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Recommending an Appropriate Type of Green Roof Taking into Account Urban Typology and Climatic Zoning in Iran

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Abstract

Population growth in the major cities of Iran has led to the limitation of land resources, higher consumption of non-renewable sources of energy and many other environmental problems. The emergence of overly built-up urban areas and a decreasing amount of green spaces cause the appearance of an undesirable landscape within cities. Green roof technology is one solution for responding to environmental concerns in urban areas. This technology combines green spaces with buildings as private or semi-private spaces. Its successful implementation in different areas depends on the accommodation of green roof type technology within the environments and urban and building typologies in Iran. This paper aims to provide some recommendations for selecting the appropriate type of green roof and for implementing approaches that take account of the climatic zoning and urban situation in Iran. Two primary aspects that are considered are environmental and urban typology factors. The research method is based on the study of indicators related to each factor mentioned in different zones of Iran, thereby leading to a feasibility study for the application of green roofing in Iran.

Key words: green roof, urban typology, climate zone.

انتخاب بام سبز مناسب براساس شاخص‌های زیست محیطی و بافت شهری در ایران

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چکیده

رشـد جمعیت در بیشتر شهرهای بزرگ، مشکلات زیست‌محیطی بسیاری را به همراه داشـــته اســـت. افزایش تراکم ســـاختمانی و کمبود فضـــای ســـبز، کیفیت زندگی در شـهرهای بزرگ را پایین آورده است. افزایش ترافیک، آلودگی هوا، افزایش دما، منظر نامناســب شهری از مهم‌ترین مشکلات و معضلات زندگی در شهرهای بزرگ همچون تهران و دیگر کلان‌شــهرهای ایران محســوب می‌شــود. افزایش حجم ســاختمان‌ها در شـهرها، امکان رشـد و گســترش فضـای سبز را از بین می‌برد و امکان جذب نزولات آسـمانی در زمین را نیز به حداقل می‌رساند و به‌جای آن، مهار روان‌آب‌ها را در سطح شـهر با مشکل مواجه می‌نماید. همچنین، مهار باد و ممانعت از گسترش ذرات معلق، به دلیل کمبود گیاهان در محیط، از معضـلات اصلی دیگر در شهرهای بزرگ، به‌ویژه در شهرهای بادخیز محسوب می‌شود.

گســترش ســاخت و ســازها و افزایش تراکم ساختمانی موجب افزایش سطوح افقی و عمودی مصـنوع شده است. این روند علاوه بر کاهش حوزه جاذب آب باران و برف در ســطح زمین، انعکاس نامطلوب نور خورشــید را نیز افزایش می‌دهد. این ســطوح در صورت مدیریت صحیح، امکان تبدیل به پتانسیلی ارزنده برای گسترش فضای سبز را فراهم می‌کنند. باغ‌های سبز و دیوارهای سبز امروزه در سطح جهان به عنوان راهکاری مؤثر جهت رفع مشکلات زیست‌محیطی شهرهای بزرگ درحال گسترش است.

دو منظر اصلی که در این تحقیق مورد بررسی قرا گرفته‌اند، عبارتند از: ابعاد محیطی و بافت شــهری. روش به‌کار گرفته شــده در تحقیق، مبتنی بر بررســی شــاخص‌های مرتبط با کارایی بام ســبز در محیط‌های مختلف ایران است . در این مطالعه مهم‌ترین مؤلفه‌هایی که قابلیت اجرایی این بام را در ایران مورد سنجش قرار می‌دهد، طرح شده و امکان‌سنجی اجرای این بام در ایران مورد بررسی قرار گرفته است. به‌دلیل قرارگیری بخش وســیعی از ســرزمین ایران در منطقه گرم و خشک، لازم است راهکارهای لازم برای حفظ و پایداری بام ســبز مورد توجه قرار گیرند. انتخاب نوع صــحیح بام ســبز، انتخاب گیاهان مناســب و منطبق بر شــرایط بومی و علاوه بر آن، فراهم آوردن امکان آبیاری بام در این زمینه از اهمیت بسیار برخوردار است.

کلمات کلیدی: بام سبز، گونه شناسی شهری، اقلیم.

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1. Introduction

Population growth in the major cities of Iran has led to the limitation of land resources, the higher consumption of non-renewable resources of energy and many other environmental problems. Green space per capita in Iran is low for two primary reasons: 1) the climatic conditions of Iran; 2) non-private (or public) ownership of green spaces.

A large part of Iran is situated in zones that have poor conditions for the spontaneous growth of plants and as such, green spaces must be implemented, nurtured and maintained. However, most green spaces in urban areas in Iran have public ownership and are under the patronage of the state. Thus, due to insufficient funds and the low priority of green spaces, their implementation and maintenance has been delayed by government. However, private ownership of green spaces has employed the benefits and advantages of green spaces skilfully in the vernacular architecture and urbanization of Iran. If private ownership of green spaces can therefore be considered in the design of all types of residential and official buildings, there may be a greater opportunity for the development and especially the maintenance of green spaces, at least in residential (and official) spaces and as a result, people will benefit from their advantages.

