***Creative City Design*** / *Vol. 2, No. 2, 2019, 1-8.*

# Investigation the Role of Green Roof and Walls in the Thermal Performance of Urban Buildings based on Sustainable Architecture (A Case Study in Mashhad-Iran)

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*Submit Date: 2020.08.12, Accepted Date: 2020.08.24*

## Abstract

Today, in all over the world, due to the problems such as excessive consumption of fossil energy, global warming, climate pollution and major environmental problems, the use of sustainable architecture technologies especially green buildings is important. One of the solutions to bring green spaces in to the buildings is the use of gardens and green walls. The development of green space in roofs, terraces and urban facades improves the performance of green spaces on the regional and urban scale. The building shell is one of the factors that has a significant effect on the energy consumption of buildings and thermal comfort. Creating green walls on the building shell due to insulation, shading and cooling caused by plants' evaporation has a significant impact on energy demand reduction in warm and cold seasons and air conditioning. In the present study, the effect of plant use on roofs and walls, in different views of the building, has been investigated for estimating energy consumption reduction. The results show that by creating green spaces on the roof and walls of the building, the energy consumption decreases. The reduction of energy consumption through the roof is equal to 26/6% and through the south, east, west and north walls, is equal to 6/9%, 8.8%, 8.8% and 6.6%, respectively. Also, the average annual temperature of these levels dropped around 5 °c

***Keyword:*** *Sustainable Architecture, Green Shell of the Building, Energy Saving, Green Roof, Living Walls*

## Introduction

In recent years, urban green spaces have been greatly reduced due to the lack of control over the city and the growth of roads and buildings. This important issue affects the quality of urban spaces and the average temperature of cities, which cause the emergence of the heat-islands phenomenon. The improper influences of modern urban life can be partly reduced by the development of urban green spaces (Pandey et al.,2013). The rise of urbanization leads to the deterioration of the quality of life of many people in major cities, compared to the effectiveness of the heat island, and an increase in indoor temperature of housing and other buildings. The entire urban population is expected to increase from 3.7 to7.9 billion by 2050 ( Feitosa & Wilkinson, 2018). In terms of the concept of urban heat islands (UHI), many suburban and urban areas are experiencing high temperatures in comparison to their rural surroundings. The average annual air tempreture of populous cities can be 1 to 3°c warmer than the surrounding area and in a quiet and clear night, this temperature difference can reach 12 degrees Celsius (Cascone et al., 2018; Collins et al., 2017). The erosive process of urbanization has brought various problems such as environmental pollution, increasing the use of fossil fuels and global warming. Creating green spaces on a city scale with a combination of green roofs and green walls may reduce the effect of urban heating island and indoor temperature. Tall buildings in many cities are a typical housing type, and due to the role of external walls in increasing heat, it is expected that a combination of green roofs and green walls has a high potential for improving the thermal performance of the buildings (Chiquet et al., 2013).Concidering that only 1 to 2 percent buldings are annually added to the total buildings, the focus must be on the completion of existing buildings to provide maximum thermal benefits (Botzat et al., 2016). In the field of reducing energy consumption and the performance of green roofs, several researches have been conducted. The features of buildings, in green roof design, generally depend on the thickness of the roof and its thermal transfer coefficient, and also the features of the trees such as type of the tree, its shading level, its evapoarion and its water capacity to absorb heat (He et al., 2017; Bevilacqua et al., 2015). According to the litrature reviwed, due to lack of investigation of the

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effect of green cover on the building shell, in different fronts, on the thermal performance of the building, the current study investigates the effect of vegetation cover on the reduction of thermal and cooling needs of the buildings. In addition to investigating the cooling and heating needs of the buildings, the external surface temperature of the building with and without green cover has been investigated because the temperature of the building surfaces has a significant impact on the heat islands of the region. The study of the surface temperature and thermal and cooling requirements of the buildings is among the innovations of this research. For this purpose, the thermal benefits of green roofs and the completion of green walls have been analyzed.

