



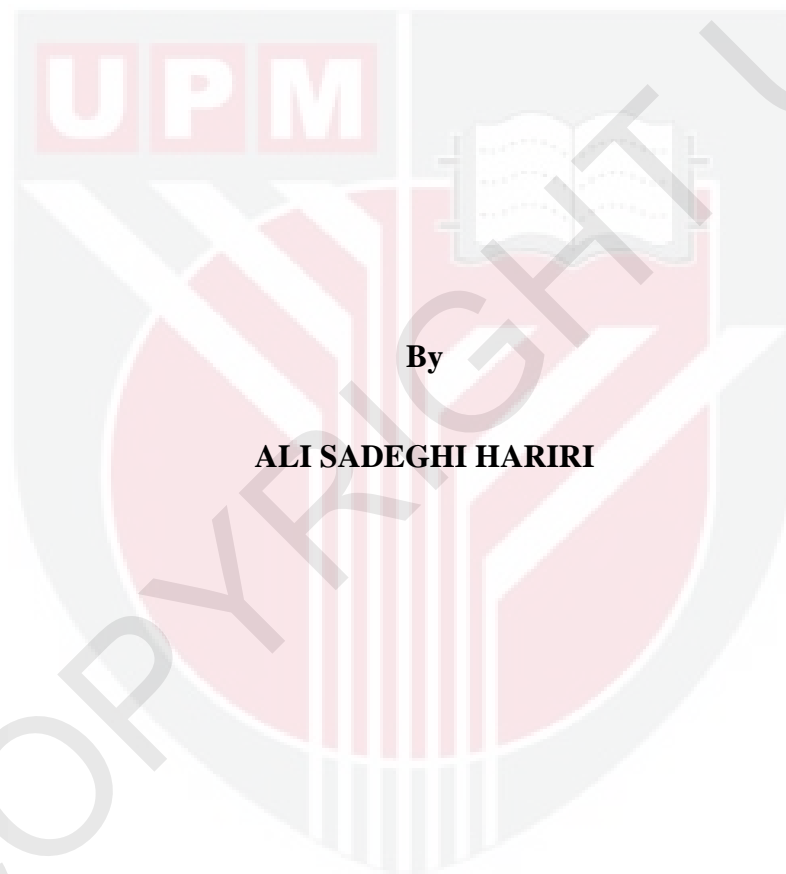
UNIVERSITI PUTRA MALAYSIA

***THERMAL PERFORMANCE OF PUBLIC COURTYARDS IN YAZD, IRAN
DURING SUMMER***

ALI SADEGHI HARIRI

FRSB 2012 4

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By

ALI SADEGHI HARIRI

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirements for the Degree of Master of Science**

July 2012

To Kiana and Abtin



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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

THERMAL PERFORMANCE OF PUBLIC COURTYARDS IN YAZD, IRAN DURING SUMMER

By

ALI SADEGHI HARIRI

July 2012

Chair: Professor Dato' Ar. Elias @ Ilias Salleh, PhD

Faculty: Design and Architecture

The cities located in the hot and dry regions are characterized by the intense solar radiation and having two extremely opposite hot summer and cold winter. The traditional architecture of this region demonstrates that the compactness in the urban form while having some open spaces like the courtyard is the best answer to this extreme climate. In the case of Yazd city, a unique public courtyard pattern surrounded with colonnades is identified in the historical area as the main solution for building urban open spaces in the past. But the contemporary urban design disregards the traditional solution due to the need to include vehicular traffic and a greater degree of activity to support social urban life. The aim of this research is to study the effects of courtyard form on its thermal environment by focusing on the role of solar radiation in Yazd during summer. The study uses ENVI-met® which is a computational climatic modeling tool that simulates the microclimatic changes within the urban environment. The effects of courtyard design parameters of orientation, size, aspect ratio H/W and colonnade aspect ratio h/w on outdoor thermal environment are evaluated in this research. Ten square shape courtyard

