UNIVERSITI PUTRA MALAYSIA

INFLUENCES OF WIND AND HUMIDITY ON THERMAL COMFORT IN URBAN CANYONS OF BANDAR ABBAS, IRAN

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By

MASOUD DALMAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

May 2012

TO BELOVED PEOPLE OF BANDAR ABBAS,
PERSIAN GULF COASTAL RESIDENTS

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

INFLUENCES OF WIND AND HUMIDITY ON THERMAL COMFORT IN URBAN CANYONS OF BANDAR ABBAS, IRAN

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May 2012

Chair: Elias Bin Salleh, PhD

Faculty: Design and Architecture

Accessibility to thermal comfort spaces for citizens and urban outdoor activities could be one of the main goals of urban designers. Urban forms and canyons have an important role on the microclimate and thermal comfort condition in such situations. Hence there is a need to understand the dynamics of urban fabric and microclimate of an urban area for good urban design of outdoor spaces. Bandar Abbas city, located in the southern part of Iran at the northern rim of Hormuz Strait, is an example of an urban growth area with a combination of traditional and modern urban fabrics. The hot and humid climate of Bandar Abbas, especially in long summers causes thermal stress for urban activities.

The aim and objectives of the present study is to investigate the possibilities that achieve thermal comfort in residential urban canyons of new developments thus improve life style for outdoor environments in Bandar Abbas. To achieve these aims, this study selected two different urban fabric typologies to identify the prevailing urban canyon patterns, to investigate microclimate conditions and explore thermal

comfort situation to propose new urban design strategies for comfortable outdoor spaces.

This research employs various research techniques involving quantitative and qualitative approaches and comprising a case study of Bandar Abbas through direct observation of urban fabric, field measurement of climatic elements, and computer simulation of wind flow patterns. To understand the influence of microclimate factors and thermal comfort situations in the study area, two different typologies of traditional and new residential development (modern) urban fabrics have been selected in south east of Bandar Abbas.

The results indicate that the traditional urban fabric is more thermally comfortable than the new residential urban fabric. According to the field measurements, thermal comfort calculation and wind simulations, the canyons with North-South direction represents better orientation for air circulation benefiting from sea breezes as compared to other canyon orientations.

The findings will throw light on the urban designers and policy makers of cities which have the same climate especially in Persian Gulf region and tropical hot and humid climate with similar conditions.

Abstrak ini dibentangkan pada Senat Universiti Putra Malaysia
bagi memenuhi syarat Ijazah Doktor Falsafah

PENGARUH ANGIN DAN KELEMBAPAN TERHADAP KESELESAAN CUACA PANAS KAWASAN LEMBAH DI BANDAR ABBAS, IRAN

Oleh

MASOUD DALMAN

Mei 2012

Pengerusi: Elias bin Salleh, PhD

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Keselesaan semasa keadaan cuaca panas (*Thermal Comfort)* bagi penempatan dan aktiviti luar kawasan bandar menjadi salah satu matlamat utama merekabentuk bandar. Bentuk bandar dan kawasan lembah mempunyai peranan yang penting pada mikroiklim dan keadaan keselesaan cuaca panas. Oleh itu adalah perlu untuk memahami dinamik fabrik bandar dan mikroiklim kawasan bandar bagi merekabentuk kawasan bandar. Pelabuhan Bandaraya Bandar Abbas, yang terletak di bahagian selatan Iran di pinggir utara Selat Hormuz, merupakan contoh kawasan pertumbuhan bandar dengan gabungan fabrik tradisional dan moden. Iklim panas dan lembap bandaraya ini, terutama pada musim panas yang panjang menyebabkan keadaan yang tidak selesa bagi aktiviti luar.

Matlamat dan objektif kajian ini adalah mengkaji kemungkinan untuk mencapai keselesaan semasa cuaca panas di kawasan lembah bandar yang sedang berkembang dan meningkatkan gaya hidup di aktiviti luar di Bandaraya Bandar Abbas. Bagi mencapai matlamat tersebut, kajian ini memilih dua fabrik tipologi bandar yang berlainan untuk mengenal pasti corak lembah bandar, mengkaji keadaan mikroiklim

dan meneroka keadaan keselesaan semasa cuaca panas untuk mencadangkan strategi rekabentuk bandar baru yang selesa.