## 1. Significance of the Study

Nowadays, due to the existence of major problems (global warming, air pollution and major environmental problems), the use of sustainable architecture technologies especially green buildings is important. The most important reasons of disappearance of the role of roofs and the semi-open sections of buildings, such as traces, are the installation components such as cooling systems, visual, air and sound pollutions, and the emergence of the concept of joint ownership and the dominance of the buildings over each other. Green spaces create a valuable environment in the buildings and increase the economic and social sustainability (Klemm et al., 2015).One of the strategies for the presence of green spaces in buildings is the use of roof gardens and green walls, because the use of green spaces is one of the most efficient methods to improve weather conditions and reduce pollution, and its efficiency is much more than other methods and technologies in order to protect the urban environment. Also considering the Fourth Developmet Plan which designed a plan called Green Government and the disscussions regarding energy saving and creating environmental culture and so forth, green roofs in the metropolitan area can serve as a ground for the growth of the green government perposes (Andarini, 2014). Green walls in some projects in Mashhad, according to some encouraging laws and codes, (and sometimes in some areas compulsory) have been implemented. This can help a lot of economic justifications and cultural development of green space in buildings.

## 2 Theoretical Foundations of Research

### 2.1 Green Roof System in the Form of Sustainable Design Principles

The idea of environmental sustainability is to remain the earth in the best shape for the next generation. With this definition, the activities of people is sustainable in terms of environment when they can be conducted without the reduction of natural resources or degradation. The purpose of environmental sustainability is to maintain the potentials of the following conditions: reduction of waste and energy distribution in the environment, reducing the effect of harmful products on human health and the use of materials which can turn back to the nature cycle (Blanusa et al., 2013). The principle of sustainable design is based on the fact that a bulding is a part of nuture and the cycle must act as a part of the ecosystem and be placed in life. Overall, the principles of sustainable design are as follows: location recognition, natural processes recognition, environmental impact recognition and people's recognition (Raheb, 2012).

### 2.2 Green Spaces in Height (Vertical and Horizontal)

#### 2.2.1 Green Walls

The green wall is one of the plants that grow in a vertical protected system connected to the internal or external wall, and of course, they are installed independently. This system consists of plant collection, medium (growth), irrigation and drainage systems. Green walls are different from the facade-green walls, because in the green wall, plants are cultivated in a large number of pots (flowers), while in vertical green spaces, a smaller number of plants in a context grow and rise high, which ultimately covers the surface of the façade or the building. The other names of Green walls are living walls and vertical gardens (Raheb, 2012).

#### 2.2.2 Living Walls (Oxygen-producing Walls)

This system is actually the newest type of green walls; the air produced by the plants is used in the air conditioning systems of the building. The walls act on the basis of biological air purification by the plant. The oxygen maker walls increase the capacity of indoor air purification, as if they are natural covers of air conditioning systems engines, and act as a filtration system, with suction from the root (La Roche & Berardi, 2014).

#### 2.2.3 Inactive Living Walls

The inactive living walls are composed of square or rectangular modular panels that provide the plant's growth environment vertically, keeping the plant's components. These modular panels are connected by a light structural system, with a distance, to the building's façade or structure (La Roche & Berardi, 2014) .

#### 2.2.4 Active Living Walls

An active living wall is one of the most recent types of green walls, which is designed and integrated in heating/cooling facilities and air conditioning in a way to refine the air of interior spaces and to perform as a heat exchanger. In this system, the air produced by the plants is used in the air conditioning system of the building, the leaves and branches of the plants absorb the carbon monooxide and dioxide, the particles in the roots purify organic compounds and particulates in the air, and the natural processes of plants produce fresh air which is led to the system through a ventilator and then spread out inside the building (La Roche & Berardi, 2014).

### 2.2.5 Green Roofs

The green roof is a light system which is provided from prefabricated layers which make a united system on the roof, and make the plants grow in a special growth medium. Green roof forming layers, usually from top to bottom, are vegetation, vegetative medium or planting layer, root stabilization and protection, drainage layer, layer of drainage, aeration and water storage, moisture protection and insulation layer to protect the layers of the roof (La Roche & Berardi, 2014).

### 2.2.6 Extensive Green Roofs

In this type of roof garden, the availibility of the roof level is limited. This type of roof garden has a shallow planting bed, and its species are mainly "cover plants". This system is also known as low altitude section and low-thickness execution. The growing bed of plants in the extensive green roofs is usually a light mixture of sand and other materials with mineral properties, compost or other organic materials and soil. Usually drought and cold resistant plants, such as grass and regional bushes, are used (Peck & Kuhn, 2010).

### 2.2.7 Semi-extensive Green Roofs

It is a combination of two concentrated and non-concentrated roofs. It has the benefits of two types of green roofs, but has a lower load capacity. Its deeper culture layers have increased the possibility of a variety of species, such as the application of grasses, permanent bushes and shrubs but trees. These green roofs are located between the extensive green roof and the intensive one. It has deeper layers (drainage, soil, plant) and more diverse plant species than extensive roofs. The depth of the layers is 20 centimeters maximum. It needs regular maintenance but irregular irrigation. Compared to the scattered green coverage, the semi-extensive coverage has more water retention capacity (Peck & Kuhn, 2010).

