technische universität
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The Impact of the Persian Garden Principles as Traditional Ecological Landscaping on Thermal Comfort

Green Strategies for Climatic Urban Landscape Design in Iran, Based on Persian Gardens Analysis

A dissertation submitted to the:
Faculty of Spatial Planning
TU Dortmund University

By

Mohammad Bashirizadeh
April 2021

In fulfillment of the requirements for the degree of
Doctor of Engineering (Dr. Ing.)

Supervisor and first reviewer:

Prof. Dr. –Ing. Dietwald Gruehn

Second reviewer:

Prof. Dr. –Ing. Seyed Hassan Taghvaei

This work has been developed with honest intent and to the best of my knowledge and ability.
I claim responsibility for all errors or misinterpretations.

Doctoral Committee

Supervisor and first reviewer:
Prof. Dr. –Ing. Dietwald Gruehn
TU Dortmund

Second reviewer:
Prof. Dr. –Ing. Seyed Hassan Taghvaei
Shahid Beheshti University of Tehran

Chairperson:
Prof. Dipl. –Ing. Christa Reicher
TU Aachen

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Mohammad Bashirizadeh
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Abstract

Outdoor thermal comfort is a key factor generally affecting both physical and mental human health. The increased temperature on days caused by the urban heat island effect is a common phenomenon in cities, which has affected various indicators of quality of urban life such as air quality, use of fossil fuels, human health, etc. Accordingly, to mitigate the heat island effects, the thermal quality of urban open spaces and cooling strategies have been considered by climatologists, urban planners, and landscape designers. In the case of Iran, despite the efforts, studies, and research conducted in this field in recent years, there is no climatic vision at the planning and site design level in most projects. Therefore, it is necessary to emphasize the significance of climatic landscape planning and design and outdoor well-being, not only among urban planners and landscape designers but also among the general public.

The Persian garden, known as a traditional ecological landscape in Iran, is the result of valuable experiences of human coexistence with nature and adaptation to climatic conditions during centuries. In fact, the Persian garden not only meets the needs of man and nature but also creates a beautiful environment and provides thermal comfort under the harsh conditions of Iran's hot and dry climate. In this term, the study of the Persian garden, which is based on Iranian culture and believes, is desired and beneficial. Therefore, in this study, after identifying the concept, the structures, and the fundamental elements of the Persian garden and after conceptualizing its ecological design principles, Persian gardens in different climatic zones are selected in order to determine their responses to the changing climatic conditions and their influential factors.

Then based on these extracted principles, several scenarios of applying a variety of Persian garden structural elements in the Fin Garden of Kashan, as an outstanding registered world heritage garden, are defined. In order to find the principles of climatic design in the Persian gardens, the ENVI-Met simulations of these scenarios are analyzed on a typical summer day. In the end, the results' efficiency was proved through hypothetical redesign and simulation applied in a similar green space in Kashan with almost equal dimensions. This study concludes that in hot and dry climates, a variety of parameters such as landscape planning, selection and combination of vegetation, water system, geometry, site orientation, surface materials, wind and sunlight control, and spatial arrangement and design influence the outdoor thermal comfort. In conclusion, these results are presented as green strategies and design guidelines for future climate designs in Iran's hot and dry climate.

Acknowledgments

I would especially like to express my appreciation to my supervisors, Prof. Dietwald Gruehn and Prof. Seyed-Hassan Taghvaei, who have been my tremendous mentors. I would like to thank you for encouraging me in my research and enabling me to grow as a researcher. Your useful suggestions have significantly contributed to improving the structure and content of this research. Furthermore, I believe that your constructive and innovative comments have significantly enriched the academic quality of the work.

I would also like to thank Prof. Christa Reicher for serving as chairperson and examiner.

I sincerely thank and acknowledge the continued and compassionate help and support of Ms. Geudens, who always kindly tried to solve and simplify the problems.

I would like to thank Ms. Ayda Ehsany, who has been very supportive during all stages of this research. And many thanks to her and my other friends, especially Dr. Danial Monsefi and Ms. Jamileh Montazer, who shared many joyful experiences with me during this time.

Words cannot express how grateful I am to my family, my amazing sisters Maryam and Mahnaz. Lastly and most of all, I would like to thank my loving, supporting, encouraging, and patient parents, whose faithful support at all stages of this research is deeply appreciated.

Mohammad Bashirizadeh

TU Dortmund

April 2021

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Chapter 1: Introduction

1.1 Urbanization and Climate Change

During the last two centuries, with the advent of the Industrial Revolution, the growth of urbanization and migration to cities has coincided with the population's growth. Urban areas currently host more than 50% of the world's population, and this percentage is expected to increase by 2030, whereas by 2030, the global population is expected to rise from 6.8 billion to 8.8 billion. In Iran's case, the urban population is predicted to reach 86% by 2050, which is about 75% today (Tehran Chamber of Commerce, Industries, Mines, and Agriculture [TCCIM], 2018).

Consequently, increasing demand for industrial products has had an impact on the environmental problems of today's world and its constituent landscapes, including the loss of biodiversity, the damaging effects on ecosystems, the pollution of biological resources, urban heat islands, global warming, and climate change. Besides the results of scientific research, there are numerous pieces of evidence that the world faces an unsustainable tragic way.

1.2 Climate Change and Green Spaces

Sustainability as a necessity for the continuation of human life is considered today as the major challenge for humanity in future life. In this context, one of the topics receiving considerable attention in scientific and academic researches has been climate change and its effects, which have been scientifically proven. Predicting the increase in the air temperature besides other effects of climate change, these all create difficulties for human life quality and conditions. In this regard, as locating approximately 75% of Iran's area in hot and dry regions with a harsh climate, the consequences of climate change are more critical for Iranians' life quality and comfort.

Emphasis on the role and importance of the urban landscape is necessary on the one hand to reduce the temperature of heat islands and the urban microclimate. On the other hand, it is essential to create comfortable thermal and environmental comfort for the residents of the city through optimal planning and design (Johansson, 2006b). Moreover, considering landscape ecology (Gruehn, 2013) and thermal comfort outdoors (Skoulika, Santamouris, Kolokotsa, & Boemi, 2014) is one of the most important strategies for enhancing urban socio-ecological sustainability, achieved through a systematic landscape planning system at all levels.

1.3 Contemporary and Traditional Urbanization and Green Spaces in Iran

Following modernization, especially in the last 50 years, in Iranian cities, numerous gardens, farms, and green spaces were destroyed or overwhelmed by altering land use due to the eight-year war and the lack of a landscape planning system. Besides, modern urbanism in Iran has been defined as a national style of urban planning. Such a national style's major disadvantage is the lack of attention to the local climate, especially in a country like Iran, which has a broad spectrum of different climate zones all at once. Moreover, it has been pointed (Eliasson, 2000; Reckien et al., 2018) that climate consideration is often disregarded, by planners and designers. According to the available studies (Chen & Ng, 2012; Johansson & Emmanuel, 2006; Mi, Hong, Zhang, Huang, & Niu, 2020), this lack has led to a reduction in urban green spaces' daily use.

For this reason, in Iran, today's main objectives are to improve the quality of the climatic design of urban landscape and to provide optimal thermal comfort in urban green spaces. In this context, it is of great importance to consider the valuable gardens and traditional landscapes which are available in most major Iranian cities, and continue to be used as a comfortable evergreen microclimate in the urban landscape (Taghvaei, Tahbaz, & Mottaghi Pisheh, 2015). What really makes Iranian gardens famous is their greenery, freshness, and pleasant shades, which can represent a sustainable and efficient garden as an urban green space according to the climate and location. Quantitative research on the microclimate characteristics and the quality of spatial structure in Persian gardens and their adaptation to the climate is very limited.

A review of scientific papers on the recognition of the Persian garden illustrates that despite valuable findings on the essential theoretical, formative, semantic, structural characteristics and essential elements of the Persian garden, the necessity of investigations on the microclimate design and characters of the Persian garden and the current role of the Persian garden as a green space in the urban landscape becomes noticeable (Motedayen & Motedayen, 2015; Shahcheraghi, 2013; Taghvaei et al., 2015). Thus, this research tries to take a positive, useful, and effective step in this regard.

However, besides investigating the Persian garden's socio-cultural and ecological aspects, it was also necessary to analyze its adaptation techniques in different climate zones. To this end, many various gardens in different climate zones of Iran must be selected, and their responses to the local climate have to be studied to identify effective elements in the climatic design of Persian gardens. It assists decision-makers in enhancing the current situation by knowing the various techniques and successful experiences gained over the centuries.

To present and recommend more useful and comprehensive guidelines, the literature review examines not only Persian gardens but also new scientific climate design guidelines, proven approaches, and applied principles, which may include new ideas and concepts of climate adaptation and outdoor thermal comfort that could be applied in Iran. As this is a vast subject, which could not be covered in one research study, this research focuses on suggesting green strategies for pedestrians' thermal comfort in outdoor urban landscapes.

Many studies have been conducted on urban climate and some on human thermal comfort in different parts of the world, but less on thermal comfort in green spaces, especially in Iran and on the current situation of its cities, thus, this lack needs to be filled.

1.4 Objectives of the Thesis

This multidisciplinary research seeks to deepen the knowledge of thermal comfort tools and to develop a set of climatic green strategies derived from traditional Iranian landscapes. Furthermore, such strategies' applicability to Iran's contemporary urban green spaces will be evaluated, especially in hot and dry climates.

The result of this research is a series of recommendations and green strategies, which are to be implemented in the Iranian Urban Landscape Design guidelines to enable climate-conscious landscape development according to scientifically based facts and findings. Cities around the central Iranian desert with arid and semi-arid climates are the focus of this research.

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Chapter 2: Theoretical Background

This chapter attempts to provide a solid theoretical background on which to elaborate and investigate the research questions. In this section, a comprehensive and systematic literature review is conducted in two main categories. Initially, the literature, after discussing the terms of ecology, urban climate, and outdoor thermal comfort, examines the existing principles and guidelines for ecological, sustainable, and climatic landscape design. The second part of the literature is devoted to the in-depth study of the characteristics of the Persian garden as a traditional landscape in Iran. These two parts provide a theoretical basis for analysis and discussion.

2.1 Ecology, Sustainable Development, and Landscape Design

2.1.1 Landscape Ecology

Among various landscape ecology definitions, Carl Troll (Troll, 1939) was one of the first people who defined landscape ecology as an interdisciplinary topic by merging varied ecology and geography concepts. Since the 1980s, analysis methods and spatial data have been more broadly used and led to the widespread use of landscape ecology concepts and methods in both nature and human landscape domains and many other fields and disciplines. The interaction between ecological process and spatial pattern is investigated by landscape ecology. Therefore, it improves the perception of reasons, effects, and outcomes of spatial heterogeneity and how they change by scale (S. S. Bell, Robbins, & Jensen, 1999; Turner, 2005; Turner, Gardner, & O'Neill, 2001; Ward, Malard, & Tockner, 2002).

Forman and Godron (1986, p. 594) defined landscape ecology as "*the study of structure, function, and change in a heterogeneous land area composed of interacting ecosystems*." Hence, landscape ecology focuses on three main characteristics of landscapes: **structure, function, and change**. These three landscape qualities are closely connected, and these connections establish the current, past, and future landscapes (Fairclough, Rippon, & Bull, 2002; Turner, 1989).

Landscape ecology helps planners finding better options and making more appropriate decisions to conserve nature and biodiversity by identifying the interactions between spatial structure, function, and change of landscape, besides determining the origin of changes (Boothby, 2000; Dramstad, Olson, & Forman, 1996).

2.1.1.1 Landscape structure

Landscape structure is the spatial relationships among different geographical units and ecosystems or landscape elements, more particularly the spatial distribution and management of materials, energy, and species in association with the measure, number, type, and size of ecosystems (Gergel & Turner, 2002; Leitao, Miller, Ahern, & McGarigal, 2006).

Farina (2000b) determined Configuration and Composition as two characteristics of landscape structures:

- **Composition:** Composition quality is described by the distribution of landscape patches and spatial elements. Its characteristic cannot be measured and is a non-spatial aspect.
- **Configuration:** Landscape configuration, as the spatial aspect of a landscape, refers to the spatial distribution, arrangement, and context of the landscape elements. Gathering these two qualities define the heterogeneity or spatial pattern of the landscape.

Forman and Gordon (1986) defined landscape structure by three basic elements: **Patch, corridor, and matrix.** Any type of landscape, such as urban, agricultural, and forest, can be described by these three elements. Afterward, Forman (1995) defined the **mosaic** model as a union of mentioned elements (Figure 2-1).

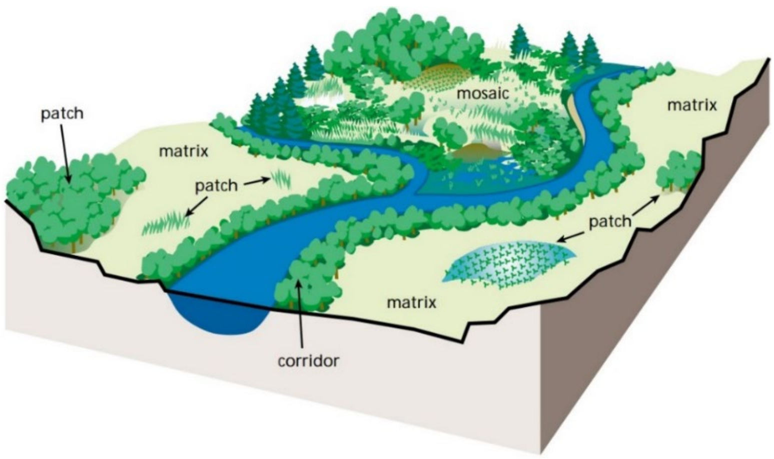

Figure 2-1 - Spatial structure. Four basic terms (matrix, patch, corridor, and mosaic) to defined landscape ecology. Regarding these elements, landscapes can be described at various scales (FISRWG, 1998).

Therefore, landscape ecologists define spatial structure by these four fundamental terms (Dramstad et al., 1996; FISRWG, 1998; Forman, 1995):

- **Matrix:** the extensive feature in landscape with a high level of connectivity, is the most dominant, interconnected, and continued landscape type over landscape dynamics. In theory, any type of land cover can be matrix but often is forest or agriculture.

- **Patch:** a homogeneous nonlinear (polygon) area that is different from its surroundings.
- **Corridor:** a linear or extended area, specific land cover type with a difference in content, and physical structure by its context, links other patches in matrix.
- **Mosaic:** a pattern description of patches, corridors, and matrix that come exclusively from one landscape and are not dominant enough to link the entire landscape.

2.1.1.2 Landscape Function

Landscape function can refer to the extensive ranges of **services** that are provided by landscape: **protection, production, and regulation** (Naveh, 1994, 1998). Regulation services provide the general assurance stability of landscape from negative feedback. Protection services support natural function (i.e., biodiversity, landscape experience, natural yield, water resources, retention, geotopes archive, and climate function), and productive landscape supplies the human needs (e.g., food, recreation, transport) (Leitao, Miller, Ahern, & McGarigal, 2006).

Landscape function can also refer to the interactions among the spatial components of landscape involving **flows** of plants, water, material, energy, species, nutrients, people, and specifically to ecological process. Materials or nutrients flow through Corridors, hedgerows, matrix, and networks are four structural characteristics of landscape functions (Forman, 1995). Corridor acts as a channel or a barrier for internal flows' movements and merges flows across landscape and adjoining ecosystems. Hedgerows can affect wind and water streams and preserve the area from animals. Various mammals also can move along hedgerows. Matrix and networks perform in a diverse way of the objects' movement and flow, whether they intersect corridor or move through the corridor. Networks include various ways for flows, different intersection types, landscape elements, and a variety of mesh sizes — species flow in a connected matrix (Forman & Godron, 1986; Gökyer, 2013).

2.1.1.3 Landscape Change

Landscape is continuously changing, strongly affected by human activities, land-use changes, climate change, fragmentation, growth, development of ecosystem /or destruction and depopulation of them, and diversity of disturbances. As a change process, the abiotic-biotic function and fundamental features of each ecosystem also can integrate. Landscape change represents variations in the structure and function of a landscape through time. However, all these should be considered at different levels, scales, and frequencies (Farina, 2000b; Forman, 1995; Forman & Godron, 1986).

The following model (Figure 2-2) is presented by Richard Hobbs (1997) to express the interrelationship between structure, function, and change of the landscape with a list of some essential features of each element. Although it does not demonstrate the socio-economic and cultural terms of landscape, it presents a suitable model according to a biological and geographical aspect of the landscape.

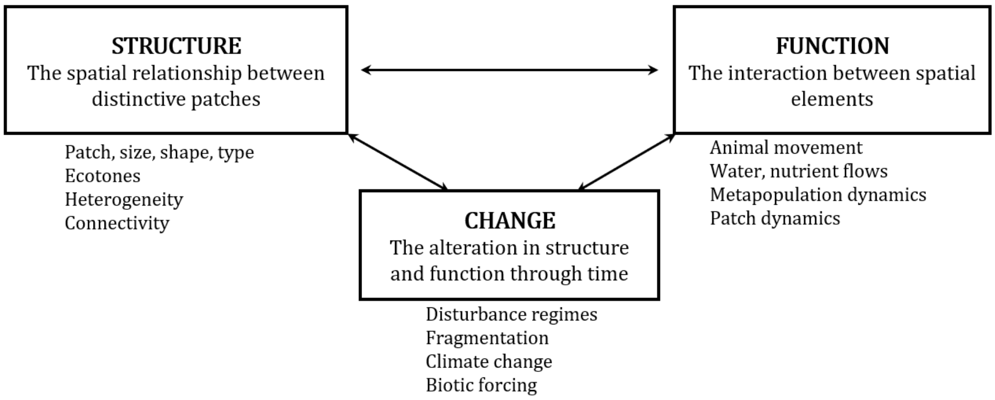

Figure 2-2 - Landscape ecology can be considered as the study of landscape structure, function, and change. Some of the important components of each of these are listed" (Hobbs, 1997).

Human activities and natural conditions are the two primary factors of landscape change so that both individual requirements and natural conditions are continuously changing (Antrop, 1998). Investigating the causes of landscape change emerges six general motivating forces effected on landscape changes (Antrop, 2005; Bürgi, Hersperger, & Schneeberger, 2005; Gökyer, 2013):

- Socio-economic forces: Urbanization, changing lifestyle, industrial activities.
- Cultural forces: Accessibility, human interference.
- Globalization forces: hypermobility, global communications, the neutralization of place and distance
- Politic forces: Incorrect applications.
- Technological forces: Infrastructure facilities, transportation.
- Natural forces: Hazard of calamities, earthquake, volcano, avalanche, landslide, flood.

2.1.1.4 Landscape Ecology Principles

Landscape planning with an ecological approach becomes noticeable in landscape planning as a unit of study and guideline, and it assists in different steps of the planning system. Consideration of landscape ecology principles, by increasing connectivity and decreasing disturbance and fragmentation, can preserve and develop the unity of landscape. According to the *Landscape ecology's principles in landscape architecture and land-use planning* (Dramstad, Olson, & Forman, 1996), **Patches**, **Edges and boundaries**, **Corridors and connectivity,** and **Mosaics** are expressed as ecological principles. The following table (Table 2-1) elaborates a categorization of landscape ecology principles based on Dramstad et al., 1996.

Table 2-1 - Categorization of landscape ecology principles based on Dramstad et al., 1996.

Principles of Landscape Ecology				
Patch	Patch size	Patch number	Patch location	
	▪ Edge habitat and species ▪ Interior habitat and species ▪ Local extinction probability ▪ Extinction ▪ Habitat diversity ▪ Barrier to disturbance ▪ Large patch benefits ▪ Small patch benefits	▪ Habitat loss ▪ Metapopulational dynamics ▪ Number of large patches ▪ Grouped patches as habitat	▪ Extinction ▪ Recolonization ▪ Patch selection for conservation	
Edges and boundaries	Edge structure	Boundaries	Shapes of patches	
	▪ Edge structural diversity ▪ Edge width ▪ Administrative and natural ecological boundary ▪ Edge as filter ▪ Edge abruptness	▪ Natural and human edges ▪ Straight and curvilinear boundaries ▪ Hard and soft boundaries ▪ Edge curvilinearity and width ▪ Coves and lobes	▪ Edge and interior species ▪ Interaction with surroundings ▪ Ecologically “optimum” patch shape ▪ Shape and orientation	
Mosaics	Networks	Fragmentation and Pattern	Scale	
	▪ Network connectivity and circuitry ▪ Loops and alternatives ▪ Corridor density and mesh size ▪ Intersection effect ▪ Species in a small connected patch ▪ Dispersal and small connected patch	▪ Loss of total versus interior habitat ▪ Fractal patches ▪ Suburbanization, exotics, and protected area	▪ Grain size of mosaics ▪ Animal perceptions of scale of fragmentation ▪ Specialists and generalists ▪ Mosaic patterns for multi-habitat species	
Corridors and connectivity	Corridors for species movement	Stepping Stones	Road and windbreak barriers	Stream and River Corridors
	▪ Controls on corridors functions ▪ Corridor gap effectiveness ▪ Structural versus floristic similarity	▪ Stepping stone connectivity ▪ Distance between stepping stones ▪ Loss of a stepping stone ▪ Cluster of stepping stones	▪ Roads and other “trough” corridors ▪ Wind erosion and its control	▪ Stream corridor and dissolved substances ▪ Corridor width for mainstream Corridor ▪ width for a river ▪ Connectivity of a stream corridor

2.1.1.5 Ecological Landscape Planning

Ecological planning tries to reduce and balance various land-uses' negative impacts and conserves an efficient landscape pattern regarding structure, function, and physical aspects by preserving natural resources. Furthermore, social and cultural processes should also be considered another aspect of ecological planning (Cengiz, 2012; Dale & Haeuber, 2001; Makhzoumi & Pungetti, 1999). Investigation in many studies (L. B. Byrne, Bruns, & Kim, 2008; L. B. Byrne & Grewal, 2008; Millennium Ecosystem Assessment [MA], 2005; Tallamy, 2009) shows the following guidelines for ecological landscaping:

- Assaying associations between Physical-ecological variables outsides and insides the parcel to reveal unanticipated associations and unexpected effects.
- Reducing inputs (material, energy, and all-natural resources) and minimizing negative outputs and their impacts (pollution and resource wastes), related to an individual parcel.
- Optimizing the usage of materials and energy inside a parcel, specifically by maximizing reuse and recycling.
- Applying the foremost upgraded principles and data to manage and design the landscape to improve biodiversity quality and maximize ecosystem services preservation, particularly social and cultural services.
- Considering cultural and socio-economic factors of landscape and asking about their significance and relevance regarding social goals and the abovementioned guidelines for creating well-urbanized and sustainable ecosystems.

It should be considered that these guidelines act much efficiently when well-understanding of ecological systems and science would be achieved to translate these guidelines into less-technical language for public policymakers and managers. On the other hand, to have more effective guidelines, developing the social, urbanized, and environmental knowledge of children and people who are daily involved, is seemed necessary (L. B. Byrne & Grewal, 2008; Thaler & Sunstein, 2008).

2.1.1.6 Human and Ecological Approach

As a part of ecological model through biological, social, and physical functions, a human ecosystem consists of producing, transforming, circulating, and storing material, information, and energy (Bubolz, Eicher, Evers, & Sontag, 1980). Indeed, human activities are one of the most important causes of the changes taking place in nature and environment that positively or negatively influence land cover, natural resources, and earth capacity at the local and global levels (Peng et al., 2006).

As discussed earlier (ref. section 2.1.1.3), social, economic, cultural, globalization, technological, and urbanization forces are general motivating forces effected landscape changes driving from human activities in environment and nature. Therefore, integration of humans and socio-economic and cultural variables, as a contemporary dimension of an ecological approach, into the study of different spatial patterns and processes in temporal scales is necessary and called **human ecology** (Redman, Grove, & Kuby, 2004). In simple terms, "*Human ecology is about the interrelationships between humans, their cultures, and their ecosystems*" (Dyball, 2010, p. 273).

Human ecology, by considering all experience aspects of well-being and by promoting the perception of the interaction between socio-economic, technical, cultural, and environmental conditions, cooperates considerably to perceive the **quality of life**'s problems (will be explained in sections 2.1.3.2 and 2.1.4.2) (Boyden & Millar, 1978).

Dayball (2010, p. 283) pointed that human ecology investigates to gain effective conceptual frameworks helping to understand dynamically changing due to various interactions impacts of both socio-cultural and biophysical. These strongly impact their alteration over time, and their effects on human activities, behavior, and ecosystem lead us directly to discussions of **sustainability.** In addition, some particular parts of the earth's biodiversity can be maintained during the time of human activities that make a valuable landscape as a **cultural landscape** (Farina, 2000a).

2.1.1.7 Cultural Landscape

Landscapes are at the junction of culture and nature and define powerful interactions of socio-cultural structure and human ideas with physical characteristics of the human environment (Selman, 2012). Cooperation between social and natural sciences is crucial due to their role in the integration and combination of diverse perspectives. Landscape ecology could be developed by transdisciplinary synergy with social sciences (e.g., human geography) and design sciences (e.g., landscape architecture and engineering) (Wu, 2010).

Cultural landscape is a geographic area of relationships between environment and human activities, during the times creating a social, economic, ecological, cultural pattern and governing presence, distribution, and abundance of communities by feedback mechanisms. Fragility and resilience are two impacts of natural forces and human activities in landscape structure and process. Fragility can control changes in socio-economic and cultural diversity. Resilience is the capacity of the recovery system or returning system facing a disturbance (Farina, 2000a; C. Nilsson & Grelsson, 1995).

According to UNESCO World Heritage Centre (2016), cultural landscapes are a great diversity of landscapes representing the combined works of nature and humankind over time, under both external and internal effects of the natural environment and social, economic, and cultural forces.

Cultural landscapes, due to their various linkage to various processes relating to their history, as well as their current state and future development, should not be seen as a separate issue (Roth & Gruehn, 2010). Plieninger, Trommle, and Kizos (2014) proposed the consideration of six main features of landscape, by the concept of ecosystem change and society, to study cultural landscape:

1. Social-ecological linkages in landscapes,

2. Landscape structures and land-use intensity,
3. Landscape history,
4. Driving forces, processes, and actors of landscape change,
5. Landscape values and meanings,
6. Cultural landscape management.

2.1.1.7.1 Selection Criteria

According to UNESCO (2016), the Operational Guidelines of the world heritage committee (Annex 3, paragraph 11), Cultural landscapes are cultural characteristics and represent "the whole work of nature and man" over time. To reflect the settlement and development of human society affected by physical constraints or opportunities created by the natural environment. Cultural landscapes are divided into three main classifications, as follows:

- **landscape designed and created intentionally by man:** The first category is the landscape designed and constructed and built deliberately by humans, as the most easily identifiable, including gardens and parks. These are designed for aesthetic reasons and are usually related to the monumental or religious buildings.
- **Organically evolved landscape**: The second category is organically evolved landscape which is the result of an early social, economic, administrative, and/or religious necessity and has been shaped by communication with and response to the natural environment, which are divided into two subsets:
    1. *Fossil landscapes:* driving from an ended evolutionary process that some of their significant features are recognizable in material forms.
    2. *Continuing landscapes:* driving from an evolutionary process that is still underway. This is one of the most active social roles in contemporary society, closely linked to traditional lifestyles, and its evolutionary process
- **Associative cultural landscape**: The third category Entries in such World Heritage sites are justified by powerful religious, artistic, or cultural associations, not just by material cultural evidence, which may be insignificant, trivial, or even absent.

Following criteria are presented as the next step of evaluation and assessment of cultural landscape (IUCN World Heritage, 2006; UNESCO World Heritage Centre, 2016):

i. Conservation of biodiversity by protecting natural ecosystems, wild species of fauna or flora, genetic diversity within wild species, and creating semi-natural habitats (as an outstanding example).

ii. Conservation of biodiversity within the farming system by developing and/or conserving wide varieties of domesticated livestock and cultivated crops (as a notable example).

iii. Sustainable land-use; how they notably respect land capability, conserve soil quality and quantity, manage rainwater, safeguard water quality, reduce runoff, and maintain plant cover.
iv. Improvement of landscape beauty.
v. Ex-situ collections of plants or fauna (e.g., botanic gardens or arboreta, waterfowl).
vi. Outstanding examples of interrelationships of humanity with nature.
vii. Historically important discoveries.

The mentioned categories of cultural landscape against each of these criteria made an assessment table to indicate their occurred places (Table 2-2).

Table 2-2 - A sample table of cultural landscape assessment (UNESCO World Heritage Centre, 2016).

Cultural Landscape type	Natural considerations most likely to be relevant						
Designed landscape					(v)		
Organically evolving landscape - continuous	(i)	(ii)	(iii)	(iv)			
Organically evolving landscape - fossil	(i)					(v)	
Associative landscape							(vii)

It is noticeable, as relevant to IUCN in investigating cultural landscape, other demands such as integrity will be considered in the assessment of natural properties. Management and integrity of the natural qualities are interested, at landscape levels, and interaction between nature and humanity. IUCN assessment of cultural landscape was nominated for incorporation on the World Heritage List (IUCN World Heritage, 2006; UNESCO World Heritage Centre, 2016).

2.1.2 Sustainable Development

2.1.2.1 Sustainability and Sustainable Development Goals

The concept of sustainability originated in German forestry in the 18th century. Sustainability was set down as the first principle of German forestry. At the time, the first concept of sustainability was documented by the Saxon mining director Hans Carl von Carlowitz (1645-1714) from Freiberg (Saxony) (Fischler, 2013; Spindler, 2013). Nevertheless, "**sustainability**" was applied as an economic, social, cultural, and environmental study in the United Kingdom in 1972. Afterward, it was used in 1974 in the United States and the United Nations in 1978 (Kidd, 1992).

However, since the 1970s, due to population growth concerns, increasing consumption of resources, vital resources reduction (e.g., wood, coal, and oil), and extensive worsening of ecological conditions, sustainability increasingly became a popular science (Du Pisani, 2006; Wu, 2013b). As Office of Sustainability - University of Alberta defines, "*Sustainability is the process of living within the limits of available physical, natural and social resources in ways that allow the living systems in which humans are embedded to thrive in perpetuity.*"

Sustainability and **sustainable development** are used in most cases as a synonym and emerged as an essential matter of international environmental policy, particularly after the United Nations Brundtland Commission's 1987 report(Emas, 2015; Huang, Wu, & Yan, 2015; Wu, 2013b). According to this report, *Our Common Future,* sustainable development is defined as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (World Commission on Environment and Development [WCED], 1987).

Sustainability, regarding three main domains of **environment**, **economy**, and **society,** has been defined. These domains have been drawn differently, as 'Pillars,' as 'Concentric Circles,' or as 'Overlapping Circles' and more recently have been expanded by some authors (Adams, 2006). According to the United Nations Conference on Environment & Development (UNCED), *AGENDA 21*, **culture** has been specified as the fourth domain (Nurse, 2006). These issues move sustainability to the central concerns of global development intention.

UNCED in Rio, *Earth Summit* 1992, emphasized the global depletion of resources, environmental changes, and climate change, set poverty as a deep concern to agenda, and reflected on Millennium Development Goals (MDGs) approved at UNCED September 2000 (Mabogunje, 2002). Over the next fifteen years, based on MDGs, goals, and targets have been improved and completed or reconsidered to seek what they did achieve or those they did not yet (Figure 2-3). Human rights and gender quality were some of the new Sustainable Development Goals (SDGs) added to the agenda as a critical significance for humanity and the planet.

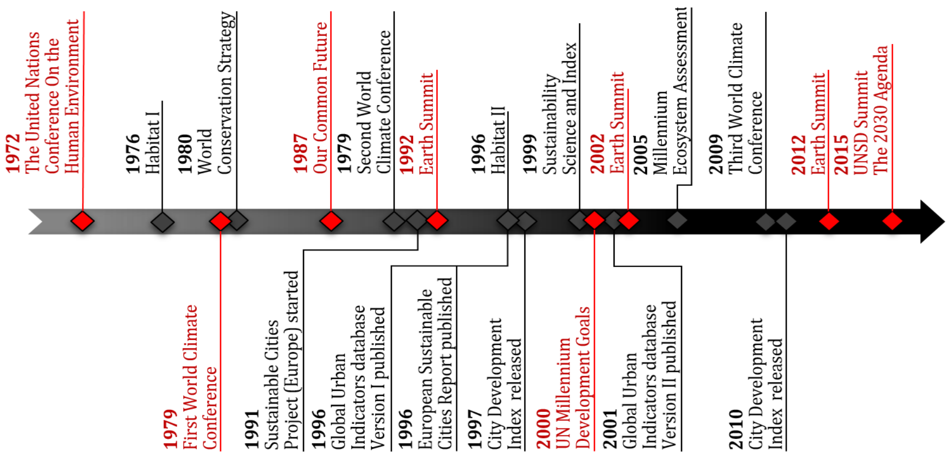

Figure 2-3 - Timeline of some significant events of sustainable development history, with eight highlighted events as milestones in sustainability literature (Source: Author).

The UN general assembly's Open Working Group on SDGs proposed an agenda that included 17 'Global Goals' (Box 2.1), with 169 targets among them, agreed in September 2015 to wildly cover range issues of sustainable development. These agendas are known officially as *transforming our world: the 2030 Agenda for Sustainable Development.*

Sustainable Development Goals

Goal 1. End poverty in all its forms everywhere

Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Goal 3. Ensure healthy lives and promote well-being for all at all ages

Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

Goal 5. Achieve gender equality and empower all women and girls

Goal 6. Ensure availability and sustainable management of water and sanitation for all

Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all

Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Goal 10. Reduce inequality within and among countries

Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable Goal

Goal 12. Ensure sustainable consumption and production patterns

Goal 13. Take urgent action to combat climate change and its impacts*

Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

** Acknowledging that the United Nations Framework Convention on Climate Change is the primary international, intergovernmental forum for negotiating the global response to climate change.*

Box 2-1 - UN Report of the Open Working Group of the General Assembly on Sustainable Development Goals (A/68/970).

The following six essential elements at the country level were proposed as Open Working Group result (Figure 2-4) to ensure and fulfill the above-mentioned Global Goals and strengthen the worldwide, comprehensive, united, and transformative SDGs.

Figure 2-4 - Based on "Figure 1" in the United Nations' report "The Road to Dignity by 2030: Ending Poverty, Transforming All Lives and Protecting the Planet", these Six essential elements were expressed to deliver the Sustainable Development Goals (United Nations Sustainable Development [UNSD], 2015).

2.1.2.2 Defining Landscape Sustainability

Coordination of landscape planning and Environmental Assessment systems (EA) as a significant mutual role could be understood as a basis for sustainable development. Indeed, the landscape not only is the essential 'Place' of study by representing a spatial unit of socio-natural interaction in sustainable science but also unites nature and culture to progress landscape-based science of sustainability (Belčáková, 2012; Wu, 2012).

More than a decade ago, landscape sustainability was recognized as a certain key research topic of landscape ecology (Wu & Hobbs, 2002). Landscape ecology by:

- providing a hierarchical and integrative ecological basis in various scales of biodiversity and ecosystem interactions,
- developing numerous humanistic and holistic approaches to study socio-natural interactions,
- providing methods and tools for studying the impact of socioeconomic configuration and spatial heterogeneity,
- developing a rigorous science of sustainability, and
- providing both theoretical and methodological tools regarding uncertainty issues in various scales,

contributes significantly to the development of sustainability science in theory and practice (Figure 2-5) (Wu, 2006, 2012; Wu, Jones, Li, & Loucks, 2006).

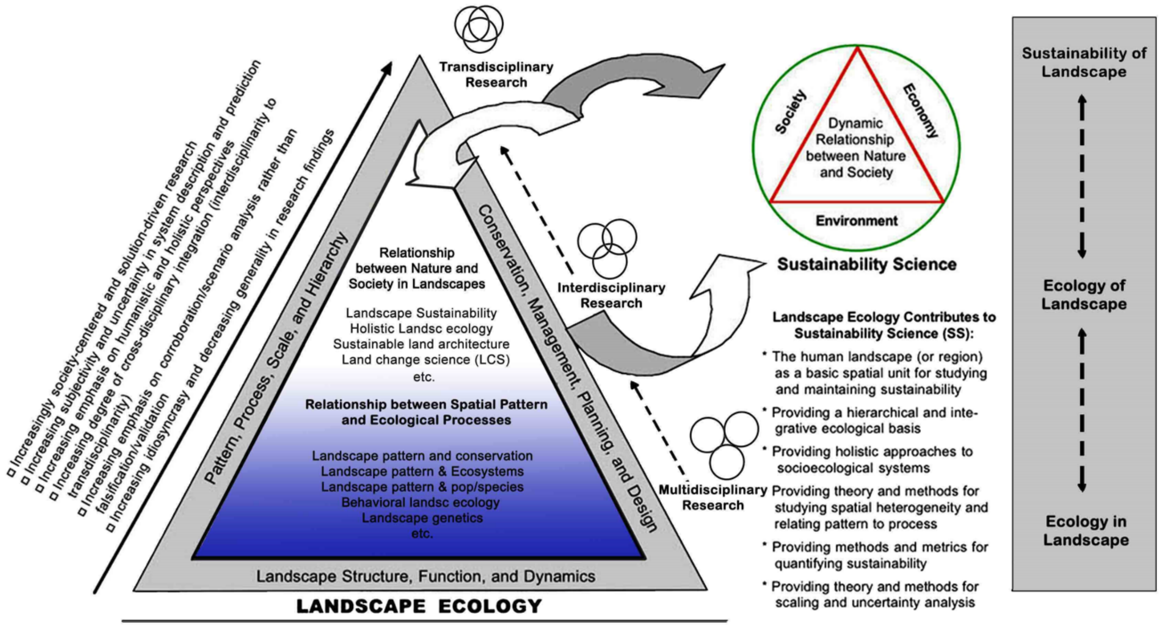

Figure 2-5 - A pyramid of landscape ecology and relationship with sustainability science (Wu, 2006, 2012) (modified).

In Spite of defining landscape sustainability is not straightforward, several researchers tried to explain it due to a different context and broad scales and regarding its significant role in studies. Selman (2008) illustrated the **environment, economics, society, governance,** and **aesthetics** as five dimensions for sustainable landscapes. Cumming, Olsson, Chapin, & Holling (2013) explored, ''*Landscape sustainability can be viewed as the degree to which patterns and processes occurring within a landscape (and their interactions) can be expected to persist indefinitely into the future*''. And Wu (2013a, 2013b) described landscape sustainability in broad terms as "*the capacity of a landscape to consistently provide long-term, landscape-specific ecosystem services essential for maintaining and improving human well-being in a regional context and despite environmental and socio-cultural changes.*"

2.1.3 Urban Ecology and Sustainability

2.1.3.1 Urban Ecology

Urban ecology as an interdisciplinary subfield of ecology science is tightly connected with many disciplines (e.g., economy, sociology, anthropology, public health, urban landscape, landscape architecture, geography, climatology, and engineering) to protect, preserve, and improve the relations of human, nature, and ecological processes in urban environment (Cengiz, 2013; Marzluff et al., 2008).

Urban ecology can be studied from three perspectives '**ecology *in* cities**' (focusing on non-human organisms), '**ecology *of* cities**' (as socioeconomic structures and as ecosystems and considering the whole city as an ecosystem), and "**sustainability of cities**"

(Grimm, Grove, Pickett, & Redman, 2000, 2008; Wu, 2014). These broad categories are controlled by landscape approaches and concern the relations of ecological processes, with the spatiotemporal patterns of urbanization to emphasize, maintain, and develop urban sustainability (Niemelä et al., 2011; Wu, 2008).

2.1.3.2 Urbanization and Sustainability

According to the European Environment Agency (EEA, 2010), in Europe, big cities have 75 % of the population, and it will be 80% by the year 2020. Even though these urbanized areas cover only a small portion of the earth, they cause a dramatic impact. Therefore, since biodiversity, ecosystems, and natural habitats have been increasingly treated with human disturbances living in urban areas, conservation efforts have been concentrated on urban environments and biodiversity.

However, these attempts are not sufficient enough to put these issues on the governance, policy, and planning agenda (Gill, Handley, Ennos, & Pauleit, 2007; Niemelä et al., 2011). Regarding these concerns in urban areas, sustainability became a central issue for responding to both qualities of natural environments and socio-economic life (Du Pisani, 2006; Ersoy, 2016; Kuhlman & Farrington, 2010).

Studying sustainability and urbanization demonstrates that their relationship hugely depends on their inter-reliance and dynamic interactions with socio-economical, cultural, and environmental processes (Antrop, 2006). Integrating landscape ecology and sustainability science has been led to obtaining an efficient approach to reach the goal of "urban sustainability" (Wu, 2008).

A sustainable city is defined by The United Nations Centre for Human Settlements (Habitat) (1996) as "*a city where achievements in social, economic, and physical development are made to last and where there is a lasting supply of the natural resources on which its development depends.*" By increasingly focus on the quality of life, participation of the citizenry, and the relations of ecosystem services with human well-being. in recent studies, sustainable city is defined as a city "*in which the community has agreed on a set of sustainability principles and has further agreed to pursue their attainment. These principles should provide the citizenry with a good quality of life, in a liveable city, with affordable education, healthcare, housing, and transportation*" (Munier, 2007, p. 43).

2.1.3.3 Urban Sustainability Indicators

In order to reach higher sustainability scores and environmental rating, in an urban area during the past two decades, numbers of assessment tools, indexes, and indicator sets have been studied and improved (Assefa, Glaumann, Malmqvist, & Eriksson, 2010; Braganca, Mateus, & Koukkari, 2010; Huang et al., 2015). These are still developed considerations of the most significant aspects of urban sustainability and development to assess sustainability of urban communities and projects.

The following table (Table 2-3) exhibits the most important indicators of urban sustainably to support the development of sustainable cities and their projects. Furthermore, it is explored as a guide for assessing, planning, and implementing processes of sustainable projects. These indicators are extracted from numbers of recent studies of urban sustainability (Castanheira & Braganca, 2014; Castanheira, Braganca, & Mateus, 2014; European Commission, 2015; Huang et al., 2015; Pakzad, Osmond, & Corkery, 2017; Suárez, Gómez-Baggethun, Benayas, & Tilbury, 2016; Thinh, Müller, Terne, & Holfeld, 2010).

Afterward, they are categorized into eighteen categories representing three main dimensions of sustainability (environment, society, and economy) as a practical guideline in the case of urban sustainability.

Table 2-3 - Practice list of sustainability indicators (Source: Author).

Dimension	Categories	Sustainability indicators
Environment	Urban Form	1. Passive solar planning 2. Ventilation potential 3. Urban network, water, sewerage, electricity, telephone, etc.,
	Land-Use and Infrastructure	4. Natural land potentials 5. Density and flexibility of uses 6. Reuse of urban areas 7. Rehabilitation of the built environment 8. Technical infrastructures network 9. Flexible infrastructure services
	Ecology and Biodiversity	10. Distribution of green spaces 11. Connectivity of green spaces 12. Indigenous vegetation 13. Environmental monitoring
	Climate and Air Quality	14. Over warming 15. Air pollution – NO2 - PM10 16. Household air quality 17. Trend in carbon intensity
	Energy	18. Energy efficiency 19. Renewable energy 20. Centralized management of energy 21. Diversity of energy sources
	Waste/ Reuse/ Recycle	22. Recycling rate 23. Volume of solid waste generated
	Water and Sanitation	24. Consumption of drinking water 25. Access to safe drinking water 26. Sanitation 27. Centralize management of water 28. Management of wastewater
Society	Outdoor Comfort	29. Outdoor thermal comfort 30. Acoustic pollution 31. light pollution 32. Areas

	Safety	33. Minimum human vulnerability 34. Safety in the streets 35. Natural and technological risks 36. Crime rates 37. Household income 38. Household purchase power parity 39. Diversity of food resources
	Health	40. Life expectancy 41. Child mortality 42. Adequate access to health care services
	Amenities	43. Social cohesion 44. Proximity to services 45. Entertainment equipment 46. Environmental aesthetics 47. Local production of food 48. Degree of citizen participation
	Housing	49. Housing quality 50. Sustainable buildings 51. Information and communication technologies
	Education	52. Number of schools with environmental education programs 53. Adult literacy rate 54. Combined enrolment
	Mobility	55. Public transportation 56. Diverse livelihood 57. Pedestrian accessibility 58. Cycle paths network
	Local and Cultural Identity	59. Public spaces 60. Local community support 61. Heritage valuation and landscapes 62. Integration and social inclusion
Economic	Employment Promotion and Investment	63. Economic viability 64. Dynamic local business 65. Employability 66. Diverse employment 67. Percentage of green jobs in the local economy
	Economic Growth	68. Annual GDP and GNP growth rate 69. Net export growth rates 70. Foreign direct investments
	Sustainable Economic	71. Diverse economic base 72. Attractive business environment 73. Strong integration with regional and global economies

2.1.4 Urban Landscape and Design

In more recent decades, the potential of relations between human systems and their environment in urban area (ecological and social network relationships) have been more considered, mainly in planning and management. This led to an intensified search for more liveable and healthy cities to obtain sustainability. According to Swanwick et al. (2003), several other factors cause increasing interests in greening the cities:

- Increased concern about the lack of urban green spaces, their conditions, and their qualities which are caused by low consideration on the political agendas on both local and national scales;

- Emphasizing the necessity of urban development, especially considering green spaces roles, in the concept of "compact cities" (high density) as the future model of European cities;
- Increasingly considering the development and management of urban brownfields more than greenfield lands that it might lead to the sacrifice of some existing green spaces (Rall et al., 2015).

However, these concerns, besides the green space benefits, lead to more consideration on managing, planning, and design of urban green spaces to:

- Preserve and rehabilitate the biodiversity,
- Preserving and improving environmental quality
- Moderate urban climate,
- Solve industrial and mechanical problems with natural solutions
- Improve human health and livelihood,
- Contribute to make better outdoor comfort and mitigate the Urban heat island effects,
- Provide recreation for everyday life
- Contribute to identify cities and conserve their cultural identities.

Therefore, urban green spaces play an important role in cities as a part of urban infrastructure, and they are understood as a necessity of livable, well-functioning, and sustainable cities. However, they are no longer use just as decorative luxury goods (K. Nilsson et al., 2007; Rall et al., 2015; Sandström, 2002; Sargolini, 2013).

2.1.4.1 Typology of Urban Green Spaces

The term of urban green spaces applies to those urban areas which are covered with vegetation naturally or planned and designed by human (natural, semi-natural, or human-made ecosystem). They emerged and developed in cities, made one or more ecosystems based on their various shapes, sizes, types, functions, and locations, for different purposes (Bilgili, B, Cemil & Gökyer, 2012; J. A. Byrne & Sipe, 2010; Manlun, 2003). Bell et al. (2007), distinguished between *parks and gardens; natural and semi-natural spaces; green corridors; allotments, urban farms and community gardens; outdoor-sport facilities; amenity green spaces; playground; cemeteries and churchyards; other public spaces*.

Hofmann and Gertenberg (2014) categorized this inventory according to usage, Byrne and Sipe (2010) established upon the scale or based on informal Urban green spaces (Rupprecht & Byrne, 2014). Therefore, they could be diversely categorized as many classifications have been proposed. In the following (Table 2-4), it has been tried to present a comprehensive classification of green space inventory based on their properties, their group of service, and elements (Barchetta & Chiodelli, 2016; Kong, Yin, James, Hutyra, & He, 2014; Rakhshandehroo, 2014; Rall et al., 2015).

Table 2-4 - Classification of Green Spaces based on their properties, group of service, and elements (Source: Author).

Classification of Green Spaces inventory			
	categories	Subcategories	
Public	1. National parks and preserve		
	2. Natural and semi-natural spaces	a. Woodlands b. Camping c. Wetland, bog d. Delta	e. Grassland f. Shrubland g. Bioswale
	3. Urban parks and gardens	a. Local parks b. City parks c. Regional parks d. Zoological parks/gardens e. Public gardens	f. Botanic gardens g. Community gardens h. Historical and cultural parks/ gardens
	4. Green riverbanks	a. Riverbanks b. Green riverbeds	c. Canals
	5. Green space dominated by lakes		
	6. Green sea coast		
	7. Green squares		
	8. Green streets	a. Treeline streets	b. Green verges
	9. Green spaces related to roads	a. Highways b. Motorways	c. Railroads
Semi - public	10. Cemeteries & churchyards		
	11. Green spaces related to civic buildings		
	12. Urban infrastructural green space		
	13. Industrial green area and scrap lands		
	14. Green sports facilities		
	15. Green playground		
Semi - private	16. Agriculture area	a. Tree meadow b. Agroforestry	c. Horticulture d. Arable land
	17. Allotment		
	18. Neighborhood green spaces		
	19. Green spaces related to apartment blocks		
	20. Intuitional green spaces		
Private	21. Private gardens		
	22. House yards/gardens		
	23. Green walls and balcony		
	24. Roof gardens		

2.1.4.2 Benefits of Urban Green Spaces

As mentioned above, urban green spaces present various services to people, nature, and existence biodiversity as urban ecosystems. Patches and matrixes act as cores, which mostly have a buffer zone as protected areas and are connected with linear corridors. The more functional and reliable networks of urban green spaces, the better the ecological characteristics of the urban landscape's sustainability can be preserved and protected (Ersoy, 2016; Heidt & Neef, 2008). Urban green spaces improve **quality of life** by providing various functions and benefits in urban context and helping to have a healthier society, a stronger local economy, and promoting biodiversity. These benefits are another emphasis on the widespread consensus of more considerations on the value and importance of urban green spaces in planning eco-sustainable cities.

In following benefits of urban green spaces are categorized into six major categories based on their function and importance (Alm, 2007; Feliciano, Gonçalves, Ribeiro, & Nunes, 2010; Gruehn, 2010, 2013; Kabisch, Strohbach, Haase, & Kronenberg, 2016; Konijnendijk, Annerstedt, Nielsen, & Maruthaveeran, 2013; Mayor of London & CABE Space, 2008; Rall et al., 2015; Sadeghian & Vardanyan, 2013; Troy, Morgan Grove, & O'Neil-Dunne, 2012):

- **Environmental benefits**
  - Providing a diversity of raw materials for construction, production, and fuel (e.g., biofuel, plant oil, wood, cotton, etc.);
  - Acting as an ecological patch, corridors, or matrix in cities;
  - Protecting and improving the quality of natural resources (i.e., water, soil, and air);
  - Providing and growing food;
  - Providing and growing traditional medicinal plants and raw materials used in Pharmaceutical Industries
  - Moderating natural hazards and extreme weather events by creating a natural and alive buffer against disasters.
  - Intercepting and storing water by reducing the volume of rainwater run-off through absorbing excess water;
  - Regulating the purification and flow of water in the hydrological cycle;
  - Filtering both human and animal waste and the surrounding environment by acting as a natural buffer;
- **Wildlife and habitats benefits**
  - Underpinning the primary living space for almost flora and fauna;
  - Providing habitats for species, especially for native tree and shrub species;

- Providing the fundamental place for making contact between the natural environment and local flora and fauna;
- Maintaining genetic diversity;
- Providing the highest potential for wildlife with less intensive management by interconnecting the green spaces;

▪ **Climate and comfort benefits**
- Improving the capacity of ecosystems to reduce and adapt to the climate; change effects by storing and sequestering carbon and greenhouse gases;
- Mitigating the heat island effects;
- Raising humidity level;
- Regulating the temperature of soil by preventing the radiation through making shades, and covering the surfaces;
- Mitigating and regulating the air temperature (i.e., in large urban green spaces 2-3 °c lower than surrounding areas);
- Decreasing carbon emission level through their photosynthesis process;
- Adjusting air quality and reducing pollutants and dust from the atmosphere;
- Improving outdoor comfort by acting like windbreaker;
- Reducing noise pollutions for both urban residents and habitats (e.g., trees act like noise barrier);
- Creating pleasant soundscapes (habitats and natural sound as pleasant sounds for human);

▪ **Social and psychological benefits**
- Improving mental health by providing a place for outdoor activities, recreation, and decreasing stress and depressive disorders, which are the foremost cause of illnesses in developed countries;
- Providing a place for social activities and promoting social cohesion and well-being sense;
- Having the usability and serviceability for different Groups of people;
- Promoting wellbeing and upturning stress by providing a suitable place for doing physical exercises;
- Increasing people participation in communal or social activities;
- Improving some emotional and behavioral problems in children by getting exposure to urban green space;
- Decreasing crime rate by increasing urban green spaces in a district;
- The aesthetic aspect of green spaces also has positive effects on reducing stress and improving mental health and rehabilitation;

- Enhancing public awareness and knowledge about the importance of environment and more consideration on scientific educations and researches;
- Increasing environmental learning by providing the initial contact between nature, flora and fauna, and urban residents;
- The vicinity and ease of accessibility of the residential area to urban green spaces providing many positive opportunities (e.g., safety of children play-yard, more physical activities, fresh air, cooler temperature);

▪ **Cultural benefits**
- Enhancing tourism;
- Increasing respect for nature and environment;
- Improving social Aesthetic sense and appreciation for culture, art, and design;
- Promotion, strengthen, dissemination, and education of the culture to future generations;
- Enhancing the perception of the sense of place and spiritual experience;

▪ **Economic benefits**
- Reducing the health expenses through the health benefits of urban green spaces;
- Cultivation and food productions;
- Providing various job opportunities through designing, constructing, and maintaining urban green spaces;
- Helping to save energy by regulating temperature;
- Making high income and new jobs from attracting tourists;
- Raising local value and cost of neighboring lands;

These many benefits of urban green space, which are related to their various size, shape, function, type, locations, and physical and biological diversity, are the causes for planners, researchers, and designers to consider their accessibility and availability to urban residents.

2.1.4.3 The Relationship between Design, Ecology, and Sustainability

As mentioned before in sections (2.1.3, 2.1.4.2), due to the increasingly negative impact of human lifestyle on environment, resources, climate, biodiversity, and human health, it is necessary to apply ecology and sustainability to recent and future green space planning and design. By establishing a scientific structure of natural processes, Ecology tries to manage natural resources and flows, prevent and improve biodiversity quality, and enhance ecosystem services, particularly social and cultural services, to achieve sustainable development (Makhzoumi & Pungetti, 1999).

In a simple word, ecology expresses the current conditions of the environment, explains how it behaves, and presents the solution for improving the ecosystem services. Moreover, design can play a negative or positive intervention role to make landscape sustainable and ecological. Therefore, meeting a comprehensive principle for reaching ecological and sustainable design of green spaces will occur when the principles of these three different filed of **ecology**, **sustainability,** and **design** are elaborated. It should be noted that what must be considered in green space design, as a part of the city, cannot succeed without regarding the whole complex of the city.

2.1.4.4 Fundamental Values of Landscape Design

Landscape design, on the one hand, relates to the principles of the architectural aesthetic composition, and on the other hand, it is dependent on the principles of natural aesthetic composition. The beauty in landscape design creates from the continuous and dynamic relationship of various knowledge (Taghvaei, 2011a).

However, when its activity extends into the realm of nature and into the context of the urban framework, the principles of the natural aesthetic combination are also must be considered. Indeed, Greenspace design is a human process that deals with the improvement of environmental quality (Taghvaei, 2012).

Moreover, the fundamental values and factors of the landscape architecture should emphasize quality, which refers to human activities and behavioral factors as a separate part between natural and human-made factors (Taghvaei, 2003). In this way, the key focus is on recognizing human beings' inherent need in their interaction with the natural and human-made environment and considering human activities and behavioral factors (Taghvaei, 2019; Yasaman Gholami, Seyed Hassan Taghvaei, Saeid Norouzian-Maleki, & Rouhollah Mansouri Sepehr, 2021).

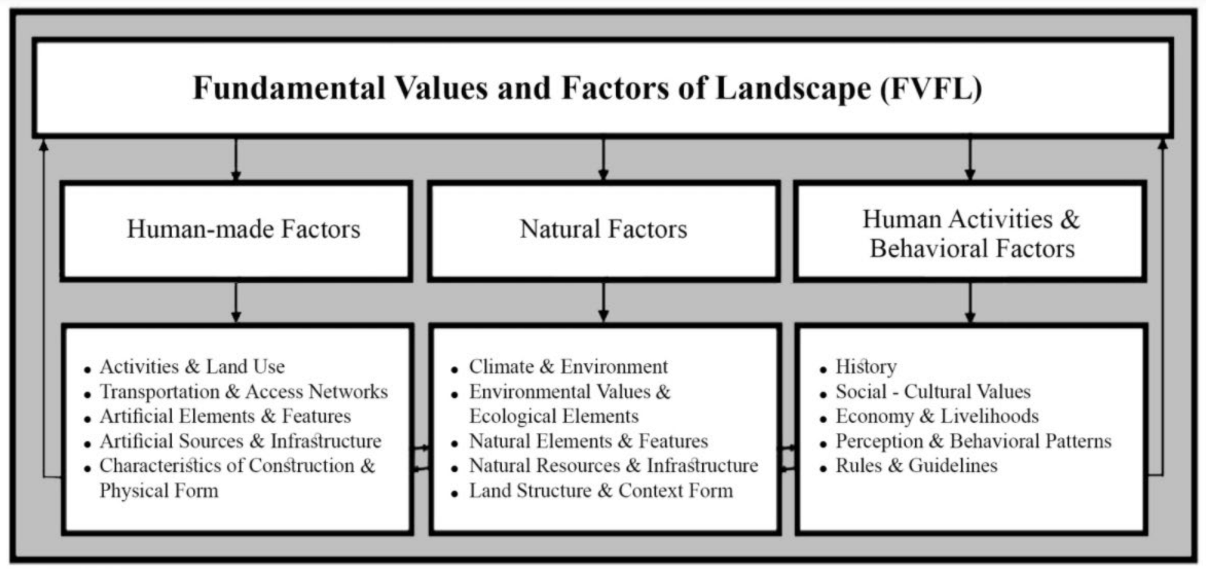

Figure 2-6 - Fundamental Values and Factors of Landscape: FVFL Model (Taghvaei, 2019).

2.1.4.5 Landscape Well-design Rules

"*Good design is not a matter of wealth, much less of the chic, the latest thing. It is not a matter of novelty for the sake of novelty, but of the production of cities and houses and goods which will best satisfy the needs of the people; their need of practical, honest, cheap, lasting and beautiful things to use and see in their everyday life.*" (Bertram, 1938, p. 19)

From the architectural aspect, design deals with the artistic knowledge of humans and follows the principles of aesthetics. In addition, regarding most people's daily needs, the design must consider social activities are much preferable to the only natural beauty aspect. In this approach, landscape designers try to present a **visually pleasing** and **functional** design by considering all ecological and sustainable aspects.

2.1.4.5.1 Aesthetic Guidelines

The quality of landscape beauty is measured in relation to its elements and their functions as a whole unit. This totality must be felt in all parts, elements, and their combinations. Ingels in *"Landscaping principles & practices"* has elaborated that Well-Design projects can be evaluated based on established principles of the fine arts and applied arts, which are (Ingels, 2009, p. 140):

- **Simplicity:** Simplicity does not mean monotony or tedium and also is not the opposite of complexity, but it will be gained through the repetition of landscape and design features such as colors, textures, plants, shapes, forms, and hardscape materials.
- **Focalization:** It means leading the viewer's attention to the significant and valuable part of the landscape.
- **Balance (symmetrical, asymmetrical, and proximal-distal):** Balance is the concept of equal visual weight and attraction, which can be symmetrical, asymmetrical, or proximal-distal balance.
- **Rhythm:** The rhythm consists of repetition, the repetition of the same items that make the combination unification. Rhythm, while creating a variety, maintains the simplicity as well as visual balance in the design.
- **Proportion and Scale:** Proportion and Scale are two tools for relative size designation, which creates a balance and arrangement in an environment. The scale is the application of the correct size of distances, dimensions, and measures the size based on human dimensions or any other unit. In comparison, proportion explains the relationship between the size of a part or between different parts.
- **Unity:** Contributing all separated parts and all individual components to create a combined and cooperative design as a whole unit.

Furthermore, **variety, complexity,** and **sequences** are other principles of design, which guide designers to create harmonious by means of Line, form, color, and texture as elements of design as well as beauty application of each element and components of landscape (e.g., plants, water, fencing, surfaces, and etc.) (Simon Bell, 2005; Berlyne, 1971; Hansen, 2010; Ulrich, 1983):

- **Variety:** The variety is the opposite of monotony. It is the application of various types of shapes, forms, colors, and textures of landscape elements in a design. The balance between the amount of variety and the degree of simplicity shows the skill of the designer. However, too much variety causes visual confusion.
- **Complexity:** "*richness in the structure and variety of a scene*" (Simon Bell, 2005, p. 204). Complexity refers mostly to the number of dissimilar, independent, and even mysterious perceptions of elements or their combination in a space. The relationship between complexity and aesthetic preference acts in an inverted-U-shaped. So that, both high and low complexity are sensed a low aesthetic preference, whereas moderate complexity tends to the high aesthetic perception.
- **Sequence and Hierarchy:** The hierarchy invariably prepares the human to gradually reach the main objective of space, which raises the dignity of this space. The movement from one area to another could be achieved by sequence.

It should be noted that if design just seeks excellent visibility in its visual range and ignores its extension to the thematic and functional dimensions, the human needs regarding welfare, health, and safety would be neglected. Accordingly, the beauty of the design will be reflected in its shapes, not in its content.

2.1.4.5.2 Functional and Spatial Guidelines

Since the designs are perceived spatially, the designer must be able to well-design the spaces. Space in different sciences has different meanings. However, the meaning of space in this discussion is the place of human activity. The Space functions are better meant by consideration of the daily needs of most people and their social activities. Thus, the functional guidelines enable designers to enhance the value of green spaces. It should be noticed that the consideration of all physical conditions and spatial components includes three main site criteria, i.e., **Site Context**, **Site Perimeter**, and **Site Layout and Design** (Napawan, 2015). Here are some of the significant functional guidelines:

- **Dynamism and Stagnation:** The linear and monotonous paths of the green spaces can be modified by breaking monotonous linear spaces into several tight and vast spaces, dynamically and statically, along with a combination of different but harmonious green bodies. This actually reduces the length of space and changes in space that makes it visually appealing. Therefore, it should be noted that (Reid, 2007):

  - Placing the static spaces into the paths grants the value and credit of place to the spaces.
  - Focusing primarily on the dynamic and static characteristics of the enclosed spaces should be considered on the design of green space access

- **Durability:** durability is the maintenance ability of the planned function of a material, product, or project for predicted life-expectancy. It means paying attention to:
  - the landscape features, their interactions, and their compositions
  - Conformity of landscape component and materials with either their function and their ambient conditions
  - the connection between green spaces their urban surrounding area as set-pieces of urban development

  These assist in establishing durability through design (Kirkwood, 2004).
- **Adaptability and Flexibility:** the adaptation need for green spaces in confronting unforeseeable environmental, social, and economic changes and fluctuations is one of the significant concerns of green space design. In fact, constant change is an inherent nature of green spaces (e.g., growth of plants over time and seasonal variation of trees). However, in this context, the following highlighted points need more consideration (Cowan & Hill, 2008; Nelson, Adger, & Brown, 2007):
  - Adaptability with local climate
  - Well-interconnected various spaces of landscape and well-connected to the urban context
  - Providing insurance of diversity preservation and promotion by Multiple similar or overlapping elements or functions within a landscape
  - Considering the capacity and ability of the spatial extent and time frame at different landscape scales
  - Shaping and managing landscape regarding the individuals, communities, and cultures
- **Wholeness and Inclusiveness:**
  - Reflecting the adjacent urban context despite distinguishing from the surrounding urban area
  - Considering neighborhood communities
  - Engaging with art and culture
  - Considering the wide range of environmental, economic, social, and physical dimensions of urban open spaces

  (Cowan & Hill, 2008; Morckel, 2015)

- **Identity and Character:** the identity of place is a wide-use concept in landscape design, which could be defined as the perceived uniqueness of a place (Stobbelaar & Pedroli, 2011). Creating and improving the landscape identity could be achievable through the following measures and Considerations:
    - Reflecting and promoting the national and local identity and culture
    - Engaging local people in the design process
    - Integrating public art into the design process
    - Emphasizing the uniqueness of nature, place, or people
    - Considering the climatic and ecological requirements of landscape and its components

    (Arreola, 1995; Kaymaz, 2013; Stobbelaar & Pedroli, 2011)
- **Enclosure:** boundaries by defining the distinction between different spaces shows people how to use the space (regarding rights of access or usage). Fences, walls, informal plants, hedges, paling, windbreak, trees, green borders, etc., are some kind of applied landscape enclosure. In larger green spaces, people can distance themselves from urban life to space where no trace of urban can be seen and enjoy nature (Cowan & Hill, 2008). Some notable factors involved in this matter are:
    - Boundaries can be defined by designers in various ways, e.g., walls, fences, hedges, planting, varying in shapes, surface material, or orientation, etc.
    - The larger green spaces, the more variety of activities, and the less impact of urban traces
    - Different types and degrees of enclosure lead to the various perception of space and its macroclimate that could affect the character of space as well.
    - Fences, walls, and informal plants need less maintenance than clipped formal hedges

    (Dee, 2001, p. 42; McNeilan, 2008)
- **Legibility:** to have an understandable or readable landscape (Simon Bell, 2005, p. 206), space should be designed in such a way that it gives people a chance to choose, use, and experience. In this regard, some points should be noticed:
    - Ease of directions and orientation
    - Applying the specific, symbolic, and unique elements
    - Using landmarks and elements that create memories for citizens
    - Using the new exciting concept to create new experiences and memories
    - Separating spaces, which have different functional essence
    - Providing a variety of options and a series of views could be achieved by designing routes through space

    (Motloch, 2000; Reid, 2007)

- **Connectivity and Accessibility:** through designing and providing a secure, integrated, and attractive network of routes, a landscape could encourage people to use and travel into the green space. Regarding this subject, some issues to bear in mind (Cowan & Hill, 2008; Ellicott, 2016):
    - Accessibility to site and within the site
    - The ability to communicate visually within site and from outside to the site
    - Giving the sense of welcome and easiness of entry into the site
    - Legibility of directions and routs
    - Considering the insertion of central gathering space or meeting spot
    - Good, safe, and equal access for all types of users (e.g., children, family, older people, disabled people, etc.)
- **Safety and Health:** The sense of security, as one of the basic human needs, is very significant in the design of spaces. A sense of security encourages people to stay in the space and enjoy healthy activities. The factors affecting the sense of security are (Ellicott, 2016; Hoffen & Säumel, 2014; Khalilnezhad, 2016; Säumel et al., 2012; Xu et al., 2017; Yan & Zhang, 2015):
    - The designed space should be legible and understandable
    - The designed space should provide sufficient information to users so that they can understand the adjacent spaces.
    - Users should be able to identify the possible activities in each space
    - Applying safe and healthy materials, equipment, facilities, and activities
    - Health-oriented planting design and considering healthy soil
    - The right mix of sun and shadow
    - Designing an optimal green or solid barrier to improve air quality and reduce air pollutant
    - Improving people participation and involvement by providing appropriate opportunities, facilities, and activities for all sections and spaces
    - Safe, recreational, and appropriate integration of the green spaces with their neighborhood context
- **Sustainability:** creating a respectful balance between using resources and gaining results. It could grow strongly by minimalizing waste, preserving water and energy, conserving clean air and oil, reducing runoff, and decreasing the pollution to improve the environment for humans, wildlife, and flora (ref. section 2.1.2.1). This could be achieved through (Calkins, 2011; Castanheira et al., 2014; Ellicott, 2016; McNeilan, 2008; Parker-Gibson, 2015; Selman, 2012; Wilson & Wu, 2016):
    - Treating water as a precious and scarce resource
    - Preserving and valuating soil
    - Benefiting the microclimate and existing terrain

    - Reducing air and noise pollution
    - Selecting appropriate plants according to the functional, aesthetic, climatic, and disease resilient aspects
    - Applying appropriate materials
    - Involving peoples in making decisions and planning
    - Providing opportunities for neighborhoods to actively participate in site projects
    - Ensuring the appropriate provision of facilities, activities, and accessibilities for all type of users
    - Conserving and enhancing natural features, wildlife, and flora (Biodiversity)
    - Conserving and enhancing buildings, structures, and landscape features to preserve and improve the culture
- **Environmental management, well maintained and clean:** applying the beneficial ways that positively impact the environment (on both local and global scale) and spend the lowest possible time and energy to maintain. For instance, by choosing the wrong plant for the project, plants will be in stress that imposes more maintenance and require more water, fertilizer, labor, time, and ultimately money. A low-maintenance landscape often is a goal for a sustainable landscape. However, the well managed and maintained project could be met through (Ellicott, 2016; McNeilan, 2008; Space, 2009):
    - Managing environmental impacts
    - Minimizing natural resource and fossil energy consumption and waste production
    - Providing the Accessibility for maintenance
    - Easy to maintain over the entire life
    - Reducing the needs of equipment, water, non-renewable energy, and expenses
    - Making the design simple
    - Applying native and appropriate plants
    - Limit the size of flowerbeds and lawns
    - Applying appropriate materials
    - Applying an underground irrigation system, especially for hot and dry climate
- **Economic feasibility:** reducing cost in time and money is one of the significant keys to landscape durability and sustainability. The designer should consider all aspects of green spaces and try to optimize their benefits (ref. section 2.1.4.2). This could

be achievable through(Danler & Langellotto-Rhodaback, 2015; Dong & Zhang, 2013):

- Saving energy
- Applying appropriate and local plants and materials
- Mitigating the heat island effect
- Applying intelligent managing and maintaining system
- Reducing maintenance and infrastructure costs
- Optimizing the water consumption
- Low intervention in nature and use the forces of nature to shape and design landscape
- Reducing landscape material pollution and its impact on the natural environment (Low emissions)
- Making green space productive

2.1.4.6 Ecological Landscape Design

Growing various environmental problems, originated in human greed and interference over the last century, is the main reason for the most critical changes affected the entire world. As discussed before (ref. section 2.1.1 and 2.1.3), landscape ecology, through planning and design, tries to reduce the negative effects of human interference and to protect and promote natural resources, natural performance, ecosystem services, and their socio-cultural components.

Sim van der Ryn and Cowan (1996) defined ecological design as "*any form of design that minimizes environmentally destructive impacts by integrating itself with living processes*" (Van der Ryn & Cowan, 1996). In other words, by applying An ecological approach to landscape design, natural systems will be united as an essential section of urban landscape, and the design process will be viewed through a biogeographical lens (Beck, 2013, p. 7; Danler & Langellotto-Rhodaback, 2015).

Farmers, through the informal application of local materials, could improve the prior instance of ecological design. They self-formed the environment based on their local knowledge of biodiversity and ecosystem (Shu-Yang, Freedman, & Cote, 2004). Nowadays, ecological planning and design are widely accepted as a rational approach in urban and landscape planning and design by emphasizing natural processes and resources, ecosystem services, human demands, and interrelations of their components (Giliomee, 1977; Hills, 1974; Lyle, 1999; Makhzoumi & Pungetti, 1999; McHale, 1969; McHarg, 2014; Selman, 1981; Steiner, Young, & Zube, 1988).

2.1.4.6.1 Guidelines and Principles of Ecological Landscape Design

In previous sections, some guidelines for ecological planning were mentioned and discussed (ref. section 2.1.1). Beck, in *"Principles of ecological landscape design"*, has pointed out, "*An ecological designer has to consider together the design goals, the size, and location of the site, and the productivity of the soils in order to create a plant community with the appropriate species richness. In general, the larger the site, the greater the diversity of habitats, and the less rich the soil, the more species can be included*" (Beck, 2013, p. 58).