models are simulated to assess the effects of design parameters on air temperature T_a , air humidity RH, wind speed WS and mean radiant temperature T_{mrt} as well as thermal index of predicted mean vote PMV. A field measurement of air and globe temperature is also conducted in an existing public courtyard in order to be compared with the result of computer simulation. The results show the courtyard space can decrease the T_{mrt} up to 40°C and the PMV value up to 2.5 in shaded area compared to unobstructed area. A comparison of all experimental models reveals that the thermal intensity and the amount of sunlit areas inside a courtyard strongly depends on courtyard orientation, aspect ratio H/W and the colonnade aspect ratio h/w. It is also found that the direct solar radiation and its resulted T_{mrt} are the primary indicator of outdoor thermal environment in hot and dry climate of Yazd during summer day. The study concludes that creating comfortable thermal environment in outdoor spaces in hot and dry climate is beyond the reach of any architectural design using passive strategies. However, mitigating the extreme heat of the summer through a careful combination of courtyard design parameters is possible. The strong cooling effect of colonnades surrounding a courtyard is also highlighted by this research. This study contributes new architectural knowledge for the architects to design more thermally comfortable public courtyards in hot and dry climate. The future researches can look forward to test the applicability of the study's findings in the winter condition as the thermal comfort is needed through the whole year and in all spaces.

Keywords: Outdoor thermal environment, Hot and dry climate, Courtyard, Colonnade, ENVI-met, PMV

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**PRESTASI TERMAL MUSIM PANAS BAGI RUANG 'COURTYARD',
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Bandar yang terletak di kawasan panas dan kering adalah terdedah kepada radiasi matahari yang kuat dan mempunyai musim panas dan musim sejuk yang melampau. Seni bina tradisional di kawasan ini memaparkan kepadatan bentuk bandar di mana ruang 'courtyard' adalah penyelesaian reka bentuk ruang terbaik untuk iklim melampau. Bagi kawasan bersejarah di bandar Yazd, reka bentuk 'courtyard' yang dikelilingi tiang 'collonades' dilihat sebagai penyelesaian bagi membangunkan ruang terbuka. Walaupun begitu reka bentuk bandar kontemporari di kawasan ini mengabaikan penyelesaian tradisional disebabkan keperluan kepada penggunaan kenderaan dan peningkatan aktiviti bagi menyokong kehidupan social bandar. Matlamat kajian ini adalah untuk mengkaji kesan reka bentuk 'courtyard' ke atas termal lingkungan dengan memfokuskan kepada radiasi solar musim panas di Bandar Yazd. Kajian menggunakan ENVI-met yang merupakan alat permodelan iklim pengkomputeran yang mensimulasi perubahan iklim mikro dalam persekitaran bandar. Kajian ini mengukur kesan parameter reka bentuk 'courtyard' seperti orientasi, saiz, aspek ratio H/W dan aspek nisbah H/W 'colonnade' pada termal

lingkungan luar. Sepuluh model 'courtyard' berbentuk segi empat disimulasikan untuk menilai kesan parameter reka bentuk ke atas suhu udara T_a , kelembapan udara RH, kelajuan angin WS dan purata suhu 'radiant' T_{mrt} serta purata jangkaan indeks termal PMV. Ukuran lapangan suhu udara dan global juga dilakukan di ruang 'courtyard' untuk dibandingkan dengan hasil simulasi komputer yang direkodkan. Keputusan menunjukkan ruang 'courtyard' di bawah teduhan boleh menurunkan tahap T_{mrt} hingga ke $40\text{ }^{\circ}\text{C}$ dan nilai PMV hingga ke 2.5 berbanding dengan ruang terbuka. Perbandingan semua model eksperimen menunjukkan bahawa tahap kekuatan termal dan pancaran matahari di dalam sebuah 'courtyard' sangat bergantung kepada orientasinya, aspek ratio H/W dan aspek ratio barisan 'collonade' h/w. Kajian ini juga mendapati bahawa pada siang hari di musim panas, radiasi langsung dari pancaran solar dan kesannya kepada nilai T_{mrt} adalah petunjuk utama kepada termal persekitaran lingkungan luar bagi iklim panas dan kering di Yazd. Kajian ini menyimpulkan bahawa di dalam reka bentuk seni bina, adalah mustahil untuk mewujudkan persekitaran terma selesa di lingkungan terbuka di dalam cuacapanas dan kering dengan menggunakan strategi pasif. Namun, terdapat kemungkinan menurunkan suhu panas yang melampau ketika musim panas melalui kombinasi secara efektif parameter reka bentuk 'courtyard'. Kajian ini juga menunjukkan kesan penyejukan yang kuat hasil dari teduhan tiang yang mengelilingi 'courtyard' tersebut. Kajian ini menyumbang kepada pengetahuan baharu reka bentuk kepadapara arkitek untuk mereka bentuk 'courtyard' awam yang mempunyai tahap keselesaan termal bagi kawasan ber iklim panas dan kering. Di masa hadapan, ujian kepadaaplikasi penemuan kajian ini boleh dijalankan di dalam konteks kawasan ber musim sejuk memandangkan keselesaan termal bagi semua jenis ruang adalah diperlukan pada sepanjang tahun.