Green roofing provides a technical and architectural solution and – because of their many advantages for solving urban problems – their use has expanded throughout the world and has been developed in many countries in Europe, Asia, Canada and America. The benefits of green roofs can be classified into three main categories:

(a) Economic benefits: energy efficiency and reduction in the use of air conditioning and energy costs (Sailor, 2008), solar panel efficiency, roof membrane protection and life extension (Takebayashi et al., 2007) and fire prevention.[1]

(b) Environmental benefits: reduction of the heat island effect (Kosareo et al., 2007), air purification (Van Renterghem et al., 2008), storm water management (Carter and Jackson, 2007; Getter et al., 2007; Hilte et al., 2008; Jarrett et al., 2008), sound insulation and creation (Yang et al., 2008), blocking electromagnetic radiation, creating ballast against wind uplift and the preservation of habitat and ecological biodiversity.

(c) Community and social benefits: these are divided into the aesthetic features of recreational space (Baumann, 2006; Brenneisen, 2006), replacing natural habitats in urban areas (Getter et al., 2006; Oberndorfer et al., 2007) and improving health and horticultural therapy. As previously stated, a large part of Iran has poor conditions for the spontaneous growth of plants and this may affect green roof development. Furthermore, in the urban form and roof design of Iran's cities, green roof application has not been considered and the physical form of these cities may not support green roof development. Rooftop conditions are challenging for plant survival and growth: moisture stress and severe drought, extreme (usually elevated) temperatures, high light intensities and high wind speeds all increase the risk of desiccation and physical damage to vegetation and the substrate (Dunnett and Kingsbury, 2004). With regard to FLL Guidelines (2008), climate and urban form are two important factors to be considered for the application of green roofs in Iran. A comparative study of related indicators for each factor stated and the consideration of each particular situation is therefore needed to conduct a feasibility study for the application of green roofing in Iran.

2. Objective and Research Method

The objective of this paper is the adjustment of green roof technology to Iran's conditions and the undertaking of a feasibility study based on local conditions. The application of green roofs in a specific area requires a full understanding of the technology and its elements in order to make the necessary changes for adjusting to environmental and social conditions. Therefore, after studying green roof systems and their elements and requirements, we investigated 'climate and weather-dependent factors' and 'urban and building conditions' as aspects affecting the use of green roofing. A field study was carried out and the theoretical framework for providing the required information was developed from the FLL Guidelines, as well as other scientific references. Finally, specific suggestions for consideration prior to building a green roof are presented.

3. Green Roofs: definitions and types

A 'green roof' has been defined as a living system that is an extension of a roof. This green space can be either below or above stage and involving systems where plants are not planted in the ground (Tolderlund, 2010). Green roofs have ancient antecedents worldwide and have been renewed in recent decades, leading to their rapid expansion worldwide. Green roof technology has been developed in many countries situated in hot and arid or semi-arid zones such as the United Arab Emirates, Algeria, Egypt and western USA. Green roofs in these areas are often equipped with irrigation systems. In addition, using local plants and specific implementing strategies will help to assure the success of this technology in arid areas.

Green Roof Types

Green roofs are divided into two main types: the *extensive* green roof and the *intensive* green roof. Indeed, green roofs range from the extensive type with a low height to heavy intensive ones with a significant height that is applied for different uses. The following table presents a comparison of different types of green roofs.

4. Effective factors for green roofs and adjusting to site conditions

The potential site conditions that have been identified during field studies are as follows:

4.1. Effect of climatic and weather-dependent factors on the use of green roofs in Iran

Selection of the plant species used in green roofs, as well as selection of the green roof type is largely influenced by climatic factors. If the green roof design is done without regard for regional considerations, the result will not be successful. The most important climatic and weather variables that

Table 1: Comparison of different types of green roofs

Types	Specifications	Height	Weight*
Extensive "Ecological"	An ecologically sound and economic green roof system that provides a meadow effect and requires only low maintenance. The entire area is drained; for small layer thickness, light seat medium, contains minerals; for dry-resistance perennial vegetation. The set is suitable for non-walk able building roofs with limited loading capacity	8-15 cm	From 150 kg/m2
Semi-extensive	Appropriate for the creation of an outdoor living space. This garden roof system utilizes basic plant types that require more maintenance than the extensive roof. The system is faced with ground-cover grass, perennials and bushes, higher-use facilities and several forms.	20-30 cm	From 350 kg/m2
Intensive "Landscaped"	The roof is used as an additional living space. Opens up practically all the possibilities of normal ground-level gardening, seating areas and ponds and requires irrigation.	40-60 cm	From 750 kg/m2
Underground	This provides a valuable garden for objects at ground level and over the building's ground contour .This is an intensive garden, covered with groundcovers, tree shanked perennials and sometimes also trees; may have direct contact with gardens built on natural ground and it may therefore be impossible to differentiate between them.	80 cm and larger	From 1200 kg/m2

Zinco Co. Catalog, Diadem Co. Catalog, Dubai municipality, "Green roof manual", 2011

*Saturated weight (without vegetation)

significantly contribute to the implementation of green roofs may be outlined as follows:

- Regional climate and micro-climates
- Patterns and volume of annual precipitation
- Average exposure to sunshine
- Any period of drought
- Any period of frost, with or without snow cover
- Prevailing wind direction (FLL Guidelines)

Although the climatological conditions in Iran are highly diverse and due to the presence of a number of different micro-climates all over Iran, an overview of the country's climate will be beneficial for assessing the feasibility of green roofs. The climatic indicators in Iran and their effect on greening up roofs have been investigated as follows.