However, based on recent studies (Beck, 2013; Çelik, 2013; Danler & Langellotto-Rhodaback, 2015; Dramstad et al., 1996; Johnson, 2013; Lyle, 1999; Makhzoumi & Pungetti, 1999; Shu-Yang et al., 2004; I. H. Thompson, 2006; R. Wang, 2014), promoting the ecological landscape design as dynamic, intuitive, holistic, and responsive design could be met (besides the aesthetics aspects) by applying following tips and considering these principles:

- The design should promote the **ecosystem services**
    - Creating and design diverse ecosystems and also considering the function of the target site as a part of wholes in different scales
    - Applying and paying especial attention to landscape ecology principles (i.e., patches, edges, mosaics, and corridors) and their size, numbers, locations, shapes, and interactions for the optimal design
    - Adjusting harmoniously proper biotic and abiotic elements to the local conditions (plants, species, habitats, materials, resources)
    - Providing wildlife habitat and supporting biodiversity
    - Reducing CO_2 and air pollution
    - Providing and storing water
    - Improving water quality
    - Designing the complete waste and water cycle
    - Managing the runoff and stormwater
    - Promoting healthy water and living soils
    - Controlling and reducing the erosion and sediment
    - Using animal to improve soil
    - Managing waste and Cycling nutrients
    - Producing food and renewable energy, medicine, or other products
    - Protecting and promoting human well-being, health
    - Considering cultural benefits
    - Mitigating Hazards

- Creating **resilience and flexible design**. The design should provide the conditions to let ecosystems self-design and to be resilience and should be prepared for common disturbances
  - Minimizing human vulnerability
  - Making the site Self-productive
  - Actively engaging the citizen
  - Easy access to all section of the site
  - Providing reliable mobility and communication
  - Contributing flexible infrastructure services
  - Reducing the exposure and fragility
  - Providing the multi-use spaces and open spaces in the site
  - Creating appropriate land use and zoning
  - Providing comprehensive community awareness and adequate education for all
- **Selecting the right plants for the right place**
  - Planting with optimal distance consideration
  - Planting proper plants together and therefore avoiding to plant which are not suitable to plant together
  - Protecting the original spices by applying different population, size, and age
  - Applying native plants and their ecotypes or suitable plants according to local climate conditions
  - Considering on fertility of the site and using productive plants
  - Creating seasonal interest by a combination of plants with different seasonal behaviors, life history, and adaptation to the local climate
  - Designing Variously for various biomes and understanding the competition mechanism in plants to design properly mixed combinations
  - Allowing the spices and plants to adapt and change over time
- **Climatic design** and reducing heat island effects
  - Heat island mitigation
  - Applying renewable energy
  - Reducing solar radiation
  - Thermal comfort design
  - Considering to control the humidity, wind, and air pollution
  - Selecting the optimal surface materials and suitable vegetation

  This part will be discussed more in detail in section 2.2.5.

- **Economically design** in order to minimize environmental disturbance
  - Saving energy and resources
  - Applying local and recyclable material
  - Using the surface materials that have the potential to adjust to changes and helps to reduce energy consumption
  - Using renewable energies
  - Increasing production of the site
  - Increasing property value
  - Applying intelligent management and maintenance
- Increasing **human benefits** (for all demographics and age groups)
  - Providing beauty, pleasure, and recreation
  - Improving human health and value equity
  - Enhancing human comfort and increasing the participation in site activities
  - Preserving and protecting **culture** and heritage
  - Blending local and cultural value through integration into the design

2.1.4.7 Sustainable Landscape Design

In the previous sections (2.1.2.2 and 2.1.3), the landscape and urban sustainability have been briefly discussed as well as their development goals and indicators. In this part, creating a sustainable landscape design and its process will be explored. The challenge of sustainable design is to create an aesthetically pleasing landscape, while not only it protects and improves the air, water, soil quality, and all other aspects of ecosystem service, but also must have economic and socio-cultural benefit. To this end, Sustainable Sites Initiative 2009 [1] distinguished some guiding principles for a sustainable landscape which are undermentioned:

- **Do not harm:** Despite not making any changes to the site that could harm the environment, regenerating and promoting ecosystem services should be given priority through sustainable design.
- **Precautionary principle:** In order to protect human health and the environment, it must be very careful in making decisions and examining a wide range of options because some of the actions cause irreparable damage.
- **Design with nature and culture:** Designs should not only be responsive to the economic, environmental, and cultural conditions, but they must also be appropriate to local, regional, and global contexts.

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1 - Partnership of the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center, and the United States Botanic Garden in conjunction with a diverse group of stakeholder organizations to establish and encourage sustainable practices in landscape design, construction, operations, and maintenance.

- **Apply a decision-making hierarchy of preservation, conservation, and regeneration:** through maintaining available environmental features, protecting natural resources, and regenerating lost or harmed ecosystem services, maximize and optimize the benefits of ecosystem services could be achievable.
- **Provide regenerative systems as intergenerational equity:** Providing a sustainable environment for future generations, an environment supported by regenerative systems, and provided with renewable resources.
- **Support a living process:** Adapting to demographic and environmental changes by constantly re-evaluating the values, features, and assumptions
- **Use systems thinking approach:** Re-establishing or valuing essential relationships like human activities and natural processes in an ecosystem with a sustainable approach.
- **Use a collaborative and ethical approach:** Establishing sustainable, long-term, direct, and open communication between all users of the landscape.
- **Maintain integrity in leadership and research:** Applying transparent and participatory leadership, developing high precision-research, and updating the system in a clear, consistent, and timely way.
- **Foster environmental stewardship:** In order to provide and promote healthy ecosystems improved life-quality for current and future generations, environmental stewardship in all aspects of land management and development is essential (Sustainable Sites Initiative, 2009).

Landscapes are dynamic and generative systems, which continually changing by growing plants, evolving maintenance methods, and additionally, they vary by changing the adjacent land-uses over time. Therefore, this process vitally requires a long-term maintenance plan. Based on the aforementioned principles and processes of site development, Calkins (2011) emphasized nine sections to evaluate the comprehensive sustainable landscape plan. These are mentioned as follows:

- **Site Selection and Planning**
- **Site design - Soils**
- **Water**
- **Vegetation**
- **Materials Selection**
- **Human Health and Well-Being**
- **Existing/Historic Facilities and Cultural Landscapes**
- **Construction**
- **Operations and Management**

2.1.4.8 Ecological Sustainable Design

As discussed earlier, in the context of today's world problems and disruption of the balance of natural systems, caused by human’s uncontrolled interferences in nature (such as air pollution, habitat loss, lack of natural resources, etc.), there is growing attention to how ecosystems and natural resources can be protected. Consequently, achieving sustainability at the global level is closely linked to proper landscape planning, design, and maintenance. Thus, the development and maintenance of sustainable landscapes in ecological terms has become one of the most important concerns of scientists and experts in this field.

In this regard, to achieve ecological sustainability, ecological landscape architecture is looking for a sustainable built environment to maintain the health of the surrounding ecosystems (as the primary source of human needs), to increase the ability to develop and provide more opportunities for today and future generations. Thus, from I. H. Thompson's point of view, landscape architecture has an **ecological** dimension in addition to an **aesthetic** and **social** dimension. So that (I. H. Thompson, 2006):

- The ecological dimension includes the natural forces that shape the landscape: climate, soil, water, vegetation, air quality, natural resources, wildlife, and ecosystems.
- The social dimension includes the human forces that shape the landscape: history, societies and traditions, culture, personal and social behaviors, activities, and functions, human participation, and human health.
- The economic dimension includes the budget and economic considerations, financial needs, potentials, and economic benefits and productivity.

The guidelines and principles of these three categories are described in detail in the previous sections. However, it should be noted that the applied principles and goals in landscape design, depending on the design scale, are defined differently from each other. Thus, different scales of design require the application of different types of ecological principles.

2.2 Urban Climate and Green Space Design

2.2.1 Urban Climate

Today, more than half of the world’s population lives in towns, cities, and their proportions of the earth’s population, which are increasingly growing in number. It is evaluated that by 2030, the population of cities will be more than 60% of the world’s population. These trends of accelerating growth are changing the urban conditions, and the result is nothing but the excessive expansion of cities and deterioration in environmental quality (Kuttler, 2008).

As areas of economic and industrial activities with high pollution density, cities might be responsible for 40% - 80% of all produced greenhouse gas emissions on the earth. These numbers emphasize the fact of changing and overcoming urban climate in the environmental domain for most of the world's population (Blake et al., 2011).

However, these changes have made differences between the climate of cities and their surroundings, which are mentioned as the "**Urban Climate**". The climatic features are especially considerable among urban environmental problems. In urban areas, the most obvious cases of "inadvertent climate modification" (Oke, 1987) are evidentially recognizable (Alcoforado, Andrade, Lopes, & Vasconcelos, 2009; Arnfield, 2003; Kuttler, 2008).

Blake and his colleagues (2011, p. 44) determined four significant elements of urban climate:

1. The current climate and its historical trends;
2. The Urban Heat Island effects and air pollution;
3. The natural variability and global climate change; and
4. Adaptation and mitigation for current and future climate

The schematic of these significant components presents their interrelation and how, directly or indirectly, they affect urban climate within their inter-relative influences (Figure 2-7). For instance, the domain, regularity, and periodicity of natural variability might be influenced by climate change, such as the frequency and intensity of the North Atlantic Oscillation (NAO) or the El Nino–Southern Oscillation (ENSO) (Blake et al., 2011).

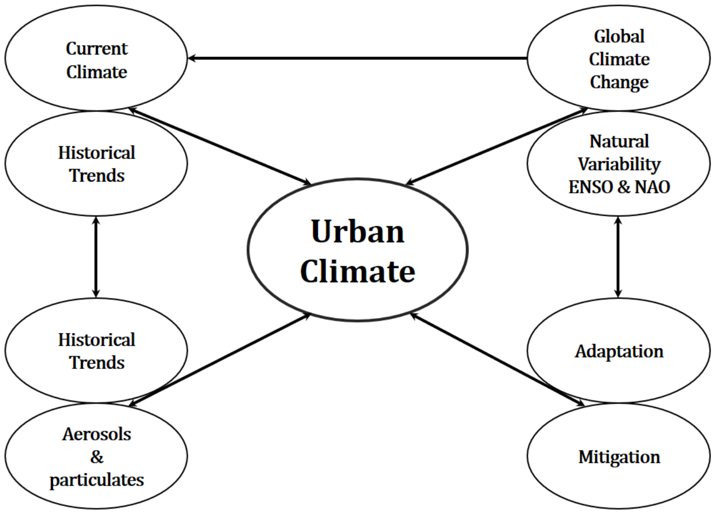

Figure 2-7 - Schematic of significant components of Urban Climate System (Blake et al., 2011).

Consideration of urban climate and environmental sustainability, urban resilience, and disaster risk management is adopted in the new UN urban agenda (UN-Habitat III, 2016), as the primary key for sustainable urban development in the next 20 years (Baklanov et al., 2017).

2.2.1.1 Urban Climate, Causes and Features

The impact of Urbanization on different aspects of climate (e.g., humidity, cloudiness, precipitation, radiation and temperature, contaminants, and air quality) have been well documented by Landsberg (1981), Berry (2008), and compared to its surrounding rural environment:

- **Radiation:** Total on horizontal surface 0-20% less, Ultraviolet-winter 30% less, Ultraviolet-summer 5% less, Sunshine duration 5-15% less;
- **Temperature:** Annual mean 0.5-3.0 °C more, Winter minimums (average) 1-2 °C more, Summer maximums (average) 1-3 °C more, Heating degree days 10% less;
- **Cloudiness:** Clouds 5-10% more, Fog-winter 100% more, Fog-summer 30% more;
- **Precipitation:** Amounts 5-15% more, Days with less than 5 mm 10% more, Snowfall inner city 5-10% less, Snowfall lee of city 10% more, Thunderstorms 10-15% more;
- **Relative Humidity:** Annual mean 6% less, Winter 2% less, Summer 8% less;
- **Contaminants:** Condensation nuclei ten times more, Particulates 50 times more, Gaseous admixtures 5-25 times more;
- **Wind Speed:** Annual mean 20-30% less, Extreme gusts 10-20% less, Calm 5-20% more;

(Marzluff et al., 2008).

Therefore, lower humidity, balance changes in wind speed and radiation, higher air temperature, and an increasing number of contaminants are part of climatic results of urbanization, which may, besides the urban climate, affect regional or even global climate. The four undermentioned causes are the main reasons for these changes in urban climate areas, which are derived from human activities and various utilizations of built-up areas (Johansson, 2006b; Kuttler, 2008):

1. Replacing the natural soil by mostly artificial, sealed, high absorbance short-wave radiation, and strong 3D structure materials and surfaces;
2. Reducing vegetated and green surfaces and replacing by mostly hard and waterproof surfaces;
3. Reducing the long-wave emission of the urban surfaces area by creating urban canyons; and

4. Release heat, gaseous, different kinds of air pollutants from vehicles, cooling and heating systems, and industrial activities.

2.2.1.2 Urban Climate Scales

Scales must be defined, especially when the spatial and temporal issues are studied. On the other hand, applying scales would be unavoidable when investigating the origin and form and afterward modeling and preparing appropriate measurements for heat islands (Roth, 2013).

Oke (2004) defined three climate scales in urban areas as **micro, local,** and **mesoscales**.

- Horizontally, the microscale comprises squares, streets, gardens, buildings, trees, etc.; the local scale includes urban neighborhoods, while the mesoscale represents the whole city (Oke, 2004).
- Vertically, urban boundary layer is divided into Roughness Sub-Layer (RSL), Internal Sub-Layer (ISL), and Mixing Layer. The microscale is found within the roughness sub-layer, which depends on the height of building atmospheric stability (Oke, 2004); Surface layer represents internal sub-layers and roughness sub-layer; and mixing layer where the downwind of its above layer is transported and with variations of urban surface is mixed to the broader atmosphere (Roth, 2013).

A better comprehension of the abovementioned scales and urban boundary layer is presented in Figure 2-8. This comprehension assists the application of micro-meteorological theory to urban and spatial planning than before. Indeed, based on this comprehension, the interactions between microclimates and exchanges of surface layer related to other neighborhoods could be more understandable and helpful to locate the urban flux measurement sites (Christen, Grimmond, Roth, & Pardyjak, 2009; Mills, 2014).

Urban Canopy Layers (UCL), as a part of urban microscale, which are created from an individual building, tree and their intervening spaces, and squares, streets, gardens, and parks as parts of microscale which are the lower part of roughness sub-layer (Oke, 2004), is the focused scale of this thesis (Figure 2-8-C).

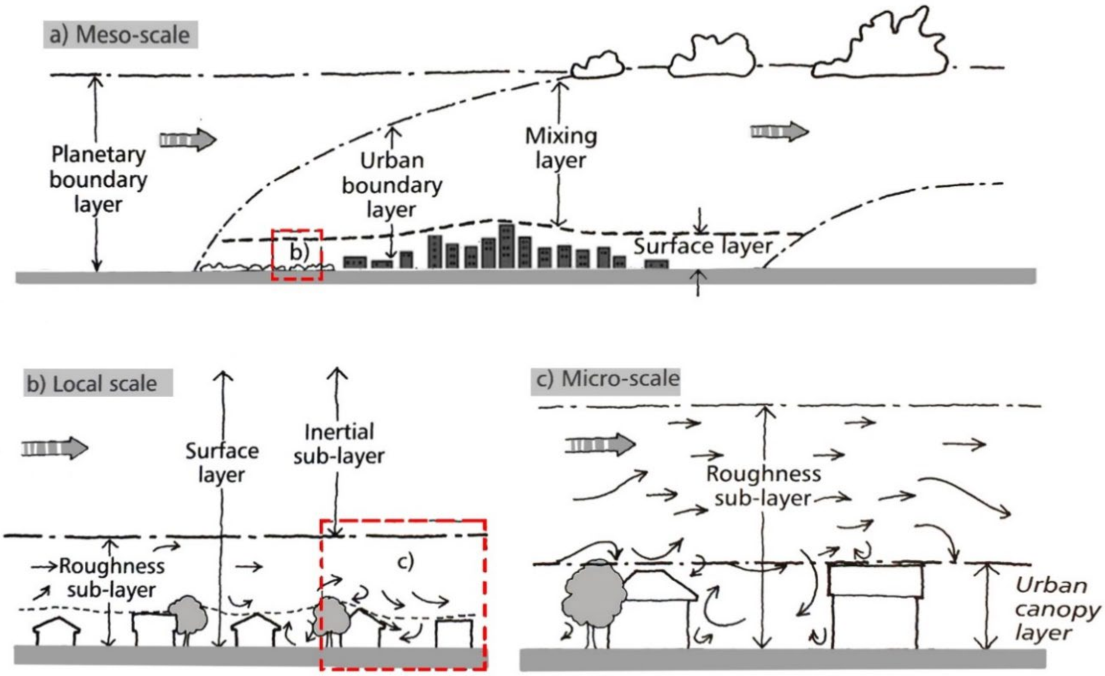

Figure 2-8 - Meso, Local, and Microscale are defined as different climatic scales of urban areas (Oke, 2004).

Scale clarifies the fact that there is more than one type of heat island. Indeed, scale specifies the conceptual structure and framework of each type by determining the size of the origin area of thermal effect and how it alters during the time, also determining affected and created processes of each heat island (Roth, 2013).

It must be considered that each target of studies (e.g., urban heat mitigation, building energy consumption, human comfort) occur at various scales.

2.2.2 Urban Heat Islands

2.2.2.1 Definition and Causes

Voogt and Oke (2003) defined the Urban Heat Island (UHI) as a phenomenon in which urban air temperature is warmer than the surrounding non-urbanized areas, specifically during nights resulting from surfaces and atmospheric modifications of urbanization. They illustrated the Urban Heat Island as one of the most significant effects of urban microclimate derived initially from surface temperature (which are mostly human-made and absorbing and capturing solar radiation) and secondly from waste heat release.

Indeed, surface materials by diurnal absorbing solar energy, capturing, and releasing it back into the urban atmosphere at night lead to a modified urban thermal climate.

The urban heat islands effect in a city with one million people is assumed to warm air temperature 1-3 °C in comparison to its rural surroundings (Oke, 1997), and is anticipated to almost 1 °C more per decade (Voogt, 2002). However, this temperature difference is assumed to be 12 °C during a calm and clear night (Oke, 1987). Besides the urban heat islands, cool islands are identified by Oke (1982), which are ascribed to the shades of vegetation and buildings.

In the case of various land-uses in cities, different air temperatures are expected, which included a mosaic of warm and cold areas, e.g., the alteration between built-up and park can lead to up 7 °C intra-urban temperature differences (Eliasson, 2000; Spronken-Smith & Oke, 1998). These modifications of urban-temporal climate can be schematically seen in Figure 2-9.

The significance of urban heat islands persuaded many researchers to study this phenomenon and investigate the features and impacts of urban heat island effects (Arnfield, 2003; Eliasson, 2000; Ghiaus, Allard, Santamouris, Georgakis, & Nicol, 2006; Johansson, 2006b; Oke, 1981, 1982, 1987; Oke, Johnson, Steyn, & Watson, 1991; Voogt, 2002; Voogt & Oke, 2003).

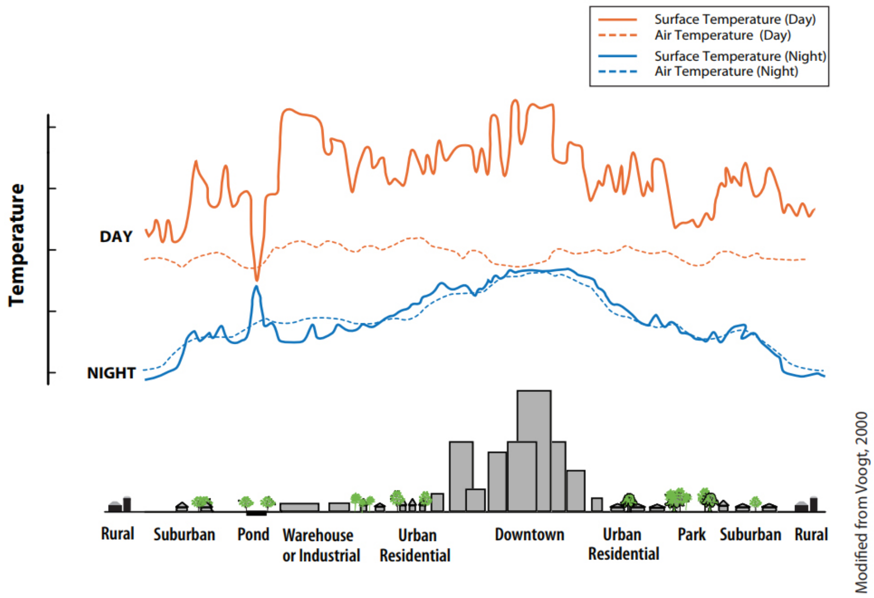

Figure 2-9 - Different land uses have various impacts on diurnal and nocturnal temperature (U.S. Environmental Protection Agency [EPA], 2008).

2.2.2.2 Impacts of Urban Heat Islands

Human health, economy, and environmental community can be affected negatively by elevating urban air temperature due to urban heat islands, especially in the summer (Corburn, 2009). Although, due to this phenomenon, there are also some beneficial impacts (e.g., increasing the season of plant-growing), but most of them are destructive and negative.

The major negative impacts of urban heat islands include (EPA, 2008):

- endangered human health and comfort;
- increase in energy consumption;
- rising emissions of air pollutants and greenhouse gases; and
- disruption in water quality.

Human Health and Comfort

Urban heat islands, besides increasing diurnal temperature, reducing nocturnal cooling, and elevating air pollution, can also aggravate the effect of heatwaves, which are almost abnormal phenomena such as periods of abnormally hot weather, lightning, tornadoes, and floods. These impacts of urban heat islands will influence human health by participating in various discomforts, heatstroke, and heat-related mortality (EPA, 2014).

However, sensitive populations such as young children, elderly persons, low-income and minority population, people who work outdoors are the most vulnerable to these effects of urban heat islands (Basara, Basara, Illston, & Crawford, 2010; Gamble et al., 2013; Kovats & Hajat, 2008; Taslim, Parapari, & Shafaghat, 2015; USGCRP., 2008).

According to the Centers for Disease Control and Prevention, In the United States, from 1979-2003, exposure to excessive heat has tended to more than 8,000 premature deaths (CDC-Centers for Disease Control and Prevention, 2006; EPA, 2014).

Energy Consumption

Due to temperature rise in the summertime and intensified by urban heat islands, energy and electricity demands increase as well. Overloading the energy consumption and blackouts are resulting from these events, which should be controlled to avoid power outages (EPA, 2008).

It is estimated by Akbari and his colleagues (2001) that the electricity consumption for cooling building, just to compensate for 0.5–3.0 °C increased air temperature resulted from urban heat islands since 1940, is 5-10% of current urban energy demands (Akbari et al., 2001). Moreover, it is assessed that for every 1 °F (0.6 °C) elevated air temperature (starting from 20-25 °C), the electricity demands would rise 1.5-2.0%, in other words, 2-4% increase energy demands for every 1 °C (Akbari et al., 2001; Akbari, 2005a). Another study computes that dwellers of Los Angeles are yearly forced to pay about US$100 million extra for excessive use of energy to reimburse urban heat island effects.

Air Pollutants and Greenhouse Gases

As abovementioned, the increase in electricity demand is a result of urban heat islands. To reply to this demand and supply more electrical energy, a higher level of air pollution and greenhouse gas emission are inevitable. Hence, related companies mostly rely on fossil-fuel-powered plants. Besides having severe adverse human health, these pollutants (i.e., SO_2, NOx, PM, CO, and Hg)[2] are also involved in all air quality problems such as acid rain. In addition, the more CO_2 produced by fossil-fuel-powered plants, the more they contribute to local and **global climate change** (EPA, 2014).

Moreover, the increased air temperature raises the rate of ground-level ozone formation, which is formed when Volatile Organic Compounds (VOCs) react in hot weather and the sunlight presence (EPA, 2014).

Water Quality

Pavement and rooftop surfaces (with 27-50 °C) can transfer their excess heat, which is warmer than the air temperature, to storm-water runoff. Field measurements have shown that urban pavement surfaces, 11-19 °C warmer than the air temperature, elevate urban rainwater temperature approximately 11-17 °C more than surrounding rural runoff. These measurements also show increasing the stormwater runoff from about 21 °C up to 35 °C by reaching temperatures from pavements with 38 °C (Roa-Espinosa, Norman, Wilson, & Johnson, 2003).

However, draining warmed rainwaters into storm sewers would rapidly increase the water temperature of streams, rivers, ponds, and lakes. In addition, changing water temperature affects all aspects of life in aquatic ecosystems. It mainly affects the reproduction and metabolism of various aquatic species. Moreover, rapid changes in water temperature could be more stressful and even fatal to aquatic life (EPA, 2014).

Therefore, according to various and detrimental impacts of urban heat islands on **macro** and **micro-climate**, and also the crucial role of its impacts on exacerbating **global** warming, the accelerated development of this effects mitigation is inevitably necessary (Aflaki et al., 2017; Klinenberg, 2002; Kolokotroni, Ren, Davies, & Mavrogianni, 2012; O'Malley, Piroozfar, Farr, & Pomponi, 2015).

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2 SO_2: sulfur dioxide
NOx: nitrogen oxides
PM: particulate matter
CO: carbon monoxide
Hg: mercury

2.2.2.3 Mitigation Strategies and their Benefits

Due to the significance of urban heat islands, numerous papers have proposed several solutions or techniques for mitigating the intensity of this phenomenon's effects in urban areas;

- Increasing vegetated urban surfaces and areas and developing urban green infrastructures (Ahmadi Venhari, Tenpierik, & Mahdizadeh Hakak, 2017; Akbari et al., 2001; Georgi & Zafiriadis, 2006; Matthews, Lo, & Byrne, 2015; Rydin et al., 2012; Santamouris et al., 2016; Taha, Akbari, & Rosenfeld, 1991; Tzoulas et al., 2007; Yu & Hien, 2006)
- Expansion of vegetated surfaces in buildings such as green walls and green roof (Hathway & Sharples, 2012; A. Niachou, Papakonstantinou, Santamouris, Tsangrassoulis, & Mihalakakou, 2001; Santamouris, 2014; Zhao & Srebric, 2012),
- Installing cool roofs (Akbari & Levinson, 2008; Dimoudi et al., 2014)
- Applying high albedo and cool materials in buildings (Akbari et al., 2001; Jalali, Parapari, & Mahdavinejad, 2019; Smith & Levermore, 2008; Takebayashi & Moriyama, 2012)
- Applying high albedo and cool materials in urban spaces, streets, and pavements(Akbari & Matthews, 2012; Santamouris, 2013; Takebayashi & Moriyama, 2012)
- Controlling natural wind (Smith & Levermore, 2008)
- And applying urban surfaces and bodies of water within cities (Kleerekoper, van Esch, & Salcedo, 2012)

These are some of the proposed strategies or measures to mitigate urban heat island effects. EPA, 2008 has categorized these strategies into four categories:

- Trees and Vegetation;
- Green Roofs;
- Cool Roofs;
- and Cool Pavements.

Afterward, Smart Growth was expressed as utilizing practices to cover a wide scope of conservation and development measures. Meanwhile, these practices prevent the natural environment and make our unions livable, attractive, and economically stronger (EPA, 2008).

However, for greater efficiency of the aforementioned strategies, comprehensive planning and design, which methodically considers in environmental conditions (e.g., geography and surface topology and local climatology), is necessary (Takebayashi, Kimura, & Kyogoku, 2014; Tan, Lau, & Ng, 2016; Wong et al., 2011).

Many negative impacts of urban heat islands were illustrated in the last section (ref. section 2.2.2.2), and the significance of the urban heat island's mitigation was clarified. Therefore, by harnessing the exacerbation of current circumstances and preventing it from more harm, many benefits could be achieved. Indeed, by applying the aforementioned mitigation strategies:

- **As public health and social benefits**, cities could be more livable. Heat-related morbidity and mortality would be reduced. Mandatory, voluntary, and social activities are three types of urban activities (Gehl, 2013). Outdoor thermal comfort and improvement of air quality improve voluntary and social activities specifically for vulnerable groups by encouraging people to attend in urban spaces (Ahmadi Venhari et al., 2017; Burden, 2008; Rhodes et al., 2011);
- **As economic benefits**, decreasing the cooling-energy would be achievable. Akbari and his colleagues (2001) have estimated that 20% of cooling demands at the national level of the united states could be avoided by implementing national measures of heat island mitigations, and these percentages only for cooling-electricity worth over $4B per year by 2015. Akbari (2005a, 2005b) also evaluated that this amount could be added up to over $10B per year, as a benefit of smog reduction;
- **As environmental benefits,** improving both air and water quality as well as reduction of water consumption, are consequences of mitigation strategies: less cooling-electricity demand, less water consumption. Moreover, as energy consumption is the most significant cause of air pollutants; therefore, both ground-level ozone and water resources would be prevented (EPA, 2008).

On the other side, water temperature reduction due to mitigation strategies could affect, directly and indirectly, many aspects of life in aquatic ecosystems (ref. section 2.2.2.2, Water Quality).

2.2.2.4 Urban Microclimate and Heat Island

The microclimate, particularly in large cities, is increasingly undergoing changes and threatened by unsustainable land-cover and land-use changes, which alter atmospheric parameters near urban surfaces (Bhatta, Saraswati, & Bandyopadhyay, 2010; Emadodin, Taravat, & Rajaei, 2016; Jingyong et al., 2005).

Air temperature, direct and diffuse solar radiation, humidity, and wind velocity are some of the essential microclimatic parameters, as well as urban climatic parameters. Altering the conditions of parameters have the potential to make the microclimate pleasant or unpleasant for people, specifically in the hot season. Therefore, for developing current circumstances, planning and new designing the urban area, and implementing renewable energy in the urban environment, considering microclimatic parameters is paramount significant (Monsefi Parapari, 2015; Shahrestani, Yao, Luo, Turkbeyler, & Davies, 2015).

Reducing air temperature, increasing humidity, and preventing surfaces from direct and diffuse solar radiation could be easily achieved within urban microclimate by greening area.

The most obvious way to mitigate heat islands is to use the cooling effect of vegetated areas and urban parks at urban microscale. It should be noted that although this cooling effect is particularly significant in the hot season, it has the potential to have a negative impact in winter as well (Cohen, Potchter, & Matzarakis, 2012).

2.2.3 Urban Green Spaces and Heat Islands

2.2.3.1 Causes, Benefits, and Costs

Most of the earliest studies have proposed the increasing urban green spaces and surfaces as the most common strategies of urban heat island mitigation. Greening the cities by adding more vegetated areas and surfaces to them could significantly mitigate the urban heat island effects (Abreu-Harbich, Labaki, & Matzarakis, 2015; Akbari et al., 2001; Burden, 2008; Chang, Li, & Chang, 2007; Cohen et al., 2012; Feyisa, Dons, & Meilby, 2014; Georgi & Zafiriadis, 2006; A. Niachou et al., 2001; Saito, Ishihara, & Katayama, 1990; Santamouris et al., 2016; Taha et al., 1991).

Johansson (2006b) illustrated two different ways of cooling cities through greening the cities;

- First, Trees and vegetation, by providing shade and keeping urban surfaces from solar radiation, diffuse, and reflected radiation reduce air temperature.
- Secondly, the significant capability of evaporation and transpiration of vegetated soil to release considerable energy than other urban surfaces have made the urban green areas cooler within cities, particularly by nights.
  (Johansson, 2006b)

As Akbari and Taha (2009; 1992) have calculated in a study of Phoenix and Sacramento, the air temperature could be declined by 38-42 °F (3.3-5.6 °C) through 25% increase in the number of trees in the summer (Akbari, 2009; Akbari & Taha, 1992).

However, urban green spaces, besides all their environmental, wildlife and habitats, climate, social, cultural, and economic services and enhancing human well-being (ref. section 2.1.4.2), have particular roles and benefits in cooling the cities, which are demonstrated as follows:

- Improving indoor thermal comfort by decreasing outdoor air temperature (Ali-Toudert & Mayer, 2006; Hitchings, 2009; Li, Zhou, & Ouyang, 2013);
- Reducing the runoff water and their temperature and decreasing the risk of the flood through high penetrability of vegetated soil (McPherson, 2000; McPherson, Simpson, Xiao, & Wu, 2011; Roa-Espinosa et al., 2003);
- Improving many aspects of life in aquatic ecosystems by controlling heat stress in water temperature (EPA, 2008);
- Reduce carbon emission (Escobedo, Varela, Zhao, Wagner, & Zipperer, 2010; Jana, Biswas, Majumder, Roy, & Mazumdar, 2010; Ren et al., 2011)and air pollution, directly through their photosynthesis process and filtering role (Tallis, Taylor, Sinnett, & Freer-Smith, 2011; Yin et al., 2011), and indirectly by reduction of energy consumption resulting from reducing air temperature (Akbari et al., 2001; McPherson, Simpson, Peper, Maco, & Xiao, 2005; Tam, Gough, & Mohsin, 2015);
- Improving voluntary social activities and human well-being by enhancing outdoor comfort (Baccini et al., 2011; McMichael & Lindgren, 2011; McMichael & Woodruff, 2005; Roy, Byrne, & Pickering, 2012);
- Acting as urban biodiversity hotspots (Cornelis & Hermy, 2004); and
- Economic benefits (Akbari & Taha, 1992; Gruehn, 2013; Maco & McPherson, 2003; McPherson et al., 2005; McPherson, 2007; McPherson et al., 2011; Moore, 2009; Taha et al., 1991; Tan et al., 2016).

As aforementioned, many studies have been fulfilled in the most recent years to emphasize the significant value of green spaces and their economic benefits. Furthermore, some studies have been accomplished to discuss the worth of each tree. It is calculated by Simpson and McPherson (1998), in residential zones of hot Mediterranean climate, each tree could have a reductive role in cooling energy consumption and decreases the cost by about 1.9%-2.5% (Simpson & McPherson, 1998).

Maco and McPherson (2003) have estimated, during the 1999-2000 fiscal year in the city of Davis, California, for every $1 management cost for street trees, they benefit $3.78 to the community (Maco & McPherson, 2003).

In another research, Mullaney, Lucke, and Trueman (2015), based on recent research of tree's benefits cost, have assessed that overall economic benefits for each street tree are annually between $21 and $159 (Mullaney et al., 2015).

Most studies emphasize the positive effect of green areas on the urban climate. However, few studies have found that vegetated areas can be warmer than the surrounding built-up environment creating unpleasant microclimatic conditions (Grimmond, Souch, & Hubble, 1996; Jauregui, 1990; Potchter, Saaroni, Yaakov, Lunka, & Bitan, 2002).

However, the potential cooling effect, as well as the potential warming effect of urban parks, is particularly significant in urban areas, which are located in hot climates, where the urban heat island can considerably develop undesirable climatic conditions.

2.2.4 Urban Green Spaces and their Thermal Effects

2.2.4.1 Urban Cooling Effects and its Indexes

As mentioned in the previous part, greening areas is an effective, recommended strategy to reduce heat stress in cities. Cooling effects of green area impact impressively the city's microclimates. In other words, the terms "Urban Cool Islands" (Hamada & Ohta, 2010) or "Green space Cool Islands" (Skoulika et al., 2014) have been applied in contrast to the term "Urban Heat Islands", which affect the economy, health, well-being and outdoor activities of city dwellers (Hajat, Kovats, & Lachowycz, 2007; Patz, Campbell-Lendrum, Holloway, & Foley, 2005).

It is clarified that urban microclimates could be more comfortable for people by reducing the ambient air temperature by greening the area. Vegetation helps to cool the surrounding environment by shading and restraining the solar radiation penetration area below the tree canopy and also through evaporation and transpiration, which raise the air humidity and release the energy from the below surface and soil (Johansson, 2006b; Srivanit & Hokao, 2013). Therefore, the cooler thermal perception is felt in their covered region and adjacent surroundings (Morakinyo, Adegun, & Balogun, 2016; Sun et al., 2017).

Reducing the amount of solar radiation, which conveys through the vegetation canopy, varies by plant species, which could be between 10% and 30% of the sunlight in summer. The leaves absorb the rest of solar radiation for photosynthesis or reflect them to the atmosphere (EPA, 2017).

2.2.4.1.1 Green Cool Island's Efficiency

Green spaces, as cool green islands, participate effectively in heat islands mitigation by decreasing the air temperature inside their area and extending this cooling effect to the outside of the green space boundary (W. Lin, Yu, Chang, Wu, & Zhang, 2015; Sodoudi, Zhang, Chi, Müller, & Li, 2018). The efficiency of cool green islands could be studied from significant aspects: cooling intensity and cooling extension. Figure 2-10 completely shows both aspects of the thermal effect of urban green open space.

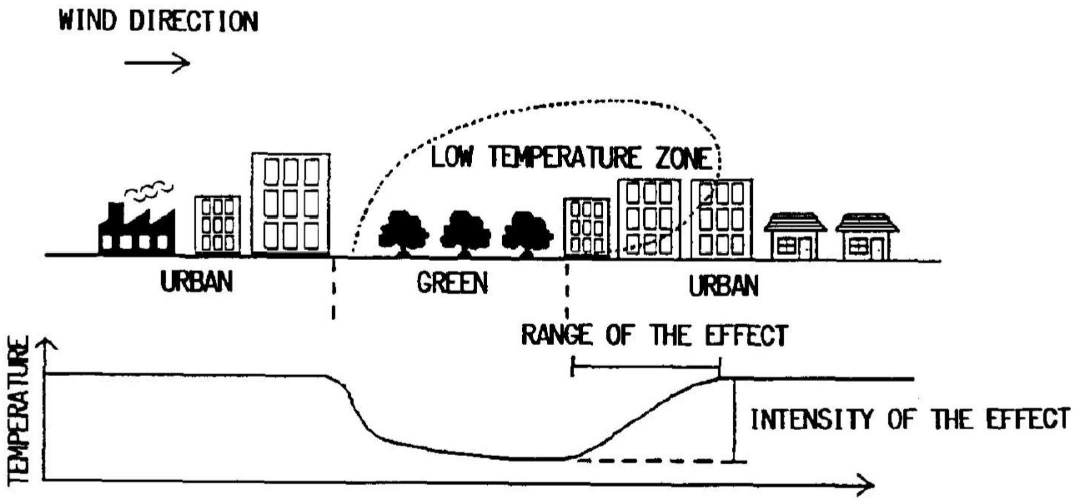


Figure 2-10 - The cooling effect of an urban open green space (Honjo & Takakura, 1990, p. 443).

2.2.4.1.2 Cooling Intensity

The variation between the temperature of the green area and its surrounding areas is determined as the cooling intensity to measure the quantity of cooling impact of urban green areas. Cooling intensity quantifies the thermal effect of green spaces by comparing the magnitude of surface temperature, air temperature, or human thermal perception in the green areas with their surroundings.

Although some studies have revealed the higher temperature of green areas than their surroundings (Grimmond et al., 1996), most of the studies indicate that the cooling effect of urban green spaces varies between 0.2 to 6.9 K (Feyisa et al., 2014; Oliveira, Andrade, & Vaz, 2011). Nevertheless, the studies demonstrate that the cooling effect on thermal comfort is more than the air temperature and surface temperature eider. In this term, Ali-Toudert and Mayer (2007) calculated the decrease in Physiological Equivalent Temperature (PET) up to 20 °C.

2.2.4.1.3 Cooling Extension

The cooling extension is the distance and radius, which are affected by the cooling efficiency of green space. The more distance from the green area, the less its cooling effect. Skoulika et al. (2014) estimated the reduction variety of 0.2 K up to 1.4 K per 100 meters. Jauregui (1990) illustrated, in Mexico, the cooling impact of a park was expanded up to 2000 m, while Saito et al. (1990) found the cooling effect of a park in Japan 15-20 m from its border.

However, the wide reported range of cooling extension indicates that various factors are involved in expanding temperature reduction caused by green spaces. These factors include the green space characters as well as characters of its surrounding area such as size and shape of green space, wind speed and direction, topography, land use, and traffic (Ahmadi Venhari et al., 2017; W. Lin et al., 2015).

However, the cooling efficiency of green spaces on air and surface temperature may vary depending on environmental factors and plant characteristics (Taha, 1997). In the following, the significant effective indexes on the cooling impacts of green spaces are expressed.

2.2.4.1.4 Cooling Effect Factors

Depending on a wide variety of internal and external factors, green spaces may variously behave in their cooling effects (Spronken-Smith & Oke, 1998; Upmanis & Chen, 1999). Most studies have categorized these factors into two categories; internal factors and external factors. The internal factors include the indexes and criteria related to green spaces characteristics (e.g., its shape, area, species, arrangement, and coverage). In contrast, the external factors encompass the features which are rising from climate and surrounding areas of green spaces (e.g., wind, air humidity, time and date, land uses, traffic, and surface material) (Ahmadi Venhari et al., 2017).

Internal Factors

Size

One of the most significant discussed issues regarding the cooling effect of green spaces is the Size Index. A research group mentioned the size index as the most crucial factor by comparing the cooling efficiency of 4 green spaces with various sizes between 4.5 to 36 ha, in the way that the cooling effect of the largest space was approximately 2k cooler than the smallest area (Lu, Li, Yang, Zhang, & Jin, 2012). In other research, Lin et al. (2015) also illustrated the cooling effect of green spaces on the surrounding areas increases by the size of green spaces (W. Lin et al., 2015).

Therefore, it is signified that the larger sizes of green spaces, the stronger and more sustainable the effect. Furthermore, Chang et al. (2007), by surveying 61 parks in Taipei, found out, the parks larger than 3 ha were steadily cooler than the surrounding area while the parks smaller than 3 ha were not invariably cooler. Moreover, they demonstrated only the parks smaller than 2 ha could be warmer than their surrounding areas (Chang et al., 2007).

Nevertheless, Honjo and Takakura (1990) express the range of affected areas as a function of the green area scale and the interval between green areas. In another study, he analyzed these relations by simulation. Therefore, Honjo (2009) suggested smaller green areas that have 300-700 m width with sufficient intervals, which applied 200m are preferable for efficient green cool islands.

Shape

Another significant factor of the cooling effect is the shape of the landscapes or green spaces. This factor is quantified by Landscape Shape Index (LSI), which could be calculated by following the famous formula (Cao, Onishi, Chen, & Imura, 2010). In this formula P_t is the perimeter and A is the area of green space.

Equation 2-1:

$$LSI = \frac{P_t}{2\sqrt{\pi * A}}$$

Regarding this formula, regular geometric shapes like circle and square have less LSI than irregular and none-geometrics (i.e., 1 for circle and 1.13 for square) (Cao et al., 2010).

Feyisa et al. (2014), in a study, compared the various shape of green space. They revealed that the higher the LSI, the larger the cool extension, while by increasing the LSI, the cooling intensity was less. Therefore, they realized that by greater the LSI, cooling intensity acts in contrast to the cooling extension. Thus, they suggested applying circular shapes of green spaces where temperature reduction is requested while they recommend the utilization of the none-geometric and irregular shapes where the higher cooling range is needed (Feyisa et al., 2014; Lu et al., 2012).

Species Index

Vegetation has various impacts and behavior on its cooling efficiency due to having diversities in their physical and biological characteristics. Physical characteristics of vegetation, e.g., the density of foliage and their color lightness, thickness, and texture, are significantly effective in their cooling effect (B.-S. Lin & Lin, 2010). So that the trees, by absorbing 60-90% of sun radiations or reflecting them to the atmosphere and also by absorbing infrared and up to 90% of UV radiation, though shadow making, accomplish a great assist in cooling the green areas and making them more comfortable (EPA, 2017). Therefore, shrubs, bushes, and grasses have a minimal cooling impact, caused by making no shadow (Petralli, Massetti, & Orlandini, 2009; B. Zhang, Xie, Gao, & Yang, 2014).

Moreover, plants behave variously to change the temperature according to their different time of photosynthesis (Lu et al., 2012) and their exclusive transpiration amount (Goyal, 2004). For instance, in contrast to trees, grasses have not appropriate thermal behavior to cool the middays area since they produce heat by their photosynthesis, which is occurred in middays. Nevertheless, by losing their surface temperature quickly overnights, grasses act more efficiently in mitigating heat stress (Nichol, 1996). Therefore, based on the requested problem, the plant should attentively choose. This emphasizes the significant role of the species index to make the green spaces more efficient.

Tree Canopy Cover

Covering the land area by shading through the expansion of plant foliage is known as "Tree Canopy Cover" (Jennings, 1999) or as "Forest Canopy Cover" in some forest researches (Hamada, Tanaka, & Ohta, 2013). Tree canopy cover has been utilized either in energy consumption or in thermal comfort studies by donating functional data of the land area of tree shade and their impact on reduction temperature. Therefore, it is an essential index for the cooling efficiency of green spaces. This index could be applied as a complementary index beside the size and shape index to analyze the number of urban landscape types (e.g., corridor and patch), which is covered by greenery (Feyisa et al., 2014; McPherson et al., 2005). Moreover, this coverage index has a significant role in controlling and moderating wind speed in urban areas (F. Yang, Lau, & Qian, 2011).

Tree canopy cover has been quantified by various methods in different studies. Some of the most well-known methods are mentioned as follows:

- The Leaf area index (LAI) (Buyadi, Mohd, & Misni, 2013; B.-S. Lin & Lin, 2010; Sun et al., 2017),
- Green Coverage Ratio (GCR) (Du et al., 2017; Srivanit & Kazunori, 2011),
- Normalized Difference Vegetation Index (NDVI) (Feyisa et al., 2014; Skoulika et al., 2014; Srivanit & Hokao, 2013),
- Sky View Factor (SVF) for the vegetated area or Tree sky View Factor(TVF) (Correa, Ruiz, Canton, & Lesino, 2012; T. P. Lin, Matzarakis, & Hwang, 2010; F. Yang et al., 2011), and
- Partially Shaded Area (PSA)(Oke, 1987; Shashua-Bar & Hoffman, 2000).

Spatial Arrangement

Another important factor in terms of the cooling efficiency of urban green spaces is the arrangement way of their elements. This factor could be a distinguishing reason when two green spaces, with the same external condition and the same size, shape, species, and coverage indexes, have a different cooling effect in both intensity and extension efficiency. Configuration and composition (ref. section 2.1.1.1) of green areas may mostly determine the differences in land surface temperature (Li, Zhou, Ouyang, Xu, & Zheng, 2012). For instance, Y. Zhang, Murray, and Turner (2011) demonstrated that the overall cooling benefits of urban landscape with a dispersed pattern is higher than the landscape with a clustered pattern, it means, to obtain more temperature reduction, the composition of land cover parameters is more significant than their configuration (B. Zhang et al., 2014; Y. Zhang et al., 2017).

Therefore, spatial pattern and arrangement of urban landscape could strongly affect the cool green island (Buyantuyev & Wu, 2010; Cheng, Wei, Chen, Li, & Song, 2015; Connors, Galletti, & Chow, 2013; Wong & Yu, 2005; Zhou, Huang, & Cadenasso, 2011). Likewise, Sun et al. (2017) implied the proper spatial arrangement of landscape parameters in both terms of thermal comfort and aesthetic aspects, which could influence the cooling efficiency to a large extent.

External Factors

Climate

Many studies have expressed the climate as an imperative factor, which influences the cool green island. Indeed, both urban **climate** and **microclimate** conditions play a significant role in cooling efficiency, named by Shashua-Bar and Hoffman (2000) " the background effect" (Shashua-Bar & Hoffman, 2000).

Ahmadi Venhari et al. (2017), in a review study, by comparing the cooling effect of urban green spaces based on different climates, mentioned the most reduction effect in an arid and semi-arid climate. So that, regarding their review, maximum reduction temperature 6.8 °C, minimum 2 °C, and average 4.4 °C is reported, while they determined this maximum, minimum, and average 5.6 °C, 1.5 °C, and 3.24 °C in a tropical climate and also 0.7 °C, 5.7 °C, and 2.8 °C in temperate/Mediterranean climate. As explained, although the most drop temperature due to the cooling effect of green spaces has occurred in the arid and semi-arid climate. Unfortunately, the least research has been accomplished in this climate.

Moreover, local climatic parameters (e.g., local wind speed and direction, local relative humidity, surrounding surfaces, air quality, and air temperature) also affect the cool green island. Thus, trees shad are more effective in arid and semi-arid while breeze has more efficiency in the Mediterranean climate due to existing higher relative humidity. Konarska et al. (2014) determined that the higher the temperature and the lower the relative humidity, the more effective green spaces (Konarska, Lindberg, Larsson, Thorsson, & Holmer, 2014). Furthermore, Oke (1987) illustrated that wind speed over 6m/s could vanish the green cooling effect versus the breeze, which could positively be effective in cooling extension.

Date and Time

The variation range of solar altitude angle in different climates directly affects the cooling effect of green spaces. Solar altitude angle alters regarding the time of day (i.e., day and night), the time over the year (i.e., different seasons), and the latitude on Earth (i.e., different climates). Based on each of these variations, vegetation behaves variously. Hamada and Ohta (2010) reported that the green spaces in summer (1.9 °C) are more effective in temperature reduction than winter (0.3 °C). They also found out that the cooling impact of green space extended 200-300 m into urban areas at night in summer, while it exceeded 300m during the day.

Land-use

Urban land-use is another practical factor, which affects the cool green island. Stabler, Martin, and Brazel (2005), in their research, by analyzing 107 random urban sites, revealed that green spaces have various cooling impacts on different land-uses. They showed that the industrial and commercial land-uses in comparison with residential land-use remarkably have a higher temperature (Stabler et al., 2005).

Another study also indicated that the cool extension of the park reduced the temperature in all its surrounding land-uses. Nevertheless, this reduction was the least in commercial land-use (Hamada et al., 2013). However, these studies show that the land-uses that release heat or make a crowd of people, respectively like, industrial and commercial land use to reduce green spaces' cooling effect.

Urban Form

Urban density, the blocks, and street orientation, build-up or green enclosure, buildings height and canopy, and their arrangement, as significant parameters of urban form, by affecting airflow vary the cooling effect of urban green spaces (Ali-Toudert, Djenane, Bensalem, & Mayer, 2005; Darbani, Parapari, Boland, & Sharifi, 2021; Ng, Yuan, Chen, Ren, & Fung, 2011; K. Niachou, Livada, & Santamouris, 2008; Santamouris, Georgakis, & Niachou, 2008). For example, Oliveira et al. (2011) indicated that green spaces, which are enclosed by high buildings, have a much lower cooling extension since high buildings block the wind and airflow.

Another study conducted by Johansson (2006a) expressed that, due to sun exposure, streets with a north-south orientation have a better thermal condition than east-west streets. Therefore, controlled wind speed and direction and also optimized orientation could increase the cooling extension (Hsieh & Wu, 2012; Santamouris et al., 2008).

Traffic

Releasing heat through traffic vehicles and thereby increase the air temperature may reduce the cooling extension. Therefore, the heavy traffic could decrease and also vanish the effect of the cool green island (Shashua-Bar, Tsiros, & Hoffman, 2012; Zoulia, Santamouris, & Dimoudi, 2009). For instance, Shashua-Bar and Hoffman (2000) measured the impact of heavy traffic on reducing the green space cooling effect around 3 °C in their case study.

Surface Material

Surface materials, which are applied in surrounding the green space, affect both cooling intensity and extension by retaining solar radiation emission (Liu, Shintaro, Zhuang, & Kuang, 2012). Materials with high absorption decrease the impact of cool green islands (Santamouris, 2014). Moreover, the water body as ground surface acts variously on the thermal condition of macroclimate and raises controversial discourses in this field. Hathway and Sharples (2012) reported the positive effect of the river for increasing the cool green island, while in another study in hot summer, the negative effect of the urban lake was determined caused by evaporation and thereby increase of humidity (Steeneveld, Koopmans, Heusinkveld, & Theeuwes, 2014).

Du et al. (2017) also found a negative relation between cooling extension and percentage of the impervious surface surrounding the green space and positive relation between the portion of the water body inside and outside of green spaces. Therefore, they concluded that by increasing water body and vegetation and versus by decreasing impervious surfaces, the range and efficiency of green space's cooling effect would strengthen (Du et al., 2017).

Land Morphology

Topography, slopes, and valley, as morphological land parameters, may also affect the cool green island. Decreasing green space cooling effect is reported by Eliasson and Upmanis (2000) through blocking nocturnal airflow through topography, slope, and direction. Moreovere, Hamada et al. (2013) emphasized on impact of an appropriate topographical utilization either inside or outside the green space could positively extend green space's cooling effect into the surrounding urban area.

2.2.4.2 Thermal Comfort and its Features

Heat islands in cities make an unpleasant environmental situation for citizens in urban areas. After the 1960s, these outdoor discomforts increased the attention on effective parameters of microclimate which influence outdoor thermal conditions, furthermore, on personal factors such as clothing, activities, sex, and psychological status, which individually alter the outdoor thermal perception (Dear & Spagnolo, 2005; Honjo & Takakura, 1990; H. Mayer & Höppe, 1987; Nikolopoulou, Baker, & Steemers, 2001; Swaid, Bar-El, & Hoffman, 1993). Discussing different aspects of thermal comfort could help to have more explicit definitions. Three significant aspects of thermal comfort are:

- **Psychological aspect** in which thermal satisfaction is depended on the personal mental conditions (Höppe, 2002; Nikolopoulou & Steemers, 2003),

- **Thermo-physiological aspect,** which is based on felt thermal sensation by human body and hypothalamus so that the sense of comfort is sensed as the minimum rate of brain nervous signals (Höppe, 1999; E. Mayer, 1993),
- **Climatological aspect**, which is in the field of **bio-meteorology,** also affects thermos-physiologically on humans. Air temperature, radiant fluxes, air humidity, and airstream velocity are the four main parameters of this field (Fanger, 1972, 1970; H. Mayer & Höppe, 1987).

As aforementioned, **psychological aspects** are significant factors, particularly outdoors. Nevertheless, due to their wide inter-individual variation, measuring and dealing with them are complicated (American Society of Heating, Refrigerating, and Air-Conditioning Engineers [ASHRAE], 2009; Brager & Dear, 1998).

However, where the environment is dynamic and complex, these factors likely to be more significant (Nikolopoulou & Steemers, 2003). Therefore, it should be considered by designers that creating a beautiful, pleasant, and sensational atmosphere could have a positive effect on tolerating discomfort conditions.

Nevertheless, regarding preventing thermal comfort **thermo-physiologically**, and obtaining energy balance of body, firstly preparing the thermal perception neutrality by composing the actual core/internal temperature (T_{er}) of body and skin temperature (T_{sr}) must be accomplished. Secondly, there should be an equivalence between the amount of heat produced by metabolism and the amount of heat that the body lost (Höppe, 1993, 2002). Due to the heat balance, the inputs are the produced heats through the body's metabolism and the total heat losses through respiration, evaporation, and sensible heat flow from the skin (Figure 2-11).

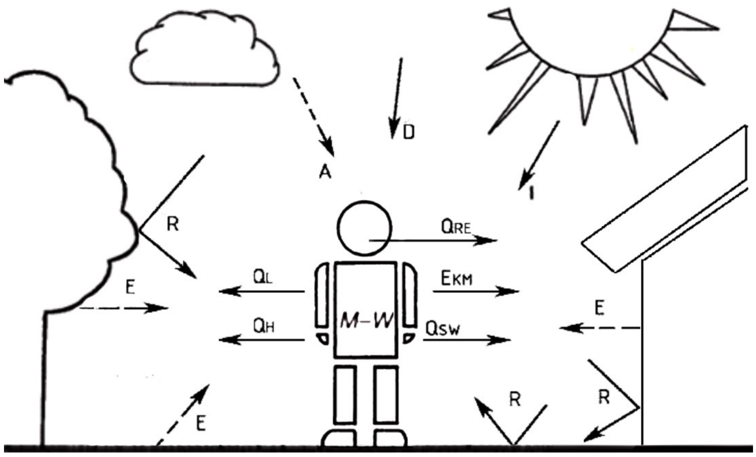


Figure 2-11 - The components of the heat exchange of people with the ambient and the components of the radiation budget (Verein Deutscher Ingenieure [VDI], 2008).

In other words, reaching the thermal balance would be possible when the following conditions are fulfilled (Marzluff et al., 2008, p. 271):

Equation 2-2:

$$M + W + Q^{*} + Q_{H} + Q_{L} + Q_{SW} + Q_{Re} + S = 0$$

Components of thermal balance:

M	Metabolic rate (activity)
W	Mechanical power (kind of activity)
Q^{*}	Radiation budget (short wave and longwave radiation fluxes)
Q_{H}	Turbulent flux of sensible heat (convection)
Q_{SW}	Turbulent flux of latent heat (Evaporation of sweat)
Q_{L}	Turbulent flux of latent heat (diffusion of water vapor)
Q_{Re}	Heat flux through respiration (sensible and latent)
S	Heat stored

Components of the radiation budget Q^{*}:

I	Direct solar radiation
D	Diffuse solar radiation
R	Reflected radiation, short wave
A	Atmospheric thermal radiation
E	Thermal radiation of surrounding surfaces
E_{KM}	Thermal radiation of the human body

As the **climatic aspect** of thermal comfort, VDI (2008) has emphasized three areas of human **bio-meteorology** (i.e., Thermal factors, air quality factors, and actinic factors), especially in urban thermal planning and design. These factors not only alter the microclimate conditions but also directly have a thermo-physiological impact on humans. Therefore, they have to be more considered regarding thermal comfort achievement.

However, the effective variables of thermal comfort could be categorized into climatic variables and personal factors influencing human thermal sensation, which will be discussed in the following.

2.2.4.2.1 Climatic Variables

Air Temperature

It is needless to discuss the significance of air temperature affecting thermal comfort. Due to the linkage of the heat balance of the human body and the sensation of comfort, by heightening air temperature, the body dry respiration heat loss would be decreased as well as its convective heat loss (Johansson, 2006b). In contrast, in cold conditions, these heat losses would be increased (due to radiation, convection, conduction, evaporation, and metabolism heat).

Solar Radiation

Solar radiation is known as one of the important climatic factors that also influence thermal comfort. In outdoor, the human body may absorb solar radiation in various ways. It may absorb directly from the sun and indirectly, which diffused through water vapor of the air and reflected from environment surfaces, e.g., building façade, ground, and trees (Ali-Toudert et al., 2005). Therefore, considering the solar altitude angle, the magnitude of the reflected and absorbed radiation, and the amount of diffuse radiation, which all vary by time and different spaces, assists in how this quantity could be measured (VDI, 1998).

In this term, mean radiation temperature (T_{mrt}) is established as an index to calculate the number of radiant interactions between the human body and its ambient. T_{mrt} has been defined by ASHRAE (1997) 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*" and is applied for evaluating the outdoor thermal perception of daytimes. This complicated quantity could be measured at the height z through the following formula, which was presented by Ali-Toudert and Mayer (2006):

Equation 2-3:

$$T_{mrt} = \left[\frac{1}{\sigma}\left(E(z) + \frac{\alpha_k}{\varepsilon_p}(\mathrm{D(z)} + f_p I(z))\right)\right]$$

σ	Stefan-Boltzmann constant (5.67*10-8W/m2K4)
E(z)	Long-wave radiation from the sky, façades, and ground
α_k	The absorption coefficient of the irradiated body surface for short-wave radiation (≈0.7)
ε_p	The emissivity of the human body (≈0.97)
D(z)	Diffuse and diffusely reflected short-wave radiation
f_p	The surface projection factor
I(z)	Direct solar beam impinging normal to the surface

And the reaching long-wave radiations E(z), at the pedestrian level height z, approximately assessing as:

Equation 2-4

$$E(z) = 0.5\left[(1 - SVF(z))E_{\omega} + \mathrm{SVF(z)}E_{sky}\right] + 0.5 * E_g$$

SVF	Sky view factor
$E\omega$	Incoming Long-wave radiation from the façades
E_{sky}	Incoming Long-wave radiation from the sky
E_g	Incoming Long-wave radiation from the ground

Air Humidity

Although humidity plays an important role in thermal sensation, mostly in cold conditions, the indirect effects are much considerable than direct ones, like varying the insulation parameters of clothes. In contrast, under warm conditions, the body's heat losses would be increased to maintain the heat balance through the latent heat of evaporation. Consequently, this led to more sweating and reducing closes, which increase the more discomfort sensation and extreme skin wetness (Givoni, 1998). Likewise, the moisture of clothes affects the comfort sensation, which should be noticed. Therefore, the significance of air humidity under warm conditions is notable and must be considered.

Airspeed

Another significant factor in terms of thermal comfort sensation is airspeed. Rapid variation in wind speed and direction may also feel the wind speed more than the mean magnitude. By increasing airspeed, both evaporations of sweat and convective heat loss will increase since the heat transfer efficiency of these two parameters increases. Therefore, in a cold climate, excessive air velocity would be a disadvantage, while it may be an advantage in a hot climate (Johansson, 2006b).

2.2.4.2.2 Personal Factors

In addition to the psychological factors that have been discussed in section 2.2.4.2, many other personal factors are also influential in outdoor thermal perception. Level and type of activity alter the metabolic heat dissipated by evaporation, Sweating, and respiration. For instance, fast walking in the cold climate, as well as slow walking in the hot condition, may be influential. Thereby, people, by adjusting their intensity of activity and choosing a suitable dress, could adapt themselves to the outdoor thermal conditions.

By increasing clothing insulation, radiative and convective heat losses will decrease. On the other hand, by increasing clothing, a lower difference temperature could be felt between ambient air temperature and the clothed body. While body skin, which contacts directly to the air, could easily lose the heat (Honjo, 2009; Nikolopoulou & Steemers, 2003).

Thermal history, as a proven effective factor in thermal sensation, has been defined as the thermal condition, which a person has been exposed to. So that, the thermal experience, between the person spending a long time in a shady location with the person who has just moved to the shady from extreme heat location, will be different (Spagnolo & Dear, 2003; Thorsson, Honjo, Lindberg, Eliasson, & Lim, 2004; Thorsson, Honjo, Lindberg, Eliasson, & Lim, 2007).

However, choosing or avoiding being in comfort or discomfort conditions, as a voluntary decision, and how they decide to adapt themselves due to their age and physical condition, sex could be variable between people.

2.2.4.2.3 Human Thermal Comfort Indices

Human thermal comfort indices have been expressed based on a combination of several variables (e.g., Surface temperature, air temperature, short-wave and long-wave radiation, humidity, and wind speed) into one measurable quantity as an index. Generally, indices represent the indoor thermal condition, but mostly, they have also been developed to predict the state of outdoor thermal comfort (Emmanuel, 2005; Pickup & Dear, 2000). Most thermal comfort indices are generally designed based on the human body's heat balance, namely, The Predicted Mean Vote (PMV) (Fanger, 1970), the Standard Effective Temperature (SET*) (Doherty & Arens, 1988; Gagge, Fobelets, & Berglund, 1986), Physiological Equivalent Temperature (PET) (Höppe, 1999), and Universal Thermal Climate Index (UTCI) (International Society of Biometeorology [ISB], 2001, 2004).

2.2.4.2.4 PMV

Even though the Predicted Mean Vote (PMV) index calculated by Fanger (1970) is one of the most widely applied indices in terms of thermal comfort. It is also recommended by ISO 7730 (ISO 7730, 1984) and ASHRAE 55 (ASHRAE, 2004). Nevertheless, many studies have been expressed that PMV may not be suitable for evaluating outdoor thermal comfort (Chen & Ng, 2012; Spagnolo & Dear, 2003).

Jendritzky and Nübler (1981) improved the PMV index by adding the complex outdoor radiation to PMV into a model called Klima-Michel Model (KMM) in outdoor conditions. Other studies also suggest applying PMV with KMM as an appropriate index to evaluate outdoor thermal sensation in different climates (Matzarakis & Mayer, 1997).

PMV index expresses the level of comfort, which is classified as the thermal perception scale, so that the mean thermal perception response of a large group of people (Table 2-5) (ASHRAE, 1997; Matzarakis & Mayer, 1997).

Table 2-5 - ASHRAE thermal perception index

-3	-2	-1	0	1	2	3
Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot

Fanger (1970) defined the PMV index as:

Equation 2-5:

$$PMV = (0.303\ e^{-0.036M} + 0.028)\ L$$

PMV= *Predicted Mean Vote Index* M= *Metabolic rate* L= *Thermal load*

Predicted Percentage Dissatisfied (PPD) is another index designed based on PMV, while its quantity forecasts the percentage of discomfort people at each PMV result (Figure 2-12) (ISO 7730, 1984; Pitts, bin Saleh, & Sharples, 2008).

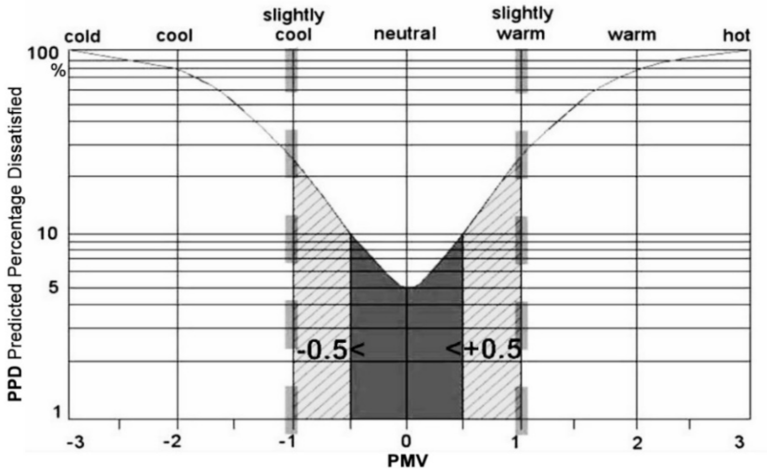


Figure 2-12 - PPD versus PMV exposing the impact of extended comfort range (Pitts et al., 2008).

2.2.4.2.5 SET*

New Effective Temperature (ET*) index, which is expressed in °C, was established based on the Two-Node model (Gagge, Stolwijk, & Nishi, 1971). Gagge et al. (1986), by developing ET*, proposed the Standard Effective Temperature (SET*), which incorporated the clothing insulation and intensity of activity.

Although both ET* and SET* are applied as indoor and outdoor thermal comfort indices, Ishii, Katayama, Shiorsuki, Yoshimizo, and Abe (1988) inferred that SET* is more appropriate for outdoor. Nevertheless, it was noticed by Spagnolo and Dear (2003) to not apply the SET* for outdoor thermal assessment without modification. Therefore, Pickup and Dear (2000) represented OUT_SET* as a special adaptation of SET* for outdoor conditions.

2.2.4.2.6 PET

Physiological Equivalent Temperature (PET), as one of the most known indexes on thermal comfort, was developed based on the Munich Energy balance Model for Individual (MEMI) (Höppe, 1993). This index tries to represent all complex variables into one quantity, which is also expressed in °C.

Höppe (1999) defined the PET as: "*the physiological equivalent temperature at any given place (outdoors or indoors) and is equivalent to the air temperature at which, in a typical indoor setting, the heat balance of the human body (work metabolism 80 W of light activity, added to basic metabolism; heat resistance of clothing 0.9 clo) is maintained with core and skin temperatures equal to those under the conditions being assessed*" (Höppe, 1999).

Although PET was designed to equate the virtual indoor temperature, however, it is not only widely applied for predicting the great range of outdoor thermal comfort, but also is one of the most recommended indices by VDI (1998) (new German guideline for urban and regional planner to calculate the variations of thermal parameters in urban or regional scales (Honjo, 2009). RayMan (Matzarakis, Rutz, & Mayer, 2007) and ENVI-Met (BioMet Plugin) (Bruse & Fleer, 1998) are two well-known software, which can easily measure the PET.

2.2.4.2.7 UTCI

The Universal Thermal Climate Index (UTCI) is a recent thermal index, which has been widely applied. UTCI was developed by commission 6 of the International Society of Biometeorology (ISB, 2001, 2004) based on body heat balance as well as other aforementioned indices. Moreover, to be as a universal temperature scale index, UTCI tries to measure accurately in all meteorological condition, seasons, and scales and also considers personal characteristics (e.g., gender, age, clothing, and level of activities) (Błażejczyk et al., 2013; Jendritzky, Havenith, Weihs, Batschvarova, & DeDear, 2008; Matzarakis, Muthers, & Rutz, 2014; Monteiro, 2005).

In other words, Walls, Parker, and Walliss (2015) defined the UTCI as "*as the air temperature in the reference condition (50% humidity, still air and full shade) that causes the same physiological response as the actual observed condition*" (Walls et al., 2015).

The following table classified the amount of PMV (Matzarakis & Mayer, 1997), OUT_SET* (Auliciems & Szokolay, 2007), PET (Matzarakis, 2006), and UTCI (Błażejczyk et al., 2013) and compared them in terms of thermal sensation and physiological stress to have a better understanding from the meaning of each index amount (Table 2-6).

Table 2-6 - PMV, OUT_SET, PET, and UTCI Categorized in terms of thermal perception and physiological stress; internal heat production (European climate, 80 W, heat transfer resistance of the clothing: 0.9 clo) (Source: Author).*

	PMV	OUT_SET* °C	PET °C	UTCI °C	Thermal perception	Grade of physiological stress
	Above +3.5	Above 37.5	Above 41	Above +46	Very Hot	Extreme Heat Stress
	+2.5 to +3.5	34.5 to 37.5	35 to 41	+38 to +46	Hot	Strong Heat Stress
	+1.5 to +2.5	30 to 34.5	29 to 35	+32 to +38	Warm	Moderate Heat Stress
	+0.5 to +1.5	25.6 to 30	23 to 29	+26 to +32	Straightly Warm	Slight Heat Stress
	-0.5 to +0.5	22.2 to 25.6	18 to 23	+9 to +26	Comfortable	No Thermal Stress
	-1.5 to -0.5	17.5 to 22.2	13 to 18	-13 to +9	Straightly Cool	Slight Cold Stress
	-2.5 to -1.5	14.5 to 17.5	8 to 13	-13 to 0	Cool	Moderate Cold Stress
	-3.5 to -2.5	10 to 14.5	4 to 8	-27 to -13	Cold	Strong Cold Stress
	Below -3.5	Below 10	Below 4	-40 to -27	Very Cold	Extreme Strong Cold Stress

Several studies have mentioned that this classification and thermal perception could alter by varying the climate and human race group despite the same condition, which is usually considered (T. P. Lin & Matzarakis, 2008; Scudo, 2002; H. Zhang, 2003).

However, these indices, besides presenting the comprehensive and understandable image of the environment in any particular date and location through considering most of the outdoor variables, have some deficiency as well. For instance, they are accurately unable to forecast thermal comfort in conditions with dynamic changes. Moreover, there is a conflict between requirements in different seasons. So that, in winter, there is a tendency to access more sunlight, while in summer, more sun protection is required (Ali-Toudert & Mayer, 2006). Furthermore, the inability of these indices to take into account personal thermal experiences from their prior environment should be considered (Spagnolo & Dear, 2003; Thorsson et al., 2004).

2.2.5 Climatic Green Space Design

Climatic design, as a significant part of ecological and sustainable design, tries to make the environmental comfort zone for humans as well as other species by reducing consumption of natural resources and energies, moderating and controlling climatic variables, and reducing air pollutants.

To attain a microclimatic design, a conceptual approach in the areas of understanding how landscape Elements can be influenced significantly by the microclimatic elements, such as wind and solar radiation, is necessary (Brown & Gillespie, 1995).

As mentioned before, plants, known as the most crucial part of landscape design, substantially impact the microclimate. The way of applying trees and other green spaces elements can differently affect cooling efficiency in cities and saving energy. For instance, the impact of various combinations of tree configurations on human thermal comfort is investigated by Klemm, van Hove, Lenzholzer, and Kramer (2017) (Figure 2-13) and other studies investigated by Sodoudi et al. (2018) (Figure 2-14).

