Microclimate and Thermal Comfort of Urban Spaces in Hot Dry Damascus

Influence of urban design and planning regulations

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This Thesis can be order from
Housing Development & Management
Lund University
Box 118
SE-221 00 Lund
Sweden
Telephone +46 46 222 05 05
Telefax +46 46 222 47 19
E-mail hdm@lth.se
Homepage http://www.hdm.lth.se

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For Syria … again.
More than ever.

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Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
ET*	New effective temperature
FAR	Floor area ratio
H/W	The ratio of building height (H) and street width (W)
IRA	Urban zone of Inhabited Rural Area
MRT	Mean radiant temperature
OD	Urban zone of Old Damascus
OUT_SET*	Outdoor standard effective temperature
PET	Physiological equivalent temperature
PMV	Predicted mean vote
PRA	Urban zone of Planned Residential Area
PT	Perceived temperature
RH	Relative humidity
SVF	Sky view factor
Ta	Air temperature
Tg	Globe Temperature
UHI	Urban heat island
W	Wind speed
Wd	Wind direction

1 Introduction

1.1 Background

In recent years, urban development has received considerable attention. This attention to create sustainable cities can be noticed in scientific meetings and conferences e.g. World Urban Forum 5 (UN-Habitat, 2010) and Sustainable Development and Planning (Wessex Institute of Technology, 2011). These and other meetings try to focus on economic, social, and environmental perspectives. In addition, much related literature and research have focused on the topic of the city and sustainable development (e.g. Harris, 2000).

The phenomenon of the rapid urbanization in cities has also become one of the important topics in urban planning and sustainable development. This is since the rapid urbanization often leads to negative environmental impacts, including modifications on the urban microclimate. Those particularly at risk include the elderly, low-income earners and residents in urban areas of high population densities with limited surrounding vegetation. Furthermore, the rapid urbanization with limited landscape negatively affects the human health due to the increased pollution (Harlan et al., 2006). This, in turn, has an impact on microclimate and thermal comfort for inhabitants.

Due to climate change, global air temperatures are expected to rise with 0.2°C per decade over the next century (Intergovernmental Panel on Climate Change IPCC, 2007). Moreover, extreme weather events will be more common in the future. For example, heat waves will be stronger and they will last longer. This is a problem especially in regions with a warm climate and the consequences include increased occurrence of heat stress and other heat-related diseases. Furthermore, human performance of both mental and physical tasks diminishes at uncomfortably high temperatures. Also, deaths and illness caused by air pollution tend to increase during extremely warm weather (Harlan et al., 2006). Cities are especially vulnerable since they – in addition to global warming – are also exposed to the urban heat island. Within cities, the urban poor are especially vulnerable to heat waves due to sub-standard housing, high population densities and lack of green areas (Harlan et al., 2006).

A given urban density can result from independent design features, that affect urban microclimate in different ways such as fraction of urban land covered by buildings, distances between buildings, and average height of buildings (Givoni, 1998). These parameters affect the urban microclimate in terms of solar radiation, solar reflection, wind speed and wind direction, etc.

Urban planning regulations are mostly guiding the city development in a certain period. These regulations include the instructions that lead the city development in terms of building constructions, urban spaces, parks, streets, etc. In addition, the urban form is strongly influenced by urban planning regulations, such as zoning ordinances, which govern spaces between buildings, building heights, building footprints, etc. Consequently, urban planning regulations have a great impact on the microclimate in urban areas (Johansson and Yahia, 2010).

In order to reduce the negative climatic impacts in our cities, those involved in urban development, planning, and design must begin to incorporate climate knowledge into planning strategies and to create links between microclimate, thermal comfort, design, and urban planning regulations.

Urban microclimate and outdoor thermal comfort are generally given little importance in the urban design and planning processes (Eliasson, 2000; Johansson, 2006b). Moreover, few studies have dealt with the relationship between urban planning regulations and the local microclimate. Several studies however indicate that the existing planning regulations in hot dry climates are not adapted to the climate.

In the city of Fez, Johansson (2006b) found that the intention of the current regulations is to guarantee daylight for buildings. This may be relevant for the winter period when solar elevations are low and passive heating of buildings is desired. However, during the long, warm summer, when there is a need for solar protection, this results in a very poor microclimate at street level. The worst conditions are found in areas designated for low-rise houses where plots are very large and plot coverage low.

Al-Hemaidi (2001) and Eben Saleh (2001) reported that current urban design in Saudi Arabia has led to an undesirable microclimate around buildings. They explained this with the prescription of an extremely dispersed urban design where the provision of shade is totally lacking. The current urban form is characterized by gridiron plans with wide streets where the detached, low-rise “villa” is the most common type of house.

Despite that some studies have been conducted recently in hot dry climates, there is a limited number of research investigations in the Middle East which study the urban design from a microclimatic perspective. This study is a part of an ongoing PhD research in the city of Damascus in the Syrian Arab Republic where the current urban form is characterized by gridiron plans with wide streets and lack of shade, besides the limited amount of green areas which affect the microclimate and thermal comfort in Damascus. This is the first study in Syria in the field of microclimate and thermal comfort in outdoor urban spaces that investigates the relationship between urban design and microclimate and studies the impact of urban planning regulations on microclimate.

The study analyzes and climatically examines the urban planning regulations by using simulations. In addition, microclimatic measurements and structured interviews in different urban environments are carried out. The study highlights the importance of microclimate and thermal comfort in the planning and design processes and it provides useful insights that can mitigate the negative aspects of urban design on microclimate and thermal comfort in Damascus.

1.2 Aim, research questions, and limitations

The aim of this study is to develop better understanding of the relationship between microclimate and urban design in the hot dry city of Damascus. This will be done by studying the impact of urban regulations on microclimate in different urban design patterns in modern Damascus. This study also investigates the behaviour of different thermal comfort indices to define the thermal comfort and acceptability limits of some of these indices. These limits, in turn, will help architects and designers to create better urban spaces by taking microclimate and thermal comfort requirements into account.

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

1. What is the effect of current urban planning regulations on microclimate in Damascus city especially at street level?
2. What are the thermal characteristics in outdoor urban spaces in Damascus (residential areas in modern Damascus, Old Damascus, and public parks)?
3. How do people perceive the thermal environment in the city of Damascus?

The study is limited to the hot dry city of Damascus, Syria. The conclusions of this study cannot be generalized for all hot dry cities since there are considerable variations between different cities in term of size, planning principles, proximity to the sea, topography, etc.

In the simulation part, the study focuses on how urban design affects the microclimate in outdoor residential spaces only at street level since streets are the common urban spaces in modern Damascus. In addition, only residential urban zones of Damascus urban regulations were studied. The study was carried out in July since this month is the hottest during summer time and the summer in turn is the problematic season according to meteorological data from the Kharabo station (see Figure 1.2).

The fieldwork was limited to residential streets, public parks, and outdoor residential spaces between buildings in modern Damascus as well as the old part of Damascus. The fieldwork was conducted in the afternoons during both work days and holidays. Furthermore, the fieldwork was only carried out during the hot summer and the cold winter. Thus, spring and autumn were not included in the study.

1.3 Structure of the thesis

The thesis contains a summary with five chapters and three appended papers. The summary includes the most important parts of the papers.

Chapter 2 is a review of literature about urban planning related to urban microclimate and outdoor thermal comfort in hot dry climates. Chapter 3 presents the research methods which have been used in the study. Chapter 4 includes the results and discussion of the simulation study, measurements, and structured interviews. Chapter 5 contains conclusions and propositions about the consideration of climate and thermal comfort in the urban design proccess. Chapter 5 also includes identifications for future studies.

The three following papers are appended:

Paper 1	Influence of urban planning regulations on the microclimate in a hot dry climate – The example of Damascus, Syria.
Paper 2	Microclimate and thermal comfort of outdoor urban environments in the hot dry city of Damascus, Syria

Paper 3	The influence of environment on people's thermal comfort in outdoor urban spaces in hot dry climates – The example of Damascus, Syria.

1.4 Geographical area studied

The city of Damascus

Damascus is the capital and largest city of Syria and it is located in the southwest of the Syrian Arab Republic. It is the oldest continuously inhabited city in the world and it used to be fully surrounded by an oasis (Al Ghouta). The Barada River waters the oasis and Al Fijeh Spring provides the city with drinking water. Damascus has two parts: Old Damascus and modern Damascus. Old Damascus has a regular planning in general, with streets oriented N–S and E–W. See Figure 1.1a. Most streets are narrow with deep canyons and projecting upper floors are common. The typical architectural style in Old Damascus is simple expression from outside and rich decoration from inside with internal orientation to courtyards like in most vernacular architecture of old cities in the Islamic world. This urban design came forth as a good response to the living conditions of both the natural and the social environment, based on age-old regional experience using local building materials and appropriate techniques of climate control (Bianca, 2000). Old Damascus' buildings are made of local building materials such as stone, clay, wood, etc, whereas in the modern part of Damascus, modern building materials such as concrete, steel, glass, artificial or natural stone, etc, are used. In addition, as a consequence of the planning regulations, modern Damascus has mainly detached buildings created according to detailed rules for spaces between buildings, setbacks, building heights, building footprints, projections, etc. Moreover, buildings are outwardly orientated. See Figure 1.1b.


(a) (b)

Figure 1.1 Urban morphology of (a) old Damascus and (b) modern part of Damascus. Source: Google Maps with eye altitude 1.25 km.

Climate in Damascus

Climatic data for temperature and relative humidity in Damascus is shown in Figure 1.2. Damascus has hot sunny summers and mild winters. Summer temperatures can exceed 36°C during the day, but evenings are generally cool. Spring and autumn are the most comfortable periods, averaging 22°C during the day. Winters are fairly cold and temperatures can reach 0°C during the night.

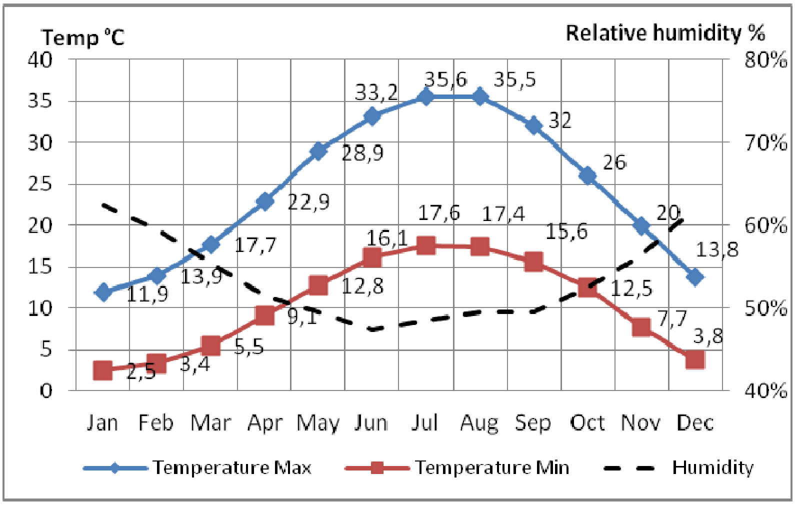


Figure 1.2 Climatic data for Damascus (average values for the period 1961–90). Source: Damascus airport meteorological station.

1.5 Urban planning regulations in Damascus

The urban planning regulations in Damascus are the essential documents for regulating urban and construction issues in the city. Literally, the name of this document translated from Arabic is Construction regulations for the city of Damascus (Damascus Municipality, 1997).

The approach to urban design changed radically during the French colonial period (1920–45). New areas were built with wide streets in a grid pattern and buildings were outwardly oriented (Al-Kodmany, 1999). During the 1950s, it was necessary to develop a new master plan for Damascus. The first attempt was by an Austrian company in 1957 and the second one started in 1963 by the French architect Michel Ecochar. In 1968 Ecochar presented the new master plan for Damascus and a few years earlier he had developed new urban planning regulations for the city; these regulations determined urban form in Damascus during a period of 20 years (1965–1985). Ecochar's master plan and urban planning regulations are essential documents that have been the basis for all updated versions after 1985.

In 1993, a special committee – from the Syrian Syndicate of Engineers and Damascus Municipality – was created in order to study, develop and complete the urban planning regulations for Damascus. The latest urban planning regulations were issued by Damascus Municipality in 1997 and they were ratified by the Syrian Ministry of Housing and Construction in the same year.

The first part of the urban planning regulations contains special conditions about administrative procedures concerning building permit, public roads and protection procedures during the construction process such as fire and safety protection. The second part contains rules concerning building heights, projections, partitions and barriers between the plots, ventilation and illumination shafts, residential and commercial units and components, common facilities such as stairs and corridors, architectural elevations, roof forms as well as regulations for setbacks, and parking. The third part contains special regulations regarding maximum floor area ratio (FAR) which is calculated as the total floor area of the building divided by the total area of the plot. The third part also contains regulations about the basement construction in case of sloping plots, regulations for small apartments in the commercial areas, temporary building conditions, and fire protection. The fourth part which deals with urban zones for Damascus contains regulations on minimum plot sizes, minimum plot frontages, minimum setbacks, maximum building heights, maximum plot coverage (building footprints), maximum projections, etc (see Table 1 and Figure 4). In addition, these regulations determine the division of Damascus into urban land use zones. Damascus is divided into 14 zones of different land use including agricultural, administrative, industrial, residential, and comercial activities. The urban zones which deal with residential areas – planned residential area (PRA) and for the zone of Inhabited rural area (IRA) – are described in Paper 1. Parts 5, 6 and 7 contain, respectively, general information about hospitals as well as electrical and mechanical installations. There are also two appendices, the first one is about urban planning regulations for Old Damascus, and the second is about heating systems and cold water generation for cooling.

2 Literature review

This chapter contains a literature review of the central topics of this thesis. The first section lists a set of fundamental books in the topics of climate and thermal comfort whereas the second section reviews the literature that studies the microclimate and thermal comfort in hot dry regions. The third section discusses literature about urban planning regulations and climate, whereas the fourth section is conclusions.

2.1 Climatic design and thermal comfort text books

The first three books discuss the climate and thermal comfort mainly for indoor climates and the issue of microclimate and outdoor thermal comfort is less stressed. The last four books focus more on the urban level than on buildings.

In the book *Design with climate – bioclimatic approach to architectural regionalism*, which was written by Victor Olgyay in 1963, the author endeavors to show the influence of climate on building principles. It contains three main parts. The book discusses the climatic approach on buildings level, the interpretation in architectural principles, and it also talks about the applications on planning level as well as on architectural level. The book has useful bioclimatic approaches, but it does not discuss the influence of urban planning on outdoor thermal comfort and how this can affect the applications on planning and architectural levels in terms of thermal comfort.

The book *Manual of tropical housing and building – Part 1: climatic design* was written by Koenigsberger et al. in 1974. It serves as a reference work for practitioners and as a guide for developers, architects, and designers. The book discusses the theory of climatic design and how practical solutions are derived from theoretical understanding. It contains a discussion about climate and comfort, principles of thermal design, means of thermal control, light and lighting, noise and noise control, applications, and design aids. The book has very useful information about climate and thermal comfort on building level, but it does not give close attention to the relationship between indoor thermal comfort and outdoor climate and how urban microclimates can affect the building design.

In 1980, Martin Evans wrote the book *Housing, climate and comfort*. The book starts by guiding the reader in the use of the meteorological data and by showing the relationship between climate and thermal comfort. The book thus provides practical advice on such matters as site selection and type of construction. It also discusses how individual solutions to the design for particular buildings can be applied together into a coherent overall scheme. The book discusses the relationship between outdoors and indoors, but the applications of this book mainly focus on indoors rather than outdoor environment.

One of the essential sources that discuss the nature of atmosphere near the ground is the book *Boundary layer climates*, which was written by T.R. Oke (1987). This book discusses the atmospheric systems and the topic of natural atmospheric environments and concentrates then on the effects upon the exchanges of energy, mass and momentum. The book discusses the topic of man-modified atmospheric environments and shows the consequences of human interference in otherwise natural climatic systems. Although the book investigates only partly the relationship between climate and urban areas (part three), it provides very useful insights for architects and urban designers to understand such relationships especially the climate modification by buildings (airflow around buildings), and climate modification by urban areas. However, the book presents the information from a climatologic point of view and not from urban design or urban planning point of view.

In the book *Climate considerations in building and urban design* which was written by Baruch Givoni in 1998, the author discusses the relationship between building, design and the climate. The first part of this book is about building climatology, indoor climate and comfort, thermal performance of buildings, and passive buildings. The second part is about urban climatology. This part of the book discusses the urban design effects on urban climate, the impact of green areas on site and urban climate. The third part discusses the topic of building and urban design guidelines for the hot dry, hot humid and cold climates. Regarding the hot dry climate, the book discusses the characteristics of hot dry regions, comfort and energy for buildings, building materials, and urban design. Although the book widely discusses the relationship between urban design and climate, it does not discuss the topic of outdoor thermal comfort in detail. In addition, the issue of climate in the book mainly treats architectural design and focuses less on outdoor urban spaces.

An urban approach to climatic-sensitive design is a book that was written by M. Rohinton Emmanuel in 2005. The book focuses on design strategies that can minimize the negative effect of urban microclimate in the tropics. It discusses the phenomenon of Urban Heat Island (UHI) and mitigation strategies, thermal comfort in the urban tropics, and climate-conscious urban design in the tropical urban outdoors. In addition, the book discusses the applications of urban design strategies and how to enhance the quality of urban environment in the tropics. The book develops the concept of shadow umbrella for radiation reduction in outdoors during the day. This concept addresses two issues: the creation of shaded urban spaces that have direct bearing on outdoor thermal comfort, and determining the location for bodies of water such as fountains, lakes, and pools. The fundamental step to achieve the shadow umbrella is to establish the shadow angles by studying the date of the year, the time of the day, the location, and the building and site orientation and dimensions. However, this book mainly focuses on the warm humid tropics and does not take other climates into account such as the hot dry climate. Furthermore, the concept of shadow umbrella depends on a theoretical analysis and was not tested in practice.

Urban microclimate which was written by Evyatar et al. in 2011 is one of the first books that focus entirely on urban microclimate and outdoor thermal comfort. The book tries to bridge the gap between climatology research and applied urban design. This book also tries to provide architects and urban designers with an understanding of how the physical structure of the built environment at all scales affects microclimatic conditions in terms of the spaces between buildings, and analyzes the interacttion between microclimate and each of the elements of the urban landscape. The book provides useful insights about the scale of urban climate, urban energy balance, urban heat island, urban airflow, human energy balance in an urban space, thermal preferences, and climate applications in urban planning and design. It also discusses the microclimate design strategies in urban space, the use of vegetation, linear space, and urban microclimate modeling. However, the book focuses more on urban microclimate than outdoor thermal comfort. Consequently, the subjective thermal perception is not deeply discussed.

Concluding remarks

The reviewed text books show that there is an increased interest in the latest decades in urban microclimate and thermal comfort. Most of the listed books discuss the climate and thermal comfort. However, the books of Olgyay, Koenigsberger, and Evans mainly focus on indoor climate and comfort and they deal with how to design buildings in different climates. They have limited information about microclimate and outdoor thermal comfort. Generally, the books of Oke, Emmanuel, Evyatar et al., and Givoni (to some extent) focus on the urban level rather than buildings. Specifically, the books of Emmanuel (2005) and Evyatar et al. (2011) deal with microclimates as well as thermal comfort on the urban level.

2.2 Urban microclimate and outdoor thermal comfort in hot dry climates

Previous studies on urban microclimate and thermal comfort in outdoor urban spaces have focused on various climates. Several researchers have studied the cold climate (e.g. Nikolopoulou et al., 2001; Thorsson et al., 2004; Eliasson et al., 2007). Some others have conducted research in warm humid climates (e.g. Emmanuel et al., 2007; Lin, 2009). Some others have studied the subtropical climate (e.g. Spagnolo and de Dear, 2003). Others have studied the temperate climates (e.g. Thorsson et al., 2007). Some others have done studies in hot dry climates (e.g. Ali-Toudert and Mayer, 2006; Johansson, 2006a; Djenane et al., 2008; Al Jawabra and Nikolopoulou, 2009; Bourbia and Awbi, 2004; Pearlmutter et al., 2006 and 2007; Shashua-Bar et al., 2011; Mahmoud, 2011). The reviewed literature below regards hot dry climates.

Bourbia and Awbi (2004a and 2004b) discussed the building cluster and shading in an urban canyon in the hot dry climate of the city El-Oued in Algeria. It is a microclimate study which was carried out by conducting a measurement study of air and surface temperatures as well as a shading simulation study by using the Shadowpack PC code version 2 (Beckham 1980). The authors examined the influence of H/W ratio – i.e. the ratio of building height (H) and street width (W) – and sky view factor (SVF) of street design on microclimate and especially the air temperature and surface temperature. The study argued that the street geometry and sky view factor give smaller variations on air temperature than on surface temperatures. Regarding the simulation study, the authors concluded that a number of useful relationships can be developed between the geometry and the microclimate of urban street canyons and these relationships are very helpful for professionals developing urban design guidelines for the street dimensions and orientations. However, the study only examined the air temperature and surface temperature and no other climatic parameters were measured such as solar radiation, wind speed, and relative humidity. Consequently, thermal comfort was not included in the study, as was not interviews and questionnaires to assess people's thermal sensation.

Ali-Toudert and Mayer (2006) conducted a simulation study on the effects of aspect ratio (or height to width ratio, H/W) and orientation of urban street canyons on outdoor thermal comfort in the hot dry climate of Ghardaia, Algeria. The study was carried out by using the ENVI-met simulation program. The results show contrasting patterns of thermal comfort between shallow and deep urban canyons as well as between various orientations studied. It also concluded that thermal comfort is very difficult to reach passively in extremely hot and dry climates, but the improvement is possible; the air temperature slightly decreases when the aspect ratio increases, but the radiation fluxes expressed by the mean radiant temperature are by far more decisive. Thus in summer time, the thermal comfort improves when H/W ratio increases. However, the simulations were only run for a typical summer day and the winter time was not taken into account in the thermal comfort analysis.

Johansson (2006a) studied the influence of urban geometry on outdoor thermal comfort in the hot dry of climate of Fez, Morocco. The study was based on measurements during the summer and winter. The study compared a deep canyon and shallow street regarding microclimate and thermal comfort. The study argued that in the summer times, the deep canyon is fairly comfortable whereas the shallow is extremely uncomfortable. On the other hand, the winter results show the opposite. The study concluded that for the hot dry climate, the compact urban design with deep canyons is preferable but for the winter in Fez, the urban design should include some wider streets or open spaces in order to provide solar access. However, the study was only based on measurements and did not include a questionnaire study about the subjective thermal perceptions. Moreover, the Physiological Equivalent Temperature index (PET) – see Chapter 3 – was the only calculated index to analyze the results and no other indices have been investigated in order to test the validity of these results.