Kajian ini menggunakan pendekatan kuantitatif dan kualitatif yang terdiri daripada kajian kes bandaraya Bandar Abbas melalui pemerhatian fabrik bandar secara langsung, ukuran bidang unsur-unsur iklim, dan simulasi ber komputer corak aliran tiupan angin. Untuk mengenalpasti pengaruh faktor-faktor mikroiklim dan keadaan keselesaan cuaca panas dalam kawasan kajian, dua tipologi pembangunan yang berbeza bagi kediaman tradisional dan baru (moden) telah dipilih di tenggara Bandar Abbas.

Hasil kajian menunjukkan bahawa keadaan semasa cuaca panas bagi fabrik bandar tradisional adalah lebih selesa daripada fabrik bandar kediaman baru. Menurut ukuran bidang, pengiraan keselesaan cuaca panas dan simulasi angin, kawasan lembah mengarah kepada Utara-Selatan mewakili orientasi peredaran udara yang lebih baik kerana mendapat manfaat daripada bayu laut berbanding dengan orientasi kawasan lembah yang lain.

Penemuan kajian ini akan dapat memberikan petunjuk kepada perancang bandar dan pembuat dasar bandar-bandar yang mempunyai iklim yang sama terutamanya di rantau Teluk Parsi dan kawasan iklim tropika yang panas dan lembap keadaan yang sama.

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I dedicate this thesis also to all beloved people of my city, Bandar Abbas.

I certify that a Thesis Examination Committee has met on 7th May 2012 to conduct the final examination of Masoud Dalman on his thesis entitled "Influences of Wind and Humidity on Thermal Comfort in Urban Canyons of Bandar Abbas, Iran" in accordance with Universities and University colleges Act 1972 and Constitution of the Unversiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The committee recommends that the student be awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

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MASOUD DALMAN

Date: 7 May 2012

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LIST OF ABBREVIATIONS

ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigerating, Air conditioning Engineers
BA	Bandar Abbas
BAIA	Bandar Abbas International Air port
BSC	Building Science Corporation
Clo	Clothing rate
CFD	Computational Fluid Dynamic
CET	Corrected Effective Temperature
DI	Discomfort Index
ET	Effective Temperature
E-W	East-West
H/W	Height-to-Width Ratio
HSE	Health and Safety Executive
IESve	Integrated Environmental Solutions (Virtual Environment)
IMO	Iranian Meteorological Organization
LES	Large Eddy Simulation
MEMI	Munich Energy Balance Model for Individual
MRT	Mean Radiant Temperature
N-S	North-South
PET	Physiological Equivalent Temperature
PMV	Predicted Mean Vote
RANS	Reynolds-Averaged Navier-Stokes
RH%	Percentage of Relative Humidity

SET	Standard Effective Temperature
SSE-NNW	South of South east- North of North West
Ta	Air Temperature
THI	Temperature Humidity Index
UBL	Urban Boundary Layer
UCL	Urban Canopy Layer
UHI	Urban Heat Island
USDOE	United State Department Of Energy
WSW-ENE	West of South west- East of North East

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter introduces the background problem and motivations of this research. In this chapter, the research questions, aim, objectives, and research design will be explained. Furthermore, this chapter presents detail of scopes and limitations of research and significance of the conducted research and organization of the thesis. Finally, the chapter concludes by justifying issues and points of departure for this research and it ends by developing theoretical framework for this research.

1.2 Research Background and Statement of Issues

The history of Bandar Abbas could be traced back to the 17th century. Bandar Abbas is a major port of the mouth of the Persian Gulf with a long history of trade and fishing. It is the provincial capital of Hormozgan. The city has a strategic position on the narrow Straits of Hormoz, and it houses the main base of the Iranian Navy. The city is an extremely important trading port and has also attracted industrial investment. The population of Bandar Abbas has increased from 87,000 in 1977 to 273,000 in 1996 (Alaedini, 2008) and 429093 in 2006 (Dadras, 2010) and is estimated to be around 500,000 people in 2011.

Like many other cities, Bandar Abbas has experienced an unprecedented population boom in the last 20 years (Alaedini, 2008). The city possesses some small creeks, known as Khoor, which are located in urban area, which are the flows of north part of the city that pours into the Persian Gulf. These Khoors function as drainage systems for flash floods as well as sewages of residential districts. Besides, they

separate the urban area in big quarters, which have special effects on urban planning of the city.

Bandar Abbas is the largest and the most developed port of Iran. Since 1980 Bandar Abbas has been rapidly developing as an import and export pole of oil, steel and aluminum industries, as well as ship construction and port services. Moreover, it is regarded as a center of service industries and tourism, especially for domestic tourists.