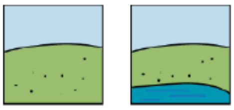
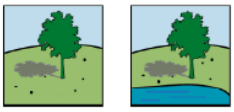
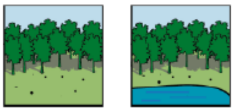
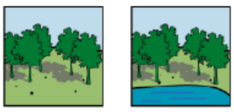
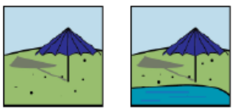
Nr	Type		Explanation	Solar exposure
1	lawn		open grass field, lawn > openness, exposure, sun	○
2	single/solitary tree		solitary tree as single 'object' on a wider lawn > openness, single object, sun/ shade depending on size of tree crown	○ ◐ ●
3	small group of trees		group of trees with overlapping foliage on a wider lawn > objects, edge between openness and enclosure, edge between sun and shade	○ ◐ ●
4	row/ edge of trees		group of trees planted in a row along a lawn > objects, long sharply defined edge between openness and enclosure and between sun and shade	○ ◐ ●
5	scattered trees/ boscage		scattered trees/ boscage on wider lawn > objects, scattered overlapping foliage create mixture of open and enclosed spaces in close vicinity	○ ◐ ●
6	individual objects		means to create a microclimate, like a parasol/ umbrella or another shade device > objects create temporary microclimate spaces for individuals	○ ◐ ●

Figure 2-13 - The impact of various trees configurations on human thermal comfort (Klemm et al., 2017, p. 144)

Configuration/ Vegetation	Time	50×50m Configuration1	25×25m Configuration2	12.5×12.5m Configuration3	100×6.25m Configuration4	100×6.25m Configuration5
Grass 10cm	2 pm	31.8	40.7	45.9	74.4	55.6
	10 pm	27.7	27.9	13.2	42.2	12.4
	5 am	24.4	17.4	3.8	20.2	0.0
Grass 50cm	2 pm	32.2	43.1	51.0	70.9	55.1
	10 pm	28.8	29.7	12.5	41.3	6.6
	5 am	26.7	22.5	6.3	31.2	0.0
Hedges-Shrubs	2 pm	32.4	46.8	59.6	79.2	67.7
	10 pm	30.4	39.1	36.7	79.1	45.9
	5 am	27.9	29.8	19.7	60.2	25.4
Tree-small canopy	2 pm	34.6	50.2	68.9	83.7	82.1
	10 pm	32.2	45.0	60.0	81.8	67.4
	5 am	27.0	30.3	19.2	50.3	20.3
Tree-big canopy	2 pm	92.0	100	100	100	100
	10 pm	100	100	100	100	100
	5 am	34.7	100	100	100	100

Figure 2-14 - The impact of green space dimensions and plant size on cooling down the air temperature more than 1.5K in percentage at three different simulation time steps (Sodoudi et al., 2018).

According to conducted researches and studies (Brown, 2011; Brown & Gillespie, 1995; Bruse, 1999; Darbani, Parapari, Mirheydar, & Mastiani, 2020; Klemm et al., 2017; Ochoa de la Torre, José Manuel, 1999; Sodoudi et al., 2018), the following criteria seems like the most important and significant factors in climatic landscape design guidelines base on the function of green space for the human comfort, as well as plant and species comfort:

- **Site selection:**
  size, borders, neighborhoods, water accessibility, urban form, geographical location, topography
- **Optimal spatial arrangement:**
  orientation, optimal ratio, area size, volume, dimension, wind, and sun direction, controlling humidity
- **Optimal vegetation selection:**
  availability of water soil type, oxygen, and mineral resource, climatic compatibility, and resistance, shape, size, color, and type (evergreen or deciduous)
- **Optimal vegetation configuration:**
  tree canopy, types, size, boundary, edge, corridors,
- **Optimize ventilation**
- **Controlling the humidity**
- **Controlling solar radiation:**
  - The right mix of shadow and sun by natural or artificial shade providers
  - Selective shading technology

- **Controlling exposure to wind and sun:**
  applying artificial and natural windbreaker
- **Optimal water-cooling strategy:**
  pool, lake, channel, fountain, water spraying, controlling evaporation and wind speed and direction
- **Climate control through surface materials:**
  - Optimal material surfaces
  - Façade greening technology
  - Intensive and extensive rooftop greening
  - Microclimate at building façade
- **Air pollution control:**
  photocatalytic surfaces, particle deposition on vegetation, particle transport to the indoor environment
- **Applying green energies and natural techniques**
- **Other subjective well-being consideration** (plants and spices)
  - Optimal land drainage
  - Soil water supply: preparing the needed water for vegetation, little or too much water in their root zone will have a negative effect
  - Soil health protection
  - Leaf water balance

2.3 Contemporary and Traditional Iranian Landscape Planning and Design

According to UNDP (United Nations Development Program) calculations, the HDI (Human Development Index) value of Iran has risen by 67 percent between 1980 and 2012, reaching - for 2012 - 0.742. In other words, in terms of HDI, Iran's annual growth has been more than twice the global average. This would also indicate that, in terms of human development, the political actions taken by Iran between 1980 and 2012 to improve human development were both effective and adequate (UNDP, 2016). Despite the growth in UNDP, many researchers and experts on the basis of criteria such as green economics, jobs, medical care and health service, transport, housing, etc., consider this growth as an unsustainable one (Khalilnezhad, 2016).

By analyzing Iran’s annual mean temperatures of the last 33 years observed by synoptic stations of IRIMO, the increasing trend of mean temperature is evidently understandable. It shows the increasing trend of mean temperature is about half a degree per decade (Figure 2-15).

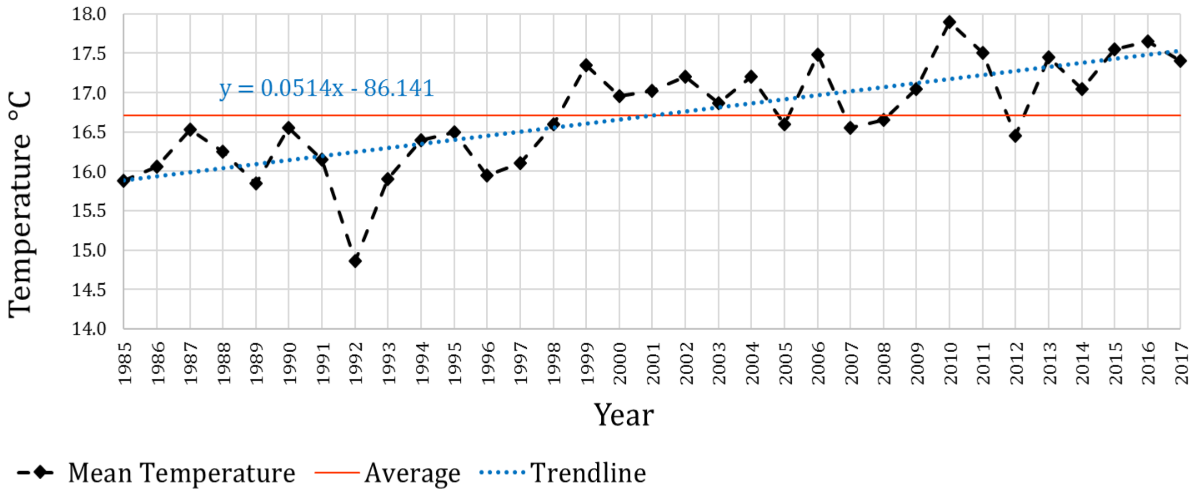


Figure 2-15 - Comparison of annual mean temperature variations in Iran between 1985 and 2017 based on synoptic stations of IRIMO

The red line shows the average annual temperature increasing to 16.7 °C. However, over the last nine years, only a negligible amount of the country's average was below the normal temperature in the year 2012. In the remaining years, each year's annual mean temperature was above their average temperature in the long term for the majority of Iran. According to available statistics, the year 2010 was the warmest in the last 35 years in Iran.

Despite considerable deviations from the average lines in this study, the general trend looks reasonable. Thus, the future climate in Iran is expected to be warmer and drier. In terms of human thermal comfort, it can, therefore, be concluded that the thermal situation will worsen during the summer. Likewise, on the one hand, the energy demand in the summer months will increase, and on the other hand, providing the outdoor thermal comfort will be more difficult, as well as mitigating the heat island effects.

However, one of the most significant strategies to promote urban social-ecological sustainability is the consideration of landscape ecology and outdoor thermal comfort (ref. section 2.1.3.3), which are ensured by a systematic landscape planning system at all levels. There is a significant gap between traditional and contemporary landscape planning and design. After modern times, especially in the last 50 years, numerous gardens, agricultural farms, and green spaces in Iranian cities have been destroyed or replaced by changing land-use.

Therefore, in the case of Iran, it is better to investigate the traditional and contemporary process of landscape planning in design separately.

2.3.1 Contemporary Landscaping

2.3.1.1 Landscape Planning in Current Iranian General Planning Paradigm

The contemporary paradigm in Iran's social transformation was begun by the Pahlavi dynasty (1925-1979), when modernization growth was accelerated due to the establishment of a powerful central government and dependent capitalist economy. Moreover, increased economic growth due to the country's high income from selling oil boosted the development of cities and urbanization. One of the consequences of this rapid growth was the emphasis on providing a comprehensive plan for the cities with more than 25000 inhabitants (Farhoodi, Gharakhlou-N, Ghadami, & Khah, 2009).

The Islamic Revolution of 1979 altered the essential attitude of the government on social issues, urban justice, and modernity, and consequently, several changes and reforms of the comprehensive planning approach that impact the content and planning process, no substantial change occurred regarding this approach and the results of the comprehensive plans. Additionally, the eight-year war has caused widespread devastation, destruction of infrastructure, lack of financial resources to fundamentally landscape planning for development and implementation (Madanipour, 1998, 2006).

However, the current general planning system in Iran is a linear hierarchy of four levels (Figure 2-16): national, regional (provincial), sub-regional (country), and local level (urban) (Rasoolimanesh, Jaafar, & Badarulzaman, 2013; B. Zamani & Arefi, 2013):

- National programs prepared and approved by various power organizations and authorities in Iran are at the first planning hierarchy level. The focus of each of these projects is different and includes different elements of development. All these plans have been prepared for the national level, and they are all existing programs in the country. Follow-up programs at the lower levels must obey and adhere to these programs.
- Subdivisions of the national programs for each province and country are set out in the second and third planning levels. In this way, the services and future perspectives of a province are provided according to the country's twenty-year vision. Besides, according to the national spatial plan, the regional spatial plan was developed. Nevertheless, there is no definite link between these levels by reason of the time lag for each level. This shortage causes occasional ignoring of the second and third levels of local planning.
- On the local level, a series of planning programs, in order to develop a city, has to be implemented. The comprehensive plan designed a long-term physical plan for cities with more than 25,000 population. Such maps indicate land-uses, road networks, public services, rules, and regulations for the construction of private and

public buildings, and protection rules for historical sites. Comprehensive plans strongly emphasize physical development and thus sacrifice social, environmental, cultural, and economic development.

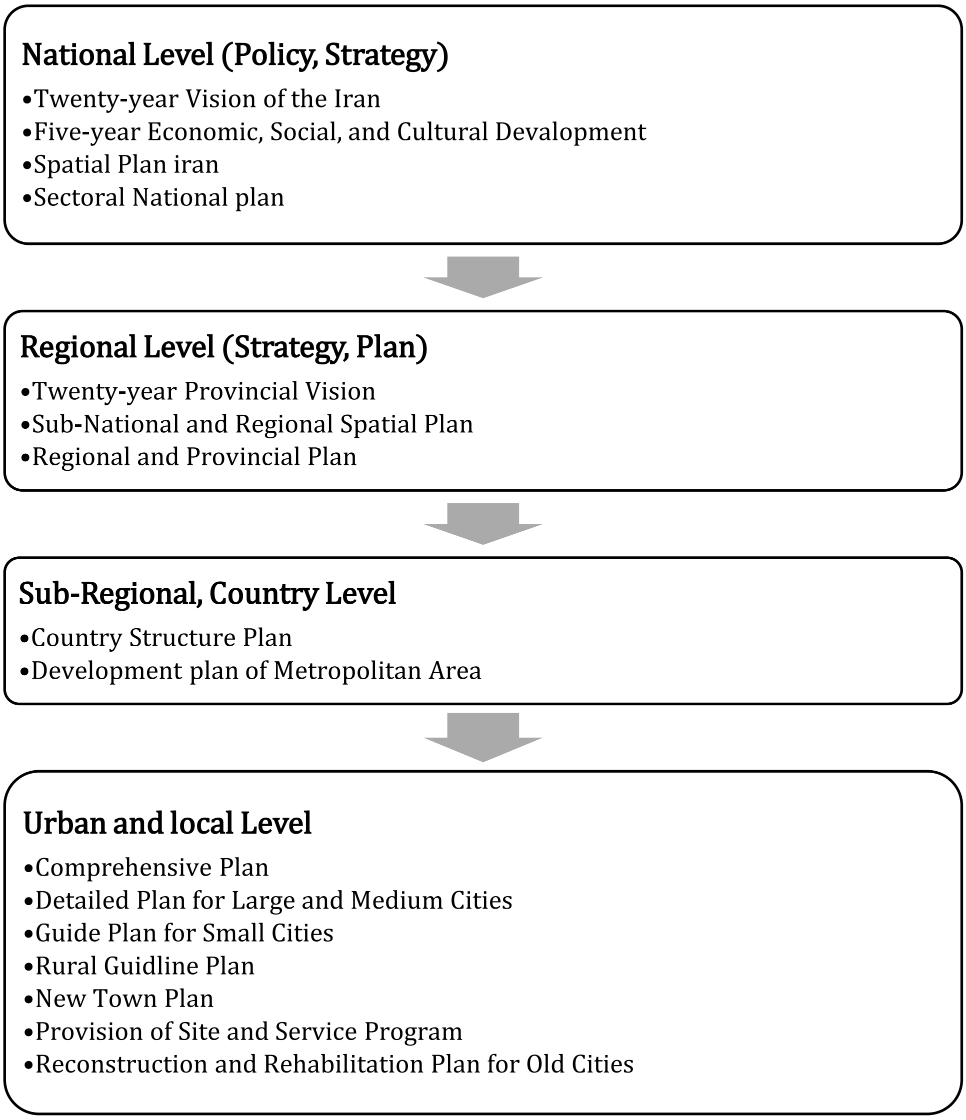


Figure 2-16 - The hierarchy of the general planning system in Iran (Rasoolimanesh et al., 2013).

In the above-mentioned linear general planning system, landscape planning is missing a prominent level. There is no such department for landscape planning at any of the national to local levels. Having said that, there is a parallel organization as the Iranian Department of environment, which is working at the national level, mainly and practically, focusing on environmental assessment reports for projects in different planning levels. There is a clear missing link between the landscape planning and planning system in Iran.

Besides the environmental considerations from the Ministry of the Environment, there are also a number of standards and rules for green spaces in cities, such as per capita green spaces. It should be noted that the per capita suggestion of green space, in the other countries and even in different cities within a country, varies depending on the ecological conditions and especially the climatic conditions.

Additionally, the concept of green space per capita is only used for the kind of green space that is available for leisure, play, and easy to access. However, awareness of green space standards can be applied as a tool for activities and guidelines. According to studies conducted by the Ministry of Roads and Urban Development, conventional and acceptable urban green spaces per capita in Iranian cities range from 12 to 15 m^2 per person, comparing to the UN environmental index (20 to 25 m^2 per person), shows a lower number.

The lack of a comprehensive landscape planning system, at any level in Iran, caused poor landscape planning and environmental ecology, concerns in regional and urban planning and design, where the urban planners and designers also play the role of landscape planners, not the landscape experts. This disadvantage has made the priority of landscape planning less and limited it to only certain considerations and standards in urban planning and design, and sometimes environmental assessments for projects and planning that are only intended to do no severe damage to the environment, while it should be aimed at protection, improvement, and development.

In order to gain a better understanding of how a well-planning system is defined, it is necessary to investigate the role of landscape planning in planning systems of pioneered countries such as Germany, where has had a long history of landscape planning, which has become a central planning instrument for prevention-oriented nature conservation (Haaren, Galler, & Ott, 2008). Moreover, the country with innovative and successful green projects such as renewable energy applications and green belts became European (Gruehn, 2013).

2.3.1.2 Lessons Learned from Germany

The Federal Nature Conservation Act (Bundesnaturschutzgesetz) was enacted in Germany in 1976 as a result of which landscape programs were prepared for the states, and regional landscape framework plans were developed for almost all parts of the state. Indeed, at several administrative levels, landscape planning has been legally implemented as a comprehensive tool to provide sustainable safeguards for a wide range of ecosystem services, encompassing habitat functions for flora and fauna, landscape scenery, biotic production, groundwater recharge, biometeorological functions, etc. (Gruehn, 2013).

The German planning system comprises a multi-dimensional classification of planning instruments considering the scale, spatial extent, tasks, competent authorities, commitment effects, participation, and some other federal characteristics. Besides landscape planning, the German planning system also encompasses regional and spatial planning, agricultural planning, forest planning, and others (Gruehn, 2006). Figure 2-17 illustrates the various planning instruments in Germany based on their tasks and scale as a nonlinear planning system.

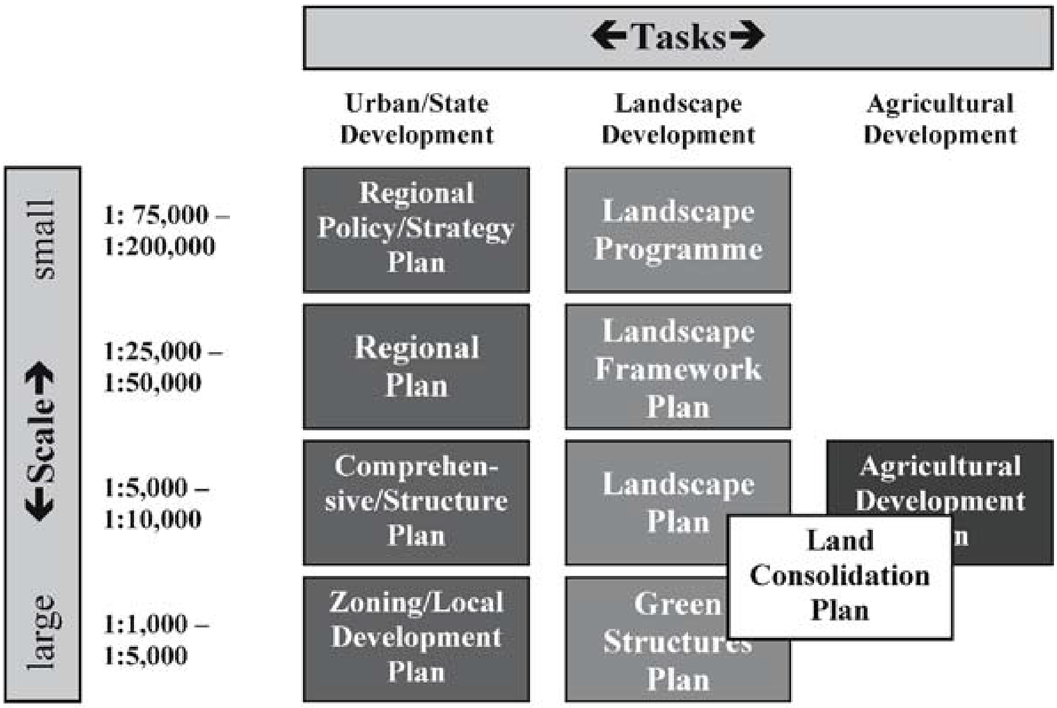


Figure 2-17 - Planning Instruments in Germany: Tasks and Scale (Gruehn, 2006).

As illustrated, there is a certain scale to every planning instrument. Although the green structure plan serves as a large-scale landscape development tool, the small-scale regional strategy focuses on regional development. It is clear that urban development tools and landscape planning are clearly consistent. This means that landscape planning possesses four various planning tools: landscape program, landscape framework plan, landscape plan, and green structure plan. Furthermore, as an integral part of the landscape planning and agricultural development, the land consolidation plan is regularly conducted on a smaller scale, with details. (Gruehn, 2006).

In Germany, landscape planning as an overall strategy for the regional and urban planning administrations enables them to apply ecological and landscape planning criteria for spatial development. Observation and review have demonstrated that environmental aspects were considerably better integrated into urban development planning once appropriate landscape plans existed (Gruehn & Kenneweg, 1998).

Gruehn (2006) demonstrated that due to the different aspects involved, landscape planning relates to communication. So that, not only does landscape planning have to provide information for communication, it also has to be convincing. If landscape planning is not convincing, it will not be successful. He also mentioned that Landscape planning in Germany is clearly more than just an instrument for the conservation of species, as it also contributes to secure and promote sustainable land-use and human culture.

Many research projects have investigated the significance and effectiveness of landscape planning on the process of the planning system in Germany (Gruehn, 1998; Gruehn & Kenneweg, 1998, 2002a, 2002b; Wende, 2000), which all show the significant role of landscape planning in all aspect of the decision-making process and emphasize on its important effect on the planning system in Germany.

As practical results and consequences of such a planning system, the following can be briefly mentioned:

- Climate protection
- Adaptation to climate change
- Ecosystem services and nature conservation
- Promoting renewable energies
- Positive economic effects
  (Gruehn, 2013).

Considering the role and importance of landscape planning, besides its impact on the planning system of countries such as Germany, and comparing it with the current situation of the planning system in Iran, the vacancy place of landscape planning and design in the decision - making and planning system of Iran is becoming more and more obvious and determined. In contrast, traditional landscaping in Iran has a long history and valuable experience in the optimal application and design of urban green spaces.

2.3.2 Traditional Landscaping

As mentioned in previous sections, the urban ecological landscape considers the city in terms of an ecosystem developed through human activities and sustained over time through both natural and human functions and processes. Traditionally in Iran, people have chosen their places of settlement and built their cities based on respect for natural environmental resources.

In the plateau of Iran, the origin of one of the oldest civilizations in the world, many examples of human lessons and activities can be seen in natural environments, landscapes, and open spaces, including agriculture, architecture, gardening, and water use management. These lessons have ultimately contributed to the foundations for building places in natural environments, the development of landscaping, and its architecture as the Iranian garden (Taghvaei, 2011a, p. 11).

Historical Persian gardens, green spaces, fruit gardens, arable and farmland, and private "Hayats" dominate most of Iran's ancient cities; have organized ecological networks linking resources and natural elements either inside or outside the cities.

Along with being influenced by modern styles and new architectural and landscape architecture approaches, the traditional experiences of utilizing green and natural energies are almost forgotten. In this regard, the art and techniques of traditional Persian landscaping have valuable advantages and achievements that require study and recognition. In the traditional Persian landscape, especially in Persian gardens, within the arid and semi-arid climate, the fundamental principles of climatic landscape design have been experienced and promoted historically through an appropriate selection of landscape elements that create a thermally pleasant outdoor microclimate.

Figure 2-18 - Providing a beautiful environment as well as thermal comfort inside the Persian garden (Shahzadeh garden) in the harsh climatic conditions of Iran (Khansari, Moghtader, & Yavari, 2004).

As a successful case of providing thermal comfort in the hot and dry climate of Iran rooted in the long history of traditions, Persian garden had not only been considered for its climatic aspects but also been noticed for aesthetic, social, and cultural characteristics. Therefore, Persian garden, as a comprehensive, sophisticated case in traditional landscaping, has to be deeply considered and studies in detail, and it is vital to revive its importance and role in traditional landscaping in Iran.

2.4 Persian Garden as Traditional Landscaping

Before discussing Persian garden and how the current structure of the garden is formed, a definition of the Persian garden will be presented briefly. Garden is a place, which is a result of combining architectural elements, planting trees and decorative flowers, and portraying different aspects of water for human use. This place is formed by the culture and climate circumstances of each region (Mirfendereski, 2004).

Climate and environmental circumstances are the most important properties to appear in various styles of Gardening in the world. This variation is obviously clear in different climates such as Persian gardens, English gardens, Japanese gardens, etc. It should be mentioned the important role of culture and people's beliefs in this area.

On the other hand, the Garden is the best location and space to present Iranian culture and ideology since the Garden is a symbol of an imaginary world in Islamic and Iranian thoughts. Therefore, gardening art has affected impressively on the other arts such as painting and miniature, handy craft, and literature. Thus, more consideration about the properties and principles of Persian gardens and their elements is needed to analyze them more optimal.

2.4.1 Background and Beliefs

2.4.1.1 Background of Iranian Belief in the Human and Nature Unity

Investigation on religious culture, rituals of ancient Iran indicated the emphasis on the cosmic place of humans and nature in the universe. It is a conclusion based on solidarity and the myth of unity between the people in this world and those who forget their origins and nature. These are life cycles in place of divine manifestation and the symbol of all cosmic life stages, the absolute unity of all heaven and earth elements and ground. In societies that have been based on farming and Gardening, keeper of the key's fertility and the gate of the birth, death, and rebirth- in the moon goddess, is the symbol of eternal rebirth. This is causing the seasons, overseeing the water of life (groundwater, springs, canals, and rivers), growth of fertile land, the resurrection of earth life, cosmic tree, protect the water of life, protector, and maintainer of land in farms and villages from floods, the symbol of the goddess of earth and water likes (Bahar, 2010; Cooper, 2012).

Figure 2-19 - The importance of nature and plants for the ancient Iranians. Patterns of cypress trees, palms, and flowers on the stairs of Apadana Palace (Shahcheraghi, 2013; UNESCO World Heritage Centre, 2011).

After active cultural information resources, ritual ceremony with universal credit is mentioned subscribe traditional between Persia and Mesopotamia to begin spring

(“Farvardin Pasht”), the beginning of autumn (“Mehregan”). Their origins are in the historical background of cultural behavior, motif, and their continual trend. In dominated of mythological culture, cultural elements, and the value of semantic function motivated by the stability of the whole earth community from strong social ties linking people, not only will regenerate trees and nature in the springtime but also will appear the time of people departure from the world of inertia. Thus, people will join in nature, space, environment and start a social and economic life in farms and gardens (Hinnells, 1987).

2.4.1.2 The Concept of Persian Garden

Persian garden is a result of human efforts in creating a pleasant environment by using natural elements. Although the participation of elements in combination and creation of a favorable environment is related to certain factors, it is accidental. It means this event occurs without human intent and with no specific order. Repetition of events forms nature, but the man in shaping the favorable environment transforms events to demand. Demand is a historical phenomenon, which is variable and targeted (Mirfendereski, 2001; Pirnia, 1994).

2.4.1.2.1 From Conceptual and Sensorial Perspective

Nature, with all the powers and abilities, prepares all the necessary conditions of existence. The Persian garden is not a natural reproduction but rather uses the decisive factors of realities hidden in nature and creates order in not-ordered nature. Garden space is both a visual form and a sensorial form. Garden in visual form is physically observed or emphasized. In sensorial form, objects belonging to the sensational human organs have stepped into the conceptual process. And in the area of cognitive knowledge, functions achieve unity with visual form and sensorial form, and their interaction on the basis of social-historical action provides discovery of unknown concepts and inspires garden space. Among the diverse and eternal aspects of nature, elements such as water, soil, plants, light, and even airflow (wind) are used in the creation of the garden (Taghvaei, 2011b).

Garden is formed as simple and clear as possible and does not leave any material ambiguity in the relation of man and space. The arrangement and creation of the Persian garden are based on mathematics and geometry. Persian garden is surrounded by a rectangular fence and is divided with perpendicular axes. Moreover, Persian garden possesses other geometric systems such as irrigation system, planting system, architectural system, and landscape system (Pirnia, 1994).

2.4.1.2.2 From Physical Perspective

In the establishment system, two main perpendicular axes divide the garden into four main sections. Dividing into four has a long history, and there is a prominent story about this: "*water gets out from the Eden and flows to the four corners of the world*." It is also believed that when the four main axes, four main streams of water, four main rows of wide shade trees, and four main roads divide the space into four parts, the word "Chahar Bagh"[3] (four garden) comes into mind (Diba & Ansari, 1995).

The main axis passes throughout the whole length and specifies the entrance of palace and residential house. Streams, pools, gardens, and main walkways are along the main axis as well. On both sides of the main axis, fruit croft continues to the lateral wall of the fence. Other required buildings are placed outside the fence, not to disturb the integrity of space in the garden. The irrigation system helps the garden in the acceleration of the establishment system. In physical and symbolic forms, water creates and enhances the spirit of the garden (Mirfendereski, 2004).

Sense of order, symmetry, multiplication, and coordination are inferred from establishment system, sense of freshness, sparkle, and cleanliness are inferred from an irrigation system, feeling of light shades, breeze, and coolness are inferred from seeding system, and all these are in the process of perceiving subjective from objective to understand the Persian garden. Therefore, the garden is defined as a space for peace and comfort and a place of contemplation (Mirfendereski, 2001).

In another interpretation, Persian gardens are a reflection of culture and human imagination in dealing with nature; that environment, culture, taste, skill, and human decision have an essential role in their formation. Moreover, in other words, the garden is the most popular art that, like other arts, has its roots in the culture; and its birth and life happen in time and place.

2.4.1.3 Antiquity and Architectural Concept of Persian Garden

Based on records of gardens, about three thousand years before Christ (3000 B.C.) garden is considered by the ancients as beauty and an expression of human comfort and enjoyment. Greek historians have mentioned gardens with many trees that were called paradise in numerous cities of Iran. The English word ‘Paradise’ means heaven that is taken from the Persian word. In the Torah, there is a part talking about ancient campuses in Khuzestan province or their eternal heaven. It seems that even before the Achaemenid

3 - “Chaharbagh” or “Chahar-Bagh” (Persian: چهارباغ, chahār bāgh, which means "four gardens") is a Persian quadripartite garden divided into four smaller parts by sidewalks or running water.

and after them, every creation of garden in Persepolis and Shush has reached the extreme of beauty (Shahidi, Bemanian, Almasifar, & Okhovat, 2010).

The architectural concept of garden reflects the concept of place. Garden is considered as an allocated space that shows a perfect reflection of the global system. There are some kind of harmonies and a series of concepts expressed through numbers, geometry, color, and material, whereas at the same time reflects the nature, meaning, and hidden dimension in a positive atmosphere. Garden is a dramatic eccentric form related to the great universe, which is evident, and the yard is a dramatic centripetal form related to microcosm, which is hidden. Both these elements are taken as perfect examples of the place concept.

At the time of the Achaemenid (500-300 B.C.), the idea of the garden reached a high degree of sophistication when the gardens are formed in defined and limited places with symmetrical and comprehensive organizations. Sasanian paradise exhibited a magnificent plan based on Mandala form, with the palace located at the intersection of four streets. Garden and yard that evolved based on paradise idea in the dry and hot plateau of Iran remained as the major form during the Islamic period (Kiani, 2004).

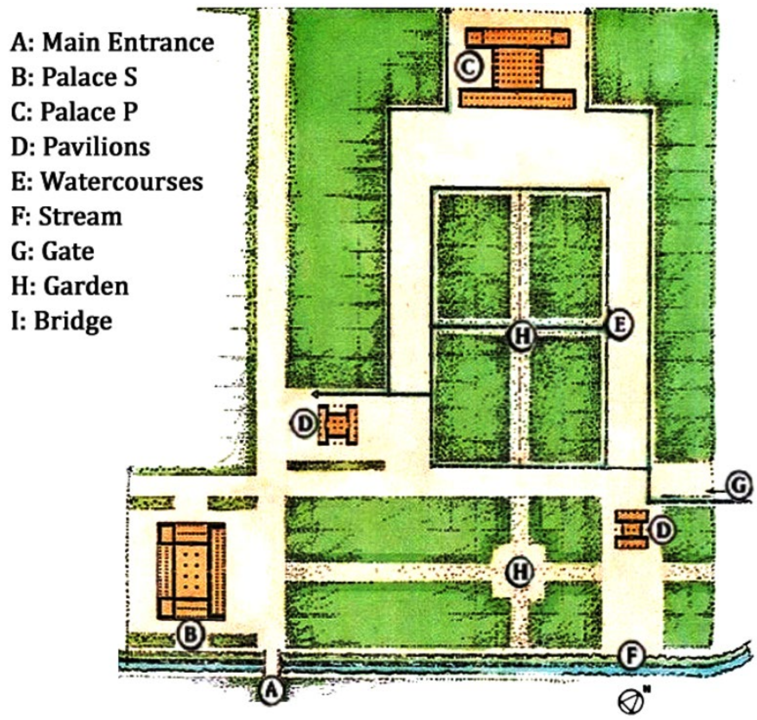


Figure 2-20 - Pasargad Garden as Iranian "Chaharbagh" sample in Achaemenid era (Stronach, 1978)

Garden follows recorded iconography on the ancient Persian motif enclosed by trees surrounding a central building. Here, Mandala features could be seen well, a centrifugal motion to the outside and into the nature (paradise) and a move to the center, inward through four of its porticos into pound and fountain that we observe the spiritual center of garden. There are many examples that all of them express the subtle and accurate return and final joint of humans with their origin through an encounter with nature (Motedayen, 2010).

However, when the Muslim Arabs conquered the Iranian people, gardens in the country reflected the image of heaven in their minds. Nevertheless, in the first several centuries of Islamic historical architecture, the garden's construction was not given enough attention until the Safavid era (dynasty of Safavi). Only in the Teymorid period, gardens, mansions, and the glory of Persian gardening were clearly mentioned. Thus, in the first seven centuries of the Islamic calendar, we see fewer gardens and luxurious mansions than in the Safavid period. In fact, gardening flourished again during the Safavid period. It should be mentioned that in the gardens of this period, the outdoor of a building is related to its indoor for the first time (Memarian, 2008; Pirnia, 1992).

In Qajar gardens, for the first time, European styles have influenced the style of Iranian and Islamic Gardening; and "Dushan-Tapeh" garden is the first garden that was made with the inspiration of both Persian and European styles (Irani Behbahani & Soltani, 2003). The gardens are generally used privately and are formed around mansions or monumental buildings or tombs and entertainment places. Nevertheless, one of the major goals of garden is a companion with nature that is an inclination of humans.

2.4.2 The Archetype for Organizing Nature and Natural Elements in Persian Garden

In order to recognize the Persian garden by conceptually reviewing its constituent order-systems, besides identifying the concept and position of the main natural elements of the garden (Water, plants, trees, etc.) and action of dealing with them (cultivation and agriculture), the most important pattern of the Persian garden, namely the "Chaharbagh", must be considered. In most articles about Persian garden, this pattern is applied similarly. Thus, it can be known as a source pattern for Persian garden (Masoudi, 2004, p. 132).

"Chaharbagh" pattern is a four-part model with two water streams intersecting and a pool at its center, which is shaped the planting order, water order, geometric order, and spatial arrangement of Persian garden's framework. Most researchers believe that the "Chaharbagh" pattern is an ancient model or archetype of Persian garden.

2.4.2.1 Quad-Basis in Iranian Art and Persian Garden

Most scholars declare that Iranian "Chaharbagh"'s design is rooted to a quad basis in art and Iranian culture. There are many pieces of evidence from quads in Iranian culture, which can be reached through Investigation about quads basis, for instance (Heydarnattaj & Mansouri, 2009; Shahcheraghi, 2013; Shahcheraghi & Islami, 2008):

- **Iranian climate:** Four seasons and four holy natural elements (water, soil, fire, and wind)
- **Iranian historical, social structure:** Four social classes, which were peasants and farmers, warriors, clerics, and princes & sovereigns
- **Iranian traditional medicine:** Four temperaments and humor, which are sanguine, phlegmatic, choleric, and melancholic.
- **Iranian literature & poetry:** "Rubaʿi" in the structure of Iranian poetry is written in a four-line (or two-couplet) poem
- **Iranian traditional music:** the tetrachord ("Dong" in Persian) is a consecutive four musical note. Four plectrum and four corners are also some terms in Iranian traditional music.
- **Iranian architecture:** "Chahartaq" (literally meaning, "having four arches" in Persian language), "Charsou" (intersection of two main Bazaar to four sides), four-Iwan, and "Charsofe" (four vaults).

Figure 2-21 - Miniatures of a "Chahar Bagh" in "Shahnameh", and the picture of tree in the Iranian carpet art (UNESCO World Heritage Centre, 2011).

Many other examples are also available in Iranian art (painting, carpet, calligraphy, etc.) to emphasize the significance of quad-basis in Iranian art and culture (Shahcheraghi & Islami, 2008).

2.4.3 The Importance and Role of Garden in the Iranian Culture

Iranian attitude about nature was always with respect and appreciation. Gardening and agriculture are vital in Persian beliefs and faith (Zoroaster); also, earth, water, and plants have certain sanctity. The significance of this subject has multiplied with the arrival of Islam in Iran, so that, as mentioned in the Qur'an, heaven is like a garden in which all human pleasures are provided and defined on the basis of beauty (Khansari et al., 2004).

In Islamic culture, water and plants are important and respectful. Planting a tree is admirable, and its elimination is very reprehensible, while wasting water is also considered a sin. Garden and nature are the places where the human finds mental peace, and the garden environment associates the ideal world for them. In Islamic mysticism, fun and thought blend together, and garden is a place in which intellect and feeling are combined. Garden is the balanced scale between the appearance of architecture (construction mind) and nature as a spring that seeps through it (Pope & Ackerman, 1964).

As mentioned earlier, the importance of garden also affects types of arts. Its excitement and beauty have been depicted in miniature and paintings. Where it is impossible to cover an area with flowers, Iranian carpet maintains this tradition with its patterns. Paying attention to the word used in this field and their concepts show the garden's place and importance.

There are many factors that affect Persian gardening. Some of them are the main reasons for creating gardens and caused gardening to reach its peak of art prosperity in some periods and some places. In general, these factors can be verified in the following divisions (Motedayen, 2010; Shahcheraghi, 2013):

- **Social factors:** One of the most important factors that influence the creation of gardens, resorts for recreational and leisure activities, celebrations, meetings, and entertainment.
- **Governmental and political issues:** Specific strategic issues in the region attract attention from the authorities. Therefore, it is necessary to consider these areas in particular lodgings like castles with gardens that provide a short-term settlement for governors and ministers.
- **Economic issues:** Gardens were one of the most expensive places where high costs have been spent on construction and maintenance. Issues such as the conveyance of water, building, and landscaping cost a lot. Therefore, prospecting in different historical periods has affected on qualitative and quantitative growth of making gardens.
- **Emphasis on memorial spaces:** Gardening around some memorial spaces and tombs is the most obvious way for emphasizing and giving importance to those spaces. This action has been caused to respect the character and more magnificent of this building.
- **Seasonal resorts:** Suitable climatic conditions in some places, especially around cities such as villages with good weather and ranges of mountains, have

provided the creation of gardens for seasonal accommodations and bungalows. Again, the environment, full of freshness, vitality, and tranquility in gardens, was a suitable resort for temporary housing and leisure. For instance, Ghavamolmolk, the governor of Shiraz, used to be in Afif Abad garden during summer and in Delgosha garden during winter; and he built Narenjestan in the city that included interior and exterior parts. The outer part was used for work, commercial and governmental affairs, and the holding of rituals and ceremonies.

2.4.4 Centrality and Symmetry in Persian Garden

The design of Persian garden has always been consistent in regular and symmetric geometry. Usually, the garden is divided into four parts by two intersecting axes. Donald Wilber, in his book "*Persian gardens*", points out from four thousand years BC, when the hunters came down from the mountains and in the Iranian plateau did farming, they illustrated various aspects of life and their convictions on pottery objects. Some potteries show the world divided into four parts, and sometimes there is water in the middle of them.

Wilber also has noticed to this type of intersecting design, in which one axis may be longer than the others, is the Iranian sample that was called "Chaharbagh", Such plans were common since the Sasanian era and, at the intersection of the axes, a palace (a type of building in the garden called Koshk in Persian) was built. The Persian word for "Chaharbagh" expresses the symmetric map concept that water divides the garden into four parts. The water irrigates the land during its flow, and it refreshes the garden.

Usually, the palace in a garden is built, in the intersection of axes in the middle of the garden, to be surrounded by the refreshing environment of the garden from all sides. In some gardens, especially those that were built on a hillside, the palace is located in a prestigious position at the beginning of this axis (Wilber, 1994). There is a beautiful landscape along this axis, which is created by combining all elements of garden.

2.4.5 Persian Garden Orders and Structural Elements

All of the historic garden frameworks have been created from planting order, watering order, and building (architecture constructions) order. The orders vary according to the climate and culture of the lands. The geometric structure of garden is a spatial combination of natural and artificial elements that can be organized in the body of the garden. This structural order creates a variety of spatial and physical qualities of garden by integrating the different layers of natural and artificial elements and orders.

Persian garden, following the combination of its main components, forms in an intellectual system, and in the meantime, some minor elements are more influential on the results of this combination. Thus, to define garden elements more precisely, the importance and necessity of each element must be considered. The main elements refer to the elements that, without their attendance, the formation of the garden is impossible. These elements (i.e., earth, water, plant, and space) will form a garden by the combination of the intellectual system of Iranian architecture and the garden's conceptual framework. There are also some minor elements or component parts, which affect the main elements (Soltanzadeh, 1999).

Except for the shape and position of the earth, which is one of the major elements in the garden, there are also some other important characteristics and other factors such as soil type, slope, levels, and capability of irrigation and fertility. For example, one of the main reasons for constructing a garden on land with slopes is the possibility of water movement within the garden naturally. Persian garden can be constructed on land with low slope or high slope, and if it is on land with high slope, the garden is usually influenced by the earth levels and is constructed on several levels. In this case, it will be possible to create a waterfall (Soltanzadeh & Soltanzadeh, 2017).

In other words, the structure of gardens created the platform for integrating natural and artificial elements in the garden, so that the natural elements are organized according to the planting order and watering order, while the artificial elements and buildings are specified in the constructional architecture and lodgment order.

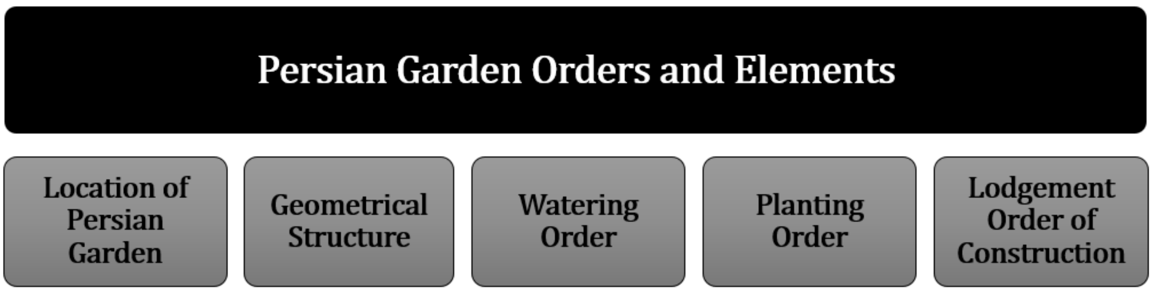


Figure 2-22 - Persian garden orders and its significance elements (Source: Author).

2.4.5.1 Location of Persian Garden

Being located in the hot and dry climate always brought about building the gardens, which are terrestrial paradises that make peace and tranquility for people of this region. Therefore, one of the most important architectural and urban elements in Iran are gardens designed by the best Iranian architects with a variety of different classes over the centuries. The design of gardens, as one of the most striking memories of Iranians, has always been considered by architects and archaeologists.

There are gardens in the desert of Iran considered valuable examples in terms of art and architecture and promote the Iranian art of Landscape Gardening in other lands, especially in Islamic lands. Based on their location in the city, Persian gardens can be categorized into two suburbs and inner-cities groups. Each category can be divided into subgroups according to their function and special features. Most suburban gardens have been used, by a particular class, for leisure and recreation. Therefore, these gardens are often called summer gardens. However, the garden's establishment in the suburb or inner-city with other features resulted in new uses and different scales (Sheybani & Esmaeeldokht, 2016).

Generally, in the issue of the location of Persian gardens, climate factors and the natural environment play a fundamental role. Therefore, by relying on simple elements of water, wind, soil, sun, and the essence of life, the landscape architect tried to domesticate nature. They used breezes from the air, soil fertility, sunlight and shadow, and refreshing water. Moreover, this garden was created with dialogue between shadow and light, open and closed spaces, full and empty with the breeze sound in the foliage leaf, the sound of running water and birds singing, blow the spirit in the body (Figure 2-23).

Control over the land and using the natural factors to create a contrast with the surrounding environment make water availability of the main factors in choosing the location of the garden, and fertile soil and suitable slope (water moves from top to bottom) are other primary factors in choosing an appropriate place for a garden.

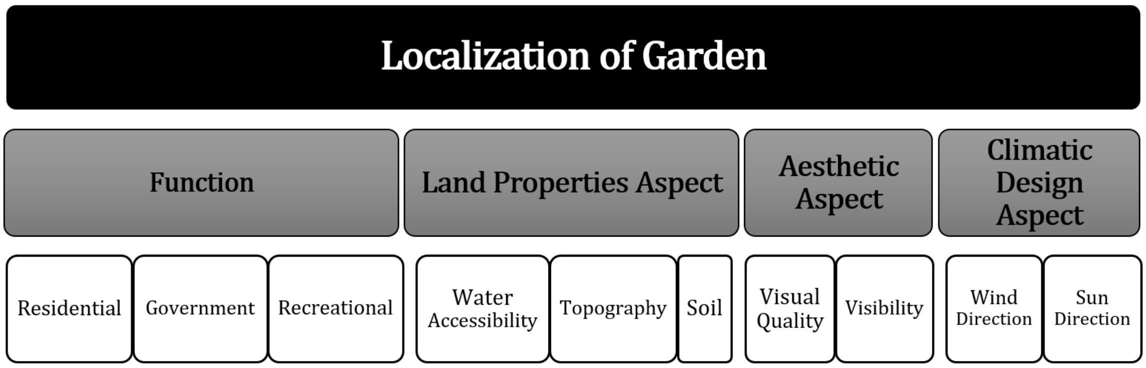


Figure 2-23 - Site inventory and localization of Persian garden (Source: Author).

Figure 2-24 - Ashraf gardens in Behshahr in the moderate climate of Iran (Source: Pope, 1938-9)
Figure 2-25 - Shahzadeh Mahan garden in Kerman province in hot and dry climate (Source: Khansari et al., 2004)

2.4.5.2 The Geometrical Structure of Persian Garden

As described in detail in section 2.4.1.3, the common chapter of the Persian gardens is the Archetype pattern of "Chaharbagh", which is intertwined with Iranian culture and art (ref. section 2.4.2.1). Therefore, Persian garden is defined as a square or rectangular area of land enclosed by a surrounding wall. This area is divided into four parts by two perpendicular intersecting axes, which mostly have the waterway. The garden area is proportional to the volume of water that can irrigate the garden (Mirfendereski, 2004). The garden is terraced on a regular geometry according to the land topography; moreover, slopes are caused to create attractive waterfalls, such as Shahzadeh Mahan garden in Kerman province.

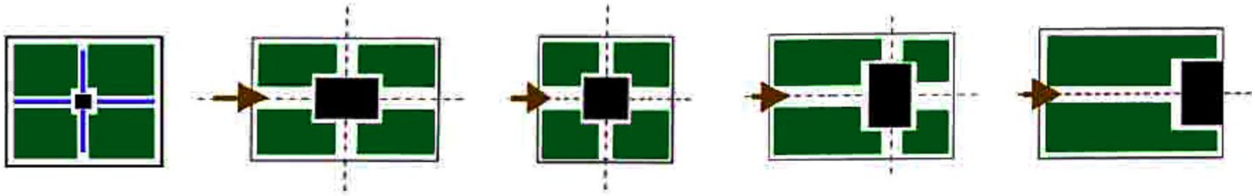


Figure 2-26 - Persian gardens' geometrical pattern (Source: Author).

Pirnia believes that in the geometry of Persian garden, two principles were important:

- Two or three axes are dividing the garden into squares with regular divisions. The history of the principles goes back for thousands of years. In agriculture, it was common to plant in square-shaped parts of the land and divide land and water into squares forms. Except for long rectangles and squares, there were octagonal shapes, "Kashkoli", and "Negini" [4] in garden that usually formed the "Howz"[5].
- Another important issue in Persian gardening was the main perspective of the long rectangle form. There was an open and long room in front of these gardens' building, which was exactly in the main perspective. In this space, they did not plant tall trees; instead, they usually planted trees, which do not grow too high, and they did not obstruct the view.

However, the geometric shape and structure of the garden can be studied from four main points of view, i.e., the symbolic and allegorical, functional, aesthetic, and climatic aspects.

4 - Traditional decorative form on design of pond or pool by combination of octagon and semi-octagon's form

5 - In traditional Persian architecturem Howz refers to a centrally located water pool in a garden or Hayat.

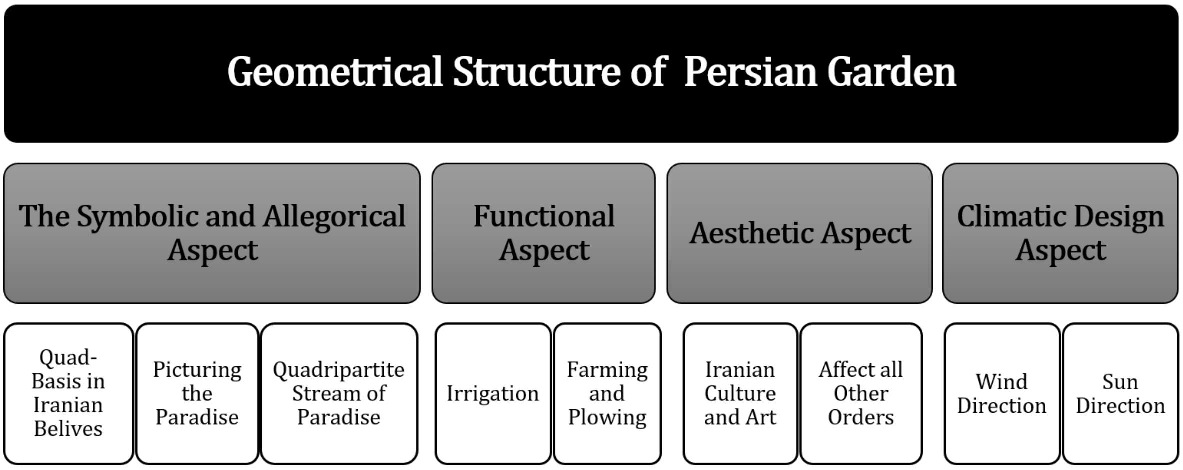


Figure 2-27 - Schematic of Geometrical Structure of Persian garden (Source: Author).

2.4.5.2.1 The Symbolic and Allegorical Aspect

Water that flows from the Palace into the Garden (water is channeled into the underground from outside the Garden and then flows from certain points inside or near the Palace), mostly running in four directions.

The Four Paths of Water is a parable of the four streams of Paradise mentioned in ten different religions. Although in many Persian gardens, water enters the “Howz” in one direction and flows in three other directions, it is reminiscent of a waterflow in the quadripartite directions (Masoudi, 2010).

In the post-Islamic era, the structure of the "Chaharbagh" can be seen as the result of the allegorical dimensions of paradise in the Qur'an (the quadripartite stream of paradise) (Heydarnattaj & Mansouri, 2009).

2.4.5.2.2 The Functional Aspect

If the artificial environment of the Persian garden is studied, the following reasons for the regnant geometrical structure of Persian garden can be explored:

- From the time human started farming and invented Plough to prepare the soil, he has learned from the experience of this geometrical rule that the easiest way to plow is, moving in a straight and parallel direction. Thus, the pieces of land became in a square and rectangular shape (Pirnia, 1994).
- The same geometrical principle was noticed as the easiest way of irrigation when it was intended to irrigate the fields by reducing the distance and preventing water loss (Diba & Ansari, 1995).

The abovementioned reasons are the efforts of the ancient Iranian to apply the most optimal possible way to save time and materials and gave them the efficiency, which are the basics of the economy.

2.4.5.2.3 Aesthetic Aspect

It should be noted that the aesthetic aspect has always been the dominant spirit of the Persian garden, which has been implemented in all areas. Moreover, this aspect has been deeply rooted in Iranian culture with sophisticated techniques to achieve its goals and functions in the best possible way. In fact, beauty is the irreplaceable principle of the Persian garden in all parts of the garden (in both details and generalities).

In the Persian garden, more attention has been paid to geometric and square shapes that show the distance between the components. The first step in planting trees is accuracy in determining the location of them from each side. Therefore, squares were formed on each side, and the rows of trees could be easily noticeable. For this purpose, each section of the garden, either square or rectangular, is divided into small squares. At each vertex of this square grid, a long-lived tree was planted. Then, it is divided into smaller squares and at each vertex of those trees of medium and longevity, likewise for the short-lived tree (Shahcheraghi, 2013).

This order works in such a way that the overall shape of the garden is maintained for long periods, with the possibility of replacement of the dead trees. In addition, adequate sunlight is provided to all trees.

The geometrical order of planted trees was excessively precise that, when it could be seen from every angle, the trees' row order has been taken into account. In the book "*The Economist*", Xenophon mentioned that Cyrus met Lysander personally to visit his garden in "Sardis". And Lysander admired and respected the beauty of the trees, the order and precision of the intervals, the straightness of the rows and angles, and the numerous pleasant aromas of the garden.

The enclosure walls of the garden define the area of the garden according to the geometric structure of interior parts of the garden and give them a rectangular or square shape. Walls act as protective elements and also act as privacy and separator of the public from the private area according to Iranian introverted culture and their religious beliefs (Pirnia, 1994).

The conformity of the exterior geometry of the building is another reason for the significance of this geometrical structure.

2.4.5.2.4 The climatic Aspect

Another geometric feature of the Persian gardens is the building's front view over the garden and the elongation of the garden's main axis in the North-South, or East-West directions (Pirnia, 1994, 1999; Shahcheraghi, 2013). However, in studies of many plan-sites from historical Persian gardens, most of the gardens' longitudinal axes lie in the

North-South direction with slight angle tolerance. In order to have a better comprehension of this, the following reasons should be mentioned:

- Modifying the sunlight in the garden area and creating the most shade during the summer day in the garden's main axis, which is a suitable and reasonable solution according to the climate of Iran.
- The rotation angle changes of the garden's elongation to the north-south axis are due to the slope of the land or the mean seasonal and local wind directions.

2.4.5.3 Water Order in Persian Garden

Since a long time ago, water has had a special significance for Iranians because farming is their main work. They have substantially improved the techniques of using water in agriculture. Water has been considered sacred and has been important in the Islamic period as well. Water preserved its aspects of sacredness as a substance essential for human life. It has always been very important because of drought in different parts of the Iran plateau. Therefore, they respect water as a life extract of nature. They believed that it was a sin if they wasted the water and the best way to use water is to irrigate plants because in this way, water would return to its original source in nature. With these interpretations, a better understanding of the role of water in gardening can be achieved (Pope & Ackerman, 1964).

Water generates the gardens in Iran, where hot and dry areas cover two-thirds of its area. Thus, providing water, extracting, conducting, splitting, and consuming water must be considered with accuracy, sensitivity, and applying special science and technology. The most important source of water supply in Iran is precipitation water and underground water (Göker, 2017; Haghshenas, 2014).

However, visual and auditory aesthetics, climatic, and irrigating functions are the main functions of water orders in Persian garden, which will be briefly explained.

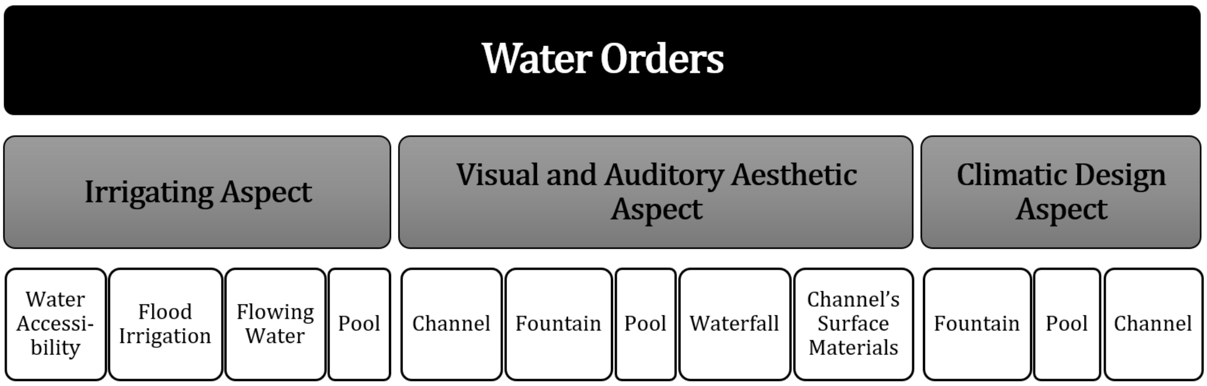


Figure 2-28 - Water Orders in Persian garden and its functional aspect (Source: Author).

2.4.5.3.1 The Irrigating Aspect

Two issues regarding using water in the gardens should be considered. First, delivering water to the garden and then delivering it to all parts of the gardens was done by some unique mechanisms and techniques. Water was brought from the depth to the surface by creating aqueducts and canals, especially in dry areas. Then by applying unique geometric split systems, not only was the garden simply irrigated but also it was demonstrated in the best way (UNESCO World Heritage Centre, 2011).

Most gardens in Iran, especially in the central region and desert, have been built in the center of the aqueduct or “Kariz” due to very little surface water is accessible in these areas. When the water comes out of the aqueduct, it is restrained and flown in the garden. An aqueduct[6] is a water facility that flows the hidden and underground water on the earth's surface by digging a canal in the soil (Masoudi, 2009).

The motion of water on the earth's surface is in the same direction as the general slope and matches with its geometric structure system. Water flows through “Kart”[7] is not permanent, so that watering every Kart is doing through flood irrigation[8], Kart by Kart. Furthermore, water in the main axis is always flowing and watering the located tress (Ansari & Moalemzadeh, 2015; Shahcheraghi, 2013).

In addition, storing water in big pools for later usage, especially in low watered seasons, is another way of irrigation management. Linear, surface, volume forms of water are the accurate answers to diverse requirements of water in Persian garden. The water system in the garden is accountable for both watering needs, flood irrigation, and irrigation with permanent running water through stream waters, proportional to any species of trees and herbs. In addition, the water cycle in the city starts from the gardens. Thus, it is responsible for transferring clean water.

2.4.5.3.2 Visual and Auditory Aesthetic Aspect

Garden designers have used some unique techniques to present water audio-visual effects; they are mentioned as follows:

Creating Steps and Waterfall:

By taking advantage of the land’s slope, stepped up the ground so that a gentle stream of water looks so fast and noisy, and it shows a beautiful level of falling water without using energies since water always comes down by gravity.

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6 - Aqueduct is called also Qanat which will be elaborated in section 5.2.1.
7 - Kart (Persian: کرت) is an agricultural land, that is distinguished by traditional irrigation system.
8 - In Flood irrigation system, water moves over the surface of Kart to wet it and penetrate into the ground.

As it was previously mentioned, one of the other ways that water flows are smooth moving by creating a slope along streams and canals. In addition, water can flow along streams and pools from top to bottom by changing the level of pools. Therefore, water mostly tends to fall off. Karaji, in the book "*Extracting hidden waters*", has specified that one of the water's characteristics is that water tends to move closer to the center of the earth, and there is no tendency in water to rise (Figure 2-29).

Figure 2-29 - Waterfalls in Shahzadeh Mahan garden (left and middle pictures) and using high-raise fountain in Hasht-Behesht Garden of Isfahan (Source: Author)

Fountains in Pools:

Fountains in the pools push up the water into the air. The water tank can be a pool or pond. After being filled, the regulator of the fountain's canal can be opened until water erupts to them. Water entrance into the tank has to be equal to the water that comes out of fountains to keep balance in the eruption, and the level of the eruption remains constant with a certain size. To achieve this goal, the water in the tank should always be at a certain level (Ansari & Moalemzadeh, 2015).

Ponds and Pools:

Various forms with various geometric shapes such as square, rectangle, octagon, and even forms with more complex designs enhance the beauty of dramatic effects. Normally, the basin is located in front of the palace. In some cases, it is also located in a smaller size inside the palace. However, these still seemed like a big mirror that reflected the building's and environment's image while the flowing water glittered in the garden (Soltanzadeh & Soltanzadeh, 2017).

The mirror effect of water surfaces causes, reflecting the surrounding objects. Therefore, these pictures (especially tall trees) or building parts (columns, palace's porches) by reflecting in the water somehow increases the virtual space in the garden (Wilber, 1994).

Besides these issues, the role of water in moderating the climatic conditions of the garden should not be underestimated.

Surface Materials of Waterways:

Water sound is a pleasant melody, which is soothing to the human soul. Besides making a visual beauty, water movement in the garden creates various sounds in the garden. Water movement in various forms such as wide and thin streams, big pools, fountains, big and little waterfalls, and passing through specific featured Sequin tiles[9] with different speeds creates various pleasant sounds. The specific featured sequin tiles or marble stones mostly painted or engraved (usually fish flake). They are usually used at the outlet or inlet surfaces of the waterway from streams to pools and vice versa. When water flows over them, it causes water to leap. Thus, the volume of water is more significant than what it is (Pirnia, 1994)(Figure 2-30).

Figure 2-30 - Applying the specific featured Sequin tiles in Ashraf Garden in Behshahr (above photos) and Dolat-Abad Garden in Yazd. Embedding ceramics or rocks on the floor of streams and places where water flows for extra dynamic waves and making foams in the water (Ismailzadeh & Hosseinpour, 2016; Shahcheraghi, 2013)

2.4.5.3.3 Climatic Aspect

The presence of water everywhere in the garden (in various forms of pool, fountain, and streams), the shade of trees, and the breeze have a major role in cooling air and increasing its moisture. Local winds with various features like touching the water surface and passing through the trees' crown are thermally cooled down and also lost dust. Thus, this water system influences the air freshness and making cool breezes. Additionally, spreading water in space through fountains multiplies these effects in the garden.

9 - called "Sine-Kabki" (سینه کبکی in Persian)

When the air that passed over the fountains and through the trees goes into the building causes freshness and vitality (passive cooling). Even shade and water together are able to create wind in different parts of the garden, and this, especially in hot and dry areas, makes the weather cool and pleasant.

Moreover, water as a surface ground material compared to paving bricks and cobblestone absorbs less solar energy and makes its ambient air cooler. In fact, water surfaces by storage solar energy in deeper layers of water prevent the rise in air temperature due to the reflection of long-wave heat to the environment.

2.4.5.4 Planting Order in Persian Garden

Following the ideology of ancient Iranian culture, the Iranian viewpoint toward nature and natural elements is based on respect for nature and its coexistence. They believe that the earth is God's property. In this culture, water is sacred, and plants are known as gifts from God. Among the plants and trees, some of them, for different reasons, are holy, beloved, and especially respected (Mahmoudi Farahani, Motamed, & Jamei, 2016). This shows the rich, intellectual, and valuable Iranian culture and the beliefs of the ancient people in Iran. After a long absence from nature, contemporary humans wish to return and demand the restoration of nature.

According to the encyclopedia of traditional symbols, plants are symbols of death and resurrection and the power of life and life cycle. In this encyclopedia, green as an element has two characters: the symbol of both life and death; spring green means life, and rusty green means death. Green is a symbol of youth, hope, joy, and also a symbol of change, death, and envy. Green means spring, breeding, trust, nature, paradise, prosperity, and peace (Mahmoudi Farahani et al., 2016). Vegetations, especially trees, are the symbol of freshness, comfort, and beauty for Iranians. Tree is also a symbol of the whole universe, the composition of the sky, earth, water, dynamic lives, and is a symbol of peace and spiritual illumination (E. Zamani, Leylian, Amirkhani, & Okhovat, 2009).

2.4.5.4.1 The Principles of Planting

Persian gardens abstain from futility. Thus, trees, plants, and flowers are rationally planted in the gardens. Garden layout and composition of plants and flowers in Persian gardens are empirical and scientific, based on relations, criteria, and principles such as efficiency, dynamics, dealing with environmental conflicts, beauty, and being eye-catching in different seasons:

- **Spring:** blooms, flowers, odors and fragrances, freshness, and happiness.
- **Summer:** wind-breaking, shade, flowers, fruits, running water, pleasant air, and resting place.

- **Fall:** colorful fruits, vibrant color, and dancing leaves.
- **Winter:** clear geometry, proudly evergreen trees in the embrace of naked fall-out branches.

However, in Persian garden, different vegetations were planted to create **shade, harvest, and decoration** based on the **geometrical structure and spatial arrangement** of Persian garden (Figure 2-31).

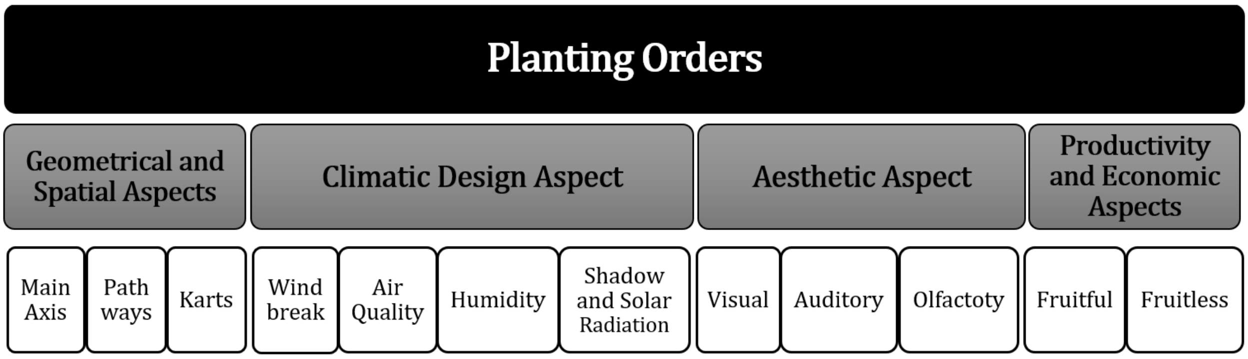

Figure 2-31 - Planting Orders in Persian garden and its functional aspect (Source: Author).

2.4.5.4.2 The Geometrical and Spatial Aspects

The planting order of Persian garden acts as a proper response to Iran's specific climatic and geographical situation. This climatic answer donated a particular character to Persian garden and made it unique.

Not only planting order of Persian garden affects the geometrical structure of garden, but also it is affected by the geometrical structure. They are a supplement to each other. On the one hand, the practical approach of planting and agriculture styles creates geometrical structures (ref. section 2.4.5.2.2). On the other hand, the planting system is influenced by geometry, so that planting trees and herbs in the Persian garden has been known by intertwining with geometry and water system.

In section 2.4.5.2.2 is illustrated on **two planting styles** in Persian garden, based on geometrical shapes and square. **The first style**, as aforementioned, was accuracy in determining the location of vegetations from each side of view. To this end, squares were formed on each side in a way that the rows of trees could be easily noticeable. For this purpose, each section of the garden, either square or rectangular, is divided into small squares. At each vertex of these square grids, a long-lived tree was planted and then divided into smaller squares. Then, at each vertex of those, medium lifespan trees were planted, and the same process for the short-lived tree(Pirnia, 1994). The geometrical order of planted trees was excessively precise that when it could be seen from every angle, the row order of the trees attracted all the attention.

This order was very effective in terms of the function and impact of the landscape system resulting from the planting system. It works in such a way that the overall shape of the garden is maintained for long periods of time, with the possible replacement of dead trees. In addition, adequate light is provided to all trees (Diba & Ansari, 1995).

The second style of planting trees in Persian garden is the planting five-point systems in which four trees at the corners are planted and one in the center in the square shape. In comparison with the first style, rows of trees are not parallel. This method not only has all the features of the first method but also creates a denser view of the trees. Moreover, it shows how wisely the Iranian people create pleasurable space by creating this planting system in the desert in Iran in which is even difficult to provide water (Shahcheraghi, 2013, p. 68).

In Persian garden, each location is allocated to the specific plant species and certain trees originating from thousands of years of Iranian gardening experiences. This valuable knowledge particularly includes the information of each region's specific plant species, the coexistence of different plants together, and identifying species of trees, which act better as filters and resist the aridity of outside weather of the garden (Diba & Ansari, 1995).

According to different functions of plants, they are planted in certain areas in Persian garden. It can be visualized in term of plants arrangement (Masoudi, 2004; Okhovat, 2014; Pirnia, 1994; Rouhani, 1991; Shahcheraghi, 2013):

- As the most important principle of the planting system, in the **main axis** of Persian garden ("Mid-Kart[10]"), trees have never been planted due to create a broad view and perspective. Plants were usually planted that did not grow tall and were mostly evergreen and beautiful such as Alfalfa, flowers, grass, etc. However, on **two pathways** on either side of "Mid-Kart" or Fountain, there were corridors covered by trees. The type of trees varied depending on the climate and soil of the region.
- To provide shadow in the Persian gardens, trees with a large crown were planted on both sides of the "Mid-Kart". Furthermore, the passages were narrow, and trees were planted along both sides of the pathway (like a corridor). They usually planted **Cypress, Pine, Platanus** or **Cypress, Pine, and Elm** tree along the garden's street in the **main axis**. Sometimes these trees were replaced by other trees like Ash and Salsify. These trees, which were planted solely for shading, were called unfruitful trees.

10 - The Kart located in the midde of the main axis of Persian garde, and sometime replaced by pool and fountain.

- In the central longitudinal section of the Persian garden, trees such as Cypress, Pine, and Platanus were intermittently planted to create a beautiful corridor on either side. Deformation of Platanus trees in four seasons (changing the color of leaves and their falling) in the vicinity of Cypress and Pine, which always have green leaves, created a large variety of colors, design, and space of Persian garden.
- In this planting system, on either side of the corridor, in front of a Cypress, a Cypress, in front of a Pine, a Pine, and a Platanus in front of a Platanus, were planted.
- In Persian gardens, deciduous and evergreen trees are planted together on both sides of Karts along corridors and streams since green is always a symbol of immortality, youth life, virility, and fertility.
- Among “Mid-Karts” (main axes), for water preservation and other issues, they used to plant Alfalfa (which is now replaced with grass) which can be harvested up to seven times. It is a useful, fragrant, beautiful, and economical plant that is easy to maintain, absorbs Nitrogen and gives it to the soil. Alfalfa repellents the mosquito while feeds bees with its flowers. Also, after reaping, it forages for livestock in winter. Alfalfa looks like a lawn landscape in the early stage of growth, and with the beautiful purple flowers spread out on the green land.
- In Persian gardens, mainly trees such as Elm, Maple, Myrtle, and Judas’s cover around the pool.
- Willows are planted in a place accessible to a sufficient amount of water but not beside the pool because their roots might destroy it.

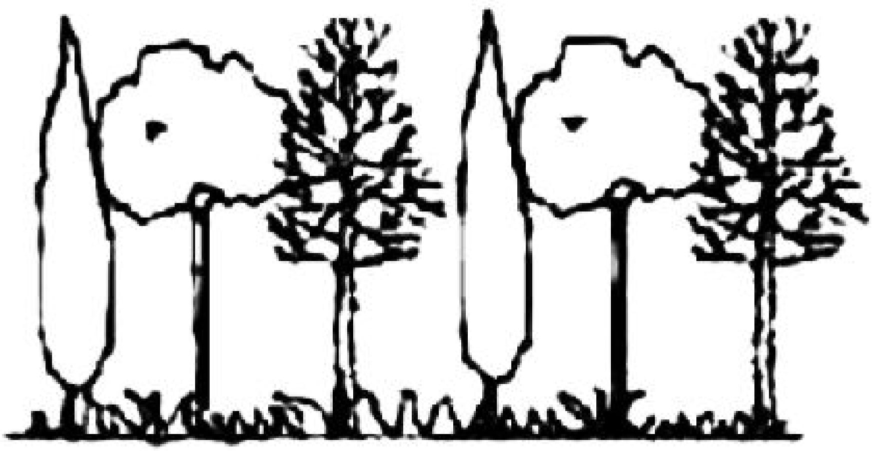

Figure 2-32 - Triple pattern of planting trees in the main axis of the Persian garden (Pirnia, 1994).

The Significance of the Symbolic Meaning of the plants and Planting Location in Persian Gardens

Each type of trees have interesting implication in term of the semiotics as the following (Mahmoudi Farahani et al., 2016; Okhovat, 2014; Pirnia, 1994; Rouhani, 1991; Shahidi et al., 2010; E. Zamani et al., 2009):

- **Cypress:** defines the death and corpse, a force that helps to protect the body from corruption and, therefore, can be used in cemeteries, also is a symbol of elegance and fun. Cypress is the most popular tree in Persian gardens.
- **Platanus:** Platanus trees widespread their shadow over a wide area, and people believe that this tree will prevent the incidence of fever and infectious disease. Platanus is a symbol of glory and training.
- **Pine:** this tree is a symbol of truth, being vertical, vital, and fertile, the power of an indicator, silence, hermitage, longevity, and faith.
- **Poplar:** these trees grow extremely fast and are used in architecture and buildings. This tree is called the tree of waters. Two different colors on two sides of its leaves represent the Yin-Yang and lunar and solar years and generally all pairs.
- **Ash:** this tree is a symbol of harmony, humility, and production and is a holy cosmic tree.