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I certify that a Thesis Examination Committee has met on 30 July 2012 to conduct the final examination of Ali Sadeghi Hariri on his thesis entitled "Thermal Performance of Public Courtyards in Yazd, Iran During Summer" in accordance with the Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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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.

ALI SADEGHI HARIRI

Date: 30 July 2012



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LIST OF ABBREVIATIONS

1D	One Dimensional
2D	Two Dimensional
3D	Three Dimensional
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
CAD	Computer Aided Design
CBD	Central Business District
CFD	Computational Fluid Dynamics
Co₂	Carbon dioxide
CTTC	Cluster Thermal Time Constant
E	East
ET	Equivalent Temperature
H/L	Height to Length
H/W	Height to Width
h/w	Height to Width of colonnade
HIP	Heat Island Potential
IES	Integrated Environmental Solutions
LAD	Leaf Area Density
LAI	Leaf Area Index
LST	Local Sidereal Time
MEMI	Munich energy balance model for individuals
MR	Mixing Ratio
N	North

NE	North East
NW	North West
OUT-SET	Standard Effective Temperature for OUTdoor environment
PET	Physiologically Equivalent Temperature
PMV	Predicted Mean Vote
POD	Point Of Departure
RH	Relative Humidity
S	South
SAI	Solar Access Index
SE	South East
SET	Standard Effective Temperature
SH	Specific Humidity
SVF	Sky View Factor
SW	South West
Ta	Air Temperature
Tg	Globe Temperature
TKE	Turbulence Kinetic Energy
Tmrt	Mean Radiant Temperature
UCL	Urban Canopy Layer
UHI	Urban Heat Island
UNESCO	United Nations Educational, Scientific and Cultural Organization
UTCI	Universal Thermal Comfort Index
W	West
WS	Wind Speed

CHAPTER 1

INTRODUCTION

This study investigates the climatic effects of public courtyard on pedestrian thermal environment. The public courtyard which acted as the main urban open spaces in the traditional architecture of Iran were very common and could still be seen in most part of the country.

In the hot and dry climate of Iran, there have been many studies indicating that the traditional architecture could create much better thermal and socio-cultural environment (Ali Vakili-Ardebili, 2006; Maleki, 2011; Tavassoli, 1982). In the city of Yazd in particular, there is a big gap between the old structure and the new development of the city in terms of the style of architecture and urban design that causes the discontinuity in creating climatic responsive urban areas. This gap has motivated this study to examine the public courtyard more deeply in order to discover those forgotten principles to apply in current practice of architecture.

1.1 Background of Study

The large area of Iran is covered by hot and dry climate. Among the cities of this region, Yazd is the most famous one for its unique architecture and urban design (Tavassoli, 1982). The historical structure of Yazd has been existed without any noticeable changes and has also been listed in the “World Heritage Centre” by UNESCO (UNESCO, 2007).

It has been globally accepted that the climatic factors are the key issues in architectural and urban design (Eben Saleh, 2001; Gaitani et al., 2007; Golany, 1996; Pressman, 1989). The usefulness of climatic responsive architecture in improving the quality of life has also been shown through the vernacular architecture of the recorded history (Cook, 1996; Zhai and Previtali, 2010). As a result of industrial revolution and access to the new types of energy, unfortunately, the attention to the environmental conditions was undermined. Consequently, the geographically and climatically oriented architecture of the past was replaced with a new worldwide style of architecture with little respect to the specific conditions of each place. In the case of Yazd city, these changes started to happen in the late 20th century (Tavassoli, 1982). What we have seen after that in Yazd and also in Iran, is the appearance of very similar urban areas in both form and structure. These similarities have led to the emergence of poor urban areas in addressing the visual, thermal and spatial needs of the people. Therefore, researchers have been recently emphasized the importance of compatible built environment with consideration of the specific conditions of its surroundings. The failure in this modern approach of urban planning and design has highlighted the need to investigate the specific characteristic of each place and make an exclusive design decision.

