averaging in general about 32.8ºC. In this season, the courtyard, which has elongated and shallow form was slightly warmer than other one with deeper form.					
		GT	Recorded the lowest GT average 32.9 (ºC), and the lowest minimum reading of GT (32.4ºC)	-	-	-	-	Recorded the highest GT average (33.6ºC), and the highest maximum reading of GT (34.1ºC)
			The globe temperature (GT) averaging in general was about 33.2ºC in this season. The courtyard with shallower form showed higher temperatures than that one with deeper form.					
		ST-F	Recorded the lowest ST-F average (27.4ºC), and the lowest minimum reading of ST-F (26.8ºC)	-	-	-	-	Recorded the highest ST-F average (31.8ºC), and the highest maximum reading of ST-F (32.2ºC)
			The general average of floor-surface temperature (ST-F) of the studied sites during summer night-time was 29.6ºC. The courtyard with black stone pavement (dark colour) showed higher floor surface temperatures than the courtyard with red brick pavement (less dark).					
		ILL	-	-	-	-	-	-
			No illuminance measurements were conducted during summer night-time survey					

Microclimatic conditions of the studied sites during summer night-time

<table>
<tr><th colspan="3">Courtyard</th><th>C1</th><th>C2</th><th>C3</th><th>C4</th><th>C5</th><th>C6</th></tr>
<tr><td rowspan="6">Microclimatic conditions</td><td rowspan="6">Summer night-time</td><td rowspan="2">ST-W</td><td>Recorded the lowest ST-W average (31.5ºC),), and the lowest minimum reading of ST-W (31.2ºC)</td><td>-</td><td>-</td><td>-</td><td>-</td><td>Recorded the highest ST-W average (33.2ºC), and the highest maximum reading of ST-W (33.4ºC)</td></tr>
<tr><td colspan="6">The general average of wall-surface temperature (ST-W) of studied sites during summer night-time was 32.3ºC. The courtyard with elongated rectangle form and surrounded by 2-storey building on three sides and single storey on the forth side (toward the sun direction) showed higher wall surface temperature than the other one which is surrounded by 4-storey building on all the sides.</td></tr>
<tr><td rowspan="2">RH</td><td>Recorded the highest RH average (34.3%), and the highest maximum reading of RH (40%)</td><td>-</td><td>-</td><td>-</td><td>-</td><td>Recorded the lowest RH average (27%), and the lowest minimum reading of RH (24%)</td></tr>
<tr><td colspan="6">In this season, the general average of relative humidity (RH) was 30.6%. The more warmth site, the less humid site.</td></tr>
<tr><td rowspan="2">WS</td><td>Recorded the lowest WS average (0.1 m/s), and the lowest minimum reading of WS (0.1 m/s)</td><td>-</td><td>-</td><td>-</td><td>-</td><td>Recorded the highest WS average (0.3 m/s), and the highest maximum reading of WS (0.9 m/s)</td></tr>
<tr><td colspan="6">For the summer night-time survey, the wind speeds (WS) were very low and more stable. The average of wind speed in this season was about 0.2 m/s. The courtyard which is located not far away from the harbour showed a tendency to be relatively good ventilated space compared to courtyard to the other one.</td></tr>
<tr><td colspan="3">Conclusion</td><td colspan="6">Based on the results discussed above, in general, both of the courtyards have slightly higher temperatures (warm environments), acceptable relative humidity levels and low air velocity (weak ventilation). In particular, the courtyard with shallow form seems to be warm site due to large amount of solar radiation received during day-time, whereas courtyard with deep form tends to be less warm due to the protection it afforded against solar radiation.</td></tr>
</table>

Summary of microclimatic variations

Summary of microclimatic variations		
	DBT & GT	There was a clear variation in the measured dry-bulb temperatures (DBT) and globe temperatures (GT) in the studied sites between the two seasons (winter & summer). In summer day-time, the average of (DBT) was about 28ºC, whereas in winter it was around 16.1ºC. The difference between the day and night averages of (DBT) in hot season is approximately 5ºC (about 32.8ºC, at night-time). A difference of about 12ºC was also found between general averages of (GT) in both seasons (19.1ºC in cold season & 31ºC in hot season), and a small difference of about 2ºC was observed between the day and night times during hot season (about 33.2ºC, at night-time).
	ST-F & ST-W	A large variation in floor / wall surface temperatures (ST-F & ST-W) was found between the hot and cold seasons. The higher surface temperatures were observed in summer day-time with averages of 34.3ºC for ST-F and 29.4 ºC for ST-W due to the large amount of solar radiation received by the surfaces. The corresponding averages in summer night-time were 29.6ºC and 32.3ºC respectively. In winter day-time, the general averages of ST-F and ST-W of the studied sites were lower (up to 21.1ºC and 14.9ºC respectively) than those of summer day-time, and this because of the short duration of surface exposure to the direct solar radiation which in some cases (sites with small aspect ratio) the direct sun cannot reach the ground even at noontime.
	ILL	The levels of illuminance (ILL) were varied from season to season and from site to another site. A great difference was observed between general averages of illuminance levels in winter and summer (up to 33400 lux) because of the effects of several factors including sky condition (sky cover), building geometry and solar incident angle (season).
	RH	As for relative humidity, the difference between general averages of (RH) during the day time in cold and hot seasons was a small below 8%. It is somewhat surprising that the general average of relative humidity (RH) in summer day time slightly higher than that of winter day-time, and this may was occurred as a result of low humidity levels recorded during unusual warm winter days in some sites. In summer night-time average of RH was largely lower than those during winter and summer day time which was probably an effect of high temperatures recorded during summer nigh-time.
	WS	The variation in wind speed (WS) between the two seasons (winter and summer day-times) was a small with difference of about 0.3 m/s. In general, averages of wind speeds in the three periods were 1.0 m/s or below, which may appear to be low levels.