Trees near the streets or the “Mid-Kart” typically are the trees, which beautifully show four seasons, and low leaf trees and original ones were planted farther. Each “Kart” is allocated to an especial tree in Persian garden. Ancient Persian gardens were mostly dedicated to the cultivation of fruit trees. Fruit trees in regular-spaced rows based on the precision of flowering and fruiting were planted in different seasons. Berry, Fig, and Grapevine trees are the most common-planted trees in Persian gardens.

- **Berry:** was the most important fruit tree. In some gardens, a section was dedicated to edible berry; and in some places, mulberry or black mulberry was planted at the junction of the borders. In traditional semiotics, due to triple colors of ripening (white, red, black), berry is a symbol of the three stages of human life and mystery of familiarity. Berry is a tree of life, the embodiment of sobriety, obedience, and life, and has a magical power to fight the force of darkness.
- **Fig:** is a symbol of fertility, life, and prosperity. Sometimes, the meaning of the fig tree is knowledge, and also it represents the combination of masculinity and feminism. In Persian gardens, this tree was planted in the corner of the garden or a curved place where it could produce more fruit because of being sheltered.

- **Grapevine:** in various types was planted such as scaffolding Vine, cavalry Vine, Infantry, and lying Vine. To prevent the influx of pesky wasps, peppers were planted nearby. Grapes are the symbol of wisdom. Truth is in wine, and a branch of grape is a symbol of agricultural and fertility deities and illustrates life and immortality.

Great other variety and high quality of fruit trees were planted in Persian garden which can be listed as below:

- **Apple:** a symbol of life, peace, and agreement, divinity, and wisdom.
- **Pear:** a symbol of hope, health, justice, good government, and fair judgment.
- **Peach:** eternity donors, evil repellent, and fairy fruit.
- **Plum:** the epitome of freedom and loyalty, longevity, pureness, isolation, and childhood.
- **Hawthorn:** fairy plant, evil repellent, Roman and Greek wedding flowers.
- **Palm tree:** a symbol of joy, lust, truth, consecration, victory, right deeds of man, and a tree of life.
- **Almond:** a symbol of virginity, self-creation, happiness in marriage, the imagination of awakening, the epitome of grace, charm, and elegance.
- **Walnut:** wisdom, fertility and longevity, sustainability in misfortune condition.

In addition to trees, flowers are the symbol of passivity and female form in traditional semiotics. Flowers with unique properties and usages were placed beside the trees in Persian gardens, such as flowers with a pleasing aroma and suitable for cooking “Halva” and jam. Some of them also had medical properties. In case there was no pool in front of the main building, flowers were planted instead. Garden was full of flowers in Iran. Decorative flowers are planted more in front of the building and along the entrance axis or main axes that show the building. Iranians are more interested in the following flowers:

- **Rose:** Rose is the most favorite and popular flower in Persian garden. In the Iranian territory of flowers, Rose has hegemony and dominance. It is natural that in Persian, the word flower means Rose and also flower in general. Rose is a very complex symbol. Rose refers to both time and eternity, heavenly perfection and earthly suffering.
- **Violet:** a symbol of virtue and beauty and modesty.
- **Lilium:** purity, peace, resurrection, and embodies fertility of earth goddess.
- **Hyacinth:** a symbol of prudence, peace of mind.
- **Primrose:** represents purity, youth, and cockiness.
- **Amaranth:** mythical eternal flower, a symbol of eternity, faith and loyalty, and stability in love.

- **Leucanthemum:** a symbol of purity and innocence.
- **Saffron:** apathy, humility, self-denial, and solar plant.
- **Iris:** the flower of light and life, king lady of sky.
- **Narcissus:** a symbol of vanity, narcissism, ego, the shadow of shining nature, introspection, silent pureness.
- **Jasmine:** planting yellow jasmine was common in the corner of Persian garden. This flower is a symbol of femininity, grace, and charm.

2.4.5.4.3 The Climatic Aspect

The plant order of the Persian garden provides an appropriate response both to the specific climatic and geographical situation of Iran. This planting system has given the Persian garden a unique character.

As aforementioned, the planting order and geometrical structure of Persian gardens are affected by each other for optimal adjusting to the local climate. Therefore, the planting order of the Persian garden based on its geometrical structure and climatic situation creates the distinguished shadow and light experience in the garden.

The Karts are partitioned based on logical order, observance of geographic direction and environmental features, optimum use of the sun, stability against the wind, encounter with the maximum and minimum of temperature, the convenience of cultivation and harvesting, providing a pleasurable environment, delightful diversification, and the establishment of dynamic beauty (Shahcheraghi, 2013, p. 65).

It is noticeable that planting locations of each kind of tree, flower, or plant are precisely identified in Persian garden design. Applying the tall and shade trees linearly in the main axis, pathways, and accesses always provides shadows during a day, which directly affects the thermal comfort quality and physical framework of the Persian garden. Furthermore, shade trees are planted around the building in the garden.

As one of the most effective parts of providing thermal comfort in Persian garden, the Shadow system acts more effectively, where the water exists as well. In fact, the coexistence of these two systems, as the two fundamental elements of the Persian garden, provides the main reason for the attractiveness of this garden (Masoudi, 2004). In most Persian gardens, using deciduous trees simplifies the absorption of direct sunlight and provides thermal comfort in winter.

As discussed in section 2.2.3, trees and vegetation improve the air quality by reducing air pollution through photosynthesis and their filtering role. Furthermore, they increase the air humidity by evaporation, which impacts on cooling effect and reducing the air temperature. It is obvious that the broad-leaved trees and herbs play a much greater role in improving **air quality** and increasing **humidity.** In the Persian garden, some plants are cultivated precisely to absorb dust from the air, such as Albizia lebbeck, which is very suitable for this purpose due to its lint leaves (Shahcheraghi, 2013, p. 73).

Compared to building materials, surfaces covered by vegetation act as heat reducers. Green surfaces, by using solar radiation and energy in their photosynthesis action, prevent the increase in ambient air temperature.

In the Persian garden, due to its location in the desert and the abundance of dust, around the garden, along the walls, tall, broad-leaved trees were planted such as White Poplar, Platanus, Ash, Persian Olive[11], and sometimes combined with Jujube, Pine and Cypress (Pirnia, 1994). In this way, on the one hand, by controlling and filtering the strong winds (**windbreaking**), the air dust was reduced. Thus, the quality of the breeze in the garden was increased. On the other hand, passing wind through the leaves of the trees and evaporating the leaves' surface moisture increased the air humidity and reduced the air temperature inner the garden.

2.4.5.4.4 The Aesthetic Aspect

Visual Aspect

Generally, over time and by growing the planted trees on both long sides of the main axis or pathways in the garden, tree-covered corridors will be created. In this case, many trees create an enclosed space on the main axis or other pathways, in which sunlight passes through the branches. These shadows and lights exhibit a special quality and specific identity to the perceptual space of the garden (Daneshdoust, 1990; Irani Behbahani & Soltani, 2003).

The green surfaces in the Persian garden are surfaces covering with low plants such as Alfalfa, Clover, or decorative flowers. Thus, in some garden parts, a carpet of the flower was made (Pirnia, 1994).

The combination of various species of trees in the garden, such as Deciduous and evergreen trees or fruit trees and fruitless trees, besides creating various color combinations at the time, also presents the beauty of each season of a year. This is one of the distinctions between Persian gardens and other gardens. Also, this subject makes different combinations of fine and rough textures, which influence the visual quality.

Auditory Aspect

A variety of trees and herbs gathers birds in different seasons; in most traveling literature*,* these birds are called. Bird's presence makes the garden space full of their

11 - Elaeagnus angustifolia

beautiful sound. In the book *"The travel into Persia and the East Indies",* John Chardin has mentioned that sparrows, parrots, nightingales, swallows, pheasants, and peafowls were freely scattered in the gardens of Safavid's period.

Moreover, wind and breeze, by passing through tree branches and leaves, according to the shape features of the tree and its planted location in the garden, could make special sounds.

Olfactory Aspect

Planting aromatic flowers such as Orange blossom, Hyacinthus, Jasmine, Rose, Damask Rose, Narcissus, etc., demonstrates Iranians' interest in aromatizing the garden's atmosphere. Generally, flowers were planted at the main axis, foot of trees, flower Karts, and around the palace (Shahcheraghi, 2013, p. 73).

2.4.5.4.5 The Productivity and Economic Aspect

The application of Fruitless trees in Persian gardens and their specific locations, particularly their shading and filtering roles, has been described in detail (ref. section 2.4.5.4.2).

Fruitful trees, in addition to their aforementioned roles, are useful for the economy in Persian gardens. The planting location of fruitful trees was in the Karts. Each "Kart" is allocated to an especial tree in Persian garden. Ancient Persian gardens were mostly dedicated to the cultivation of fruit trees. In regular rows based on the precision of flowering and fruiting, fruitful trees were planted in different seasons. Each kart has its own unique tree and was named the same as the tree. The productivity of each kart was various due to the different climate (Irani Behbahani & Soltani, 2003; Pirnia, 1994).

Many varieties of vegetables and plants, other than the edible application, are applied in therapeutic as well. Medicinal plants are mostly planted among Karts, in sunshiny parts, away from palaces such as mint, alfalfa, and fennel. Moreover, as productivity aspect of trees and herbs, some of them have their own specialty. For example, from the branches of the willow tree, baskets could be weaved, and willow skin tee used for malaria treatment (Pirnia, 1994).

2.4.5.5 Lodgment Order of Constructions

Lodgment order of constructions in Persian garden puts all architectural constructions and artificial elements in order, organizes the garden's area, and unifies all Persian garden orders. In fact, the lodgment order of constructions in Persian garden, the same as other orders of garden, follows the geometric structure. This order, in addition to forming architectural constructions, establishes their location. These architectural constructions of the Persian garden are included the enclosure wall and palace, as the most common and known parts, besides the main entrance construction, and sometimes residential building and other service spaces.

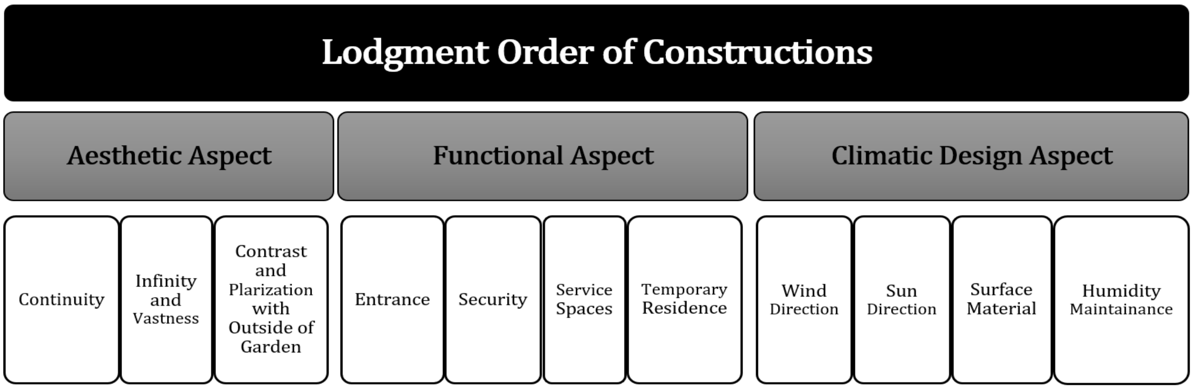

Figure 2-33 - Lodgment Orders of constructions in Persian garden and its features (Source: Author).

2.4.5.5.1 The Enclosure Walls

One of the most known human-made elements of Persian garden is the enclosure walls. These high walls surround all elements of Persian garden. Trees are planted close to the walls, besides following the geometry of the wall's establishment; they are selected in accordance with the purpose and function of the walls (Masoudi, 2004). The roles of enclosure walls in Persian garden could be investigated from various aspects as the following:

Functional Aspect

The garden's enclosure walls, particularly when the garden is defined as a private space, have a protective and security function. Walls, by protecting the garden from dangerous animals and animals hurting garden's products and protecting the residents from enemy attacks, provide a sense of safety for residents (Shahcheraghi, 2013, p. 79).

The walls also act as a border and separator of the public from the private area. The walls prevent strangers from entering and provide a barrier of sighting into the garden as a private space, which creates a psychological safety sense according to Iranian introverted culture and their religious beliefs (Soltanzadeh, 2003).

Climatic Design Aspect

Gardens surrounded by high walls can make a balanced environment that is provided by the green space inside the garden. High walls protect the pleasant environment against heat and dry weather outside the garden.

Indeed, on the one hand, walls protect the inner space of the garden from warm and dry wind and prevent it from shifting sands. On the other hand, walls provide shadows and keep the humidity inside the garden, which in addition to increasing the thermal cooling efficiency, is also suitable for plant growth. Thus the enclosure walls prevent the inside weather of the garden against the unpleasant wind and also make shadows on both sides, which directly affect the thermal condition (Taghvaei et al., 2015).

Moreover, the wall's surface material was mostly covered by adobe, mudbrick[12], or brick, which are sustainable, recyclable, effectively store heat, and then slowly release it over time (UNESCO World Heritage Centre, 2011).

Above mentioned properties of the enclosure walls of Persian garden and wisely designing and establishing these enclosure walls have let the beautiful distinction between both sides of garden walls.

Aesthetic Aspect

It is the distinct specification of gardens, especially in dry regions, and its purpose was the creation of a small paradise in the hot desert. Using high walls is a state of introspection for the garden, introspection that palace could be extroverted with all the pleasures, freshness, and vitality into it. In other words, in Persian garden, the wall separates two different worlds. The walls beautifully and artistically make this contrast and polarization, which indicated paradise and inferno. Meanwhile, in most gardens ascribed to the Persian garden, these characteristics of Persian garden are not clearly obvious and distinctive (Masoudi, 2005).

In addition to the enclosure walls, the lodgment order considers the short walls breaking the levels, stairs, yards edges, etc., which all follow the garden's geometrical structure. It means the lodgment order in compliance with the geometrical structure of the garden creates the architectural landscape of the Persian garden (Mirfendereski, 2001, p. 7).

Figure 2-34 - The contrast and polarization between inside and outside atmosphere in Shahzadeh garden, Mahan, Kerman (Source: https://iranindepth.com/)

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12 - Mudbrick is made from mixture of mud and laom mixing with straw or rice husks as a binding material.

2.4.5.5.2 Palace[13]

Functional Aspect

Palace, as architectural construction, has been built with an extroverted design and has been mostly used for leisure or temporary accommodation. Palace was established on the main axis of the garden, influenced by the garden's geometric structure, which was providing the best sight to the palace. So that from entering the garden and passing entrance construction, a palace located in axis's sight.

Climatic Aspect

Most palaces' features have been similarly designed on their four main sides. However, the location of the palace and its main facade have been selected and designed according to the climatic direction, view, and location.

The climatic considerations on place designing are that the greater the residential function of the palace, the more climatic design aspects are evident. Thus, like other Iranian architectural buildings, special attention has been paid to climatic conditions and choosing the right materials (Shahcheraghi, 2013, p. 80).

The building has been orientated according to the sunlight direction to avoid scorching summer sun and also to protect from hot and stormy winds. The buildings have thick walls in order to prevent the penetration of hot summer heat and severe winter cold and winds, especially into the residential building.

Moreover, the appropriate materials with high heat capacity and low reflectivity have been applied. Iranian used adobe, mudbrick, or brick as appropriate materials, which are local-made, inexpensive, and at the same time have high heat capacity.

Another unique climatic solution technic applied by Iranians was creating Small and large "Badgir" (wind-catcher), which has become one of the most Iranian architectural symptoms. The Badgir is a natural air conditioner. The shape of the Badgir is a function of the wind direction. Badgir, through air suction, cools and cleans the outside air and transfers into the residential. Instead, it drives warm air outside (Akhgar & Shaker Ardakani, 2013; Deldar & Tahsildoost, 2007).

13 - Called "Koushk" in Persian "کوشک"

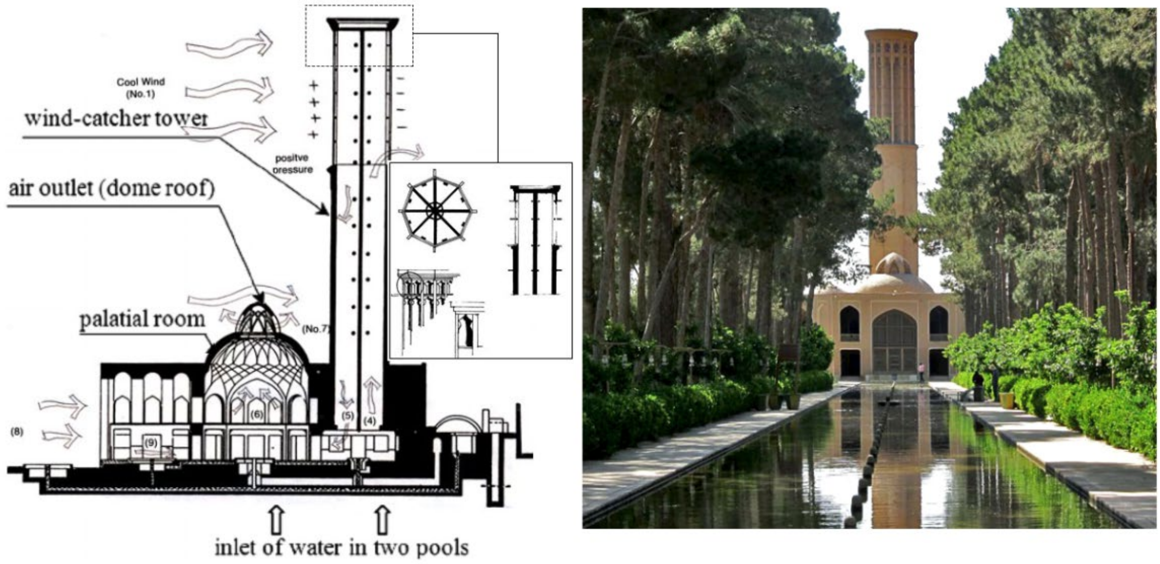

Figure 2-35 - Passive cooling system in Dolat-Abad Garden's palace (Feizabadi, Rezaei, & Raisianzadeh, 2016) (modified).

Aesthetic Aspect

In addition to the location of the palace in the garden, the form of the palace was also important, which was usually in proportion to the situation of the palace in the garden. Palace in the center of the garden usually was built in four-side or octagonal forms, which allows a comprehensive relationship with the garden. Thus, rooms, platforms, and salons were placed on octagonal edges.

Nevertheless, palace located at the top of the garden was generally built in rectangular form. In addition, the most important parts of buildings, such as porch and platforms, were built toward garden for having the best control over the surrounding environment (Wilber, 1994).

Among other factors considered in the design of the palace was the relation of it with the external environment; through platforms and porches around the building. In many gardens, water flows from the garden into the building and comes out from the other side of the building; for instance, in Fin garden in Kashan. Flowers and plants and even images of flowers, plants, and birds, which are exhibited on the walls, play an important role in this regard (Pope & Ackerman, 1964).

On the one hand, the elongation of the main perspective by planting tall trees on both sides of the main axis shows the inner space of gardens wider. On the other hand, the natural slope, which has been used in most Persian gardens, created a great position for locating the palace in the highest point of gardens, and shows the gardens longer. This optical illusion is related to differences between the human perspective at high and low horizons. In this way, palace seems closer to the entrance, and makes viewers encourage going there and passing this distance. Opposite when (especially from upper floors) looking at the garden from the palace, the mentioned distance seems longer and gives more vastness to the garden (Figure 2-36). Therefore, Persian garden creates some **virtual area and vastness of space** in the architectural aspect of landscape (Shahcheraghi, 2013, p. 84).

Figure 2-36 - The vastness of space through the specific design in Shahzadeh Garden (Source: Author).

Transmission from space to another space is always seen and felt in Persian gardens. Basically, one of the most important architectural features in Persian garden is combining building and garden. In fact, it could be said that palace inside of garden is a little garden itself. The presence of the palace does not prevent the flow of visibility into the Persian garden, which passes through the palace and connects with other garden spaces. Additionally, water also could easily flow from the inside of the building to the garden (Figure 2-37).

Figure 2-37 - The continuity of space in Fin Garden, Kashan (Source: Author).

The garden's elements prompt all human senses. These provokers are significantly spread in the garden, which gives connected feelings in every space. Provoking visual sense and a visual relationship between inner space and outside of the palace creates continuity between these two. In addition, passing water from inside the building and flowing in garden space connects both out and inside spaces. Furthermore, transferring sounds from outside to inner space also doubles this feeling, which affirms the creation of continuity of space in the Persian garden. Thus, such a borderless space appears in Persian garden since Iranian designers put no border between their palaces and gardens (Wilber, 1994, p. 103).

Moreover, due to the existence of a big pool in front of the main palace, the building's reflection and seeing both real and virtual pictures of the palace create a vertical relationship of visual sense. In other words, it connects the sky to the earth.

2.4.6 Climatic Considerations in Persian Gardens

While cultural and social conditions of Iran matter a significant part in creating a Persian garden, however, its distinguishing aspect from the examples in other countries (e.g., Japanese, English, and other famous gardens) has been driven from trying to overcome the harsh and difficult climatic conditions to create an elegant, pleasant climatic comfort environment (Ali Alai, 2012; Pope & Ackerman, 1964).

As mentioned in the investigation of each Persian garden's order (ref. section 2.4.5.1, 2.4.5.2, 2.4.5.3, 2.4.5.4, and 2.4.5.5), attention to climatic aspects is an integral part of the design and structure of each of these orders (Figure 2-38). Inside the Iranian garden, a new and different microclimate from the surrounding environment was created, with pleasant and suitable weather conditions like a paradise in the burning desert of Iran.

In brief, the selection of a suitable site and the orientation of the land, based on the prevailing wind direction and sunlight, the optimal use of water, the planting of native trees compatible with the surrounding climate, the proper use of the shading system, and the improvement of air quality by controlling and preventing the garden from the outside warm winds and dust storms and enclosing the garden with walls, provide a suitable and pleasant environment for an ecosystem.

On the other hand, the artificial structures and architecture in the garden, derived from Iran's traditional architecture, paid particular attention to climatic conditions and characteristics. It includes selecting the proper orientation to the sunlight and wind direction, choosing the suitable materials and geometry appropriate to the climate, and cleverly designing the spaces (Memarian, 2008; Taghvaei et al., 2015). In this regard, clever innovations have been born and applied, such as the aforementioned wind-catchers, to provide natural air-conditioning and passive cooling systems with no fossil fuel consumption (Feizabadi et al., 2016).

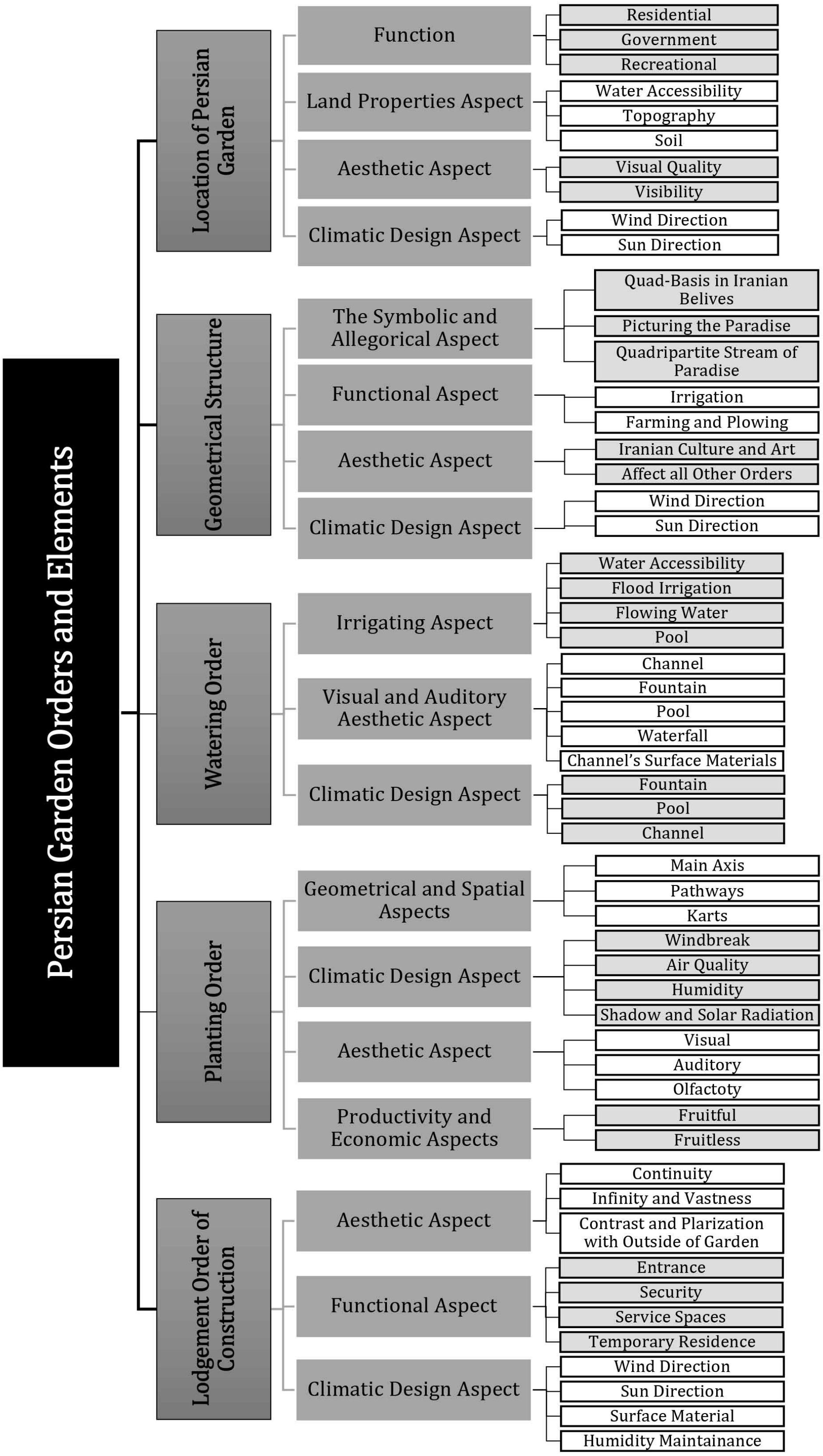

Figure 2-38 - Persian garden orders and elements (Source: Author).

It must be noted, although Persian garden, known as a treasure trove of Iranian art, history, culture, skills, and abilities, has been studied, investigated and reconsidered in recent years, the study and analysis of the methods and techniques used in Persian gardens to provide thermal comfort are essential and beneficial for future designs. Thus, despite valuable efforts and studies conducted in this field, it is still necessary to obtain more detailed analysis and evaluation on each main element of the garden as well as the interaction of these elements as a whole complex.

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Chapter 3: Research Problems, Questions, and Goals

3.1 Importance and Statement of Topic

Climate is one of the most important and significant factors for human survival, which shapes people's lives all over the planet accordingly. Therefore, climate factors play a very vital role in all planning and design in cities to reach the ultimate aim of meeting people's needs in their environment. In the last few decades, climate change has brought up extreme weather, frequent weather disasters, and caused changes in human and natural systems. The UN International Panel on Climate Change special committee (IPCC) in 2018 emphasizes all sorts of global warnings in cities due to climate change.

3.1.1 Adverse Effects of Climate Change on Human Thermal Comfort

A wide range of climate change impacts on cities and their dwellers have been investigated and identified; however, this study focuses on human thermal comfort. In the arid and semi-arid climate of central Iran, climate change will lead to decrease further the humidity and increase air temperature, which negatively affects thermal comfort. Such impacts on thermal comfort have direct and indirect consequences on human health, both physically and mentally.

In Iran, due to modern urbanism, thermal comfort obtains insignificant attention in both urban and landscape design and planning. Since urban public areas such as green spaces are the public places for social and economic activity for urban dwellers, severe thermal conditions directly affect people's outdoor behavior and public participation (Gehl, 2011).

Studies also show an indirect correlation between outdoor microclimate and indoor conditions, with the result that the more severe the outdoor microclimate is, the worse the indoor conditions are (Johansson, 2006b). This is obviously translated into more frequent use of air conditioners, higher energy consumption, higher air pollution, and worse power disruption. These unquestionable signs of climate change impacts in cities call for a paradigm shift in urban planning and landscape design and for immediate action regarding mitigation and adaptation strategies.

3.1.2 Lack of Climate Studies in Landscape Design

Landscape design has become one of the tools to moderate climate change effects in cities. The use of green spaces, as cool green islands, by decreasing the air temperature inside their area and extending this cooling effect to the outside of the green space boundary effectively moderate urban heat islands (Honjo & Takakura, 1990; W. Lin et al., 2015; Spronken-Smith & Oke, 1998). Consequently, it is vital to address climatic Landscape design at different scales to improve all the green spaces that urban dwellers spend their time outdoors.

"*By careful site planning and design, it is possible to create very local climates where people can be screened from the worst extremes of an area's climate. The possibility of manipulating local climate can be used to encourage people to use the outdoor areas associated with buildings*" (Beer & Higgins, 2004, p. 40).

There is a gap in landscape design in Iran due to the modern and the traditional landscape difference. The climatic landscape dimension is absent from contemporary planning and the site design level in Iran. After modernity, particularly in the past 50 years, on the one hand, many gardens, farms, and green spaces in Iranian cities have been destroyed. On the other hand, the vacancy of landscape planning and design field in regional and urban planning and design by relying solely on environmental considerations has led to a lack of awareness, recognition, and use of this field.

Indeed, landscape planning is an important infrastructure tool for protecting and enhancing ecosystems, controlling climate change, and mitigating Iran's severe climate for cities' residents, which is absent in Iran's general planning processes. Despite positive action over the past few years, the landscape has not yet achieved its true status in planning and design, and people believe that the landscape is only for aesthetics and decoration and does not consider its ecological, climatic, and cultural dimensions.

Therefore, it is vital to revive the importance of the role of landscape, and particularly, urban green spaces, for the coming future generation. Moreover, the significance of creating a thermally outdoor comfortable space must be emphasized and highlighted for Iranian researchers, landscape architects, and planners.

3.1.3 The Necessity of Learning from Persian Gardens

As mentioned above, the impact of climate change on human comfort in cities has not been really taken into account in planning and design in Iranian cities due to the lack of interdisciplinary work between urban climatology, architecture, and landscape design. In contrast, the traditional Iranian landscape and architecture have a long history of climate adaptation. Old Central garden, ”Hayat”, Bazar, “Badgir”, “Qanat”, “Chaharbagh” and a variety of Persian gardens all over the country are just the more famous examples of such traditional architecture and landscape. However, as this study focuses on green public spaces, in an attempt to bridge the knowledge of the past into new landscape guidelines, it focuses on Persian gardens.

Moreover, Many Specialists and experts are convinced to award the value of the Persian garden in its efforts to create a climatic comfort zone in the desert, based on Iran's cultural and social criteria, so that this makes the difference between the Persian garden and the specimens in other civilizations (Khansari et al., 2004; Masoudi, 2004; Ojaghlou & Khakzand, 2019; Pirnia, 1994; Taghvaei et al., 2015; Wilber, 1994).

The Persian garden concept is rooted in the long history of traditions, gone through centuries, which had not only been considered for its climatic aspects but also been noticed for aesthetic, social, and cultural characteristics. Therefore, as a comprehensive, sophisticated case in traditional landscaping has been considered and suggested as the topic of research and study for many scholars (Memarian, 2008; Norouzian Pour, Motahari Rad, & Mottaghi Pisheh, 2012; Pirnia, 1992; Pope, 1967; Shahcheraghi, 2013; Taghvaei, 2004). However, although this thesis explores the socio-cultural aspects of this garden, it is mainly focused on climatic and thermal comfort as the main aspect of Persian garden.

3.2 Research Objectives

Due to the harsh dry and hot climate in Iran, which will be harsher in the future based on climate change forecasts, enhancing human thermal comfort in green spaces is of great significance. The main objective of this research is to “Define green strategies for climatic landscape design in contemporary Iranian cities”. In order to do so, this research refers back to traditional ecological landscape principles, which have been applied in Persian gardens. These principles enhance thermal comfort in green spaces in a variety of arid and semi-arid areas in Iranian cities.

This thesis is an attempt to deepen the knowledge about the traditional thermal comfort tools in Persian gardens and update landscape design strategies in contemporary Iranian cities. By investigating and simulating Persian gardens as traditional ecological landscape, it highlights the impact of climatic landscape design strategies on the urban microclimate.

Moreover, it emphasizes the outdoor thermal comfort in the context of the hot and dry climate by testing the extracted result of the Persian garden’s analytical simulations on current Iranian parks. Below are the more detailed goals based on the abovementioned objective:

- Introduction to the historic gardens and recognition of cultural landscape in the modern context
- Preparing the distinguished green strategies of the climatic landscape design for landscape architecture.
- Examining the appropriateness, the structure, principles, and design of Persian garden for contemporary urban green spaces

3.3 Research Questions

This research seeks to answer the following questions, based on the abovementioned aims:

- What are the climatic aspects of Persian garden as traditional Iranian landscaping? And how the Persian gardens adapt to varieties of climate context?
- How the specific orders, factors, and structural elements of Persian garden affect outdoor thermal comfort?
- What green strategies are extracted from Persian garden analyses, which could be applied and suggested for future climatic landscape design in Iran's hot and dry climate?

The guidelines and recommendations extracted from the results of this research can be developed for the climate-conscious design of urban green space in Kashan and other Iranian cities with a similar climate.

3.4 Research Scope and Limitations

This research emphasizes traditional landscape principles in Persian gardens and tries to translate those elements into new landscape guidelines for urban parks in a dry and hot climate in Iran. In order to do so, different Persian gardens from a variety of climates are compared and described. The main focus is on the Persian gardens in a dry and hot climate; however, it does cover other climatic situations such as moderate and humid in a very brief description. However, among all those studied gardens, one of the most famous ones, as UN world heritage sites, Fin garden in Kashan is investigated deeply and is the focus of the analysis by simulation.

Due to time and data collection limitations, a contemporary park in Kashan is chosen with similar area coverage in the same city within the same climate. By using the

ENVI-Met program, for thermal comfort, a comfort index is estimated based on simulated environmental parameters.

This study focuses only on objective thermal comfort and does not include subjective, perceived by pedestrians. The extracted results from the simulations in Kashan as a city in a hot and dry climate provide a reasonable basis for generalization to Iranian cities within the same climate.

The main focus of this research is on green strategies for climatic landscape design inner the green spaces rather than the detailed planning level or comprehensive planning aspects, for instance, the location of urban green spaces within a city.

Simulations and analyses of human thermal comfort are only investigated in the summertime since, on the one hand, due to the presence of deciduous trees in most Persian gardens and their lesser role as providers of shade in winter, and on the other hand, because summers in the study area are generally longer, and winters have a shorter period. Moreover, the forecasts for the future of Iran suggest milder winters and more severe summers.

Furthermore, this research does not seek a comprehensive model of green space design and implementation. This is at the hypothesis level and proposes solutions that have been theoretically successful in optimizing the currently selected parks based on the climate approach.

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Chapter 4: Research Methods and Data

4.1 Research Methodology

The focus of this multidisciplinary research is to study the impact of traditional ecological landscaping on human thermal comfort in arid and semi-arid areas in Iran. It takes Persian garden as traditional landscaping and attempts to extract its climatic principles. To this end, an extensive systematic literature review is done in two main categories. Firstly, the international principles and guidelines on climatic landscape design and thermal comfort are studied. The second part of the literature is allocated to deeply studying the features of Persian garden as a traditional landscape in Iran.

Afterward, a number of most well-known Persian gardens from different regions in Iran are chosen and analyzed to understand the concept, structural orders, geometry, location, watering order, planting order, orientation, and lodgment order of construction, and their climatic behaviors in various climate zones.

After identifying the climatic behaviors and impacts of Persian garden features in a different climate, Fin Garden as representative of all the traditional Persian gardens, is simulated in ENVI-Met software. The aim is to explore the thermal behavior of all these features in one day of a typical summer in the city of Kashan. The result shows a detailed impact of every element in human thermal comfort inside the garden.

Within the same setting, a contemporary park in Kashan has also simulated whit the same climate in the same city and almost equally green coverage and space area as a representative of existing landscape guidelines in action. Comparing the result of the two simulations illustrates the thermal behavior difference between the two mentioned green spaces as representative of traditional and current landscape design.

In the last section, optimal design in the contemporary park based on the traditional landscape features is applied and simulated. To bridge the knowledge of the past into current climatic landscape guidelines, this thesis is concluded with a set of green strategies to enhance the climatic landscape design in Iran.

The research process to answer the research questions is a combination of various methodologies, both qualitative and quantitative, including Literature review, case study Comparison, and Simulations. The empirical research includes ENVI-Met software run, fieldwork, and site visiting and observation.

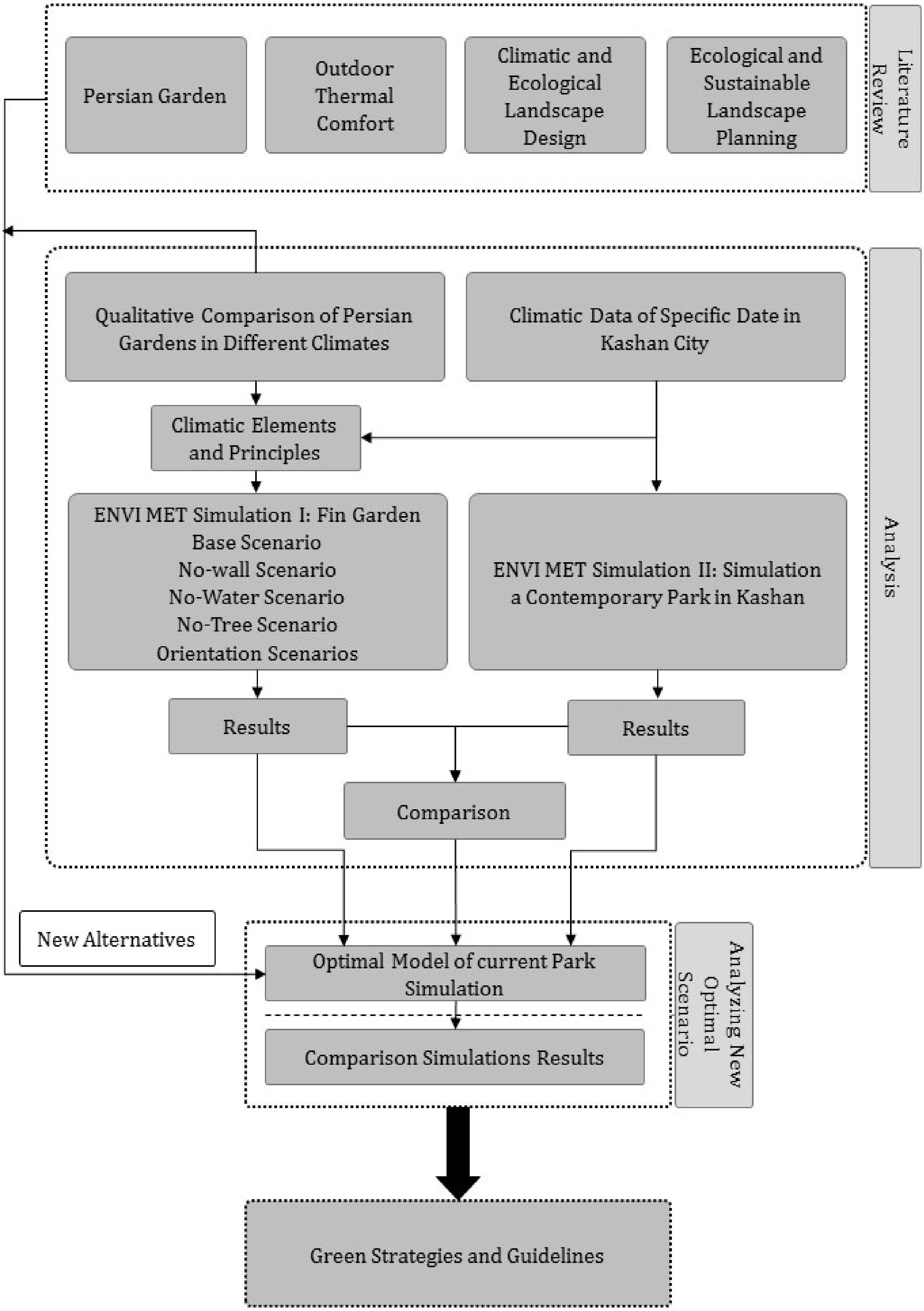

Figure 4-1 - Analysis and Conclusion workflow

4.2 Literature Review and Qualitative Study

The theoretical framework of this research is built on two columns of extensive literature review: first, the principles of climatic landscape design extracted from the literature on issues of urban green open spaces, their cooling effects on mitigating heat islands, urban climate, outdoor thermal comfort, and climatic landscape design. The second fold is mainly on Iranian literature of Persian gardens as traditional ecological landscaping. This section focuses on the Persian garden's principles, historically used in Iran, how they affected climatic landscape design. In addition, a part of the literature review is dedicated to necessary tools, such as research methods and simulation techniques.

To build a systematic literature review, it was a necessity to be selective on a great deal of literature on such a significant subject as climatic and ecological landscape design. To do so, by the assistance of online databases such as websites of web of knowledge, Scopus, ScienceDirect, etc., the validity of sources, their citation, and relevance to this thesis topic were examined. It led to draw focus mainly on official reports such as IPCC publication, UNESCO world heritage center, UN-Habitat, and many more. Moreover, it helped to focus on more reliable scientific publications rather than uncontested, less cited ideas and publications. The main library of TU Dortmund, the library of the faculty of spatial planning, and the inter-library service were to access references, which were not available online.

As for the Iranian traditional landscape principles, there is a vast spectrum of publications available in Persian and a few in English. Persian garden has been the topic of research in landscape design, urban architecture, and planning. However, only a few scholars studied its climatic effects and thermal behavior. Thus, the fieldwork was the main part of the data collection for this thesis to visit and collect information from some existing and still in use Persian gardens. Moreover, during that time to necessary books and articles about Persian gardens were purchased.

Furthermore, comparative and analytical studies between some Persian gardens from a variety of climates came from the fieldwork as part of the qualitative studies. This has led to a list of main common features in the traditional landscape in Iran, including water, plants, palace, material, wall, orientation, geometry, and spatial arrangement. This list, later on, was used in the simulation section to evaluate each of those features' thermal behavior.

4.3 Qualitative and Quantitative Comparison

Since this is a mixed-method thesis, a quantitative and qualitative set of methodologies is applied. In the qualitative part, based on the literature review, a list of guidelines on the issues of sustainable landscape design, ecological landscape design, and climatic landscape design were extracted. Afterward, a section was dedicated to investigating different landscape aspects of Persian garden as the main focus of this thesis, including cultural landscape, sustainable, ecological, and climatic landscape design. This leads to a better understanding of Persian garden importance in future green guidelines for landscape design in Iran.

To compare the different features of Persian gardens in a variety of climates, a number of Persian gardens from different regions in Iran are examined. By these comparisons, the most important and effective elements in Persian gardens in terms of climate adaptation are identified, which are further used in the simulation section.

As for the quantitative methods in this thesis, Fin garden, a contemporary [ark in Kashan and an optimal scenario is simulated in ENVI-Met, Rayman, Excel, Biomet, and LEONARDO programs to examine the thermal behavior of selected Persian garden principles as guidelines for future climatic design in Iran. Below is the description of the simulation process and methods applied in this thesis.

4.4 Urban Climate and Human Thermal Comfort Simulations

The tendency to apply numerical modeling methods has increased in both terms of urban microclimates and outdoor comfort rather than carrying out experimental studies (Ali-Toudert & Mayer, 2007b). As Arnfield (2003) pointed out, in recent decades, the popularity of numerical modeling has been mainly related to the expensive and time-consuming task of measuring all of the relevant meteorological parameters directly with high accuracy.

In this regard, Ali-Toudert and Mayer (2007a) also explained, two significant advantages of carrying out thermal comfort analyses using numerical methods have been identified. First, to highlight the relationship between physical urban structure, microclimate and comfort, numerical modeling is very appropriate. The outcome of these models can, therefore, easily be converted into practical design guidelines. Secondly, since this method is relatively fast and inexpensive, it allows the comparisons of a large number of case studies.

As already mentioned, in this particular case, on the one hand, variations in the climatic situation are moving in the direction of milder and shorter winters and more severe and longer summers. In winter, the minimum temperature will rise as well as the maximum temperature in summer.

Moreover, precipitation will be reduced considerably. As a result, the thermal situation in winter will be more pleasant rather than the current situation. On the other hand, deciduous trees located in most Persian gardens lose their leaves and do not play their role as shade providers in winter. For these reasons, it was considered to concentrate on human thermal comfort in summer.

Furthermore, since people are much easier adapted to the cold in winter, summer thermal stress is a major challenge. Although it can be suggested that taking off clothes in hot conditions is equivalent to wearing more clothes in winter, it is important to be aware that in this specific case, various types of clothing, particularly for women, are culturally unacceptable or can be considered illegal. Therefore, a person could more easily adapt to a cooler outdoor temperature in comparison to warmer environments.

4.4.1 Microclimate Analysis

Model-based simulations were conducted to study the effectiveness of urban interventions on thermal comfort at the pedestrian level. An example environment was modeled in ENVI-Met software. In these models, several scenarios were simulated, and the results in Rayman software were used. This software calculates many environmental indicators such as PMV, SET*, and PET. The physiological equivalent temperature or PET was chosen as the major assessment indicator for this research.

As illustrated before in Table 2-6, the upper limit of human thermal discomfort has been defined as PET=35 °C. In this study, this limit was set as a reference point.

4.4.1.1 ENVI-Met

ENVI-Met is a three-dimensional numerical simulation model for calculating the microclimate and air quality in urban landscapes and open spaces. It is intended to simulate the most important atmospheric processes influencing the microclimate by simulating wind flows, humidity, radiation fluxes, temperature, turbulence, and other parameters, using the laws of thermodynamics and fluid dynamics.

The ENVI-Met system simulates vegetation and buildings of different shapes and heights with a very high spatial and temporal resolution. As a result, microclimates at the pedestrian level are better understood. So that, the effects of the microclimate and air quality on the individual can be calculated. ENVI-Met requires only a few input parameters; however, it is able to perform the calculation of the most important meteorological factors, including the mean radiation temperature as needed for thermal comfort analysis. T_{mrt} , which is essential for the calculation of human heat indices, can also be calculated by ENVI-Met (Bruse, 1999).

In order to investigate a city structure in a model, all structural elements such as buildings, vegetation, or the various surface types must be combined with a rectangular model block. To cover a larger area, the grid sizes should be increased so that the spatial resolution is reduced due to the maximum limit of the total number of grids. Unfortunately, these limitations in resolution result in inaccuracies.

Furthermore, the models' simulations run at a very slow speed due to the high complexity of the processes used in ENVI-Met. Thus the resolution or the size of the area of interest is also limited as well as the calculated duration time (Fröhlich & Matzarakis, 2013).

Most research, especially on the context of outdoor thermal comfort, has been carried out by using and assistance of ENVI-Met software in recent years (Huttner & Bruse, 2009; Ozkeresteci, Crewe, Brazel, & Bruse, 2003; Perini, Chokhachian, Dong, & Auer, 2017; Rosheidat, Hoffman, & Bryan, 2008; Salata, Golasi, Lieto Vollaro, & Lieto Vollaro, 2016; Sodoudi et al., 2018; Y. Wang & Zacharias, 2015; Yahia & Johansson, 2014; W. Yang, Lin, & Li, 2018).

ENVI-Met V.4.0 Preview III was used in this study for calculating the simulations. However, on this platform, complicated and big models need a long time to simulate. In this study, some models lasted up to 16 days to be completed. Moreover, another limitation of this software is the size of the modeling. Due to the dimensions of the case studies and the importance of the accuracy of the calculations to obtain reasonable results, this study focuses more on the thermal comfort conditions inside the garden.

By using ENVI-Met LEONARDO application creation of 2D and 3D graphic-colored maps of the simulation results is possible. It is also possible to present the PET map of site simulation by LEONARDO, which was used in this research. To this end, firstly, the outputs of simulation must be calculated to PET possible by the use of ENVI-Met plugin named BioMet. BioMet is used as a post-processing tool to calculate human thermal comfort indices on the basis of the simulation data. It works directly with the ENVI-Met output, and it enables us to set the personal parameters interactively, the Thermal Comfort Index, and the calculated range (http://www.envi-met.info).

4.4.1.2 RayMan

The RayMan model originated at the Meteorological Institute of the University of Freiburg in Germany. The RayMan model aims to calculate the sunshine duration, radiation flux densities, shadow spaces, and relevant thermophysiological evaluation indices by means of a limited data set of meteorological and other input data. The results of the RayMan model have already been proven by experimental studies. (Matzarakis, Rutz, & Mayer, 2010; Matzarakis, Rutz, Mayer, & others, 2000).

In this study, the T_{mrt} as the final result of ENVI-Met needed in the human energy balance model and consequently in the urban bio-climate assessment is given to Rayman as imported data for the calculation of thermal indices such for each selected location (receptor) as predicted mean tuning (PMV), physiologically equivalent temperature (PET) and standard effective temperature (SET*).

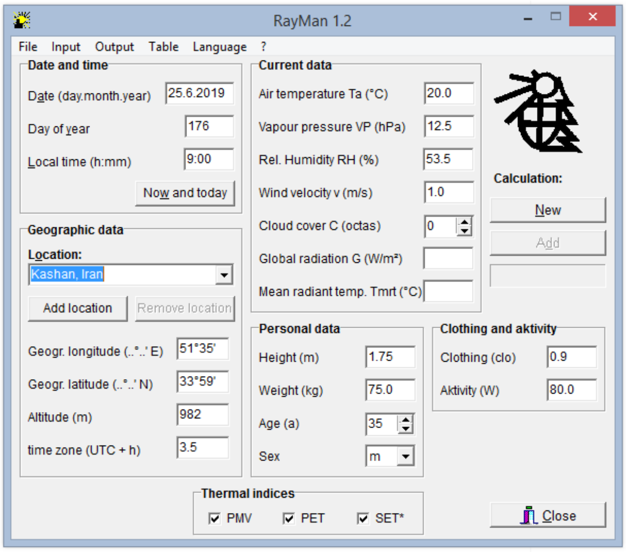

Figure 4-2 - RayMan Main interface

With RayMan, the sunshine duration can be calculated with or without sky view factors; the daily mean, maximum, or total global radiation can be estimated; and shaded areas can be determined. In order to calculate the sky view factors, it is possible to freely draw and output the horizon (natural or artificial). Entering data can be manually done by adding meteorological data or inputting existing files. Graphics and text data formats can be generated as outputs (Matzarakis, 2001; Matzarakis & Rutz, 2005).

4.5 Calibration of Simulation Model

Calibration of the model was necessary to ensure the credibility of the outcome of these model-based simulations. Slight changes must be made to the input values to make the output values a more precise reflection of reality. This required the development of a preliminary model relying on a real site where climate data is available. A 24-hour data collection was carried out at the local office of the Meteorology Department in Kashan. The climatic parameters data were recorded every three hours at a specific location in the city and included temperature, relative humidity, wind speed, and direction (Table 4-1).

Table 4-1 - Recorded climatic data for the preliminary simulation model

Time	Date	Temp (°C)	Relative humidity (%)	Wind speed (m/s)	Wind direction	Pressure (hPa)
00:00	25.06.2015	18.2	18	3	13	845
03:00	25.06.2015	21.6	19	3	8	845.5
06:00	25.06.2015	24.5	18	11	7	844.9
09:00	25.06.2015	28.4	16	8	5	844.3
12:00	25.06.2015	33.9	14	7	5	844.1
15:00	25.06.2015	32.1	17	7	4	844.9
18:00	25.06.2015	27.9	21	3	7	846.3
21:00	25.06.2015	24.9	23	3	8	846
00:00	26.06.2015	21.2	24	2	13	843.9

For the simulation calibration of the study area, in the first place, the same area was modeled by the software and calculated and simulated from 8:00 am for a period of thirteen hours. In this simulation, the observed data is used as input data to the software, and the rest of the unavailable data was set as software default parameters such as moisture of the soil. As a next step, after comparing the results of the preliminary model with the observed real data, it was found that in the model, the relative humidity was much higher than expected.

Consequently, Trial-and-Error is applied to create a new set of input data, which results in acceptable and valid outcomes. In this modeling, these alterations were caused basically by a higher surface level of soil moisture and simulation time steps. As ENVI-Met only requires initial data for calculation and analysis, a calibration must be performed to ensure the conformity and similarity of results and pattern of the modeled environment with the reality of the particular case.

Further relevant information about the practical details of the ENVI-Met models and scenarios applied in this study are elaborated on in chapters six and seven.

4.6 Human Thermal Comfort Indices' Calculations

In this study, as well as the preliminary model, all microclimate simulation models and scenarios were conducted by ENVI-Met for 13 hours, the period when most outdoor activities occur in summer from 8:00 am to 9:00 pm. The results are stored in a set of data files. As discussed earlier, in this study, two different software tools of PET calculations were applied to obtain more comprehensive comparisons of different scenarios' thermal behavior as well as specified locations of each scenario, which are called receptors[14]. Each receptor has the same location in all scenarios of the specific model area. More details about simulations and receptors are elaborated in section 6.2.1.

On the one hand, to compare the thermal behavior of various scenarios, the entire PET differences of site maps were required. These datasets could be provided by using ENVI-Met BioMet for calculation and LEONARDO for the final presentation. The atmosphere data set of scenarios provided by ENVI-Met, with 30 minutes intervals, used as required data for the BioMet calculation of thermal comfort indices such as PMV, PET, and UTCI. By RayMan, the thermal indices of chosen hours are calculated and stored in a new dataset for use in the LEONARDO workplace. LEONARDO has the ability to transfer the PET datasets or datasets of other thermal indices as well as other climatic parameters to 2D graphic-colored maps (Figure 4-3)

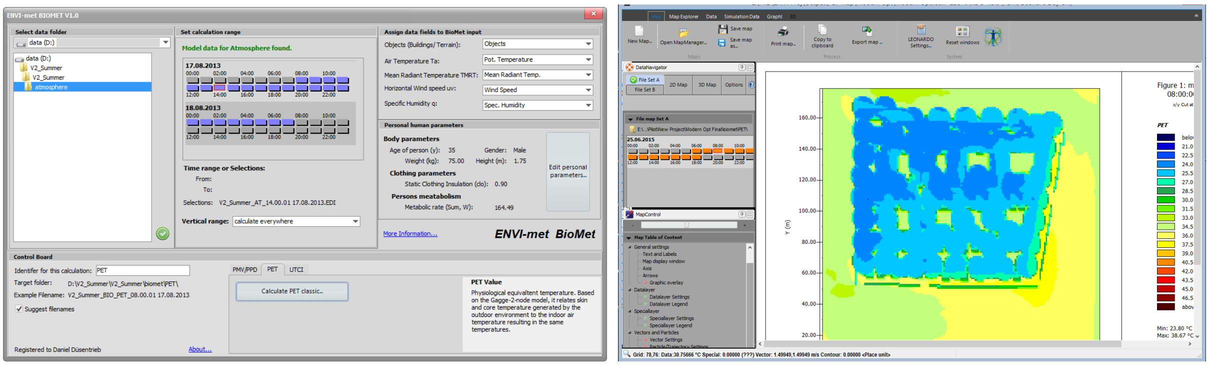

Figure 4-3 - ENVI-Met BioMet Main interface (left) (http://www.envi-met.info) and ENVI-Met LEONARDO working interface (right)

On the other hand, for a more detailed investigation at the specific points selected, based on the different combinations of the investigated elements and their different spatial combinations, at the modeled scenarios, each of the receptors' thermal behaviors has to be calculated by Rayman. The datasets, including time, date, temperature, humidity, wind speed and direction, and T_{mrt}, which are required as input data for RayMan, are already calculated by ENVI-Met for every 30 minutes of stimulation duration.

It should be noticed that RayMan skips the sky view factor calculation since it is already conducted by ENVI-Met with high preciseness. Afterward, to possess the calculated results conducted through RayMan in developed graphs and charts, the outcomes were imported and analyzed in Microsoft Excel, which assists for further investigations.

14 - "Receptors are selected points inside the model area, where processes in the atmosphere and the soil are monitored in detail. For more information about the data stored in the receptor files" Michel Bruse (2009).

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Chapter 5: Results of Case Studies I: Historical Persian Gardens

For the purpose of obtaining a greater knowledge of traditional climate regulating elements, the traditional landscape and urban green structure have to be investigated in more detail. One of the main issues about the role of the Persian garden in the development of the Iranian urban landscape is the evaluation of its spatial and structural design. There is an extraordinary amount of literature in this field, most of which are in Persian.

To this end, in this chapter, firstly, after a review of the climatic conditions in Iran, the role, status, and significance of Persian gardens in the traditional Iranian landscape are investigated. After determining the climatic importance of the garden in Iranian cities and its impact on the public and private landscape, in order to develop the knowledge, the various aspects of the Persian garden are studied.

As it is essential for future design, its ecological aspect and climatic design are investigated and discovered. In addition, comparisons between Persian gardens in different climatic conditions are conducted to learn more about how Persian gardens and their fundamental elements react and respond to their specific conditions.

5.1 Iran, Climate and Landscape History

5.1.1 Relation Between Vegetation Dispersion and Climate in the Plateau of Iran

Iran, with 1,648,195 km^2area, is the 18th largest country in the world. It stretches from the Caspian Sea in the north to the south and lies in the north of the temperate zone, between latitudes 25°03' to 39° 47' North and longitudes 44° 14' to 63° 20' East.

In the climate division of the world, Iran is considered a warm and dry country; however, it has a very variable climate in its different districts due to special geographical and geomorphological features, location of mountains, and seas. Outside slopes of the northern and western mountains are humid and have abundant vegetation and dense forests, while inner slopes are dry and without any plant.

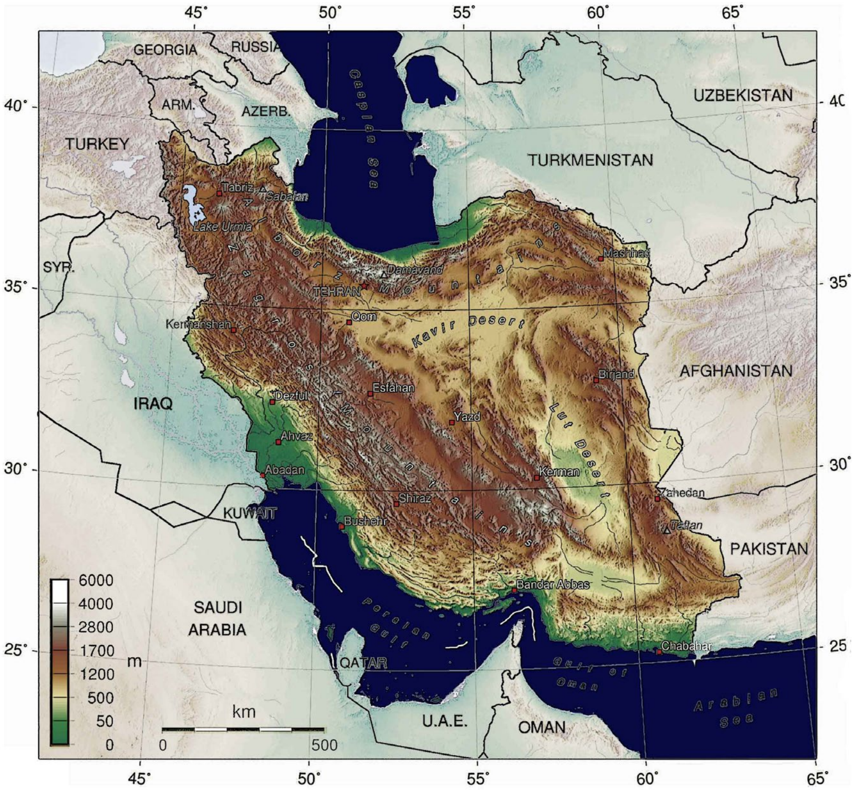

Figure 5-1 - Location and topography of Iran (Benkert, 2017) (modified).

Rainfall in the north and west of Iran is far more than in the south and east. The climate of the north and south coasts is generally different from each other. The climate on the southern coast of the Caspian Sea is rainy, humid, and mild overall (Figure 5-2).

Abundant rainfall in the plain area and beaches in Gilan, Mazandaran, and Golestan provinces (annual average 1000 mm) has developed plains, vegetation, and dense forest-like gardens; in comparison, the shores of the Persian Gulf and Oman Sea have a hot and humid climate with little rainfall, which resulted in sparse vegetation nearby.

A large part of the high plateau is occupied by a dry and arid desert. Central “Kavir” (salt desert) in the center of Iran and “Dasht-e-Lut” in the southeast constitute approximately 2/3 of the plateau, 250000 km^2. Cold parts of Iran cover almost 1/4 of the land. High lands and the areas surrounded by mountains include Kurdistan, Azarbaijan, Khorasan, and Lorestan province.

The original morphology of the Iran plateau and location of northern ranges (Alborz), the western Zagros mountain, ranges of central, beside the eastern mountain in Iran around the internal low land, is the main reason that these mountains not only affect the moderation of climate in central plateau but also, like a high wall, prevent water and moisture of sea from penetrating into the central parts (Figure 5-2).

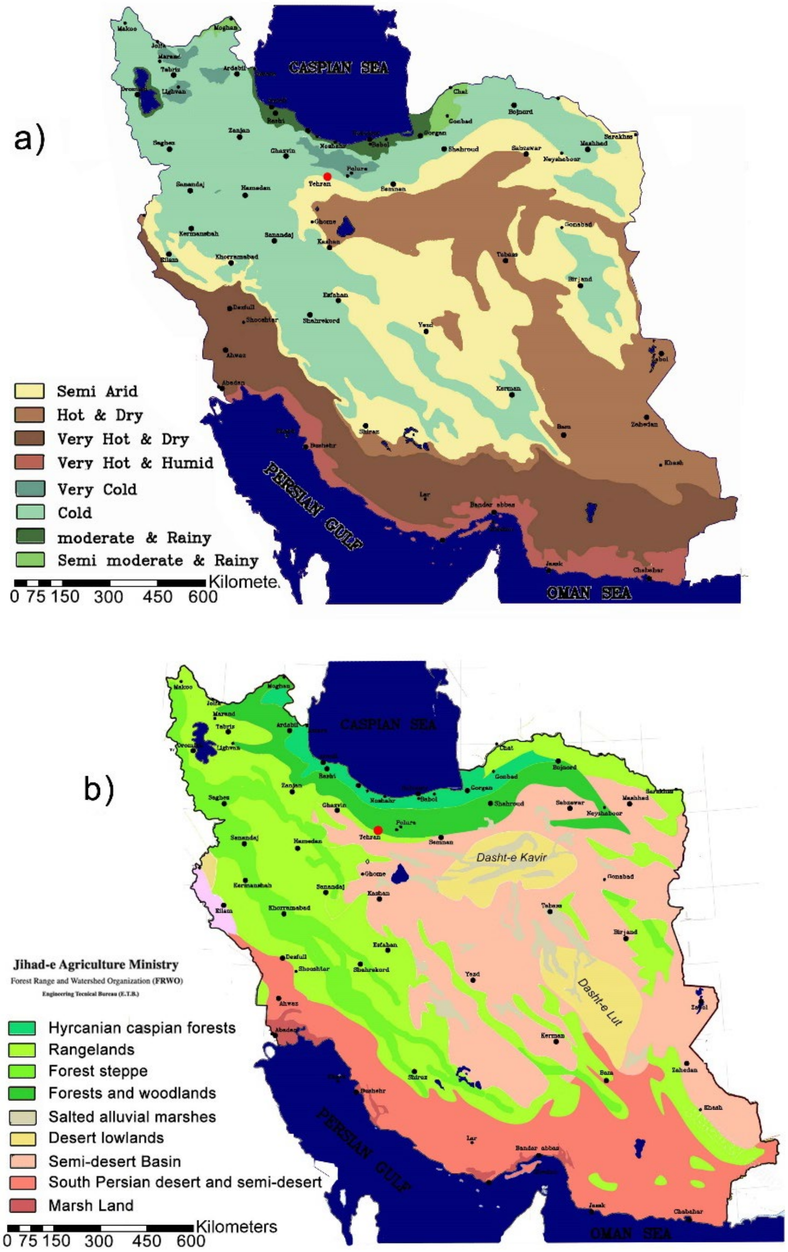

Figure 5-2 - a) Climatic zoning map of Iran (Kasmaei, 1991), b) Vegetation zoning map of Iran Land cover (GEODAD Consulting Engineers Co., 1997).

The amount of rainfall is not enough to feed the central regions. According to the climate features of the inner parts of Iran, which are surrounded by vast desert lands with low rainfall (100 to 200 mm per year) (Figure 5-3-a), there is consequently a lack of vegetation, high temperature in days, and warm season, the extreme cold at nights and cold season and also different temperature between day and night.

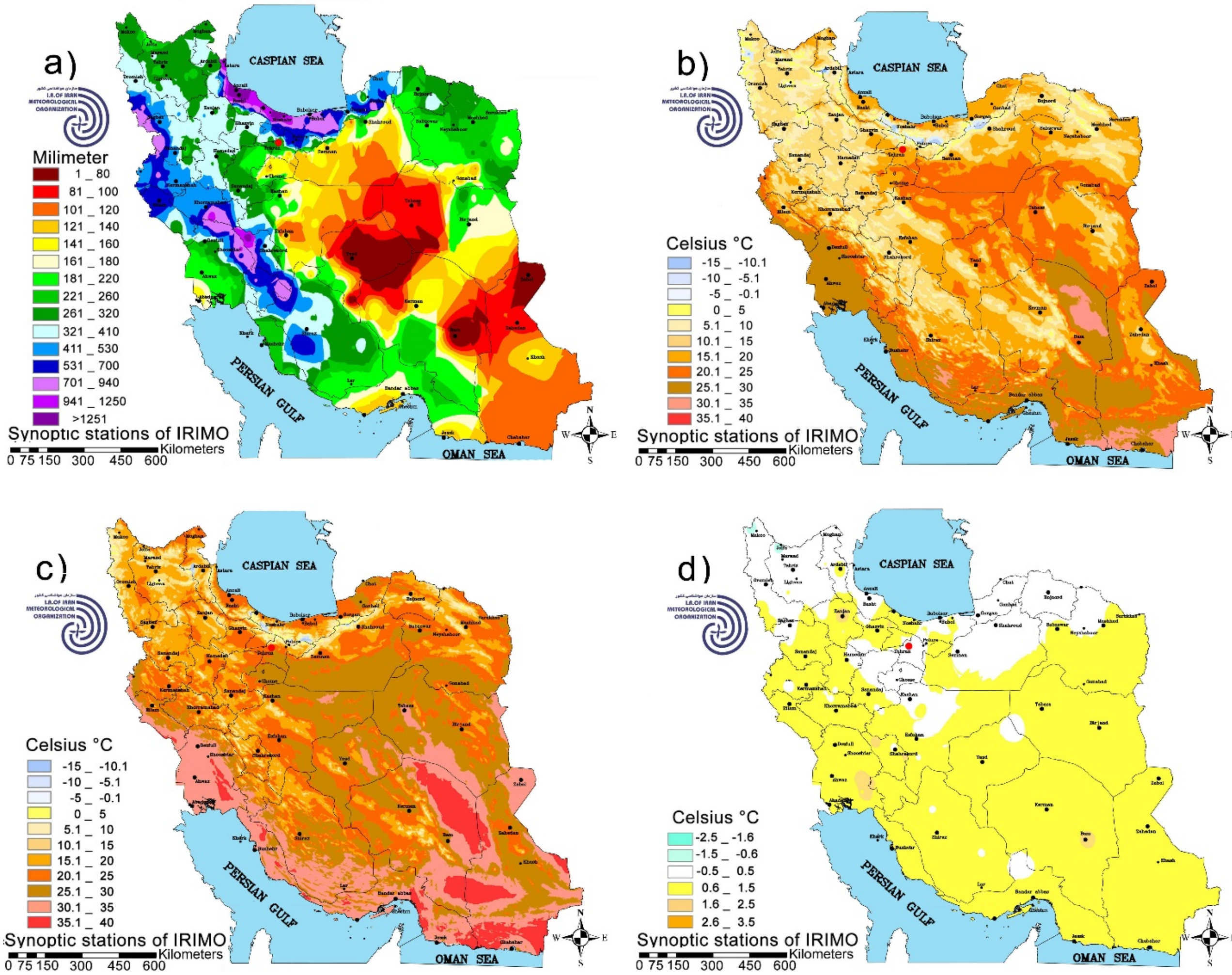

Figure 5-3 - Classification maps of: a) Precipitation from long term average, b) mean annual temperature, c) mean annual maximum temperature, d) The difference in mean annual temperature of 2017 compared with the same period in the long term (I.R. of Iran Meteorological Organization [IRIMO], 2017).

According to Figure 5-3 b, which involves the average temperature of the country, the shores of Oman sea, the Loot desert, and some parts of southern Fars Province, with an average temperature of 30-35 °C, had been the warmest parts of the country. At the same time, some parts of the Alborz and Zagros Mountains had average temperatures below zero °C, and the rest parts of the country have experienced a temperature between 10 to 30 °C. It is considerably noticeable for climatic research that a great part of the country has an annual mean maximum temperature over 25 °C (Figure 5-3 c).

Figure 5-3 d) shows the temperature difference of various parts of the country in comparison to the long-term in the water year 2017. According to this map, almost all regions of the country, during the water year 2017, have been warmer than long-term.

This warm and dry climate in central Iran has directly affected the principles of traditional Iranian architecture, landscape, and urban planning. The most significant climatic features in this region could be listed as follows (Tavassoli, 2003):

- Strong solar radiation
- Excessive heat
- Significant temperature variations during the day (hot days and cold nights)
- Significant temperature differences throughout the year (hot summers and cold winters)
- Low air humidity
- Minimum precipitation and water scarcity
- Dust storm with occasional sandstorm

In order to adapt to these climatic conditions, all the cities, landscapes, and architectural structures have developed during the centuries.

5.1.2 The Recent Climate Change Effects in Iran

According to the analysis of the average annual temperature for the last 33 years collected by the synoptic IRIMO stations (ref. section 2.3), the trend of increasing the average temperature in Iran by an average of half a degree per decade is very concerning (Figure 2-15). Moreover, as mentioned there, for the past nine years, the average annual temperature has been higher than the average temperature. More so, 2010 was the warmest year in the last 35 years in Iran.

Therefore, in the face of the alarming trend of climate change in Iran, which includes rising temperatures in the coming years, along with the current challenging, harsh, and severe climate in Iran, more attention needs to be paid to the climate design of the surrounding environment and urban green spaces. To this end, firstly, as having a great experience and history of Iranian in climatic design, it is necessary to investigate and analyze climatic aspects of Iranian traditional landscape and urbanism.

5.2 Climate Aspects of Iranian Traditional Landscape and Urbanism

The beginning of dwelling in cities and urbanization is one of the most important periods of human history, which was a tremendous transition and huge revolution in its civilizational process. In the Middle East, the city has a history of more than seven thousand years, which appears with the gradual transformation of rural communities (Yousefifar, 2010). In the Middle East, the earliest and most ancient cities are known in Iran. “Tepe Hissar” in Damghan, “Geoy Tepe” in Urmia, “Gian” in Nahavand, and “Shahr-e-Skhookhteh” near Zabol are clear evidence of prehistoric urban settlements in Iran(Diakonoff, 1956, p. 127).

5.2.1 The Significant Aspect of Sustainable Water

Although various factors are involved in the creation of cities such as climatic, economic, religious, political, social, cultural, commercial, logistical, natural and geographical, factors, however, for Iranians, natural and climatic factors have been one of the most significant factors to construct cities. The relation between easy access to sustainable water sources or water supply facilities with the creation of early Iranian settlements and afterward ancient Iranian cities has expressed the significance and value of water as the most important climatic factor (Bonine, 1979).