Hence, this causes a rapid increase in population by attracting more workers which leads to the development of a national class city called Bandar Abbas, regarded as the biggest city in the entire cities of south of Iran. This population increase causes high demand for quick housing which sometimes neglects the local climate and traditional architecture, especially, in most of the modern and commercial contexts that are covered by high and medium rise buildings (Dalman et al., 2011). These attributes have an intense effect on the use of energy in buildings, outdoor thermal comfort and urban air quality.

Climate situations of study area especially in summer time are affected by a hot and humid wave created by Persian Gulf and Peninsula of Saudi Arabia (Thapar, 2008). Air temperature cycle in Bandar Abbas consists of three periods, which are outlined below:

1) - A moderate weather period from December to March which has a daily mean outdoor air temperature of 18-23°C;

2) - A warm period in November and April which has a daily mean outdoor air temperature of 24-27°C;

3) - A very hot and humid period from May to October with average temperatures of 30-34.5°C

Maintaining thermal comfort conditions during the hot period is more challenging compared to the other two periods. Intensifying temperature by a high incident of solar radiation as well as high levels of absolute and relative humidity at certain times of the day causes the thermal discomfort for outdoor and indoor spaces during the hot period. The potential of evaporative cooling could be one of the best solutions in order to achieve thermal comfort but this might also be quite limited at the highest level of hot and humid period (Thapar, 2008). Nevertheless, there is a good potential for nocturnal radiated cooling throughout the year and the mean wind speed exceeding 6.0 m/s assists to provide comfort in outdoor spaces.

The direction of prevailing wind in Bandar Abbas is southward; therefore, the streets and alleys that are exposed to sea breezes coming from South-North direction have less humidity and are more comfortable for pedestrians in certain time of the day because of the shaded sidewalks.

In this region the urban setting in traditional urban fabrics is designed to allow air to circulate through urban canyons and it also uses high walls and vegetation for reducing the heat by shading effect. Consequently, the general orientation of the urban setting in this region follows the direction of the coastline and wind; for example, the streets and paths are arranged in order to sway the pleasant winds coming from the sea (Dalman, 1992).

Modern urban fabrics of Bandar Abbas were constructed over the course of 25 years (since 1985) mainly in the eastern part of the city. Canyon orientation of these urban fabrics predominantly is West of South West- East of North East (WSW-ENE), which is Perpendicular to prevailing wind. The selected modern urban fabric is located in the south east of the city near the seashore. The prevailing canyons in this urban fabric are extended along WSW-ENE orientation; the subsidiary alleys have South of South East- North of North West (SSE-NNW) orientation. The widths of prevailing canyons vary from 6m to 12m, whereas the subsidiary canyons' width is a variant between 1.5m to 3 m (Sharmand, 2009).

The main issue confronting modern urban fabrics today is that the buildings' layout and canyon orientation are maybe unsuitable for providing thermal comfort for pedestrians in outdoor spaces during the hot and humid summer period (Figure 1.1). Consideration has to be given to the environment factors in planning and finally designing. The traditional principles seem to be more environmentally and thermally comfortable than current designs in new residential developments. This implies that there is a great deal to learn from the former rather than the latter. A couple of questions need to be addressed; firstly, what are the elements of comfortable outdoor spaces? And secondly, will residents and people feel comfortable with the proposed new residential developments?