Pearlmutter et al. (2007) constructed an open air scale model to quantify pedestrian radiation and convective energy exchange in street canyons of varying geometry as well as surface atmosphere energy exchange above the urban canopy. The results indicate that in a hot arid climate, the deep canyons which have north–south orientation can reduce overall pedestrian thermal discomfort, while in east–west oriented canyons the effect of street proportions is much less pronounced. However, this study does not represent the real urban canyons since it was conducted in an open air model and not in real city canyons which normally have irregular building heights, different roof forms, and different materials in elevations such as cement, glass, etc. The author calculated the Index of Thermal Stress (ITS) (Givoni, 1976) which was developed under laboratory conditions and does not directly provide real responses of pedestrians in an outdoor thermal environment. Using ITS makes the results difficult to compare with other studies since this index it is not commonly used.

Djenane et al. (2008) investigated the microclimatic behaviour of urban forms in the hot dry city of Béni-Isguen located in the M'zab Valley region, Algeria. The aim of the study was to approach the interaction between the climatic constraints and the solutions adapted in terms of occupation modes of the ground and urban morphology in the streets. The study was based on practical microclimatic measurements in four locations during the summer time. The study was conducted in four different morphological areas which varied between high and low urban density with H/W ratios between 1.6 and 9.7 and with plot coverage between 10% and 87%. The authors demonstrated the importance of morphological characteristics of the urban tissue in the hot dry climate regarding H/W ratio. They also showed that the thermal behaviour at the street level is related both to the solar exposure and the wind speed effect. And the streets overheating during one day is strongly affected by heat dissipation the previous night. However, the study was conducted only in the summer time and no measurements were conducted in the winter. The results were only based on air temperatures and wind speed and the study did not examine the effect of urban forms on solar radiation, mean radiant temperature, or thermal comfort.

Al Jawabra and Nikolopoulou (2009) studied the outdoor thermal comfort and the effect of socio-economic background and cultural differences in the hot dry climate of Marrakech in North Africa and Phoenix in North America. The authors aimed to develop better understanding of the complex relationship between microclimate and human behaviour in outdoor urban spaces in a hot arid climate. Microclimatic measurements and questionnaire surveys were carried out in two sites in Marrakech and three in Phoenix. The authors argued that particularly in the summer, the number of people and activities outdoors are influenced by the solar radiation. And people from different social backgrounds in hot arid climates have different approaches to the use of outdoor spaces. The study also concluded that the design is an important tool that can significantly improve microclimatic conditions in the specific climatic context. However, the study only calculated the Predicted Mean Vote (PMV) index and did not investigate the behaviour of other thermal indices.

Bourbia and Boucheriba (2010) assessed the impact of geometry on microclimate in Constantine, Algeria during the summer time. A series of site measurements (air and surface temperatures) were conducted in seven sites which varied between high and low H/W ratios from 1 to 4.8 and with sky view factor between 0.076 and 0.58. The study indicated an air temperature difference of about 3–6°C between the urban and its surrounding rural environment. The authors argued that the larger sky view factor, the higher air temperatures were reported. Moreover, the higher H/W ratio, the lower air and surface temperatures were recorded. However, the study was only conducted during one season (summer time). Furthermore, the study did not calculate the mean radiant temperatures and did not use any thermal index to assess the outdoor thermal environment.

Shashua-Bar et al. (2011) studied the influence of trees and grass on human thermal stress in a hot arid climate. The Index of Thermal Stress (ITS) was calculated in order to evaluate thermal comfort in the different spaces. The efficiency of water use in providing improved comfort was gauged for each of the vegetative landscaping treatments by comparing the total evapotranspiration (ET) with the reduction in thermal stress. The study found that with shading, either by trees or mesh, discomfort was reduced when the shading was placed above paving. When combined with grass, both shading mechanisms yielded comfortable conditions at all hours. The study argued that the effect of trees was more pronounced than that of the mesh. However, the study was only conducted during the summer time (August) and did not take into account the influence of vegetation on human thermal comfort in winter. Furthermore, the authors used ITS to assess the thermal stress. Thus, it is hard to compare the results with other studies because the thermal stress index is not widely used.

Mahmoud (2011) investigated people's thermal comfort in an urban park in the hot arid city Cairo, Egypt, during the summer and winter seasons using field measurements and questionnaires. The Physiological Equivalent Temperature (PET) index – see Chapter 3 – was calculated in each measurement spot (nine spots in the park were studied). The study argued that differences in the PET index among these spots are due to different sky view factors (SVF) as well as wind speed. It also reveals an alteration in human comfort sensation between different landscape zones. The study found that the comfort range of PET for the urban parks in Cairo is 22–30°C in summer and 21–29°C in winter. However, this study was only based on calculating PET index which does not take clothing and activities into account as variables (see Chapter 3). Since PET is independent of clothing and activity, it is not an absolute measure of thermal strain or comfort but it is a tool to assess the thermal environment (Höppe, 2000). In addition, this study was only conducted in an urban park and not in all types of urban spaces in Cairo. Therefore, the thermal comfort range which was found in the study is valid only for urban parks and it is difficult to generalize the results for other types of urban spaces in Cairo.

Concluding remarks

The studies reviewed show that the microclimate and thermal comfort in hot dry regions have been studied in different ways and have provided useful insights in the field. However, some of these studies investigated microclimate and thermal comfort only during the summer time (e.g. Djenane et al., 2008; Bourbia and Boucheriba, 2010). Some studies on thermal comfort were based only on field measurements and no questionnaires were done (e.g. Johansson, 2006a; Pearlmutter et al., 2007). Most studies used only one thermal index (e.g. Al Jawabra and Nikolopoulou, 2009; Pearlmutter et al., 2007; Shashua-Bar et al., 2011). Others have determined microclimate and thermal comfort only in an urban park (e.g. Mahmoud, 2011). Some others conducted pure simulation studies (e.g. Ali-Toudert and Mayer, 2006).

Hence, there is no study in the hot dry climate that investigates microclimate and thermal comfort based on field measurements and questionnaires during the summer and winter seasons for different types of urban design and that calculates different thermal indices in order to compare with other studies. Thus, this review shows that there is a need for in-depth research in the field of microclimate and thermal comfort in hot dry regions.

2.3 Urban planning regulations and climate

Salehi (2007) claims that "composing urban codes and regulations is a means of achieving the goals of sustainable development and ensure the formation of sustainable residency". Yet, there are no in-depth studies about urban planning regulations and microclimate. A few studies in different climates have however highlighted the importance of these regulations for the city development.

Al Hemaidi (2001) studied the urban fabric in Riyadh, Saudi Arabia from cultural and climatic perspectives in connection with the current urban planning regulations that have been imported to the country. The author reported that these regulations relate neither to the traditional built environment and culture nor to the local microclimate in Riyadh city. Cultural and climatic problems have emerged because of these urban regulations. In order to establish the future urban planning regulations in harmony with climate and culture, the author claimed that the inward dwellings orientation, courtyards, and the high parapets are examples for planning principles derived from the culture. The narrow streets, buildings without setbacks, building materials, textures and colors are also planning principles and guidelines that respond to the local climate. But, the study has mainly dealt with theoretical concepts about the climate effect and the results were not proved by measurement fieldwork. On the other hand, the study focused on the negative aspects of the imported urban regulations. However, it did not give examples of how we could improve the thermal environment in the existing built areas that was constructed according to the imported urban regulations.

Baker et al. (2002) discussed the considerations concerning mitigation of the urban heat island in the hot dry climate of Phoenix, Arizona. The authors highlighted the importance of the urban planning and design policy to be redesigned in order to mitigate the urban warming. In addition, the study suggested a set of recommendations derived from the City of Phoenix General Plan's Goal 7. Moreover, the study provided recommendations about encouraging the planting of mature trees but these recommendations may not be easy to achieve in other hot dry climates due to the lack of water for irrigation. However, the study suggested only recommendations about mitigating the heat and sunshine but it did not take into account other climatic parameters that affect thermal comfort and the human body such as wind speed and Mean Radiant Temperature (MRT).

Grazziotin et al. (2004) developed the CityZoom 3D simulation computer program as a tool for evaluating the impact of urban regulations. It helps to generate large sets of buildings in different urban scenarios by applying urban regulations on the plot geometry according to input parameters that determine the building characteristics such as the number of floors, setbacks, plot coverage, building height, etc. It also addresses environmental comfort issues such as sunshine access and shading visualization. However, this tool is limited only for the visualization of urban regulations and not for a deep microclimatic analysis regarding thermal comfort, mean radiant temperature, and wind speed and direction.

Kakon et al. (2010) investigated the effect of building height on outdoor thermal comfort in the tropical climate of Dhaka, Bangladesh. The authors focused on the building height as an important parameter in urban design and planning regulations in the city development. The study showed that the air temperature decreased to some extent in the canyon by increasing building height. The study concluded that the policy to increase the building height could provide a preferable thermal microclimate in cities with high densities. The conclusions of the study were depending on both measurements and simulations. However, the measurements were only conducted in one summer day and no winter measurements were conducted. In addition, the study was only performed in one specific area in the city of Dhaka and did not study other types of urban morphology. Furthermore, no questionnaires or interviews were applied to investigate the effect of the existing buildings height on people's outdoor thermal comfort.

Concluding remarks

The studies reviewed show that the effects of urban planning regulations on microclimate have received little attention. Only a few studies have reflected the importance of the climate in urban planning regulations. Thus, further studies are needed to highlight the effect of urban planning regulations on microclimate. Such studies must be based on climatic analyses of the urban zones and regulations.

2.4 Conclusions

This chapter reviewed literature on urban microclimate and outdoor thermal comfort in hot dry climates. It also discussed literature on the relationship between urban planning regulations and climate. The main conclusions from this chapter are:

1. Urban microclimate and outdoor thermal comfort are rarely considered in the studied text books while the indoor climate and thermal comfort have received considerable attention.
2. There are few studies in hot dry regions on urban microclimate and outdoor thermal comfort. Thus, there is a need to conduct further research, which examines the relationship between urban design and subjective thermal comfort.
3. There is a lack of research on the relationship between climate and urban planning regulations. Thus, there is a need to investigate the impact of urban planning regulations on microclimate based on serious climate analysis.

This thesis aims at developing better understanding of the relationship between microclimate and urban design in the hot dry city of Damascus. This study is based on the analysis of planning regulations regarding aspect ratio, setbacks, plot coverage, etc. Moreover, it takes the common types of urban design into account. In order to assess the thermal environment in outdoor urban spaces in the hot dry climate, the study is based on both field measurements and questionnaires during the summer and winter seasons. In addition, it investigates different thermal comfort indices for the hot dry environment and taking clothing and activities into account. Furthermore, since the outdoor space is a part of urban life, this study examines the influence of urban spaces on people’s thermal perception. The study highlights the importance of microclimate and thermal comfort in the planning and design process and it provides useful insights that can mitigate the negative aspects of urban design on microclimate and thermal comfort in Damascus.

3 Methodology

This study is multidisciplinary in character including the fields of urban planning, urban design, architecture, urban climatology, and environmental psychology. Its aim is to develop better understanding of the relationship between microclimate and urban design in the hot dry city of Damascus. In order to achieve the aim, a set of methods were applied:

- Analysis of urban planning regulations. The study includes a qualitative analysis of these regulations, and also a simulation study that focuses on the three main residential urban zones of Damascus.
- Field measurements study. This was conducted in six different locations in Damascus to study the real situation concerning microclimate, urban design and outdoor thermal comfort.
- Structured interviews. It was simultaneously carried out during the field measurement study in order to investigate people's actual thermal sensation and how they perceive the thermal environment in different locations.

3.1 Analysis of urban planning regulations

Selection of the urban zones studied

Damascus is divided into 14 zones of different land use including agricultural, administrative, industrial, residential, and commercial activities (see Appendix A). The analysis part of this study contains the following steps:

After translation of the documents of urban planning regulations from Arabic into English by the author, three main residential urban zones of these fourteen were selected for analysis. These three zones are:

- PRA: The zone of Planned Residential Area that is exemplified by the sub zone of palaces area in modern Damascus (see Table 1 in Paper 1). This zone contains only detached buildings (Figure 3.1). The reason for choosing the palaces area sub zone is that it contains the biggest plot size (>1500 m^2), lowest plot coverage (20%), lowest maximum buildings height (10 m), and widest setbacks dimensions (10 m) (see Table 1 in Paper 1). The location of PRA zone is shown in Figure 3.3 where PRA zone is mainly found in the city center as well as Damascus municipality area.
- IRA: The zone of Inhabited Rural Area that is exemplified by the sub zone of new planning area in modern Damascus. This zone also contains only detached buildings (Figure 3.1). The idea of choosing the sub zone of new planning area is that it contains the biggest plot size (>600 m^2), and highest maximum buildings height (15 m). It also contains clear setbacks dimensions (see Table 1 in Paper 1). The location of IRA zone is shown in Figure 3.3 where IRA zone is mainly found in the suburbs of Damascus.
- OD: The zone of Old Damascus. This zone contains only attached buildings (Figure 3.1). Old Damascus was built in different periods in the past and it has special regulations regarding restoration and rehabilitation works. The location of OD zone is shown in Figure 3.3.

The idea of choosing two urban zones from modern Damascus together with Old Damascus is to compare different urban patterns in terms of microclimate and thermal comfort. This comparison could help to develop the future urban planning regulations for the modern part of Damascus.

The analysis part also includes a comparison between these three urban zones regarding the type of use, plot size, maximum plot coverage and number of floors, maximum height, and setbacks (Table 1 in Paper 1). The zones represent the common residential areas in Damascus. Although the regulations for them were issued before the latest version in 1997, they are still valid in the latest version. Many parameters of the existing buildings in these zones – such as the heights, the shape of the roofs – could be modified to develop the microclimate and thermal comfort in the urban spaces between these buildings in modern Damascus. In the case of new urban areas, many parameters such as setbacks, building height, and distance between buildings could be modified.

Drawings as architectural plans, sections, and perspective model were made with Auto CAD in order to show the spaces around buildings, building heights, and H/W ratios (Figure 3.2).

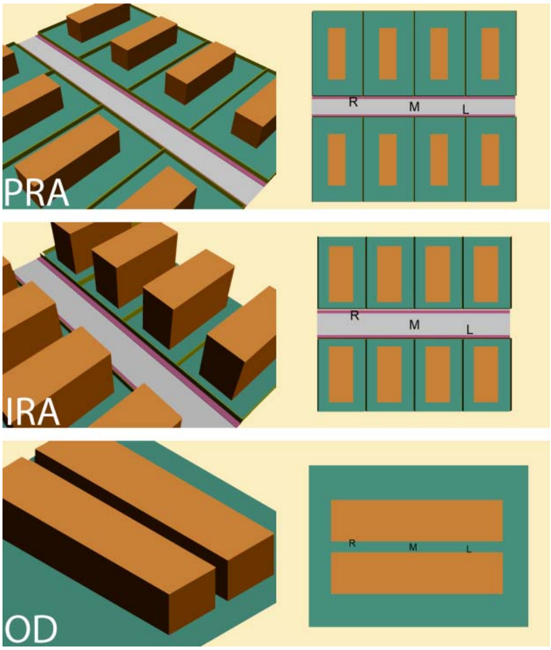


Figure 3.1
Perspective models and plans of the studied zones for PRA (Palaces area), IRA (New planning area) and OD (Old Damascus) including the 2 m high wall which surrounds the plots for PRA and IRA. The ground surface temperature and the thermal comfort were studied at the right side of the street (R), at the middle of the street (M), and at the left side of the street (L).

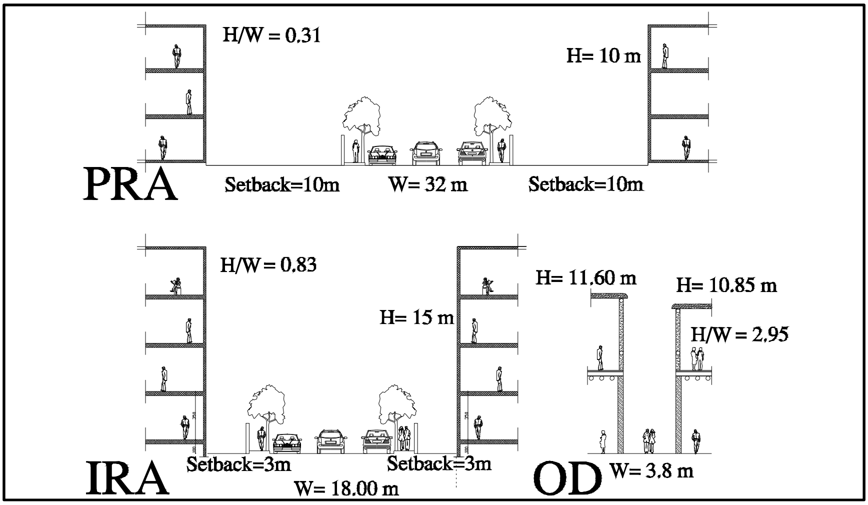


Figure 3.2 Typical sections and H/W ratios for PRA zone (palaces area), IRA zone (New planning area), and OD zone with rows of trees on the pavements for IRA and PRA zones.

Simulations

The simulation study was carried out only at street level since the street in Damascus is the most common public space; this is the main place where people can stroll and pass by for different reasons such as going to work and shopping as well as for recreational purposes.

The three zones were mainly chosen in order to test the impact of various aspect ratios, i.e. height-to-width ratios (H/W) on the microclimate. The palaces area of the PRA zone has the lowest H/W ratio (0.31) and Old Damascus (OD) zone has the highest H/W ratio (2.95). The new planning area of the IRA zone has a H/W ratio of 0.83. The chosen zones include two extremes in the city of Damascus where the palaces area of the PRA zone is the most dispersed (lowest density) and old Damascus is the most compact (highest density). The residential area of the IRA zone is somewhere in between. The PRA (Palaces area), IRA (New planning area) and OD zones are clearly different concerning the distance between buildings, building heights, H/W ratios, and building footprint.

Microclimate simulations

The microclimate at street level was simulated with ENVI-met 3.0 (Bruse, 2009). The programme uses a three-dimensional computational fluid dynamics and energy balance model. The model has a high spatial and temporal resolution enabling a detailed study of how the microclimate varies within the studied space over time. The model gives a large amount of output data including the necessary variables to be able to calculate thermal comfort indices. A simulation study such as this one has the advantage that an unlimited number of points from the model can be analyzed, whereas in a measurement study, only the results derived from the measured spots are reliable.

The input data for the simulation model contained the physical properties of the studied urban areas (buildings, soil and vegetation) and limited geographical and meteorological data. The input data used in this study is shown in Paper 1 and included meteorological data from the station Kharabo near Damascus.

The study was carried out on the 21st of July since this month is the hottest during summer time according to meteorological data from the Kharabo station. The simulated period lasted from 7:00 in the morning until 16:00 in the afternoon in order to include the maximum air and surface temperatures, which normally occur at 14:00. In this study, both east–west (E–W) and north–south (N–S) street orientations were investigated. In modern Damascus, the street width was 12 m since this width is the most common one. On the other hand, the width of the studied street in Old Damascus was 3.8 m and it was derived from an existing street. See Figure 3.2c.

Both surface temperature and thermal comfort were studied in the simulations with ENVI-met. The reason of choosing the surface temperature as an indicator is that the surface temperature is well known and it is easier for architects and designers to understand than the other indicators such as thermal indices equations.

Assessment of thermal comfort for simulation models

In this study, thermal comfort was estimated by calculating the Physiological Equivalent Temperature (PET) index (Höppe, 1999). PET, which is expressed in °C, is based on the energy balance of the human body. Although PET has not been calibrated for Damascus, the index makes it possible to compare different urban designs (see more details in Paper 1 and 2). For the three studied zones, the PET index was calculated at pedestrian level (1.1 m height) for three points of the street: both pavements and the middle of the street. The positions of the studied points for which the surface temperature and PET has been calculated are shown in Figure 3.1 for the PRA and IRA zones. In the case of old Damascus, the studied points are located in the deep urban canyon near the building facades and in the middle of the street.

This simulation study deals with two cases; the first one is the model which was built according to urban planning regulations. The second case is the model with rows of trees on the pavements in both PRA and IRA zones. The position of the trees is shown in Figure 3.2.

3.2 Field measurements

In order to find out the characteristics of urban microclimate and thermal comfort in Damascus, both field measurements and a questionnaire survey were conducted during the summer of 2009 and the winter of 2010 in Damascus City, Syria. The combination of the methods (measurements and structured interviews) allowed to assess different thermal environments and to simultaneously determine the user's thermal perception through investigating different thermal indices.

Selection of measurement locations and time period

Since outdoor thermal comfort is of importance both for residential areas and parks in Damascus, the locations selected were divided into three categories: two types of residential areas and parks. Since the three categories constitute the most common environments in Damascus, it was possible to carry out many measurements and questionnaires for a given type of common physical environment.

The first category – residential areas in modern Damascus – contained three measurement locations: Al Gassany area which was built in 1950s (point 1 in Figure 3.3), the New Dummar area which started to be built in 1980s (point 2) and the Barzza area which was built in the end of 1970s (point 3). The second category – Old Damascus – contained a deep canyon: Al Qaymarieh Street (point 6). The third category – parks in modern Damascus – contained two locations: Al Tigara Park (point 4), and Al Mazza Park, (point 5). The measurement sites are also shown in Figure 3.4.

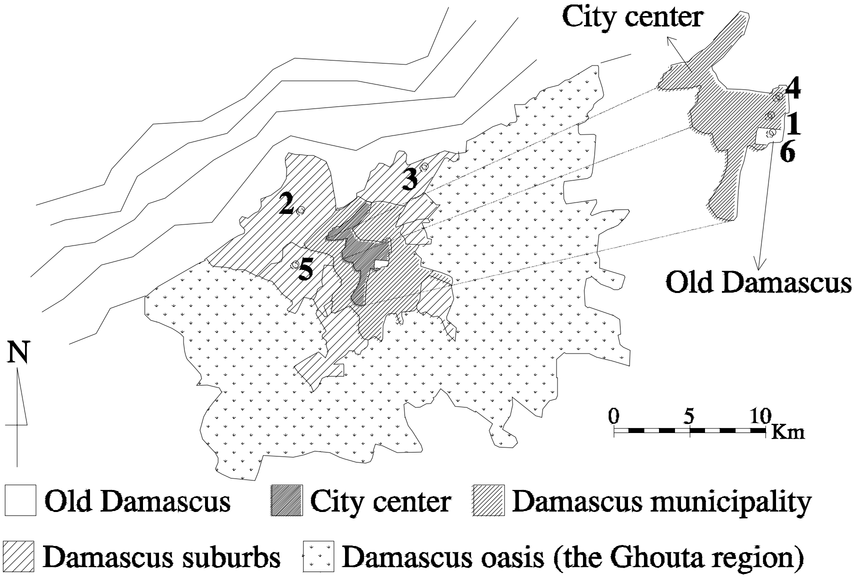


Figure 3.3 Locations of the measurement sites on a simplified map of the city of Damascus, which is located between the Kassioun mountain chain in the North West and an oasis in the south. See Figure 3.4 for description of the sites.