4.1.1. Regional weather and micro-climates

Iran has a warm climate with a mid-latitude continental temperature regime. The thermal regime model of Iran results from solar radiation angle changes, but the temperature at any place depends on a set of elevation, latitude and moisture content conditions of the atmosphere in that location (Masoudian, 2005). Thus, the simultaneous role of latitude and elevation on the temperature and topographical complexity of Iran has led to the emergence of temperature contrasts in different parts of the country. Considering the above, the Iranian climate zone patterns that vary within each micro-climate also vary and the different patterns of climatic zoning in Iran are thus presented. In these patterns, usually one or more climatic factors have been selected as zoning criteria. One of the special zoning samples carried out, in which almost all climatic factors considered for this study were taken into account and discussed, was the research conducted by Masoudian (2003). Based on a factor analysis of the 27 climatic elements, the Iranian climate is primarily considered to be the functional outcome of six contributing factors: heat, humidity and clouds, precipitation, wind, dust, radiation and thunder. On the basis of such data analysis, Masoudian classifies Iran into 15 climatic zones:

1. The southern coast zone: this incorporates mainly the coasts of the Oman Sea and parts of the Persian Gulf. The most striking climatic features of the area, respective to their order of significance are: heat, radiation and humidity. It may therefore be labelled as a hot, arid and humid climate.
2. The Caspian backshore zone: covers a relatively large part of the Caspian coasts from Astara city to the Bandar Turkman port city on the northern slopes of the Alborz Mountains. The area’s climate is characterized as rainy and humid.
3. The central zone of Iran: climatically, this covers the most extensive area in central Iran and a small part in the northeast. Solar radiation and heat are the main characteristics of this area.
4. The Azeri zone: the northwest-southeast ring, a large part of which is located in the Azerbaijan territory; its climate is thundery-humid.
5. The Khuzi zone: the Khuzestan plain is the territory of this zone with a hot, rainy, thundery, windy and dusty climate.
6. The Moghani zone: includes the Moghan plain up to Khalkhal city and has a humid and windy climate.
7. The Western Zagros zone: a northwest-southeast ring that starts from Kurdistan and ends on the backshores of the Persian Gulf. The prevailing feature of the climate in this area is rain and thunder.
8. The Eastern Zagros zone: this area begins in Azerbaijan Province and runs parallel along the Western Zagros zone; it has a rainy, windy and radiant climate.
9. The Caspian coast zone: a small area of land stretching from Talesh to Nour, located well in the heart of the Caspian backshores; it has a rainy and humid climate.
10. The southern backshore zone: an east-west ring on the backshores of the Persian Gulf and the Oman Sea that in some places spreads to the Persian Gulf coasts. The zone has a hot, radiant,

windy and dusty climate.

11. The large Sistani zone: an area stretching north-to-south across the eastern borders of Iran along South Khorasan Province towards the north of Baluchistan Province; the prevailing climate of the zone is windy and dusty.
12. The Baluchi zone: in the southeast corner of the country in Baluchistan; limited territory with a thundery climate.
13. The Makuee zone: in the northwestern corner of the country; small territory with a thundery and humid climate.
14. The small Sistani zone: a small territory in the heart of the large Sistani zone with the same weather conditions, but a more powerful and entirely windy and dusty outlook.
15. The high Zagros zone: a small territory that encompasses the highly elevated Zagros area; has a rainy and radiant climate.

The climatic zones are shown on the following map, based on the noted classifications.

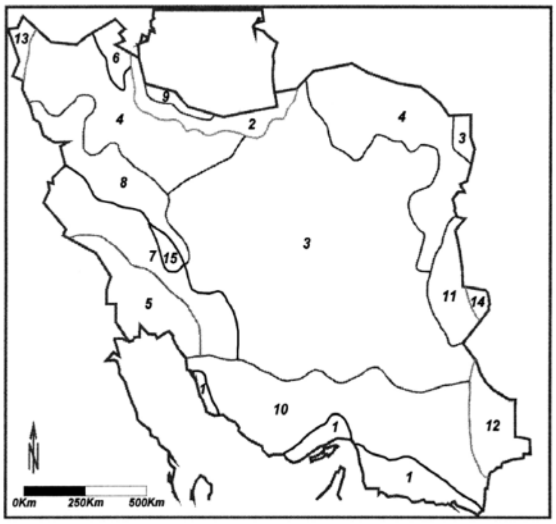


Figure 1: Iran's climatic zoning. Source: Masoudian, 2003.

According to the diversity of physical topographies across the country, various micro-climates exist within each of the climatic zones in Iran that are not considered in this study. The purpose of this discussion is instead to understand the distinct climatic features of Iran in the fields that will impact the design, implementation and maintenance of green roofs. After identifying the general characteristics of the country's climatic zones, other features that affect the implementation of green roofs will be examined separately.

4.1.2. Pattern and volume of annual precipitation

Selection of the green roof type and plant species depends on rainfall rate and pattern. One of the primary benefits of green roofs is that they preserve rainwater and prevent increased water runoff. In some European countries like Germany, Belgium, Poland and Spain, homes with green roofs are exempted from payment of all or part of the costs associated with the collection and disposal of ceiling waste water by their municipalities.