The influence of urban geometry on microclimate of studied sites

Effect of built urban form on microclimate conditions	Proximity to the sea	The results showed that the proximity to the sea may affect the pattern of airflow and air temperature inside the courtyards. This study found that the courtyard which is located close to the sea (with no barrier between them) showed relatively low temperatures and recorded the highest average of wind speeds in both seasons compared to the other studied sites. This is in agreement with the results obtained by Saaroni et al. (2000) and Emmanuel and Johansson (2006).
	Vegetation	Vegetation seems to have some effects on some elements of the courtyard microclimate. Courtyard with large amount of vegetation and grassed floor area showed the lowest floor-surface temperatures in both seasons and also showed a tendency to cool faster towards the afternoon than rest of sites during the summer day time. This is in line with the results reported by Dimoudi, et al (2003), Ali-Toudert, et al. (2004), Picot (2004), Shashua-Bar and Hoffman (2004b), Attia (2006), Biller, (2007a) and Berkovic et al (2012) which have stated that vegetation may help to improve the microclimate in urban spaces.
	Geometry & architectural form	Courtyard geometry (H/W/L) and architectural form of the studied courtyards (openings, degree of enclosure, shading devices and aspect ratio) were identified as the most factors influencing courtyard microclimate. It was observed that illuminance (daylight) levels increase with increasing the aspect ratio of the studied sites. Courtyard with small size form, no external openings, high degree of enclosure and located in very compact built-up area showed a tendency to have poor ventilated environment in both seasons, while courtyards which are provided with large external openings tended to have better ventilated environments than others in both seasons, and this in good agreement with what Chatzidimitriou and Yannas (2004) and Tablada et al. (2009b) have stated about role of openings in increasing airflow inside the courtyard. Courtyard with deep form and very small aspect ratio (less than 1) showed low air temperature, low day light levels (illuminance), low floor surface temperature during the winter and also showed slow reduction in its air temperatures at summer night time. Courtyards with large aspect ratio generally showed higher temperatures than courtyards with small aspect ratio in particular those who are located away from the sea, more specifically; the effect of the shade generated by the courtyards' geometry was greater on microclimatic conditions especially in the deep courtyards particularly during the winter season. This is in accordance with the results reported by Muhaisen and B Gadi (2006) and Emmanuel & Johansson (2006).
	Surface colour & material	In this study, surface colours and materials of the studied sites showed a clear effect on the measured surface temperatures. Courtyards with dark coloured surface showed higher surface temperatures than those with light coloured surface in both seasons, and this is in strong agreement with the results obtained by Chatzidimitriou et al. (2006), Yilmaz et al. (2007), Yang et al. (2012). Courtyard with high-albedo surface (e.g., marble) showed high readings of dry-bulb temperature and illuminance during the summer day-time despite its size and aspect ratio are small (below 1.5). In general, among all types of the courtyards' pavements, the concrete pavers showed the highest temperatures, whereas the grass had the lowest temperatures in both seasons.
Conclusion		In sum, microclimatic conditions in the studied courtyards are varied from site to site and from season to another due to the difference in their built urban form (spatial characteristics). They are varied depending mainly on the amount of solar radiation received by their surfaces. Courtyard's geometry & architectural form seemed to have the key role in shaping the microclimates of the studied sites. The proximity of the site to the sea and surfaces colour & material appeared to have some influences on some of the microclimate elements of the studied sites.

Thermal comfort conditions in the studied sites during winter day-time

<table>
<tr><th colspan="3">Courtyard</th><th>C1</th><th>C2</th><th>C3</th><th>C4</th><th>C5</th><th>C6</th></tr>
<tr><td rowspan="6">Thermal comfort conditions</td><td rowspan="6">Winter day-time</td><td rowspan="2">Thermal Sensation Votes (TSV)</td><td>Mean of subjects' TSV is (-.70). The subjects were in slightly cool condition</td><td></td><td>Mean of subjects' TSV is (-1.03). It is in the interval between slightly cool (-1) and cool (-2).</td><td>Mean of subjects' TSV is (.11). It is in the interval between neutral (0) and slightly warm (+1) (on warm side of neutral). It is around neutral.</td><td>-</td><td>-</td></tr>
<tr><td colspan="6">The subjects in C4 were marginally warmer than those in other courtyards. This might be related to the microclimate of this courtyard as it was ranked as the warmest site among the studied sites. The subjects in C3 had slightly cooler sensation than those in C1 despite both courtyards had same average of air temperature. The reason for this might be because of the effect of the wind speed, where C3 was experienced higher average wind speeds than courtyard C3. In general, The mean of TSV in winter day-time was marginally cooler than neutral (-.50).</td></tr>
<tr><td rowspan="2">Thermal Comfort Votes (TCV)</td><td>The distribution of TCV was 58.5% for comfortable, 22.6% for uncomfortable and 18.9% for neutral. Mean of subjects' TCV was (3.28).</td><td>-</td><td>The distribution of TCV was 50% for comfortable, 25% for uncomfortable and 25% for neutral. Mean of subjects' TCV was (3.34).</td><td>The distribution of TCV was 64.4% for comfortable, 15.6% for uncomfortable and 20% for neutral. Mean of subjects' TCV was (3).</td><td>-</td><td>-</td></tr>
<tr><td colspan="6">The large portion of thermal comfort votes of the subjects in the three studied courtyards was on the comfort side of neutral. Mean of subjects' TCV in C1 and C3 was in the interval between slightly comfortable (3) and neutral (4), whereas in C4 was slightly comfortable.</td></tr>
<tr><td rowspan="2">Thermal Preference Votes (TPV)</td><td>Responses to the McIntyre scale were 45.3% preferring ‘‘no change’’, 5.7% for cooler and 49.1% for warmer.</td><td>-</td><td>Responses to the McIntyre scale were 18.75% preferring ‘‘no change’’, 0% for cooler and 81.25% for warmer.</td><td>Responses to the McIntyre scale were 55.6% preferring ‘‘no change’’, 17.8 for cooler and 26.7% for warmer.</td><td>-</td><td>-</td></tr>
<tr><td colspan="6">About 54.7% of the subjects in courtyard C1, 81.25% in C3 and 44.4% in C4 still wanted a change in their thermal state (preferred to feel warmer or cooler). The large per cent of subjects who were dissatisfied with their thermal state was in C1 followed by C3.</td></tr>
</table>