Figure 3.4 Measurement sites in the city of Damascus, where (a) is Al Tigara park, (b) is Al Gassany area, (c) is New Dummar area, (d) is Barzza area, (e) is Al Mazza park, and (f) is Old Damascus.

Both time-period and orientation were considered when carrying out measurements of thermal comfort. In addition, the investigation was carried out during the most extreme weather conditions; the study was conducted during August and September 2009 for the summer, and during

January and February 2010 for the winter. Northwest–southeast (NW–SE), northeast–southwest (NE–SW), and east–west (E–W) street orientations were included in the measurements as well as open spaces in parks. In these six locations, the measurement fieldwork was scheduled mainly during the three hours starting from around noon, since this time is the hottest time of the day. However, in order to extend the study of thermal comfort – to get a greater variety in microclimatic conditions – measure ments were also carried out in the morning – in the Barzza area (8:00–11:30) – and in the evening in old Damascus (15:30–18:30) (See Paper 2). Moreover, the official climatic data in Damascus during the measurement periods are shown in Paper 2.

The measurement equipment was placed at the points where people could be expected to sit or walk either under the sun or in shade. Air temperature (Ta), globe temperature (Tg), relative humidity (RH), wind speed (W) and wind direction (Wd) were measured. The characteristics of the thermal environment in all studied locations will be discussed. However, three areas – Al Gassany area, Old Damascus, and Al Mazza park – which represent the three studied categories of urban environments in Damascus were studied more in detail. The urban characteristics of these three areas are shown in Paper 2.

Outdoor thermal comfort and thermal indices

Thermal comfort has been defined in various ways in the literature. In ASHRAE (1997), thermal comfort is defined as the condition of mind that expresses satisfaction with the thermal environment. A great number of indices, which try to predict the state of thermal comfort, mainly for indoor applications but also for outdoors, have been developed. The Predicted Mean Vote (PMV), the Standard Effective Temperature (SET*) and the New Effective Temperature (ET*) were all developed for indoor condtions (McIntyre, 1980). In addition, many indices have been primarily designed for outdoor applications, e.g., the Perceived Temperature (PT), which is based on the comfort equation of Fanger (Jendritzky et al., 2000), OUT_SET*, which is an adaptation of SET* for outdoor use (Pickup and de Dear, 2000), and the Physiological Equivalent Temperature (PET) (Höppe, 1999). In this study, PET, OUT_SET*, ET*, and PMV have been used to assess and evaluate the outdoor thermal environment in Damascus. The RayMan PC application (Matzarakis, 2010) was used to calculate PET, whereas the ASHRAE Thermal Comfort Program (Fountain and Huizenga, 1994) was used to calculate the OUT_SET*, ET*, and PMV indices. More details about thermal comfort have been shown in Paper 1 and 2.

3.3 Structured interviews

A structured interview survey was performed simultaneously with the measurements in each location in order to estimate actual thermal perception and to compare with the calculated PET and OUT_SET* indices derived from microclimatic measurements. The survey study covered a random sample in all measurement locations. People were interviewed by the author and by an assistant group (6 students) from the faculty of architecture in Damascus University. In both summer and winter, people were interviewed by the same group in the same locations.

The structured interviews were designed to assess the people's thermal perception and other parameters such as climatic and aesthetic preferences and emotional state on people in Damascus. Moreover it covered questions about gender and age, clothing, living or working in the city, reason for being in the places, time spent outdoors and in the places, assessment of the microclimate, and assessment of the attitude to urban outdoor exposure. For more details, see Paper 2 and 3. In this study, the questions of thermal perception, aesthetical quality of the place, and the influence of air conditioning devices on people's thermal perception were studied.

Assessment of transition and neutral temperatures

To determine transition temperatures between different thermal sensation zones, i.e. the index temperatures at which the thermal sensation changes from one zone to another – e.g. from comfortable to slightly warm – as well as the neutral temperature, which is defined as the temperature at which people feel thermally neutral (neither cool nor warm) and which corresponds to the value zero in the thermal sensation scale, probit technique (Ballantyne et al., 1977) was used (See Paper 2). SPSS 18 (Statistical Package for the Social Sciences Software for Windows) was used to perform the probit analysis and to analyze the results of the structured interviews.

4 Results and discussion

This chapter includes the results and discussion of the simulations, measurements, and structured interviews. The first section of this chapter discusses the results of simulated surface temperatures and thermal comfort in the summer. The second section is about the results of the measurements during the summer and winter seasons, whereas the third one presents the results of the structured interviews. The fourth section is about the relationship between actual thermal sensation and thermal indices. The fifth section presents the thermal comfort zones and neutral temperatures in Damascus. The sixth section is about the effect of clothing on people's thermal comfort. Finally, the seventh section discusses the relationship between thermal perception and aesthetical qualities of urban design.

4.1 Simulated surface temperatures and thermal comfort in summer

Influence of H/W ratio and orientation on surface temperatures and PET

The surface temperatures in all three studied zones between 07:00 and 16:00 in July at the three points (L, R and M) are shown in Paper 1. For the PRA and IRA zones that consist of detached buildings in modern Damascus, the influence of street orientation on surface temperatures is not decisive. On the other hand, for both E–W and N–S orientation, the surface temperatures of the two zones in modern Damascus are considerably higher than those of Old Damascus because in the latter case the street has a much higher H/W ratio. The street in Old Damascus is in shade during all hours of the simulation except at around noon for the N–S case as well as at around 10:00 and around 15:00 for the E–W case since the azimuth is nearly parallel to the street orientation for these hours. Surface temperatures in Old Damascus are normally the same in all points and rarely above 35°C whereas in modern Damascus they can reach as high as 48°C.

Table 4.1 shows the influence of H/W ratio on the PET index at 14:00 in the PRA, IRA and OD zones. For the PRA and IRA zones with H/W equal to 0.31 and 0.83 respectively, the maximum PET reaches 51.7°C and 50.7°C respectively. On the other hand, in Old Damascus with a higher H/W ratio equal to 2.95, the maximum PET value reaches only 33.2°C. The results show that the H/W ratio has a large impact on outdoor thermal comfort and that the PET tends to decrease with increasing H/W. The main reason for the lower PET in the OD zone is the reduction of radiation fluxes due to increased shading which results in a lower mean radiant temperature. Table 4.1 also shows only a small influence of orientation on PET in modern Damascus. This is because this study deals with detached buildings and not canyons. Consequently, in urban environments that have detached buildings, the influence of street orientation and aspect ratio on outdoor thermal comfort is not decisive. Other studies for urban canyons (Ali-Toudert and Mayer, 2006; Johansson, 2006b) have shown that in general N–S streets tend to be more comfortable than E–W streets. This is because the N–S street is exposed to solar radiation during a shorter period than the E–W street.

Table 4.1 Influence of H/W ratio on PET values in the PRA, IRA, and OD urban zones for east–west (E–W) and for north–south (N–S) street orientations (maximum daily values at 14:00 in July).

Zone	*PET°C (E–W)*			*PET°C (N–S)*		
	L	*R*	*M*	*L*	*R*	*M*
PRA Zone H/W= 0.30	*49.9*	*51.7*	*49.4*	*45*	*52.1*	*48.8*
IRA Zone H/W= 0.83	*50.7*	*50.4*	*48.5*	*50*	*50.7*	*48.4*
OD Zone H/W= 2.95	*33.2*	*33.2*	*33.2*	*33.2*	*33.2*	*33.3*

Influence of vegetation on PET

Table 4.2 illustrates the effect of street trees on thermal comfort expressed as the maximum daily PET value in both the PRA and IRA zones. The result reveals that there is a great influence of vegetation on PET since when rows of trees are added on the pavement, PET values are lowered by about 17°C for the PRA and by about 16°C for the IRA zone due to the shading of the pedestrian pavement. Consequently, in urban environments that have low aspect ratios as well as detached buildings, the influence of vegetation on outdoor thermal comfort is significant. Similar results were indicated in other studies and they found that the direct solar radiation under a tree canopy strongly decreases (e.g. Ali-Toudert and Mayer, 2007; Ochoa et al., 2009).

Table 4.2 Iinfluence of street trees on PET values in the PRA and IRA urban zones (maximum daily values at 14:00 in July).

	PET without vegetation	*PET with vegetation*
PRA Zone H/W= 0.30	*52.1°C*	*35.3°C*
IRA Zone H/W= 0.83	*50.7°C*	*34.3°C*

4.2 Measured microclimate and calculated thermal comfort indices

Microclimatic measurements were carried out in three areas of Damascus: outdoor spaces in residential areas of Modern Damascus, outdoor space as a deep canyon in old Damascus and public parks in modern Damascus. The division into these three categories allowed gaining insight into the effects of urban design on traditional, modern and natural outdoor settings. In addition, microclimatic measurements allowed investigating the behaveior of different thermal comfort indices (PET, OUT_SET*, ET*, and PMV) in the hot dry climate of Damascus (see methodology chapter).

Microclimatic variations

The study shows there was a considerable variation in measured Ta, RH, W, and MRT between summer and winter for all locations (see Table 4 in Paper 2). However, the average values of wind speed were nearly the same (0.7 m/s in the summer and 0.8 m/s in the winter). Considerable microclimatic differences were found between the old part and the modern part of Damascus, especially in the summer time, due to completely different urban design features in terms of aspect ratios, building materials, and building geometries (Fig. 3 and Fig. 4 in Paper 2). The reason why the average values of MRT in Al Gassany area and Al Tigarra park in the summer were lower than the values in other locations in modern Damascus was the shade from trees that affected the measurements. For both seasons, it was noticed that high values of MRT are not necessarily correlated with the high values of Ta. It was found that the thermal conditions of different outdoor environments varied considerably in terms of Ta, Tg, RH, and MRT and this is mainly because the weather was changing from one day to another during the measurement period (see Table 2 in Paper 2) and sometimes the change even occurred during the measurements (see Paper 2).

Calculation of thermal comfort indices

Table 4.3 shows the calculated of PET, OUT_SET*, ET*, and PMV for all studied locations. For all indices, the results reveal that in the summer Old Damascus is less stressful than the outdoor urban spaces in modern Damascus, whereas in winter, Old Damascus is colder due to the lack of solar exposure as a result of the high building density. Al Gassany area and Al Tigarra park, where there was some shade from trees, were less stressful than the other sites in modern Damascus where the measurement spots were exposed to sunshine all the time. The results in summer reflect the strong influence of the urban geometry on the microclimate within built environments. Old Damascus has deep street canyons with high aspect ratios, which create a more comfortable microclimate since direct solar radiation and the mean radiant temperature decrease with the increase of the aspect ratio (Ali-Toudert and Mayer, 2006). In contrast, the outdoor spaces in modern Damascus have a low aspect ratio and consequently these spaces are more exposed to solar radiation, which has a negative impact on outdoor thermal comfort. Moreover, no places in the studied areas of modern Damascus have been designed to protect against solar radiation, especially in the Barzza and New Dummar areas. However, in the parks and in Al Gassany area, less stressful environments can be found due to the existence of shading trees. In winter, it was more difficult to compare the microclimate qualities between the areas since the weather conditions varied from day to day during the fieldwork. Old Damascus was the coldest area and that is because of the cold weather on the measurement day as well as the deep canyon, which prevents the direct solar radiation to reach the ground. In contrast, Al Gassany area was most comfortable, and that is because of the warm weather on the measurement day as well as the fact that the urban geometry in Al Gassany area allows the solar beam to reach the ground.

Table 4.3 shows that the average values of the PET index are higher in summer and lower in winter than the average values of both the OUT_SET* and ET* indices. ET*, in turn, has higher values in summer and lower in winter than OUT_SET*. One of the reasons why PET and ET* have more extreme values is that they do not take clothing and activity into account as input variables. Another reason why OUT_SET* is slightly lower than ET* in the summer may be because the effect of wind speed is included in the calculation of OUT_SET* and not in ET*. For the PMV index, the calculated values in winter time are within the range from –3 (very cold) to +3 (very hot) except in Old Damascus in the evening. Only Al Gassany area was comfortable, i.e. within the comfort range of the index of –0.5 to +0.5 but this was mainly because the particular afternoon was exceptionally warm. In the summer the values were in general well above the defined range of PMV and reached as high as 8 in the Barzza area. Only the values of Old Damascus, both during the day and in the evening, were within the defined scale of the PMV index.

Table 4.3 Average values in summer and winter in all locations for the physiological equivalent temperature (PET), the outdoor standard effective temperature (OUT_SET), the new effective temperature (ET*), and the predicted mean vote (PMV) where (W) is winter and (S) is summer.*

	Avg PET °C		***Avg OUT_SET* °C***		***Avg ET* °C***		***Avg PMV***	
	S	***W***	***S***	***W***	***S***	***W***	***S***	***W***
Al Gassany area	*46.1*	*23.2*	*36.0*	*27.6*	*36.7*	*23.9*	*5.5*	*0.2*
Dummar area	*53.3*	*7.2*	*38.4*	*15.6*	*38.4*	*10.6*	*6.5*	*–2.8*
Barzza area	*54.0*	*7.8*	*38.2*	*15.8*	*39.3*	*11.2*	*8.0*	*–2.5*
Al Tigarra park	*42.7*	*17.2*	*34.6*	*21.3*	*36.1*	*19.9*	*4.8*	*–1.6*
Al Mazza park	*53.2*	*11.1*	*37.9*	*19.4*	*39.1*	*15.2*	*7.7*	*–2.1*
Old Damascus	*35.3*	*6.7*	*32.3*	*14.4*	*31.9*	*8.6*	*2.9*	*–2.2*
Barzza area (morning)	*46.1*	*17.1*	*36.2*	*23.5*	*36.9*	*19.3*	*5.7*	*–1.1*
Old Damascus (evening)	*26.3*	*2.0*	*25.7*	*9.9*	*25.5*	*5.5*	*0.5*	*–3.9*
All locations	*44.6*	*11.6*	*34.9*	*18.4*	*35.5*	*14.3*	*5.2*	*–2.0*

4.3 Subjective thermal perception

Figure 4.1 illustrates the clear differences between people's answers concerning thermal perception in the summer and winter seasons for all studied locations together. The result shows that the people's thermal perception in the summer time is between cool and very hot, whereas in winter time the thermal perception is between very cold and hot. The highest percentage feels comfortable in the winter time, whereas they feel hot in the summer time. The distribution of the comfort votes is widely spread in both summer and winter due to the varying weather conditions between the measurement days (especially in winter), but also due to individual differences in people's thermal perceptions. A similar difference in distribution between seasons was found in Sydney, Australia, by Spagnolo and de Dear (2003).

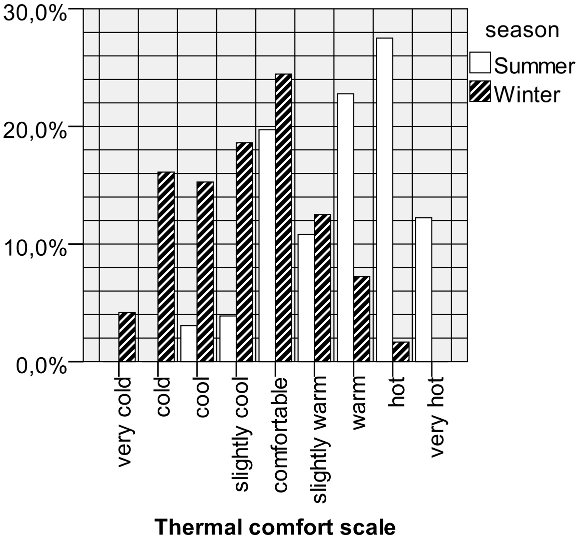


Figure 4.1 Frequencies for people's thermal perception in the summer and winter seasons.

4.4 Relationship between thermal sensation votes and thermal indices

When looking at the relationship between Thermal Sensation Votes (TSV) and the calculated indices, it was found that the original thermal sensation scales of these indices (PET, OUT_SET*, ET*, and PMV) often do not correspond to people's actual thermal perception in Damascus. Figure 4.2 shows the relationship between TSV and the index temperatures for PET and OUT_SET*. At all index temperatures there is a wide spread of votes. This reflects the variations in people's thermal perception, which supposedly is due to differences in activity, clothing, thermal history, emotional state, etc as well as individual thermal preferences. The distribution of people's answers reflects the real situation in summer and winter regarding the calculated thermal comfort and people's perception. In this case, the R^2 for all studied indices varied between 0.054 and 0.14 (see Paper 2). If instead the average TSV is calculated for bins of 3°C index temperatures, the R^2 increases to around 0.7 for all studied indices.

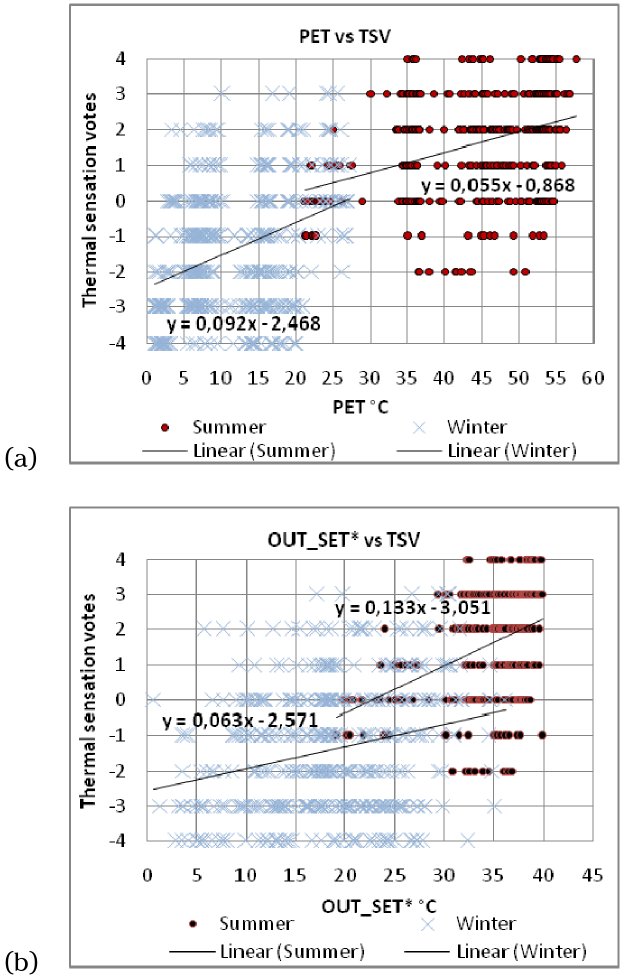


Figure 4.2 Relationship between people's thermal sensation votes (TSV) and (a) the PET index and (b) the OUT_SET index in summer and winter where the scale of actual thermal sensation is between very cold (–4) and very hot (+4).*

Similar patterns of the wide spread have been found by Thorsson et al. (2004) and Krüger and Rossi (2011). The large individual differences in thermal perception between the subjects may have many reasons. For PET, one reason is the clothing and activity factors that this index does not take into account. Other reasons are believed to be related to different thermal preferences, differences in thermal history and emotional state as well as the influence of aesthetic qualities of the place that affect the thermal perception (Knez and Thorsson, 2006).

4.5 Thermal comfort zones and neutral temperatures

Table 4.4 illustrates the comfort zones and neutral temperatures in both summer and winter for PET and OUT_SET*. For PET, the comfort zone in the summer is wider than in the winter, whereas for OUT_SET*, the comfort zone in winter is wider than in summer. The neutral temperatures in the summer time for both PET and OUT_SET* are considerably lower than the neutral temperatures in the winter. It should be noted that in the winter, there are few votes in the range of +1 to +4 and in the summer there are even fewer votes in the range –1 to –4. Thus, the upper limit of the winter comfort zones and the lower limit of the summer comfort zones are uncertain.

Table 4.4 Values of the comfort zones and neutral temperatures for the PET and OUT_SET indices in the winter and summer seasons.*

Index	*Comfort zone (°C)*		*Neutral temperature (°C)*	
	Winter	*Summer*	*Winter*	*Summer*
PET	*18 –28.7*	*6.7 –24.9*	*23.4*	*15.8*
OUT_SET*	*25.6 –44.6*	*15.9 –30.3*	*35.1*	*23.1*

For the PET index, the neutral temperature for Damascus in the summer is lower than in the winter (Table 4.4). This may seem surprising since one would expect the local population to be adapted to the weather conditions in each season. However, the results agree with those of Spagnolo and de Dear (2003). They explained the phenomenon by applying the concept of alliesthesia which is a psychological mechanism explaining the differences in sensation between seasons, i.e. if people feel warm then anything which makes them feel colder will be pleasant and vice versa. Conversely, the results disagree with the results for Taiwan where Lin (2009) found a slightly higher neutral temperature in summer than in winter. In the case of OUT_SET*, Table 4.4 shows that the winter neutral temperature in Damascus is also higher than the summer one and the difference between the summer and winter neutral temperatures is 12°C. Spagnolo and de Dear (2003) found a similar result for subtropical Sydney where the difference was the same (around 12°C). Moreover, the summer neutral temperatures in Damascus (23.1°C) and in Sydney (23.3°C) were almost equal (see Table 9 in Paper 2).

The present study has defined two different thermal comfort ranges for the summer and winter, whereas the other studies defined only one comfort range for both summer and winter. The reason to study the seasons separately is that people have adapted themselves differently to each season physiologically and psychologically as well as in terms of behaviour (e.g. clothing). However, due to the uncertainty of the upper winter value and lower summer value one could create a common comfort range for both summer and winter based on the lower winter value and the upper summer value. For the PET and OUT_SET* indices, the ranges in our case are:

$$18.0°C \leq PET \leq 24.9°C$$

$$25.6°C \leq OUT\_SET^* \leq 30.3$$

For the PET index, this agrees fairly well with the Central European comfort range from18–23°C (Matzarakis and Mayer (1999).