In the hot and dry climate, the designers are faced with two opposite conditions which are the extreme heat in the summer versus the extreme cold in the winter. In theory, the architecture need to be exposed to the sun in the winter to receive solar heat, but in the summer, the solar radiation should be avoided. The traditional architecture of this region demonstrates that the compactness in the urban form while having some open spaces for urban activities is the best answer to this extreme

climate (Johansson, 2006). But the new aspects of urban life such as the use of vehicles and the need to have bigger spaces are against the traditional concepts and lead to the creation of uncomfortable thermal environment in urban areas (Ali-Toudert and Mayer, 2006; Tavassoli, 1982). Therefore, the continuation of traditional style of architecture was doomed to failure in recent decades and similar urban design patterns started to appear in most parts of the country.

In the field of urban design, the role of urban open spaces and urban canyons is very important, because they affect both indoor and outdoor microclimate (Ali-Toudert and Mayer, 2006; Johansson, 2006). As a result, the thermal sensation of people and the energy consumption inside buildings are influenced by these open spaces. The importance of the open spaces is multiplied in the cities with extreme climate like Yazd. It is because of the dominant role of climatic factors in creating urban spatial form in this context. Moreover, it has been revealed that the solar radiation has the main role among these climatic factors in Yazd (Tavassoli, 1982).

In the traditional Iranian architecture, the solution to the issue regarding the need of urban open spaces was the creation of courtyard. The courtyard idea has been widely used in both residential houses (private courtyard) and urban areas (public courtyard) since 2000 B.C. all over the Persian Empire (Tavassoli, 1982). The regular application of this idea especially in hot and dry climate of Iran until a few decades ago inherited us a great numbers of cities and villages with private and public courtyards. Furthermore, the popularity and the positive experience towards the public courtyard encourage the designers to still practice this idea in their new designs. Therefore, there is an opportunity to find out more about the relations between the climatic factors and the thermal conditions of public courtyard in the

traditional Iranian architecture. Eventually, we can adapt and improve the past experience to use in the current practice of architecture and urban design.

This study seeks to examine the microclimatic effects of traditional public courtyard in order to promote the human thermal environment that can benefit the current practice of architecture and urban design.

1.2 Research Problem

The contemporary architectural and urban design have failed to address all aspects of urban life as well as the need for comfortable thermal environment (Golany, 1996). It is due to the lack of attention to the particular climatic conditions of each place and design based on the global matters. It is stated that the traditional architecture and urban design within the hot and dry climate has much better thermal environment in comparison to their surrounding contemporary urban areas (Al-Azzawi, 1994; Johansson, 2006; Tavassoli, 1982). The recent bioclimatic studies have also revealed that the climatic responsive architecture strengthens the use of urban open spaces (Johansson, 2006; Nikolopoulou et al., 2001).

In the case of Yazd city, there are still a lot of efforts to build open spaces in new urban development based on the traditional courtyard idea. But the effort to create suitable thermal environment in these new urban open spaces is deemed unsuccessful due to the lack of design knowledge on building climatic responsive public courtyard. As a result, there is a lack of urban open spaces to improve thermal environment especially in new developed area in spite of having some good examples in nearby historical area of Yazd.

The courtyard idea in traditional architecture of Yazd has been identified as a valuable architectural pattern for further investigation in this study. The purpose is to develop the potential of the courtyard idea to be applied in the current situation by discovering the relations between its form and different thermal boundaries. The aim is to provide more comfortable thermal environment in the selected geographical context.

1.3 Research Questions

The main research question is:

How can we control solar radiation in a public courtyard of Yazd for improving thermal environment?

Sub-research questions are:

Sub RQ1<who>: What is the traditional public courtyard pattern in the city of Yazd?

Sub RQ2<what>: What is the current condition of thermal environment in these traditional public courtyards?

Sub RQ3<how>: How to utilize design parameters for public courtyard to achieve more comfortable thermal environment and be used in the current urban design practice?

1.4 Point of Departure

In the field of outdoor thermal environment, there is still a shortage of study especially on urban open spaces. Most of the previous studies have been conducted in the public spaces such as streets which are shared by both vehicle and pedestrians (Ali-Toudert and Mayer, 2006; Fahmy and Sharples, 2009; Shashua-Bar and Hoffman, 2003). Therefore, additional studies are highly advisable in particular in pedestrian streets and urban open spaces where comfort is required all day and in the whole area of urban canyon.

In addition, previous studies mentioned above have focused their analysis on the thermal conditions of the whole urban space. The results are gathered by using the average of climatic conditions of the whole area or by choosing a single point to represent that area. So, the need to study different thermal boundaries in a single space and analyze the different sides separately is therefore necessary (i.e. different sides of a street).