In arid and semi-arid areas of the planet, supplying adequate water needed by green roof plants is considered to be one of the most significant problems and obstacles to their development. Due to its geographic area, Iran is more or less characterized by such a climate. The country's average annual rainfall is estimated to be 250 mm, less than one-third of the average global rainfall (Zolfaghari et al., 2011). Due to its location on an arid geographic ring, as well as the presence of a desert strip, both of which are on a 25 to 40 degree northern latitude, Iran is considered one of the low rainfall regions on the globe; however, in cold seasons and concurrent with a slip-back in the high-pressure system close to the tropical zone, Iran comes under the influence of Mediterranean low pressure systems (lps) from the west and the Sudanese lps from the southwest. These systems exploit the Iranian west wind corridor as their field of action and force major levels of precipitation. During this time, the Siberian high pressure system also progresses and influences the central and northern parts of Iran, due to a slip-back of the high-pressure system close to the tropics. The northern and northeastern currents winds associated with temperature drops and concomitant cold and dry air create considerable rainfall (their primary characteristic as a system), and create new fronts when crossing western air flows (Rahmanian, 2000). Low atmospheric precipitation, severe rainfall fluctuations from one year to the next and high variability are considered the most noticeable characteristics of Iran's climate. The spatial distribution of rainfall in Iran is not homogeneous, as its rate is reduced from west to east and north to south (Zolfaghari, 2000). While rainfall level on the Caspian shores and the Zagros and Alborz mountain ranges are roughly 1560 mm, 930 mm and 530 mm, respectively, it is reduced to 62 mm in the central regions which, in addition to heterogeneous spatial distribution, reveals a severe time variability, such that the coefficient of rainfall variations at many stations reaches more than 40 per cent (Babaee and Farajzadeh, 2001).

In addition to the annual level of rainfall and its distribution pattern throughout the year, another significant indicator that has influenced the design of optimum efficiency green roofs is the intensity of daily rainfall. This issue is directly related to humidity absorption and its storage in the soil. The slower the precipitation rhythm and the smaller the rain particles, the more time will be available to the soil to capture and store rainfall. By contrast, floods and heavy rains are less well absorbed and the level of water runoff is increased. The ratio of daily rainfall to its annual quantity is a criterion for identifying daily rainfall intensity. A high ratio indicates the likelihood that all or most of the yearly rainfall occurs over several days. In other words, a high ratio indicates that the occurrence of a severe rainfall shower is perfectly normal. Conversely, a low ratio is indicative of moderate rainfall and more frequent rainy days (Jahanbakhsh and Zolfaghari, 2000). The results of studies by Zolfaghari et al. (2011) revealed that the maximum ratio of daily rainfall to its annual quantity increases along with latitude decreasing from north to south; 24-hour rainfall in southern Iran is relative to similar rainfalls in more northern areas of higher severity. Iran is divided into the following five climate zones, based on the maximum ratio of daily rainfall to its annual quantity:

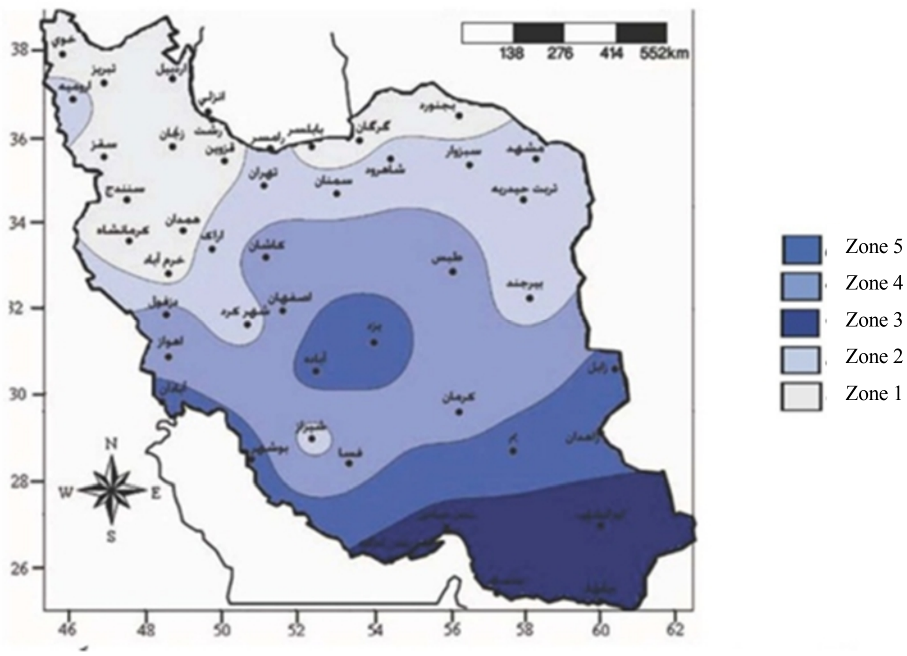


Figure 2. Iranian rain zones. Source: Zolfaghari, 2011.