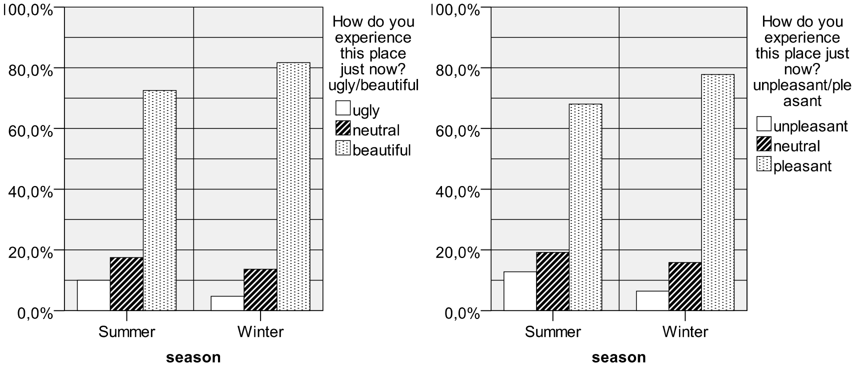
4.6 Clothing and thermal comfort

Investigating the relationship between clothing and the thermal comfort indices PET and OUT_SET* shows that in the winter season, the distribution of clothing values is more widely spread than in summer (see Figure 8 in Paper 2). In winter, clothing values varied between 0.5 and 2.5, whereas in summer the values varied between 0.4 and 0.8. Moreover, in the winter, high clothing values occur also at fairly comfortable temperatures. These clothing values are represented by the values far from the regression lines in Figures. 8a and 8b. Thus in the winter, some people adjust their clothing according to the weather, whereas others use heavy clothing although it is fairly warm. The latter explains why there are high OUT_SET* values (up to 36°C, see Figure. 7b in Paper 2) also in winter.

As expected, this study found that the insulation value of people's clothing tend to decrease with increasing temperatures. The summer (hot season) values in this study are similar to those of Taiwan – around 0.6 clo. The winter (cool season) values are however much higher in Damascus due to much colder winters. This study has shown that in the case of Damascus, the choice of clothing is to some extent also linked to cultural aspects. As can be seen in Figure. 8a there is also a tendency at high PET values in summer that some users have heavier clothing (clo about 0.8) than the rest (clo 0.4 – 0.6). Thus, the dress code of some of the people of Damascus seems to depend on cultural traditions rather than climate whereas most people choose their clothing according to the weather conditions when they feel thermally discomfortable.

4.7 Thermal sensation and aesthetical qualities of the place

Figure 4.3a shows the percentage frequencies for the aesthetical quality of the places (beauty, ugliness). The results show that the majority of the people, 72% and 82% in summer and winter respectively, experience the same places during the summer and winter seasons as beautiful, whereas only 18% and 13% in summer and winter respectively experience the places as neutral, and 10% and 5% in summer and winter respectively experience the places as ugly (Chi-square = 10.52, P=.005, df = 2). The results show that the people experience the same places in the winter season slightly more beautiful than in the summer season. The results indicate that people's perception of beauty is influenced by the weather and climate. The reason could be that when people feel more comfortable, they experience the aesthetical quality of the place as higher. Other studies in different climates found similar results (e.g. Knez & Thorsson, 2006). Figure 4.3b also illustrates the percentage frequencies for the aesthetical quality of the places (pleasantness, unpleasantness). The result shows that the majority of the people, 68% and 78% in summer and winter respectively, experience the same places during summer and winter seasons as pleasant whereas, only 19% and 16% in summer and winter respectively experience the place as neutral, and 13% and 6% in summer and winter respectively experience the place as unpleasant (Chi-square = 11.14, P=.004, df = 2). The result shows that the people experience the same places in the winter season more pleasant than in the summer season. The results indicate that people's perception of pleasantness is influenced by the weather and climate. Similar results were found in other studies in different climates (e.g. Knez & Thorsson, 2006).



(a) (b)

Figure 4.3 Frequencies in summer and winter. (a) People's perception of beauty. (b) People’s perception of pleasantness.

5 Conclusions and propositions

5.1 Existing urban planning regulations

This study analyzes the urban planning regulations in Damascus from climatic perspective. The simulations reveal the shortcomings of the current planning regulations in Damascus city as regards the outdoor thermal comfort at street level in the summer time. The regulations for modern Damascus prescribe wide streets and pavements, large setbacks and relatively low building heights. This leads to a dispersed urban form where a large part of the buildings and streets are exposed to solar radiation. The existing planning regulations in Damascus have no requirements for shading for pedestrians, e.g. shading devices, arcades and projecting upper floors or shading trees. Apart from leading to poor microclimatic conditions in the summer, land use in the modern part of Damascus is highly inefficient, with a disproportionately large amount of ground occupied by streets, pavements and front yards.

In the case of urban canyons (attached buildings), one conclusion of this and other studies (e.g. Ali-Toudert and Mayer, 2007) is that the aspect ratio, street orientation, and vegetation are very important in street design. On the other hand, in urban environments consisting of detached buildings, the influence of street orientation and aspect ratio on surface temperatures and outdoor thermal comfort is less important, whereas the use of vegetation may reduce surface temperatures and improve the outdoor thermal comfort substantially.

In order to increase shade at street level in future urban areas in Damascus, it is important to develop the existing urban planning regulations according to the climatic requirements. This can be done by reducing front setbacks or to have none at all, planning narrower streets, increase the permissive maximum number of floors, and allowing projections of upper floors. Moreover, architectural elements, which provide shade for pedestrians at street level such as balconies and horizontal shading devices, should be encouraged in the urban planning regulations. In addition, outdoor thermal comfort in existing urban areas in modern Damascus could be improved by introducing vegetation and landscaping in the urban design process. The use of vegetation would also have a positive influence on the air quality as well as the quality of life. It is therefore important to create a link between landscape design and urban planning regulations. Such a link could be as a set of guidelines for street design and plant selection.

5.2 Field measurements and structured interviews

This study assesses the microclimate of the outdoor urban environment and investigates the relationship between different thermal comfort indices and people's actual thermal sensation in the hot dry city of Damascus. It is concluded that the thermal conditions of different outdoor environments vary considerably, mainly as a function of solar access. In general, areas that provide shade – either by buildings, such as Old Damascus, or vegetation – are more comfortable in summer than in winter. Conversely, street canyons and parks in modern Damascus, which are open to solar access, are more comfortable in winter than in summer.

Furthermore, this study defines the summer and winter comfort zones and acceptability limits for PET and OUT_SET* in hot dry Damascus. This is important information for urban designers aiming at a climate-conscious urban design. The study also shows the influence of culture and traditions on clothing. While most people choose the clothing according to the climate, some people in Damascus are influenced by their cultural traditions when they choose how to dress.

In summer time, which is the most problematic season, the study finds that the majority of interviewees felt hot. This can be improved by enhancing the urban design in Damascus city as well as by adding trees or shading devices in order to provide shade for people who pass by and linger on these places.

The results highlight the importance of a climate-conscious urban design and design flexibility. It is important to consider microclimate and thermal comfort in the urban design process. This can be done by providing a basic knowledge for architects, designers, and planners about the importance of microclimate and thermal comfort and how to create better urban spaces in harmony with climate. Based on this knowledge, summer and winter comfort zones and acceptability limits for Damascus can be understood and promoted as a goal to design better urban spaces by taking these limits into account.

5.3 Future studies

Further studies in the field of microclimate and thermal comfort are needed since this and other studies have shown that the actual thermal perception is not only affected by microclimatic parameters (air temperature, solar radiation, relative humidity, and wind speed) but also by personal parameters such as people's activity and clothing. Thus, more studies about the relationship between the actual thermal perception and other parameters – such as gender, age, thermal history, and people's emotional states – are needed.

For all climates, the thermal comfort range and acceptability limits are needed to be defined. Such limits are absolutely important to develop the urban spaces in the city in harmony with microclimate. Additionally, it would be important to develop the urban planning regulations in every city according to the climatic requirements. Thus, further studies to analyze the existing regulations from a climatic point of view are needed.

For the hot dry city of Damascus, in-depth studies including both summer and winter seasons will be performed within the context of the ongoing project, including statistical analysis of the structured interviews regarding emotional states, preferable weather conditions, and evaluating the outdoor activities for the people who live in Damascus. Simulation studies will also be conducted for summer and winter to provide new insights on how to develop the urban design in Damascus and how the current urban design could be modified to improve outdoor thermal comfort conditions.

Furthermore, guidelines for a climate-sensitive urban design and suggestions to improve the urban planning regulations in the city of Damascus will be proposed.

In the long-term period, further studies about climate-conscious urban design in Damascus could be carried out such as a climatic map for Damascus. Such a map will be helpful for planners and architects to see which areas are more comfortable than others so as to determine where to build new urban areas in the city of Damascus for future development.

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Appendix A

Damascus urban zones. Source: Damascus urban planning regulations, Damascus municipality (translated into English by the author).

Zone code	Land use	Description
AG–A	*Agricultural activity (A)*	*Only for agricultural activities – no residential buildings. It is located out of Damascus administrational limits and it is a part of the oasis (the Ghouta region) which surrounds Damascus.*
AG–B	*Area of protection with agricultural activity (B)*	*Only maintenance of existing buildings. It is located in the Kasioun mountain and also located on the area which surrounds urban areas to the east and to the south of the city.*
AG–C	*Agricultural area in the city itself (C)*	*Only maintenance of existing buildings.*
G–D	*Green area (D)*	*Public gardens and parks.*
A	*Administrative area*	*Only for constructing governmental buildings.*
IRA	*Inhabited rural areas*	*A residential area according to its own detailed plan. This zone contains seven villages which were in the past out of Damascus and mainly on the city's urban fringe but now they have become a part of Damascus.* *Mixed between residential use and commercial use. Commercial purposes should be only in the ground floor.* *It contains four sub-zones: 1–Old town area, 2–Old town area's expansion, 3–Modern residential areas, 4–New planning areas.*
I	*Industrial area*	*Only for industrial activities – no residential buildings.*
PRA	*Planned residential area*	*It is a purely residential zone and it contains four sub-zones: Palaces area, 1st class modern residential area, 2nd class modern residential area, 3rd class modern residential area.*
OQA	*Old quarters area*	*Residential area according to its own detailed plan in the Old quarters areas.*
AUP	*Areas under planning process*	*Residential area according to its own detailed plan after finishing its planning purposes.*
REA	*Residential area for future expansionism*	*Residential area according to its own detailed plan after finishing its planning purposes.*
R–K	*Residential area (K)*	*Mixed between residential use and commercial use. Commercial purposes should be only in the ground floor.*
R–L	*Residential area (L)*	*Mixed between residential use and commercial use, but not in the same storey. (Hotels, restaurants, commercial offices, etc).*
OD	*Old Damascus*	*Only for restoration and rehabilitation works.* *Mixed use (residential and commercial) according to its own regulation system.*

Paper 1

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Influence of urban planning regulations on the microclimate in a hot dry climate – The example of Damascus, Syria

Moohammed Wasim Yahia, Erik Johansson.
Housing Development & Management, Lund University, Sweden.

Abstract

Urban planning regulations influence not only the urban form; they also have a great impact on the microclimate in urban areas. This paper deals with the relationship between the urban planning regulations and microclimate in the hot dry city of Damascus. The main purpose is to highlight the shortcomings of the existing urban planning regulations. The microclimatic parameters necessary for the thermal comfort assessment of pedestrians were determined through simulations with the software ENVI-met. It is shown that the street design – as regards aspect ratio, orientation and the presence of street trees – has a great influence on ground surface temperatures and thermal comfort. Moreover, the type of buildings – whether detached or attached (street canyons) – has an impact. For deep canyons, there is an interactive relationship between aspect ratio, orientation and vegetation. However, for streets with detached buildings, there is only a weak influence of street orientation and aspect ratio but a strong influence of vegetation on surface temperatures and outdoor thermal comfort. The study shows the importance of modifying the planning regulations in Damascus for new areas to be constructed by allowing smaller setbacks, narrower streets, higher buildings, etc.

Keywords: Aspect ratio; Damascus; Hot dry climate; Microclimate; Planning regulations; Street design; Thermal comfort; Vegetation.

1 Introduction

The fact that cities are warmer than its surrounding open, rural areas, especially during night time – the urban heat island effect (Oke, 1987; Voogt, 2004) – affects human comfort and energy use in buildings. Within the urban canopy layer, however, the microclimate may vary considerably as a function of the urban design (Givoni, 1998; Ali-Toudert et al., 2005; Johansson, 2006a). Urban microclimate depends both on the type of city in terms of size, geographical location, population size and density and land use as well as street design features such as height of buildings, street widths and orientation, subdivision of the building lots, etc. In fact, the urban design of each neighbourhood in a city creates its own particular local climate (Givoni, 1998).

Previous studies of urban microclimate have focused mainly on the impact of the physical environment on climatic parameters (air temperature, relative humidity, radiation, and wind speed) in different climates such as warm humid (e.g. Johansson and Emmanuel, 2006), cold (e.g. Thorsson et al., 2004), and hot dry (e.g. Yahia and Johansson, 2011). Generally, most of the studies in hot dry climates provided new insights to improve the outdoor thermal environment. Several studies have focused on microclimate and outdoor thermal comfort in street canyons based on either simulations (e.g. Ali-Toudert and Mayer, 2006; Emmanuel et al., 2007) or measurements (e.g. Ali-Toudert et al., 2005; Johansson, 2006a; Ali-Toudert and Mayer, 2007a). Others have studied the pedestrian energy exchange depending on a physical open air scale model in urban street canyons as well as urban canopy (Pearlmutter et al., 2006; Pearlmutter et al., 2007). Some others have focused on the influence of trees and grass on outdoor thermal comfort and have studied the cooling efficiency of urban landscape strategies considering the efficiency of water use (e.g. Shashua-Bar et al., 2009; Shashua-Bar et al., 2010).

Urban microclimate and outdoor thermal comfort are generally given little importance in the urban design and planning processes (Eliasson, 2000; Johansson, 2006b). Moreover, few studies have dealt with the relationship between urban planning regulations and the local microclimate. Several studies however indicate that the existing planning regulations in hot dry climates are not adapted to the climate. In the city of Fez, Johansson (2006b) found that the intention of the current regulations is to guarantee daylight for buildings. This may be relevant for the winter period when solar elevations are low and passive heating of buildings is desired. However, during the long, warm summer, when there is a need for solar protection, this results in a very poor microclimate at street level. The worst conditions are found in areas designated for low-rise houses where plots are very large and plot coverage low. The current urban design in the modern parts of Fez stands in stark contrast to the old city where narrow alleyways and projected upper floors create adequate shade at pedestrian level.

Al-Hemaidi (2001) and Eben Saleh (2001) reported that current urban design in Saudi Arabia has led to an undesirable microclimate around buildings. They explained this with the prescription of an extremely dispersed urban design where the provision of shade is totally lacking. The current urban form is characterized by gridiron plans with wide streets where the detached, low rise “villa” is the most common type of house. Baker et al. (2002) reported from a similar experience in hot dry Phoenix, in Arizona (USA), wide streets dispersed low-rise buildings and oversized parking lots have contributed to urban warming. Bouchair and Dupagne (2003) found a similar situation in the Mzab valley, Algeria, where contemporary urban design lacks the microclimatic qualities of the traditional cities in the region.

The urban form is strongly influenced by urban planning regulations, such as zoning ordinances, which governs spaces between buildings, building heights, building footprints, etc. Consequently, urban planning regulations have a great impact on the microclimate in urban areas (Johansson and Yahia, 2010).

The street is one of the important urban components of a city’s physical structure and it acts as the physical interface between urban and architectural scales. The form of the street can climatically affect both outdoor and indoor environments in terms of solar gain in summer and winter, building surfaces absorption and reflection of solar radiation, wind speed and direction and its implication for building passive cooling systems and urban ventilation. Conseq- uently, the shape of the street influences the outdoor thermal comfort – which affects people’s human health and well-being – as well as the energy use of buildings in the urban areas. Therefore, designing streets is essential for an environmental urban design (Ali-Toudert, 2005).

This paper deals with the relationship between the urban planning regulations and microclimate in the hot dry city of Damascus in Syria. The main purpose is to highlight the shortcomings of the existing urban planning regulations. This is done by assessing the thermal comfort for pedestrians as well as surface temperatures in different thermal environments within residential streets in Damascus. Whereas most previous studies have focused on street canyons (e.g. Ali-Toudert and Mayer, 2006; Perlmutter et al., 2006). This study focuses on the residential streets that have both detached and attached buildings (canyons). These two different cases represent the common outdoor urban space patterns in Damascus' built environment. This paper provides new insights to the design of residential streets and to the improvement of the existing urban regulations in Damascus from a climatic perspective.

The city of Damascus

Damascus which is located in the south west of the Syrian Arab Republic is the capital and largest city of Syria. It is the oldest continuously inhabited city in the world and it used to be fully surrounded by an oasis (Al Ghouta). The oasis is watered by the Barada River and Al Fijeh Spring provides the city with drinking water.

Damascus has two parts: Old Damascus and modern Damascus. Old Damascus has a regular planning in general, with streets oriented N–S and E–W. Most streets are narrow with deep canyons and projecting upper floors are common. See Figure 1a. The typical architectural style in Old Damascus is simple from outside and rich from inside with internal orientation to courtyards like in most vernacular architecture of old cities in the Islamic world. This urban design came forth as a perfect response to the living conditions of both the natural and the social environment, based on age-old regional experience using local building materials and appropriate techniques of climate control (Bianca, 2000). Old Damascus' buildings are made of local construction materials such as stone, clay, wood, etc, see Figure 1a, whereas in the modern part of Damascus, modern construction materials such as concrete, steel, glass, artificial or natural stone, etc. are used. In addition, as a consequence of the planning regulations, modern Damascus has mainly detached buildings created according to detailed rules for spaces between buildings, setbacks, building heights, building footprints, projections, etc. Moreover, buildings are outwardly orientated. See Figure 1b.

Figure 1 (a) Typical style for streets in Old Damascus. Projected upper floors increase shade at street level. (b) Typical streets and buildings in the modern part of Damascus.

Climate in Damascus

Damascus has sunny summers (June to August) and fairly cold winters (December to February). Snowfall is common in winter on the mountains surrounding the city. Summer temperatures can reach in excess of 35°C during the day, but evenings are generally cool. In winter, minimum temperatures can reach 0°C. Spring and autumn have the most comfortable climate with average temperatures in the range of 16 to 20°C.

2 Urban planning regulations in Damascus

The urban planning regulations in Damascus are the essential documents for regulating urban and buildings issues in the city. Literally, the name of this document translated from Arabic is building regulations for the city of Damascus (Damascus Municipality, 1997)

The approach to urban design changed radically during the French colonial period (1920–45). New areas were built with wide streets in a grid pattern and buildings were outwardly oriented (Al-Kodmany, 1999). During the 1950s, it was necessary to develop a new master plan for Damascus. The first attempt was by an Austrian company in 1957 and the second one started in 1963 by the French architect Michel Ecochar. In 1968 Ecochar presented the new master plan for Damascus and a few years earlier he had developed new urban planning regulations for the city; these regulations determined urban form in Damascus during a period of 20 years (1965–1985). Ecochar's master plan and urban planning regulations are essential documents which have been the basis for all updated versions after 1985.

In 1993, a special committee – from the Syrian Engineers Association and Damascus Municipality – was created in order to study, develop and complete the urban planning regulations for Damascus. The latest urban planning regulations were issued by Damascus Municipality in 1997 and were ratified by the Syrian Ministry of Housing and Construction in the same year.

The first part of the urban planning regulations contains special conditions about administrational procedures concerning building permit, public roads and protection procedures during the construction process such as fire and safety protection.

The second part contains rules concerning building heights, projections, partitions and barriers between the plots, ventilation and illumination shafts, residential and commercial units and components, common facilities such as stairs and corridors, architectural elevations, roof forms as well as general regulations about street width, setbacks, and parking.

The third part contains regulations regarding maximum floor area ratio (FAR) which is calculated as the total floor area of the building divided by the total area of the plot. The third part also contains regulations about the basement construction in case of sloping plots, regulations for small apartments in the commercial areas, temporary building conditions, and fire protection.

The fourth part which deals with urban zones for Damascus contains specific regulations on minimum plot sizes, minimum plot frontages, minimum setbacks, maximum building heights, maximum plot coverage (building footprints), maximum projections, etc (see Table 1 and Figure 2). In addition, these regulations determine the division of Damascus into urban land use zones. Damascus is divided into 14 zones of different land use including agricultural, administrative, industrial, residential, and commercial activities. The urban zones which deal with residential areas – planned residential area (PRA) and for the zone of Inhabited rural area (IRA) – are described in Table 1.

Parts 5, 6 and 7 contain, respectively, general information about hospitals as well as electrical and mechanical installations. There are also two appendices, the first one is about urban planning regulations for Old Damascus, and the second is about heating systems and cold water generation for cooling.

Table 1 Urban planning regulations pertaining to urban form in the city of Damascus for the zone of planned residential area (PRA) and for the zone of Inhabited rural area (IRA).*
Source: Damascus urban planning regulations (Damascus Municipality, 1997).

Zone code	***Type of area***	***Type of use***	***Plot size (m^2)***	***Max. Plot coverage** (%)***	***Max. no. of floors*****	***Max. H (m)***	***Min. plot frontage (m)***	***Min. setbacks (m)***		
								Front	***rear***	***side***
PRA	Palaces area	Residential	>1500	20%	no limit	10	—	10	10	10
PRA	1st class modern residential area	Residential	> 600	33.3% See Figure 2	3+B	14	—	5	5	5
PRA	2ed class modern residential area	Residential	> 400	50%	3+B	14	—	3	3	3
PRA	3rd class modern residential area	Residential	> 200	66.6%	3+B	12	—	—	—	—
IRA	Inhabited rural area (Old town area)	Residential, commercial	> 125	= 5X+ 2/3.X (Y–5). see Figure 2	4+B	14.25	> 8	—	—	—
IRA	Inhabited rural area (Old town area expansion)	Residential, commercial	> 150	= 5X+ 2/3.X (Y–5). see Figure 2	4+B	14.25	> 9	—	—	—
IRA	Inhabited rural area (Modern residential area)	Residential, commercial	> 300	50%	4+B	14.25	> 14	3	7	—
IRA	Inhabited rural area (New planning area)	Residential, commercial	> 600	40%	4+B	15	> 20	3	4	5

B= Basement; H = Building height.