It is found that the data collection strategy of the previous studies in Yazd was based on the field research (mainly on-site observation and interview) and field measurement (Maleki, 2011; Tavassoli, 1982). This method limits those studies to only examine the existing traditional architecture in its current situation. As a result, all the information produced is a description about the suitable ideas and techniques of traditional architecture and their degree of effectiveness. To deeply examine the traditional public courtyard pattern in a wider range, we therefore need to conduct an experiment using a computer simulation approach.

1.5 Research Aim and Objectives

The aim of this research is to study the effects of courtyard form on its thermal environment by focusing on the role of solar radiation in the city of Yazd.

Based on the above aim, three objectives are developed as follows:

- 1) To determine the traditional public courtyard pattern of Yazd by studying the existing courtyards.
- 2) To evaluate the current thermal environment of an existing public courtyard by both field measurement and computer simulation.
- 3) To assess the different possibility of design parameters by computer simulation and propose recommendations for designing more thermally comfortable public courtyards.

1.6 Research Methodology

This study uses a quantitative research methodology by conducting a computational experiment of the climatic factors using ENVI-met model.

In order to answer the research questions, this research adopts the following methods:

First, is to gather the observational data of the historical area of Yazd city by maps, photos and manual sketch. This data will indicate the traditional public courtyard pattern of the Yazd city.

Second, is to conduct a field measurement of the climatic factors in a selected public courtyard in the historical area of Yazd. The measurement includes air temperature T_a and globe temperature T_g .

Third, is to do a computer simulation of the selected public courtyard along with ten other proposed courtyard models to predict their microclimatic conditions. This data will be used to make the design recommendations for building more thermally comfortable public courtyards in the city of Yazd.

1.7 Research Framework

The research is organized as illustrated in the Figure 1.1.