### 2.2.8 Intensive Green Roofs

In this type of roof garden, the surface of the roof is accessible and can contain tree, plant and other elements of the park. This system is also known as a deep section or roof garden that consists of various types of plants and is designed similar to a park. Some of the green roofs have large trees and fountain, which needs a major strengthening of structures. In an intensive roof garden to grow bigger plants more soil is used in the growth bed of the plant. Sometimes it is necessary to provide the large plants with the windbreake, especially at the heights of the roof. In this type of roof, more diverse plant species are used along with irrigation, fertilizer and further care and maintenance (Peck & Kuhn, 2010).

## 3. Research Method

The research relies on theoretical concepts collected from books, instructions, external and internal articles and sites, in a library-based method, and in the data collection stage, to achieve an understanding of the effect of these walls on the thermal performance of the building with a case analysis of Mashhad City, the simulator tools have been used.

## 4. Simulation

Green roof modeling and research on energy consumption of the building is possible through the use of the simplest and most common methods (selection of suitable heat transfer coefficient and the use of energy balancing); however, more detailed and precision methods are also used. The details which hace to be considered:

- The short waves and the large waves radiates transmitted into green space
- Conductive heat in the soil layer
- Convective heat transfer
- Surface transpiration of soil and plant

The best and most comprehensive of these methods is the silver technique (Aravantinos & Eumorfopoulou, 1998) based on the calculations of Francesten and Koening (Frankenstein & Koenig, 2004) which is also the computational basis of Energy Plus software. Energy Plus is a computational application for building modeling with heating, cooling, ventilation, lighting and other systems. This program is an independent computing machine and does not have a user-friendly environment.

This is why we use the Designbuilder software that uses the same computational method and has a good and beautiful image environment. In order to investigate the effect of green walls in different building walls, a sample building with an infrastructure of 300 square meters and according to the common wall and ceiling materials in Mashhad climate has been simulated.

In this building, using 15 cm of agricultural soil and materials and plants with the following characteristics, the energy of the cooling and heating systems was studied and compared. The roof garden materials were according to the following table, the heat transfer coefficient of which is equal to 0/462W/M$^2$. K. The common roof materials are according to the following table and its heat transfer coefficient is 0/533 W/m$^2$. k. At first, the effect of soil thickness has been studied and analyzed. In this section, the planting bed was simulated with two thicknesses of 15 and 30 cm, and based on the results, a thickness of 15 cm was selected to continue the study.

Figure 3 shows how the heat transfer of the ceiling in these two modes is compared with the basic mode. According to Figure 3, the use of green roof reduced the waste of heat in summer greatly and caused the building to lose heat through the ceiling in hot seasons and caused the space to be cool. Increasing the thickness of soil did not affect significantly the improvement of roof heat transfer. Using a green roof with a thickness of 15 and 30 cm, the energy consumption of the building has decreased by 6.26 and 6.27% compared to the normal roof, which shows that with increasing soil thickness, energy consumption of cooling and heating system did not decrease significantly.

### 4.1 Heat Loss through the Wall

In the basic mode, the external wall materials are in accordance with Figure 5, and the heat transfer coefficient is equal to 0/898W/M$^2$. K. The energy consumption of heating and cooling systems was reduced in the south, east, west and north walls by 9.6, 8.8, 8.8 and 6.6%, respectively, using green façade and also the temperature of these levels was reduced about 5 °c, compared to the basic mode throughout the year. In the following figure, the amount of energy consumed by heating and cooling system has been shown in different modes.

The average temperature of the surfaces, in the basic mode and using the green wall, is simulated in different modes and in accordance with the following shapes.

Finally, the annual average temperature of the surfaces, before ans after being green, has benn shown, and based on the results of simulation, the green cover has reduced about 5 degrees of surfaces' temperature.

### 4.2 Simulation Results

According to the results of the simulation in the table below, the amount of energy needed to be used for cooling and heating of the presumed building has been investigated in 6 states as well as the percentage of energy efficiency with or without green space.

According to the results, by doubling the soil thickness, the energy consumed was only a percentage more reduced, but this thickness is not offered due to the administration cost,. Also in this model according to the results, the best front for the implementation of green roofs, is the eastern and western walls of the building.