**This zone consists of neighborhoods situated outside the core of Damascus and surrounded by green areas.*
*** The maximum FAR (Floor Area Ratio) can be calculated by multiplying the maximum plot coverage with the maximum number of floors.*

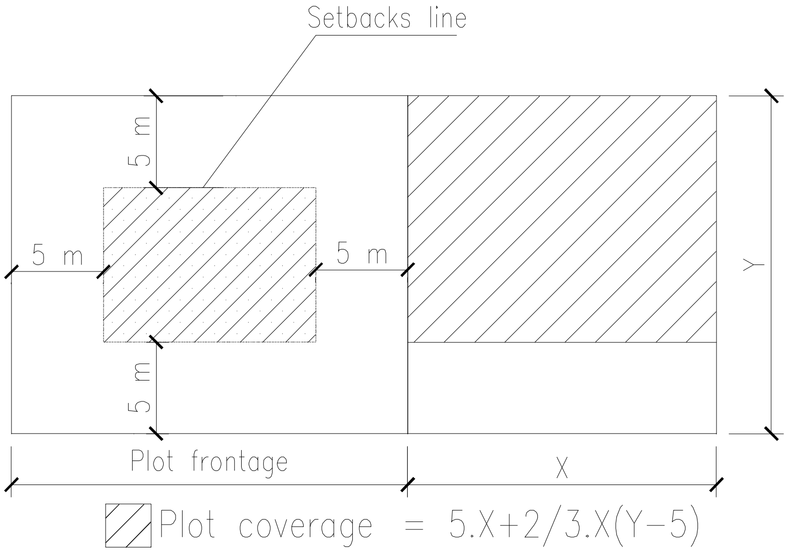

Figure 2 Two examples of setbacks, plot coverage and plot frontage. (a) Front, side and rear setbacks for zone PRA (1st class modern residential area). (b) The formula to calculate the maximum plot coverage and front setback for IRA zone where X = the plot frontage and Y = the dimension of the side of the plot.

3 Methodology

Selection and characteristics of the studied zones

This study focuses on the three land use zones that represent the main residential urban zones in Damascus (See Table 1):

1. The zone of Planned residential areas (PRA) exemplified by the sub zone palaces area in modern Damascus. This zone contains only detached buildings (Figure 3a).
2. The zone of Inhabited rural area (IRA) exemplified by the sub zone new planning area in modern Damascus. This zone also contains only detached buildings (Figure 3b).
3. The zone of Old Damascus (OD). This zone contains only attached buildings (Figure 3c).

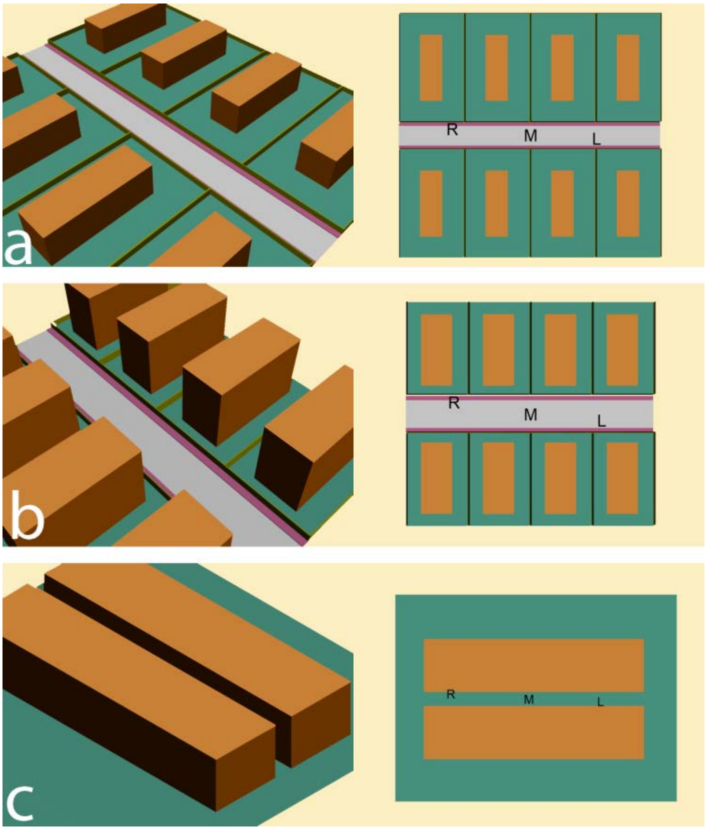

Figure 3 Perspective models of the studied zones for (a) PRA (Palaces area), (b) IRA (New planning area) and (c) OD (Old Damascus) including the 2 m high wall which surrounds the plots. The ground surface temperature and the thermal comfort were studied at the right side of the street (point R), at the middle of the street (point M) and at the left side of the street (point L.)

For modern Damascus, the models have been created according to urban planning regulations, whereas in Old Damascus, the dimensions for the model were derived from existing street.

The study was carried out only at street level since the street in Damascus is the most common public space; this is the main place where people everyday stroll and pass by for different reasons such as going to work and shopping as well as for recreational purposes.

The three zones were mainly chosen in order to test the impact of various aspect ratios, i.e. height-to-width ratios (H/W) on the microclimate. The palaces area of the PRA zone has the lowest H/W ratio (0.31) and the new planning area of the IRA zone has a H/W ratio of 0.83, whereas Old Damascus (OD) zone has the highest H/W ratio (2.95). The chosen zones include two extremes in the city of Damascus where the palaces area of the PRA zone is the most dispersed (lowest density) and Old Damascus is the most compact (highest density). The residential area of the IRA zone is somewhere in between. The PRA (Palaces area), IRA (New planning area) and OD zones are clearly different concerning the distance between buildings, building heights, H/W ratio, and building footprint (See Figure 3 and Table 1).

Microclimate simulations

The microclimate at street level was simulated with ENVI-met 3.0 (Bruse, 2009). The programme uses a three-dimensional computational fluid dynamics and energy balance model. The model has a high spatial and temporal resolution enabling a detailed study of how the microclimate varies within the studied space over time. The model gives a large amount of output data including the necessary variables to be able to calculate thermal comfort indices. A simulation study such as this one has the advantage that an unlimited numbers of points from the model can be analyzed, whereas in a measurement study, only the results derived from the measured spots are reliable.

The input data for the simulation model contained the physical properties of the studied urban areas (buildings, soil and vegetation) and limited geographical and meteorological data. The input data used in this study is shown in Table 2 and included meteorological data from the station Kharabo near Damascus.

Table 2 Basic input configuration data applied in the ENVI-met simulations.

Configuration data	
Start of simulation (h)	6:00
Wind speed at 10 m above ground level [m/s]	1
Wind direction	E–W , N–S*
Initial temperature of the atmosphere [in degrees Kelvin]	303
Solar adjustment factor**	0.85
Specific humidity [g/m^3]	7
Relative humidity at 2m [%]	50
Initial Temperature Upper Layer (0–20 cm) [K]=291	291
Initial Temperature Middle Layer (20–50 cm) [K]	293
Initial Temperature Deep Layer (below 50 cm)[K]	298
Relative humidity in all layers [%]	25
Albedo of walls for buildings	0.3
Albedo of roofs for buildings	0.3

** The wind direction was always parallel to the street.*
*** The solar radiation, which is calculated depending on latitude, was slightly over-estimated by ENVI-met for Damascus conditions and was therefore decreased to 85%.*

The study was carried out on the 21st of July since this month is the hottest during summer time according to meteorological data from the Kharabo station. The simulated period lasted from 7:00 in the morning until 16:00 in the afternoon in order to include the maximum air and surface temperatures which normally occur at 14:00. In this study, both east–west (E–W) and north–south (N–S) street orientations were investigated. In modern Damascus, the street width was 12 m since this width is the most common one. On the other hand, the width of the studied street in Old Damascus was 3.8 m and it was derived from a real street. See Figure 4.

In the ENVI-met simulation program (version 3), the walls of the buildings have no thermal mass. Therefore, the surface temperatures calculated by ENVI-met will be overestimated, especially in Old Damascus where the walls on the ground floor have high thermal mass. Another shortcoming with ENVI-met is that the effect of motor traffic is not considered. However, since the study focused on residential streets and not on the centre of Damascus, the impact of motor traffic is likely to be negligible.

Assessment of thermal comfort

Thermal comfort is defined as the condition of mind, which expresses satisfaction with the thermal environment (Plumley, 1975). There are four environmental variables affecting the thermal comfort of the human body: air temperature, mean radiant temperature, air humidity and air speed. Additionally, several personal variables influence thermal comfort: clothing, the level of activity, height, weight, age, and gender. However, of these, clothing and the level of activity have the largest impact on thermal comfort (Givoni, 1998).

The mean radiant temperature (MRT) is defined for the real environment in practice (actual non-uniform enclosure) as “the uniform temperature of an imaginary enclosure in which radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure” (ASHRAE, 1997). In the outdoor environment, it is complicated to determine MRT because the body exchanges radiation with various sources. The human body receives direct, diffuse and reflected solar radiation. Moreover, the body exchanges thermal (long-wave) radiation with the sky, with urban surfaces and with objects such as trees. The magnitude of the radiation from the different sources varies greatly in space and time. The MRT is calculated by ENVI-met for a standing person taking all radiation aspects mentioned above into account (Ali-Toudert and Mayer, 2006).

The most commonly used thermal comfort indices are based on the heat balance of the human body, e.g. the predicted mean vote (PMV), the new effective temperature (ET*), the standard effective temperature (SET*), and the physiologically equivalent temperature (PET). These indices have in common that they take into account all environmental variables influencing thermal comfort (Ali-Toudert, 2005).

In this study, thermal comfort was estimated by calculating the PET index (Höppe, 1999). PET, which is expressed in °C, is based on the human energy balance model MEMI and includes the physiological thermoregulatory processes of human beings in order to adjust to a climatic situation outdoors (Ali-Toudert and Mayer, 2006). The thermal comfort zone for the PET index was originally defined as 18–23°C. This range applies to European climatic conditions (Germany). A recent study in the warm humid climate of Taipeh, Taiwan, found a PET summer comfort zone for Taiwan as being 21.3–28.5°C which is considerably higher than Western/middle European scale (Ping Lin, 2009). Although PET has not been calibrated for Damascus, the index makes it possible to compare different urban designs.

The PET index was calculated with RayMan (Matzarakis, 2000) using input data from the ENVI-met simulations (MRT, air temperature and RH) and from the meteorological station in Kharabo (wind speed).

For the three studied zones, the PET index was calculated at pedestrian level (1.1 m height) for three points of the street: both pavements and the middle of the street. The positions of the studied points for which the surface temperature and PET has been calculated are shown in Figure 3 for the PRA and IRA zones. In the case of Old Damascus, the studied points are located in the deep urban canyon near the building facades and in the middle of the street.

The impact of street trees on thermal comfort

In order to evaluate the impact of vegetation, rows of trees were added on the pavements in both the PRA and IRA zones, see Figure 4. The street trees affect outdoor thermal comfort mainly in points R and L. No street trees were added in Old Damascus due to the lack of space.

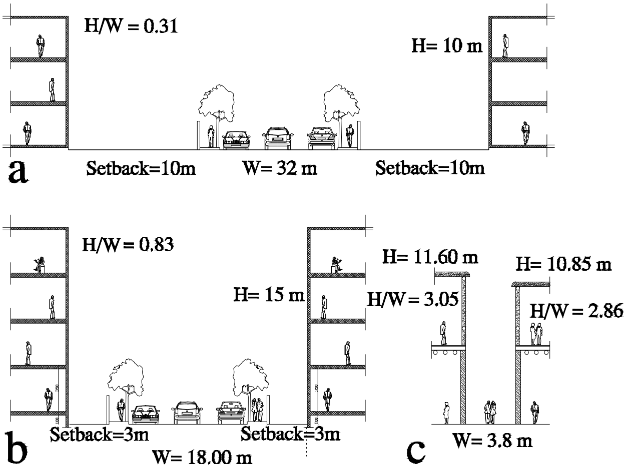

Figure 4 Typical sections and H/W ratio for (a) PRA zone, (b) IRA zone, and (c) OD zone with rows of trees on the pavements for IRA and PRA zones.

4 Results and discussion

This section presents the results of surface temperatures and thermal comfort, expressed as the PET index, as well as the influence of vegetation on surface temperatures and PET.

The influence of H/W ratio and orientation on surface temperature and PET

The surface temperatures in all three studied zones between 07:00 and 16:00 at the three points (L, R and M) are shown in Table 3. As can be seen in the table, the highest surface temperatures in modern Damascus are in the middle of the streets (M) where temperatures reach as high as 48°C. The temperature difference between the pavements (positions L and R) is very small in both the PRA and IRA zones. For these zones – which consist detached buildings in modern Damascus – the influence of street orientation on surface temperatures is not decisive. On the other hand, for both E–W and N–S orientation, the surface temperatures of the two zones in modern Damascus are considerably higher than those of Old Damascus because in the latter case the street has a much higher H/W ratio. The street in Old Damascus is in shade during all hours of the simulation except at around noon for the N–S case as well as at around10:00 and around15:00 for the E–W case since the azimuth is nearly parallel to the street orientation for these hours. Surface temperatures in Old Damascus are normally similar in all points and rarely above 35°C.

Table 3 Surface temperatures in all three studied zones, for (a) E–W and (b) N–S orientations, between 07:00 and 16:00 at the three points (L, R and M). L = left pavement, R = right pavement and M = middle of the street.

Time	PRA			IRA			OD		
	L	R	M	L	R	M	L	R	M
07:00	23.9	21.9	24.9	23.2	22.2	24.9	25.3	21.6	21.0
08:00	30.6	24.6	33.8	30.4	24.7	33.8	32.7	31.5	27.5
09:00	35.7	27.0	38.9	35.2	26.9	38.9	36.7	31.6	28.5
10:00	39.5	33.7	42.9	38.7	28.6	42.9	40.0	32.0	30.3
11:00	42.3	39.8	45.7	41.2	35.4	45.7	35.1	32.8	32.0
12:00	44.2	42.7	47.3	43.0	41.3	47.3	35.1	33.7	33.5
13:00	45.4	44.4	48.0	38.3	43.6	48.0	35.3	34.5	34.7
14:00	40.3	45.0	47.5	36.5	44.4	47.5	35.6	35.1	35.7
15:00	38.2	44.3	45.7	35.9	43.8	45.7	40.6	38.9	37.2
16:00	37.0	42.7	42.9	35.2	42.0	42.9	37.8	39.5	40.1

(a)

Time	PRA			IRA			OD		
	L	R	M	L	R	M	L	R	M
07:00	25.0	24.3	27.8	25.7	22.8	28.0	20.9	21.0	21.0
08:00	30.8	30.5	34.7	30.9	30.2	33.6	23.4	23.6	23.6
09:00	35.7	35.5	40.0	35.5	35.2	38.3	25.8	26.1	26.0
10:00	39.3	39.3	43.7	38.8	38.9	41.8	28.0	28.4	28.3
11:00	41.9	42.1	46.3	41.2	41.5	44.2	30.1	30.5	30.4
12:00	43.8	44.1	47.9	42.8	43.3	45.7	38.1	38.4	39.0
13:00	44.9	45.2	48.6	43.5	44.2	46.4	34.6	34.8	35.7
14:00	45.1	45.4	48.2	43.5	44.2	46.0	35.0	35.2	35.6
15:00	44.2	44.5	46.6	42.6	43.2	44.6	35.3	35.5	35.7
16:00	42.3	42.6	43.9	40.9	41.4	42.1	35.4	35.5	35.6

(b)

Table 4 shows the influence of H/W ratio on the PET index at 14:00 in the PRA, IRA and OD zones. At this hour, PET reaches its maximum value. The table illustrates the high PET values in both PRA and IRA zones in modern Damascus (PET around 50°C). These values are far above the thermal comfort zones mentioned in Section 3.3. On the other hand, PET in Old Damascus zone (OD) is around 33°C. However, within each studied zone there is no decisive difference in PET value between the studied points R, L, and M. The main reason is that in zones PRA and

IRA, both for E–W and N–S orientation, all points are exposed to solar radiation, whereas in the OD zone, all points are in shade. Furthermore, for the PRA and IRA zones with H/W equal to 0.31 and 0.83 respectively, the maximum PET reaches the value of 51.7°C and 50.7°C respectively. On the other hand, in Old Damascus with a higher H/W ratio equal to 2.95, the maximum PET value reaches only 33.2°C. The results show that the H/W ratio has a large impact on outdoor thermal comfort and that the PET tends to decrease with increasing H/W. The small difference in PET values between the PRA and IRA zones is explained by the small difference in the aspect ratio as discussed for the surface temperatures above. The main reason for the lower PET in the OD zone is the reduction of radiation fluxes due to increased shading which results in a lower mean radiant temperature. The results agree well with other studies in hot dry climates which found that outdoor thermal comfort is affected by H/W ratio variation (Ali-Toudert and Mayer, 2006; Johansson, 2006a). Table 4 also shows only a small influence of orientation on PET in modern Damascus. This is because this study deals with detached buildings and not canyons. Consequently, in urban environments that have detached buildings, the influence of street orientation and aspect ratio on outdoor thermal comfort is not decisive. Other studies for urban canyons (Ali-Toudert and Mayer, 2006; Johansson, 2006b) have shown that in general N–S streets tend to be more comfortable than E–W streets. This is because a N–S street is exposed to solar radiation during a shorter period than an E–W street. The simulated PETs in modern and Old Damascus are similar to measured values in other hot dry cities (Ali-Toudert et al., 2005; Johansson, 2006a).

Table 4 The influence of H/W ratio on PET values in PRA, IRA, and OD urban zones for east–west (E–W) and for north–south (N–S) street orientations (maximum daily values at 14:00).

Zone	**PET°C (E–W)**			**PET°C (N–S)**		
	L	**R**	**M**	**L**	**R**	**M**
PRA Zone H/W= 0.30	49.9	51.7	49.4	45	52.1	48.8
IRA Zone H/W= 0.83	50.7	50.4	48.5	50	50.7	48.4
OD Zone H/W= 2.95	33.2	33.2	33.2	33.2	33.2	33.3

The influence of vegetation on surface temperature and PET

The hourly variations of the surface temperatures in the PRA and IRA zones at the left pavement (point L) with and without rows of trees along the pavements for E–W and N–S orientations are shown in Figure 5. The figure shows that the surface temperatures below the trees are considerably lower than for an exposed surface in both E–W and N–S street orientations.

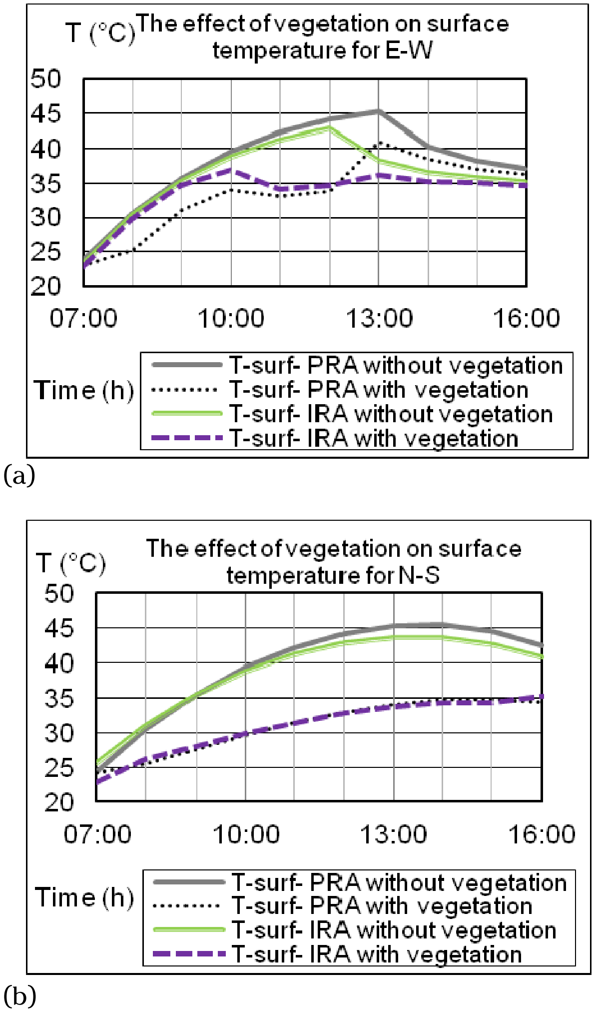

Figure 5 Hourly variations of the surface temperatures in the PRA and IRA zones with and without rows of trees along the pavements for (a) E–W and (b) N–S orientations.

Table 5 illustrates the effect of street trees on thermal comfort expressed as the maximum daily PET value in both the PRA and IRA zones. The result reveals that there is a great influence of vegetation on PET since when rows of trees are added on the pavement, PET values are lowered by about 17°C for the PRA and by about 16°C for the IRA zone due to the shading of the pedestrian pavement. Consequently, in urban environments that have low aspect ratios as well as detached buildings, the influence of vegetation on outdoor thermal comfort is crucial. This result agrees well with other studies which found that the direct solar radiation under a tree canopy strongly decreases (Ochoa et al., 2009; Ali-Toudert and Mayer, 2007b).

Table 5 The influence of street trees on PET values in PRA and IRA urban zones (maximum daily values at 14:00).

	PET without vegetation	PET with vegetation
PRA Zone H/W= 0.30	52.1°C	35.3°C
IRA Zone H/W= 0.83	50.7°C	34.3°C

5 Conclusions

The results reveal the shortcomings of the current planning regulations in Damascus city as regards the outdoor thermal comfort at street level. The regulations for modern Damascus prescribe wide streets and pavements, large setbacks and relatively low building heights. This leads to a dispersed urban form where a large part of the buildings and streets are exposed to solar radiation.

The existing planning regulations in Damascus have no requirements for shading of pedestrians, e.g. shading devices, arcades and projecting upper floors or shading trees. Apart from leading to poor microclimatic conditions in the summer, land-use in the modern part of Damascus is highly inefficient, with a disproportionately large amount of ground occupied by streets, pavements and front yards.

In order to increase shade at street level in future urban areas in Damascus it is important to modify the current planning regulations. This can be done by reducing front setbacks or to have none at all, planning narrower streets, increase the permissive maximum number of floors, and allowing projections of upper floors. Moreover, architectural elements, which provide shade for pedestrians at street level such as balconies and horizontal shading devices, should be encouraged in the urban planning regulations.

In the case of urban canyons (attached buildings), one conclusion of this and other studies (e.g. Ali-Toudert and Mayer, 2007b) is that it is very important to consider the interactive relationship between aspect ratio, street orientation, and vegetation when designing streets. On the other hand in urban environments that have detached buildings, the influence of street orientation and aspect ratio on surface temperatures and outdoor thermal comfort is less important, whereas the use of vegetation may reduce surface temperatures and improve the outdoor thermal comfort substantially.

Consequently, the outdoor thermal comfort in existing urban areas in modern Damascus – which were constructed according to the current urban planning regulations – could be improved by introducing vegetation and landscaping in the urban design process. The use of vegetation would also have a positive influence on air quality as well as the quality of life. It is therefore important to create a link between urban landscaping and urban planning regulations and this link could be as a set of guidelines for street design.

This study is limited only to a numerical simulation study of summer conditions. However, the study is part of larger project about climate-sensitive urban design in the city of Damascus, and microclimatic measurements will be carried out in order to calibrate the results of this study. More investigations, including both the summer and winter seasons, will be performed within the framework of the project including field studies about the influence of microclimate on outdoor thermal comfort, guidelines for a climate-sensitive urban design and suggestions for improvement of the urban planning regulations in the city of Damascus.