Thermal comfort conditions in the studied sites during winter day-time

<table>
<tr><td rowspan="8">Thermal comfort conditions</td><td rowspan="8">Winter day-time</td><td colspan="2" rowspan="2">Clothing Insulation (clo)</td><td>Mean clothing insulation value was (1.08 clo)</td><td></td><td>Mean clothing insulation value was (1.09 clo)</td><td>Mean clothing insulation value was (1.00 clo)</td><td></td><td></td></tr>
<tr><td colspan="6">The mean clothing values were approximately equal in C1 and C3 but in the courtyard C4, it was slightly lower (1.00 clo), that probably happened because the weather was slightly warm on the survey day in this courtyard.</td></tr>
<tr><td rowspan="6">Thermal Acceptability</td><td rowspan="2">Voting within the 3 central categories of TS scale (acceptable = -1, 0, 1)</td><td>88.7% of the subjects in the courtyards were satisfied with their thermal environment</td><td>-</td><td>65.6% of the subjects in the courtyards were satisfied with their thermal environment</td><td>86.7% of the subjects in the courtyards were satisfied with their thermal environment</td><td>-</td><td>-</td></tr>
<tr><td colspan="6">By using this indirect measure of acceptability, two courtyards (C1 and C4) were successfully meeting the ASHRAE Standard-55's 80% acceptability criteria, whereas C3 did not meet the 80% acceptability criterion.</td></tr>
<tr><td rowspan="2">Voting within 4 categories of TC scale (acceptable = 1, 2, 3, 4)</td><td>77.4% of subjects were comfortable in this site</td><td>-</td><td>75.0% of subjects were comfortable in this site</td><td>84.4% of subjects were comfortable in this site</td><td>-</td><td>-</td></tr>
<tr><td colspan="6">By using four categories (comfortable-neutral categories) of TC scale, only courtyard C4 was successfully meeting the intent of ASHRAE Standard 55. One reason may be that this site was warmer and less airy site compared to the other two sites.</td></tr>
<tr><td rowspan="2">Voting for (preferring no change) of TP scale (acceptable = 0)</td><td>45.3% of subjects considered their site to be thermally acceptable</td><td>-</td><td>18.75% of subjects considered their site to be thermally acceptable</td><td>55.6% of subjects considered their site to be thermally acceptable</td><td>-</td><td>-</td></tr>
<tr><td colspan="6">By using McIntyre preference scale, the ASHRAE’s 80% thermal acceptability criterion was not met by any of the samples on any of the studied sites (C1, C3 and C4) during the cold season (winter).</td></tr>
<tr><td colspan="4">Conclusion</td><td colspan="6">The three scales (TS, TC and TP) used in the assessment gave different results. The highest levels of acceptability was obtained from using TS scale followed by that from TC scale, while TP scale gave percentages are much less than those gained from TS & TP scales. People in courtyard C4 tended to feel more comfortable than other courtyards in winter, with air temperature ranges between 15.6 and 22.7 ºC.</td></tr>
</table>

Thermal comfort conditions in the studied sites during summer day-time

<table>
<tr><th colspan="3">Courtyard</th><th>C1</th><th>C2</th><th>C3</th><th>C4</th><th>C5</th><th>C6</th></tr>
<tr><td rowspan="8">Thermal comfort conditions</td><td rowspan="8">Summer day-time</td><td rowspan="2">Thermal Sensation Votes (TSV)</td><td>Mean of subjects' TSV is (.30). The subjects were around neutral condition</td><td>-</td><td>Mean of subjects' TSV is (.23). The subjects were around neutral condition</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td colspan="6">In this season, the subjects in both courtyards were around neutral condition, but respondents in C1 tended to have slightly warmer sensation than those in C3. The reason for this might be that the mean bulb-dry temperature and mean globe temperature in C1 were higher than those in C3. Moreover, average of wind speed in C3 was higher than that in C1, which may had some impacts on subjects’ sensation votes as well.</td></tr>
<tr><td rowspan="2">Thermal Comfort Votes (TCV)</td><td>The distribution of TCV was 59.5% for comfortable, 13.5% for uncomfortable and 27% for neutral.</td><td>-</td><td>The distribution of TCV was 62.9% for comfortable, 20% for uncomfortable and 17.1% for neutral.</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td colspan="6">The large portion of thermal comfort votes of the subjects in the two studied courtyards was on the comfort side of neutral.</td></tr>
<tr><td rowspan="2">Thermal Preference Votes (TPV)</td><td>Responses to the McIntyre scale were 67% preferring ‘‘no change’’, 29.7% for cooler and 2.7% for warmer.</td><td>-</td><td>Responses to the McIntyre scale were 65% preferring ‘‘no change’’, 31.4% for cooler and 2.9% for warmer.</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td colspan="6">Around ⅔ of the subjects in both courtyards were satisfied with their thermal state and preferred ‘‘no change’’, due to moderate microclimate conditions</td></tr>
<tr><td rowspan="2">Clothing Insulation</td><td>Mean clothing insulation value was (0.52 clo)</td><td>-</td><td>Mean clothing insulation value was (0.60 clo)</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td colspan="6">There was variation in clo values because most of C3 users their clothes were formal, whereas in courtyard C1, most of its users were wearing casual clothing. Moreover the sample in C3 included number of female participants which contributed in increasing the average of clo values for the sample as a whole because of their high clo values due to the impact of religion, culture and tradition.</td></tr>
</table>