In addition to the role of water, the continuity of social life in Iranian cities was dependent on the food security strategy. One of the strategic methods was the establishment of the city in the sub-montane areas with fertile arable soil and sufficient accessible water. Cities used the surplus of arable land products in their suburbs and rural products (Kheirabadi, 2000, p. 112).

Living in harsh climatic conditions forced Iranians who live in a hot and dry region to deal with natural problems and find sustainable solutions to create more livable and comfortable cities. Therefore, it has been customary to apply different types of irrigation methods such as "Kariz or Qanat[15]", aqueducts, wells, and so forth. All of these methods show the relentless struggle of residents of these areas to dispel their water needs (Nabavi, 2017).

The oldest and one of the most Authentic books which are written about finding and extracting water in the plateau of Iran is a book named "*Extracting hidden waters*". This book has been compiled by Karaji in 1010 AD. This book shows that finding techniques, extracting, and conducting hidden waters from underground layers through tunnels by gravity, was possible because of advanced Iranian science and their accurate calculations (e.g., the science of trigonometry). Karaji has tried to explain this knowledge as simple way as possible to people living in that period of time. Karaji writes: "*I don't know any other profession which has more profit than extracting hidden waters. Since by its help lands would be growing and developing and lives would be blooming and huge profits would be reachable*" (Khadivjam, 1966, p. 2).

15 - Kariz (Persian: كاريز) (also spelt kareez / karez / kariz and later called qanat in Arabic). Kariz was an ancient water pipe system laid from the source of spring water in the mountain valleys to places where it could be used.

Figure 5-4 - Plan of Kariz located in south Khorasan ("http://www.earth.google.com")

Qanat is known as the most significant Iranian cooperation in world hydraulic science. This is also known as the most important water supplying technique for many centuries in Iran, applying for irrigation and creating gardens in a desert area with semiarid and arid climate (Alemohammad & Gharari). Qanat was the Iranian invention and has been prevalent throughout history in 34 other countries (Behnia, 2000, p. 36).

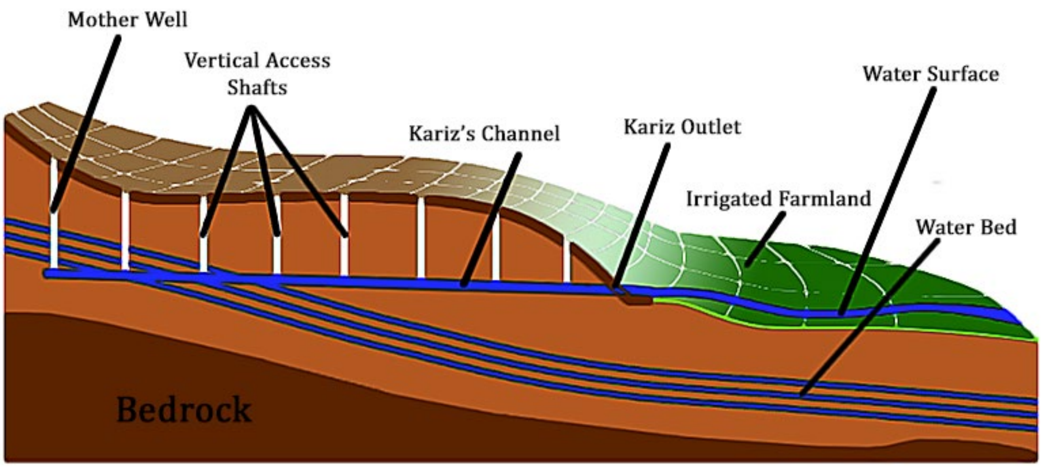

Figure 5-5 - Section of the Kariz aqueduct ("https://de.wikipedia.org/wiki/Qanat")(modified)

5.2.2 Urban Formation and Traditional Landscape Structure

The importance of water resources and fertile soil in the construction and dynamic of urban and rural societies considerably was significant, that its effects on all aspects of urban life were prominently remarkable (Yousefifar, 2010).

The ecological construction and the pattern of the physical development of the urban habitat were mostly in accordance with the local conditions of the natural geography of the areas. They were adjacent to the city and in the direction of **the water flow path**, and the formation of the ancient cities of Iran corresponded to the expansion of the city over the blocks of arable land and **Gardens** (Pour Ahmad, 1992, p. 12).

By growing cities and developing agriculture in Iran, **water, Gardens** and farms, and central architectural core (non-agricultural affair) was identified as three main factors of traditional urban formation for most of the traditional Iranian cities in the semiarid and arid climate. Gradually, the architectural spaces also accommodated the green space (e.g., Hayāt[16]) (Sheybani & Esmaeeldokht, 2016). Therefore, the interaction between water and the central core of the city, which had blocks of green spaces and also surrounded by Gardens and farms, resulted in making a comfortable microclimate in a harsh climate (Sheybani, 2010).

From this perspective, historical cities of Iran were such a dynamic, alive space which were born, developed, prospered in the context of their specific geographical environment and by sustainable interactions of three mentioned factors, make itself sustainable which is not only optimized utilization of nature by Human, but also Has given eternal life in traditional Iranian cities.

In this regard, **Persian gardens** play a key role in the formation of the city structure and the landscape of traditional cities. Indeed, Persian garden was the basis and foundation for the pattern of the whole or part of the city in the past (Abbasalizadeh Rezakolai, Samadi, & Tabatabaian, 2015; Rostami, Lamit, Khoshnava, & Rostami, 2016; Shahcheraghi, 2013; Sheybani & Esmaeeldokht, 2016; Taghvaei, 2011a).

"Proceed evolutions of City palaces and Gardens and the structural relationship between Garden and the city as is which can be named Garden as a city and the city as a garden. On the other hand, garden was regarded as a manufactory of city design" (Mirfendereski, 1996, p. 124). In other words, Persian garden was recreated from the architectural scale up to urban scale "*as antecedents of the city*" (Mirfendereski, 1996).

Thus, In order to obtain a deeper comprehension of the traditional landscape structure of Iranian cities, it is necessary to investigate the different aspects of Persian gardens.

5.3 Persian Garden in Different Approach

The investigation of the Persian garden from different aspects as traditional Iranian landscaping demonstrates not only a better understanding of the Persian garden but also the necessity to explore this valuable treasure in order to preserve and promote its principles for future design.

So far, in the previous sections, the Persian garden has been investigated and studied in detail from the conceptual, structural, and formal aspects. Thus, in this section, other functional and practical aspects of the Persian garden are examined.

16 - Refer to section 5.3.1.3.1

5.3.1 Persian Gardens in Terms of Architectural and Urban Scales

What is known as the Persian garden, has been found in various shapes and forms based on its function. The impacts of Persian garden on ancient Iranian architecture and urban development are quite evident. In fact, Iranian architecture and urbanism are the foundation of the presence of the garden in its own distinctive style, and it creates unique patterns of interconnectedness, intertwining, and unity of the garden (landscape), architecture, and the city. On the one hand, this connection creates structural and formative effects, and on the other hand, establishes the spiritual, conceptual, and psychological aspects, as well as the vital needs of the people.

The impact of the Persian garden and its area of influence can be classified into three scales in terms of functionality; urban scale, local/neighborhood scale, and architectural scale. Gardens have appeared in various shapes and features, which were varied based on their functional varieties.

5.3.1.1 Garden in Urban Scale

In terms of the formation of historical Iranian cities and their growth and development, particular attention has been given to the discussion of garden and landscaping, whether in the structural relationship between the garden and the city or the application of gardens and their main elements.

In this regard, both the gardens and urban structure have been affected by each other, and sometimes even the gardens have formed the structure of the main axes of the city.

5.3.1.1.1 Garden City

Persian garden is the fundamental structure of the whole or part of ancient Iranian cities. The evaluation of ancient Iranian cities has been in such a way that the constructive relation of Persian garden with Iranian cities was very intertwined. So that, it could be named a city as a garden or a garden as a city. However, so far, there is no precise theory as to when the city's garden pattern was the basis of the city's construction, and the cities were built on a garden pattern (Shahcheraghi, 2013).

The great Cyrus has tried to build a capital city with many gardens[17]. Later in the Sasanian era, cities have been built full of gardens. The earliest known examples after the

17 - Mentiond in the report of David Stronach (Scottish archeologist of ancient Iran and Iraq)

Sasanian era are Samarra in the Abbasid caliphate[18]. Samarra has been built based on seasoned city design for a wide range of enclosed spaces approximately 30 km on the eastern side of the Tigris River. This city has been founded from a series of extensive gardens that each of them contained a great palace in the midst of his own. In the Later era, Timur[19] built a ring of royal gardens as his capital around and near Samarkand, but these gardens have not been described in order to define the geometry of the city structure and have a regular communication system (Mirfendereski, 1996).

According to studies, garden city is one of the main Iranian urbanism patterns in the Safavid era, which has taken the logical form. This pattern can be clearly investigated in the establishment or development of the Qazvin and Isfahan garden city. It should be noted that this pattern affects the whole structure and arrangement of the city (Diba & Ansari, 1995).

Isfahan garden city is one of the most accomplished experiences and examples in this context of urban design in Iran about four hundred years ago. So that, a new city has been created among the gardens which were in the vicinity of the old city. Dividing this new city by two main axes hast shaped the city as an enormous "Chaharbagh". During the Safavid era, the development of the city continued by following the same structural relationship between the garden and city. This type of urban design also has been applied to the vicinity gardens of Shiraz, Kashan, Tabas, Qazvin, etc., to make the interconnection between city and gardens (Mirfendereski, 1996).

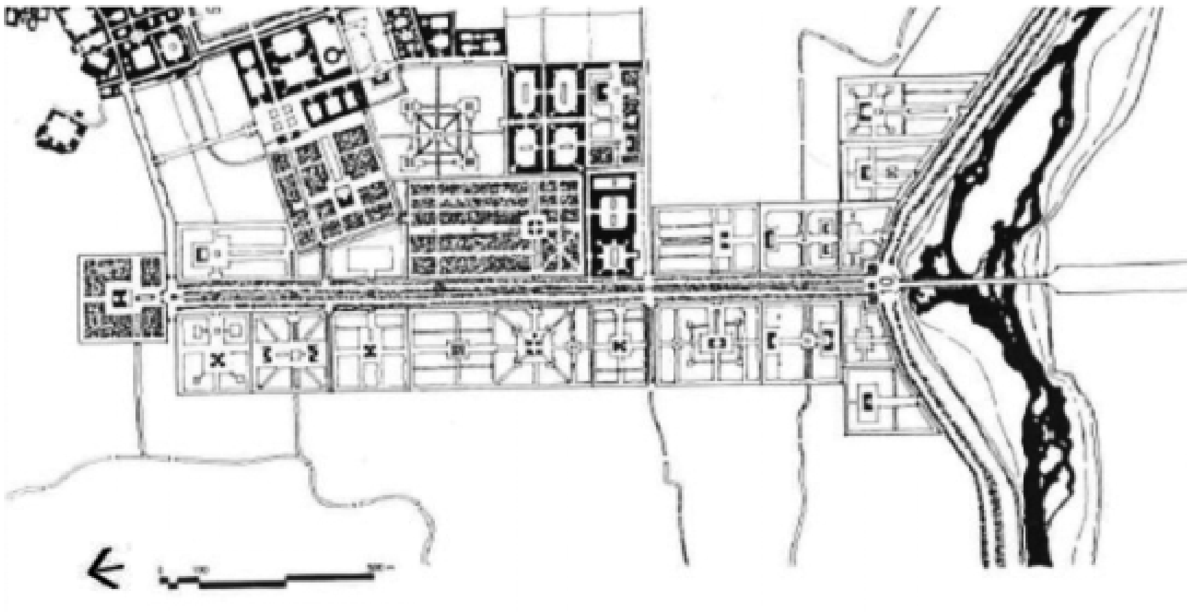

Figure 5-6 - Chaharbagh Isfahan, plan (Wilber, 1994).

18 - The year 750-1258
19 - Timur is the first ruler of the Timurid dynasty in realm of modern-day Iran.

Figure 5-7 - Chaharbagh Isfahan (Source: Author)

It should be mentioned that this concept of Garden City, which is common in modern and western literature and known as Howard's theory[20], is not the notion of Iranian garden city. Unscientific exposure to theory may lead to a fallacy that provides corrupt results and incomplete and inaccurate understandings of the field in subsequent theorizing. However, the meaning of garden city for most of the historical Iranian cities refers to a green naturalized city. Perhaps just Safavid Isfahan city and few similar cities would be almost called Garden city as Howard's definition (Etezadi, 2016).

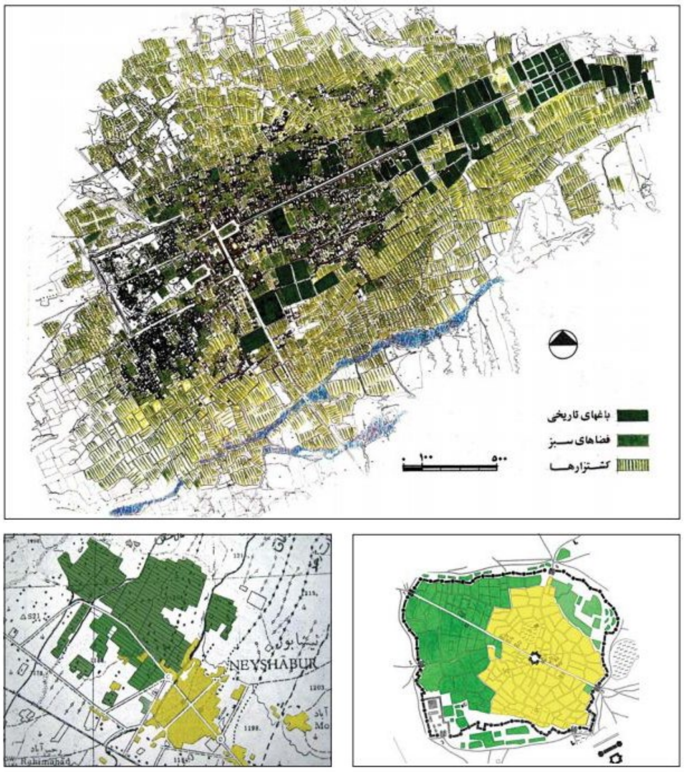

Figure 5-8 - A few cases of natural association of the garden with the city, top image is Tabas city, left is Neishabour, and the right image is Mashhad (Etezadi, 2016).

20 - Garden cities of To-Morrow, Howard and Osborn (2001)

5.3.1.2 Local Scale / Neighborhood Scale

5.3.1.2.1 Persian Gardens

The previous sections (ref. section 2.4.1.3, 2.4.4, and 2.4.5) describe the visual, structural, and semantic features of the Persian garden in detail. Persian gardens were built for a variety of applications, usually around or outside the city. The most important functions of the Iranian garden are residential, governmental, residential integration with the government, and tomb function. Among these Persian gardens, the national gardens and tombs were designed for public usage, and the rest of the gardens were generally used for governmental or private usage.

The amount of available water for irrigation and the garden's function are two important and determining factors of the size and area of the garden. This indicates the high potential for the compatibility of the Persian garden's features and structure in various dimensions (Daneshdoust, 2004). So that, Narenjestan Garden is the smallest Persian garden by approximately 1500 m^2 area, and the greatest Persian gardens according to their size of the area is about 10-11 hectare (Ilgoly garden of Tabriz and Golshan garden of Shiraz). However, they follow the same structure and principles (Shahcheraghi, 2013, p. 63).

The public faction of the Persian gardens has been started in the Safavid era. Since then, all people could be able to enjoy and use the garden space, which could be noted as a start of public parks in Iran. These parks were known as National Gardens. In fact, they were the public promenade in ancient city centers generally used by the public that became common in the Qajar era, for instance, Tehran National garden (Shahcheraghi, 2013, p. 56).

5.3.1.3 Architectural Scale

5.3.1.3.1 Hayat

Iranians have been considering measures in Iranian architecture to modify the climate and to further connect with nature. One of them is the innovation of "Hayat" (courtyard) in Iranian architecture. According to many studies, Hayat, in the past architecture and urbanization of Iran, is one of the main systems, which forms the central structure of all mosques, madrasas, caravansaries, and residential buildings. It dominates all architectural scales and unites the residential building with masque, caravansary, and madrasa through the same visual quality, form, and spatial arrangements and design. Indeed, Hayat is the heart of the building, which organizes all the components of constructions (Soltanzadeh, 2003).

All Iranian courtyards have a square-rectangular shape. In such a harsh environmental condition, the central courtyard has created a secure territory that ensures the comfort of its users, and in the midst of it, a limited nature included fountains, parterre, and trees as its components. Environmental conditions may be one of the determining factors that have led to a stable form of space-based structures over time experiences (Armaghan, Soltanzadeh, & Irani Behbahani, 2014).

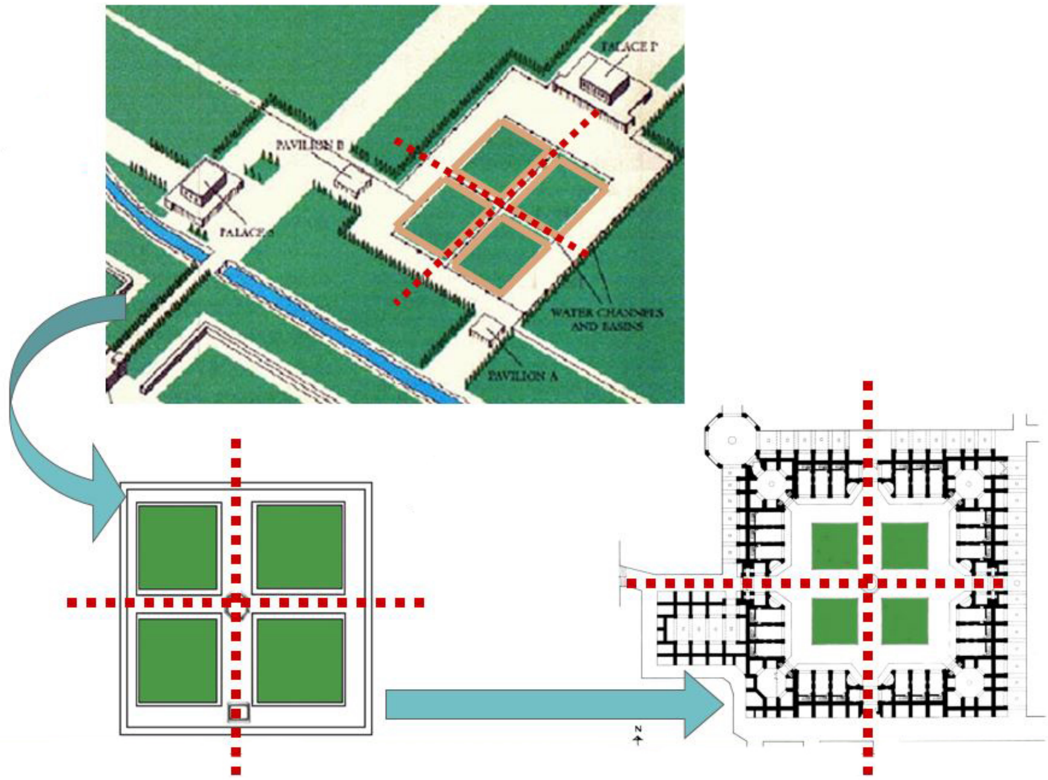

Figure 5-9 - Chaharbagh pattern and its impact on the yard such as caravanserais, schools, and residential houses (Source: Author).

Residential Architecture

The central courtyards are the main space of homes in a hot and dry climate. The "Howz"[21] in the middle of the courtyard, which reaches its maximum size, by absorbing the solar radiation's energy, and cooling the warm winds, supplies cool and fresh air to each residential unit. The courtyards are surrounded by enclosed spaces on all sides, like a cavity, deposit the cool night air, and used it on days. The combination of Parterres, Howzes, and trees, while providing shade and beauty, compensate for the lack of moisture in the environment.

In most cases, the traditional Iranian settlements have an introverted approach to space inside to provide privacy. Moreover, the security and privacy role of the perimeter

21 - In traditional Persian architecturem Howz refers to a centrally located water pool in a garden or Hayat.

wall in Persian gardens, with all their extroverted character from inside, remains the Persian garden as introverted architecture (Brookes, 1987).

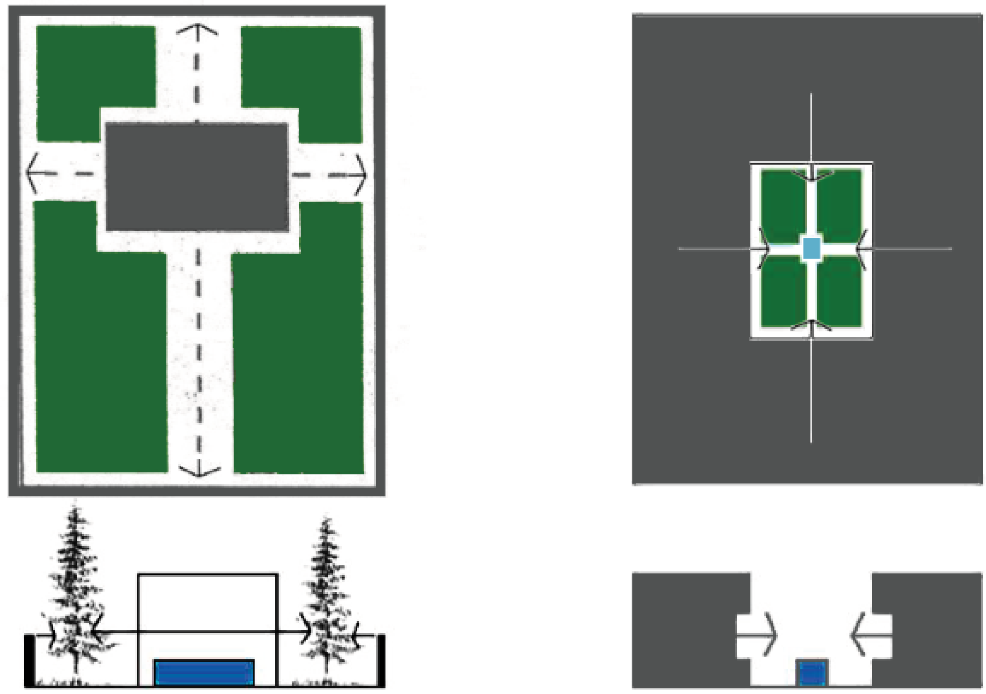

Figure 5-10 - Comparing garden to an introvert traditional Hayat (Mahmoudi Farahani et al., 2016) (modified).

5.3.2 Persian Garden in Terms of Cultural Landscape

As aforementioned in section 2.1.1.7.1, based on UNESCO report (2016), cultural landscapes are cultural characteristics and represent "the whole work of nature and man" over time which are divided into three main classifications, as follows:

I. **Defined landscape**
II. **Evolved landscape**
III. **Associative cultural landscape**:

It also discussed that, in line with the natural qualities of certain cultural landscapes listed in Annex 3(11), IUCN's (International Union for Conservation of Nature and Natural Resources) assessment addresses the following factors:

I. conservation of natural and semi-natural systems and wild fauna and flora species
II. conservation of biological diversity in cultivation systems;
III. Sustainable land use;
IV. Improving the beauty of the landscape;
V. Ex-situ collections;
VI. Excellent examples of interaction between man and nature;
VII. Historically significant discoveries

The world heritage center list is containing three cultural landscape sites in Iran, which are “Bam” and its cultural landscape, **Persian garden**, and cultural landscape of “Maymand”.

5.3.2.1 The Persian Garden as a Cultural Landscape

From the sixth century B.C., Persian gardens have been known with buildings, pavilions, walls, and intelligent irrigation systems. All the way to India and Spain, gardens were influenced by the art of Persian garden’s design principles (Masoudi, 2005). The inspiring and sophisticated use of different fields of knowledge, namely technology, water management and engineering, architecture, agriculture, and botany, makes the design of the Persian garden unique and able to respond to severe climatic conditions. The concept of the Persian garden and its impact can be found in all kinds of Persian art, such as literature, poetry, music, calligraphy, and carpet design (Pirnia, 1994).

Therefore, the Persian garden has been recognized as a cultural landscape candidate at UNESCO. So far, nine Persian gardens, including Pasargad in Marvdasht, Fars, Eram garden in Shiraz, Chehel-Sotoun garden in Isfahan, Fin garden in Kashan, Abbasabad garden in Behshahr, Shahzadeh garden in Mahan (Kerman), Dolatabad in Yazd, Pahlavanipour in Mehriz (Yazd), and Akbariyeh in Birjand, have been registered on the UNESCO World Heritage Sites’ list.

The Persian garden was recognized and registered as a cultural landscape in 2011 by UNESCO. So that, in assessing the criteria of UNESCO's cultural landscape, the Persian garden has met criteria I, II, III, IV, and VI of the total seven criteria as follows (UNESCO World Heritage Centre, 2011):

- **Criterion (I):** Applying intelligent technical solutions, developing advanced water access and water management systems, as well as selecting climate-adapted plant species and their intended arrangement in the Persian garden created a paradise on earth in the desert. In addition to creating a pleasant atmosphere for people, this garden has also become a breeding ground for animal species.
- **Criterion (II):** As an important factor in the exchange of human values, the Persian garden has had an enormous influence on the development of design, geometry, shape, and water management systems for gardens in Western Asia, Arab countries, and even in Europe.
- **Criterion (III):** The Persian garden is unique evidence of the cultural and social developments in Iran and the Middle East over approximately two and half millennia. Persian garden, by accepting and adapting to social and cultural developments, has become one of the main features of Iranian culture, whether in

private residences, gardens, and palaces, or public spaces such as squares, tombs, parks, and city gardens.

- **Criterion (IV):** The Persian garden diffused around the world as a geometric and conceptual prototype of garden design, resulting from the application of natural and human elements and the integration of significant achievements of Persian culture expressed in the physical and symbolic-artistic form that are all harmonized with nature.
- **Criterion (VI):** The Persian garden was engaged continuously with outstanding cultural developments around the world, inspiring them in many areas such as architecture, carpet, and textile design, music, and painting. The Chaharbagh also represents a mythical understanding of the system of nature and the world and the four natural sacred elements, which have been interwoven with religious beliefs

5.3.3 Persian Garden in Terms of Ecological and Sustainable Context

In the previous sections (ref. sections 2.1.4.6 and 2.1.4.7), the ecological and sustainable view of architecture, the principles and guidelines of landscape design, and also in sections 2.4.4 and 2.4.5, the Persian garden and its fundamental elements were reviewed and discussed in detail. Based on these studies, this section investigates the Persian garden from the perspective of ecological sustainability. Since the structure of the Persian garden consists of natural elements (water, plants, etc.) and artificial, human-made elements, it is necessary to examine all its structural dimensions.

The Persian garden is the result of more than two and half millennia of decision-making, continuous design, development, and management of resources and the environment, as well as supporting a living process, accepting and adapting to social and cultural developments without harming the environment, which has made the Persian garden as a successful example and pattern of Iranian landscaping and design.

- **Site selection:**
  - The location of the garden depends on its environmental and climatic conditions. The natural site potentials have been considered, improved, and their values have been protected (Norouzian Pour et al., 2012).
  - The optimal use of natural elements water, wind, soil, sunlight direction, and topography makes part of nature habitable for humans, fauna, and flora with no harm (Ahmadi & Kiashari, 2018; Shahcheraghi, 2009).

    - Although this resulted that the garden seems to be very different from the surrounding nature, which is not intended to conquer nature, but only to be a part of it, and makes it habitable (Mirfendereski, 2004; Pirnia, 1994).
- **Site design:** Of course, as previously mentioned (ref. section 2.4.5.2), the symbolic and allegorical aspects of the formation and geometry of the Persian garden, deriving from Iranian culture and beliefs, became important factors in the succession, popularity, and durability of the Iranian Garden over the centuries. Furthermore, the following factors can be mentioned:
    - On the basis of the type of irrigation and the agricultural usage of the garden, the geometric shape of the garden helps them to be optimized in the best possible way, which has more advantages to manage the water consumption in this harsh climate (Aryanpour, 1986; Diba & Ansari, 1995; Masoudi, 2010; Pirnia, 1994).
    - Furthermore, the gardens' longitudinal plan shapes mostly follow a north-south direction with low angular tolerance to modify the scorching sunlight in the garden area and create the most shade in the garden's main axis, which makes them durable.
- **Water:**
    - **Water access:** The water supply, as the most vital factor in creating gardens in such a hot and dry climate of Iran, has always required the precise application of science and technology and the sensitivity for their optimal utilization. In this regard, the invention of Qanat enabled easy and sustainable access to groundwater, without wasting energy and costs, due to the gradient of the earth and gravity (Behnia, 2000; Nabavi, 2017).
    - **Irrigating aspect:** Many experts consider the square and rectangular plots, which have formed the geometric shape of the garden as the result of the irrigation and cultivation system applied in the Persian garden. They cited this geometric rule as the simplest way to irrigate with the shortest distance to avoid water wastage(Diba & Ansari, 1995; Haghshenas, 2014; Mahdi Nejad, Azemati, Zarghami, Abad, & Sadeghi, 2017; Pirnia, 1994).
    - **Climatic aspect:** The representation of water in a variety of forms; the attempts to make water appear huge, such as waterfalls, fountains, a wide, shallow pool for visual enjoyment, and the use of passive cooling by evaporation; covering the surface of the waterways with sand or ceramic to prevent penetration and wastage into the ground which increases its speed and reduce the evaporation; and also the hiding of water on side paths and water transfer routes; all indicate that the designers made optimum

utilization of the water in the Persian garden (Ansari & Moalemzadeh, 2015; Göker, 2017; Soltanzadeh & Soltanzadeh, 2017).

- **Vegetation:**
    - **Pattern:** The planting system in the Persian garden is a precise and well-thought system, where the location of every plant and tree is determined to ensure that all plants get the sunlight they need, and the garden always looks green and fresh. Furthermore, the combination of trees with different lifespans is very measured, as well as their Irrigation system, which is implemented in the most optimal way (Diba & Ansari, 1995; Khansari et al., 2004; Shahcheraghi, 2013).
    - **Selecting the plants:** The aesthetic aspects have not been the only reason for choosing a plant in the Persian garden. Each tree and plant, based on the place of planting in the garden and the local climatic conditions, have been selected from indigenous and native plants, which also improve and enhance the soil. For example, alfalfa has been used instead of grass in the Mid-Karts, which not only reduced water consumption and had economic benefits, but also repelled insects, attracted nitrogen for soil fertility, and provided livestock fodder in winter (Daneshdoust, 1984; Fadaie Tamijani, 2011; Masoudi, 2004).
    - **Productivity and economic aspect:** Most trees in the Persian garden, in addition to providing beauty, have other benefits, such as scent, medicine, commerce, and food supply for humans or animals. Furthermore, The diversity of plant species applied in the garden also led to greater protection against pests (Akbarzadeh & Adibi, 2014; Fadaie Tamijani, 2011; Pirnia, 1994).
    - **Climatic aspect:** The optimal usage of the shadow characteristic of the trees to reducing heat reflection on the ground surfaces along with special attention to their cultivation place in order to prevent sandstorms and hot winds, decreasing the air dust, improving the air quality, and increasing the air humidity, all this has created a pleasant environment in the heart of the hot and burning desert (Masoudi, 2004; Pirnia, 1994; Shahcheraghi, 2013; Taghvaei et al., 2015).
- **Material:** The materials used in the artificial parts are eco-friendly materials that can be recycled and easily repaired, have high heat capacity, low reflection, and suitable color. These materials were provided at reasonable cost from the local area and mostly include clay, “Kaahgel[22]”, mud-brick and brick, and somewhere

22 - Kaahgel consists of clay and straw mixture suitable for covering building facades and providing moisture insulation on roofs.

stone or cube-stone. In these cases, it has been tried to use them in the shadow area. Other land-coverings are mainly natural materials such as grass, flowers, plants, and water (Fadaie & Parhoodeh, 2017; Fadaie Tamijani, 2011).

- **Ecosystem service:** Persian garden as a unified system due to access to a new water source obtained through Qanat, by increasing the moisture from the evaporation of surface water and leaves transpiration of plants, in addition to preventing hot winds and sandstorms and reducing the air pollution, it reduces the temperature, which provides a good breeding ground for animals, especially birds and insects. Moreover, there are farms under the garden for optimal water use, which help in this process and reduce the rapid erosion by intense winds or rainstorms (Norouzian Pour et al., 2012; Shahcheraghi, 2013).
- **Cultural aspect:** As discussed in the previous section, The Persian garden as a Cultural Landscape, it was clearly explained how the Persian garden was linked to and adapted to the cultural and social developments of Iran over centuries and was known as a model of garden design in the world. All these have been major parts of the continuity, acceptance, and persistence of the Persian garden over the centuries.
- **Human health:** Enhancing different aspects of human life through the production of food, a comfortable climate, and optimal consumption of energy and resources in the Persian garden does not mean ignoring resources. On the contrary, it means choosing the best possible responses to today's issues without causing additional problems.
    - The Persian garden is a multifunctional landscape that tries to meet human needs. It meets the climatic needs, the individual needs such as food, fruit, and medicine, and even the needs of the domestic animals and the garden itself. In other words, this garden is an excellent connection between beauty and need (Abolghasemi, 1997; Pirnia, 1994).
    - The atmosphere of the Persian garden seeks to create human mental health by experiencing the interior space, the feeling of enclosure, and subsequently strengthening the feeling of security through the activation of the five senses in a beautiful environment with fresh and clean air. In addition to its physical systems, the Persian garden has semantic systems that directly impact human mental health (Akbarzadeh & Adibi, 2014).
    - For Iranians, the garden is known as a place for social relations. Indeed, the garden is not a place where Iranians just want to have fun and visit, but a place to sit and talk with friends, and a place of music, philosophy, and entertainment (Stronach, 1978, p. 52).

- **Economic consideration:**
  - No evidence has been found in the Persian garden that species were planted only for decoration, while other factors such as scent, medicinal properties, and food preparation for humans or animals were also taken into account for this purpose. In fact, considering economic policy and the use of products as one of the main reasons for the development of gardens (Heydarnattaj & Mansouri, 2009; Khalilnezhad, 2016) makes gardens a source for society to achieve self-sufficiency (Naghizadeh, Mohammad, 2013). Consequently, for this economic benefit concept, productive trees and plants have been noticed (Motedayen, 2010).
  - In addition, the use of natural and indigenous resources and materials, the application of renewable and green energy, and the minimal consumption of non-renewable natural resources reduce and optimize costs in production and maintenance (Fadaie Tamijani, 2011; Norouzian Pour et al., 2012).
- **Climatic design:**
  - A new microclimate has been created behind the walls of the Persian garden with the aim of providing an environment with pleasant and suitable atmospheric conditions. This new microclimate has been able to bring a paradise to the heart of the burning desert (Pirnia, 1994). By continuing the water flow, growing vigorous trees, extending the shadows, improving air quality, controlling and preventing strong and warm winds, and enclosing the garden with walls, a suitable environment has been established to protect the water from evaporation and moisture loss in a deserted region. This place shows the hidden power of the environmental region, and it brings new lives to a useful ecosystem (Irani Behbahani & Soltani, 2003; Taghvaei et al., 2015).
  - In the artificial and architectural structures of the garden, which have been derived from the traditional and sustainable urban and architecture of Iran, special attention has been paid to climatic conditions and characteristics. These measures include choosing the proper orientation to sunlight and wind direction, selecting the right materials and geometry which are appropriate to the climate, and intelligent design of spaces. For instance, Small and large wind-catchers are among the Iranian architectural symbols that work as natural air conditioning systems. So that, Hot unrefined air is converted into cold and refined air by passing through the water and transferring air into the residential spaces (Memarian, 2008; Shabestari & Maleki; Tavassoli, 2003).

As mentioned before, the difference between the Persian garden and the examples in other civilizations is that the Persian garden is an appropriate response to its harsh and difficult climatic conditions. Although the cultural and social conditions also play an important role in this respect, however, the researchers believe that the reason for the comparative value of the Persian garden derives from the attempt to create a climatic comfort zone, which is based on the cultural and social criteria of Iran (Khansari et al., 2004; Masoudi, 2004; Memarian, 2008; Pirnia, 1994; Shahcheraghi, 2013; Taghvaei et al., 2015; Wilber, 1994).

Although the Persian garden is a treasure trove of Iranian art, history, culture, and skills and abilities that should be analyzed as an integrated set, the study of the methods and techniques applied in the Persian gardens for providing thermal comfort in such a harsh climatic situation can also be useful for future designs.

5.4 Persian Garden as a Traditional Response to Climate

In order to understand the climatic behavior of the Persian garden complex in each region, some of the most famous Persian gardens from different climatic parts of Iran are selected, compared, and analyzed with the aim of understanding how they adapt to their specific climate and how each basic element behaves.

It should be noted that, due to locating the larger area of Iran in the hot and dry region (75%) and the importance of the garden in these areas compared to other climatic zones, most of the existing, valid, and unique specimens of Persian gardens have been located in the hot and dry region.

However, for this purpose, Persian gardens have been selected from the three main climates of Iran, which include hot and dry climate, cold and dry climate, and moderate climate. So that, gardens of Fin (Kashan), Chehelston and Hasht-Behesht garden (Isfahan), Shahzadeh (Kerman-Mahan), and Dolat-Abad (Yazd) from Hot and Dry Climate; Gardens of El-Goli (Tabriz) and Fath-Abad (Tabriz) from cold and dry climate; and the set of garden series of the Behshahr and Abbas-Abad from the moderate climate are chosen for climatic analytical comparison.

5.4.1 Analytical Investigation of Persian Gardens Elements on Different Climates

According to studies and reviews conducted in previous sections, at this stage, the climatic behavior of main orders and elements of the Persian garden in different climates are compared to examine and understand how they try to adapt to their local climates and how are their changes in their behavior in each climate.

5.4.1.1 Location of Persian Garden

As a general rule, the climatic factors and the natural environment conditions are the main factors for determining the location of the Persian garden. The comparison of gardens in different climates also emphasizes that in all garden the water access, as the main and most important factor, and then fertile soil, land slope, visibility, and the climatic factors of proper wind and sunlight direction are the most important factors in this context (also ref. section 2.4.5.1).

As a point, it should be noted that, in moderate climates, the right topography in terms of having a greater view of the region and the sea, as well as the higher positioning of the building to enjoy the sea breeze and the air current, are essential points in the choice of the location of the garden, which is more important compared to other climates (Figure 2-24).

5.4.1.2 Water Order:

In Iran, where its two-thirds is covered by hot and dry areas, water supply, water extraction, water pipe, water splitting, and water consumption must be considered with accuracy, sensitivity, besides using unique science and technology. Regarding the high value of water, it has been attempted to use and exhibit all its aspects and characteristics as well as its climatic aspect inside the garden. The right application of the water existence all over the garden (in different forms of pools, fountains, streams, etc.), as well as the shade of the trees and breeze, resulted in the increase in air humidity, the reduction of the air temperature, and improving the air quality and thermal comfort (ref. section 2.4.5.3).

Hot and dry climate zone:

- Due to the lack of water in this area, most gardens access their required water through historical Qanats.
- Water is displayed in most pathways, and besides irrigation applications, water is also applied for cooling purposes and freshening the air.
- In all Persian gardens, due to the high value of water, it has always been attempted to exaggerate the volume of water and to present all visual and auditory beauty

aspects and cooling effect of water in the best possible way, spatially in this climate zone.

- To this end, in this climate zone, large pools with shallow depth have been applied. Thus, Increasing the area of water surfaces in contact with air resulted in increasing the air humidity and making the ambient air cool and fresh. Additionally, increasing the width of the water paths inside the garden and using fountains and waterfalls along the pathway would also help to reduce the garden temperature.
- Moreover, as a consequence of water shortages in the region, these pools have also been designed and used as a source of irrigation management.

Figure 5-11 - Decrease the height of water level and increase the water surface not only to present a more extensive water surface but also increase the evaporation and air humidity, in Dolat Abad garden, Yazd (Source: Author)

Cold and dry climate zone:

- Rivers and permanent water springs usually provide the water required for gardens in this area.
- The desire to show the abundance and beauty of water and to respect its value in this climate can also be observed. So that in designing the gardens of this climate, large and deep pools are applied. For example, the depth of El-Goli's pools was up to 12 meters.
- Of course, these apparent characteristics are also considered in terms of their climatic conditions, which firstly increases humidity and consequently reduces the air temperature in summer and secondly prevents water from freezing in winter.
- On the other hand, by enlarging the size of the pool, which saves more water, water consumption for agriculture is easier to control, and the irrigation rate can be raised and improved.

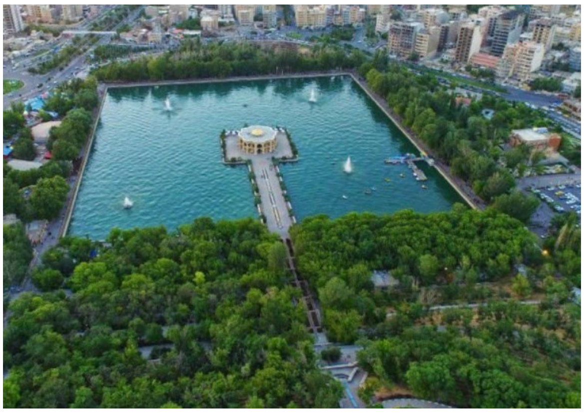

Figure 5-12 - The left image shows the amount of water surface in the El-Goli garden of Tabriz (Source: https://www.karnaval.ir/) and the right image shows the capacity of a huge volume of water in this garden (Source: Archives of ICHTO) (modified).

Moderate climate zone:

- The water required for gardens in this climate is supplied from permanent springs, rivers, or lakes.
- Despite the high level of precipitation and relative humidity, yet the water remains the fundamental and archetypal element of the garden's design and has tried to demonstrate its great values and beauty. So that, emphasizing the presence of water and its visual and auditory beauty aspects in the garden was more considered than its climatic aspects.
- Unlike other climates, there were not many techniques to circulate water in the garden; and also, not many unique features, which are applied particularly for this climate zone, could be counted.
- The need for less irrigation of the plants in this climatic area, besides the abundance of water resources, has caused the water in the garden to play a more decorative role, and its visual and auditory aspects have received more attention.

5.4.1.3 Planting Order:

As mentioned before, an appropriate response to both the specific climatic and geographical situation of Iran, provided by the plant order of the Persian garden, gives the Persian garden a unique character (ref. section2.4.5.4). Achieving this would not have been possible without the right choice of plant species adapted to the climate, without special attention to shading, as well as to the visual and biological characteristics of the plants, and without the correct spatial management of the planting system.

Hot and dry climate zone:

- Shading system, in this climate, is one of the most effective parts of providing thermal comfort in Persian gardens. By applying high and shady trees in linear and dense form along the main axis, pathways, and access routes, it is guaranteed to provide shade during the day in these areas. And sometimes, a corridor covered with crowns of trees was created through the compaction and specific arrangement of the planted trees.

- The trees planted in this area (e.g., Cypress, Pine, Ash, Elm, Jujube, etc.) have been selected from indigenous plants, which adapt completely to this climatic condition.
- A particular combination of deciduous and evergreen plants in the paths of the Persian garden not only keeps the garden green all year round but also in winter when the leaves of the deciduous trees fall and provide less shade, it is easier to absorb the solar radiation directly and indirectly via the ground surfaces, thus reducing the intensity of the coldness.
- Due to the desert location of the Persian garden and the strong dusty winds in this region, large and broad-leaved trees were planted along the perimeter walls (e.g., white poplar, platanus, ash, Persian olive, and sometimes combined with jujube, Persian olive, pine, and cypress). In this way, firstly, the dust in the air was reduced by controlling and filtering the strong winds (windbreak). Secondly, the humidity was increased, and the air temperature inside the garden was lowered. Thereby improving the quality of the air would be occurred inside the garden.

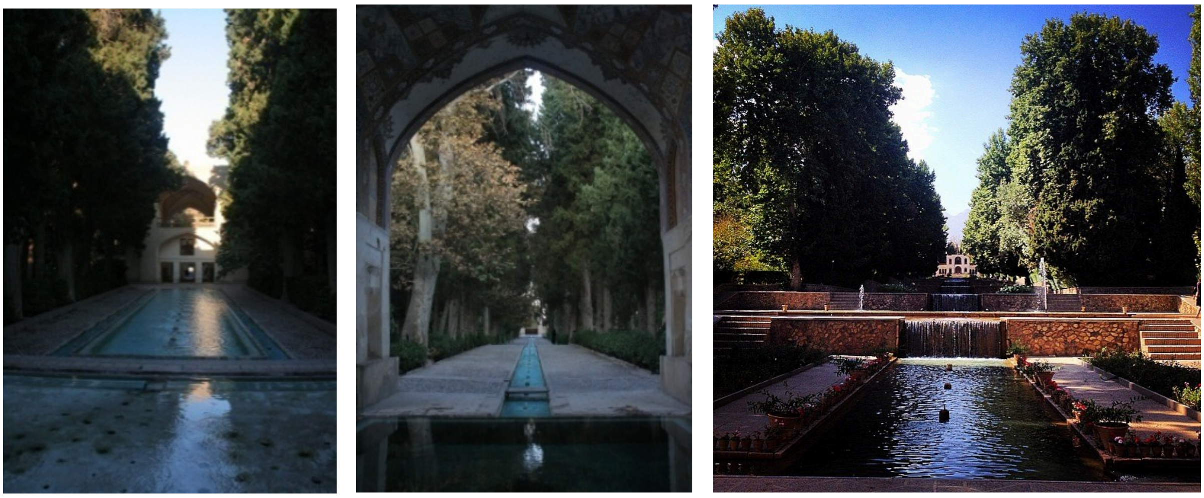

Figure 5-13 - Fin garden in Kashan (left and middle) and Shahzadeh garden in Kerman (right) (Source: Author)

Cold and dry climate zone:

- Due to the less hot weather in summer in this area compared to the hot and dry area, the shading system of the trees with less shade in summer and more solar radiation absorption in winter has been considered.
- As a result, lower shading is provided along the main axis; trees are planted with more distance; the width of the pathways became wider; and also, the number of applied evergreen trees is reduced.

- Selected trees and plants are still suitable for this climate, therefore, instead of cypresses and palm trees, trees of spruce and poplar with conical crowns have mostly been planted.
- The plants along the main axis are usually tall and have a conical crown.
- High and compact trees around the garden in this area, mostly planted to define the garden boundary.

Figure 5-14 - Absence of evergreen trees in El-Goli garden (left) and absence of shade trees at the end of the main axis of the garden in this garden (right) (source: https://tripyar.com/)

Moderate climate zone:

- In this region, due to the high relative air humidity, and the decrease in the intensity of sunlight, to create thermal comfort, the role of using natural wind is much more prominent than in other climatic regions, and the intelligent use of suitable shade and wind is obvious. Thus, trees are planted in the distance from each other in order to let the air circulation make the garden's atmosphere fresh and pleasant.
- Compared to hot and dry climates, side trees around the garden play a greater role in the determination of the garden area. Moreover, these trees are planted at a greater distance from each other to allow the wind to inter (unlike the hot and dry climate).
- In this area, due to the proper climatic conditions, it is possible to plant different species. Thus, most of the common plants have been planted in these gardens.

5.4.1.4 Geometrical Structure

In section 2.4.5.2, in the case of the geometrical structure of the Persian garden, it has been mentioned that the elongation of the gardens' main axis mostly lies in the north-south, or in some cases, east-west directions with slight angle tolerance.

The orientation of the main axis of the garden can be examined from two points of view. One is the general orientation of the garden plan in relation to climatic factors since the main axis determines the shape orientation of the garden's plan. And the other one relates to the arrangement of the trees and the dimensions of the pavement in the main axis, which is the most important and most widely used space in the garden.

5.4.1.4.1 Land Proportions and Orientation

Hot and dry climate zone:

- Gardens are often in rectangular form.
- The main axis of gardens is usually from north to south or East to West because
- A slight rotation along the main axis was made based on the dominant and prevailing winds of the local region.
- In this climate, the width of the pathway is directly proportionate to the shading zone provided by the trees (use the most shadows zone of trees). So that, the larger the shade, the wider the pathway. However, where a wider axis is required for more visibility, the space in between is filled with the waterway or flowerbed.

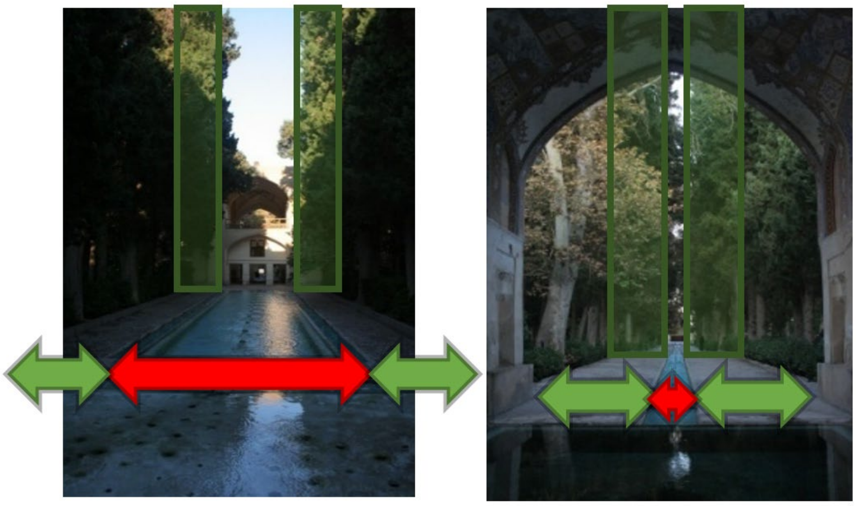

Figure 5-15 - Design of pathways and the proportion of shading in Fin garden in Kashan (Source: Author)

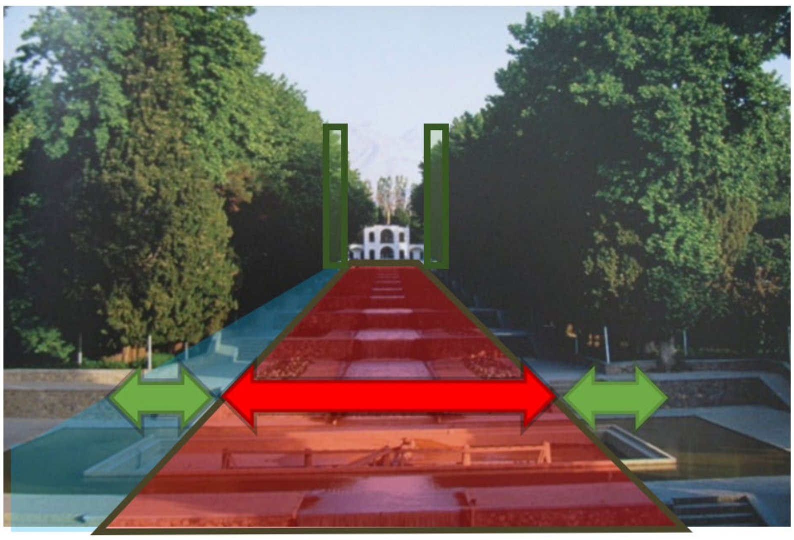

Figure 5-16 - Design of pathways and the proportion of shading in Shahzadeh Mahan garden in Kerman (Source: Author)

Cold and dry climate zone:

- Gardens in this are mostly in rectangular or square form.
- The main axis of gardens is usually from north to south because of the sun rising and setting (in the east and west) and to use proper sunlight and shadow.
- A slight rotation along the north-south axis was made based on the dominant and prevailing winds of the local region.
- In the area, the width of the pathways is mostly wider, and the height of the trees is shorter. Also, they have been planted with more distances to use more solar energy, particularly in winters.

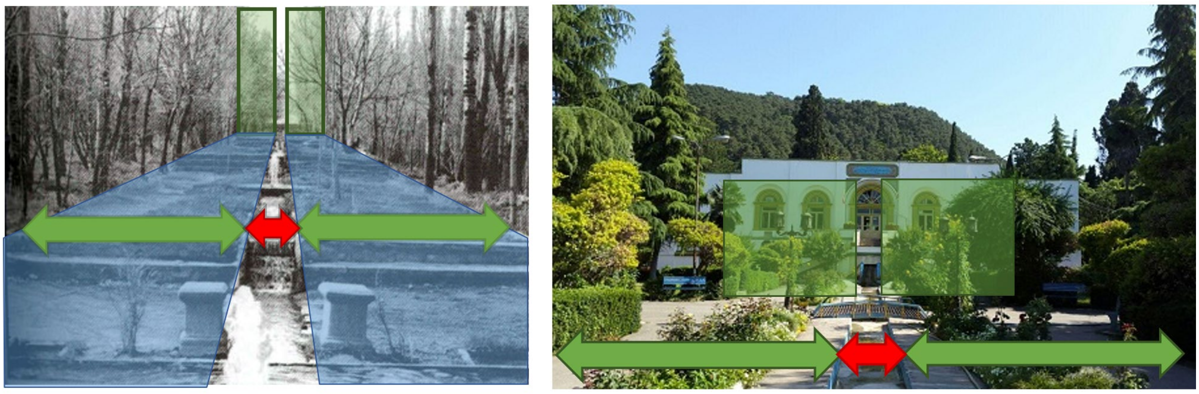

Figure 5-17 - Design of pathways and the proportion of shading in Fath Abad garden located in cold and dry climate (left), in comparison with Behshahr Garden located in moderate climate (right) (Source: Author)

Moderate climate zone:

- In this climate, gardens were often in rectangular form; but were built on distinguished and high places with a wide view.
- Elongation of the garden follows topography, the best view of the sea, and wind direction.
- The effect of the angle and direction of sunlight and the creation of shadow in this climate area is less than in the other climates.
- In the area, the width of the pathways is mostly wider, and the height of the trees is shorter. Thus, the wind can more easily enter and penetrate inside the garden and the palace. In this term, trees have also been planted with more distances.

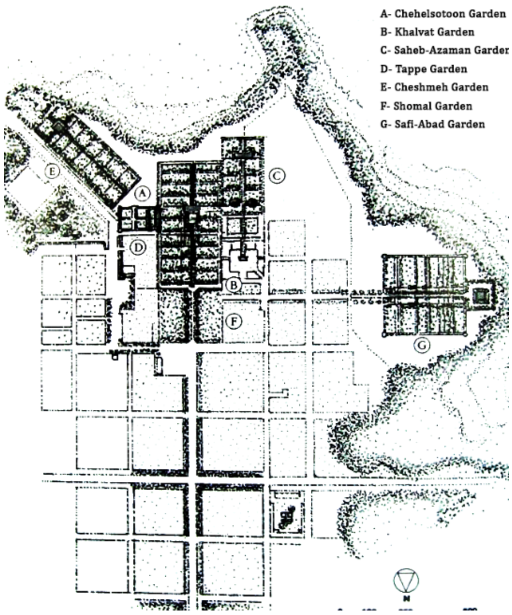

Figure 5-18 - The orientations of Ashraf gardens' complex in Behshahr based on their topography and land-slop. The Caspian see also is located the north of gardens (Source: Archives of ICHTO)

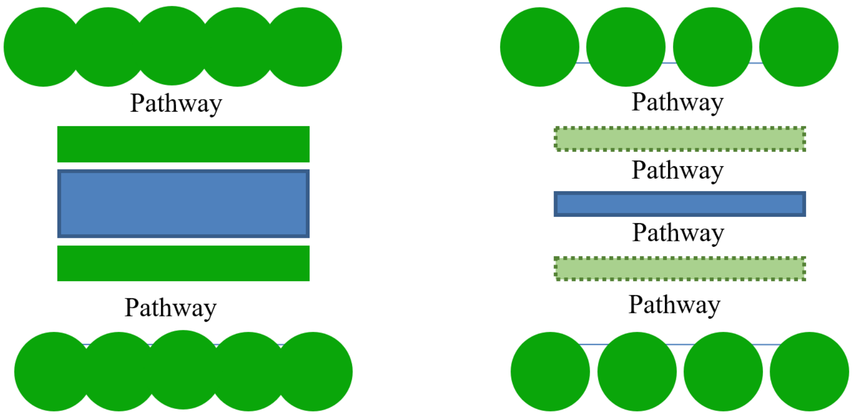

Figure 5-19 - Schematic diagram of the density of planting trees and the width of the pathways in the Persian garden. Hot and dry climate (left) vs. Cold and dry, and Moderate and humid climate (right) (Source: Author)

5.4.1.5 Lodgment Order of Constructions

In the Persian garden, as previously mentioned, the lodgment order of constructions arranges all architectural constructions and artificial elements. This order not only forms architectural constructions but also determines their location and unifies all orders of the Persian garden. Persian garden architectural constructions consist of the palace and the enclosure wall as the most common and well-known parts.

5.4.1.5.1 Palace

Hot and dry climate zone:

- The location of the palace is always perpendicular to the main axis.
- In hot and dry climate, the location of palaces in the garden could be categorized into three types:

- Middle of garden
- In 1/3 from the end of the garden
- End of garden

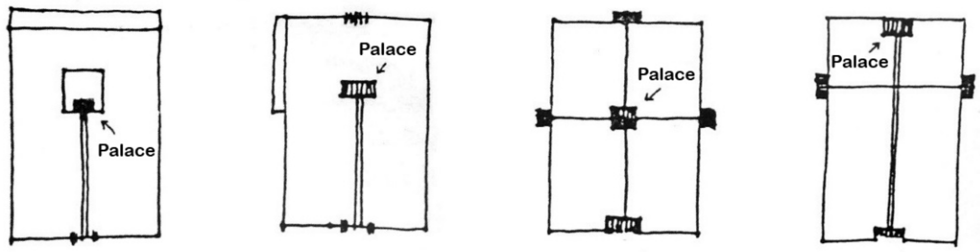

Figure 5-20 - Location of palace in Persian garden (Source: (Pirnia, 1994))

- As the weather moderated inside the gardens, palaces have often been extrovert, and they did not follow any particular form.
- In this climate, palaces have usually been built on two floors; and the number of openings was more than common local buildings to increase the connection inside and outside the Palace and to improve the space fluidity.
- Use of porch in the southern body of the building
- Cooling the inside temperature of the buildings by using the smart passive cooling system, like “Badgir” (windcatcher)

Figure 5-21 - Use of porch in the southern body of the building, Hasht-Behesht garden (right) and Chehelsotoon Garden (left) in Isfahan (Source: Author)

Cold and dry climate zone:

- In this climate, palaces are mostly located at 1/3 end of the main axis.
- In this climate, palaces were usually built on two floors; and the number of its opening was too lower than other regions because of the cold weather, especially in winters.

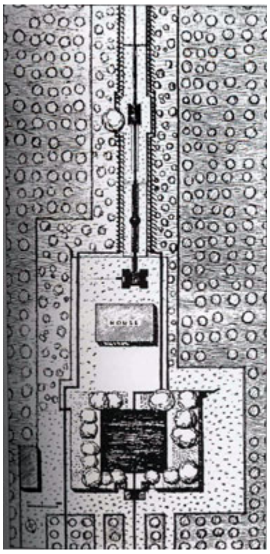


Figure 5-22 - Fath Abad garden in Tabriz, Palace (Source: Archives of ICHTO)

Moderate climate zone:

- In moderate and humid climate and cold and dry climate gardens, the palace is mostly located at 1/3 end of the garden.
- In this climate, palaces usually have 2 floors, but the height of floors are more than palaces in other climates to make air circulation possible
- Number of openings are maximum
- Reducing the thickness of the walls compared to the other two climates
- Palace plans are usually in square or rectangular form


Figure 5-23 - Palace location and futures of Safi-Abad gardens and Palace of Ashraf gardens located in Behshahr, in moderate climate (Source: Archives of ICHTO)

5.4.1.5.2 Enclosure Wall

- In Hot and dry climate zone:
    - Walls prevent the interior of the garden from warm and dry wind and block the shifting of sand.
    - Walls provide shade and keep moisture inside the garden.

- Mostly, the surface material of the wall has been covered with adobe, mudbrick, or brick, which stores heat effectively and releases it slowly over time.

- As can also be seen in the following figures, the role of the enclosure wall in the other two climates is only to determine the boundaries of the garden and focuses on its security role.

Figure 5-24 - The comparison of the role of the enclosure wall and the palace position in Shahzadeh Mahan gardens in Kerman vs. Behshahr Garden (Source: Pope, 1938-9)

Figure 5-25 - The characteristics of enclosure wall in Fin Garden, Kashan (Source: Author) vs. Fath-Abad garden in Tabriz (Source: Archives of ICHTO)

The comparative study of elements and components of Persian gardens has demonstrated their climatic behavior and the way they responded to the varying climatic conditions. This comparative study illustrated that changing weather conditions had changed the determining factors in the choice of location for the garden, except for stable access to water.

As a result, Table 5-1 determines the climatic behavior of the main elements in different climatic conditions. These show how the complex works together to prepare the pleasant and comfortable microclimate in their harsh climatic situations.

Table 5-1 - The comparative results of Persian gardens elements in different climate conditions of Iran (Source: Author)

Garden Elements / Climate Conditions		Hot and Dry	Cold and Dry	Moderate
Wall	Height	High 1. Climate 2. Security	Average 1. Security 2. Climate	Average 1. Security
	Material	Clay wall, mud	Clay wall, mud, stone, mortar	Stone, mortar
Palace	Height	Average	Low	High
	Opening	High	Average	High
	Position in the Garden	On the main Axis 1. Middle 2. 1/3 end of garden 3. End of garden	On the main Axis 1/3 end of garden	On the main Axis 1/3 end of garden
	Porch	Yes	No	No
	Cooling Strategy	Shadow, humidity, and wind	Sunlight, wind	Wind, shadow
Plant	Planting System in Main Axis	High density	Average density	Low density
	Shadow Provision	Very High	Average/low	Average/low
	Plant Types on the Main Axis	Deciduous/evergreen combination	Deciduous	Deciduous and few evergreens
	Windbreaker	High	Average	Low
Water	Play with Water	Very much in the best and highest value	High	High
	Depth	Low with arrangement	High	average
	Surface	Wide	Wide	Wide
Geometry	Orientation	North-South and East-West	North-South	No specific direction
	Overall Geometry	Rectangular and square form	Rectangular form	Rectangular form
	Width of Pathways	Low	Average	High
Site location	Topography	Often with low slope	Average/high slope	High slope
	Site Selection	1. Water accessibility 2. Soil 3. Slope of land	1. Water accessibility 2. Soil 3. Slope of Land	1. Water accessibility 2. Soil 3. Slope of Land 4. View

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Chapter 6: Results of Case Studies II: Persian Garden, Fin Simulation

Based on the results obtained in the previous chapters, for a detailed analysis of the behavior of each essential element of the Persian garden in the provision of thermal comfort, and how they respond in adapting to these climatic conditions, in this chapter, microclimate simulation Kashan Fin garden is conducted. In fact, Fin Garden, as a representative of the traditional Iranian landscape, is simulated by ENVI-Met software to be able to analyze the thermal behavior of each of these elements on a typical summer day in Kashan, as well as to examine and analyze the performance of the garden as a whole.

Afterward, the second part of this chapter, one contemporary park in Kashan, with the same climate in the same city and almost equally has the same amount of green areas and regions, is also simulated as a representative of the existing landscape code. The results of the two simulations are compared, and the difference in thermal behavior between the two green spaces is illustrated as a comparative representation of the traditional and contemporary landscape design in Kashan.

6.1 Kashan

6.1.1 Kashan, Geography, and Climate

The city of Kashan, with a population of nearly 400 thousand[23] and about 5000 square kilometers area, is located at 33°59′N 51°26′E of the geographical area of Iran. Kashan is surrounded by a variety of climates in most seasons and days of the year. Kashan is one of the northern cities of Isfahan province. The northern and eastern areas of Kashan are surrounded by "Dasht-e Kavir" which is a large desert situated in the middle of the Iranian Plateau. While in the western part of Kashan, the well-weather villages with beautiful natural scenery are located at the foot of "Karkas" Mountainous.

23 - With 364482 population at 2017 census.

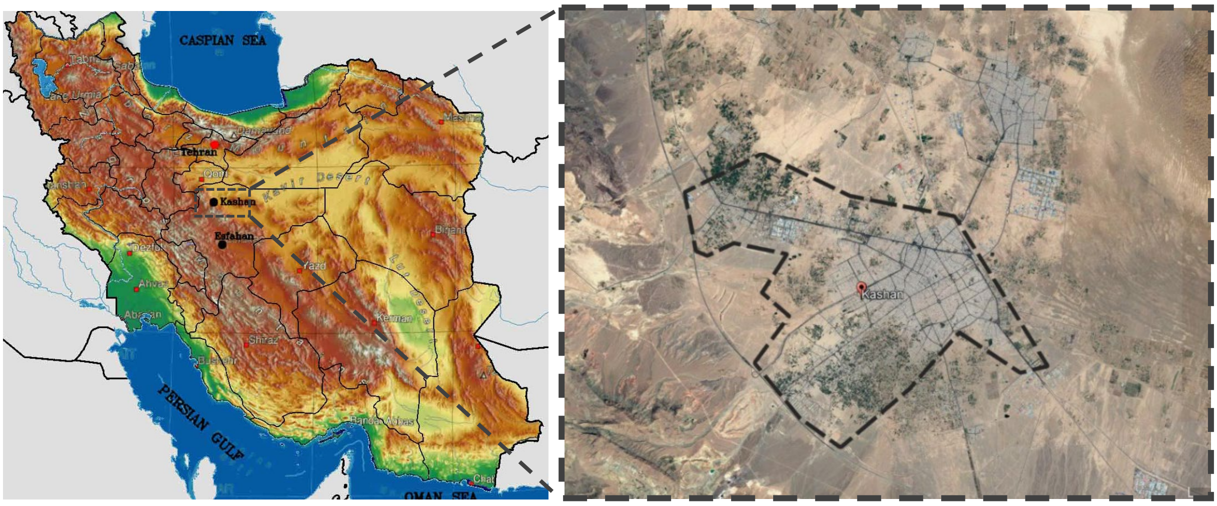


Figure 6-1 - Kashan location (Google Map)

The famous winds of this area mostly blow from the desert to Kashan. In terms of climatic division, the city is located in a climate zone with relatively cold winters and very hot summers. However, due to the severe influence of the central desert in Iran, Kashan has a hot and dry climate (IRIMO, 2015).

Based on Köppen climate classification, Kashan's climate is BWhsa (class B: desert and semi-arid), in which "B" indicates dryness and "W" intensity of dryness, in which the amount of annual precipitation (13.5) is lower than the average annual temperature in the centigrade (19.7 °C). "h" indicates that the mean annual temperature is more than 18 °C. "s" indicates that the rain comes in the cold season of the year or winter and "a" indicates that the warmest month of the year is more than 22 °C (IRIMO, 2015).

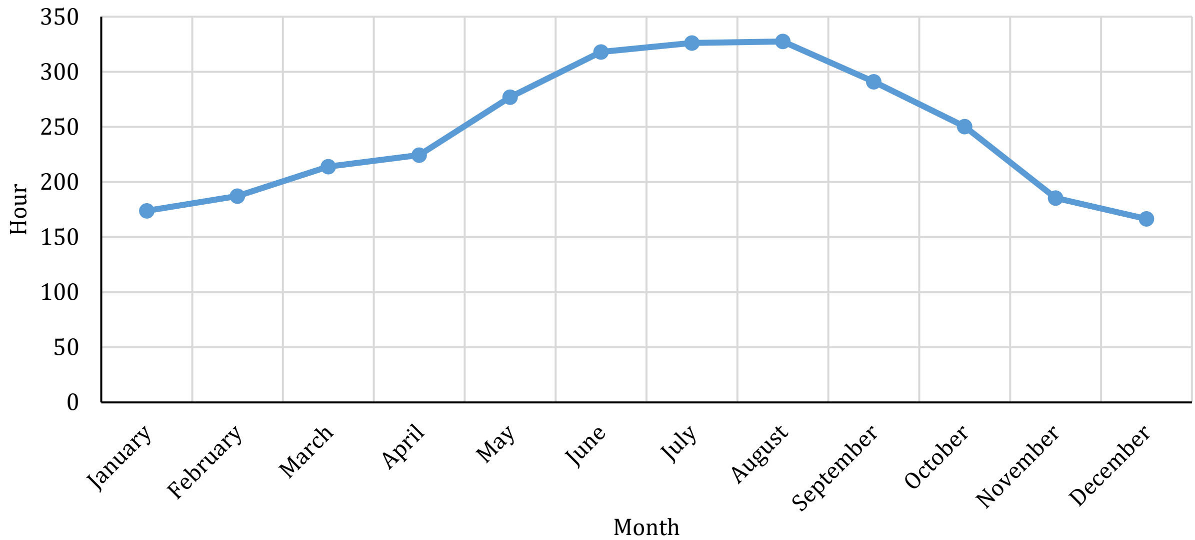


Figure 6-2 - Monthly mean sunny hours of Kashan between 1967- 2014 (IRIMO, 2015).

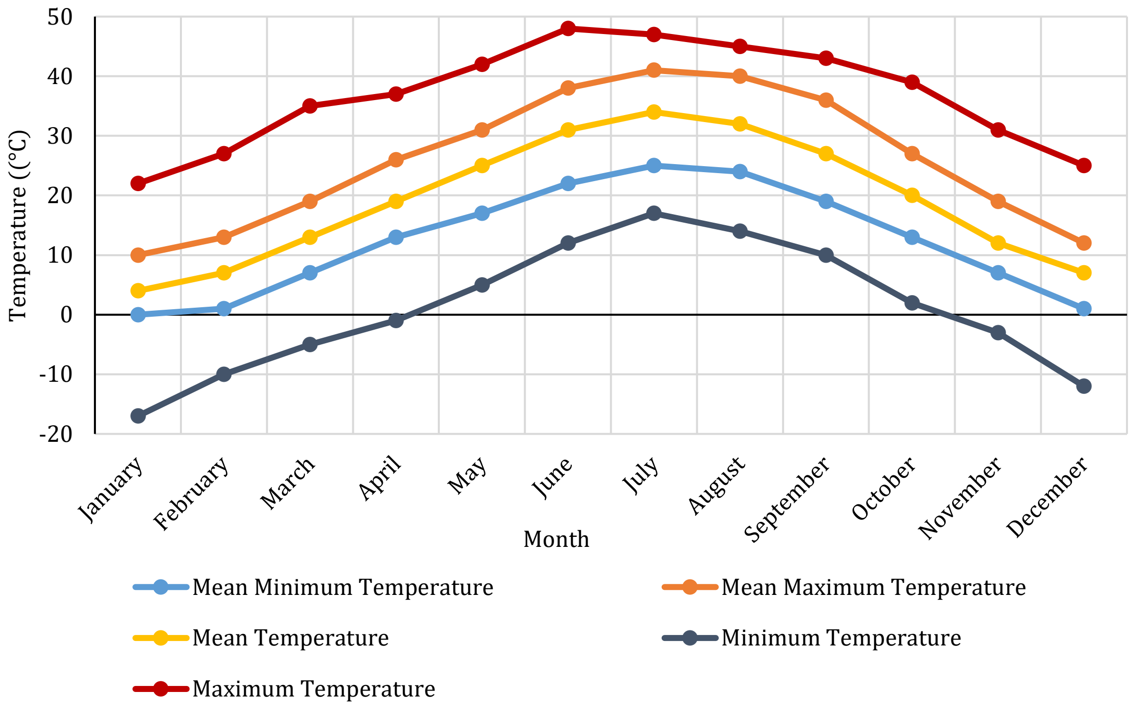


Figure 6-3 - Monthly mean temperature of Kashan between 1967-2014 (IRIMO, 2015).

Based on a long-term statistical study(1967-2014), by Iran Metrological Organization (IRIMO, 2015), Kashan's mean annual temperature is 19.7 °C; the mean annual maximum temperature is 34 °C in July; and the mean monthly maximum sonny hours is 327.5 hours in August. In this period, the mean relative humidity is calculated at 40%, with the mean annual precipitation of 136.5 mm (IRIMO, 2015).