The rainfall specifications for the above mentioned zones are:

Table 2. Rainfall specifications in stations (Zolfaghari, 2011).

zone	Max. daily rainfall (mm)	Av. Max. daily rainfall (mm)	Av. Max. Yearly rainfall (mm)	Av. Max. daily rainfall/ Av. Max. Yearly rainfall
Zone 1	-240, Anzali	46.4	574.6	**8.2%**
Zone 2	-340.2, Ramsar	40.5	335.9	**11.8%**
Zone 3	-106, Chabahar	38.9	147.6	**32%**
Zone 4	-107, Ahvaz	34.3	213.4	**16%**
Zone 5	-144, Bushehr	28.3	121	**23.4%**

4.1.3. Average exposure to sunshine

Although solar radiation has significant positive effects on plant growth, the level of radiation energy received from the sun has a direct effect on irrigation water requirements. Sunlight hastens soil surface evaporation, which intensifies the need for water care and plant growth. Lack of homogeneity between precipitation and evaporation will always cause problems for plant growth. In arid and water-scarce areas where rainfall is low, evaporation is at its highest (Iran Water Resources Management, cited in Lashti, 2000). On this basis, the water required for plant irrigation and solar radiation, in addition to precipitation, should also be considered. On 90% of Iranian territory, a daily average of 5.5 kilowatt hours of solar energy per square meter of ground is available, along with 300 days of sunshine per year (Renewable Energy Organization of Iran, 2012). In a study conducted by Safai et al. (2005), the amount of solar energy received in different parts of Iran was calculated using the hybrid model. The following map displays the sum total radiation energy received on a horizontal surface in one year in megajoules per square meter for different parts of Iran.

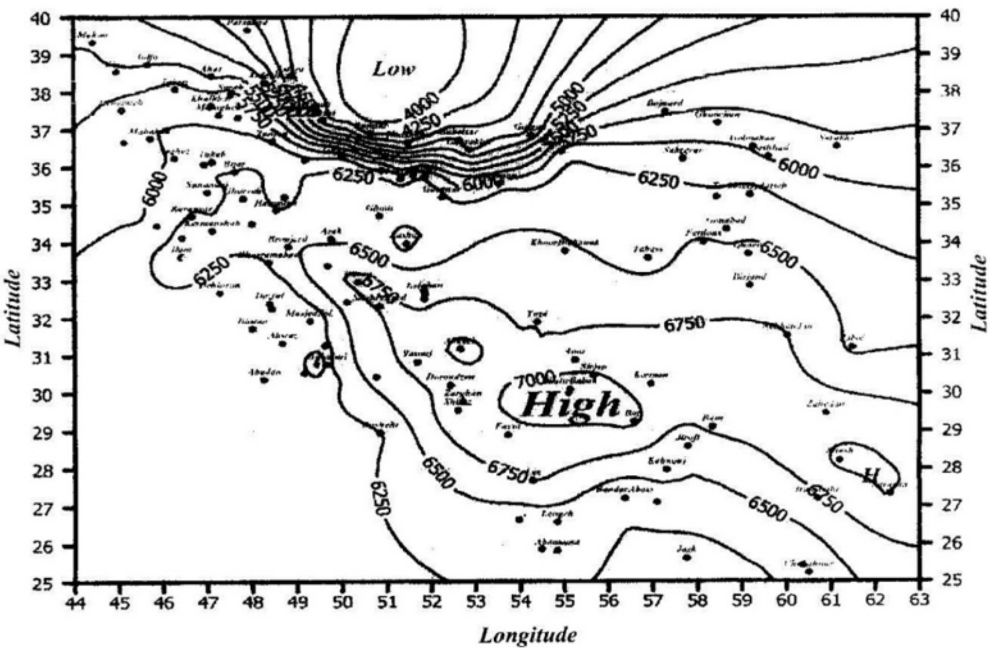


Figure 3: Sum total radiation energy received on a horizontal surface in one year in Iran (MJ/m2) (Safai, 2005).

Based on the data obtained, solar radiation is a prominent feature of Iran's climate, except in some northern parts of Iran where its intensity is lower. This issue should be considered as a climatic feature when selecting plants for green roof and for providing the water required by plants. On the other hand, considering the significant source of solar energy in Iran, the use of solar energy (for example, installing photovoltaic cells on roofs) is appropriate. Green roofs improve the efficiency of photovoltaic systems installed on roofs due to the reduced temperature of weather on the roof.

4.1.4. Period of drought

Drought is affected by two factors, i.e., rainfall and sunshine. In other words, drought is defined according to local weather patterns in different climatic regions of the globe (Baren, 1985). In the present study, the average rainfall value of 70 to 80 per cent is considered as a weak drought, 55 to 70 per cent as a moderate drought, 40 to 55 per cent as a severe drought and below 40 per cent as a very severe drought (Farajzadeh, 1997). According to various studies, the occurrence of droughts is the main characteristic of a country's climate, and is observed in humid as well as in dry climate conditions. A study of the relationship between the total percentages of drought frequencies and rainfall shows that they are negatively correlated, meaning that the frequency of dry years, months and seasons will rise proportionate to a reduction in rainfall (Farajzadeh, 1995). The results of Heidari Sharif Abad et al. (2002), taken over a 20-year period of rainfall and based on the Dumartin dryness coefficient, specify that 35.54 per cent of Iran area (573,884 square kilometres) have a super dry climate and 29.15 per cent (472,562 square kilometres) have a dry climate; thus, in total, 65 percent of the land is in the range of dry to super dry climates. The result is that rainfall content in central regions of the country during drought years will be reduced to nearly zero.