Thermal comfort conditions in the studied sites during summer day-time

<table>
<tr><th colspan="4">Courtyard</th><th>C1</th><th>C2</th><th>C3</th><th>C4</th><th>C5</th><th>C6</th></tr>
<tr><td rowspan="6">Thermal comfort conditions</td><td rowspan="6">Summer day-time</td><td rowspan="6">Thermal Acceptability</td><td rowspan="2">Voting within the 3 central categories of TS scale (acceptable = -1, 0, 1)</td><td>91.9% of the subjects in the courtyards were satisfied with their thermal environment</td><td>-</td><td>97.1% of the subjects in the courtyards were satisfied with their thermal environment</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td colspan="6">By using this indirect measure of acceptability, both courtyards in summer day-time exhibit acceptable thermal environments using ASHARE scale.</td></tr>
<tr><td rowspan="2">Voting within 4 categories of TC scale (acceptable = 1, 2, 3, 4)</td><td>86.5% of subjects were comfortable in this site</td><td>-</td><td>80% of subjects were comfortable in this site</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td colspan="6">By using four categories (comfortable-neutral categories) of TC scale, the percentage of acceptable votes in both courtyards exceeded the limit of 80%. The percentage of the subjects who found the condition to be satisfactory (acceptable) in C1 was slightly higher than in C3 despite the later courtyard had lower air temperature and higher wind speeds, and this probably related to the clothing insulation values which was higher in C3 than in C1.</td></tr>
<tr><td rowspan="2">Voting for (preferring no change) of TP scale (acceptable = 0)</td><td>67.6% of subjects considered their site to be thermally acceptable</td><td>-</td><td>65.7% of subjects considered their site to be thermally acceptable</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td colspan="6">By using McIntyre preference scale, the majority of subjects in both courtyards (around 65%) were satisfied with their thermal environments, but the percentages are still below the 80% acceptability criterion. Thus, the results indicate that ASHRAE's 80% thermal acceptability criterion was not met by both studied courtyards during this season.</td></tr>
<tr><td colspan="4">Conclusion</td><td colspan="6">In summer day-time, only TP scale gave percentages were below the required thermal acceptance criteria. Based on the results, both courtyards (C1 & C3) were strongly meeting the ASHRAE Standard-55's 80% acceptability criteria.</td></tr>
</table>

Thermal comfort conditions in the studied sites during summer night-time

Courtyard			C1	C2	C3	C4	C5	C6
Thermal comfort conditions	Summer night-time	Thermal Sensation Votes (TSV)	Mean of subjects' TSV is (+1.07). The subjects were slightly warm.	-	-	-	-	Mean of subjects' TSV is (+1.08). The subjects were slightly warm.
			The mean of TSV in both courtyards were in the interval between slightly warm (+1) and warm (+2) (on the warm side of neutral). The difference between them is very small, and this was expected that because their recorded environmental data (temperatures, wind speed and relative humidity) were very close to each other (similar). In general, the mean of TSV was slightly warm for summer night-time.					
		Thermal Comfort Votes (TCV)	The distribution of TCV was 28.6% for comfortable, 57.1% for uncomfortable and 14.3% for neutral.	-	-	-	-	The distribution of TCV was 26.9% for comfortable, 50% for uncomfortable and 23.1% for neutral.
			The large portion of thermal comfort votes of the subjects in courtyard C1 was on the un comfort side of neutral, whereas in courtyard C6 was for neutral.					
		Thermal Preference Votes (TPV)	Responses to the McIntyre scale were 14.3% preferring ‘‘no change’’, 85.7% for cooler.	-	-	-	-	Responses to the McIntyre scale were 7.7% preferring ‘‘no change’’, 92.3% for cooler.
			The majority of the subjects in both courtyards were dissatisfied with their thermal conditions during the summer night-time. This was because of the high air temperatures and very low air flows which were recorded in these sites.					
		Clothing Insulation	Mean clothing insulation value was (0.53 clo)	-	-	-	-	Mean clothing insulation value was (0.52 clo)
			Similar clo values in the two courtyards because people in both courtyard were wearing casual clothing.					