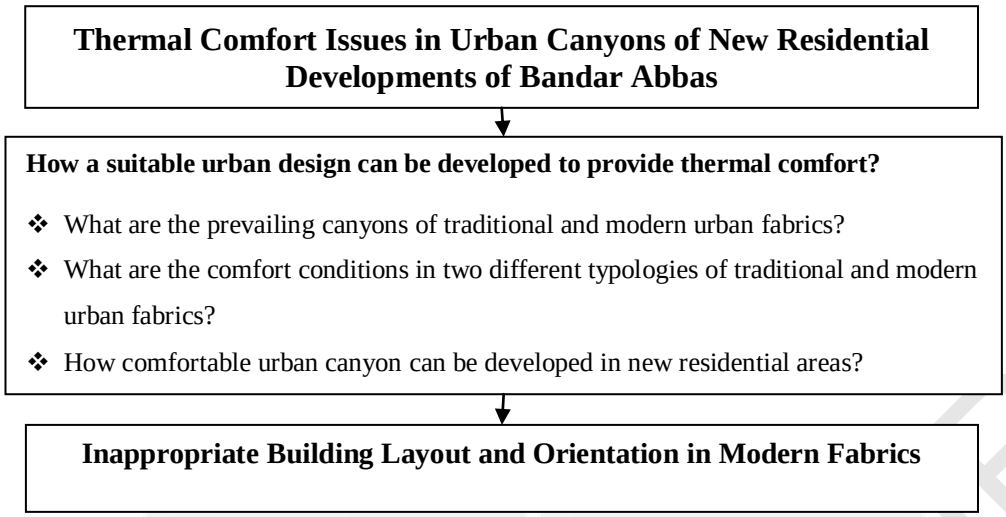

Figure 0.1. Review of Problem Statement and Research Questions

1.3 Research Questions

The following questions related to field of the study will be addressed in present research:

Main Research Question:

How can a suitable urban design be developed to provide thermal comfort?

Sub-research questions:

- Q1: What are the prevailing patterns in urban canyon for modern and traditional urban fabrics of Bandar Abbas?
- Q2: What are the microclimate characteristics of two different typologies of traditional and modern urban fabrics of Bandar Abbas?
- Q3: What is the comfort conditions found in traditional and modern urban fabrics of Bandar Abbas?

- Q4: what are the conditions needed to develop comfortable outdoor spaces for pedestrians in residential areas of urban canyons in Bandar Abbas?

1.4 Aim and Objectives

The main objective of microclimate study in hot and humid cities is to enhance the natural ventilation to reduce thermal stress in outdoor spaces and provide proper shaded areas when required (Bekele et al., 2008).

The primary aim of this research is to investigate the possibilities that will achieve thermal comfort in residential urban canyons of new developments and improve life style for outdoor environments in Bandar Abbas.

The specifics objectives of this thesis are:

1) To identify the prevailing patterns of urban canyon in modern and traditional urban fabrics of Bandar Abbas;

2) To investigate microclimate condition of two different typologies: traditional and modern urban fabrics in Bandar Abbas;

3) To identify and explore comfort condition in these two identified types of urban typology;

4) To propose urban design strategies for comfortable outdoor pedestrian spaces in new residential development in urban canyons.

1.5 Research Methodology

This research methodology employs a combination of research techniques that includes quantitative and qualitative approaches and comprises a case study research through field measurements, simulations and direct observations for data collection.

According to Bekele et al. (2008), the main parameters of urban microclimate design are: local climate, city location, urban density, orientation and canyon's width, anthropogenic heat, traffic, neighbourhood shape, and distribution.

The first objective, which refers to the characteristics of prevailing urban canyons in two different residential urban fabrics in Bandar Abbas, will be addressed through documents review and field observations. The second and third objectives will be achieved through field measurements and CFD simulations, which respectively refer to comfort conditions and urban canyon typologies and influencing factors on the thermal comfort situation. Direct observations, field measurements and CFD simulations are the main supporting methods to achieve these objectives.

1.6 Scope and Limitations

The urban climate study of this research is limited to hot and humid condition of summer season and the study of vegetation and shading effects are not included and is beyond the scope of this study. This research is particularly appropriate to geographical, climate, and urban conditions of Bandar Abbas city. Therefore, findings can only be generalized in relation to hot and humid cities of Persian Gulf region and other hot and humid cities with similar characteristics, architectural and urban-style settings.

A particular research is needed when utilizing the findings of this research in case of similar residential urban canyons with varied H/W ratios. The conducted study depends on climate situation and outdoor spaces of selected study areas. Finally,

other influencing factors and models in study thermal comfort and non-climate elements (dust, glare, noise, and psychological condition) are not considered.

1.7 Significance of the Study

The results of this study is expected to provide information on the importance of air movement on thermal comfort which, could assist in reducing outdoor air temperature, humidity, and PET index for pedestrians and outdoor activities. Hence, these findings will enable and provide the urban planner and designer with wide range of options in selecting suitable thermal comfort strategies for achieving comfortable urban spaces in areas with similar climate. The developed design strategies and criteria could be used as a future reference for urban designers, city planners, city managers and researchers of the same fields of study.

1.8 Organization of the Research

This thesis comprises of 8 chapters (Figure 1.2) that are explained as follows:

Chapter1 introduces the issues and motivations of the research and draws a perspective of the study by discussing important topics such as research questions, aim, and objectives, significant of study, scope and limitation.