4.1.5. Period of frost, with or without snow cover

Studies by Fattahi and Salehi-pak (2009) demonstrate that the domination of freezing cold air and the occurrence of glacial weather in Iran are due to the penetration of atmospheric high pressure air masses comprising high-pressure central, eastern-northern European and Siberian air flows. The arrangement of these four flows of air masses (primarily the last three) provide for the transfer of polar and northern European air masses and the subsequent entry and pouring of cold air into the country. The dominance of Siberian high pressure air expands cold air flows and covers the northeastern, northern and southwestern parts of Iran under a covering of ice (Fattahi and Salehi-pak, 2009). Usually, with the entry of a cold air front, soil surface freezing occurs faster than weather. In most mountainous regions of the country, including the Alborz, Zagros and Azerbaijan mountains, as well as North Khorasan, the glacial period begins from September and October. On the KopehDagh and Binaloud heights in northern Khorasan and even on the Bezman highlands of northern Khorasan and Sistan-Baluchestan, the glacial period begins in October. In the Alborz and Zagros piedmonts, glacial weather begins and ends in November and March, respectively. Glacial weather is rarely observed in December on the northern coasts and in central and eastern regions, or in January in the southern and south-eastern and western parts of the country (Kamali and Habibi, 2005). The following map shows spatial and temporal distributions of glacial weather periods in Iran.

4.1.6. The prevailing wind direction

Wind occurs due to a pressure gradient resulting from non-uniform radiation of the sun onto the Earth's surface. Although wind speed is a function of many factors such as micro-climates and the physical structure of the urban fabric, perspectives about its influence are inconclusive. Although the statistics and maps received suggest that the average wind speed of many regions in Iran is little higher than 9 metres per second, the maximum annual wind speed is in fact much higher than the average value. For example, in statistics available since 2007, among the capitals of

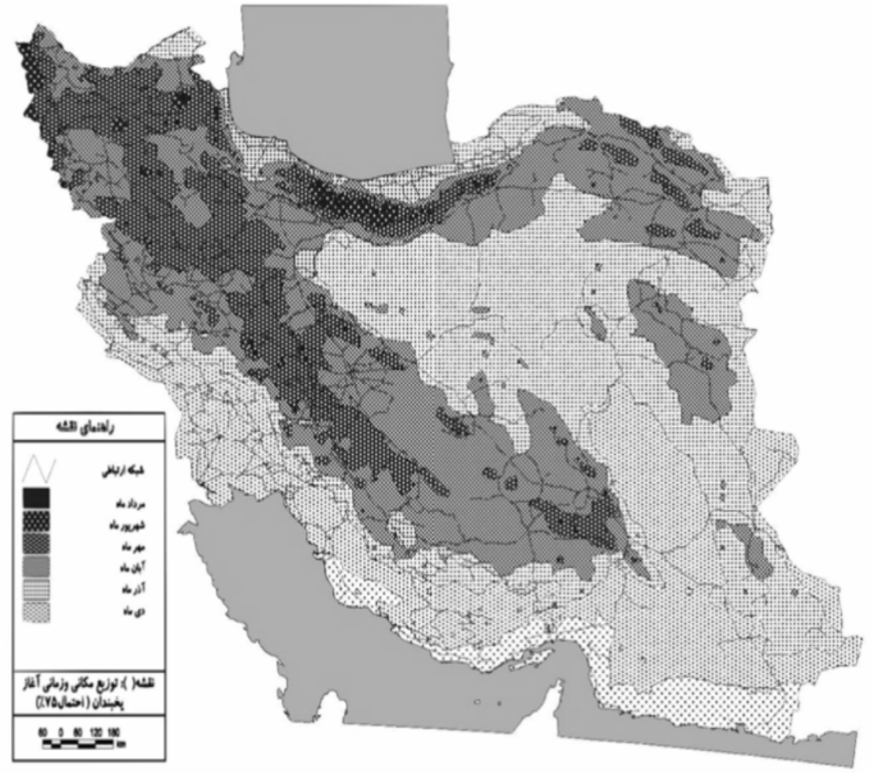


Figure 4: Distribution of the start of frosts in Iran (Kamali and Habibi, 2005).

Iran, Shiraz had the lowest ranking with a wind speed of 14 m/s, while Qazvin had the highest with wind speed at 39 m/s (Iran Meteorological Organization, 2012).

4.2. Considerations concerning effects of urban typology

According to the FLL Guidelines (2008), the most important issues that have been considered as urban form factors affecting green roof development in cities are the following.

4.2.1. Buildings shading one another, especially in compact and disharmonic urban fabrics

The length of shadow is dependent on the angle of the sun's radiation, building height and orientation and other independent factors that can easily be calculated. It is important to use shade tolerant plants in such cases in order to maintain a sustainable green roof.

4.2.2. Effect of urban form and structure on wind flow direction and deflection of precipitation

For green roofs, despite the benefits of wind – including pollination, the expansion of green space and also cooling the weather – it also has many associated disadvantages. Abnormalities in wind are often problematic from two perspectives:

- In cases where human attendance under green roofing receives attention; in other words, in cases where green roofs are used as open living spaces. In these cases, providing human comfort regarding wind flow is essential.
- Wind speed increment, rotation and direction changes can cause the demolition of the layers used with which to create green roofs. In corners, in particular, it causes uplifting and back- curved roof layers.