Thermal comfort conditions in the studied sites during summer night-time

Thermal comfort conditions	Summer night-time	Thermal Acceptability	Voting within the 3 central categories of TS scale **(acceptable = -1, 0, 1)**	78.6% of the subjects in the courtyards were satisfied with their thermal environment	-	-	-	-	76.9% of the subjects in the courtyards were satisfied with their thermal environment
Thermal comfort conditions	Summer night-time	Thermal Acceptability		By using ASHARE scale, none of the studied sites was able to achieve an acceptable thermal environment with 80% of the subjects expressing satisfaction with the thermal condition.					
Thermal comfort conditions	Summer night-time	Thermal Acceptability	Voting within 4 categories of TC scale **(acceptable = 1, 2, 3, 4)**	42.9% of subjects were comfortable in this site	-	-	-	-	50.0% of subjects were comfortable in this site
Thermal comfort conditions	Summer night-time	Thermal Acceptability		By using four categories (comfortable-neutral categories) of TC scale, none of the studied courtyards was able to achieve an acceptable thermal environment with 80% of the subjects expressing satisfaction with the thermal conditions. The results seem to show that a large portion of the summer nigh-time subjects were uncomfortable in both courtyards across an air temperature range of 32 – 34.3ºC.					
Thermal comfort conditions	Summer night-time	Thermal Acceptability	Voting for (preferring no change) of TP scale **(acceptable = 0)**	14.3% of subjects considered their site to be thermally acceptable	-	-	-	-	7.7% of subjects considered their site to be thermally acceptable
Thermal comfort conditions	Summer night-time	Thermal Acceptability		By using McIntyre preference scale, only a small portion of the subjects (does not exceed 15%) were satisfy with their thermal environments, whereas the majority of the subjects have considered their thermal environments unacceptable and they wanted to be cooler. Therefore, these results indicate that both courtyards was not meeting the 80% acceptability criteria prescribed by ASHRAE Standard 55.					
Conclusion				In summer night-time, none of the three methods (scales) in the two studied courtyards (C1 & C6) was able to achieve an acceptable thermal environment with 80% of the people expressing satisfaction with the thermal conditions.					
Thermal comfort adaptive behaviour				It has observed in this study that people used different behavioural actions to adjust themselves to the environment during the cool and hot seasons. Most of these actions were in form of personal adjustments such as altering clothing levels, consumption of hot or cold drinks, changing position. Some environmental adjustments were observed such as covering the courtyard's roof during the extreme weather.					

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APPENDICES

Appendix 1: Questionnaire form in English

Outdoor Thermal Comfort Questionnaire Form

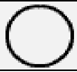
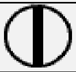
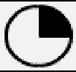
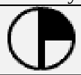
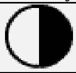
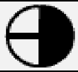
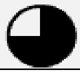
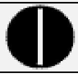
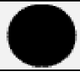
Case Study Site: .... **Date:** ...... /...... /...... **Day:** .... **Survey No**: .... **Health State**: ....

Gender: male / female **Age**: .... **Time**: from .... to........... **Area**: shaded / semi-shaded / open

----

PART I / Question 1: **Weather condition**: sunny / cloudy

If cloudy please circle one of the figures in the table:

Oktas	0	1	2	3	4	5	6	7	8
Definition	Sky clear	1/8 of sky covered or less, but not zero	2/8 of sky covered	3/8 of sky covered	4/8 of sky covered	5/8 of sky covered	6/8 of sky covered	7/8 of sky covered or more, but not 8/8	8/8 of sky completely covered, no breaks
Category	Fine	Fine	Fine	Partly Cloudy	Partly Cloudy	Partly Cloudy	Cloudy	Cloudy	Overcast
									

Question 2: **Activity**

For the last half hour have you been mainly (circle the appropriate answer):

Moving Standing Sitting Lying

Question 3: **clothing**

Please write down what you are wearing at this moment:

Underwear.................... Trousers / Skirts...................... Shirts / Blouses....................... Shoes.......................

....

Robes / Coats............... Sweaters / Dresses................. Jackets / Parkas..................... Others.............................

....

Are your clothes mainly <u>light</u> or <u>Medium</u> or <u>Thick.</u> (Circle appropriate answer):

Question 4: **Drink / Food**

Please indicate what you have consumed before or after coming to the site:

Non Hot drink/food Cold drink/ food Smoking

Question 5: **Duration of Stay & Visits to the site**

How long have you been outdoor:............ minute

Do you always visit this site: First time Regularly Occasionally

----

Question 6: **Thermal Sensation**

Please indicate on the scale how do you feel now

-3	-2	-1	0	+1	+2	+3
Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot

Question 7: **Thermal Comfort**

what do you currently feel?

1	2	3	4	5	6	7
Very comfortable	Comfortable	Slightly comfortable	Neutral	Slightly uncomfortable	Uncomfortable	Very uncomfortable

---

PART II / Question 1: **Preference**

1- **Temperature**: At present time,

How you would like to be (circle appropriate answer): Warmer | No change | Cooler

2- **Wind**:

Would you prefer (circle appropriate answer): More air movement | No change | Less air movement

3- **Sunshine**:

Would you prefer (circle appropriate answer): More sun | No change | More shade

4- **Greenery**:

Would you prefer (circle appropriate answer): More vegetation | No change | Less vegetation

---

Question 2: **perception**

1- **Wind**:

How much wind there is (circle appropriate answer): More air movement | Moderate | Less air movement

2- **Sunshine**:

How much sun there is (circle appropriate answer): More sun | Moderate | More shade

---

Thank you for your cooperation

Appendix 2: Questionnaire form in Arabic

استبيان لدراسة الارتياح الحراري داخل الفراغات العامة المفتوحة (داخل الباحات المغلقة) بمدينة طرابلس

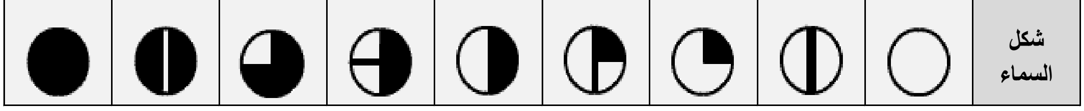
موقع الدراسة : .... **التاريخ** : .... / .... / .... **اليوم** :............... **رقم المسح** : .... **الحالة الصحية** : ....

الجنس : ذكر / أنثى **العمر**: .... **الوقت** : من .... إلي .... **مكان التواجد** : مظلل/ شبه مظلل / مفتوح

الجزء الأول /

س1. حالة الطقس : مشمس (صحو) / غائم

إذا كان غائما يرجى وضع دائرة علي الشكل الذي يعكس شكل السماء تقريبا.