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Paper 2

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Microclimate and thermal comfort of outdoor urban environments in the hot dry city of Damascus, Syria

Moohammed Wasim Yahia, Erik Johansson.
Housing Development & Management, Lund University, Sweden.

Abstract

The consideration of urban microclimate and thermal comfort is absolutely needed in the urban development process, and a set of guidelines for every type of climate must be elaborated. However, to develop guidelines, the limits of thermal comfort and acceptable thermal conditions need to be defined. The main aim of this study was to investigate the behaviour of different thermal comfort indices in the hot dry climate of Damascus and to define the thermal comfort and acceptability limits of some of these indices. The study was based on comprehensive microclimatic measurements combined with a questionnaire survey during summer and winter. It was found that the thermal conditions of different outdoor environments vary considerably. In general, Old Damascus, with its deep canyons, is more comfortable in summer than modern Damascus where there is a lack of shade. Conversely, residential areas and parks in modern Damascus are more comfortable in winter due to more solar access. The neutral temperatures of both the physiologically equivalent temperature (PET) and the outdoor standard effective temperature (OUT_SET*) were found to be lower in summer than in winter. The study defined the lower comfort limit in winter to 18.0°C and the upper comfort limit in summer to 24.9°C for the PET index. For OUT_SET* the corresponding lower and upper limits were 25.6 and 30.3 respectively. The study also highlighted the influence of culture and traditions on people's clothing.

Keywords: Microclimate; Thermal comfort; Thermal indices; Thermal perception; Urban design.

Introduction

Due to the complexity of urban microclimates and thus of determining thermal comfort in outdoor urban spaces, it is very necessary to deepen our knowledge about these issues. Such knowledge can help us to create useful and realistic guidelines for the urban planning and design processes. It is absolutely needed to improve the physical and climatic aspects of urban spaces, to make it possible to animate underused parts of a city, and to enhance the quality of life by achieving a level of harmony between the microclimate and urban spaces.

Many previous studies have focused on thermal comfort in outdoor urban spaces and behaviour in public spaces. Some studies examined behaviour, use of place and spatial variation (e.g. Nikolopoulou et al. 2001; Zacharias et al. 2001). Others have focused on psychological variables related to thermal comfort in outdoor spaces (e.g. Thorsson et al. 2004). Still others have focused on cultural and climatic characteristics which influence the usage of outdoor urban spaces (e.g. Knez and Thorsson 2006).While these studies have provided extremely useful insights for urban designers, to put these insights into practice, reliable and relevant methods are needed for gathering information about the urban microclimate and how it is affected by the current urban design.

The outdoor thermal sensation range is wider than that indoors, spanning from thermal comfort to a stressful environment (Spagnolo and de Dear 2003; Emmanuel 2005). Moreover, outdoor conditions show large temporal and spatial variations, and the thermal balance of the body is seldom in steady state, as it is in controlled indoor environments. This situation is especially true for hot dry climates such as that in Damascus where the large temperature variation between night and day makes adaption to the climate difficult.

Several studies related to microclimate and outdoor thermal comfort have been conducted in hot dry climates and most of these studies have provided new insights to improve the outdoor thermal environment. Quite a few studies have focused on microclimate and thermal comfort in street canyons based on simulations (e.g. Ali-Toudert and Mayer 2006), measurements (e.g. Ali-Toudert et al. 2005; Johansson 2006a; Ali-Toudert and Mayer 2007a) and a physical open air scale model (e.g. Pearlmutter et al. 2007). There are, on the other hand, very few studies on subjective thermal sensation in hot dry climates. Mahmoud (2011) investigated the microclimate and thermal sensation in an urban park in Cairo, Egypt. However, this study included only one thermal comfort index and did not include built-up areas. Moreover, the study was not conducted during the hottest and coldest months. There is thus a need for further studies in hot dry climates.

The consideration of urban microclimate and thermal comfort is imperative in the urban development process. To achieve a climate-conscious urban design, a set of guidelines for every type of climate must be elaborated. However, to develop guidelines the limits of thermal comfort and acceptable thermal conditions need to be defined.

The main aim of this study was to define the thermal comfort and acceptability limits of different thermal comfort indices in the hot dry climate of Damascus. The study was based on comprehensive microclimatic measurements combined with a questionnaire survey on people's actual thermal perception during summer and winter. This study is one of few studies which deal with microclimate and subjective thermal comfort in the Middle East and the first of its kind in Damascus.

The city of Damascus

Damascus city is located in the south-west of the Syrian Arab Republic in the Middle East (Elevation: 620 meters, Latitude: 33.5° N, Longitude: 36.5° E). The city has two main parts:

- The old part: It has a regular planning in general, with streets oriented N–S and E–W. Most streets are narrow in the form of deep canyons. The typical style of architecture in Old Damascus is simple from outside and rich with decoration and furnishings from inside, with inward orientation to the courtyards.

- The modern part: The approach to urban design changed radically during the French colonial period (1920–45). New areas were built up with wide streets in a grid pattern and buildings were outwardly oriented (Al-Kodmany 1999).

Damascus is surrounded by an oasis – the Ghouta region – watered by the Barada River that used to provide the city with drinking water.

Climate in Damascus

Climatic data for temperature and relative humidity in Damascus is shown in Fig. 1. Damascus has hot sunny summers and mild winters. Summer temperatures can reach in excess of 35°C during the day, but evenings are generally cool. Spring and autumn are the most comfortable periods, averaging 22°C during the day. Winters are fairly cold and the temperatures reach as low as 2°C at night.

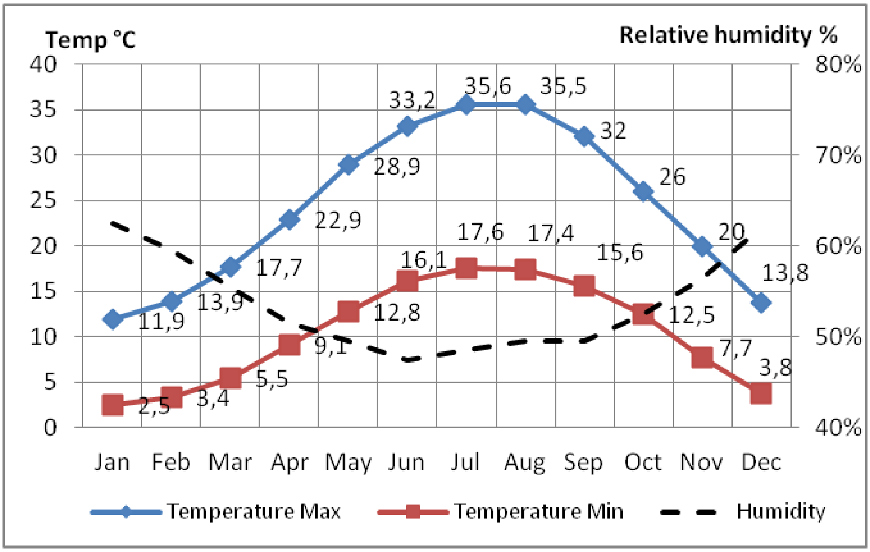


Fig. 1 Temperature and relative humidity in Damascus (average values for the period 1961–90).

Materials and methods

A combination of measurements and structured interviews was used for assessing different thermal environments to simultaneously determine user's thermal perception through investigating different thermal indices.

Selection of measurement locations and time-periods

The locations selected were divided into three categories: two types of residential areas and parks. These three categories represent the most common environments in Damascus. The first category – residential areas in modern Damascus – contained three measurement locations: Al Gassany area (circle 1 in Fig. 2), the New Dummar area (circle 2 in Fig. 2) and the Barzza area (circle 3 in Fig. 2). The second category – Old Damascus – contained a deep canyon: Al

Qaymarieh Street (circle 6 in Fig. 2). The third category – parks in modern Damascus – contained two locations: Al Tigara Park (circle 4 in Fig. 2), and Al Mazza Park (circle 5 in Fig. 2). The measurement sites are also shown in Fig. 3.

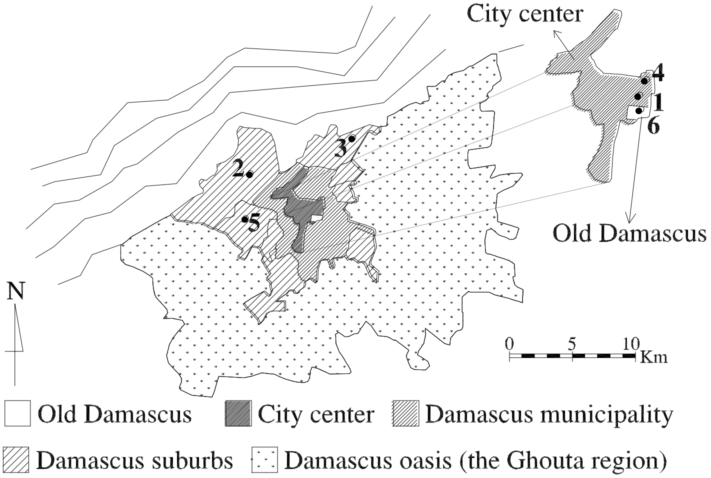


Fig. 2 Locations of the measurement sites on a simplified map of the city of Damascus which is located between the Kassioun mountain chain in the northwest and an oasis in the south.
See Fig. 3 for description of the sites.

Fig. 3 Measurement sites in the city of Damascus, where 1 is Al Tigara park, 2 is Al Gassany area, 3 is New Dummar area, 4 is Barzza area, 5 is Al Mazza park, and 6 is Old Damascus.

The investigation was carried out during the hottest and coldest seasons; during August and September 2009 for the summer, and during January and February 2010 for the winter. Northwest–southeast (NW–SE), northeast–southwest (NE–SW), and east–west (E–W) street orientations were included in the measurements as well as open spaces in parks. In all six locations, the fieldwork was scheduled mainly during the three hours starting from around noon since this time is the hottest time of the day. However, in order to extend the study of thermal comfort – to get a greater variety in microclimatic conditions – measurements were also carried out in the morning in the Barzza area and in the evening in old Damascus. See Table 1.

Table 1 Orientation and land use of the measurement locations as well as date, and time of measurements.

Category	Location's name	Orientation	Land use	Date of measurements	Time of measurements
Modern Damascus	1-Al Gassany	NW– SE	Residential road	13-08-2009 10-01-2010	13:00 to 15:00 12:15 to 15:25
	2-New Dummar	---------------	Residential space	15-08-2009 24-01-2010	12:40 to 14:40 12:35 to 14:30
	3-Barzza	NE– SW	Residential and commercial space	18-08-2009 26-09-2009 31-01-2010 06-02-2010	13:20 to 15:00 08:50 to 11:35 11:55 to 14:35 08:00 to 11:11
Old Damascus	6-Al Qaymarieh street	E–W	Residential, commercial and recreational road	19-08-2009 30-09-2009 06-02-2010 05-02-2010	12:30 to 14:20 15:30 to18:15 12:10 to 15:10 16:30 to 18:30
Public parks	4-Al Tigara Park	---------------	Recreational space	12-08-2009 17-01-2010	13:00 to 14:40 11:45 to 15:05
	5- Al Mazza Park	---------------	Recreational space	17-08-2009 05-02-2010	12:50 to 15:00 11:50 to 15:10

The official climatic data in Damascus during the measurement periods are shown in Table 2. It can be seen that the measurement days during summer were all similar to a normal day in August (see Fig. 1) whereas in winter, the weather varied considerably.

Table 2 Official climatic data for the period of the fieldwork in summer and winter seasons (air temperature, relative humidity, and wind speed).
Source: Damascus airport meteorological station.

Date	Max. air temp. (°C)	Min. air temp. (°C)	Rel. humidity (Average) (%)	Wind speed (Average) (m/s)
12-Aug[a]	37.0	17.3	33	3.2
13-Aug[a]	37.4	18.0	33	4.1
15-Aug[a]	38.2	19.8	38	4.4
17-Aug[a]	39.4	20.0	31	5.4
18-Aug[a]	39.6	19.0	37	5.4
19-Aug[a]	37.8	20.0	40	5.1
10-Jan[b]	20.2	2.00	47	1.5
17-Jan[b]	19.7	7.00	54	4.0
24-Jan[b]	14.0	4.80	84	6.4
31-Jan[b]	19.5	5.60	67	4.0
05-Feb[b]	9.50	0.00	45	4.7
06-Feb[b]	9.80	–5.0	53	1.2

a Measurement days during the summer time (August 2009) for the six studied locations.
b Measurement days during the winter time (January and February 2010) for the six studied locations.

Microclimatic measurements

The measurement equipment was placed at the points where people could be expected to sit or walk. Air temperature (Ta), globe temperature (Tg), relative humidity (RH), wind speed (W) and wind direction (Wd) were measured. The measured microclimatic variables, measurement instruments, and their accuracy are presented in Table 3. The measurements in Al Gassany area, the Barzza area, and Al Mazza park where mainly conducted under the sunshine, whereas in Al Tigara park and Al Gassany area, the measurements were conducted partly in shade. Furthermore, the measurements in Old Damascus were completely in shade due to the high aspect ratio. Three areas – Al Gassany area, Old Damascus, and Al Mazza park – which represent the three studied categories of urban environments in Damascus were studied more in detail. Fig. 4 shows the urban characteristics of these three areas.

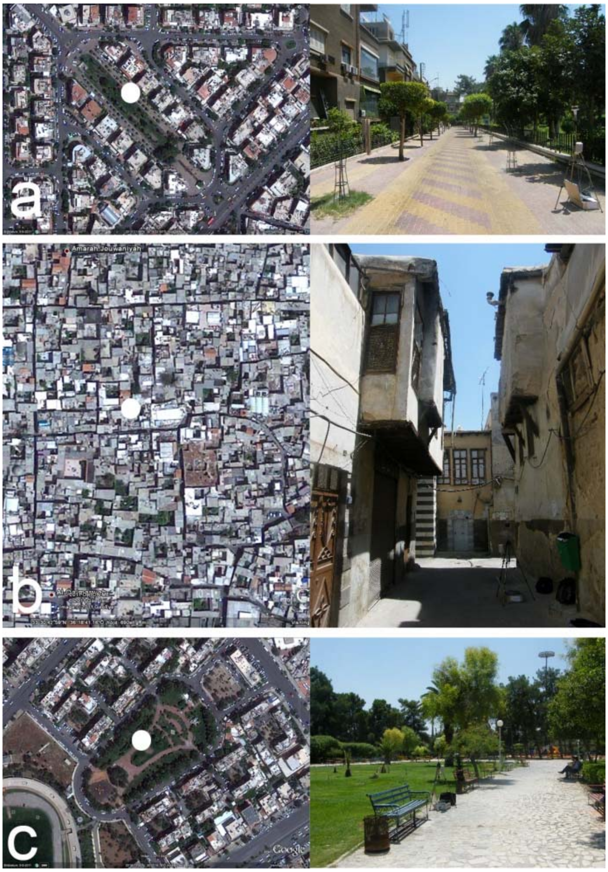


Fig. 4 Urban characteristics and measurement spots in (a) Al Gassany area, (b) Old Damascus and (c) Al Mazza park.

Table 3 Measured microclimatic variables, instruments, and accuracy of the instruments.

Variable[a]	**Instrument**	**Accuracy**
T_a	Rotronic Hydroclip S3	±0.3%°C
T_g	Pt100 in a grey plastic ball	±0.3°C at 0°C
RH	Rotronic Hydroclip S3	±1.5% RH
W, W_d	Gill WindSonic anemometer	±2%@12m/s

a Ta = air temperature, Tg = globe temperature, RH = relative humidity, W = wind speed, Wd = wind direction.

For all measurements except wind, the height of the equipment was 1.1 m, which corresponds to the average height of the centre of gravity for adults (Mayer and Höppe 1987). The wind speed was measured at the height of 2 m, but it was later extrapolated down to 1.1 m using the following formula:

$$W_{1.1} = W_{2.0} \times (1.1/2.0)^{0.25} \qquad (1)$$

Where $W_{1.1}$= wind speed at the height of 1.1 m, and $W_{2.0}$= wind speed at the height of 2 m. Furthermore, the mean radiant temperature (MRT) was calculated using the following formula (Thorsson et al. 2007):

$$MRT = \left[(T_g + 273.15)^4 + \frac{1.335\times10^8\, W^{0.71}}{\varepsilon D^{0.4}} \times \left(T_g - T_a\right)\right]^{\frac{1}{4}} - 273.15 \qquad (2)$$

Where T_g = the globe temperature (°C), W = the air velocity (m s^{-1}), T_a = the air temperature (°C), D = the globe diameter = 40 mm, ε = the globe emissivity = 0.97.

Calculation of outdoor thermal comfort indices

A great number of indices, which try to predict the state of thermal comfort, mainly for indoor applications but also for outdoors, have been developed. The Predicted Mean Vote (PMV), the Standard Effective Temperature (SET*) and the New Effective Temperature (ET*) were all developed for indoors (McIntyre 1980). In addition, many indices have been primarily designed for outdoor applications, e.g., the Perceived Temperature (PT), which is based on the comfort equation of Fanger (Jendritzky et al. 2000), OUT_SET*, which is an adaptation of SET* for outdoor use (Pickup and de Dear 2000), and the Physiological Equivalent Temperature (PET) (Höppe 1999). In this study, PET, OUT_SET*, ET*, and PMV have been used to assess and evaluate the outdoor thermal environment in Damascus. The RayMan PC application (Matzarakis et al. 2007) was used to calculate PET, whereas the ASHRAE Thermal Comfort Program (Fountain and Huizenga 1994) was used to calculate the OUT_SET*, ET*, and PMV indices.

Structured interviews

A questionnaire survey was performed at the same time as the measurements in each location in order to compare the actual thermal perception with the calculated thermal indices derived from the microclimatic measurements. A structured interview form was designed to assess the people's thermal perception and other parameters such as gender and age, clothing, reason for being in the places, time spent outdoors, thermal preference, assessment of the microclimate, aesthetic qualities of the place, emotional state, and assessing the attitude to urban outdoor exposure. However, this paper discusses only the results about thermal comfort perception, activity and clothing. The structured interview forms were not answered by people individually but by support from an assistant group belonging to Damascus University. Each interview took an average of 5 min to complete. A total of 920 people in both summer and winter were interviewed by a random selection. In each season, there were 60 interviews in each location plus 50 interviews in the Barzza area in the morning and in Old Damascus in the evening. The majority of the interviewees were between 20 and 65 years of age. Of the total sample 76% were male and 24% female. This percentage, which was similar in all areas in both seasons, reflects the fact that fewer women than men are present in public space for cultural reasons. The subjects were asked to report their thermal perception according to a 9-point scale: very cold, cold, cool, slightly cool, comfortable, slightly warm, warm, hot, and very hot.

Assessment of transition and neutral temperatures

To determine transition temperatures – i.e. the index temperatures at which the thermal sensation changes from one zone to another, e.g. from comfortable to slightly warm – as well as the neutral temperature, which is defined as the temperature at which people feel thermally neutral (neither cool nor warm) and which corresponds to the value zero in the thermal sensation scale, probit technique (Ballantyne et al. 1977) was used. The probit method to analyze subjective votes of thermal sensation allows unequally large thermal sensation ranges. After investigating the comfort range separately for the summer and winter by using probit analysis, the neutral temperatures were determined by using two different methods. In the first, they were calculated as the average values of the upper and lower limits of the comfort range. In the other method, the sample was split by grouping all thermal sensation votes (TSV) < 0 into a group of cooler than neutral, and all votes TSV > 0 into a group of warmer than neutral. The votes TSV = 0 were randomly split between the groups TSV < 0 and TSV > 0. The neutral temperature was then determined as the index temperature at which 50% of the sample voted cooler than neutral and 50% voted warmer than neutral. SPSS 18 (Statistical Package for the Social Sciences Software for Windows) was used to perform the probit analysis.

Results

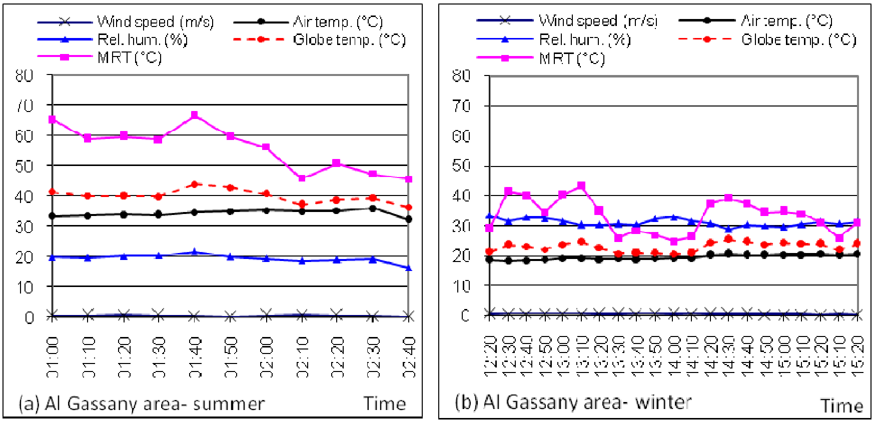
Microclimatic variations

Table 4 shows the variations of measured Ta, RH, W, and MRT in summer and winter for all locations. Table 4 illustrates the considerable differences between the seasons. However, the average values of wind speed were nearly the same (0.7 m/s in the summer and 0.8 m/s in the winter). The results also show the microclimatic differences between the old and the modern part of Damascus, especially in summer, due to completely different urban design features in terms of aspect ratios, building materials, and building geometries (Figs. 3 and 4). The reason why the average values of MRT in Al Gassany area and Al Tigara park in the summer were lower than the values in other locations in modern Damascus was due to the shade from trees that affected the measurements. For both seasons it was noticed that high values of MRT are not necessarily correlated with high values of Ta.

Table 4 Average values of measured air temperature (Ta), relative humidity (RH), wind speed (W), and mean radiant temperature (MRT) in summer and winter in all locations. The measurements were taken on different days in the afternoon, unless otherwise stated.