The dimensions and shape of buildings and their proximity to each other serve as the causes of wind speed and direction changes. Buildings and the built environment affect the type and the impact of wind on buildings' roofs, depending on the following parameters:

- Building density

- Building height
- Elongation and orientation of buildings relative to wind flow
- Pores in the building, as well as the building's form

Due to greater elevation and since air is less dense higher up than on the ground, wind velocity is higher at roof level. Therefore, attention to the effect of wind is paramount when designing green roofs. Gander (an aerodynamic engineer) and Gieve (an architect), investigated the impact of wind in urban areas in a series of experimental and laboratory studies under different conditions and in different volumetric combinations. They also explored human comfort as it related to wind under various conditions and presented practical approaches for providing human comfort (Gander and Gieve, 1994). Accordingly, the effects of wind on buildings' roofs and the proposed methods for reducing its negative impacts may be outlined as follows:

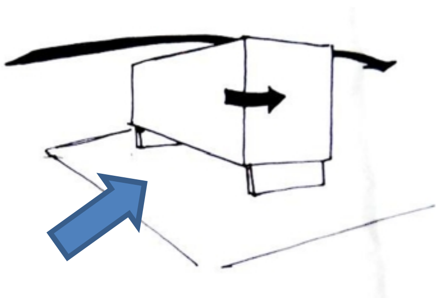


Fig. 5, Wind flow in the space of pilot and over the building

1. In highly dense urban textures where buildings share more or less the same average height, wind impacts are minimized. Attention should also be paid to the issue that, at this level, due to the reduced friction with the terrain, wind speed rises relative to the ground surface.
2. If the green roof is a parking lot roof, with a structure built on top of it as a pilot, wind flow in the space under the pilot, depending on the total height of the building against the wind and the extent of open space in front of it, will have the following effects: increasing building height will increase wind speed. In order to reduce the adverse impacts of wind in these conditions, it will be better for the building to be located parallel to the wind direction or with an increased porosity, so that air flow is scattered at the foot of the building.
3. At the corners of the building, wind velocity and the building's horizontal gradient will rise. The impact of this airflow for adjacent buildings that use green roofs can be problematic. A gradual breakdown in height, curved corners and providing physical barriers or curves at corners are among strategies for reducing wind speed at buildings' corners.

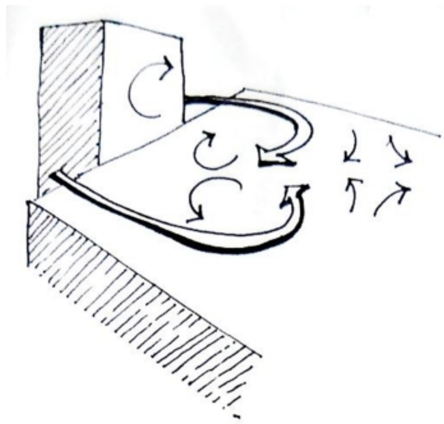


Figure 6. Wind shadow.

4. Height difference between adjacent buildings causes negative wind impacts on the roofs of shorter buildings located behind taller buildings. Taller buildings therefore act as a barrier against wind flow and create an area with moderately turbulent air flow. The extent of the wind shadow depends on the resultant wind forces interacting with the vertical image of the structure. If the height difference between two buildings is 15 to 35 meters, the length of the wind shadow or wind shadow area limit will be nearly four times the height of the building. Areas that are especially affected by wind flow are confined areas with a depth twice the height and width of the buildings on either side (Figure 26).
4. When the height difference between buildings is over 15 meters, a turbulence ring is formed at the foot of the building front-facing the wind, i.e., the

roof of the shorter building. If another building with an average height is placed at a distance in front of the taller building, the turbulence ring in the space between the two buildings will be more severe (Figure 7).

5. If the building stands at a 45 degree angle as a barrier against the wind, air bending and twisting develops and an improper area regarding the impact of air flow at the back and centre of the barrier is formed.
6. If a building is surrounded by taller buildings, so that a funnel-like shape is developed against wind that moves from its large section toward the small section, the accumulation of wind forces causes an improper area with respect to comfort in the lower funnel (or small) section. This phenomenon is referred to as the Vanturi effect.

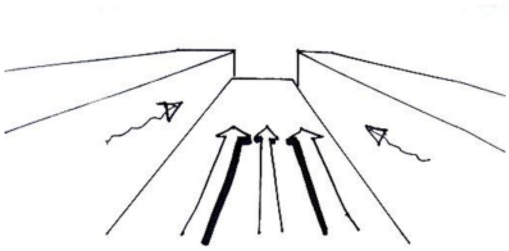


Figure 8: Corridor for airflow passage.

7. If a building is located among taller buildings, a corridor for airflow passage will create. This phenomenon will occur when the buildings forming the corridor body are not porous and the distance between them is less than 5% of their lengths (Figure 8).