Chapter 2 provides a critical analysis of relevant literature regarding Bandar Abbas as a study region and its urban canyon characteristics, definitions and concepts. In this chapter geographical condition, climatic factors and characteristics, and urban fabric patterns are also discussed.

Chapter 3 elaborates on the previous literature, which discusses outdoor thermal comfort elements such as urban climate and thermal comfort models and criteria.

Different theories and models will be discussed as general review of the nature of the hot and humid climate, thermal comfort aspects and air flow simulation and their relation to the present study, which outlines the proper procedure to conducting this research. Furthermore, the chapter concludes by presenting different dimensions, influences, and the application of aspects of urban climate and outdoor thermal comfort in residential urban canyons.

Chapters 4 and 5 explain the adopted research design, methodology, and strategies for data collection, analysis, and validation during the study, which aims to answer the research questions. These chapters categorize the research methodology into three parts, namely analysis of research questions, detailed explanation of the research process, and validation and reliability of the findings. These chapters are divided into 12 subsections in order to address, research approach, research procedure, components of case study research, validation and reliability, and the scope and limitation of this study.

Chapter 6 expresses the main findings of the conducted field measurements and analysis of microclimate factors, canyon details, and thermal comfort investigations. The findings are derived through the use of software analysis, field measurements, and visual data in the form of tables and charts.

Chapter 7 illustrates the findings of air flow simulations inside the selected canyons during data collection in July 2010. The results of the simulations are discussed in form of visual data such as figures, tables and charts. These results also relate the findings to the reviewed models and theories in order to triangulate the results and intensify the validation of the findings. Finally, the results based on the achieved

findings calibrated in terms of canyon orientation, building layouts, and air flow characteristics, shows the correlations between air movement, residential canyons and thermal comfort.

Finally, Chapter 8 summarizes the whole thesis and its findings and discusses the conclusions based on the achieved results. This section makes general conclusions and recommendation for further research and discusses how the findings of this study can be applied to the cases, which are not quite similar to the case studied in this research. The chapter concludes by highlighting the contributions the thesis has made and providing references for future research.

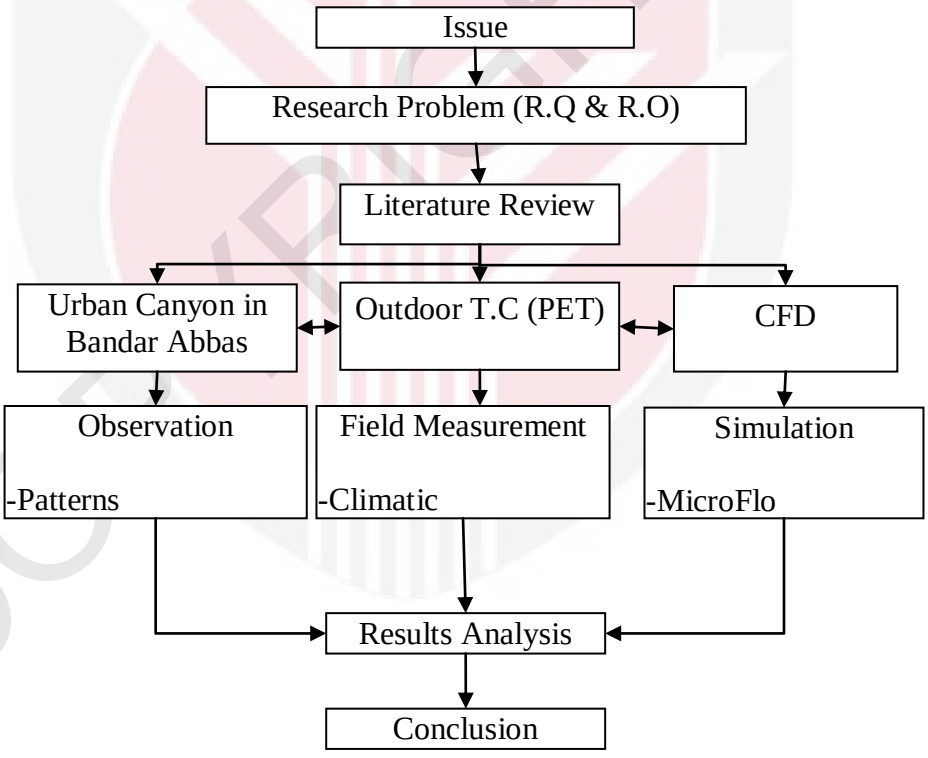

Figure 0.2. Diagram of Research Design / Framework

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