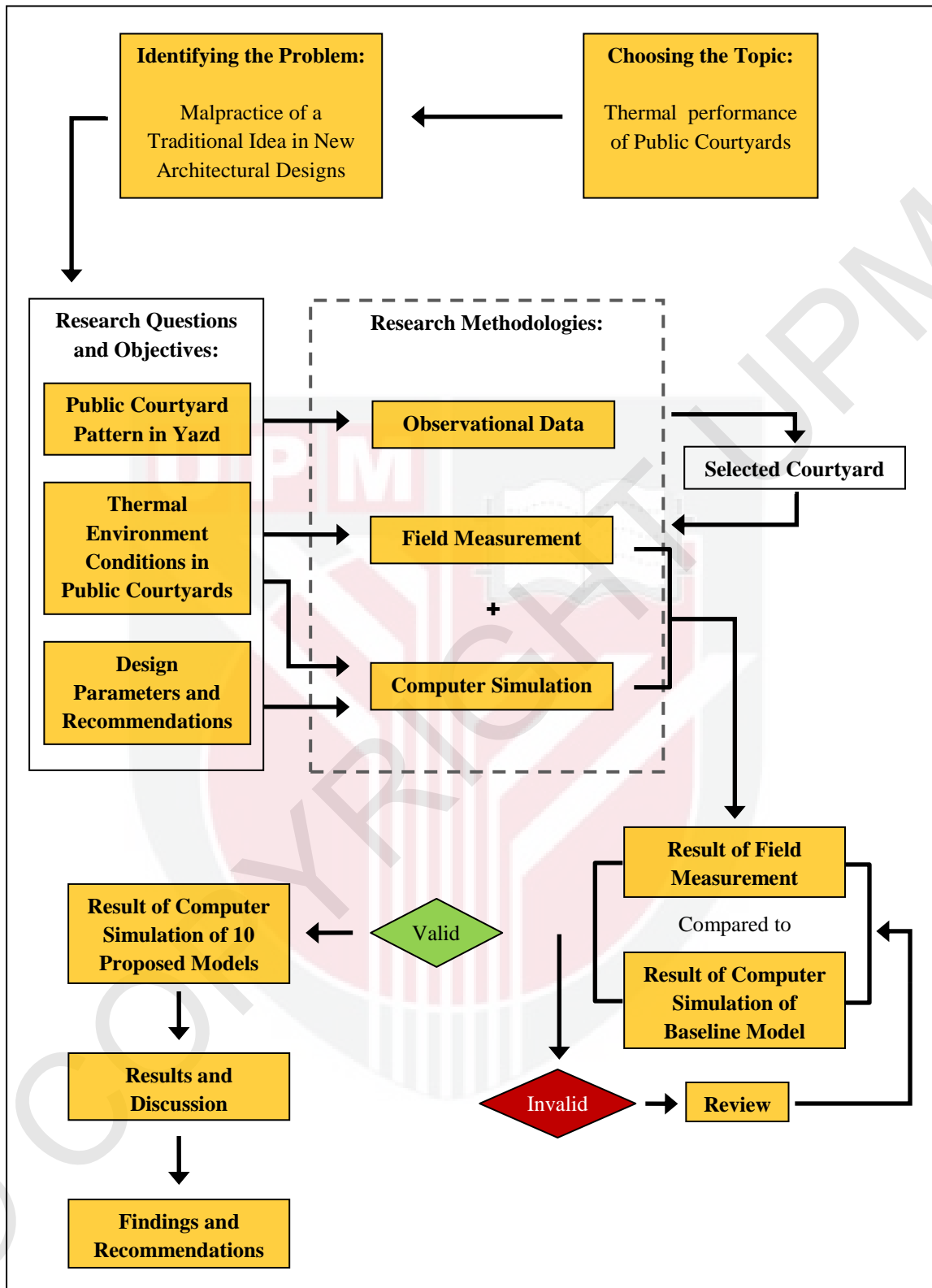


Figure 1.1 Research framework

1.8 Scope and Limitation of Research

This research deals with the effects of solar radiation on creating different thermal environment in public courtyards of Yazd. The focus of this research is on Mean Radiant Temperature (T_{mrt}) which sums up all short-wave and long-wave radiation fluxes absorbed by a human body in urban environment. However, the effects of other factors like Air Temperature (T_a), Wind Speed (WS) and Relative Humidity (RH) is also considered by the use of PMV index. Although the strategy toward the use of solar radiation in the summer and winter are opposite, this study is limited to the summer condition.

Therefore, the outcome of this research is applicable to the design of public courtyards for the summer use only. Additional studies will be needed to test if the findings of this research are applicable to the winter condition. However, this lack would be resolved if a designer check the solar access index SAI in his design to insure the presence of desired winter solar radiation while applying the recommendations of this study.

1.9 Significance of Research

First and foremost, a common traditional pattern for building urban open spaces is evaluated in this study. The outcome of this research will provide a helpful resource (Aldawoud, 2008; Muhaisen and B Gadi, 2006) for designing the public courtyard in Yazd and even other cities with similar climate. It can be used as a guide for architects to design more thermally comfortable urban open spaces particularly in the urban development in the hot and dry regions.

Second, the usefulness of colonnade attached to the courtyard sides to provide shading is examined in this study. Consequently, the cooling effects of colonnade with the different formal properties will be presented in detail.

Third, the results of this study will contribute towards the application of a traditional pattern into the current urban design to promote comfortable thermal environment. Furthermore, by defining conditions of comfort for outdoor environments, an important step towards designing the optimum urban pattern for the city of Yazd can be made.

Fourth, the new microclimatic tool of ENVI-met for simulating all the interactions between the climate and urban form is used in this study. Using the ENVI-met model, this research is able to examine the effects of courtyard form on all the climatic factors of Ta, WS, RH and particularly the Tmrt. Consequently, the most suitable use of each courtyard design parameters will be recommended for providing comfortable thermal environment in outdoor spaces.

1.10 Research Organization

This thesis includes five chapters. Chapter 1 provides a brief introduction of the study includes the background and the problem of research, research questions, POD, aim and objectives, research methodologies, scope and limitation, and significance of research. Chapter 2 presents the most significant findings in the literature related to urban form, courtyard form and design, microclimatic condition in outdoor spaces particularly in hot and dry climate, and outdoor thermal environment and its assessment methods. This chapter also introduces the Yazd

climate and the relevant simulation tools with a detailed description of ENVI-met tool for simulating climatic condition in micro scale urban areas. Chapter 3 describes three methodologies of gathering observational data from Yazd, field measurement and computer simulation used in this study. The results of courtyard study, field measurement and computer simulation using ENVI-met are presented and analyzed in Chapter 4. The results presented in the previous chapter are comprehensively discussed in Chapter 5 in order to highlight the findings of this study and make recommendations for designing public courtyards in Yazd. Chapter 6 finalizes this study by summarizing its findings and making conclusion and recommendations for further studies.

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