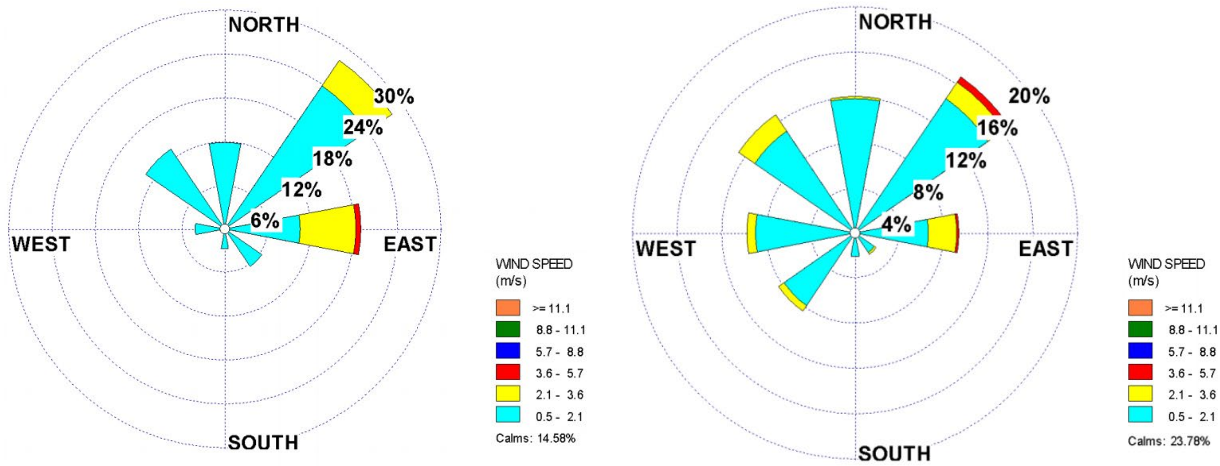


Figure 6-4 - Summer mean wind direction (left) and annual mean wind direction (right) between 1967-2014 (IRIMO, 2015).

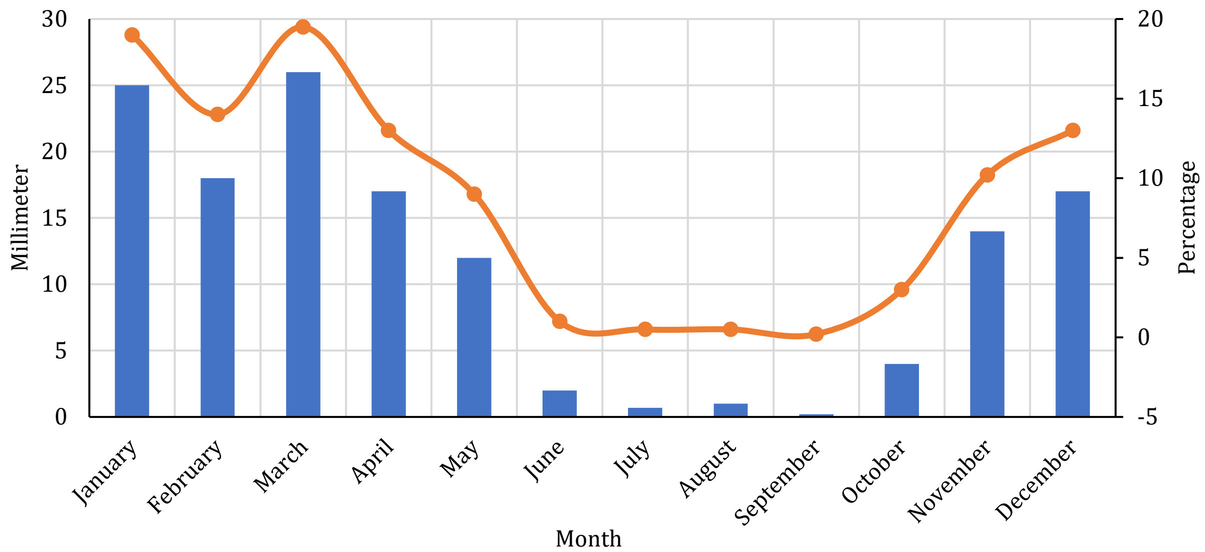


Figure 6-5 - Monthly mean precipitation between 1967-2014 (IRIMO, 2015).

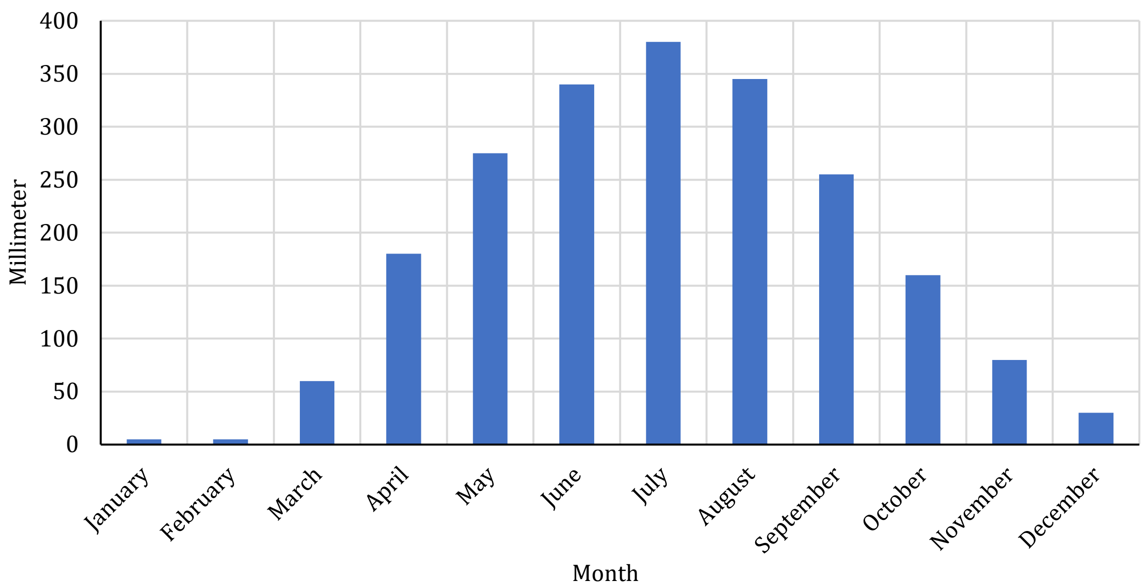


Figure 6-6 - Monthly mean amount of evaporation between 1967-2014 (IRIMO, 2015).

6.1.2 History of Kashan

Regarding the aforementioned climatic statistics, all indicate the extent and severity of the problems people face living in this region. Despite all this, this region has an ancient civilization. Moreover, it would be very worthwhile and remarkable to investigate how to adapt to this dry and violent climate and made it sustainable over thousands of years.

The historical evidence found in Kashan and around the city indicates this region as one of the primary centers of civilization in pre-historic ages. "Sialk" history, as the first urban civilization in Iran, dates back to about 7000 years ago, placed 4 km west of Kashan

(Childe, 1939). In the "Medes" and other ancient times, Kashan was stabilized, and in historical texts has been mentioned Kashan as a small city. Subsequently, by development on the Iranian plateau and the central location of Kashan, which was on the route of communication, Kashan became an important industrial center. From then on, it was mostly referred to as a moderate and successful city of Kashan.

In the "Safavid period"[24], Kashan was paid attention by most of the kings, and they often settled in it. Therefore, this city is considered a big and rich business center (Schwarz, 1936; Xavier de Planhol, 2012). Fin Garden is a collection formed in various historical periods, established and developed by different kings to settle and also hold the royal feasts.

6.1.3 Fin Garden Traditional Landscape

6.1.3.1 History and location

The Fin Garden of Kashan, as one of the most prominent Persian gardens, is the manifestation of Iranian genius and art in overcoming the environmental and climate limitations and converting them in the best possible way to a beautiful and pleasant space. This garden, after several hundred years of its construction, was destroyed by the earthquake in 1573. The current building of the garden was established at the behest of "Shah Abbas I" of Persia during the "Safavid period" (Newman, 2006). It considerably expanded during the reign of "Fat'h Ali Shah Qajar"[25],[26].

Figure 6-7 - Fin garden in the past (www.kashancht.ir)

The area of the garden is 23700 square meters and includes a central courtyard surrounded by walls, barrows, and cylindrical towers. The existence of dynamic elements such as water and trees alongside the building and other architectural elements have given a vivid identity to this cultural and historical collection of art. The abundance of

24 - The Safavids ruled Iran from 1501 to 1722.
25 - Second Shah (Qajar emperor) of Iran, 1797-1834.
26 - The Qajars ruled Iran from 1789 to 1925.

water and its flow in turquoise tiles, in an environment where the water is scarce, and widespread shade trees are in great contradiction with the dry desert behind the walls of the garden (UNESCO World Heritage Centre, 2011).

The Garden of Fin is one of the most important examples of Iranian gardens that remains. The Garden of Fin was registered on No. 238 in 1935 in the National Heritage List, and in 2011, along with eight other historic gardens, and was listed as Persian garden on the World Heritage List. Water engineering and the adventures of “Amir Kabir”'s[27] death are among the most important reasons for the popularity of the garden (Kashan Cultural Heritage, Handicrafts & Tourism Organization [CHHTO], 2015).

Figure 6-8 - Location of Fin garden in Kashan city (Google Map and UNESCO World Heritage Centre, 2011)

6.1.3.2 Natural and Architectural Features Existing in Fin Garden

6.1.3.2.1 Water

The importance of water for the Iranians and its holiness in Iranian culture and the way water was reached and extracted from this dry area through the “Qanat” was detailed in the previous section (ref. section 5.2.1). The Fin Garden is also known as one of the most comprehensive Persian gardens, especially in the use of water.

27 - Mirza Muhammad Taqiqan Farahani, famous for Amir Kabir, was one of the Chancellors and chief ministers of Iran during the Qajar period.

Figure 6-9 - Water as one of the most significant elements of Fin garden design (Source: Author).

Water is the most significant basic element in Fin garden design. Various aspects of water; Audio, spiritual, freshening, and life-giving aspects, besides the landscape and design aspects of water, have been skillfully and artistically performed in this garden. So that, various forms of water used in Fin garden's design; Stagnant water (in the pool, pond, and basin); flowing water (in the waterway); bubbling water (from the regular holes of the pond floor); and fountains; which each of one is reminiscent of various concepts (Jeyhani & Omrani, 2007).

Figure 6-10 - Different ways to use water in Fin garden design (Source: Author).

Figure 6-11 - The different kinds of water application in Fin garden (Source: Author).

6.1.3.2.2 Plants

Different aspects of plants are applied in Fin garden, such as climatic, productive, and decorative aspects. However, the most important garden plants are a large number of cypress trees and several oriental plane trees, which are native and completely resistant to this climate.

Considering the age of these trees (i.e., most trees are between 100 and 470 years old) illustrates that the shadow and evergreen trees have played an important role in garden design. Moreover, the limited planting of shrubbery trees in the garden has only been done to enhance visual quality and to cool down the air temperature (Farrokhyar, 1996; UNESCO World Heritage Centre, 2011).

Figure 6-12 - Cypress and oriental plane trees are the most applied and effective trees in shaping Fin garden (Source: Author).

6.1.3.2.3 Palace

Fin garden consists of various buildings and architectural constructions inside and around the garden. “Koushk Safavi” [28] which is in the center of the garden, besides the bathhouse and the entrance construction, belongs to the “Safavid” period.

“Qajars pavilion”[29], “Shah-Neshin”[30] and “Karim-Khani” building, the museum, and library are other constructions added to the garden’s building after “Safavid” period (Farrokhyar, 1996).

28 - Called also “Shah Abasi Shotor Galu”
29 - Called also “Fat’h Ali Shahi Shotor Galu”
30 - In Farsi means where the king sits

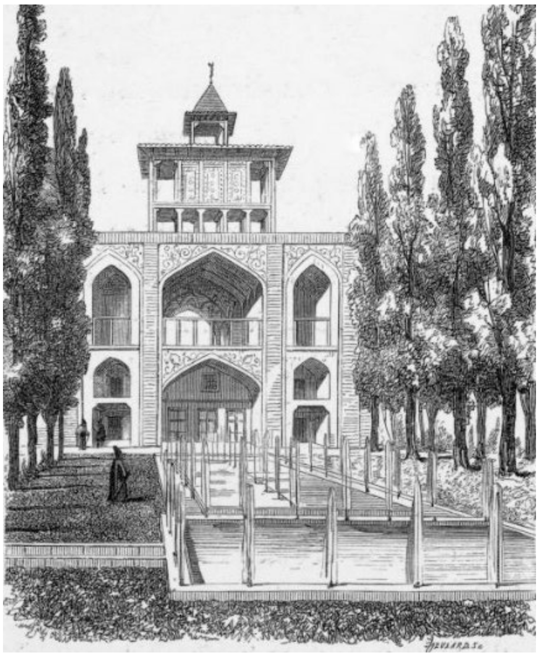


Figure 6-13 - Fin Garden Palace (Coste, 1867).

"Koushk Safavi", as the only architectural construction located at the focal point of the main axis of the Fin garden, was built in two stories based on a square-shaped design, which has access to the garden's pathways from its all edges. A small pond was located in the middle of this building. The openness of this space in four directions was created to better air circulation in shadow, as well as locating two pools outside the northern and southern sides of the building, creating a delightful, pleasant, and beautiful atmosphere (Faghih & Sadeghy, 2012).

Of course, it should not be neglected and ignored the beauty of the architecture of the building, which makes it much more pleasant.

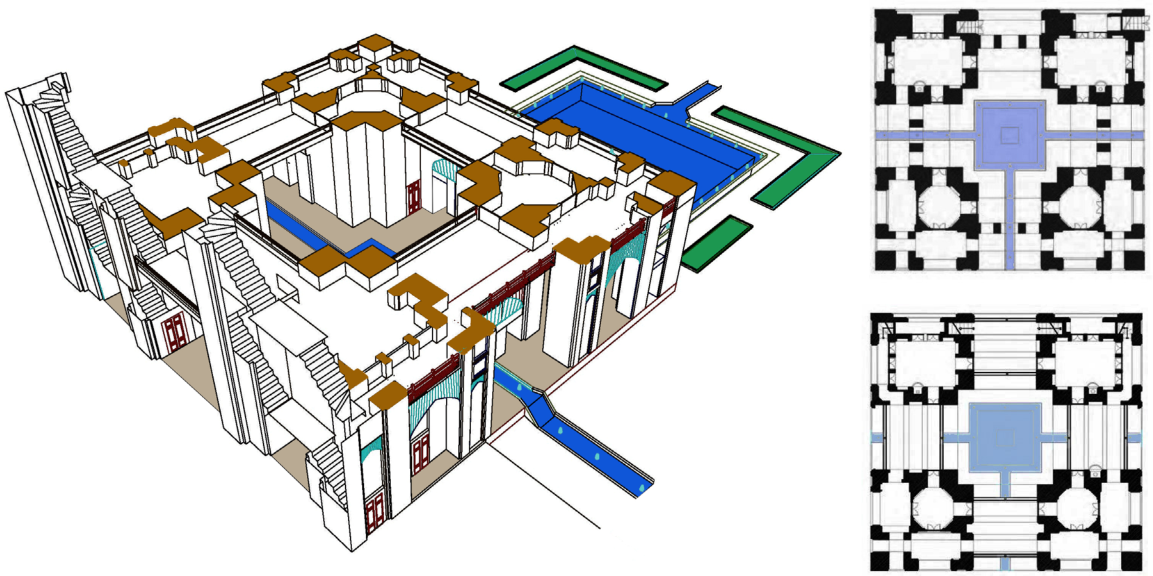


Figure 6-14 - 3D model and plans (basement is the Top plan and the plan of the first floor is shown in Bottom) of the central palace in Fin garden (Archive of Kashan CHHTO) (modified).

6.1.3.2.4 Garden Enclosure

Fin garden is secured by an enclosure, which gives a pure, geometrical form to the spatial structure of the Fin garden as well. This enclosure in which many towers and ramparts are embedded has been built by stone (foundation), bricks, and mud-bricks (Farrokhyar, 1996).

Figure 6-15 - The enclosed garden wall (Source: Author).

6.1.3.2.5 Materials

Materials, which have been used in the facade of architectural constrictions, mostly include mud, mud-brick, and brick, and in some places, stone. Pedestrian ways have been made of cobblestone and bricks. All these materials have been available from the regions around and environmentally suitable for this hot and dry climate. Other land-covers included soil, grass, flowers, and plants. Moreover, pools and canals were decorated with ceramic tiles and filled with water (UNESCO World Heritage Centre, 2011).

6.1.3.2.6 Orientation, Geometry, and Spatial arrangement

The orientation of the Fin Garden also follows the general orientation of the urban fabric, which is itself the result of the sunlight and wind direction. Furthermore, the garden's shape is in the direction of the water access and the waterway.

Figure 6-16 - Orientation of Fin garden and other buildings towards the north (Google Map 2013)

The Garden, with a pure, geometrical form, is divided into four sections by two main perpendicular axes. Hence, this garden also has the geometry of the "Chaharbagh" (ref. section 2.4.5.2). The overall spaces inside the garden were also subdivided into smaller spaces, following these geometric structures and with perpendicular lines. The main palace is located in the last third part of the main axis at the intersection of the main axis of the garden. Along the main street and the other side of the palace, there is an open space, which is an extension of the main axis in terms of the spatial structure of the garden. This hierarchical relationship between the entrance and the "Shah-Neshin" has created a continuum of beauty.

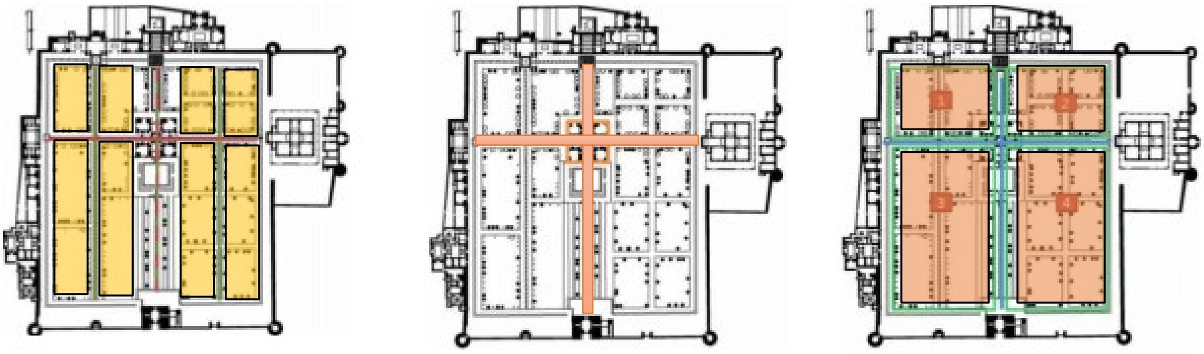


Figure 6-17 - Quadratic divisions in both main and sub-divisions of Fin Garden (Source: Author).

6.2 Microclimate Simulations I: Fin Garden

According to the analytical studies carried out in the previous sections on Persian gardens as traditional Iranian landscapes and the results of the analysis of their climatic regulating mechanisms (ref. section 5.4.1), it was determined to investigate the impact of seven important elements of Persian garden on human thermal comfort, through microclimatic simulations. These are including vegetation, water, material, wall, palace, lodgment, and orientation, and finally, the spatial arrangement of these elements in the pure and geometrical space of Persian gardens.

6.2.1 Model Details and Results

To accomplish the purpose of this research, based on the literature review, the features of this model were determined. In order to analyze the effects of the Persian garden's elements on human thermal comfort, several scenarios were defined. By comparing these scenarios and specific sections of them in different aspects, the best sections and situations would be chosen to suggest for future designs.

One of the deficiencies (or features!) of ENVI-Met is the inability to change or manage the initial input values for the whole simulation. Thus, no alternation could be possible after running the simulation. For instance, in this version, when the simulation starts with a particular value of wind direction, there is no way to modify it during the simulation's time span. Therefore, as wind direction and its value vary during the day, and despite the availability of real-world values, it was decided to consider the lowest wind for these simulations.

Simulation areas have been conducted in 180(X)*180(Y)*25(Z) model area, in which each X and Y unit has been defined as 1 meter, and each Z unit has been allocated to 2 meters. As mentioned before, all simulations have been run based on the same climatic input datasets of the Kashan city for the 25.06.2015 as a typical summer day in a hot and dry climate in Iran.

In this step, different scenarios are defined, and eleven receptors were used in each scenario. These receptors are located in the same place in all scenarios (Figure 6 -18), which are described in more detail in the following. As well as the preliminary model, all models and scenarios have been run for 13 hours, the period of time when it encompasses the most outdoor activities starting from 8:00 am to 9:00 pm.

As mentioned earlier, although the PET maps are calculated by BioMet plugin and the graphical results are calculated by LEONARDO plugin of ENVI-Met, however, for each receptor, to calculate PET, the ENVI-Met simulation results were exported to Rayman. Although ENVI-Met enables the calculation of many environmental values, in terms of PET calculation for receptors, just parts of these results are used for calculation, which are: relative humidity, temperature, wind speed, and mean radiant temperature (T_{mrt}).

Rayman requires some other input data as well. Some are related to the geographical location of the case study and others to the experiment's subject (physical situation and activities). The Sky View Factor (SVF) is also needed by Rayman, but as it has already been calculated in the T_{mrt} calculations in ENVI-Met, thus the SVF was taken as 1.

6.2.1.1 Receptors and Scenarios

The eleven defined receptors are located in the Fin garden plan. In order to better and more accurately investigate the thermal behavior of the main elements and how they affect their ambient PET value in the Persian gardens, these eleven receptors are located near each element in different spatial arrangements and compositions. In fact, A combination of different spatial arrangements, geometry, material, architectural constructions, vegetation, and size of water surfaces, as well as the order of the elements, are considered effective factors in defining the receptors' location. The spatial arrangement and position of each receptor are shown in detail in section 6.2.1.7.

Moreover, it should be noted that the following defined scenarios (i.e., Basic, No-Water, No-Wall, No-Tree scenarios) also have an important role in determining the receptors' location.

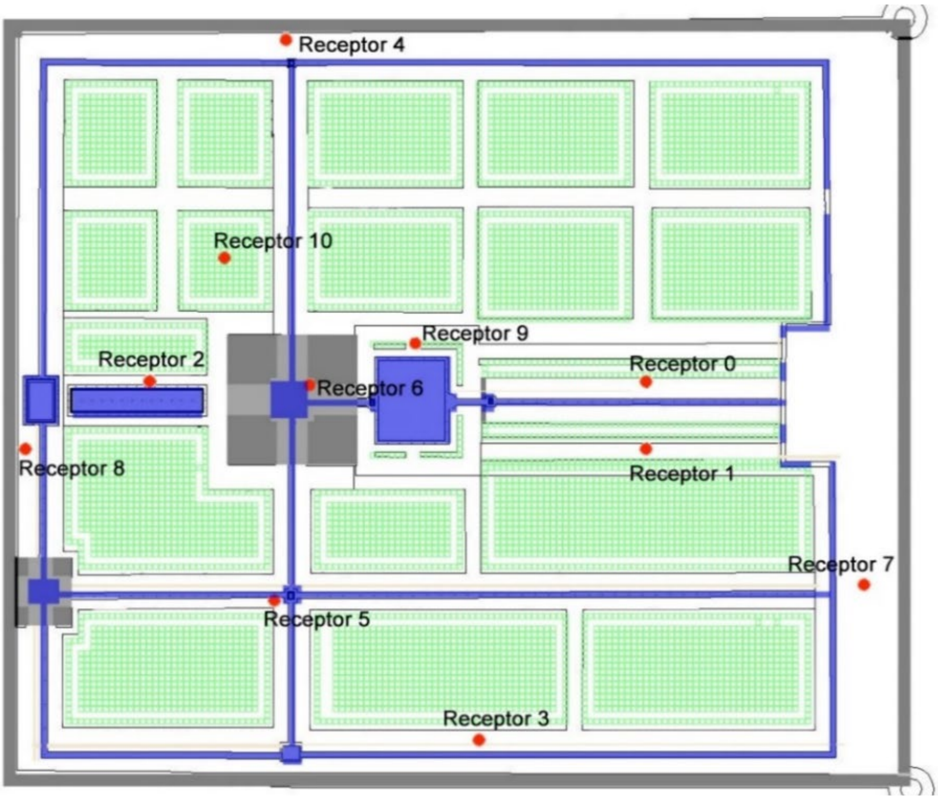


Figure 6 -18 - Simulation plan of Fin Garden along with showing the location of selected receptors

It is necessary to mention that all the estimated PET values for receptors and plans are simulated for all heights. Nevertheless, for the purpose of this research, the chosen calculations are for 140 cm in order to have a better understanding of human scale thermal feeling. Based on Table 2-6 (ref. section 2.2.4.2.7), the strong heat stress for PET is started from 35 °C.

Table 6-1 - PET Categorized in terms of thermal perception and physiological stress; internal heat production base on Table 2-6

PET °C	Thermal perception	Grade of physiological stress
Above 41	Very Hot	Extreme Heat Stress
35 to 41	Hot	Strong Heat Stress
29 to 35	Warm	Moderate Heat Stress
23 to 29	Straightly Warm	Slight Heat Stress
18 to 23	Comfortable	No Thermal Stress
13 to 18	Straightly Cool	Slight Cold Stress
8 to 13	Cool	Moderate Cold Stress
4 to 8	Cold	Strong Cold Stress
Below 4	Very Cold	Extreme Strong Cold Stress

To explore the role of Persian garden's elements, the following scenarios are defined with the aim to eliminate each essential elements of Persian garden and estimate their climatic efficiency on thermal comfort:

- **No garden – vacant place:** This simulation explores the changes in temperature and environmental conditions within the limits of the Fin Garden's walls, as a vacant land with no palace, no garden, or any other Persian garden feature.
- **Basic:** Base scenario is the simulation of the current situation of Fin garden with all elements that are defining the Fin garden as a traditional landscape.
- **No-Water:** To analyze the efficiency of water-element on the climatic aspect, it was decided to eliminate any water-related feature, including water canals, water basins, and water fountains.
- **No-Wall:** The walls around the garden are removed from the basic scenario simulation to define the No-Wall scenario. In traditional Persian architecture, their primary roles are defined as enclosure order, frontier to wind and shadow provider, and land privatization.
- **No-Tree:** tree, as the most important and significant landscape feature, is omitted in this simulation scenario in this scenario, to investigate its role in thermal comfort.

6.2.1.2 Base Scenario

This scenario analyzes the climatic behavior of landscape features in detail for Fin garden in its current situation. First, simulation displays changes in Physiological Equivalent Temperature (PET) during the day over 13 hours' time span. The PET plans assists in gaining a better understand of the whole garden once and enable us to compare other parts and spatial arrangements of the complex.

Before studying the thermal behavior in the Persian garden and its various scenarios, the presentation of other effective factors such as wind speed and direction, relative humidity, air temperature, and mean radiant temperature (T_{mrt}) can be helpful to understand and explain the calculated thermal behavior (Figure 6-19).

Figure 6-19 shows the changes in the inside condition of the Fin Garden compared to the outside in various aspects. It is quite clear that the air temperature and relative humidity have noticeable differences inside and outside the walls.

Additionally, the wind direction analysis, shown in this Figure, also explains how humidity is increased inside the garden and subsequently why the temperature lowers in the corner of the garden.

Moreover, these also explore that which part of the garden has the lowest (better) and highest thermal function. This analysis provides a basis to assess the effects of different elements.

Base Scenario

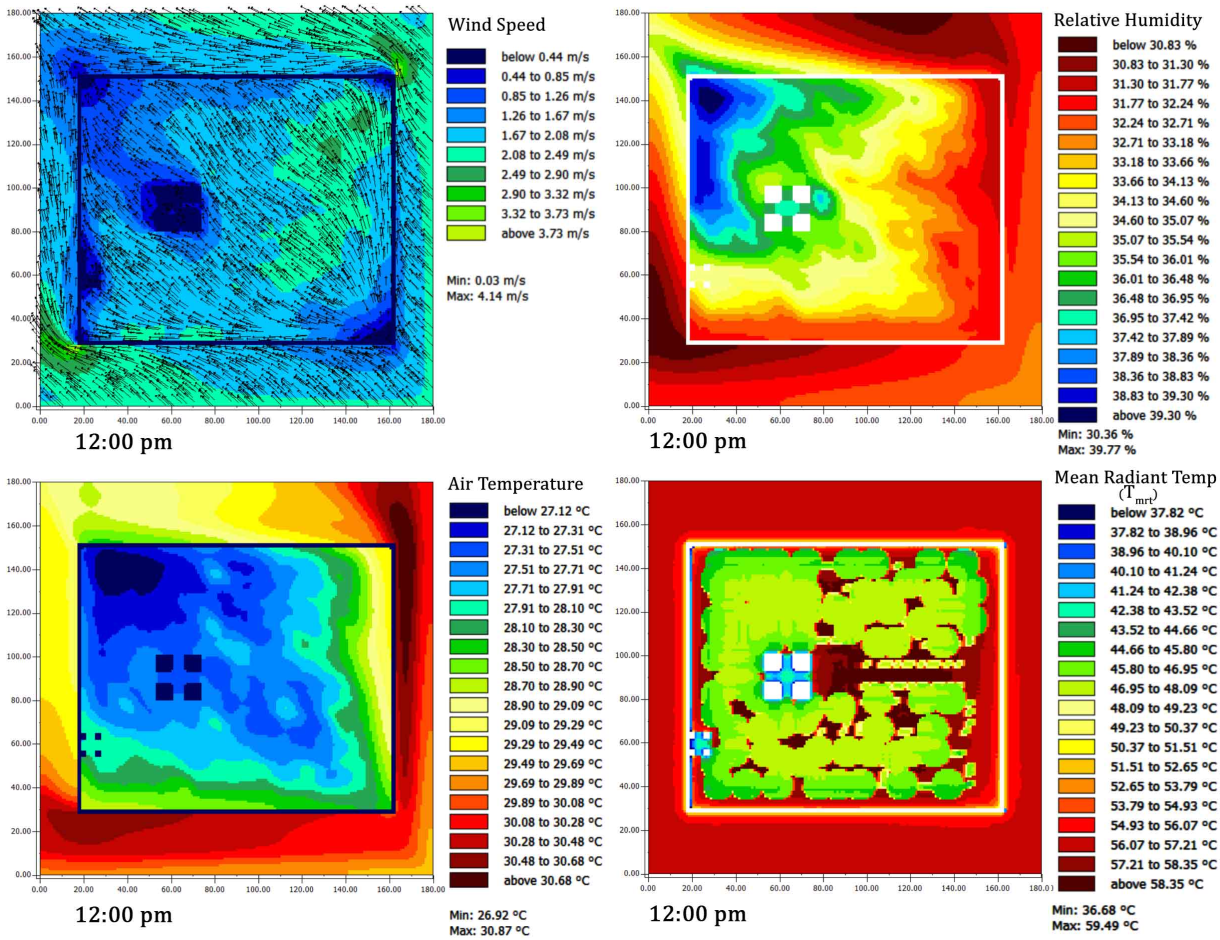


Figure 6-19 - Presenting the various climatic factors of The Base Scenario of Fin garden in 25.06.2015 at 12:00 pm and 1.4m height-level, wind speed and direction (Top-left), relative humidity (Top-right), air temperature (Bottom-left), and T_{mrt} (Bottom-right)

Comparing different receptor's hourly behavior (Figure 6-20) lead to the below points:

- Receptor 7 stands as the warmest spot among the selected places in the garden. Based on hourly-simulated PET, it shows similar behavior to receptors 8 and 9 until 13:00, and then in the latter two, the temperature drops significantly, which is resulted from the shadows time.
- Apart from the aforementioned Receptors, the rest behave steadily along the day, also behaves similarly to each other and with minimum estimated temperature. However, among these receptors, receptor 1 stands as the coolest one until 12:00, from 12:00 until 16:00, it belongs to receptor 1, and after

16:00, by reducing the direct solar radiation impacts, the coolest place belongs to receptor 9, which is located near the biggest water surface in this garden.

- The coolest receptors during a day, which are receptors 0, 1, 2, and 9 demonstrate that the main axis of the garden has the best thermal behavior in Fin garden.
- The receptors 10, 6, 5, and 2 have the minimum thermal deviation during the time span. This is also related to their position in the shadow during the day.

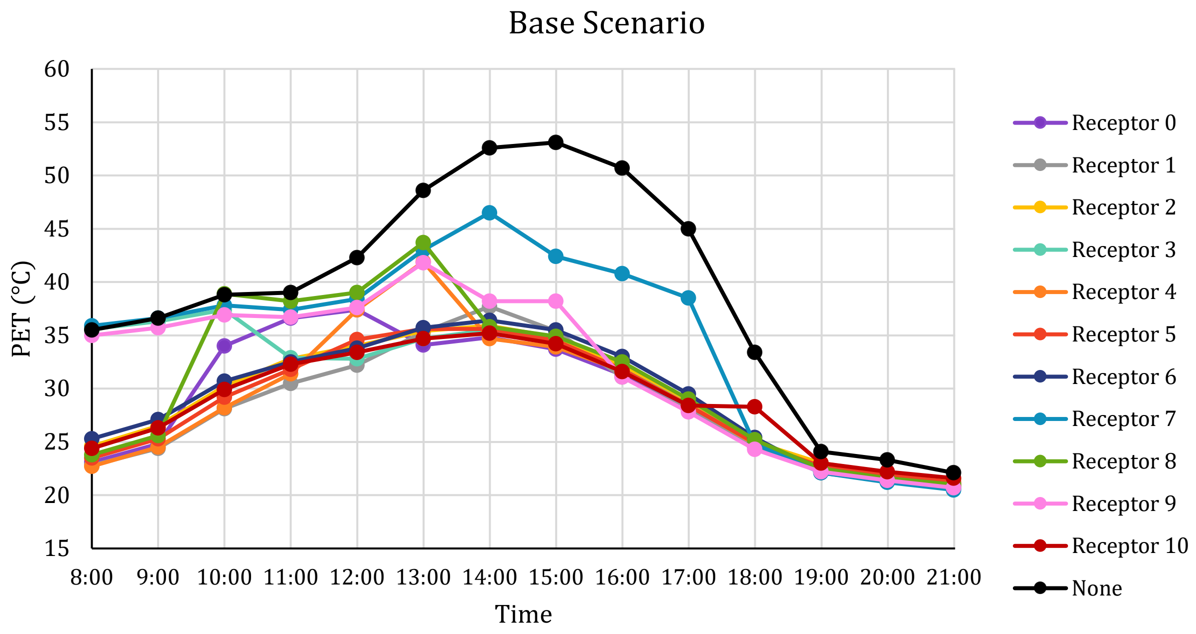


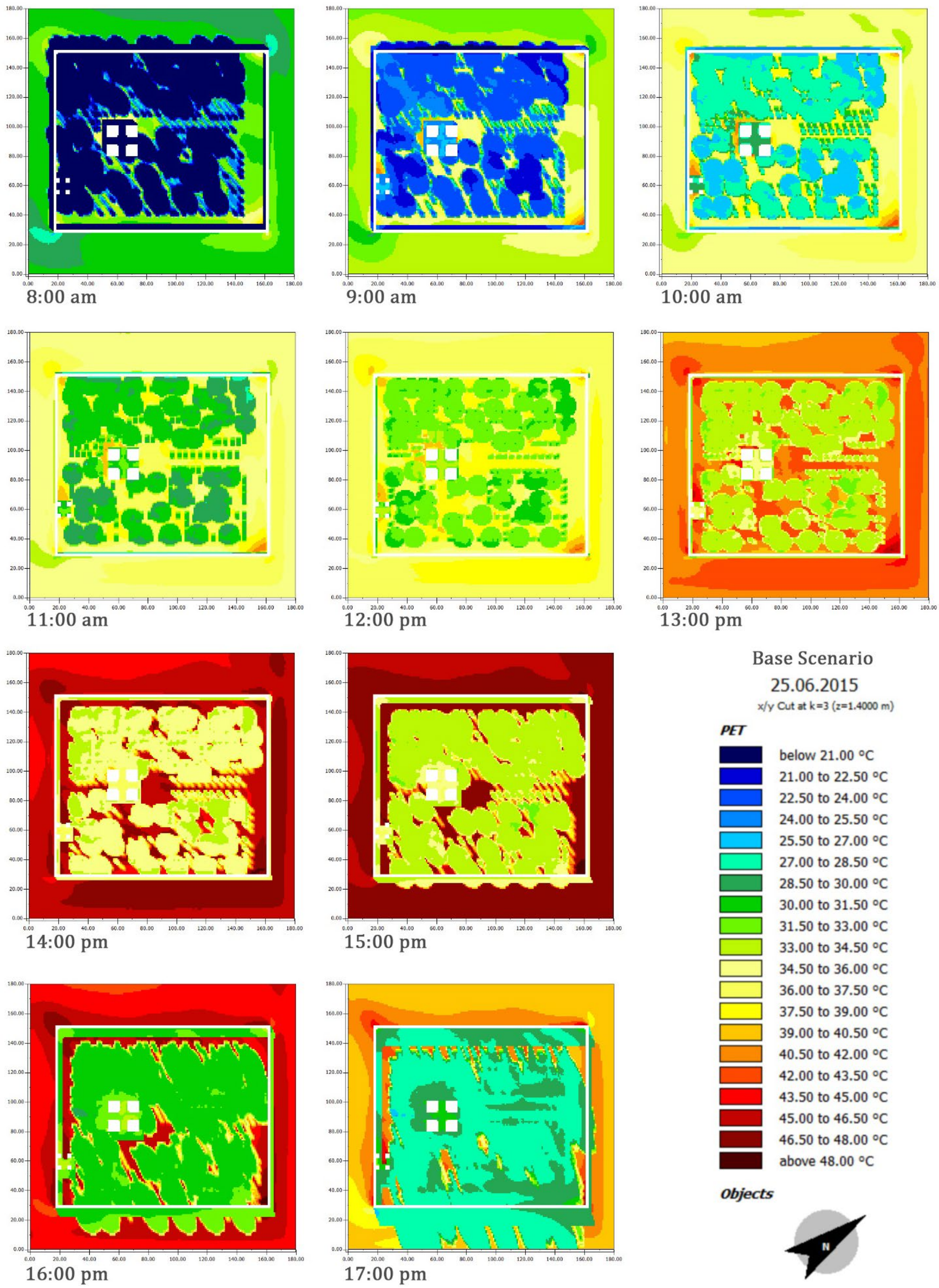
Figure 6-20 - Receptors' comparison in the Base scenario and thermal behavior of eleven-selected location at the height of 1.4m

On the other hand, to investigate the thermal behavior of the entire garden during the day as a complex, Figure 6-21 shows the thermal behavior of Fin garden (Base scenario) during the selected day in summer from 8:00 am to 21:00 - at the level of 1.4m height as the same as receptors.

Moreover, as it clearly explored, although at the noontime, outside the garden, the PET is more than 45 °C, which is much more than the extreme heat stress (Above 41 °C), however, there are always places in the garden with the range of moderate heat stress.

The calculations on the receptors provide more accurate information for these specified points and make it easier to compare them numerically. Both Figure 6-20 and Figure 6-21 show that the highest PET difference between inside and outside PET value is around 19 °C.

Figure 6-21 also displays that despite the cooler PET value inside the garden during the day, it is warmer during the earlier hours of the night. However, the result shows the cooling efficiency inside the garden in comparison with the outside area.


8:00 am
9:00 am
10:00 am
11:00 am
12:00 pm
13:00 pm
14:00 pm
15:00 pm
16:00 pm
17:00 pm
Base Scenario
25.06.2015
x/y Cut at k=3 (z=1.4000 m)
PET
below 21.00 °C
21.00 to 22.50 °C
22.50 to 24.00 °C
24.00 to 25.50 °C
25.50 to 27.00 °C
27.00 to 28.50 °C
28.50 to 30.00 °C
30.00 to 31.50 °C
31.50 to 33.00 °C
33.00 to 34.50 °C
34.50 to 36.00 °C
36.00 to 37.50 °C
37.50 to 39.00 °C
39.00 to 40.50 °C
40.50 to 42.00 °C
42.00 to 43.50 °C
43.50 to 45.00 °C
45.00 to 46.50 °C
46.50 to 48.00 °C
above 48.00 °C
Objects
N

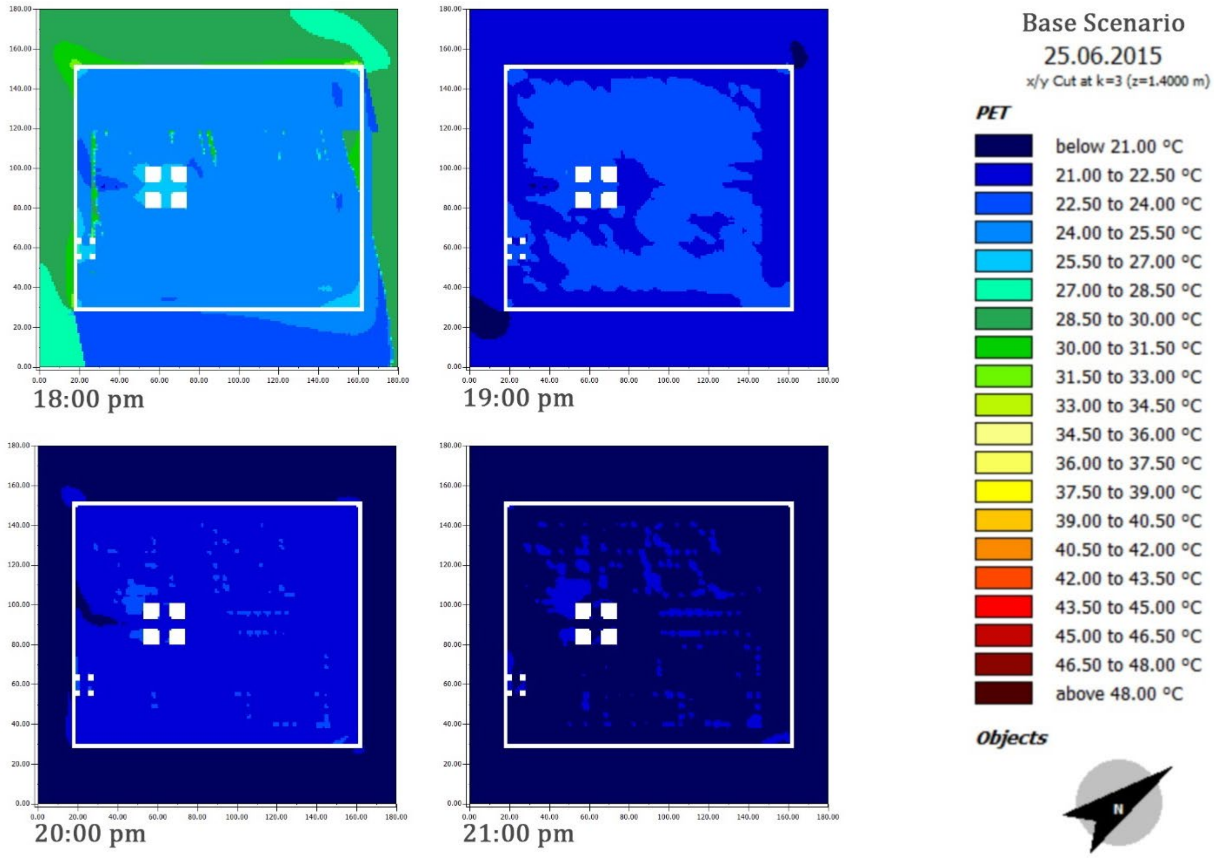


Figure 6-21 - Thermal behavior of Fin garden as the Base scenario for 13 hours a summer day

6.2.1.3 No-Wall Scenario

In traditional Persian architecture, walls initially play a role as enclosure order, frontier to outside warm and dusty wind and shadow provider. In addition, culturally and from a land-use perspective, walls have a security and property privatization role, which are completely discussed before in section 2.4.5.5.1.

In this scenario, in an attempt to assess the enclosure-wall climatic impacts, by removing them all, but the rest of the landscape stays the same as in the basic scenario simulation. The figure below displays the PET computation of the aforementioned receptors in the garden in case of No-walls around.

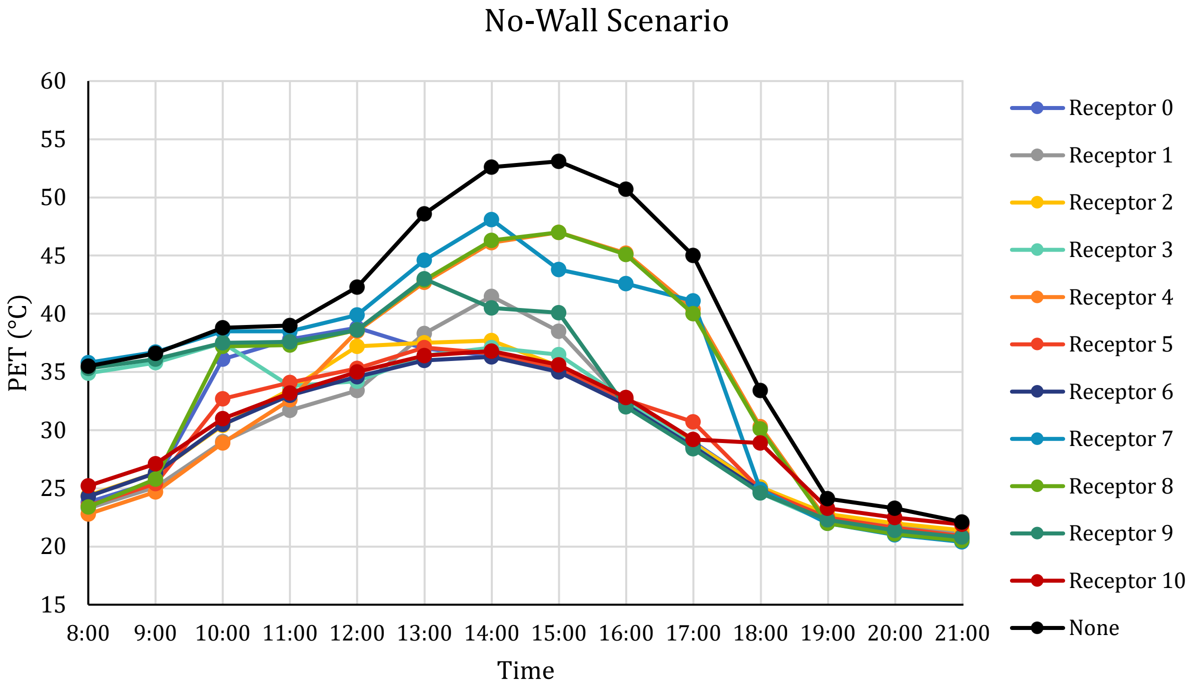


Figure 6-22 - Receptors' comparison in No-Wall Scenario

Comparing different receptor's hourly behavior lead to the below points:

- Receptors 4, 8, and 7 stand as the warmest spots in the garden among the selected locations. They show a higher PET since they are located along the walls inside the garden, as well as receptor 9 until 14:00 o'clock.
- It is interesting to compare receptor 3, as it is also located along the walls but does not follow the aforementioned terminal pattern in the absence of the wall shadows. These phenomena could be explained as the effect of nearby trees shadow all long the simulation time span.

Furthermore, comparing the PET in the Base and No-wall scenarios indicates a significant difference in the temperature inside and outside the garden. The figures below clearly show the impacts of eliminated walls around the garden on thermal comfort.

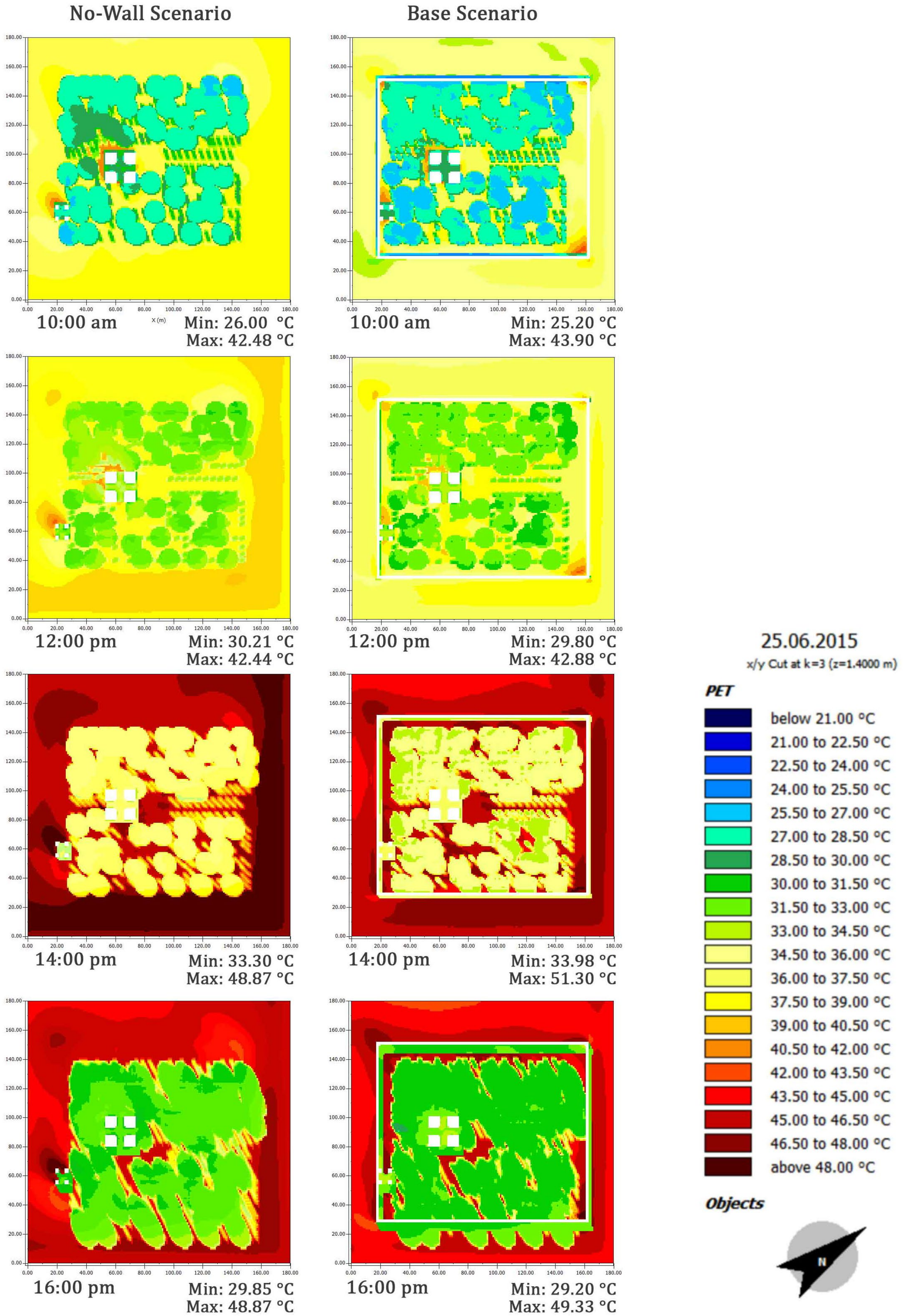


Figure 6-23 - Comparing the thermal behavior of Fin garden as the Base-scenario (right) with its No-wall scenario (left) during a summer day

It should be mentioned that although the PET performance of the Base scenario is better than the No-Wall scenario (up to 2 °C PET), the maximum thermal output of the Base scenario is a little higher in most hours. Further investigation and a closer look at existing maps and analysis reveal that the highest temperatures occur at a small location at the junctions of walls, where there are very low winds and high heat reflectivity (Figure 6-23).

From another point of view, Fig. 4.3 illustrates how the walls contribute to maintaining and conserving the humidity inside the garden as well as showing the differential temperature between the outside air and the inside of the garden on either side of the wall.

In addition to human thermal comfort, walls have an impact on vegetation since they provide shadows and prevent hot wind from flowing into the garden. Investigating air temperature at the lowest height level (20cm) displays their impact on vegetation and grass in the form of higher air temperature, translating to higher water consumption.

Figure 6-24, by comparing the air temperature of Base and No-Wall scenario at 20cm height level, demonstrates the small thermal effect of the enclosure wall. As it clearly shows, just in garden border spaces, for example, at 14:00 o'clock, the maximum air temperature difference is about 2 °C degrees.

Moreover, at 12:00 pm, most ground surfaces in Base scenario have a lower temperature than 27.5 °C, whereas, in No-Wall scenario, they have a higher temperature than 27.5 °C, which is about 0.5 °C difference as also impacted on the minimums (Figure 6-24).

Finally, all of these are good indications of positive effects of the garden wall in preventing the penetration of outside hot air to the inside and its small positive impact on reducing the indoor temperature of the ground surfaces by up to 2 °C degrees comparing with No-Wall scenario. From other points of view, in Figure 6-27, the negative thermal role of enclosure-wall and other constructional surface materials is obvious in their ambient environments, which have affected up to 10 °C PET in less than the one-meter distance from the wall.

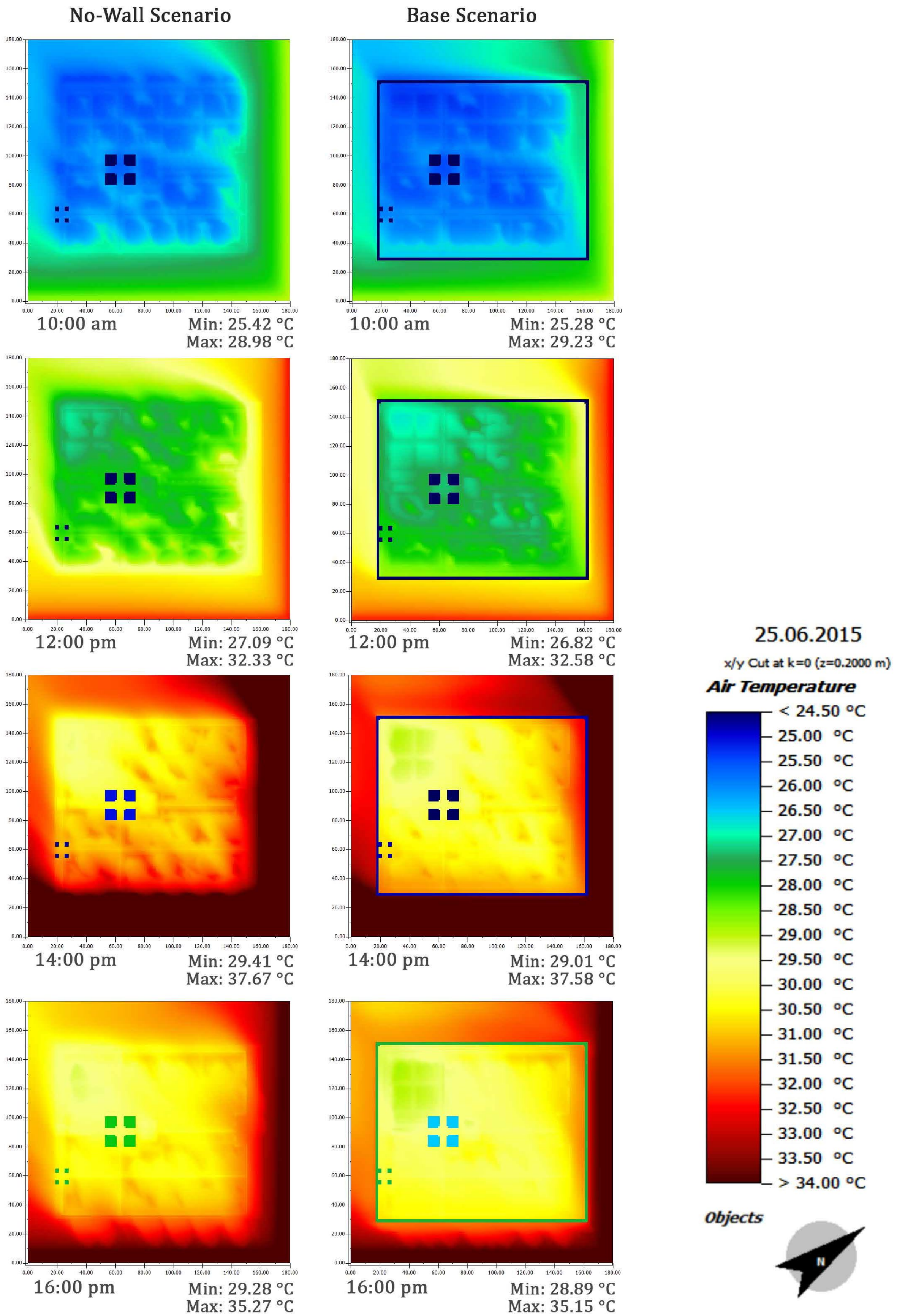


Figure 6-24 - Comparing the air temperature of Fin garden as the Base-scenario (right) with its No-wall scenario (left) during a summer day at the 20 cm height level

6.2.1.4 No-Water Scenario

In a hot and dry climate such as Iran, water is not only a scarce and valuable component in everyday life but also is interwoven symbolically in Iranian culture and beliefs. To that point, Fin Garden is one of the best examples and most famous illustrations of the symbolic and practical application of water in the traditional Iranian landscape (Figure 6-10 and Figure 6-11).

This section assesses the water impact on PET by disregarding all water elements such as short height fountains water, waterways and canals, and basins in the Fin garden. In other words, how the thermal behavior of the garden would be without the existence of water. The figures below display the PET performance of the selected receptors in the Fin garden in the case of the No-Water scenario.

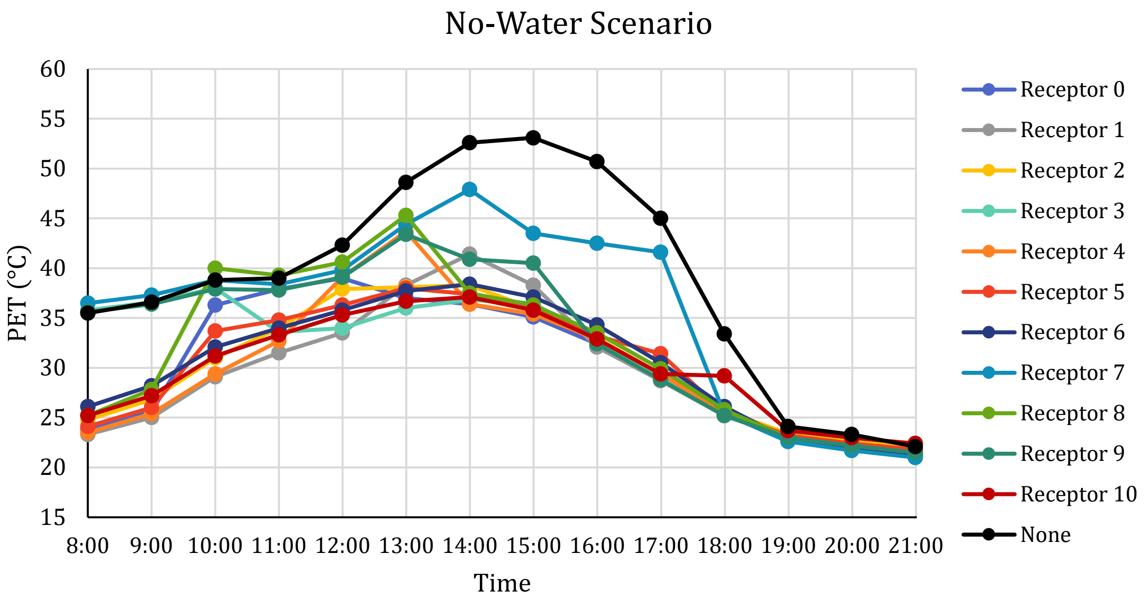


Figure 6-25 - Receptors' comparison in No-Water scenario and thermal behavior of eleven-selected location at the height of 1.4m in thirteen hours a day

Comparing different receptor's hourly behavior lead to the below points:

- The receptors 7 and 9 have the warmest thermal behavior among the other receptors inside the garden, which are explained as the impact of direct solar radiation time as the same as Base scenario.
- Removing water basins and water canals followed by the significant temperature increase in receptors 9, 2, and 8, which are explained by their close location to the water resources.

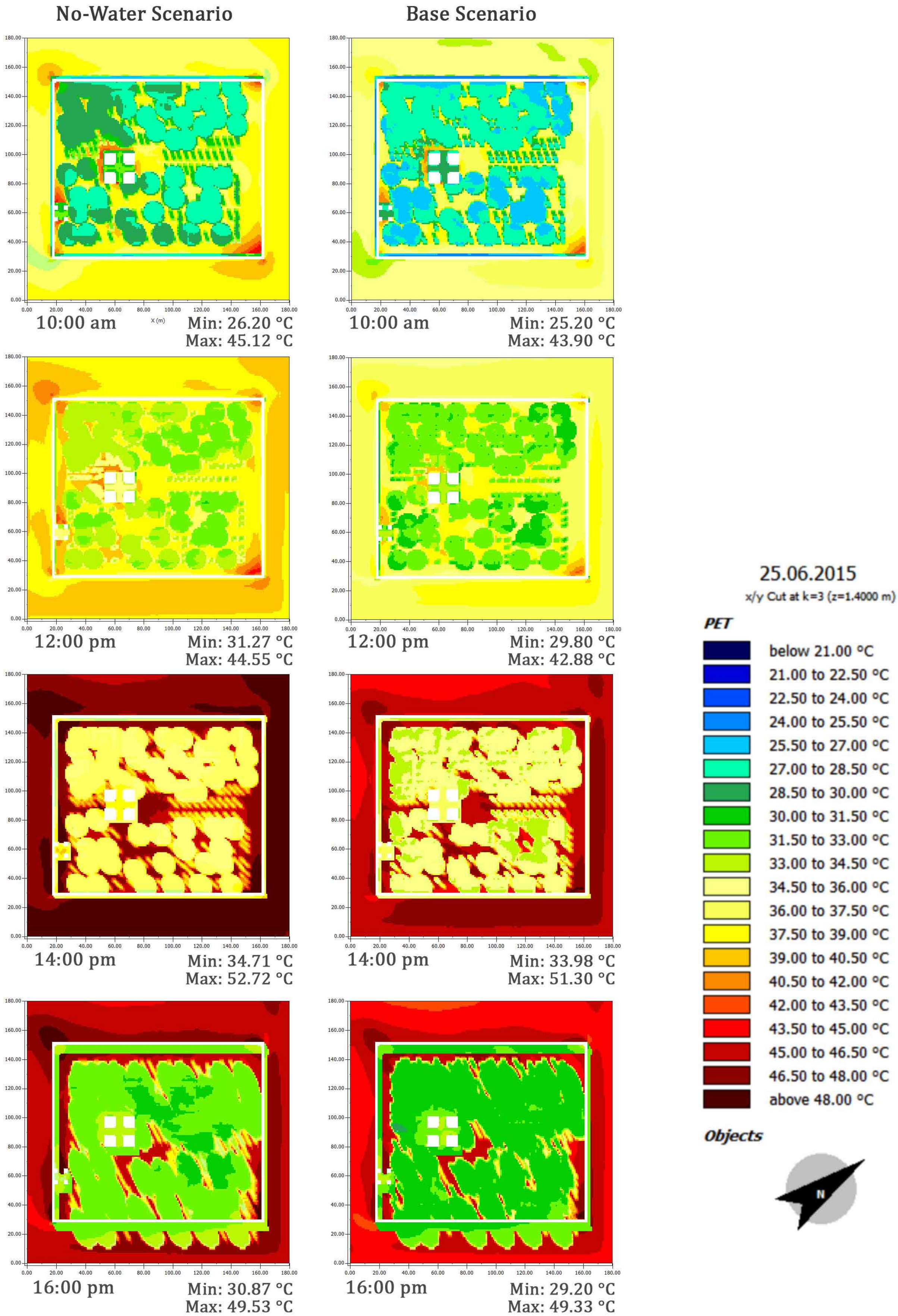


Figure 6-26 - Comparing the thermal behavior of Fin garden as the Base-scenario (right) with its No-water scenario (left) during a summer day

Comparing the PET map of the Basic and No-Water scenario (Figure 6-26) indicates the PET-degree alteration in minimum, maximum, and average temperatures. So that, all the minimum, maximum, and average temperatures have increased and intensify in their PET value. It means that the water existence inside the garden has a positive impact on cooling the temperature in all parts and the design of the garden during the summer day in a hot and dry climate.

Figure 6-25 and Figure 6-26 demonstrate that the short height fountain has a trivial effect on the PET value at the human level, as well as the narrow canals. On the other hand, water basins' impacts depend on their size. Indeed, the greater the water surface, the more humidity that leads to a more significant cooling effect inside the garden.

6.2.1.5 No-Tree Scenario

Tree is one of the main vital elements in landscape design, and this scenario looks into its thermal impact in Persian garden by means of eliminating all the trees from the Basic scenario. The figures below display the PET performance in the garden in case of No-trees, on a summer day, at the pedestrian level.

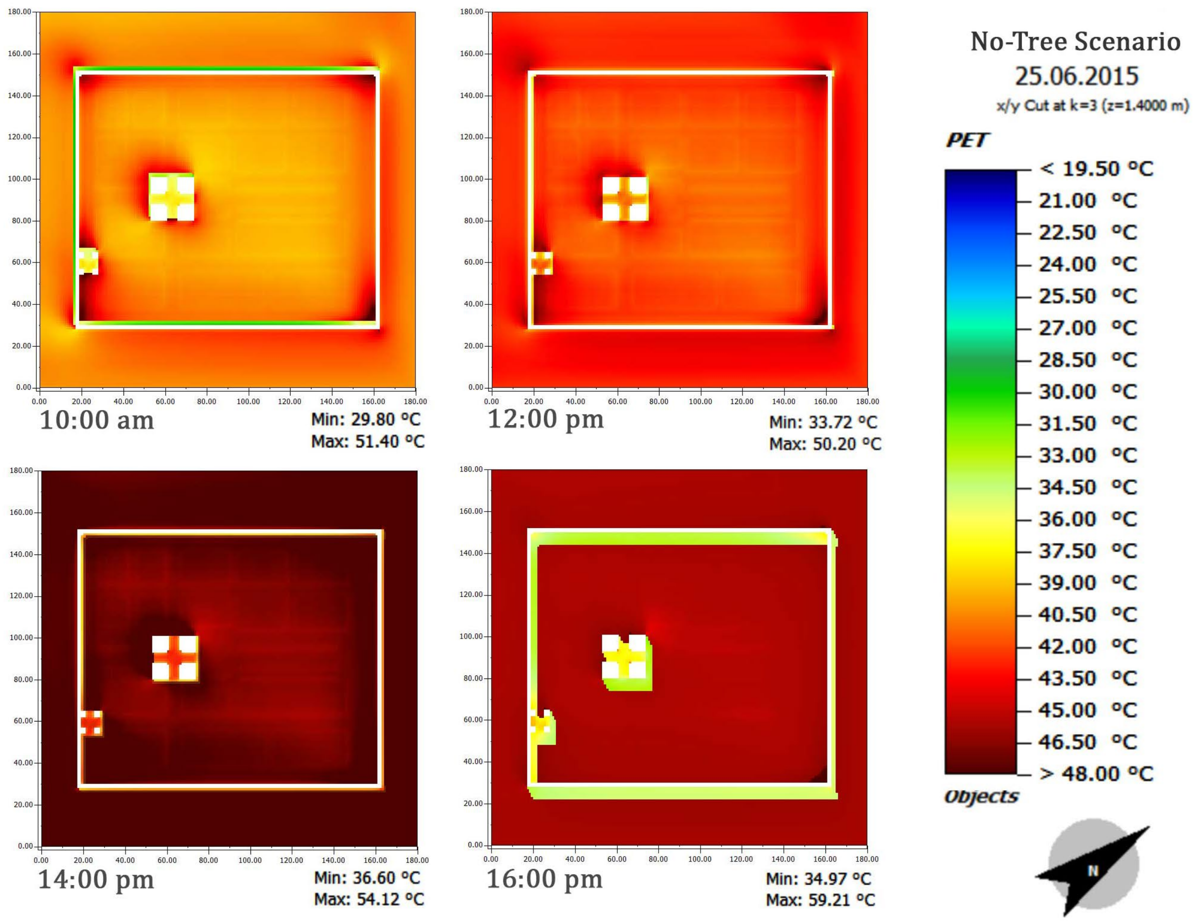


Figure 6-27 - Thermal behavior of Fin garden as the No-Tree scenario during a summer day at the pedestrian level

Figure 6-27 illustrated that the PET alterations, in the No-Tree scenario at noontime, dramatically increased. In comparison with the previously conducted scenarios, trees clearly are the most effective cooling component in Persian garden. As mentioned before in section 2.2.4.1, it is related to evaporation and shadow provided by trees. Indeed, trees considerably block direct sunlight, moderate wind speed and direction, lower the ambient air temperature and increase the air humidity.

Hourly PET evaluation in the No-Tree scenario from 8:00 am until 9:00 pm demonstrates up to 32 °C temperature variation. The figure below provides the hourly PET of selected receptors in more detail.

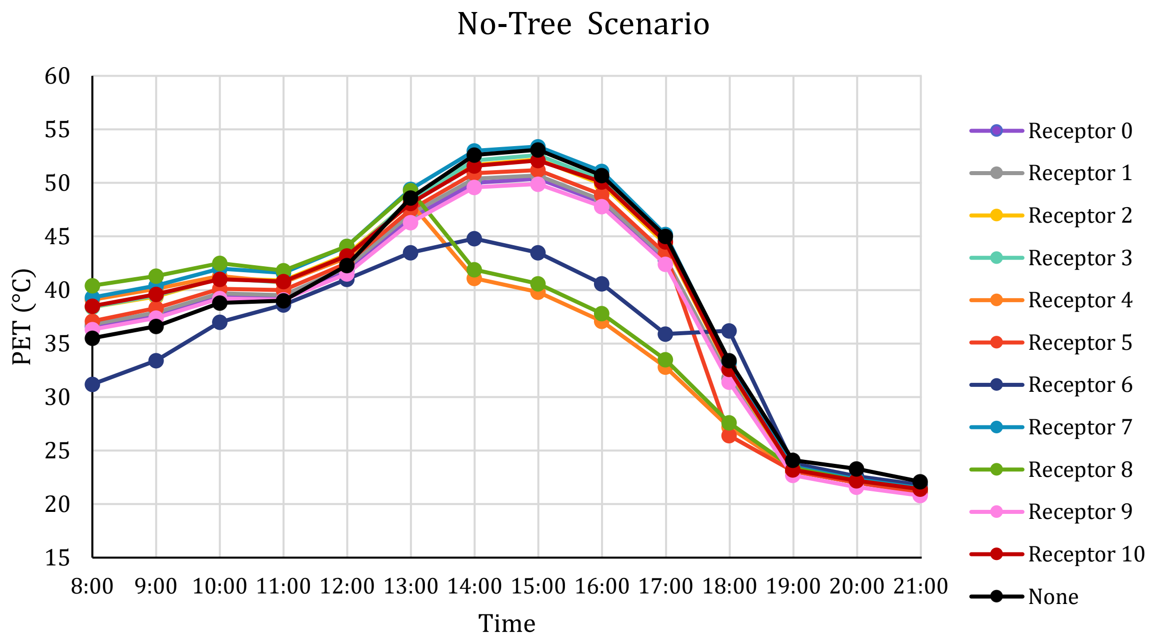


Figure 6-28 - Receptors' comparison in No-Tree scenario and thermal behavior of eleven-selected location at the height of 1.4m in thirteen hours a day

Comparing different receptor's hourly behavior of No-Three scenario leads to the below points:

- All Receptors demonstrate a noteworthy alteration in PET in the absence of trees except the numbers 6, 4, and 8. Receptor 6 is the one under the palace shadow, and receptors 4 and 8 are under wall shadow, which explains the reason behind their lower PET variation.
- Except for receptor 6, the rest of the receptors show a warmer thermal feel in the first four hours of simulation in comparison with the None scenario. Among them, receptors 8, 7, and 4 are the hottest places resulting from the vicinity of the garden wall.