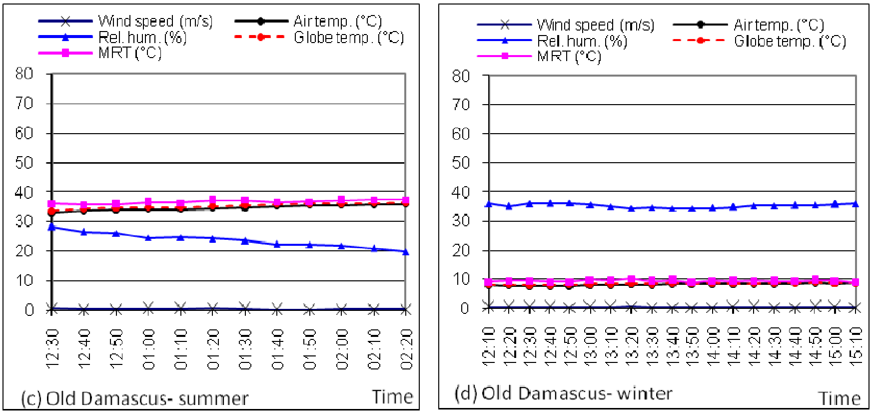
Location	**Avg T_a °C**		**Avg RH %**		**Avg W m/s**		**Avg MRT °C**	
	Summer	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**
Al Gassany area	34.0	19.5	20.2	30.5	0.7	0.6	59.4	34.2
Dummar area	36.3	9.7	18.9	74.2	0.7	0.8	69.8	11.7
Barzza area	36.9	9.8	18.1	73.3	0.9	0.8	71.4	13.4
Al Tigara park	30.8	15.4	31.6	46.7	0.9	0.8	58.3	28.5
Al Mazza park	37.0	6.7	18.1	42.4	1.0	1.4	70.6	36.2
Old Damascus	34.4	8.3	24.3	35.1	0.4	0.3	36.5	9.3
Barzza area (morning)	31.1	8.0	20.5	35.8	0.5	0.4	61.6	35.2
Old Damascus (evening)	26.9	5.6	23.2	40.7	0.4	0.8	27.4	5.4
All locations Avg	33.4	10.4	21.8	47.3	0.7	0.8	56.9	21.7

Fig. 5 shows the characteristics of the thermal environment and spatial variations for Al Gassany area, Old Damascus, and Al Mazza park as examples of the three studied categories which represent the outdoor urban environment in Damascus. It can be seen that for the summer Ta was similar in magnitude and nearly stable during the measurement period in all three locations. Tg, and consequently the MRT, varied greatly between different sites. The values were higher in Al Mazza park than in Al Gassany area. The values in Old Damascus were considerably lower than in the two other places. The instability of T_g and MRT in Al Gassany area was due to the positioning of the measurements equipment, which was mounted beside a pedestrian path under a row of small trees where the globe thermometer during the measurement period was alternately in shade. For the winter, there were major differences between the studied areas in terms of Ta, Tg, RH, and MRT and this is mainly because the weather was changing from one day to another during the measurement period (Table 2) and sometimes the change even occurred during the measurements (Fig. 5f).



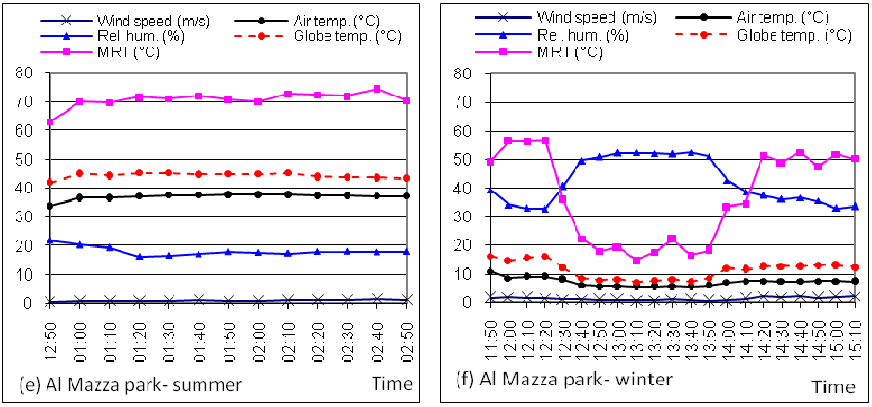
(a) Al Gassany area- summer

(b) Al Gassany area- winter



(c) Old Damascus- summer

(d) Old Damascus- winter



(e) Al Mazza park- summer

(f) Al Mazza park- winter

Fig. 5 Results of microclimate measurements in Al Gassany area, Old Damascus, and Al Mazza park during the summer and winter seasons.

Calculation of thermal comfort indices

Table 5 shows the calculated PET, OUT_SET*, ET*, and PMV for all studied locations. For all indices, the results reveal that in the summer Old Damascus is less stressful than the outdoor urban spaces in modern Damascus, whereas in winter, Old Damascus is colder than the other areas due to the lack of solar exposure as a result of the high building density. In summer, Al Gassany area and Al Tigara park, where there was some shade from trees, were less stressful than the other sites in modern Damascus where the measurement spot was exposed to sunshine all the time.

Table 5 shows that the average values of the PET index are higher in summer and lower in winter than the average values of both the OUT_SET* and ET* indices. ET*, in turn, has higher values in summer and lower in winter than OUT_SET*. One of the reasons why PET and ET* have more extreme values is that they do not take clothing and activity into account as input variables. Another reason why OUT_SET* is slightly lower than ET* in the summer may be because the effect of wind speed is included in the calculation of OUT_SET* and not in ET*. For the PMV index, the calculated values in winter are within the range from -3 (very cold) to +3 (very hot) except in Old Damascus in the evening. Only Al Gassany area was comfortable, i.e. within the comfort range of the index of -0.5 to +0.5 but this was mainly because the particular afternoon was exceptionally warm. In summer the values were in general well above the defined range of PMV and reached as high as 8 in the Barzza area. Only the values of Old Damascus, both during the day and in the evening, were within the defined scale of PMV.

Table 5 Average calculated values in summer and winter in all locations for the physiological equivalent temperature (PET), the outdoor standard effective temperature (OUT_SET), the new effective temperature (ET*), and the predicted mean vote (PMV). The values are from different days in the afternoon, unless otherwise stated.*

	Avg PET °C		**Avg OUT_SET* °C**		**Avg ET* °C**		**Avg PMV**	
	Summer	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**
Al Gassany area	46.1	23.2	36.0	27.6	36.7	23.9	5.5	0.2
Dummar area	53.3	7.2	38.4	15.6	38.4	10.6	6.5	-2.8
Barzza area	54.0	7.8	38.2	15.8	39.3	11.2	8.0	-2.5
Al Tigara park	42.7	17.2	34.6	21.3	36.1	19.9	4.8	-1.6
Al Mazza park	53.2	11.1	37.9	19.4	39.1	15.2	7.7	-2.1
Old Damascus	35.3	6.7	32.3	14.4	31.9	8.6	2.9	-2.2
Barzza area (morning)	46.1	17.1	36.2	23.5	36.9	19.3	5.7	-1.1
Old Damascus (evening)	26.3	2.0	25.7	9.9	25.5	5.5	0.5	-3.9
All locations Avg	44.6	11.6	34.9	18.4	35.5	14.3	5.2	-2.0

Subjective thermal perception

Fig. 6 illustrates the clear differences between people's subjective thermal perception in summer and winter for all studied locations together. The result shows that the people's thermal perception in summer is between cool and very hot, whereas in winter it is between very cold and hot. The highest percentage of people feels comfortable in the winter time, whereas they feel hot in the summer time. The reason why the distribution of the comfort votes was widely spread in both summer and winter is due to the varying weather conditions between the measurement days (especially in winter) but also due to individual differences of people's thermal perceptions. A similar difference in distribution between seasons was found in Sydney, Australia, by Spagnolo and de Dear (2003).

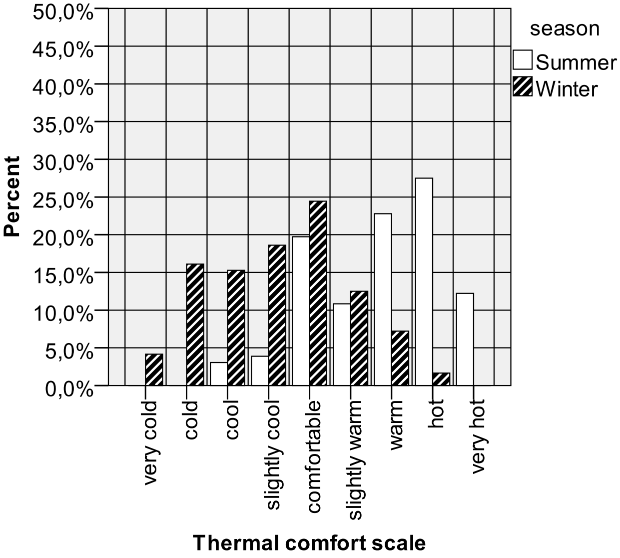


Fig. 6 Percentage frequencies for people's thermal perception in the summer and winter seasons.

Relationship between thermal sensation votes and thermal indices

When comparing the relationship between TSV and the calculated indices it was found that the original thermal sensation scales of these indices (PET, OUT_SET*, ET*, and PMV) often do not correspond to people's actual thermal perception in Damascus. Fig. 7 shows the relationship between TSV and the index temperatures for PET and OUT_SET*. At all index temperatures there is a wide spread of votes. This reflects the variations in people's thermal perception which supposedly is due to differences in thermal history, emotional state, etc as well as individual thermal preferences. For the PET index variations are also caused by differences in activity and clothing,. The regression lines for all the tested indices for both seasons are as follows:

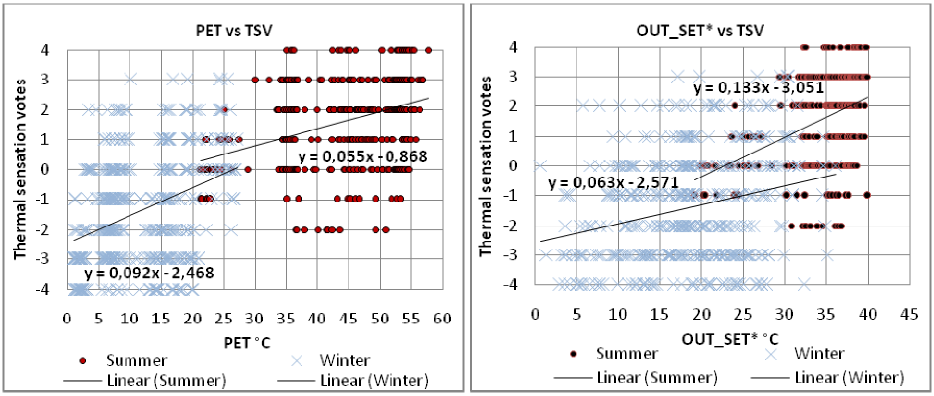


Fig. 7 Relationship between people's thermal sensation votes (TSV) and (a) the PET index and (b) the OUT_SET index in summer and winter where the scale of actual thermal sensation is between very cold (–4) and very hot (+4).*

PET
Summer
TSV= 0.055 PET – 0.868 (R^2= 0.12) (3)
Winter
TSV= 0.092 PET – 2.468 (R^2= 0.13) (4)

OUT_SET*
Summer
TSV= 0.133 OUT_SET* – 3.051 (R^2= 0.14) (5)
Winter
TSV= 0.063 OUT_SET* – 2.571 (R^2= 0.061) (6)

ET*
Summer
TSV= 0.100 ET – 1.966 (R^2= 0.095) (7)
Winter
TSV= 0.094 ET – 2.753 (R^2= 0.115) (8)

PMV
Summer
TSV= 0.154 PMV – 0.814 (R^2= 0.074) (9)
Winter
TSV= 0.215 PMV – 0.969 (R^2= 0.054) (10)

The distribution of people's answers reflects the real situation in summer and winter regarding the calculated thermal comfort and people's perception. In this case, the R^2 for all studied indices varied between 0.054 and 0.14. If instead the average TSV is calculated for bins of 3°C index temperatures, the R^2 increases to around 0.7 for all studied indices.

The slopes of the regression lines indicate the sensitivity to changes of the index values. In summer for PET, the slope is 0.055 corresponding to 18.2°C PET per actual thermal sensation unit, whereas in winter, the slope is 0.092 corresponding to

10.9°C PET per actual thermal sensation unit. This shows that people's thermal sensation is more sensitive to the variations of PET in winter than in summer. A similar tendency was found by Lin (2009) in Taiwan. In the case of the OUT_SET*, the slope for the summer is 0.133 which corresponds to 7.5°C, whereas in winter, the slope is 0.063 and it corresponds to 15.3 °C. This means that the people's thermal sensation is more sensitive to the variations of OUT_SET* in summer than in winter. A similar tendency was found by Lin et al. in Taiwan (2011). As for ET* and PMV people's thermal sensation is more sensitive to the variations in winter than in summer.

Thermal comfort zones and neutral temperatures

Table 6 illustrates the comfort zones and neutral temperatures in both summer and winter for PET and OUT_SET*. Both methods used to calculate the neutral temperatures gave similar results. For PET, the comfort zone in the summer is wider than in the winter, whereas for OUT_SET*, the comfort zone in winter is wider than in summer. The neutral temperatures in the summer time for both PET and OUT_SET* are considerably lower than the neutral temperatures in the winter. It should be noted that in the winter there are few votes in the range of +1 to +4 and in the summer there are even fewer votes in the range –1 to –4. Thus, the upper limit of the winter comfort zones and the lower limit of the summer comfort zones are uncertain.

Table 6 Values of the comfort zones and neutral temperatures for the PET and OUT_SET indices in the winter and summer seasons.*

Index	**Comfort zone (°C)**		**Neutral temperature (°C)**	
	Winter	**Summer**	**Winter**	**Summer**
PET	18 – 28.7	6.7 – 24.9	23.4	15.8
OUT_SET*	25.6 – 44.6	15.9 – 30.3	35.1	23.1

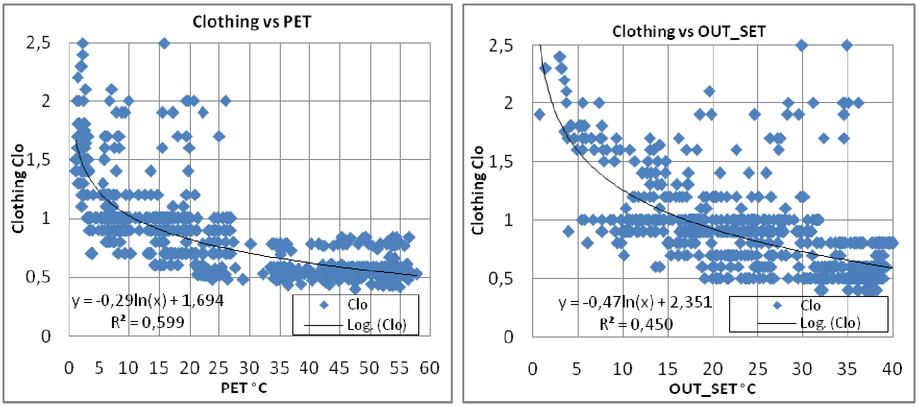
Relationship between clothing and activity and thermal sensation

Table 7 shows the reported average values of activity level and clothing insulation in all studied areas during summer and winter. In general, very small differences were found between areas and seasons in terms of people's physical activity and the reason is that during the fieldwork the people were mainly standing, walking slowly, or sitting. These actions represent the typical daily behaviour of the people in Damascus city in the outdoor urban environment both in summer and winter. On the other hand, the clothing values in summer time were significantly lower than the values in the winter due to the weather differences between these two seasons (see Table 7). However, the clothing levels were similar within each season except during the measurements in Al Tigara Park on 17 January, which was a warm winter day (see Table 2); on this day the clothing value was clearly lower than the other winter values.

Table 7 Reported average values of activity and clothing in all studied areas during the measurement periods for the summer and winter seasons.

Location name	**Activity (average) met**		**Clothing (average) clo**	
	summer	**winter**	**summer**	**winter**
Al Gassany area	1.6	1.6	0.56	0.96
Dummar area	1.7	1.5	0.57	1.00
Barzza area	1.4	1.6	0.56	0.99
Al Tigara Park	1.4	1.4	0.57	0.85
Al Mazza Park	1.4	1.6	0.58	1.02
Old Damascus	1.8	1.7	0.57	1.01
Barzza area (morning)	1.4	1.6	0.54	0.94
Old Damascus (evening)	1.6	1.5	0.59	1.00
All locations Avg	1.5	1.6	0.57	0.97

Fig. 8 shows the relationship between clothing and the thermal comfort indices PET and OUT_SET*. In the winter season, the distribution of clothing values is more widely spread than in summer. In winter, clothing values varied between 0.5 and 2.5, whereas in summer the values varied between 0.4 and 0.8.



(a) (b)

Fig. 8 Relationship between clothing and (a) the PET index and (b) the OUT_SET index in summer and winter.*

Discussion

Effect of urban geometry on microclimate

In summer, streets and parks in modern Damascus are more thermally stressful than the streets in Old Damascus. This reflects the strong influence of the urban geometry on the microclimate within built environments. Old Damascus has deep street canyons with high aspect ratios, which create a more comfortable microclimate since direct solar radiation and the mean radiant temperature decrease with the increase of the aspect ratio (Ali- Toudert and Mayer 2006). In contrast, the outdoor spaces in modern Damascus have a low aspect ratio and consequently these spaces are more exposed to solar radiation, which has a negative impact on outdoor thermal comfort. Moreover, few places in the studied areas of modern Damascus have been designed to protect against solar radiation, especially in the Barzza and New Dummar areas. However, in the parks and in Al Gassany area less stressful environments can be found due to the existence of shading trees.

In winter, it was more difficult to compare the microclimate qualities between the areas since the weather conditions varied from day to day during the fieldwork. Old Damascus was the coldest area and that is because of the cold weather on the measurement day as well as the deep canyon, which prevents the direct solar radiation to reach the ground. In contrast, Al Gassany area was most comfortable, and that is because of the warm weather on the measurement day as well as the fact that the urban geometry in Al Gassany area allows the solar beam to reach the ground.

Thermal comfort zones and neutral temperatures

The relationship between thermal sensation votes and the PET and OUT_SET* indices showed a wide spread. Similar patterns have been found by Thorsson et al. (2004) and Krüger and Rossi (2011). The large individual differences in thermal perception between the subjects may have many reasons. For PET, one reason is the clothing and activity factors that this index does not take into account. Other reasons are believed to be related to different thermal preferences, differences in thermal history and emotional state as well as the influence of aesthetic qualities of the place that affect the thermal perception (Knez and Thorsson 2006).

In this study, all the studied indices had basically the same tendency in assessing the outdoor physical urban environment in the hot dry climate of Damascus. The study of Spagnolo and de Dear (2003) found that many of the thermal comfort indices they tested were statistically better to predict the outdoor thermal comfort in summer than in winter due to the skewed nature of the winter sample in their study. In this study no significant difference could be found between summer and winter predictions which may be because both the summer and winter samples were skewed. This means that the lower values of the summer comfort zones and the upper values of the winter comfort zones are uncertain and it may also affect the neutral temperatures. In Table 8 the calculated thermal comfort ranges and neutral temperatures from this study in Damascus (see Table 6) are compared with results from some other studies.

Table 8 Comparison of neutral temperatures and comfort ranges of the PET index in different climates.

Climate	**Neutral temperature °C**		**Comfort range °C**		**Author**
	Summer	**Winter**	**Summer**	**Winter**	
Western/ middle Europe	n/a	n/a	18 – 23[a]		Matzarakis and Mayer 1996
Warm humid (Taiwan)	25.6[b]	23.7[b]	21 – 28.5[c]		Lin 2009
Subtropical (Sydney)	22.9	28.8	n/a	n/a	Spagnolo and de Dear 2003
Hot dry (Damascus)	15.8	23.4	6.7 – 24.9	18 – 28.7	This study

a Theoretical comfort scale for all seasons.
b The summer season in Taiwan is called hot season whereas the winter is called cool season.
c Defining one comfort range for the summer and winter together.

For the PET index, the neutral temperature for Damascus in the summer is lower than in the winter (Tables 8). This may seem surprising since one would expect the local population to be adapted to the weather conditions in each season. However, the results agree with those of Spagnolo and de Dear (2003). They explained the phenomenon by applying the concept of alliesthesia which is a psychological mechanism explaining the differences in sensation between seasons, i.e. if people feel warm then anything which makes them feel colder will be pleasant and vice versa. Conversely, the results disagree with the results for Taiwan where Lin (2009) found a slightly higher neutral temperature in summer than in winter.

In the case of OUT_SET*, Table 9 shows that the winter neutral temperature in Damascus is higher than the summer one and the difference between the summer and winter neutral temperatures is 12°C. This agrees well with the results in subtropical Sydney (Spagnolo and de Dear 2003) where the difference was also around 12°C. Moreover, the summer neutral temperatures in Damascus (23.1°C) and in Sydney (23.3°C) were almost equal. However, Lin et al. (2011) higher neutral OUT_SET* in the hot season (29.3°C) than in the cool season (28°C) and the difference between these two is only 1.3°C.

This study has defined different thermal comfort ranges for the summer and winter, whereas the other studies defined only one comfort range for both summer and winter. The reason to study the seasons separately is that people have adapted themselves differently to each season physiologically and psychologically as well as in terms of behaviour (e.g. clothing). However, due to the uncertainty of the upper winter value and lower summer value, a common comfort range for both summer and winter based on the lower winter value and the upper summer value could be created. For the PET index this range will in our case be 18.0–24.9°C. This agrees fairly well with the Central European comfort range from 18–23°C (Matzarakis and Mayer 1996). For OUT_SET* the range will be 25.6–30.3°C.

Table 9 Comparison of neutral temperatures and comfort ranges of the OUT_SET index in different climates.*

Climate	Neutral temp °C		Comfort range °C		Author
	Summer	**Winter**	**Summer**	**Winter**	
Subtropical (Sydney)	23.3	33.3	n/a	n/a	Spagnolo and de Dear 2003
Hot dry (Damascus)	23.1	35.1	15.9 –30.3	25.6 – 44.6	This study
Warm humid (Taiwan)	29.3	28	n/a	n/a	Lin et al. 2011

Clothing and thermal comfort

Many studies have investigated the relationship between clothing and thermal comfort. Andrade et al. (2011) concluded in their study in Lisbon that the clothing values varied between 0.24 and 1.75 mainly as a result of seasonal and daily variations in air temperature and wind conditions. Similarly, the studies of Nikolopolou and Lykoudis (2006) in different countries in Europe and Lin (2009) in Taiwan found a strong relationship between average air temperatures and clothing. Lin (2009) also found a strong relationship between the PET and clothing values and concluded that changing clothing is one of the individual ways of thermal adaptation. As expected, this study found that the insulation value of people's clothing tend to decrease with increasing temperatures. The summer (hot season) values in this study are similar to those of Taiwan – around 0.6 clo. The winter (cool season) values are however much higher in Damascus due to much colder winters. This study has shown that in the case of Damascus, the choice of clothing is to some extent also linked to cultural aspects. In the winter, high clothing values occur also at fairly comfortable temperatures. These clothing values are represented by the values far above the regression curves in Fig. 8a and 8b. Thus in the winter, some people adjust their clothing according to the weather, whereas others use heavy clothing although it is fairly warm. The latter explains why there are high OUT_SET* values (up to 36°C, see Fig. 7b) also in winter. Also in summer, there is a tendency at high PET values that some subjects have heavier clothing (clo about 0.8) than the rest (clo 0.4 – 0.6). Thus, the dress code of some of the people of Damascus seems to depend on cultural traditions rather than climate whereas most people choose their clothing according to the weather conditions when they feel thermally uncomfortable.