Oktas	0	1	2	3	4	5	6	7	8
التعريف	السماء صافية	1/8 السماء مغطاة أو أقل و لكنها ليست صفر	2/8 السماء مغطاة	3/8 السماء مغطاة	4/8 السماء مغطاة	5/8 السماء مغطاة	6/8 السماء مغطاة	7/8 السماء مغطاة أو أكثر و لكنها ليست 8/8	8/8 السماء مغطاة بالكامل
الفئة	صافية	صافية	صافية	غائمة جزئيا	غائمة جزئيا	غائمة جزئيا	غائمة	غائمة	متلبدة بالغيوم (مظلمة)
شكل السماء									

س2. النشاط :

لآخر نصف ساعة هل كنت : (ضع دائرة علي الإجابة المناسبة) : تتحرك واقف جالس مستلقي

س3. الملابس :

الرجاء كتابة ما ترتدي من ثياب في هذه اللحظة :

ملابس داخلية..................... سراويل / تنانير(جونات) .... القمصان / تيشرت (بلوزات) .... أحذية ....

جلابيب / معاطف (جيبوتيات) .... كنزات صوفية (فانيليات)/ فساتين .... جاكيتات / ستر(دجيليهات) ....

آخري ....

هل ملابسك تكون : **سميكة** أو **متوسطة** أو **خفيفة** (ضع دائرة علي الإجابة المناسبة)

س4. الأكل و الشراب :

يرجى الإفادة عن ماذا تناولت قبل أو بعد وصولك للموقع : لم أتناول شئ شراب أو أكل / ساخن شراب أو أكل / بارد سجاير

س5. مدة البقاء في الهواء الطلق & تكرر الزيارات إلي الموقع :

منذ متي و أنت موجود في الهواء الطلق .... دقيقة.

هل تزور هذا الموقع دائما : لأول مرة بشكل منتظم أحيانا

س6. الإحساس الحراري :

يرجى التحديد على المقياس التالي كيف تشعر الآن :

بارد جدا　بارد　بارد قليلا　معتدل　ساخن　ساخن قليلا　ساخن جدا

درجة حرارة الجلد للشخص المقابل (العينة) : لليدين .... للرأس (الجبهة) ....

س7. الراحة الحرارية :

ماذا تشعر في الوقت الحالي :

مريح جدا　مريح　مريح قليلا　متعادل (محايد)　غير مريح قليلا　غير مريح　غير مريح جدا

الجزء الثاني /

س1. التفضيل :

1. **الحرارة :**
   كيف تريد أن تكون (ضع دائرة حول الإجابة المناسبة) :　دافئ　لا تغيير　بارد

2. **الرياح :**
   هل تفضل (ضع دائرة حول الإجابة المناسبة) :　مزيد من حركة الهواء　لا تغيير　حركة هواء أقل

3. **أشعة الشمس :**
   هل تفضل (ضع دائرة حول الإجابة المناسبة) :　مزيد من الشمس　لا تغيير　أكثر ظل

4. **الخضرة (النباتات) :**
   هل تفضل (ضع دائرة حول الإجابة المناسبة) :　مزيد من نباتات　لا تغيير　نباتات أقل

س2. التصور (التوقع) :

1. **الرياح :**
   كم هي حركة الهواء الموجودة حسب تصورك (ضع دائرة حول الإجابة المناسبة) :
   حركة الهواء أكثر　معتدل　حركة هواء أقل

2. **أشعة الشمس :**
   كم هي كمية الشمس الموجودة حسب تصورك (ضع دائرة حول الإجابة المناسبة) :
   شمس أكثر　معتدل　ظل أكثر

شكرا جزيلا لتعاونكم

Appendix 3: Observation form (winter survey)

OBSERVATION FORM

Case study site.............................. Date......................... Weather condition............................

The surroundings : - Smell ....

- Sight – visual complexity (what can be seen on the site) :

Site furniture	
Water elements	
greenery	
Others	

- Hearing (surrounding sounds) :

People talking, laughing and etc		Sounds from a fountain	
Cars, vehicles		Construction machinery	
music		birds	
Sounds from wind		Others	

The people :

Time	Total Number Of Site Users	Age Category Of The Site Users						Sex		Clothing					Activity				Location			No. Of Photo Taking	Notes
		Babies	Kids	Teenager	Yong People	Adults	Older People	Male	Female	Super Light	Light	Medium	Thick	Extra Thick	Sitting	Standing	Lying	Moving	Shaded Area	Semi Shaded Area	Open Area		
09.00 - 09.30																							
09.30 - 10.00																							
10.00 - 10.30																							
10.30 - 11.00																							
11.00 - 11.30																							
11.30 - 12.00																							
12.00 - 12.30																							
12.30 - 13.00																							
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14.30 - 15.00																							
15.00 - 15.30																							
15.30 - 16.00																							
16.30 - 17.00																							
17.00 - 17.30																							
17.30 - 18.00																							
Total																							

Appendix 4: A sample of data collection form

Environmental data collection form Case study site: .... Date: ....