- Receptor 9, as the coolest receptor in this scenario after receptor 6, stays just a little warmer than thermal behavior of None scenario in the first three hours caused by its vicinity to the biggest basin in this garden.

6.2.1.6 Palace

In section 2.4.5.5.2, the architectural and cultural role of a palace ("Koushk") in Persian garden has been established. To assess its climatic impact in Fin garden, one of the receptors is placed (receptor 6) inside the palace's ground floor. It is located next to the water basin.

In comparison with the rest of the receptors (Figure 6-20), receptor 6 is among the lowest PET due to humidity and shadow provided along the day. It is also a steady and stable PET with minimum fluctuation. However, it shows that Receptors 0, 1, 2, 5, and 10 still have cooler thermal behavior than receptor 6 during the simulation.

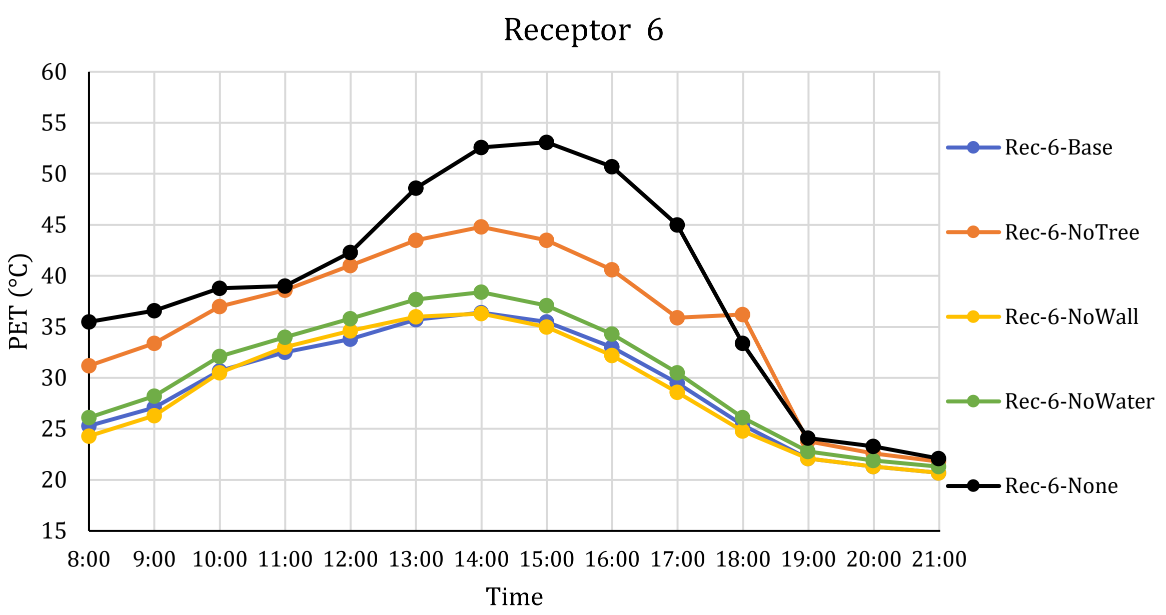


Figure 6-29 - The comparison of Receptor 6's thermal behavior located inside the Palace, in different scenarios during the 13 hours a summer day.

The investigation and comparison of the thermal behavior of this site in different scenarios reveal the following results:

- Although there is no tree inside the building, the effect of removing the garden's trees on the thermal feeling of this receptor is, on average, 6 degrees during the simulation time span. However, the No-Tree scenario inside the place still has a cooling effect up to 10 °C comparing to the None scenario.
- Removing water from this place alters the PET about 2 degrees warmer
- Elimination of the enclosure wall has a trivial impact on the PET of this receptor in comparison with the Base scenario.

6.2.1.7 Spatial Arrangement

To study different combinations of landscape elements in their thermal behavior and their effects at PET, this part is dedicated to evaluating 11 receptors, which have different combinations and orders (Figure 6 -18). In order to do so, 11 location inside the Fin Garden is selected, and in each of them, the above-mentioned scenarios are simulated. The result demonstrates as follows:

Receptor 0 and 1:

These two receptors are located close together but with a different spatial arrangement. The figure below displays these different spatial combinations in the existence of water elements and their differences in the Height/Width ratio caused by the different distances between the row of trees and the pathways' width.

Figure 6-30 - The spatial arrangement of Receptor 0 (left) and Receptor 1 (right) (Source: Author).

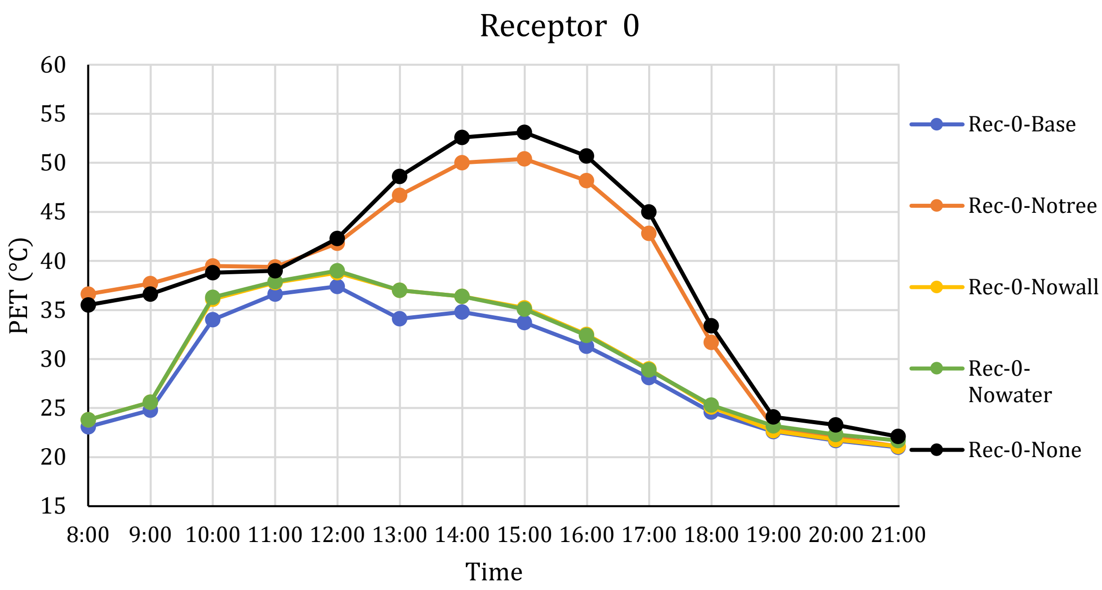


Figure 6-31 - The thermal behavior of Receptor 0 in different scenarios

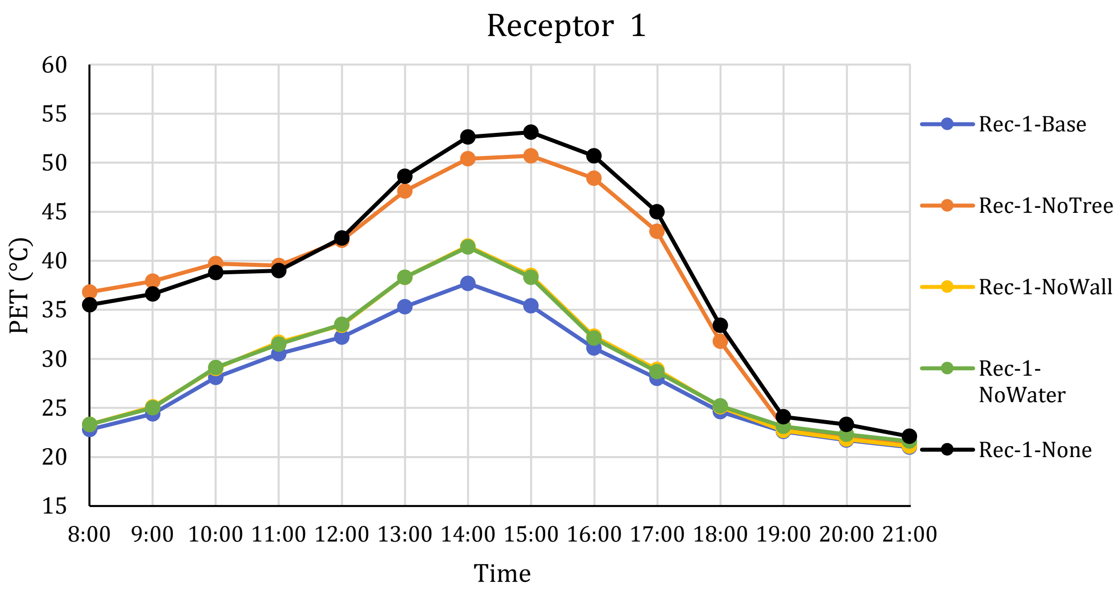


Figure 6-32 - The thermal behavior of Receptor 1 in different scenarios

However, simulation for these receptors shows, in Figure 6-31 and Figure 6-32, that eliminating walls or water has a minor impact on PET up to 3.5 °C, while tree has the most vital role in cooling the temperature. This minor effect of wall elimination could be explained by the distance of the receptors from the wall that remove the shadow factor. In the case of water, here, water canals have more aesthetic roles than climatic, and the fountains and their elimination show insignificant impacts although it has the low-height fountain (Figure 6-30). Comparing the Base scenario with the other scenarios demonstrate that the Base scenario arrangement is the optimal combination.

Receptor 2:

Figure 6-33 - The spatial arrangement of Receptor 2 (Source: Author)

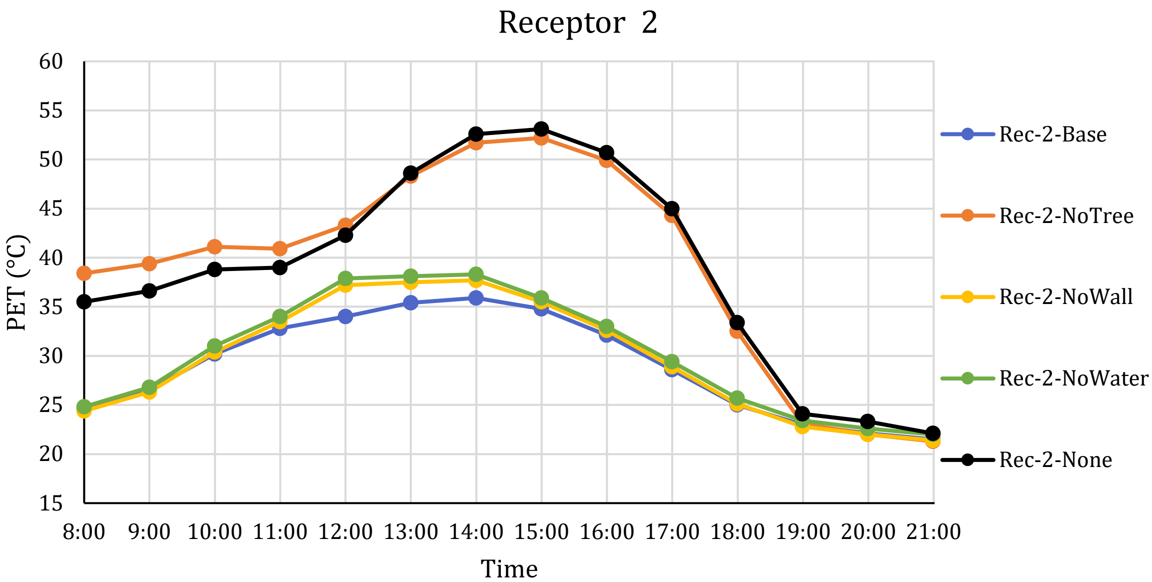


Figure 6-34 - The thermal behavior of Receptor 2 in different scenarios

This receptor is located next to the water basin, which is eight times bigger than the canals. It was expected to show a major influence on thermal behavior, however, the figure above proves once again that, despite the more cooling efficiency than the canals, the water basin still has a minor cooling effect on PET than the shadow. Similar to receptors 0 and 1, trees have shown the most substantial influence.

Receptor 3:

Figure 6-35 - The spatial arrangement of Receptor 3 (Source: Author)

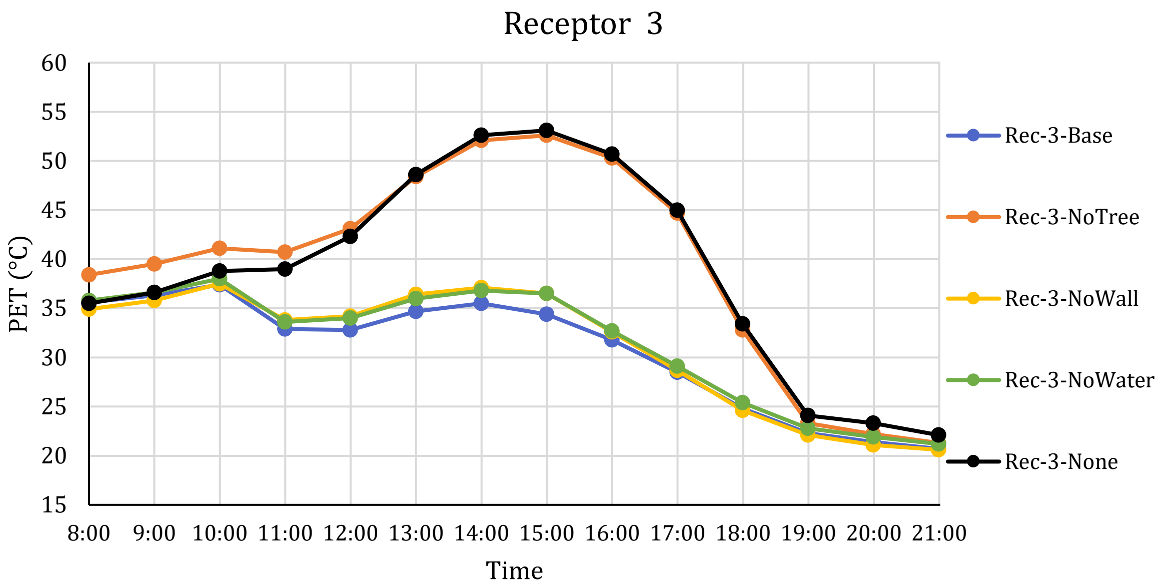


Figure 6-36 - The thermal behavior of Receptor 3 in different scenarios

Although this location includes wall, tree, and water-canal, the simulation still shows a small cooling effect (Maximum 2 °C) for the elimination of water and wall on PET. This is despite the fact that the receptor is next to the wall and explained since the tree-shadows are a dominant factor, covering the receptor all day long.

Receptor 4:

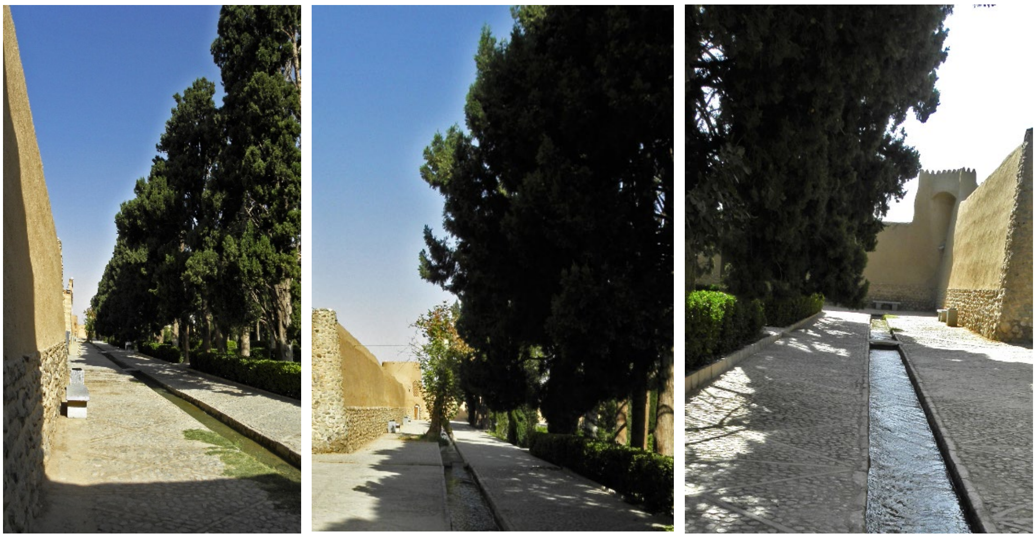


Figure 6-37 - The spatial arrangement of Receptor 4 (Source: Author)

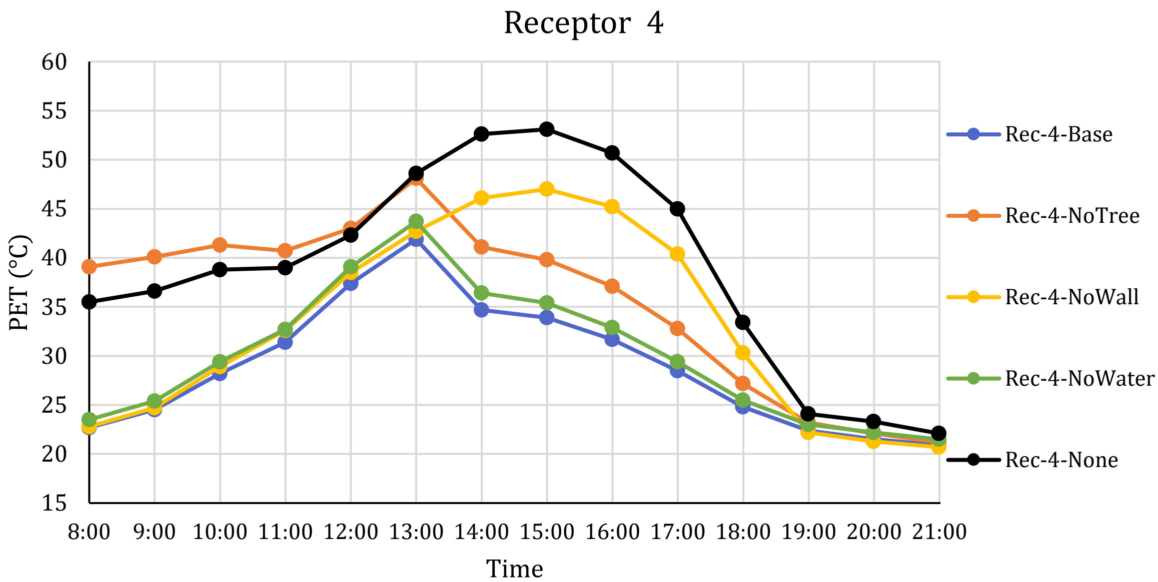


Figure 6-38 - The thermal behavior of Receptor 4 in different scenarios

As explored in the figures above, similar to receptor 3, this receptor also includes the elements of water, tree, and wall. The only difference in this receptor is that it is located close to the wall, under its shadow. Compare to the previous receptor, the dominant shadow is the wall, not the trees, and this explains the higher PET fluctuation during the peak hot hour by removing walls more than trees.

However, water still is the least effective factor on PET, despite its cooling effect is a little higher than receptors 3, which could be explained by the wind direction and amount of air relative humidity in this receptor (Figure 6-19).

Receptor 5:

Figure 6-39 - The spatial arrangement of Receptor 5 location (Source: Author)

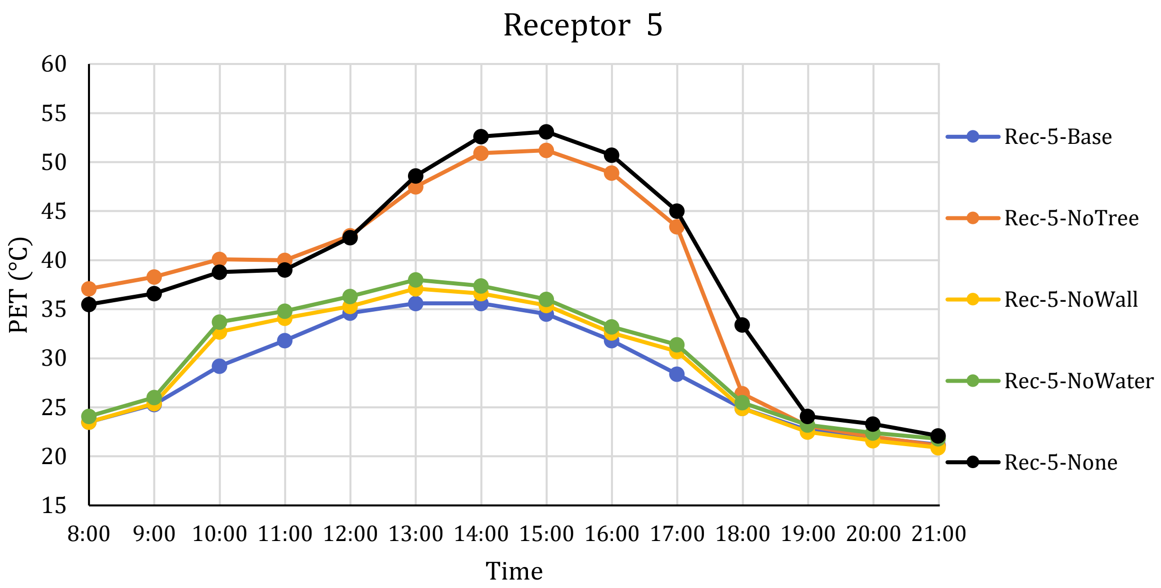


Figure 6-40 - The thermal behavior of Receptor 5 in different scenarios

Receptor 6 is located in the perpendicular pathways and intersection of the two waterways, with a basin in their focal point. Here, the simulation still shows only 2 °C degree difference in PET for both no water and no wall scenario, while by removing trees, PET rises up to 17 °C degrees.

Compared to the first three mentioned receptors, which have equal approximations cooling effect in No-Wall and No-Water scenario, the effect of water removal at this site is only slightly more up to 1 °C degree greater than the effect of wall removal on decreasing PET value.

Receptor 6

Figure 6-41 - The spatial arrangement of Receptor 6 location (Source: Author)

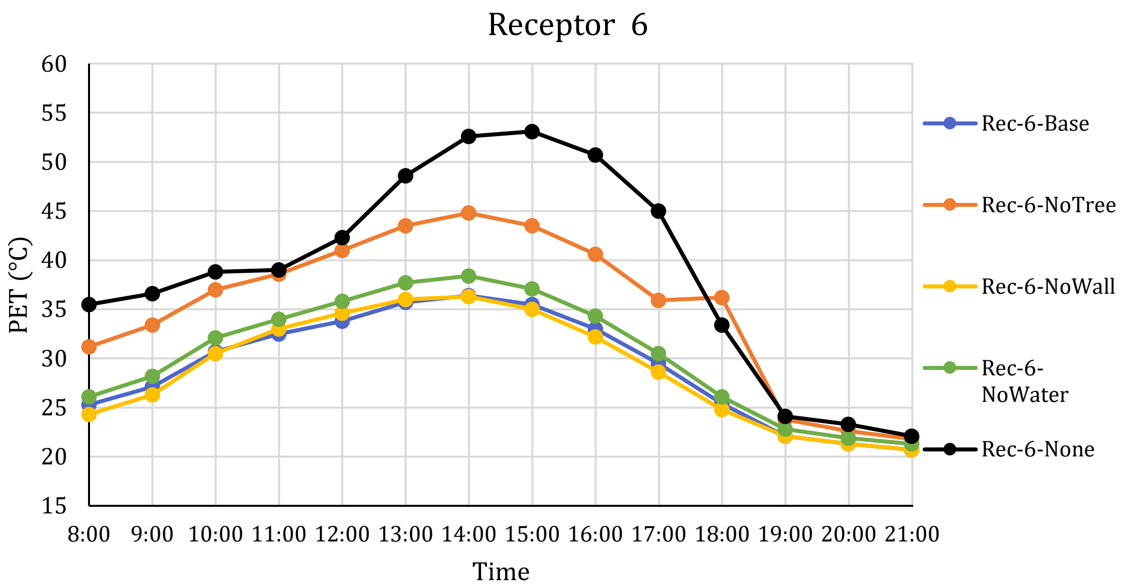


Figure 6-42 - The thermal behavior of Receptor 6 in different scenarios

The palace in this garden is a roofed space where the outside air stream flows into the interior, and the humidity increases, while building materials have surrounded parts of the palace. The study showed that although the temperature tolerance in this room during a day is low, its PET value is up to 2.5 degrees warmer than the comparable PET value in the main axis of the garden.

Inside the "Koushk" beside its basin is the location of receptor 6; removing water from the Base scenario displays up to 2 degrees higher PET due to the existence of a water basin and waterways inside the palace. In comparison with the other sections, the elimination of trees has a lower cooling effect, up to 8.5 PET degrees.

Receptor 7

Figure 6-43 - The spatial arrangement of Receptor 7 location (Source: Author)

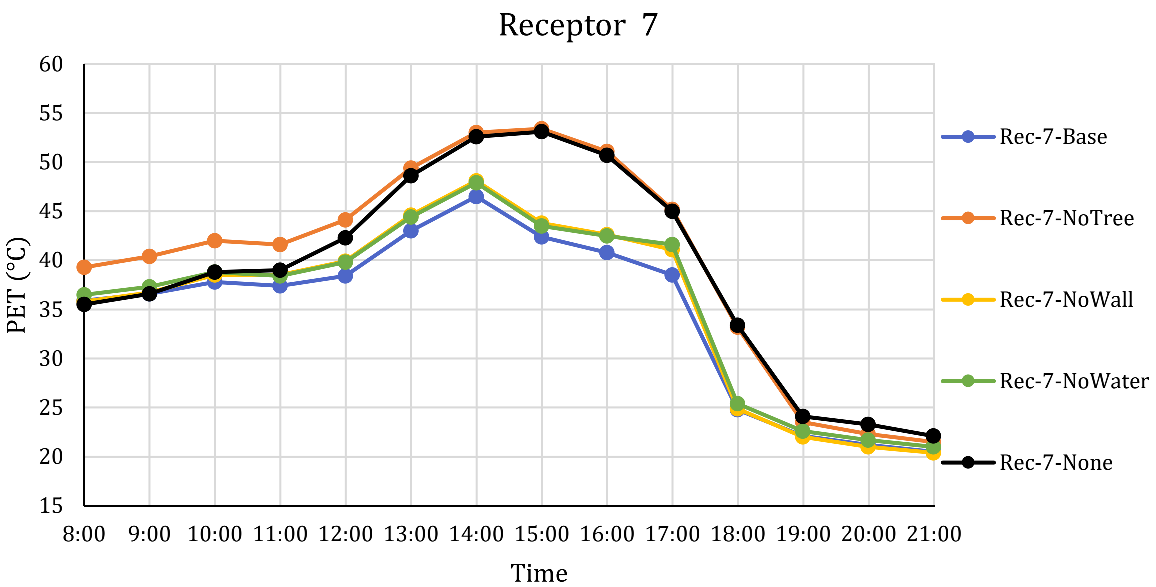


Figure 6-44 - The thermal behavior of Receptor 7 in different scenarios

This receptor is also located next to the walls, similar to Receptors 4 and 3, but this wall is located in a Perpendicular direction. As this receptor is mostly exposed to direct solar radiation, this spot became one of the hottest spots inside the garden. Therefore, eliminating only trees resulted in a simulation as if there is no garden at all. In addition, closing to the hot enclosure wall and wind direction and speed are the intensifying reasons for increasing PET in this location (Figure 6-19).

Receptor 8

Figure 6-45 - The spatial arrangement of Receptor 8 location (Source: Author)

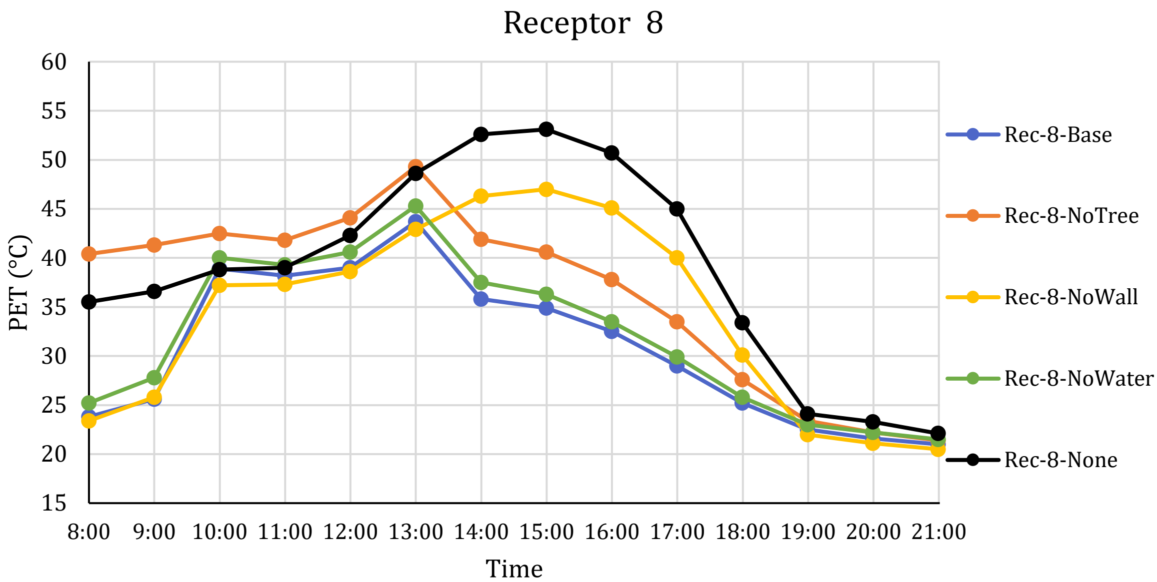


Figure 6-46 - The thermal behavior of Receptor 8 in different scenarios

This section is a combination of all Persian garden factors at one spot, next to a water basin and waterway, under the shadow of trees and a wall. As indicated in the figure above, from the results conducted by simulation, in this location, walls have the most important effect on PET cooling after 14:00 o'clock by providing shadows beside the basin. Obviously, then trees and basins help the cooling effect with humidity. Nevertheless, before 13:00, removing the wall has a positive effect in this location, which could be explained by tree-shadows and increasing the wind speed. This made this location even cooler than the Base scenario.

Receptor 9

Figure 6-47 - The spatial arrangement of Receptor 9 location (Source: Author)

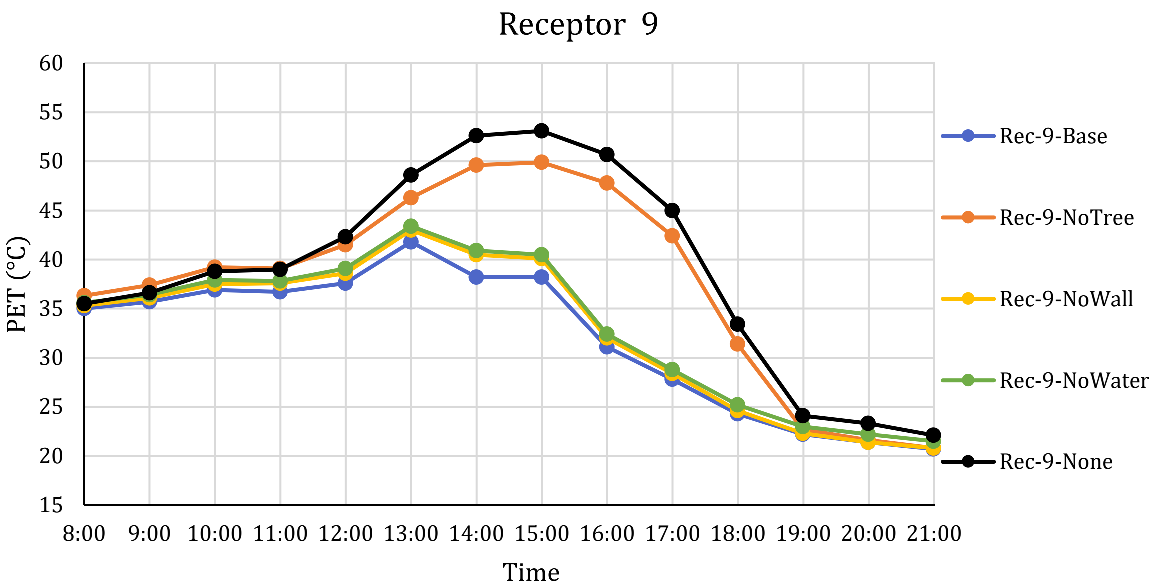


Figure 6-48 - The thermal behavior of Receptor 9 in different scenarios

Receptor 9 is located next to the main largest water basin inside the garden (~14m wide). In this location, trees are still the most effective cooling element than the water. Although, here water basin has shown more cooling efficiency than other receptors, which is up to 4 °C PET degree on its hot peak hour.

Receptor 10

Figure 6-49 - The spatial arrangement of the Receptor 10 location (Source: Author)

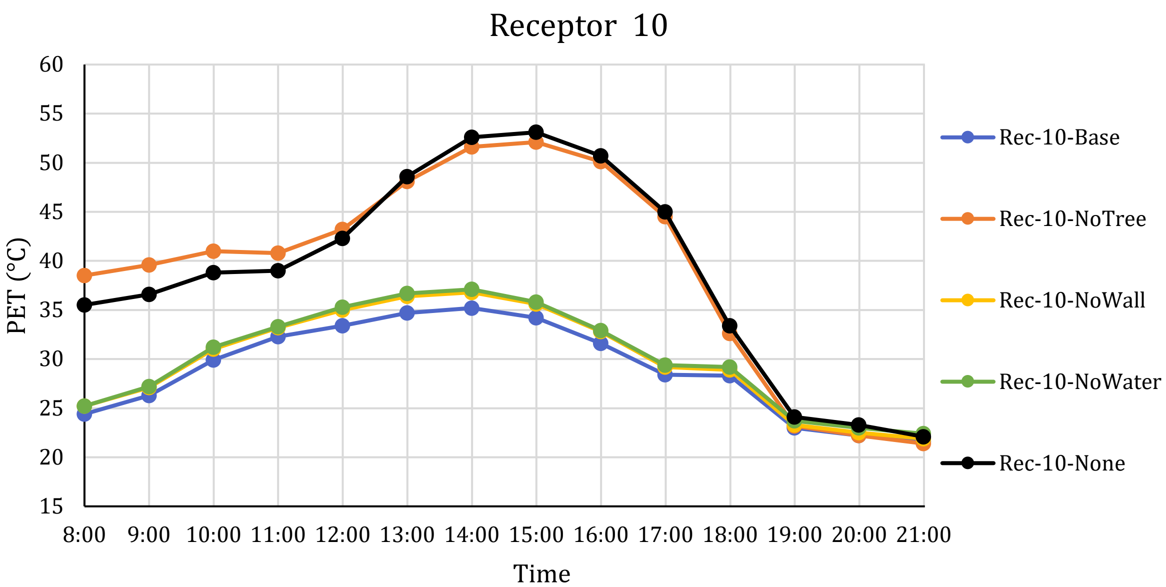


Figure 6-50 - The thermal behavior of Receptor 10 in different scenarios

Under the trees, inside one of the "Karts", the ground material is grass, all surrounded by trees. Under these circumstances, tree is the most efficient cooling factor on PET.

6.2.1.8 Orientation

Fin garden‘s plan is orientated from the East at 35° degree (Base scenario), to evaluate orientation role in its climatic behavior, a set of simulations is run at every 30 degrees rotation from the north that are 0°, 30°, 60°, 90°, 120°, and 150° (Figure 6-51).

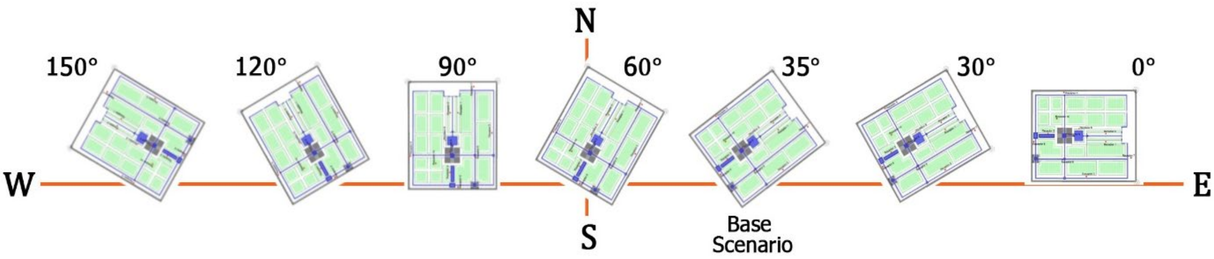


Figure 6-51 - Schematic of different orientation's scenarios

These simulation scenarios are investigated from two points of view: first, the whole receptors' climatic behavior during the day in the aforementioned angels are examined and compared to the current garden situation. Then the main axes in the garden and some of the selected spatial arrangements of the garden are analyzed in different rotations.

The following figures are comparing the PET behavior of Fin Garden in various orientations with the Base scenario along the selected summer day, the same as all other simulations. In order to assess the effect of different orientations in a variety of spatial arrangements, all the receptors are stimulated, as shown in the following figures.

As explored in Figure 6-52 above, the PET tolerances in receptors 2, 5, And 10 are trivial in the variation of the orientation scenario. Receptor 5, by locating in the intersection of two perpendicular axes, shows that the rotation has an insignificant effect on this subject.

Moreover, receptors 3, 4, and 7 are located near the enclosure wall among the remaining receptors. In receptor 3, orientations 30°, 60°, and Base scenario have the coolest behavior, while orientations 150°, 120°, and 0° are the warmest. Receptor 4 is located near the wall (Figure 6 -18), which is parallel to the wall near receptor 3, Base scenario, 30°, and 120° are the coolest behavior, but 150° and 0° are the warmest.

On another side, receptor 7 with the perpendicular wall to the wall of the previous two receptors, 150°, 120°, and Base are the coolest, while the 90°, 60°, and 30° calculated as the warmest PET behavior during the simulation span time.

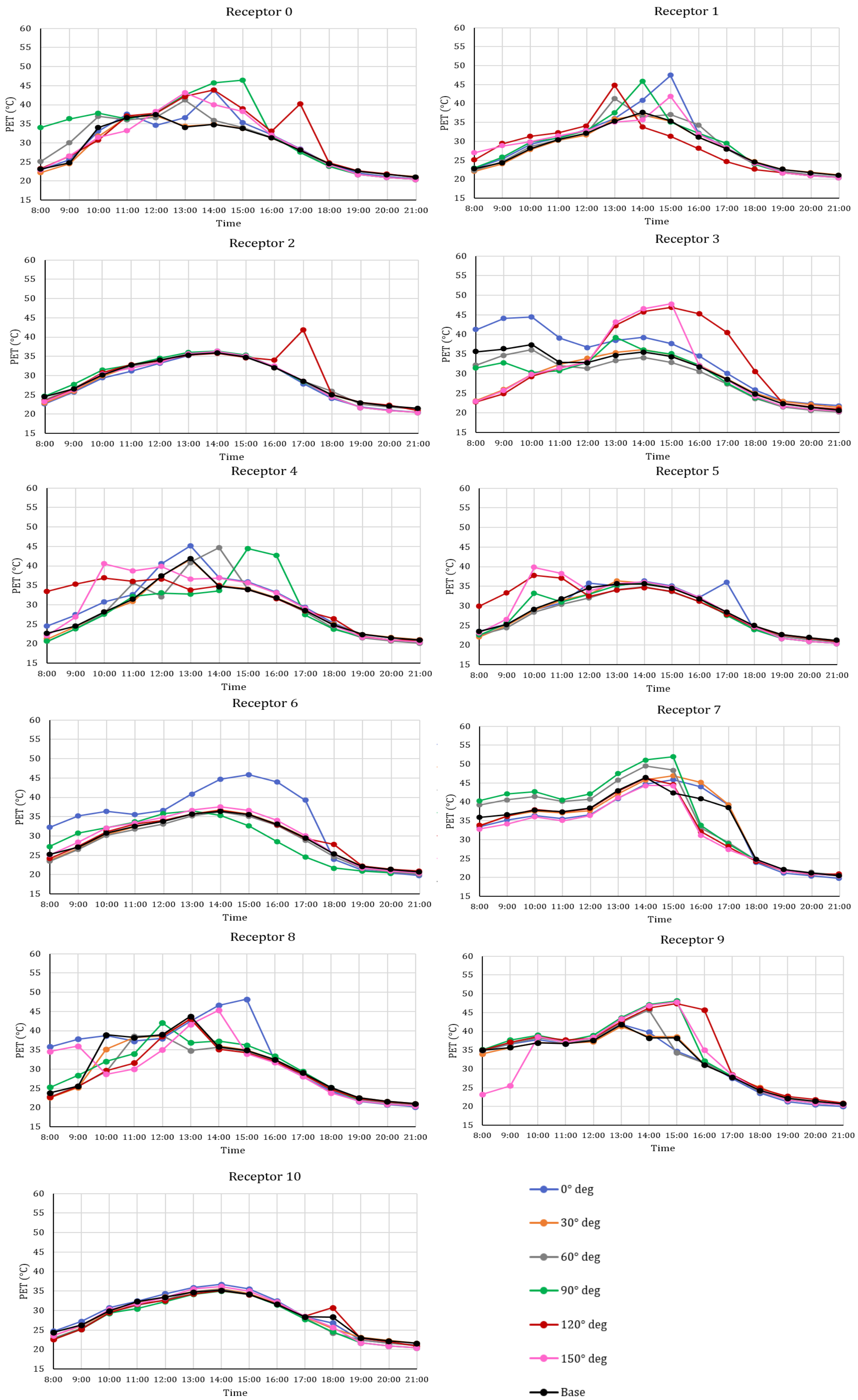


Figure 6-52 - Thermal behavior of all the selected receptors in different orientation scenarios

However, as the main activity space in the garden is the main axes, only the main axis's receptors in the various spatial arrangement are assessed in detail. The selected receptors for the main axes are receptors 0, 1, 2, 6, and 9.

As mentioned above, there are not significant PET changes in receptor 2 in different orientation scenarios. Thus, the rest receptors of the main axis are investigated as the following.

Receptor 0

For receptor 0, as the following figure shows, rotating the garden at Base scenario, 30°, and 60° degrees, has the least PET variation and is the coolest PET during the day. On the other side, at 90°, 120°, and 0° are the warmest PET.

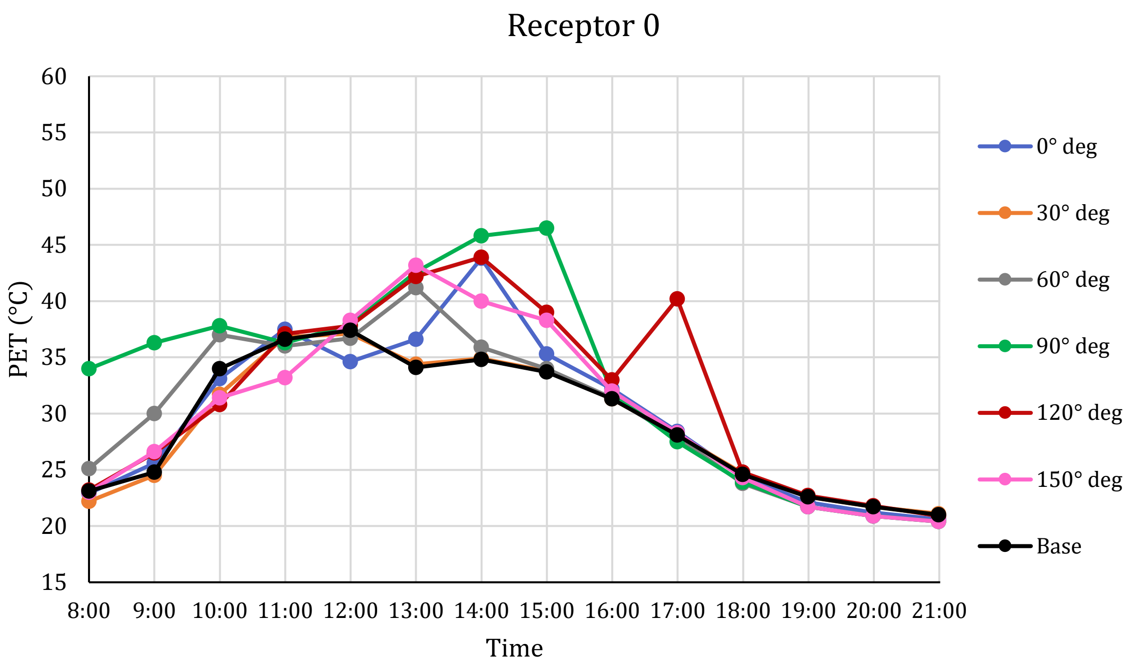


Figure 6-53 - Thermal behavior of Receptor 0 in different orientation scenarios

Receptor 1

Due to a higher Height/Width ratio of receptor 1's location than receptor 0, varying the garden direction does not play a particular role. However, as displayed in Figure 6-54, this receptor also in Base scenario, and 30° has the cooler PET situation, while 0° and 90° have the warmest.

The figure below also shows a noticeable thermal behavior at 120° rotation scenario, which is 30° + 90° rotation. After 13:00 o'clock, it significantly has a cooler thermal status than the rest of the scenarios. It means the thermal behavior in the perpendicular axis could have a cooler PET.

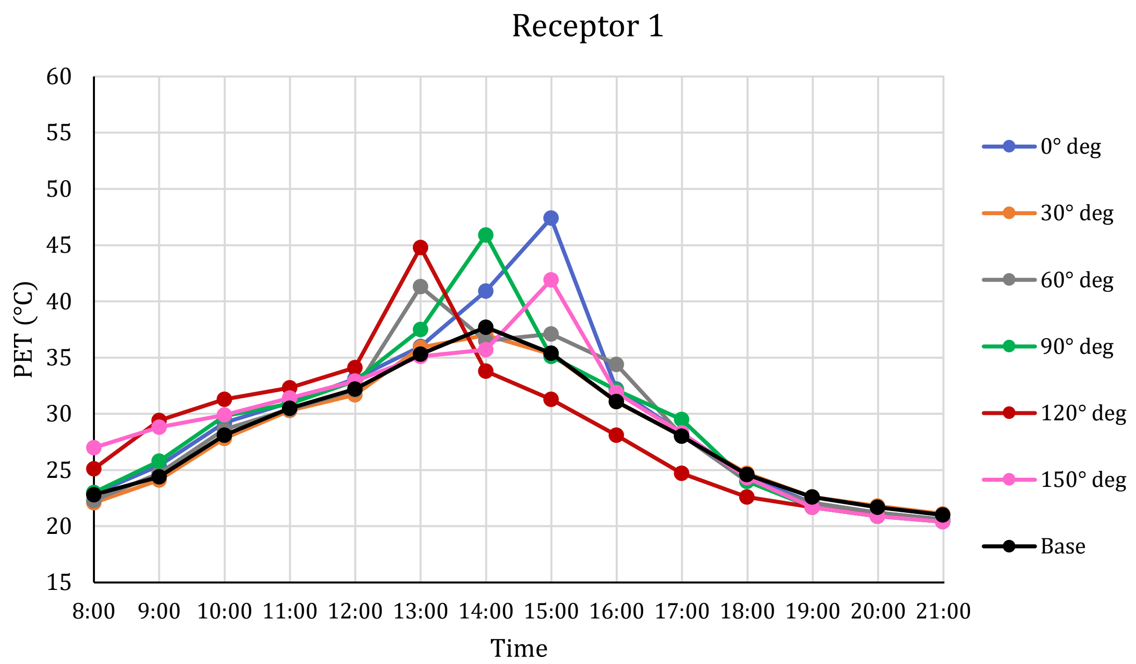


Figure 6-54 - Thermal behavior of Receptor 1 in different orientation scenarios

Receptor 6

As analyzed before (ref. section 6.2.1.6 and 6.2.1.7), this receptor, due to its location (Figure 6 -18), which is under the shadow during the day, has an insignificant thermal tolerance on PET.

However, as shown in Figure 6-55, except 0° and 90° scenarios, the rest of the orientations scenarios act approximately similar to the Base scenario. Indeed, in 0° rotation scenario, the receptor, by placing under the direct solar radiation after 12:00 o'clock, has such a significant warmer thermal behavior.

Conversely, the 90° rotation scenario, placing the receptor far from direct solar radiation and in the wind direction after 13:00, has the coolest thermal behavior among all the orientation scenarios (Figure 6-55).

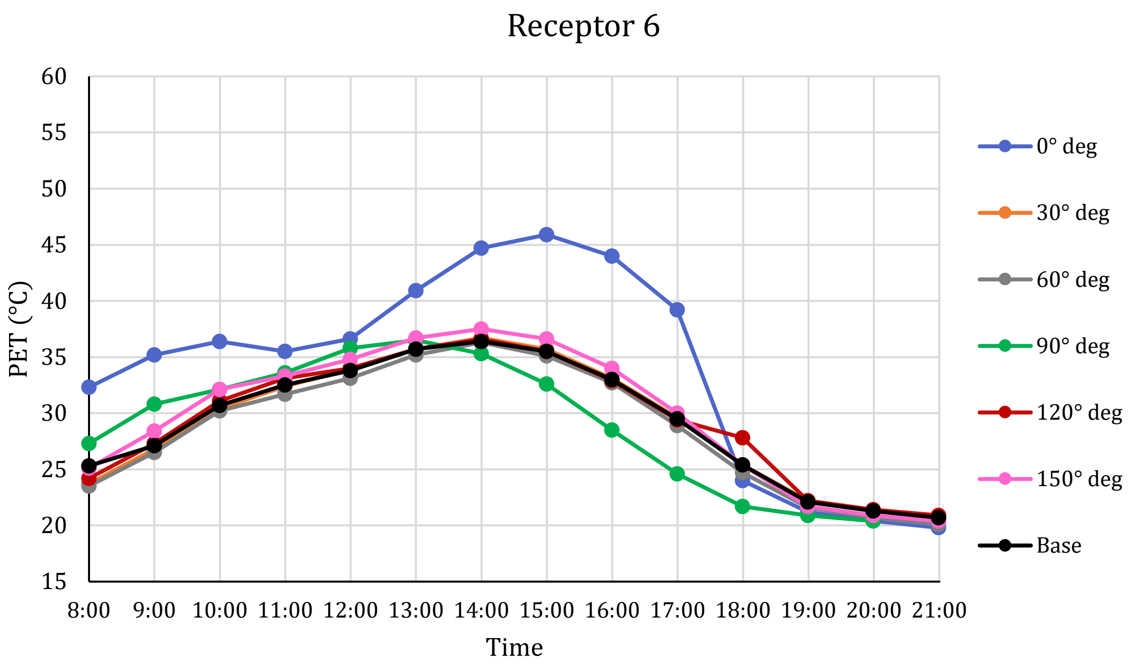


Figure 6-55 - Thermal behavior of Receptor 6 in different orientation scenarios

Receptor 9

For receptor 9, as the figure below shows, rotating the garden at Base scenario, 30°, and 0° degree has the least PET variation and is the coolest PET during the day. On the other side, 120°, 150°, and 90° show the warmest PET.

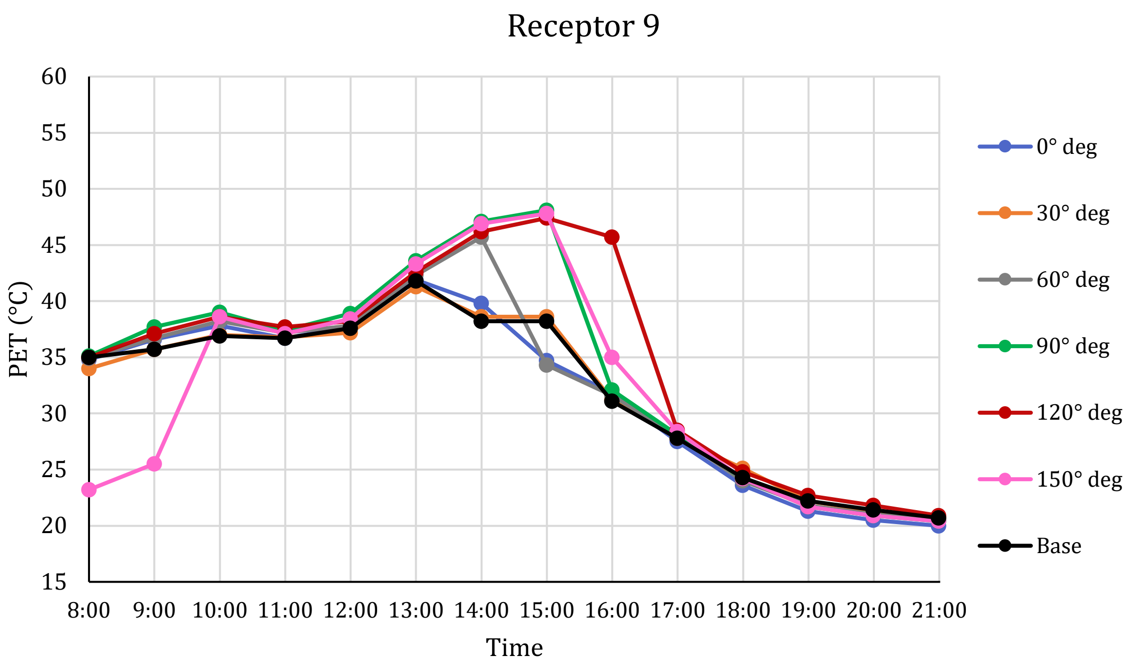


Figure 6-56 - Thermal behavior of receptor 9 in different orientation scenarios

Based on the overall PET behavior, it is noteworthy that the best rotation for this garden is the Base scenario and 30°. However, as discussed earlier, apart from these two rotation scenarios, the thermal behavior of scenario120°, which is the 90° rotation from these scenarios, was more beneficial and cooler than the rest of the scenarios, especially in the axes and intersections.

6.2.1.9 Material

Land cover materials in Persian gardens mainly include vegetation, water bodies, soil, and build-up materials. In the case of Fin garden, grass, water, stone pavement, and soil are considered as the land-cover materials.

In order to evaluate the effect of different types of land-cover materials applied in Persian garden, the air temperature of the simulations performed in both Base and No-tree scenarios at the height of 20 cm above the ground is calculated and shown in the figure below. By analyzing the investigated results, the thermal effects of these materials were determined in either shadow or direct sunlight situation (Figure 6-57).

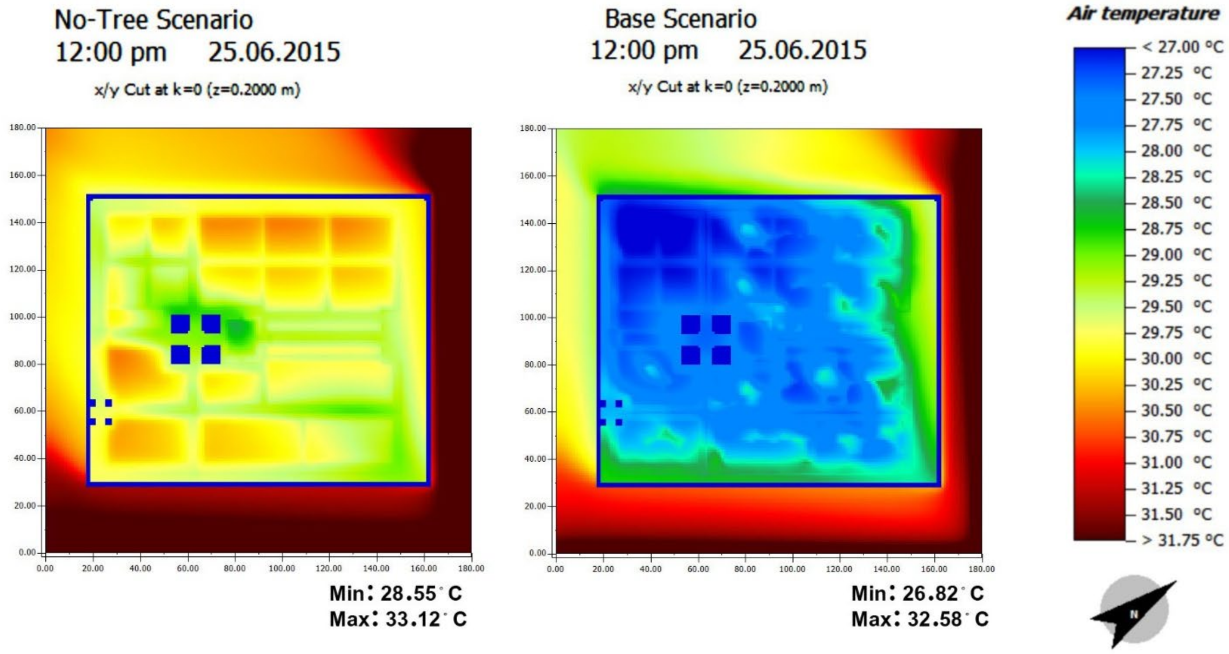


Figure 6-57 - The above air temperature (20 cm height) of the ground-surface materials at 12 o'clock. The left figure shows the results under the direct sunlight condition, while the right figure presents the under tree-shade condition.

Fin garden simulations demonstrated that under direct sunlight, the air temperature above the water body was significantly lower than in built-up or grass-covered areas. These differences were more tangible in direct sunlight than in shadow conditions. For example, the above picture clearly shows how this occurs on a summer day at 12 o'clock.

It was also found that in the case of direct radiation, the dimensions of the material surfaces play a more significant role in the thermal effect on the ambient air temperature.

A noteworthy point in this study is that in direct sunlight, the air temperature above the grassy areas is higher than that of the architectural material, while the grass-covered surfaces are cooler under the shade. However, in these scales of surface materials, the difference in air temperature above the grass and the built-up surfaces is calculated as not more than 0.75 °C.

After determining the effect of the different materials, in the next step, to demonstrate their influence on thermal comfort, however, their PET maps were compared at human height. The results revealed that their impacts in comparison with other factors of the climatic design were not noticeable in this arrangement and design, especially under the shadow conditions (Figure 6-58).

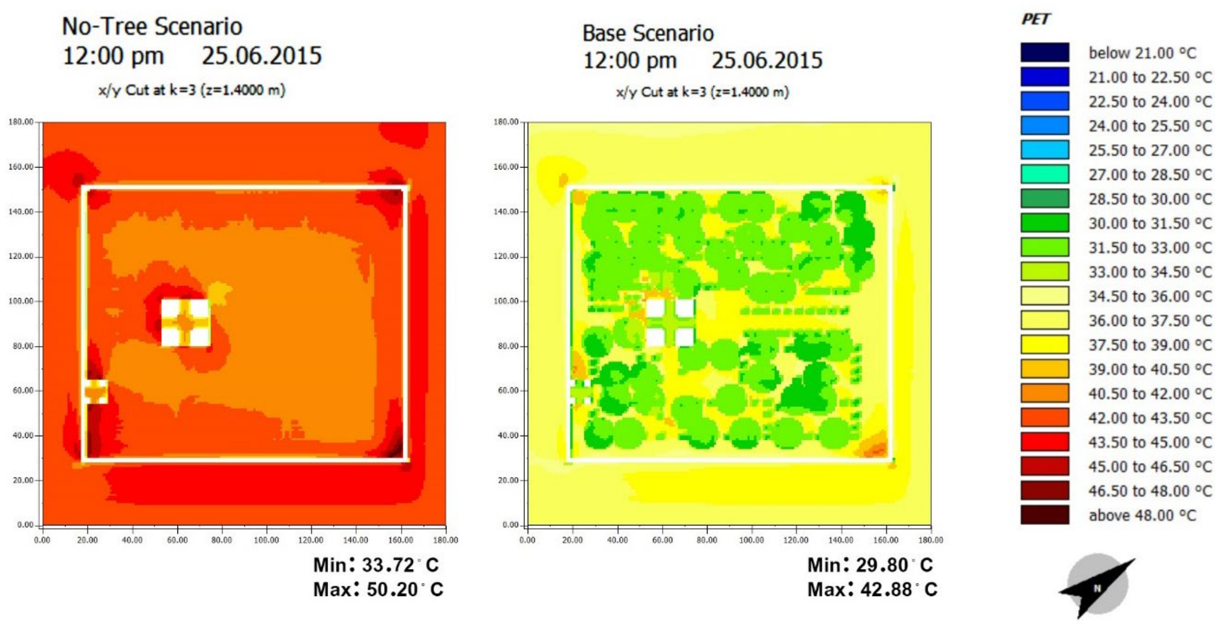


Figure 6-58 - The PET values (at human level) of the ground-surface materials at 12 o'clock. The left figure shows the results under the direct sunlight condition, while the right figure presents the under tree-shade condition.

6.3 Microclimate Simulations II: A Contemporary Park in Kashan

6.3.1 Case Selection

In order to be able to compare the concept of traditional Persian garden and investigate the usage of its indicators in relation to thermal comforts, a temporary park within the same climatic situation as Fin garden, with an approximately equal area, must be selected and simulated in Kashan city.

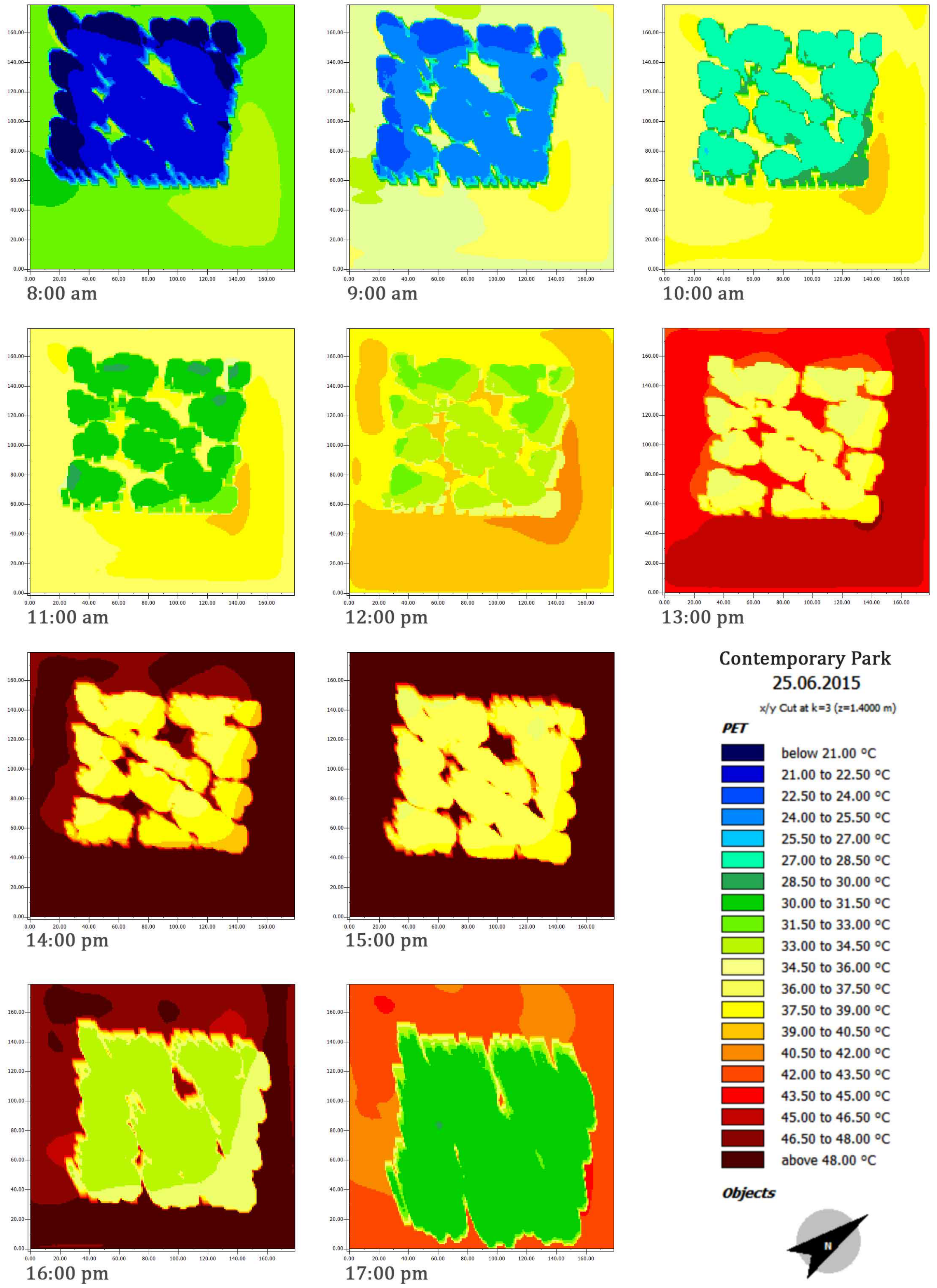
Therefore, a Contemporary Park, located 6 km from Fin Garden, is selected. This park is approximately equal to the number of trees (about 10% more), as well as its green coverage and water surfaces within ≅14000 m^2 (~15% smaller than inside of the Fin garden area), while designed structurally different (Figure 6-59).

Figure 6-59 - Location of the Contemporary Park in Kashan city (Google Map (2017))

6.3.2 Microclimate Simulation Analysis

In this section, the park's simulation has been run for 13 hours, the period of time when encompasses the most outdoor activities starting from 8:00 am to 21:00 pm, as well as Pervious simulations for Fin Garden, in the same date and climatic input dataset.

It should be mentioned again that each type of tree (used in all modeling of this research) was used with equal physical characteristics to have a better and more accurate comparison. Moreover, these simulations just focus on the inside of the garden and park area as the aim of this research and also because of the limitation on the area size of simulations (180*180*30). Therefore, similar to the Fin garden simulations in these simulations, the outside of the park is also not modeled. However, after simulation, the following PET maps, extracted from LEONARDO software, explore the thermal behavior of the Park during the day (Figure 6-60).



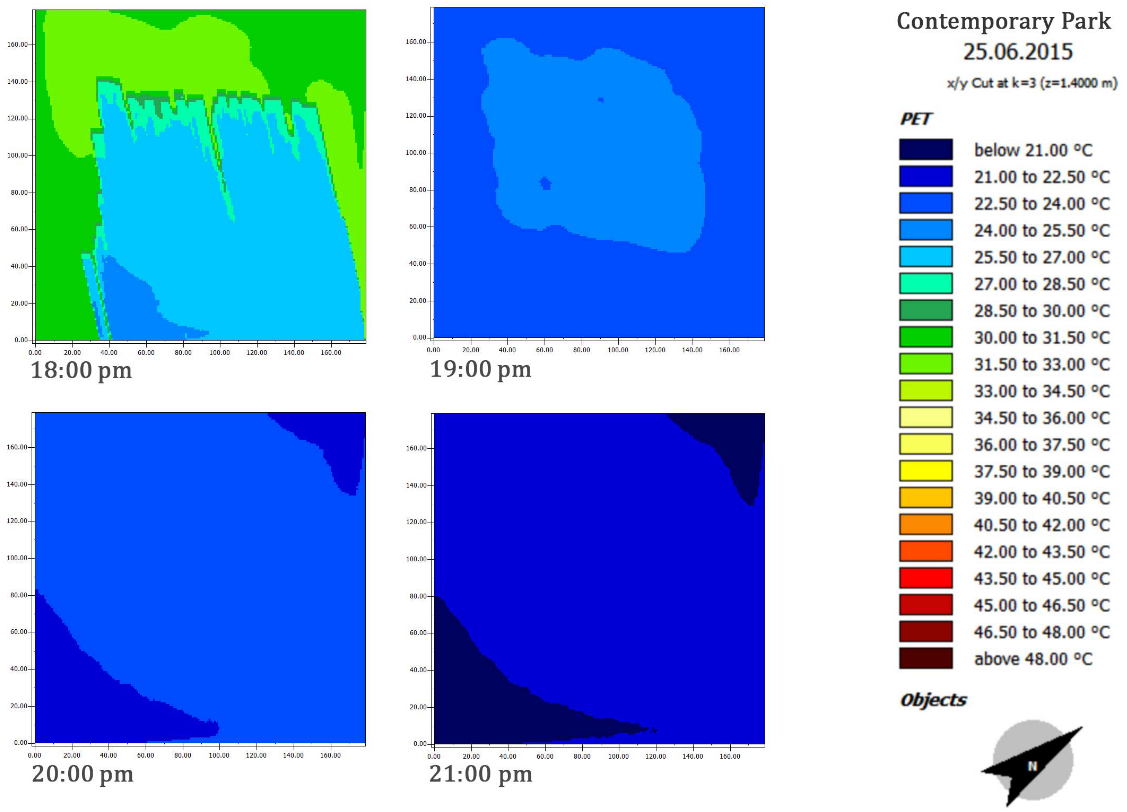


Figure 6-60 - Thermal behavior of the selected contemporary park in Kashan during 13 hours a summer day

A close examination of the above figures illustrates the points as the following:

- The park area is warmer than its surrounding area after 19:00 o'clock
- The impact of Wind direction on expanding the cooling effect of the park is obvious, and also it explains the coolest area of the park
- 14:00 and 15:00 o'clock are the hottest hours of the day.
- The cooling effect of water surfaces in this park is not recognizable, so that it is negligible. It could be related to their size and also the usage of low-rise fountains.
- The warmest area during the day belongs to the area covered with asphalt.

6.4 Comparison of the Results of Simulations I vs. Simulations II

At this step, a comparison should be made to determine how the thermal behavior of the park and the Fin garden is and which one's cooling effect works optimally.

As mentioned before, to have a better and more accurate comparison, the simulation model of the contemporary park as well as the Fin garden, focus only on the thermal behavior and design area inside the garden and park rather than their outside, which is in line with the goal of this study.

The Comparison of the thermal maps of the Fin garden with the contemporary park during the day clearly represents a cooler atmosphere within and around the Fin garden rather than the park, in spite of having more than ten present trees and green coverage and ~15% smaller area. This PET difference is much more obvious at the hottest time of the day (12-16 pm).

Although the comparison of the thermal behavior of these two areas with each other due to their design differences and also the small difference in the number of trees and their area (not exactly equal) cannot be cited.

Nevertheless, the maps and results indicate a better thermal behavior of the Fin garden. In contrast, the smaller area of the selected park and the larger number of trees in this park did not lead to having a cooler efficiency than the Fin garden (Figure 6-61).

With an overview of Figure 6-61, it is easy to recognize that the minimum PET degree always occurs in Fin garden during the day in comparison with the contemporary park. Furthermore, as explored in this figure, these minimum PET differences are calculated as up to 4 °C.