Thermal comfort limits for urban design in Damascus

This study could not identify any of the tested thermal indices as more suitable than the other and choosing indices will depend on the aim of the study. However, among the tested indices ET* does not take variations in wind speed into account and is thus less suitable for this reason. If the aim is only to assess and evaluate the physical environment independently from the people's sensations, e.g., if the aim is to compare the thermal comfort of different design proposals through simulations, the urban designer or researcher can use any of other the indices tested in this study. If on the other hand, the aim is to assess the thermal environment taking into account people's thermal sensation, one can use an index that takes clothing and activity into account such as OUT_SET* or PMV. The use of these indices however requires knowledge – or at least an estimate – about people's clothing and activity. The fact that OUT_SET* is expressed in °C makes it easier to interpret than PMV.

The results of this study give valuable information of which comfort limits urban designers in Damascus should aim at. The primary aim should of course be to reach the thermal comfort zone. However, the combined winter and summer comfort zones of PET (18.0 – 24.9°C) and OUT_SET* (25.6 – 30.3°C) suggested above may be difficult to achieve during the coldest and hottest periods of the winter and summer respectively. Since the outdoor environment is very complex with large microclimatic variations both spatially and temporally, and since people expect larger variations outdoors than indoors (Spagnolo and de Dear 2003), it seems reasonable to aim for thermal conditions within the acceptable range, i.e. from slightly cool (–1) to slightly warm (+1) as suggested by Lin (2009). Applying the probit technique to determine the index temperatures of the thermal sensation levels –1.5 and +1.5 resulted in acceptable thermal sensation ranges of 11.2 – 39.5°C for PET and 18.4 – 33.9 for OUT_SET*.

Conclusions

This study assessed the microclimate of the outdoor urban environment and investigated the relationship between different thermal comfort indices and people's actual thermal sensation in the hot dry city of Damascus. Thermal conditions of different outdoor environments vary considerably, mainly as a function of solar access. It was concluded that the urban design in Danascus needs to include well shaded spaces for pedestrians – e.g. by using high building density or vegetation – to protect pedestrians in summer as well as open spaces to provide solar access in winter.

Furthermore, this study defined the summer and winter comfort and acceptability zones for PET and OUT_SET* in hot dry Damascus. This is important information for urban designers aiming for a climate-conscious urban design. The study also showed the influence of culture and traditions on clothing. While most people choose the clothing according to the climate, some people in Damascus are influenced by their cultural traditions when they choose clothes to wear.

This study highlighted the importance of a climate-conscious urban design and design flexibility. It is important to consider microclimate and thermal comfort in the urban design process and requirements for a climate-conscious urban design should preferably be included in the planning regulations for cities such as Damascus. In addition, existing urban environments in Damascus could be modified in order to provide a better outdoor thermal environment. Such studies could enhance the thermal comfort and suggest improvements of the existing urban planning regulations.

Further studies are needed since this and other studies have shown that the actual thermal perception is not only affected by microclimatic parameters (air temperature, solar radiation, relative humidity, and wind speed) and personal parameters (people's activity and clothing). Future studies should look into other parameters such as the aesthetic qualities of the place, as well as psychological factors such as thermal history, emotional state, and attitude towards urban outdoor exposure.

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Paper 3

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The Influence of Environment on People's Thermal Comfort in Outdoor Urban Spaces in Hot Dry Climates – The example of Damascus, Syria

Moohammed Wasim Yahia, Erik Johansson.
Housing Development & Management, Lund University, Sweden.

Abstract

It is well known that the quality of outdoor urban spaces becomes one of the important items in the urban design process not only for ecological and economical purposes, but also it is important from the social point of view. This study is part of a project in the city of Damascus, Syria which aims to point out the impact of current urban design on microclimate and outdoor thermal comfort in a hot dry climate during summer and winter. The aim of this study is to examine the influence of urban spaces on people's thermal perception. The aim is also to examine how people experience the aesthetical quality of the urban design in the studied areas (beautifulness, pleasantness). The study also examines the influence of the use of air conditioning devices on people's thermal perception. This study is based on over 720 structured interviews during summer and winter. Results show clear differences between people's thermal perception in both summer and winter seasons. Moreover, people's perception of pleasantness and beautifulness is influenced by the weather and climate. On the other hand, no significant impact could be found for the influence of air conditioning devices on people's outdoor thermal perception.

Keywords: Hot dry climate; Outdoor thermal comfort; Outdoor urban spaces; Thermal perception.

1. Introduction

In urban settlements, the concentration of people and their activities create intensified demands on the environment. However, this concentration offers opportunities, through microclimatic adaptation, design and actions at an urban scale to minimize the impact on the ecosystem of the region without causing damage. It can then be said that a level of sustainable existence has been reached at which the community can live in symbiotic harmony between design, microclimate, and its environment. On the other hand, it is well known that the quality of outdoor urban spaces becomes one of the important items in the urban design process not only for ecological and economical purposes, but also it is important from the social point of view.

Efforts by public agencies and private interest groups to revitalize the central business districts in urban environments have often included large expenditures for outdoor pedestrian spaces. Many such amenity spaces have failed to receive more than light use. This failure has been attributed partly to a general disregard for the physical-comfort needs of the users [1].

The need for thermal comfort is ubiquitous, but it seems often to be forgotten in the designs of outdoor spaces. On the other hand human comfort and energy use of buildings are affected by the local climate conditions within the urban canopy [2] and the microclimate in the urban environment may have a great influence on thermal comfort and the human body.

In warm climates, it is well known that mental and physical performance deteriorates at high temperatures and that heat stress may lead to heat- related illness [3]. Moreover, when the body´s adaptive mechanisms to heat stress fail to keep core body temperature close to 37°C, a number of physiological disorders can occur. Among the more common are: Heat exhaustion, heat stroke, heart attack [4].

Thermal comfort is defined as the condition of mind which expresses satisfaction with the thermal environment [5]. Variables of thermal comfort are the air temperature, radiant temperature, relative humidity, air velocity, activity and clothing [6]. The microclimatic factors are affected by the urban surface and at a given point; these factors affect the human activities from ground level up to 2 m height.

Recently, the importance of the concept of thermal comfort can be noticed in the latest related scientific researches. Some studies have focused on the influence of urban design and urban geometry on outdoor thermal comfort [7, 8]. Some others have focused on thermal comfort and outdoor activity in urban public places [9]. Others tried to study the thermal perception, adaption and attendance in urban public spaces [10].

This study is part of a project in the city of Damascus, Syria (see Figure 1).which aims to point out the impact of current urban design on microclimate and outdoor thermal comfort in a hot dry climate during summer and winter. This is an area of research which has received little attention in the Middle East from the architectural perspective and it would be the first study of its kind in Damascus.

The main aim of this study is to examine the influence of outdoor urban spaces on people’s subjective perception of thermal comfort. The aim is also to examine how people experience the thermal environment in outdoor urban spaces during summer and winter time in Damascus as an example of the hot dry climate.

This study is based on over 720 structured interviews to evaluate people’s actual thermal perception and to estimate the aesthetical qualities of places in six different types of outdoor spaces in Damascus city (streets, parks, spaces between buildings). This study also takes into account the influence of the use of air conditioning devices on people’s thermal perception in outdoor urban spaces.

Figure 1: The location of Damascus city in Syria.

2. The city of Damascus

The city of Damascus (Elevation: 620 meters, Latitude: 33.5°N, Longitude: 36.5°E) is located in south–west of Syrian Arab Republic in the Middle East.

Damascus (Latitude: 33.5°N) has a hot dry climate but it is actually located on the limit of hot dry zone which is normally found between latitudes 15° and 35°. Damascus has two main parts:

1. The old part. Old Damascus has a wealth of historical sites dating back to many different periods of the city's history. It has a regular planning in general; with streets oriented N–S and E–W. Typical style of architecture in Old Damascus is simple from outside and rich from inside with an inward orientation to the courtyards. Narrow streets and canyons are the main form of outdoor urban spaces in Old Damascus.

2. The modern part. The approach to urban design changed radically during the French colonial period 1920–1945. New areas were built with wide streets in a grid pattern and buildings were outwardly oriented [11]. The current features of architecture in modern Damascus were derived from the master plan made by French architect Michel Ecochar. Ecochar presented the new master plan for Damascus in 1968 and in addition he developed new planning regulations for Damascus which determined urban form for a duration of 20 years 1965–1985. Michel Ecochar's master plan and his planning regulations were the essential documents when updating the next urban regulations in Damascus in 1997.

3. Climate in Damascus

Damascus has hot sunny summers from June to August and mild winters from December to February. Snowfall is common in winter on the mountains surrounding Damascus. Summer temperatures can reach in excess of 35°C during the day, but evenings are generally cool. Spring and autumn are the most comfortable periods, averaging 22°C during the day.

The average maximum air temperature according to the weather stations for the period 1961–1990 in Damascus during summer time is 35.6°C and the average minimum temperature during summertime is about 17.6°C. On the other hand, the average maximum air temperature during winter time is about 13.9°C while the average minimum air temperature during winter time is about 2.5°C, see Figure 2.

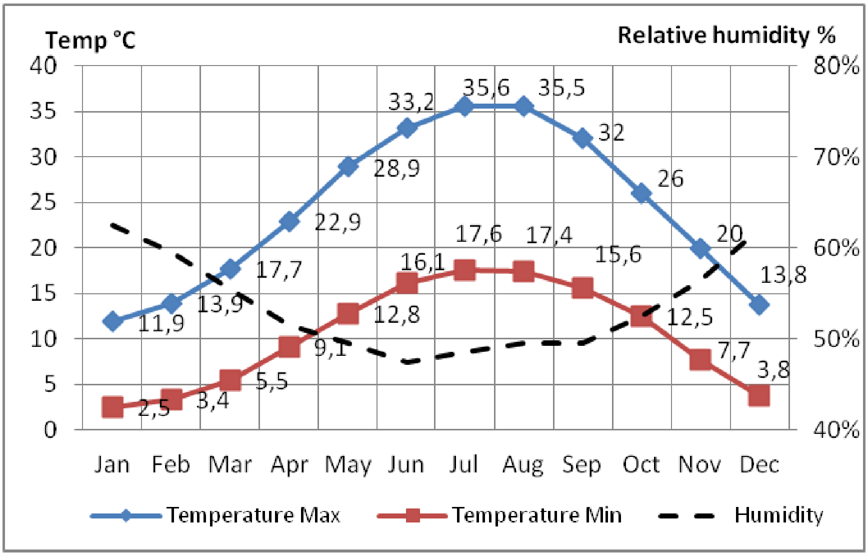

Figure 2: The average values of temperature and relative humidity in Damascus city for the period 1961–90.

4. Materials and methods

Field measurements and a questionnaire survey were conducted during summer and winter in Damascus City to describe different thermal environments as well as to determine outdoor thermal comfort. However, this paper discusses only the survey study.

Since the summer and winter seasons in Damascus have the most extreme weather, the study was only conducted during August and September 2009 for the summer, as well as during January and February 2010 for the winter time. In both summer and winter seasons, a survey in outdoor physical environment was carried out through structured interviews, collecting data about thermal sensation, clothing and people's activities both in old and in modern Damascus.

4.1 Sample

The sample of this study contained 720 participants of which 360 in the winter season and 360 in the summer season. Six locations were selected for case studies and 60 interviews were conducted in each location. The interviewees were between 20 and 65 years of age of which 78% were males and 22% were females.

4.2 Environment of the studied areas

Since outdoor thermal comfort is of importance for residential areas as well as for parks in Damascus, six locations were selected for case studies and were divided into three kinds of categories. The purpose of dividing those six locations into three categories was to study various physical environments in Damascus in order to see the differences between them concerning outdoor thermal comfort and its relationship with urban design. The first category – outdoor spaces in modern Damascus – contained three studied areas: Al Gassany area which is located in the east of Damascus, see number 2 in Fig. 3, New Dummar area which is located in the west of Damascus, see number 3 in Fig. 3, and Barzza area which is located in north east of Damascus, see number 4 in Fig. 3. The second category – outdoor spaces in Old Damascus – contained only deep canyons and narrow streets and Al Qaymarieh Street was selected to represent Old Damascus, see number 6 in Fig. 3. The third category – parks in modern Damascus – contained two measurement areas: Al Tigara Park which is located in the east of Damascus, see number 1 in Fig. 3, and Al Mazza Park which is located in the west of Damascus, see number 5 in Fig. 3.

The field study took place between 12:00 and 15:00 on both weekdays and weekends. At this time of the day, both the air temperature (Ta) and solar radiation reach their daily maximum, and all places have the most visitors. The field study was only performed on days without precipitation. Answers when precipitation occurred were excluded from the analysis.

Figure 3: The six urban spaces in Damascus for the case studies. Read section 4.2.

5. Results and discussion

In each season, a total of 360 people were interviewed in order to examine people's thermal perception, aesthetical qualities of places, and the influence of the use of air conditioning devices on people thermal perception.

5.1 Thermal comfort perception

Figure 4 illustrates the clear differences between people's answers concerning thermal comfort perception in both the summer and winter seasons (Chi-square = 294.6, P=.000, df = 8). Figure 4 shows that the people's thermal perception in the summer time is between cool and very hot, whereas in winter time their thermal perception is between very cold and hot. The majority of people feel comfortable in the winter time whereas they feel hot in the summer time. The result shows that the distribution of the answers are widely spread in both summer and winter seasons and that this is because of differences of people's thermal perceptions besides the complexity of the outdoor thermal environment concerning the weather conditions. A similar distribution between the summer and winter seasons has been found in the subtropical climate of Sydney, Australia [12].

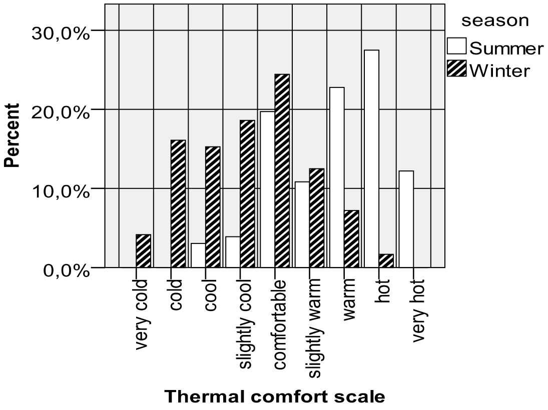

Figure 4: Percentage frequencies for people's thermal perception in both summer and winter seasons.

5.2 Aesthetical quality of the place

Figure 5 shows the percentage frequencies for the aesthetical quality of the places (beautifulness, ugliness). Result shows that the majority of the people, 72% and 82% in summer and winter respectively, experience the same places during the summer and winter seasons as beautiful whereas, only 18% and 13% in summer and winter respectively experience the places as neutral, and 10% and 5% in summer and winter respectively experience the places as ugly (Chi-square = 10.52, P=.005, df = 2). In addition, the results show that the people experience the same places in the winter season more beautiful than in the summer season. The results imply that, people's perception of beauty is influenced by the weather and climate. The result agrees with other studies in different climates [13].

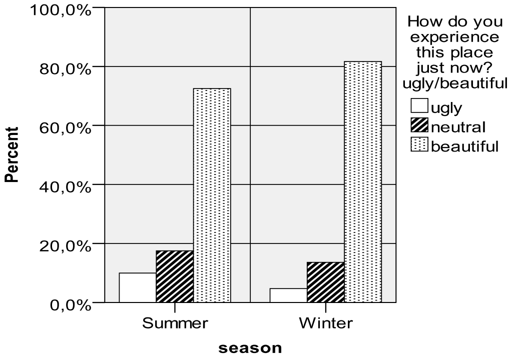

Figure 5: Percentage frequencies for people's perception of beauty in both summer and winter seasons.

Figure 6 illustrates the percentage frequencies for the aesthetical quality of the places (pleasantness, unpleasantness). Result shows that the majority of the people, 68% and 78% in summer and winter respectively, experience the same places during summer and winter seasons as pleasant whereas, only 19% and 16% in summer and winter respectively experience the place as neutral, and 13% and 6% in summer and winter respectively experience the place as unpleasant (Chi-square = 11.14, P=.004, df = 2). In addition, result shows that the people experience the same places in the winter season more pleasant than in the summer season. The results imply that people's perception of pleasantness is influenced by the weather and climate. The result agrees with other studies in different climates [14].

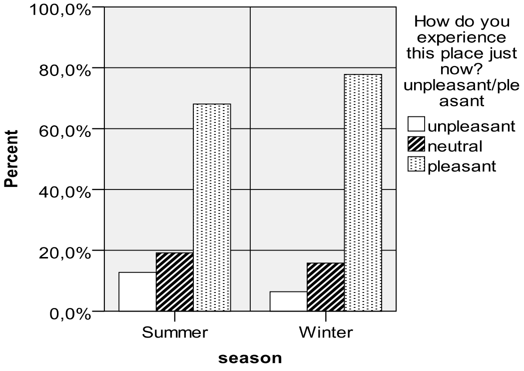

Figure 6: Percentage frequencies for people's perception of beauty (pleasantness) in both summer and winter seasons.

5.3 The influence of air conditioning devices on thermal comfort

Since Damascus has a hot dry climate, people usually have air conditioning devices either at home or at work. Figure 7 shows the percentage frequency in summer and winter seasons for people who use the air conditioning devices and for those who do not. The result shows that around 73% of the interviewees use air conditioning devices whereas, 27% of the interviewees do not use them. Thus, air conditioning devices in Damascus city are widely used during summer and winter time either for heating or for cooling purposes. This can be explained by the lack of the comfortable conditions and the need for better thermal adaption between indoor and outdoor environment.

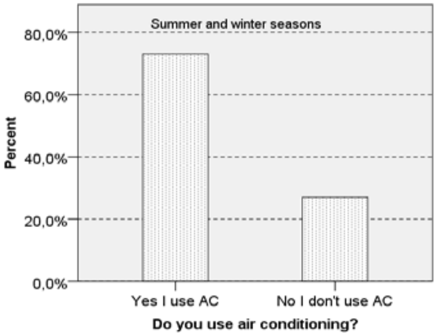

Figure 7: Percentage frequencies for people who use the air conditioning devices.

Figure 8 shows the influence of the use of air conditioning devices on people's outdoor thermal perception in summer time. The result shows that there is no significant difference between the people who use air conditioning and those who do not concerning outdoor thermal perception (Chi-square = 6.3, P=.390, df = 6).

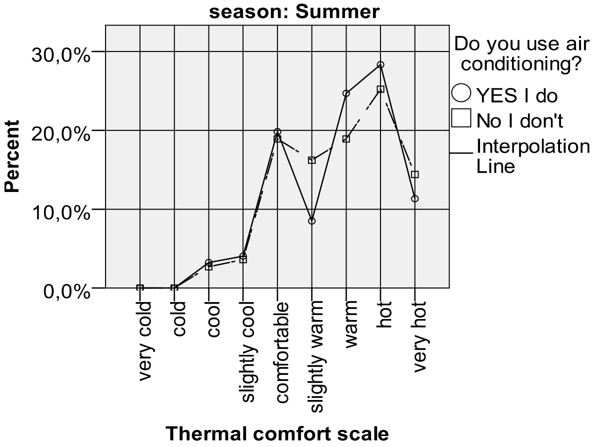

Figure 8: The influence of the air conditioning devices on people's outdoor thermal perception in summer season.

Figure 9 reveals the effect of the use of air conditioning devices on people's thermal perception in winter time. Figure 9 illustrates that there is no significant difference between the people who use air conditioning and the people who do not concerning outdoor thermal perception (Chi-square = 10.5, P=.162, df = 7).

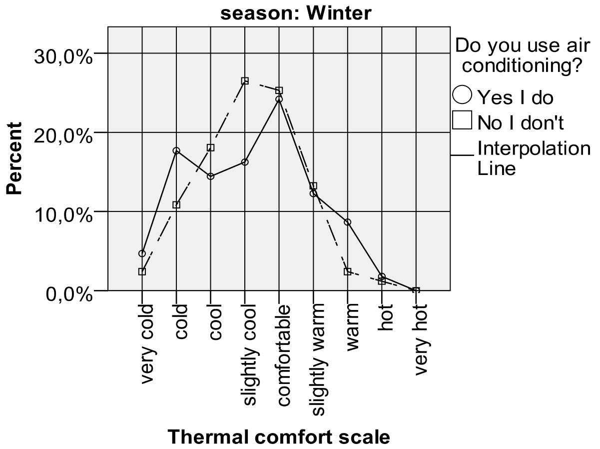

Figure 9: The influence of the air conditioning devices on people's outdoor thermal perception in winter season.

Consequently, there is no clear relationship between outdoor thermal perception and the use of air conditioning devices. The reason could be that people adapt quickly to their outdoor conditions in spite of the differences between indoor and outdoor environments.

Other studies for indoor environments reported that there is significant difference between the people who use air conditioning at home or in the office and the people who do not concerning thermal comfort perception [15].

6. Conclusions

As regards the thermal comfort in Damascus city, the influence of microclimate on people's thermal perception in the summer season is completely different from the influence in the winter season at the same places. In summer time, the study found that the majority of interviewees felt hot. This can be improved by enhancing the urban design [16] in Damascus city as well as by adding trees or shading devices [17] in order to provide shade for people who pass or linger on these places.

In spite of the differences in people's thermal perception at the same places between summer and winter seasons, people experience the places as beautiful and pleasant regardless of the differences in seasons. So the current urban design of the study areas has been recognized by interviewees as beautiful and pleasant. On the other hand, the beautifulness and the pleasantness of the place is affected by the quality of the urban design, In addition, thermal comfort is very well needed for enhancing the quality of the urban spaces especially in a hot dry climate. Therefore, the considerations of outdoor thermal comfort should be taken into account in the urban design process.

Regarding the influence of the use of air conditioning devices on people's outdoor thermal perception, no significant result was reported in spite of the big number of the people who use air conditioning devices. However, when people use air conditioning, the microclimate in the summer time will be negatively affected because the exhaust heat from the air conditioning devices will lead to increased air temperatures in outdoor urban spaces. Therefore, encouraging people's desire to spend much more time in outdoor urban spaces will help to reduce the use of air conditioning. On the other hand, the good quality of urban design is needed to attract people to spend time in outdoor environments.

7. Future studies

More studies, including both summer and winter seasons will be performed within the framework of the project including statistical analysis of the emotional states, preferable weather conditions, and evaluating the outdoor activities for the people who live in Damascus. In addition, simulation studies will be conducted in order to give examples to enhance the thermal environment in outdoor urban spaces in Damascus city.

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