<table>
<tr><th rowspan="2">Measuring</th><th rowspan="2">Unit</th><th colspan="36">Time</th></tr>
<tr><th colspan="6">09.00-09.30</th><th colspan="6">09.30-10.00</th><th colspan="6">10.00-10.30</th><th colspan="6">10.30-11.00</th><th colspan="6">11.00-11.30</th><th colspan="6">11.30-1200</th></tr>
<tr><td>Spatial category</td><td></td><td colspan="6"></td><td colspan="6"></td><td colspan="6"></td><td colspan="6"></td><td colspan="6"></td><td colspan="6"></td></tr>
<tr><td>Weather</td><td></td><td colspan="6"></td><td colspan="6"></td><td colspan="6"></td><td colspan="6"></td><td colspan="6"></td><td colspan="6"></td></tr>
<tr><td>Dry bulb temperature</td><td>C</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Wet bulb temperature</td><td>C</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Relative humidity</td><td>%</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Globe temperature</td><td>C</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td rowspan="2">Illuminance</td><td rowspan="2">K. lux</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td></tr>
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<tr><td rowspan="2">Wind speed</td><td rowspan="2">m/s</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td><td>max</td><td>min</td></tr>
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</table>

Appendix 5-i: Thermal sensation votes (winter survey)

Thermal sensation Votes for courtyard C1 / winter

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral	23	17.7	43.4	43.4
	Slightly cool	24	18.5	45.3	88.7
	Cool	5	3.8	9.4	98.1
	Cold	1	.8	1.9	100.0
	Total	53	40.8	100.0	
Missing	System	77	59.2		
Total		130	100.0		

Thermal sensation Votes for courtyard C3 / winter

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral	13	10.0	40.6	40.6
	Slightly cool	8	6.2	25.0	65.6
	Cool	8	6.2	25.0	90.6
	Cold	3	2.3	9.4	100.0
	Total	32	24.6	100.0	
Missing	System	98	75.4		
Total		130	100.0		

Thermal sensation Votes for courtyard C4 / winter

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Warm	5	3.8	11.1	11.1
	Slightly warm	4	3.1	8.9	20.0
	Neutral	28	21.5	62.2	82.2
	Slightly cool	7	5.4	15.6	97.8
	Cool	1	.8	2.2	100.0
	Total	45	34.6	100.0	
Missing	System	85	65.4		
Total		130	100.0		

Thermal sensation Votes for the All / winter

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Warm	5	3.8	3.8	3.8
	Slightly warm	4	3.1	3.1	6.9
	Neutral	64	49.2	49.2	56.2
	Slightly cool	39	30.0	30.0	86.2
	Cool	14	10.8	10.8	96.9
	Cold	4	3.1	3.1	100.0
	Total	130	100.0	100.0	

Appendix 5-ii: Thermal sensation votes (summer day-time survey)

Thermal sensation Votes for courtyard C1 / summer day time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Warm	3	4.2	8.1	8.1
	Slightly warm	5	6.9	13.5	21.6
	Neutral	29	40.3	78.4	100.0
	Total	37	51.4	100.0	
Missing	System	35	48.6		
Total		72	100.0		

Thermal sensation Votes for courtyard C3 / summer day time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Warm	1	1.4	2.9	2.9
	Slightly warm	6	8.3	17.1	20.0
	Neutral	28	38.9	80.0	100.0
	Total	35	48.6	100.0	
Missing	System	37	51.4		
Total		72	100.0		

Thermal sensation Votes for the All / summer day time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Warm	4	5.6	5.6	5.6
	Slightly warm	11	15.3	15.3	20.8
	Neutral	57	79.2	79.2	100.0
	Total	72	100.0	100.0	

Appendix 5-iii: Thermal sensation votes (summer night-time survey)

Thermal sensation Votes for courtyard C1 / summer night time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Hot	3	5.6	10.7	10.7
	Warm	3	5.6	10.7	21.4
	Slightly warm	15	27.8	53.6	75.0
	Neutral	7	13.0	25.0	100.0
	Total	28	51.9	100.0	
Missing	System	26	48.1		
Total		54	100.0		

Thermal sensation Votes for courtyard C6 / summer night time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Hot	2	3.7	7.7	7.7
	Warm	4	7.4	15.4	23.1
	Slightly warm	14	25.9	53.8	76.9
	Neutral	6	11.1	23.1	100.0
	Total	26	48.1	100.0	
Missing	System	28	51.9		
Total		54	100.0		

Thermal sensation Votes for the All / summer night time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Hot	5	9.3	9.3	9.3
	Warm	7	13.0	13.0	22.2
	Slightly warm	29	53.7	53.7	75.9
	Neutral	13	24.1	24.1	100.0
	Total	54	100.0	100.0	

Appendix 6-i: Thermal comfort votes (winter survey)

Thermal comfort Votes for courtyard C1 / winter

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very comfortable	4	3.1	7.5	7.5
	Comfortable	16	12.3	30.2	37.7
	Slightly comfortable	11	8.5	20.8	58.5
	Neutral	10	7.7	18.9	77.4
	Slightly uncomfortable	7	5.4	13.2	90.6
	Uncomfortable	5	3.8	9.4	100.0
	Total	53	40.8	100.0	
Missing	System	77	59.2		
Total		130	100.0		

Thermal comfort Votes for courtyard C3 / winter

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very comfortable	2	1.5	6.3	6.3
	Comfortable	3	2.3	9.4	15.6
	Slightly comfortable	11	8.5	34.4	50.0
	Neutral	8	6.2	25.0	75.0
	Slightly uncomfortable	6	4.6	18.8	93.8
	Uncomfortable	2	1.5	6.3	100.0
	Total	32	24.6	100.0	
Missing	System	98	75.4		
Total		130	100.0		

Thermal comfort Votes for courtyard C4 / winter

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very comfortable	4	3.1	8.9	8.9
	Comfortable	17	13.1	37.8	46.7
	Slightly comfortable	8	6.2	17.8	64.4
	Neutral	9	6.9	20.0	84.4
	Slightly uncomfortable	5	3.8	11.1	95.6
	Uncomfortable	2	1.5	4.4	100.0
	Total	45	34.6	100.0	
Missing	System	85	65.4		
Total		130	100.0		

Thermal comfort Votes for the All / winter

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very comfortable	10	7.7	7.7	7.7
	Comfortable	36	27.7	27.7	35.4
	Slightly comfortable	30	23.1	23.1	58.5
	Neutral	27	20.8	20.8	79.2
	Slightly uncomfortable	18	13.8	13.8	93.1
	Uncomfortable	9	6.9	6.9	100.0
	Total	130	100.0	100.0	