In order to reduce its adverse effects on humans, it is necessary that wind speed be calculated and compared with the rates desirable for human comfort. If the considered building is at the design and construction stage and a green roof design has previously been anticipated, the aforementioned issues should be considered as part of the design. In existing buildings, if the wind speed is beyond human comfort or the wind direction is undesirable (i.e., twisting), the following approaches may be used to reduce the adverse effects of wind:

- Create artificial barriers against air flow to prevent the impact of wind or change the air flow direction to the desired course, such as raising the wall around the roof or using a windbreaker
- Use of adjustable shutters to control the entrance rate of wind and to change its direction
- Use of mass trees and shrubs that can create barriers against the negative impacts of wind
- Use of curved elements in corners so as to reduce the adverse impacts of wind
- Create porosity in the body of building in order to properly guide wind flow experiencing twisting due to confinement

To protect cultivated plants, in addition to the above, the following approaches may be applied:

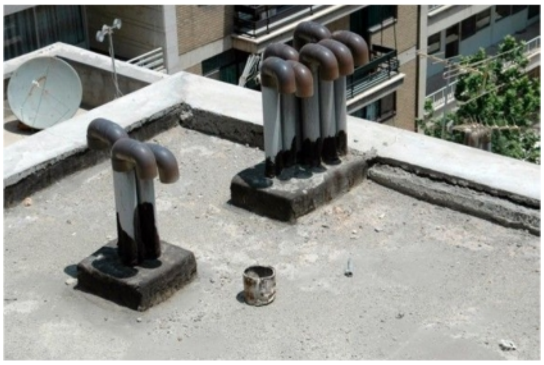
- Use of heavy elements in corners and especially when vegetation, in the form of a roll cover, may be applied to the roof floor
- Protect vulnerable plants by placing them among stronger plants
- Fixation of young and growing vegetation textures using vertical elements that already adhere to the roof floor

4.2.3. The effect of flue gas emissions

A flue gas stack is a type of chimney – a vertical pipe, channel or similar structure – through which combustion product gases called "flue gases" are exhausted to the outside air. Flue gases are extremely harmful to green roof plants. Nowadays, one or more stacks that are connected to the boilers of utility systems or chimneys can be found on the roof of all buildings. The following solutions will be useful for decreasing the negative effect of flue gases on plants:

- Treating exhausted gas with a series of chemical processes and scrubbers to remove pollutants. Electrostatic precipitators or fabric filters remove particulate matter.

- Identifying the appropriate height and diameter for the stack according to specific codes that govern how such design calculations must be performed
- Conducting exhausted gas to a desirable orientation



Figures 9 and 10. Flue gas stacks (Shahre, farang.com).

Figure 11: Reflection from building façade.

4.2.4. Reflection from facades of higher surrounding buildings

Glass facades – in essence a reflector platform – exacerbate the effect of solar radiation on neighbouring roofs. This may provide an undesirable situation for the vegetation that covers a green roof neighbouring a reflector facade, especially in summer. In this instance, the solution depends on the specific situation. It should be noted that recently, in Tehran and other big cities in Iran, glass façades covering more than 40 per cent of the total surface area of a building have been prohibited by municipalities.

4.2.5. Form of building roof (gradient of roof surface)

As previously stated, intensive green roofs are executed on slopes of up to five degrees, while extensive green roofs are created on slopes of up to 30 degrees (Dubai Municipality, 2011). Green roofs should not be applied to roofs with slopes greater than 45 degrees, due to the extreme difficulty in managing soil moisture on a roof of such steepness. Except in northern Iran and in the countryside surrounding the north of Tehran, sloped roofs have rarely been found in either traditional or more modern architecture. Most roofs of buildings in Iran are flat. Moreover, in some areas where sloping roofs are common, the amount of rainfall will allow for replacing the sloped roof with a flat, green roof that can store storm water. This is possible especially in the countryside and towns surrounding the north of Tehran.

4.2.6. Additional technical installations

Many technical utilities like antennae, air conditioning units, satellite dishes, water tanks, etc. are placed on the roofs of buildings where they occupy large areas of space. In addition, the shade created by these elements may inhibit plant growth. Regarding the above, all elements that need to be maintained on the roof must be properly organized.

Figures 12-14. Additional technical installations (Shahre, farang.com).

5. Conclusion

Studying climatic factors show that there are some zones in Iran where green roofs can be conserved without the need for irrigation. Only in the north of Iran, on the Caspian Sea coast, is there an appropriate zone for green roof construction due to the high amount of rainfall and low radiation in the area, as well as a short period of frost that is often not accompanied by snow. Plants on green roofs in this zone (if selected correctly) will rarely need irrigation and when they do, this will only be the case during some hot summer days. Green roofs in central, southern and eastern Iran will definitely require irrigation and maintenance. In the west of Iran, in the Zagros Mountains and also in the northwest of Iran, the amount of precipitation is greater than in central Iran. In this zone, the irrigation of green roofs will be needed for about one third of the year. However, the frost period in these parts of Iran is considerable. Tehran and its surrounding towns have medium conditions for green roof development, but an irrigation system will be required for almost half of the year.

According to the aforementioned situation, the extensive type of green roof is suggested for most zones of Iran. Moreover, increasing the thickness of the substrate and selecting local plants will be useful for additionally greening up roofs. All urban typological suggestions that have been mentioned should also be considered. For selecting the type of green roof and its plants, zone tolerances and urban tolerances should also be considered.

Not:

1. There is evidence suggesting that green roofs can help slow the spread of fire to and from the building through the roof, particularly where the growing medium is saturated.

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