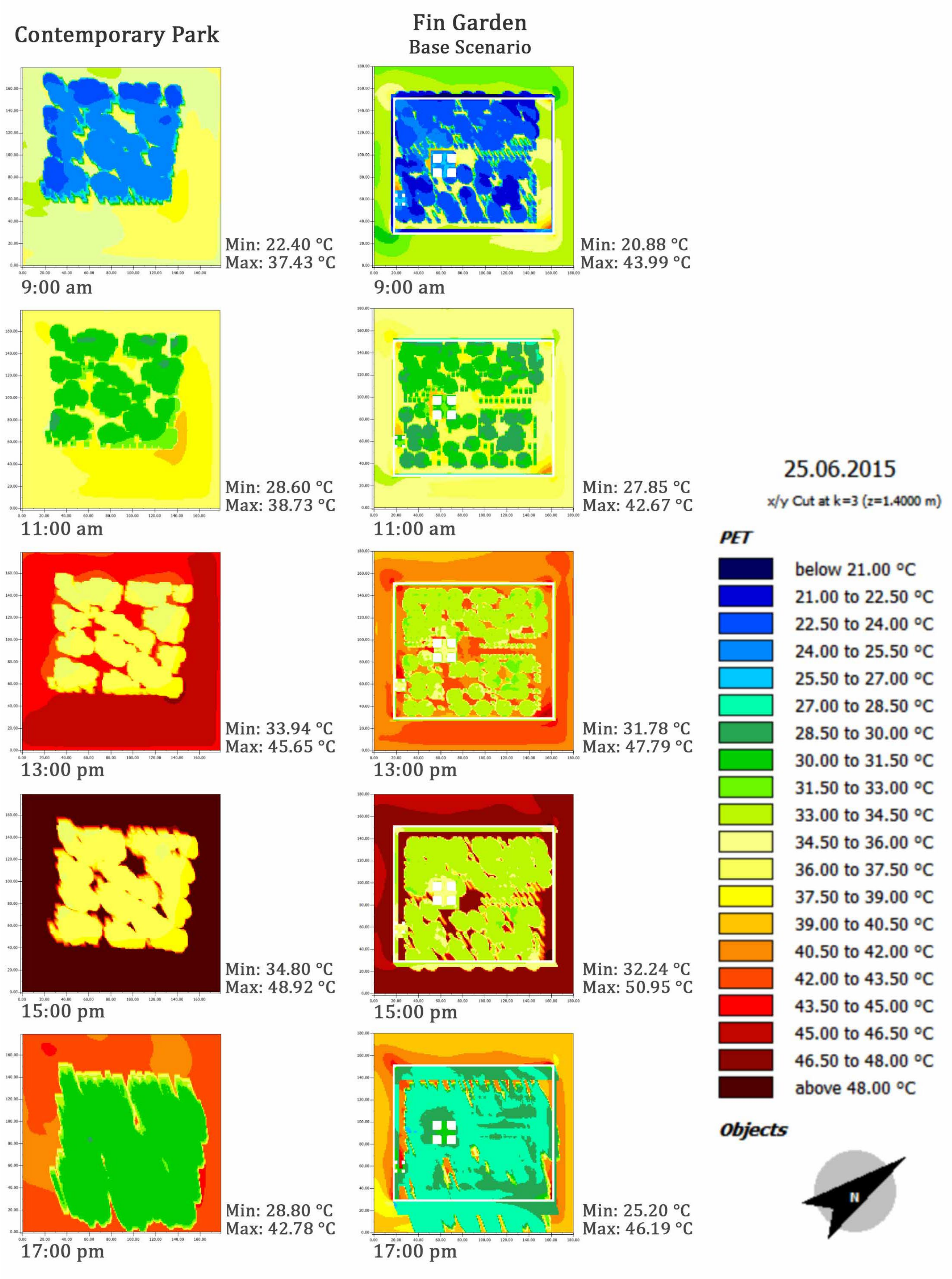


Figure 6-61 - PET comparison of Fin garden (right column) with the selected contemporary Park (left column) of Kashan during the day

As can be seen in Figure 6-61, although the Fin garden has a cooler thermal behavior, which emphasizes the more successful design of Fin garden, the maximum PET degrees are also seen in the Fin Garden's map. As mentioned before in section 6.2.1.3, these occur just in a small area of wall junctions in corners, which are caused by reflecting the heat radiation of the walls surfaces where there is the least wind speed.

Therefore, in the next step, it is tried to redesign the contemporary park to make it more efficient and comfortable, based on analyzes and studies on the Fin Garden and the results obtained from the performance of its elements in the Thermal Comfort. Afterward, the optimal design will be simulated to compare and analyze its thermal behavior during the day.

Chapter 7: Simulation Results, Optimal Green Strategies

In the previous section, considering the comparison between the contemporary park in Kashan and the Fin Garden in terms of thermal comfort of these two green spaces, the greater thermal performance of the garden was clearly noticeable compared to the park. Therefore, based on the extracted results from the Fin Garden simulation, besides some other techniques applied in other Persian gardens and also the new strategies of climatic designs, in this chapter, it is tried to improve the thermal behavior of the Park by redesigning.

To this end, firstly, some design techniques, which are not applied in the design of Fin Garden, are elaborated and investigated. Afterward, the selected methods are applied in designing the optimal version of the park, which has the exact number and type of trees as well as the equal area of applied water surfaces.

In the next step, the optimal version of the contemporary park is simulated, and the thermal performances of this park are compared with the current park and Fin garden.

7.1 Extracted Results from Simulations

Water: The greater the water surface area, the greater the cooling effect. Thus, water canals in Fin garden had a greater role in the beauty and psychological impact than the cooling effect. Besides this, it was demonstrated that the cooling effect of low-height fountains is trivial and negligible.

Wall: There are advantages and disadvantages to having an enclosure wall around the garden in such a hot and dry climate. As explored before, in the case of Fin garden, the presence of this wall could generally have a small positive effect on the decrease in PET value while it could also have a negative thermal effect on the wall-side, which is exposed to direct solar radiation. Walls also assist in keeping and preventing the moisture inside the garden besides protecting the garden from the outside dusty-warm, while they also block the wind flow to the garden.

Trees: The role of trees as the most effective PET value-reducing tool has been clearly identified. It was also noted that the amount of shade related to the size of the tree canopy is the main factor in this regard. Obviously, in the selection of trees, local trees should be applied, which are adapted to the local climate and its climatic conditions as it has been applied in Persian gardens.

Spatial arrangement: According to the Fin garden's simulation, the best PET behavior in Fin garden was belong to the receptors of the main axes and receptors 5 and 10. Thus, applying their spatial arrangements could improve and optimize the thermal conditions of the outdoor spaces.

Orientation: On the basis of the simulation, it is remarkable that one of the best rotations for the main axis is 30° - 40° and also 120° from the East.

7.1.1 Alternatives Extracted from Other Persian Gardens

To achieve the best thermal performance in the green space, it is advisable to consider other ideas that have been implemented in other Persian gardens, such as applying high-rise fountains, variation in basin size, and different types and heights of the enclosure walls.

7.1.1.1 Fountain

The role of water in increasing air humidity commonly seen in Persian gardens, as well as Fin Garden, as water ponds or low-rise fountains, has been studied. However, high-rise fountains are also applied in Persian gardens such as Shahzadeh-Mahan and Hasht-Behesht Gardens. Thus, in this part, the thermal impact of the high-rise fountain is examined by simulation. For this purpose, different distance combinations of a high-rise fountain are modeled and simulated to calculate their cooling effect.

This simulation contains 4 equal basins (20m*2m), one of them consists 5 fountains with 3-meters high and 3-meter distance between them, the next one has no fountain, the other has 2 fountains with 3-meter distance together, and the same high, and the last one also has 2 similar fountains but with 6 meters (doubled) distance in between. For each basin, 4 receptors are defined. Two of them are located at a distance of 2 meters from the middle of the basin on either side, and the other two are located 6 meters from its middle on both sides of the basin (Figure 7-1).

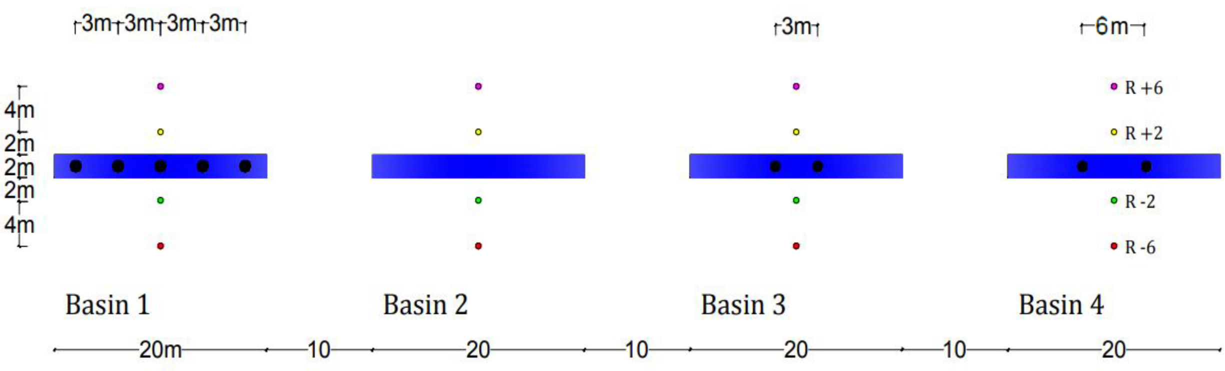


Figure 7-1 - Plan view of modeled Basins, five fountains (Basin 1), No fountain (Basin 2), two fountains with tree meters distance (Basin 3), and two fountains with five meters distance (Basin 4). The place of receptors is shown as R +6, +2.-2, and -6 so that the numbers indicate their distance from the Basins.

The simulations are run and calculated based on the similar input climatic data set, date, and time span, as well as other simulations in this research. The results are displayed in the figures below.

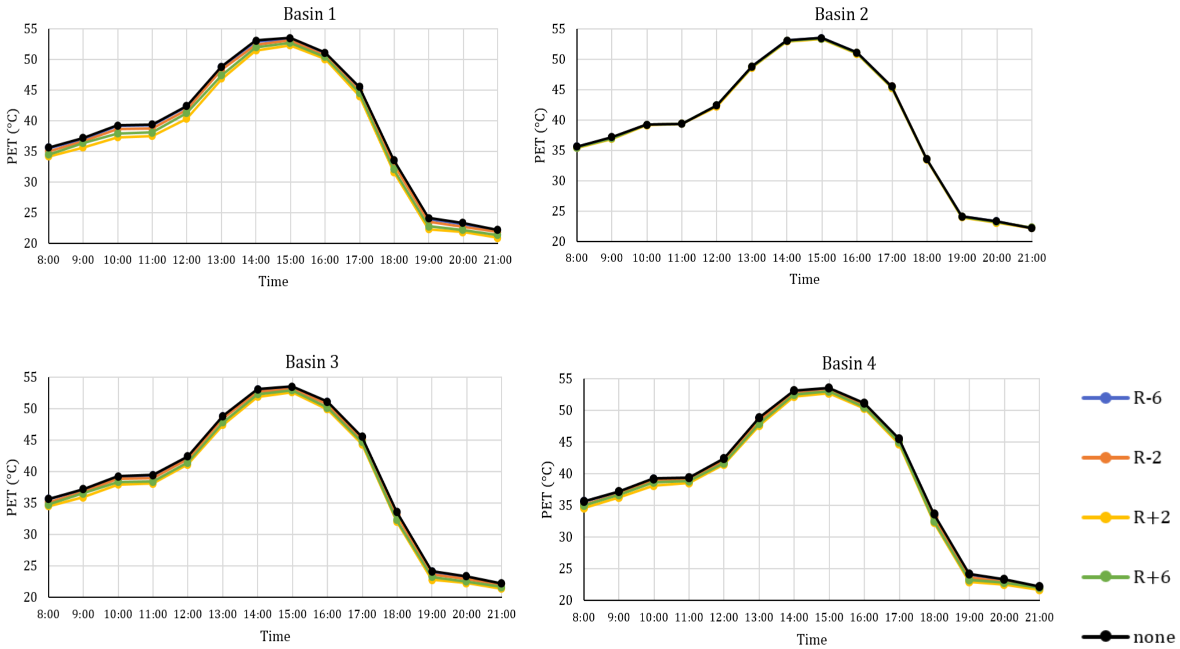


Figure 7-2 - Comparison of all receptors of each scenario together, the receptors' places are shown as R+6, +2.-2, and -6 so that the numbers indicate their distance from the Basins

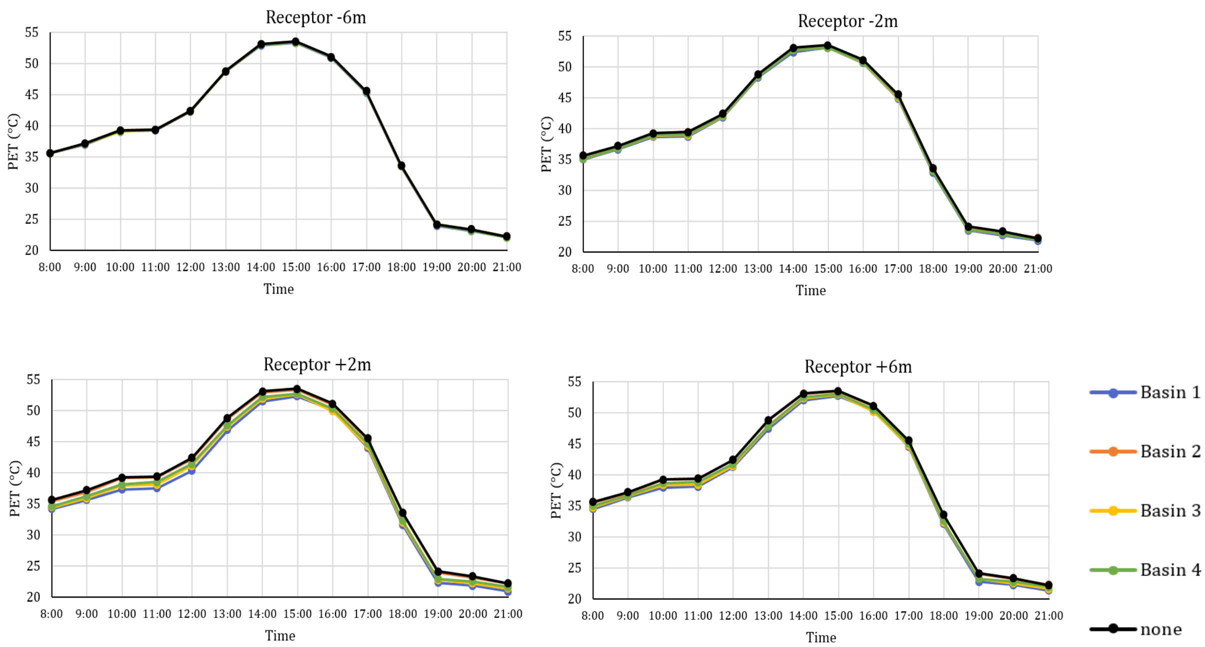


Figure 7-3 - Comparison of the receptors with the same distance from the basins in different scenarios

Based on the graphs above (Figure 7-2 and Figure 7-3), the following results are derived about the cooling effect of fountains, which have three meters high in the determined time span:

- The higher the number of fountains, the greater their cooling effect.
- The greater the distance between the fountains, the less their cooling effect on their ambient areas
- The further distant from the fountains, the less their cooling effect. It should be mentioned that their cooling efficiency, in the case of the equal fountains' characteristics, depends on the number of fountains, the direction of the wind, and the distance the fountains are from each other.
- Just having a basin with these defined dimensions has almost no effect on cooling
- In this case, the direction of the wind has a very decisive factor in cooling the fountains' ambient PET value, so that the temperature difference of the PET is calculated on both sides of Basin 1 with an equal distance (2 meters) up to 1.7 °C. Moreover, in the opposite wind direction, the recorded PET of 6m distance from the fountains is almost equal to the None Scenario's PET.
- However, to determine the number and distances of the fountains, an accurate analysis based on the environmental conditions should be carried out to ensure the optimal design for the needs of the project.

7.1.1.2 Wall

In the study of the element of Persian garden in Fin Kashan garden, only the effect of presence or absence of wall element on thermal comfort is investigated, including its advantages and disadvantages. As discussed before (ref. section 5.4.1.5.2), the variety of wall-heights has been applied in different Persian gardens due to their region-climate of their functions. While suitable materials, which were locally produced with high heat capacity and low reflectivity, have been applied to build the walls and other architectural constructions (2.4.5.5.1). Therefore, studying the thermal effect of these factors on human comfort can be helpful.

For instance, studies emphasize the significant role of surface material selection for the constructions on outdoor thermal comfort. So that, they indicate that the greater tendency to absorb and store more heat energy is seen in dark and rough materials, while materials with high albedo mitigate heat storage through reflection. Thus, high albedo materials should apply with a consistent sky view factor (Ali-Toudert & Mayer, 2007a, 2007b; Gupta, Anand, & others, 2015; Kwon & Lee, 2017; Nikolopoulou, 2011; Rosso et al., 2018).

Moreover, applying the green wall that has been mentioned and even recommended in many new studies, which have better thermal behavior and are more sustainable (Köhler, 2008; Manso & Castro-Gomes, 2015; Pérez-Urrestarazu, Fernández-Cañero, Franco-Salas, & Egea, 2015; Sheweka & Magdy, 2011; Urrestarazu & Burés, 2012). However, these alternatives are also examined in the next step as the alternative simulations.

However, in this part, before redesigning the contemporary park, the thermal impact of the enclosure-wall material and height is examined by simulation. To this end, enclosure walls with one-meter width are assumed around the park border. As a material comparison, only the thermal effect of the brick wall applied in Fin garden is compared to the green wall material because different materials (even each of brick and cement materials) have a wide range of thermal reflective and capacities, regarding their structural density and color. In these terms, many studies have been conducted and widely discussed in more detail in other studies.

The ground surface material is the same throughout the plan without any tree or vegetation and water basin. Most parts of these walls are considered green walls, excluding the two parts of the horizontal wells in the plan, which are made of bricks (Figure 7-4). The left vertical wall of the plan consists of a green wall with four-meter high (average height of the wall in Fin garden), but two parts, which are illustrated in Figure 7-4, are considered as two meters high. Some openings are also implemented in both vertical and horizontal walls.

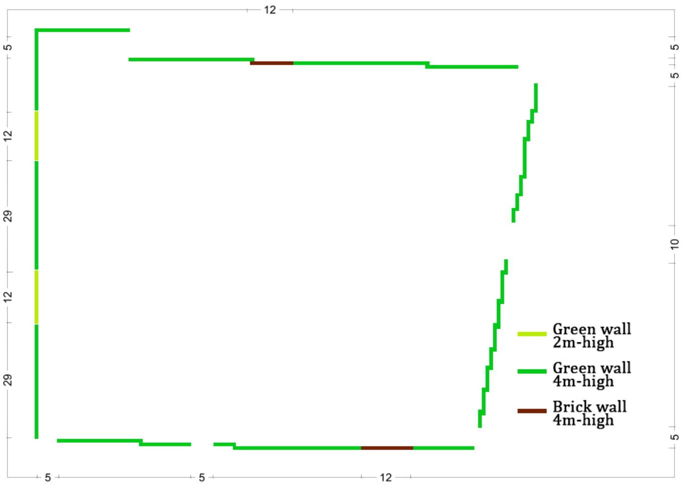


Figure 7-4 - Plan view of modeled enclosure walls alternatives in the contemporary park area

As well as other simulations of this research, these simulations are performed and calculated based on the similar climatic input data set, the date, and time span. The results at the pedestrian level are shown in the following figures.

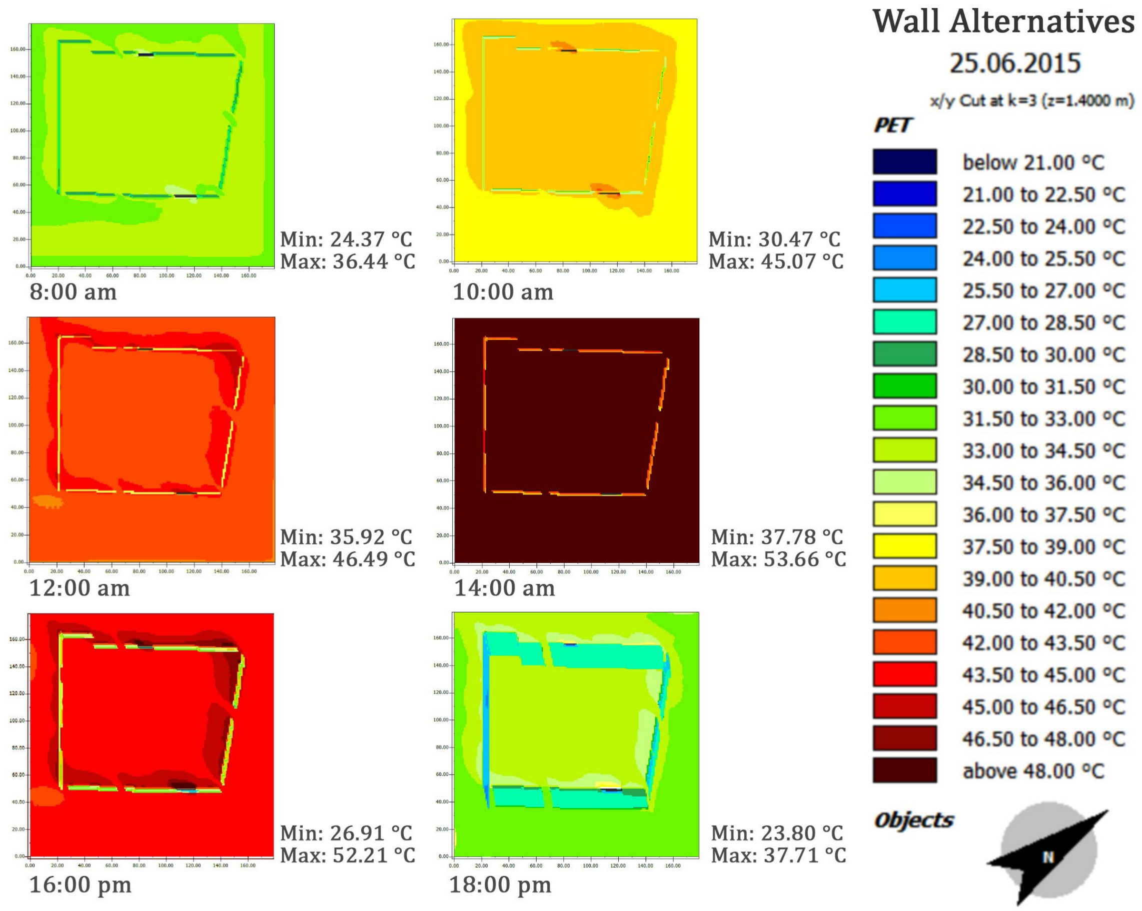


Figure 7-5 - PET map of enclosure-wall alternatives in contemporary park area during the summer day

Based on Figure 7-4 and Figure 7-5, the following results are derived about the cooling effect of enclosure-wall in the determined time span:

- The wall increases the PET temperature behind the wall by blocking wind
- As the figure above illustrates at 8, 10, and 18 o'clock, the walls not only increase the PET temperature in the vicinity of the walls but also increase the total temperature inside the area.
- In the horizontal walls of the plan, it is obvious that the brick walls increase the ambient PET temperature up to four PET values relative to the green walls within two meters distance of the wall in the simulation climatic conditions.
- In vertical walls of the plan, the figure above indicates that the green walls with a two-meters-height are less effective in increasing their ambient PET temperature than green walls with four-meter height.

- The openings are cooler than the space behind the walls due to allowing the wind to blow. However, there are three openings in the corners that have no changes in decreasing their ambient PET values because of their position relative to the wind direction.

According to what was observed in the Fin garden's simulation and the role of the enclosure wall in thermal comfort was clear (up to 2 °C PET reduction in most parts of the garden), but this simulation demonstrated the thermal performance of the wall in the way to increase PET values. As noted above, the reason for this difference is related to the different ratios in temperature inside and outside the garden relative to the inside and outside the modeled scenario. In the Fin garden, in the No-Tree scenario where the PET value differences between and outside the garden were very low, similar results are visible.

What is certain is that the wall prevents the wind, and the environment behind the wall will increase in PET temperature due to reduced wind (at equal temperatures on both sides of the wall). However, when the temperature inside the area is cooler than its outside, the wall will keep the inside air cooler by preventing the hot wind from outside. Therefore, the higher the temperature difference within the inside and outside, the more noticeable the thermal effect will be.

Of course, these effects can vary depending on the height of the wall and its material. It should be noted that the directions of the wind are not always constant.

7.2 Microclimate Simulation IV: New Optimized Model for The Contemporary Park

Based on the extracted results from the performance of the elements of Fin garden in the Thermal Comfort, literature reviews, and studies of other Persian gardens, the contemporary park is redesigned as the optimal park.

It should be noted that in this optimal design, all the changes have been made inside the contemporary park; all the numbers, types, and characteristics of trees have not been altered, and also the amounts of water surface areas are exactly the same. Therefore, the changes applied to optimize the thermal behavior of the park are as follows:

- Applying water basins in the main axis and placing the three-meters-high fountains in them so that the total surface area of water is equal to their amount in the contemporary park.

- Since the materials applied on the ground surface of the contemporary park are similar to the Fin garden, thus there is no alteration in the materials.
- The directions of the main and secondary pathways change in the direction of 30 degrees or its perpendicular degree, which is 120 ° from the east.
- Since the number and type of trees are constant, the optimal scenario attempts to rearrange the trees in a way to focus most of the shade in the main axes and functional areas and also to use the combination of evergreen and deciduous trees, especially in the main axes, similar to the trees' structural orders in Fin garden.
- Since optimization has attempted to make the minimum changes to the number of existing elements in the current park (as abovementioned), and since the contemporary park has only walls around the park with a height of one meter, therefore, for optimization, one-meter hedges are applied.

The aforementioned changes have been applied to improve thermal performance inside the contemporary park displays as the following plan. As mentioned before, these changes have been conducted within the limited area of this park with the same numbers, type, and characteristics of trees; and also the same amount of water surface areas.

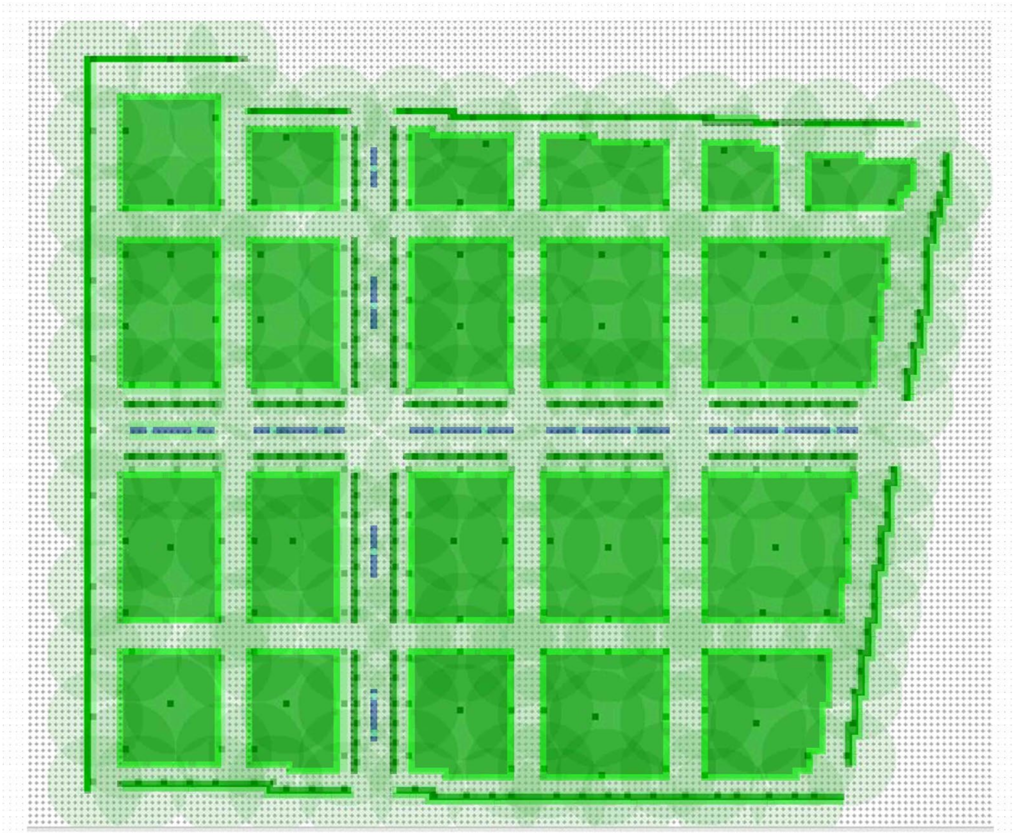
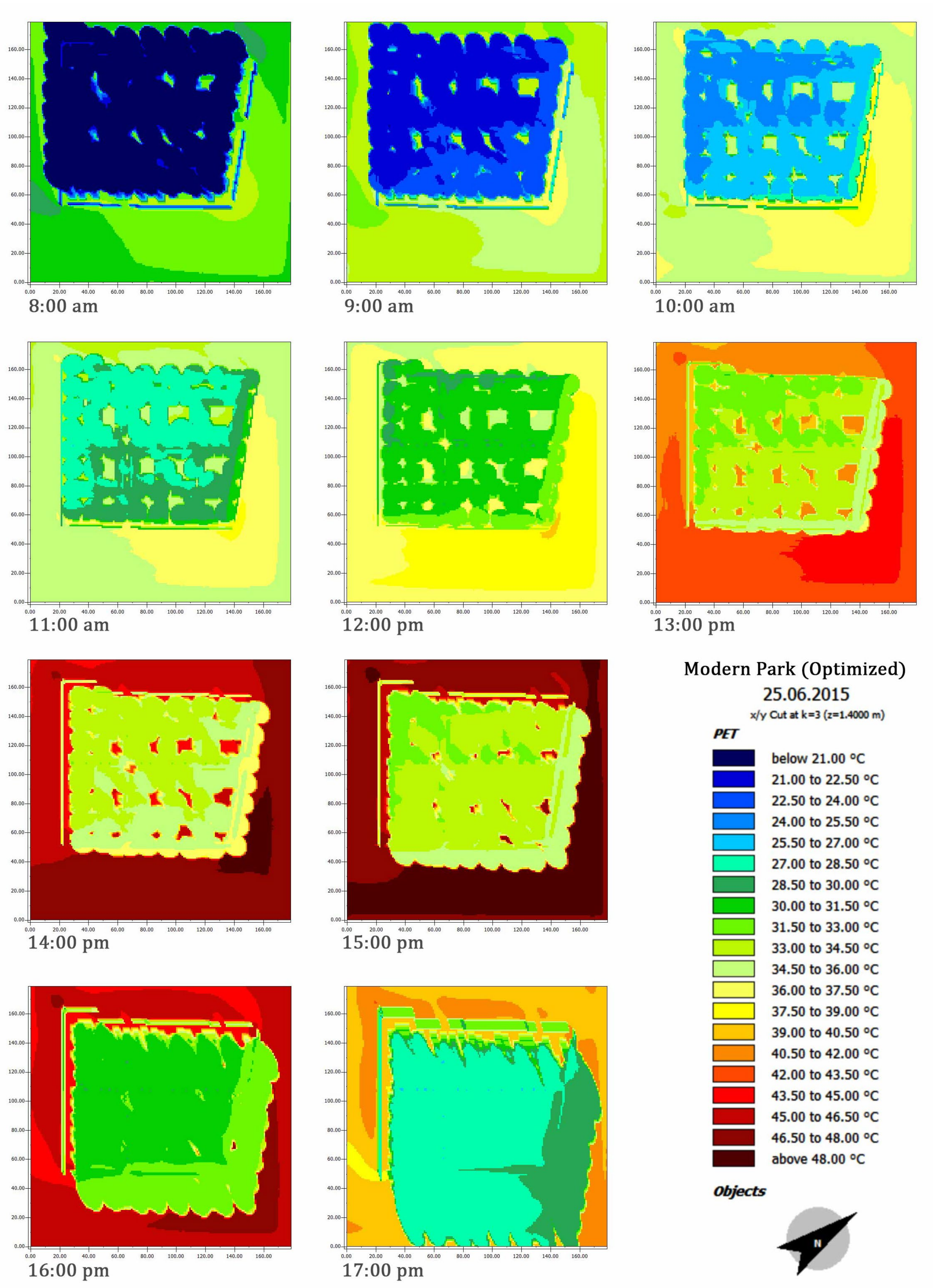


Figure 7-6 - Plan view of modeled optimization of the contemporary park area

7.2.1 Analyzing Model Details

To explore the thermal behavior of the redesign park, the optimal park is simulated with the same climatic input data set on the same date and span time at the pedestrian level (1.4m-high).


8:00 am
9:00 am
10:00 am
11:00 am
12:00 pm
13:00 pm
14:00 pm
15:00 pm
16:00 pm
17:00 pm
Modern Park (Optimized)
25.06.2015
x/y Cut at k=3 (z=1.4000 m)
PET
below 21.00 °C
21.00 to 22.50 °C
22.50 to 24.00 °C
24.00 to 25.50 °C
25.50 to 27.00 °C
27.00 to 28.50 °C
28.50 to 30.00 °C
30.00 to 31.50 °C
31.50 to 33.00 °C
33.00 to 34.50 °C
34.50 to 36.00 °C
36.00 to 37.50 °C
37.50 to 39.00 °C
39.00 to 40.50 °C
40.50 to 42.00 °C
42.00 to 43.50 °C
43.50 to 45.00 °C
45.00 to 46.50 °C
46.50 to 48.00 °C
above 48.00 °C
Objects
N

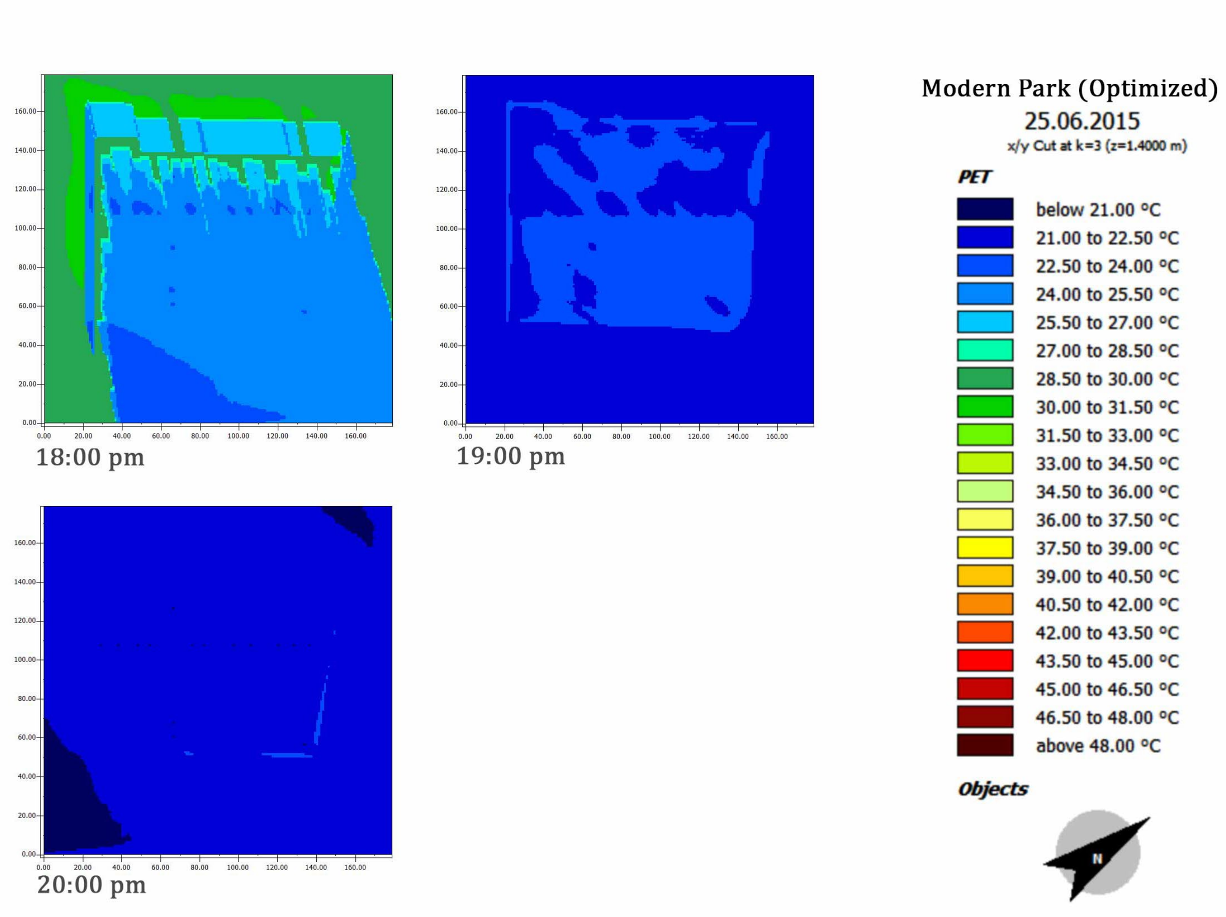


Figure 7-7 - Thermal behavior of the Optimized Model in Kashan during 13 hours a summer day

A close examination of the above figures demonstrates the points as the following:

- The park area is warmer than its surrounding area after 19:00
- The influence of wind direction on the extent of the park's cooling effect is very clear, which also clarifies why the coldest area is created.
- 14:00 and 15:00 o'clock are the hottest hours of the day.
- At 15:00 o'clock, as one of the hottest hours of the day, the highest PET value differences between inside and outside the park are calculated at about 18.5 °C.
- The cooling effect of fountains are obviously explored at most of the hours
- Although the focus of the project is on thermal comfort inside the park, this figure shows that regarding the wind direction, the cooling effect of the park is up to 5 °C on both sides of the park.

7.3 Comparison II: Contemporary Park Vs. Optimized Model

In this part, to have a better comparison of the changes made, the following figure shows a PET map of the contemporary park map before and after redesigning.

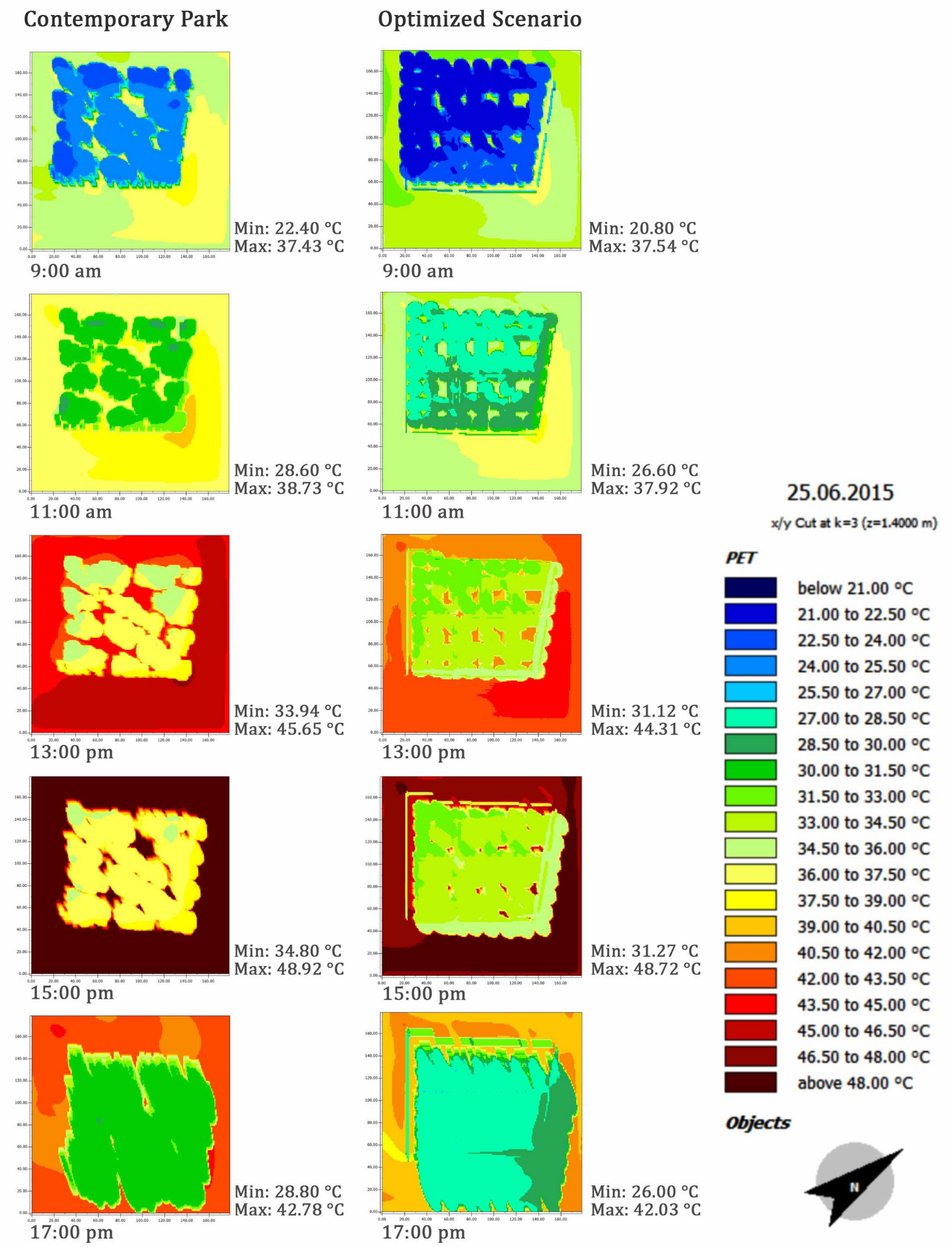


Figure 7-8 - PET comparison of the Contemporary Park (right column) with its Optimized Scenario (left Column) in the city of Kashan during the day

Regarding the figure above, by comparing the PET behavior of the current park to the optimized scenario, the proof of the positive impact of the new strategies in creating better thermal comfort and cooling down the air inside the park can clearly be seen. Some of these proofs are as follows:

- At all hours of the day, the maximum and minimum PET value of the optimized scenario has a smaller number than the current park's PET status
- 14:00 and 15:00 o'clock are the hottest hours of the day
- At 15:00 o'clock, the maximum PET differences of the minimums are calculated as 3.5 °C, while the PET differences of their maximums are only 0.2 °C
- Although the PETs differences between the maximums are mostly less than one degree and the maximum difference of the minimum is three and a half degrees recorded, as shown in the figure, the average PETs of the inside the parks have a greater temperature difference.
- The average PET difference between the two simulations is calculated about 5 °C at 13:00 o'clock (33.44 °C is PET average of optimized scenario vs. 38.46 °C calculated for the contemporary park) and 5.5 °C at 15:00 o'clock (33.93 °C Vs. 39.37 °C).

The 5.5 °C decrease in average PET value inside the optimized scenario in comparison with the average PET inside the contemporary park, in the hottest hours of the day, indicates the positive thermal performance of the optimization and confirms the success of changes to increase thermal comfort within the park.

Chapter 8: Discussion and Conclusion

As Persian garden is one of the most significant concepts of traditional ecological landscaping not only in Iran but also in the Middle East, it is essential to study and analyze the Persian garden concept and its fundamental principles and structure. Regarding both design and meaning, Persian gardens have been studied in various ways but rarely take into account their microclimatic characteristics. However, the driven results from studying the garden's elements, structural orders, and spatial arrangement, as a model of design, can encourage designers to enhance the thermal comfort of their environments.

Based on the results of the analyses carried out in the context of this research, this chapter briefly reviews the results and attempts to address research questions. It aims to provide suitable alternatives for the development of the Iranian urban landscape by suggesting green strategies to be implemented in climatic landscape design and enhance thermal comfort in green spaces in a variety of arid and semi-arid areas in Iranian cities.

Firstly, based on the results of comparative studies accomplished within the framework of this research, it is explained how Persian gardens adapt to the different climatic conditions. Afterward, regarding the conducted simulations, the influence of Persian garden design features on outdoor human thermal comfort is discussed. Later on, the impacts of these influences on urban landscape design codes are debated and evolved.

Subsequently, climatic green strategies for the future design of urban landscapes in the hot and dry climate of Iran are presented to encourage designers to make their environment thermally more comfortable. Finally, some suggestions for further studies are presented.

8.1 The climatic aspects of Traditional Iranian landscaping

As mentioned in section 2.3, the prediction for the forthcoming climate in Iran is going to be warmer and drier. Regarding human thermal comfort, it consequently follows that the thermal situation will deteriorate, particularly in summer. Therefore, creating outdoor thermal comfort is of great importance in the harsh conditions of the hot and dry climate of Iran, which is covered more than 75% of its territory.

In this regard, as the most outstanding and prominent examples of traditional Iranian landscaping, Persian gardens have created pleasant, well-being, and habitable landscapes by applying accurate planning and intelligent design, besides the optimal use of available resources, computed techniques, and new technologies (ref. section 2.4).

The significance of the Persian garden in the ancient urban structure of Iran was also investigated in this study, and it was demonstrated that all green structures in ancient Iran, from the construction of the Iranian residential buildings, squares, and public places structure to the formation of Iranian garden cities, were influenced by the structure and principles of the Persian garden (ref. section 5.3.1).

On the other hand, it was also illustrated that the Persian garden as a cultural-historical treasure has also influenced the design of green spaces and gardens in other nations. As evidence of this claim, the Persian garden was recently registered in UNESCO's list of cultural landscapes (ref. section 5.3.2). Thus, Iranian culture and belief are also part of the identity of the Persian garden, interwoven with its design principles and fundamental rules, which should not be ignored.

Moreover, the ecological study on the design of the Persian garden, which was based on the principles of contemporary knowledge, was further proof of the ability, knowledge, and skills of Iranians in landscaping. This all highlights the importance of recognizing the skills and knowledge of traditional Iranian landscaping for inspiration and the development of new designs.

In this regard, the results extracted from the study conducted in this research (ref. section 5.3.3) regarding how Persian gardens considered as ecological and sustainable landscaping have been briefly explained as following guidelines and principles:

1. **Site selection:**
   1.1- Interacting with nature, environment, and local climate. **1.2-** Improve potentials and enhance natural resources. **1.3-** Mitigating these harsh environmental conditions without harming nature. **1.4-** Optimal usage of natural resources
2. **Site design:**
   2.1- Design based on culture, nature, and climate**. 2.2-** Appropriate geometric orientation of the site. **2.3-** Designing the proper geometric shape for irrigation, cultivation, managing water, and human activities. **2.4-** Design the garden as a unified system by interconnecting all the elements of the garden.
3. **Water:**

   3.1- Access to water in an innovative sustainable way with no extra pressure on resources and energy. **3.2-** Proper water transfer management and prevention of water leakage and wastage. **3.3-** The simplest way to irrigate with the shortest transferring distance and to manage the surface water with proper drainage. **3.4-** Optimal Increase of air humidity through controlling water evaporation, based on the functional usage of spaces. **3.5-** Respect for the beauty and value of water by optimum utilization of the water and exhibiting the beauty of various aspects of water.

4. **Vegetation:**

   4.1- Plant selection: 4.1.1-Selecting indigenous and native plants. **4.1.2-** Applying the diversity of plant species to greater protection against pests. **4.1.3-** Selecting trees based on their shadow provision's characteristics, their abilities to block the wind, and to filter the air dust (climatic aspect).**4.1.4-** Selecting plants that have other advantages such as medicine, productiveness, aroma, etc., besides aesthetic benefits. (economic aspect).

   4.2- Pattern and spatial arrangement: 4.2.1- Ensuring that every plant receives the right amount of sunlight. **4.2.2-** The intelligent and accurate location of the plants according to their type of functions. **4.2.3-** Pay special attention to the lifespan of plants in the planting arrangement. **4.2.4-** Use a wise choice of planting location to reduce dust. **4.2.5-** Choose a suitable planting arrangement to reduce the air temperature inside the garden. **4.2.6-** Establish proper planting patterns to ensure optimal irrigation.

5. **Material:**

   5.1- Use eco-friendly materials that can be recycled and easily repaired. **5.2-** Applying the materials with high heat capacity, low reflection, and suitable color **5.3-** Use the locally produced material with low cost.

6. **Ecosystem service:**

   6.1- The Proper arrangement for plans community and accompaniment. **6.2-** Providing a good breeding ground for animals, especially birds and insects. **6.3-** Reducing air pollution, increasing the air humidity, and thus enhancing the air quality. **6.4-** Improve soil quality. **6.5-** Applying low and zero-carbon technologies and green energies on-site. **6.6-** Preparing the needed water for vegetation.

7. **Cultural aspect:**

   7.1- Recognition, conservation, and development of Iranian culture and art. **7.2-** Interaction with social developments. **7.3-** Investigating and understanding the identity and principles of Iranian landscaping. **7.4-** Improve and enhance Iranian landscaping by using the concepts and principles of traditional Iranian landscaping and combining them with modern technology.

8. **Human health:**

   8.1- Optimal response to human needs. **8.2-** Creating visual beauty and improving mental health. **8.3-** Provide outdoor thermal comfort and improve the outdoor thermal condition. **8.4-** Improving air quality. **8.5-** Creating optimal ventilation and airflow. **8.6-** Creating a multi-functional space suitable for leisure and social activities.

9. **Economic consideration:**

   9.1- Saving energy and resources. **9.2-** Applying local, low-cost, and recyclable materials. **9.3-** Applying intelligent management and easy to maintain. **9.4-** Optimal utilization of natural green energies. **9.5-** Producing food, fruit, and vegetational medicine.

10. **Climatic design:**

    10.1- Choosing the right location for the garden. **10.2-** Selecting indigenous and suitable plants **10-3-** Use the wise spatial arrangement, suitable geometry, and orientation. **10.4-** Controlling the air humidity. **10.5-** Proper ventilation. **10.6-** Applying the right mix of shadow and sun. **10.7-** Preventing the inside space of the garden from hot and dusty winds. **10.8-** Optimal Water-cooling strategy. **10.9-** Controlling evaporation as well as wind speed and direction. **10.10-** Use the right material. **10.11-** Proper use and design of architectural constructions and elements to assist in achieving the goals.

Since the main distinguishing feature of the Persian garden from other famous gardens is the creation of a pleasant and comfort microclimate in harsh climatic conditions, in this study, after extracting general principles from ecological and climatic aspects, the comparative study of elements and components of Persian gardens has conducted. The results demonstrated their climatic behavior and the way they responded to the varying climatic conditions (ref. section 5.4). This comparative study illustrated that:

Site selection: Changing weather conditions have changed the determining factors in the choice of location for the garden, except for stable access to water.

Water order: Water always plays an essential role in creating a garden. The methods of accessing the required water resources and transferring water are different, but the irrigation system has not changed. Only in hot and dry areas, more initiatives efforts have been taken to prevent unnecessary evaporation of water and water wastage. These measurements included the invention of aqueducts for sustainable access to water, and covering and concealing the water path, increasing the speed of water transfer, shortening the path, and insulating water transfer surfaces.

Moreover, the methods of displaying water in the Persian garden have been observed in almost all the studied climates, but the methods of their implementation were different in numbers and sizes. So that in hot and dry areas that need to increase air humidity, the contact of water surface with air was increased, and consequently, its depth became less, while in cold areas to prevent water freezing, the depth of the pools is increased rather than the size of water surface. Additionally, it is found that the decorative role of water in areas with high humidity is more than its climatic role.

Planting order: The role of varying climate conditions in the choice of plant species is undeniable. Trees and plants were selected from indigenous plants and plants adapted to each climate, and the way they were planted was appropriate to the need of each environment to provide shade or sunlight to meet thermal comfort.

External wind control is another major factor in the selection of trees around the garden, which is strongly influenced by climatic factors. Thus, in cold and hot and dry climates, the surrounding trees have been selected to prevent and control the penetration of cold or warm and dry winds into the garden, but in temperate climates, winds need to be able to enter without difficulty.

Geometry and spatial arrangement: The square and rectangular geometric structure of the garden has not changed in different climates, and they consistently followed the "Chaharbagh" pattern.

In hot and dry climate and also cold and dry climates, the direction of the main axis of the garden is often with a slight rotation in the north-south and sometimes east-west direction, which was based on sunlight and the direction of the local wind, while in temperate regions, the topography, Sea views, and wind direction play more important roles.

In addition to providing a wider view, the width of the main axis of the garden and its passage in the hot and dry region was in the proportion of the amount of shadow space, while in cold and dry climates providing more visibility and the use of solar energy was of importance. Furthermore, in temperate climates entering more wind had a significant role in creating the comfort zone besides providing wider visibility. Thus, compared to the latter two climates, the passways' width has been designed wider.

Palace: In this study, the change in the height of the pavilion building, the dimensions and number of openings, and the amount of enclosure of the building by the trees have been clearly observed by changing the climatic conditions in the gardens.

In these gardens, the higher the air humidity, the greater the number and dimensions of openings in the palace. Also, the higher the height of the palace location than its environment. Moreover, the colder the outside air temperature, the fewer the openings and the thicker the walls. And the warmer the air and the lower the humidity, the more trees have surrounded the palace to provide more shadow.

In hot and climate, paying attention to the above measurements, along with intelligent control and guidance of the wind and passing over the water, create the tremendous passive cooling system in the buildings.

Enclosure wall: In this study, it was found that only in hot and dry climate the enclosure wall plays a significant climatic role in creating thermal comfort inside the garden. Thus, the higher the wall creates more shade and meanwhile prevents the garden from the outside hot winds and sandstorms. Moreover, the proper wall material with high heat capacity reduces solar reflections.

However, in cold climates, the wall only partially prevents the penetration of cold winds in winters, whereas in temperate climates, it only plays a role in providing security and privacy.

Investigating and considering the behavior of effective elements in the adaptation of the Persian garden to changing and optimizing the climatic conditions and recognizing essential factors in this context was conducted. Therefore, these elements were selected to study their thermal behavior through an analytical simulation.

8.2 The effect of Persian Garden Features on Human Thermal Comfort

In this study, simulation Analyses of the historic Fin Garden of Kashan highlight important points regarding the adaptation of these gardens in summer to create human thermal comfort. The simulation results have explored that in the summer at the pedestrian level, the system of geometrical structure, structural orders, and the main elements of Fin garden have been greatly able to create a situation in the garden that has an effective reduction on PET. So that during the day, PET values inside the garden are up to 18 degrees cooler. While, in the late hours of the day, simulation results indicate the greater PET value, inside the garden, than its surroundings which agree with the findings of other studies such as (Grimmond et al., 1996), (Jauregui, 1990), and (Potchter et al., 2002).

The PET values measured in this study could be overestimated compared to the reality for several reasons, particularly the wind direction, which can change during the course of the day. In other words, when the wind blows parallel, it causes a higher wind speed at the level of pedestrians resulting in PET value reduction.

Examination and analysis of the simulations demonstrated how the thermal performance of each climatic element of Fin garden is to provide thermal comfort and cool the area inside the garden. In other words, how the specific orders, factors, and structural elements of Persian garden affect outdoor thermal comfort.

Water:

The simulations demonstrated that Eliminating water from basins and water channels, accompanied by a significant increase in PET value. So that the biggest change occurred in receptor 9, located next to the largest basin in the Fin garden. Also, as the size of the basins getting smaller, their cooling effect is reduced, and in the canals, which have just one-meter-width this amount, was negligible. Therefore, in this climate condition, the larger the water surface, the higher the cooling effect, while Steeneveld et al. (2014) believe that in hot and humid areas, the use of large bodies of water requires more attention and consideration.

It is important to note that wind direction and wind speed play very effective roles in the cooling effect of water resources. However, as a result, water canals played a more significant role in the beauty and psychological impact than the cooling effect.

The results show that the fountains are suitable to improve the outdoor thermal conditions in hot and dry climate, which are in line with the finding of research conducted by Xue, Li, Ma, and Zhang (2015). Although it was also revealed that the cooling effect of low-height (less than 50cm high) fountains is trivial and negligible, in contrast, the three-meter-high fountain has a significant cooling effect. Thus, the higher the number of fountains, the greater their cooling effect, and the higher the distance between the fountains, the less their cooling effect in the surrounding area.

Moreover, in this climate condition, more fountains with the same physical properties are more effective in their domain and range of cooling effect than their cooling effect at the same distance. However, the number and distances of the fountains should be determined by an accurate analysis based on the environmental conditions to have the optimal and efficient design for a project.

However, when investigating the entire water system in the garden, it was found that this integrated system running in the whole garden had a positive effect on increasing relative humidity and cooling the PET temperature during the summer day in the hot and dry climate. So that by eliminating this system, all minimum, maximum, and average temperatures have increased and intensified in their PET value.

Wall:

To have an enclosure wall around the garden in such a hot and dry climate has advantages and disadvantages. By concerning Fin Garten's simulations, it was found that the presence of enclosure-wall overall has a small positive effect on the decrease in PET, on average inside the garden up to 1 degree, and occurred maximally up to 3 °C in the margin of the garden.

These findings show that shadow provision is the major concern in outdoor thermal comfort. Therefore, enclosure walls can provide shade during the day, and apparently, the higher the height, the wider the shaded area. However, since adaptation to colder temperatures is easier (e.g., tighter wearing) and the summer season lasts longer, most of the pavement needs to be designed to provide proper thermal comfort in summer. In a similar study, Taghvaei et al. (2015) also found that the wall plays a significant role in creating and maintaining the microclimate in the garden. The orientation and height of the walls, and thus its shading area, are identified as an effective factor in creating a comfortable situation for the adjacent pathway's areas during the summer. In addition, their research shows that the wall material significantly affects the ambient temperature regarding heat absorption and radiation.

Walls beside helping to prevent moisture inside the garden and provide the proper humidity for vegetation, protect the garden from the outside dusty-warm wind. However, it must be noted that these blocking winds could also increase the temperature inside the garden.

Furthermore, the results of simulation on air temperature at the height of 20 cm demonstrated the positive cooling effect of the enclosure wall. It has shown, just in garden border spaces, the maximum air temperature difference is about 2 °C degrees, while the average difference inside the garden is between 0.5 and 1 °C. It means the absence of an enclosure-wall impact on vegetation and grass in the form of higher air temperature, translating to higher water consumption and creating difficult environmental conditions for plant growth.

On the other hand, based on the simulations, the PET values increased behind the wall by blocking the wind. When temperatures are equal on both sides of the wall, the wall blocks the wind, and consequently, the temperature of the PET behind the wall will increase due to the lower wind. However, when the internal temperature of the area is cooler than the outside, the wall would block the outside hot wind, and it keeps the inside air cooler. Therefore, as the difference in temperature between inside and outside increases, the thermal effect becomes more evident. This effect can, of course, vary depending on the height of the wall and its material.

Material:

This study showed that the land-surface materials in the Persian garden mainly include vegetation, water bodies, soil, and architectural materials. Among these, water bodies and vegetation reduced the ambient temperature and PET values. The water bodies had a greater cooling effect than the plants.

However, built-up materials have a noticeable impact on the increase in temperature even with appropriate color and having a low conductivity. For this reason, attempts were made in the Persian garden to cover these materials with shadow. It should be noted that materials applied in Persian gardens were recyclable, native, and eco-friendly.

Trees:

It has been clearly identified the role of trees as the most effective tool in reducing PET values. In this term, the results of the simulation indicated the 32 °C PET differences in the scenario for eliminating trees. Trees are not only effective by shade-providing but also lower the air temperature by evapotranspiration.

Furthermore, solar radiation can penetrate through the tree crown and reduce the shade below. However, by providing shade, they cover a much larger area than the walls. Obviously, these all depend on the species and size of the applied vegetation. Nevertheless, trees enhance longer periods of time during the day. Of course, trees should be selected among local trees adapted to the local climate conditions, as applied in Persian gardens.

By applying deciduous trees, which usually have larger crowns than evergreen trees, larger tree canopies are made, and subsequently, more cooling air temperature and decreasing PET values will be achieved. While in the winter, by shedding the trees' leaves passing, the sun radiations through the trees are easier, thus the winter discomfort could be moderated. In line with this, the particular study conducted by Fröhlich and Matzarakis (2013) illustrations that the decrease in shading resulted in the greatest impact on thermal comfort due to the direct absorption of solar radiation. Therefore, it is desirable to find an optimal balance for the thermal situations of the two seasons.

Orientation:

On the basis of the simulations, it is remarkable that pathway orientation could impact thermal comfort. In this study, it was found that one of the best rotations for the main axis is the East-west orientation, which coincides with the main axis of the Fin Garden. Moreover, Ojaghlou and Khakzand (2019) also indicated in their study that the east-west orientation is the best orientation in the Persian garden, which is a confirmation of this assertion.

As solar radiation is the most important determinant of thermal comfort in this climate, tree crowns are again becoming a key parameter. In the axis where the tree crowns' shadows cover the pathways, the rotation of the axis network has a negligible influence on human thermal comfort. Meanwhile, in pathways with low and small tree canopies, the pathway rotation could substantially impact its thermal comfort.

Spatial arrangement:

Simulations of the Fin Garden demonstrated that the best PET behavior in the Fin Garden belonged to the receptors of the main axes. Thus, the PET situation of the outdoor spaces could be optimized by applying their spatial arrangement. These spatially arranged through providing the most shadow of space during the day, increasing the air humidity through locating basin or water surfaces, controlling the outside, warm winds, and cooling them down to use as the proper breeze, applying the right materials, and arrange all these in the right orientation.

The particular design and geometry of the garden have determined the pathways as straight axes without curvature or angles, which, due to the appropriate orientation of the garden to the Sunlight direction, creates the most shadows during the summer days.

Wherever the width of the pathway was wider than the shadow spaces created by the trees on either side of the path, it is better to create a space covered with water or flowers in the middle of the passing axis in the same width that the axis needs to become wider. In this way, in addition to providing proper visibility and open view, the added space is covered with plants or water, which are much more effective in reducing their ambient temperature than the architectural materials used in the pathways.

Although other researchers (Cui, Rupprecht, & Shibata, 2021; Taghvaei et al., 2015) also point to the greater cooling effect of tree canopies than architectural and artificial spaces, since shading is recognized as the most important factor in the reduction of PET value in these climatic conditions, the creation of shade by architectural structures can effectively contribute to the creation of thermal comfort, through the selection of suitable materials and the use of green solutions to increase the humidity of the space.

The above-mentioned outcomes show the thermal behavior of Persian garden's elements and how they result in thermal comfort. However, in order to verify these findings and to determine their effects, based on these research results, changes were made to the design of a park with almost the same dimensions and climatic conditions and also were simulated.

The positive results of the applied changes indicate the effectiveness of these strategies and design principles through the reduction of the number of PET values. As a consequence of these changes, the average and minimum PET value of the inner area of the park was respectively reduced to 5,5 °C and up to 2,5 °C. Furthermore, the effects of this PET reduction were also significant in the outside area of the park.

8.3 Green Strategies for Future Landscape Design

Despite all barriers of this research, it can be concluded that through this climatic study, the thermal behavior of the elements and structural orders of a Persian garden has been demonstrated, its success in providing thermal comfort inside the garden has been clearly explored, and its design's principles and strategies have been extracted. This also confirmed the adaptive responses of Persian gardens to their local climatic conditions.

The following are green strategies and guidelines for landscape design concerning human thermal comfort. They originate from analytical studies of Persian gardens, the comparison of their adaptation response to climatic conditions, and the analysis of simulation studies conducted in the Fin Garden and in a selected park in Kashan. Although they are based on simulation studies, the current practices of landscape design were also considered. Within this study, Kashan represents Iranian cities in a hot and dry climate, and it is possible to generalize the results to most of them.

Obviously, considering the climatic conditions, Land characteristics, and ecological potential, as well as easy and cost-efficient access to the required natural resources, are of great importance in selecting the site location.

Optimal vegetation selection and arrangement:

In terms of the proper vegetation selection, the choice of the indigenous and native plants, which are greatly compatible with the local climate conditions, must be considered. Moreover, it has to pay particular attention to the physical characteristics of the plant, such as shape, crown size, color, and type (evergreen or deciduous).

The location of each tree must be determined intelligently based on the climatic functions and project needs. For example, the exact location of tall and shady trees must be specified, particularly on both sides of the main axis, and suitable trees must be planted around the garden to prevent the penetration of external hot winds and to purify the air dust and pollution.

Make sure that each plant receives the right amount of sunlight in the planting arrangement. The arrangement of deciduous and evergreen plants should be in the way of creating maximum shade in summer and use the right amount of sunlight in winter. In Persian garden, the common patterns were the repetitional combination of Cypress, Pine, Platanus or Cypress, Pine, and Elm trees along the main axis of the garden. Moreover, a suitable planting method to provide the palace and buildings with the right amount of shade must be chosen.

Optimal spatial arrangement:

To create an innovative and appropriate spatial arrangement, not only the choice of the proper geometry and orientation is of importance but also the optimal ratio and size of the space based on the wind and sun direction. Moreover, the proper spatial arrangement for having optimal results requires the provision of an internal connection between all design components to create a coherent and responsive unit and to enable control of the essential climatic factors.

In terms of the pathways and axes design, their width should be considered as a proportion to the crown dimension of the trees and their canopy size. So that the wider the dimensions of the pavement, the larger the canopy dimensions or, the higher the height of the canopy. If the width of the pathway should be wider than the shadow spaces created by the trees on either side of the pathway, the appropriate solution is to design the requested additional space in the middle of the passing axis covered with water or plants.

It is recommended to design the paths as straight axes without curvature or additional angles to provide maximum shadows in summer, as the axes are correctly oriented to the direction of sunlight.

Optimal orientation:

It was found that north-south and east-west are the most commonly implemented orientations in Persian gardens, with a slight deviation depending on the locally prevailing wind. However, in this study, the optimal rotations for the main axis were determined as east-west orientation.

Controlling air humidity:

According to the study, for optimal control of air humidity, especially in this climate, firstly, the humidity must be increased, and secondly, try to control it inside the garden. The proper amount of air humidity is proportional to the amount of humidity required to cool the air temperature and the amount of humidity required to balance the leaf water for the plants.

The analysis of the Persian garden demonstrated that the presence of the enclosure wall, in combination with the planting of dense trees around the green space, helps to protect and control the internal air humidity of the garden. However, to design a functional wall or fence, many factors must be considered, such as material, height, the difference between internal and external temperatures of the space, and the direction of sunlight and the prevailing wind.

Controlling solar radiation:

Due to the fact that solar radiation plays the most important role in determining thermal comfort in this climate, the creation of the right and proper mixture of shadow and sunlight by natural or artificial shade providers is of great importance.

Although in this climate, the more shadow that can be created, the cooler the ambient temperature, however, it is necessary to ensure that the plants receive sufficient light and that sufficient solar radiation can be obtained in winter.

Controlling exposure to wind and provide the proper ventilation:

The interior of the garden has to be protected from hot and dusty winds by natural and artificial windbreakers. Afterward, winds must be controlled, cooled, and cleaned by passing through trees and water surfaces, while the fresh breeze can be guided into the garden to create thermal comfort.

Optimal irrigation system:

Determining an optimal and suitable irrigation system is of great importance for plants and trees as well to avoid water wastage and unnecessary evaporation. Furthermore, the control of soil moisture is an essential factor for plant health, and it should be noted that little or too much water in their root zone will have a negative effect. These measures are effective not only on plant health but also in reducing the air temperature.

Optimal water-cooling strategies:

The use of pools, lakes, canals, basins, water sprays are some climatic design elements that can be effective in cooling the environment. In fact, their cooling effect is optimized by determining the appropriate dimensions, number, and distances, besides the proper control of evaporation and wind speed and direction.

It is now known that water basins and water channels only have a very limited domain of influence on their ambient Thermal situation. And if they are considered as a single influencing factor, their cooling impacts can be neglected. However, as this study has examined, when channels and water basins, as a unified water system, intelligently cover the entire site, they can have a noticeable effect on lowering The PET value and creating thermal comfort. Obviously, their cooling effect increases with greater size, but in order to determine the optimal result, an analysis should be made.

Moreover, as this study has shown, the cooling capacity of a high-rise fountain is much higher than a basin in the mentioned scale, so applying high-rise fountains is highly recommended. However, in selecting the number and distance of fountains, it is recommended to make a precise analysis based on the environmental conditions in order to determine the optimal condition according to the needs of the project.

Optimal surface materials selection:

The selection of the best and most suitable material plays an important role in climate design. The results showed that land surface materials, including water bodies and vegetation, are much more effective than architectural materials in reducing ambient air temperature and PET values.

However, in areas where the built-up materials must be used, the choice of materials with suitable color and low reflectivity characteristics must be considered. Nevertheless, to minimize the impacts of temperature increases, these areas should be covered by shadow.

Furthermore, as this study shows, the use of green facades and walls is strongly recommended, which has a better thermal effect than the built-up materials. If these selected building materials are chosen from indigenous, eco-friendly, and recyclable materials, their economic and environmental benefits are certainly much greater and can be accompanied by a reduction in the harmful effects of the environment and climate change.

Buildings climatic design:

The right orientation to the sunlight, the optimal use of materials, the determination of the wall thickness, the dimensions and the number of openings, the position and height of the building, the enclosure in the shade of the trees and create an intelligent passive cooling system, are the key points of the climate design in the palaces and buildings, which must be calculated according to function and space requirements.

The solutions provided in the Persian garden could be useful to create a passive cooling system inside the buildings. These solutions can be implemented by applying green energies and zero-carbon technology, designing the water basin and fountain outside or inside the building, controlling and directing the wind, increasing its humidity by crossing the water surface, and providing shadows around the building by surrounded trees.

Besides the above-mentioned guidelines and design strategies, it must be noted that many factors of persistence and stability of the Persian garden for many centuries have been studied and presented in detail. While the focus of this study is on the creation of comfort conditions by analyzing the climatic design of the Persian garden and not the design, which represents the identity of the Persian garden, however, consideration of these factors can indirectly affect the resulting quality of the comfort design.

For instance, on the one hand, the use of green energy and zero-carbon technology in all parts, the consideration of the economic aspect (such as the use of indigenous materials and the planting of productive trees), and on the other hand, the identic, artistic, and cultural aspect of the Persian garden, which creates beauty according to the Iranian aesthetic taste. These facts enhance mental health, which is an effective factor in the feeling of a pleasant environment and, consequently, thermal comfort.

Eventually, using ENVI-Met software as an essential assistant tool for landscape architects and urban planners in the design process of outdoor facilities is strongly recommended.

8.4 Limitations and the Necessity of Climate Consideration in Iranian Landscape Planning and Design

There is a considerable potential to enhance both the resilience and adaptability of Iranian cities to the challenges of climate change, mainly based on the successful experience of traditional Iranian landscaping and urbanism within similar adaptation strategies. The adaptability in Iran is affected by socio-economic factors, technology matters, and other factors such as governance structures.

As noted in chapter 2, the decision-making process in Iran concerning climate change is affected mainly by uncertainties regarding future climate change, various social and individual attitudes to risks, culture, and values. Indeed, the lack of awareness by both the public and among decision-makers can limit proper responses to mitigating the climate change impacts.

In terms of social and cultural obstacles, a noticeable gap exists between the older generations, who had experienced climate-friendly urban development, and the modern generation, who are highly dependent on fossil fuels to regulate the climate of their environment. They also see beauty as taking distance from the past, not developing and improving the traditional experiences. In addition, the lack of essential resources and infrastructure, low prioritization of threats, international sanctions, and other concerns create obstacles to the adaptation to climate change in Iran.

Landscape planning and consequently climate-specific regulations have not yet found their important role in urban and regional planning in Iran. Moreover, environmental recommendations are often kept very general and only to ensure that they do not negatively impact the environment (ref. section 2.3.1). In some cases, these regulations can even act as a barrier to climate-conscious urban and landscape development. Indeed, the essential mechanism and strategies for principle-oriented urban and landscape planning and design should be installed to provide a more practical solution for optimal adaptation as well as mitigating heat island effects.

However, in Iran, as a developing country, planners and designers do not usually have access to conventional tools and services. Upgrading these tools and equipment, such as the microclimate simulation software, can also provide a vital service in raising awareness and enhancing the abilities of the landscape planners and designer's community.

Eventually, in order to control the actual implementation of climatic considerations in the projects, it is also necessary to improve the planning and design processes and make them more transparent. Furthermore, it is essential to provide external investigation and monitoring to ensure the maximum performance of the results.

8.5 Suggestions for Future Studies

As described earlier, several factors have led to a number of limitations regarding this research design. In fact, each of these limitations can be considered as a valuable research opportunity. The main focus of this research was the effects of landscape design on outdoor thermal comfort in summer as a way to adapt to climate change.

Although this study is one of the first steps in scientific understanding of the climatic aspects and thermal behavior of the Persian garden through fieldwork and performed simulations, it is hoped that further research will be undertaken to clarify the hidden aspects of the Persian garden in order to assist in the design of environmentally-friendly landscapes and human thermal comfort.

These studies can be expanded by more investigating other Persian gardens in different climates and by analyzing more comparative examples of both field-based information and computer simulations to develop quantitative climatic research. These could be led to take effective steps in identifying and expanding the value of Persian garden. Or, in other points of view, investigating the effect of the beauty of Iranian art and culture applied in the Persian garden to improve mental health and its effect on the perception of thermal comfort.

In this respect, similar research can be carried out under a combination of alternative scenarios and times. Concentrating on thermal comfort in winters, studying alternative landscape patterns and design, investigating further the thermal comfort in urban green spaces through applying the productive vegetation can be considered as the proper themes of further investigation.

Moreover, the new user-friendly approaches, instruments, and software should be supported and promoted to assist designers and decision-makers in discovering the impact of their decisions on environmental and landscape projects.

Other public strategies to support urban greening should also be developed and promoted. Besides, as aforementioned, it is essential and also needs further study to carry out a detailed practicability analysis of green energies and their implementation in the Iranian context.

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