Appendix 6-ii: Thermal comfort votes (summer day-time survey)

Thermal comfort Votes for courtyard C1 / summer day time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very comfortable	6	8.3	16.2	16.2
	Comfortable	11	15.3	29.7	45.9
	Slightly comfortable	5	6.9	13.5	59.5
	Neutral	10	13.9	27.0	86.5
	Slightly uncomfortable	3	4.2	8.1	94.6
	Uncomfortable	2	2.8	5.4	100.0
	Total	37	51.4	100.0	
Missing	System	35	48.6		
Total		72	100.0		

Thermal comfort Votes for courtyard C3 / summer day time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very comfortable	6	8.3	17.1	17.1
	Comfortable	13	18.1	37.1	54.3
	Slightly comfortable	3	4.2	8.6	62.9
	Neutral	6	8.3	17.1	80.0
	Slightly uncomfortable	6	8.3	17.1	97.1
	Uncomfortable	1	1.4	2.9	100.0
	Total	35	48.6	100.0	
Missing	System	37	51.4		
Total		72	100.0		

Thermal comfort Votes for the All / summer day time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very comfortable	12	16.7	16.7	16.7
	Comfortable	24	33.3	33.3	50.0
	Slightly comfortable	8	11.1	11.1	61.1
	Neutral	16	22.2	22.2	83.3
	Slightly uncomfortable	9	12.5	12.5	95.8
	Uncomfortable	3	4.2	4.2	100.0
	Total	72	100.0	100.0	

Appendix 6-iii: Thermal comfort votes (summer night-time survey)

Thermal comfort Votes for courtyard C1 / summer night time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very comfortable	1	1.9	3.6	3.6
	Slightly comfortable	7	13.0	25.0	28.6
	Neutral	4	7.4	14.3	42.9
	Slightly uncomfortable	11	20.4	39.3	82.1
	Uncomfortable	5	9.3	17.9	100.0
	Total	28	51.9	100.0	
Missing	System	26	48.1		
Total		54	100.0		

Thermal comfort Votes for courtyard C6 / summer night time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very comfortable	3	5.6	11.5	11.5
	Comfortable	2	3.7	7.7	19.2
	Slightly comfortable	2	3.7	7.7	26.9
	Neutral	6	11.1	23.1	50.0
	Slightly uncomfortable	11	20.4	42.3	92.3
	Uncomfortable	2	3.7	7.7	100.0
	Total	26	48.1	100.0	
Missing	System	28	51.9		
Total		54	100.0		

Thermal comfort Votes for All summer night time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very comfortable	4	7.4	7.4	7.4
	Comfortable	2	3.7	3.7	11.1
	Slightly comfortable	9	16.7	16.7	27.8
	Neutral	10	18.5	18.5	46.3
	Slightly uncomfortable	22	40.7	40.7	87.0
	Uncomfortable	7	13.0	13.0	100.0
	Total	54	100.0	100.0	

Appendix 7-i: Thermal preference votes (winter survey)

Thermal Preference Votes for courtyard C1 / winter

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Want cooler	3	2.3	5.7	5.7
	No change	24	18.5	45.3	50.9
	Want warmer	26	20.0	49.1	100.0
	Total	53	40.8	100.0	
Missing	System	77	59.2		
Total		130	100.0		

Thermal Preference Votes for courtyard C3 / winter

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No change	6	4.6	18.8	18.8
	Want warmer	26	20.0	81.3	100.0
	Total	32	24.6	100.0	
Missing	System	98	75.4		
Total		130	100.0		

Thermal Preference Votes for courtyard C4 / winter

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Want cooler	8	6.2	17.8	17.8
	No change	25	19.2	55.6	73.3
	Want warmer	12	9.2	26.7	100.0
	Total	45	34.6	100.0	
Missing	System	85	65.4		
Total		130	100.0		

Thermal Preference Votes for the All / winter

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Want cooler	11	8.5	8.5	8.5
	No change	55	42.3	42.3	50.8
	Want warmer	64	49.2	49.2	100.0
	Total	130	100.0	100.0	

Appendix 7-ii: Thermal preference votes (summer day-time survey)

Thermal Preference Votes for courtyard C1 / summer day time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Want cooler	11	15.3	29.7	29.7
	No change	25	34.7	67.6	97.3
	Want warmer	1	1.4	2.7	100.0
	Total	37	51.4	100.0	
Missing	System	35	48.6		
Total		72	100.0		

Thermal sensation Votes for courtyard C3 / summer day time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Warm	1	1.4	2.9	2.9
	Slightly warm	6	8.3	17.1	20.0
	Neutral	28	38.9	80.0	100.0
	Total	35	48.6	100.0	
Missing	System	37	51.4		
Total		72	100.0		

Thermal Preference Votes for All / summer day time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Want cooler	22	30.6	30.6	30.6
	No change	48	66.7	66.7	97.2
	Want warmer	2	2.8	2.8	100.0
	Total	72	100.0	100.0	

Appendix 7-iii: Thermal preference votes (summer night-time survey)

Thermal Preference Votes for courtyard C1 / summer night time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Want cooler	24	44.4	85.7	85.7
	No change	4	7.4	14.3	100.0
	Total	28	51.9	100.0	
Missing	System	26	48.1		
Total		54	100.0		

Thermal Preference Votes for courtyard C6 / summer night time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Want cooler	24	44.4	92.3	92.3
	No change	2	3.7	7.7	100.0
	Total	26	48.1	100.0	
Missing	System	28	51.9		
Total		54	100.0		