Figure 1. Tahran Book Garden (Source: Authors, 2018)

Table 1. Green Roof Details (Source: Authors, 2018)

| **Special heat (J/kg.k)** | **Conduction coefficient (w/m.k)** | **Density (kg/m$^3$)** | **Thickness (cm)** | **12** |
|---|---|---|---|---|
| 1680 | 0/56 | 800 | 15 | Agricultural soil |
| 1000 | 1 | 1100 | 1 | Membrane layer |
| 840 | 0/55 | 1000 | 5 | Drainage |
| 1400 | 0/04 | 15 | 5 | Polystyrene insulation |
| 1000 | 23 | 1000 | 1 | Humidity insulation |
| 800 | 0/25 | 700 | 5 | Concrete |
| 1000 | 0/8 | 1220 | 10 | Composite roof |
| 1000 | 0/4 | 1000 | 1/5 | Plaster |

Table 2. Common Roof Details (Source: Authors, 2018)

| **Special heat (J/kg.k)** | **Conduction coefficient (w/m.k)** | **Density (kg/m3)** | **Thickness (cm)** | **Materials** |
|---|---|---|---|---|
| 840 | 0/55 | 1000 | 5 | Drainage |
| 1400 | 0/04 | 15 | 5 | Polystyrene insulation |
| 1000 | 23 | 1000 | 1 | Humidity insulation |
| 800 | 0/25 | 700 | 5 | Concrete |
| 1000 | 0/8 | 1220 | 10 | Composite roof |
| 1000 | 0/4 | 1000 | 1/5 | Plaster |

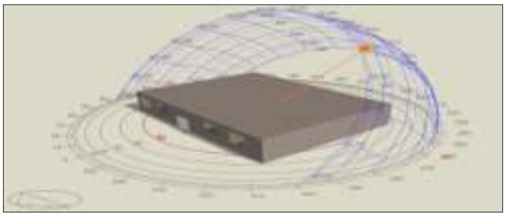


Figure 2. The Schematic Building (Source: Authors, 2018)

Table 3. The Plant Specifications (Source: Authors, 2018)

| **Leaf release coefficient** | **Leaf reflection coefficient** | **Leaf surface index** | **Maximum height** | **Name** | **Plant family** |
|---|---|---|---|---|---|
| 0/95 | 0/34 | 4/49 | 0/15 | Mother of thyme | Lamiaceae |

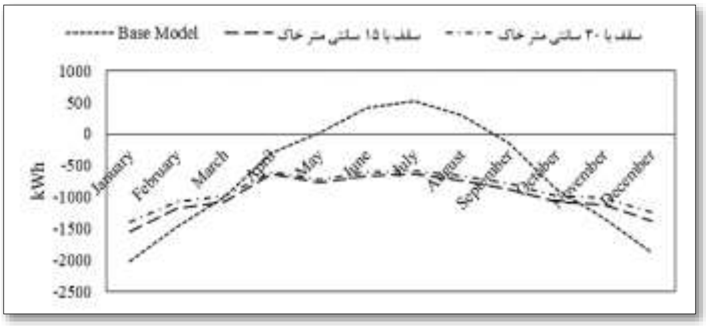



Figure 3. Transmission of Heat through the Roof

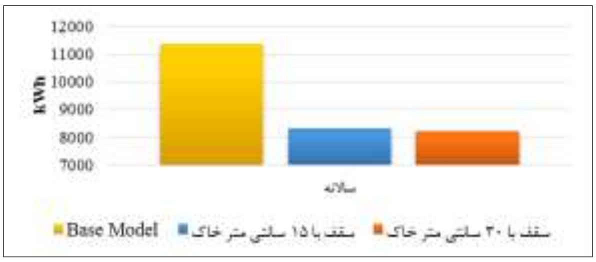



Figure 4. Energy Consumption of the Building (Source: Authors, 1397)

Table 4. Common Wall Details (Source: Authors, 2018)

| **Special Heat (J/kg.k)** | **Conduction coefficient (w/m.k)** | **Density (kg/m3)** | **Thickness (cm)** | **Materials** |
|---|---|---|---|---|
| 1000 | 2/2 | 2000 | 1/5 | Stone, facade |
| 920 | 1/15 | 2000 | 2 | Mortar & Sand Cement |
| 1000 | 0/18 | 500 | 15 | heblex |
| 1000 | 0/25 | 800 | 1/5 | Plaster |

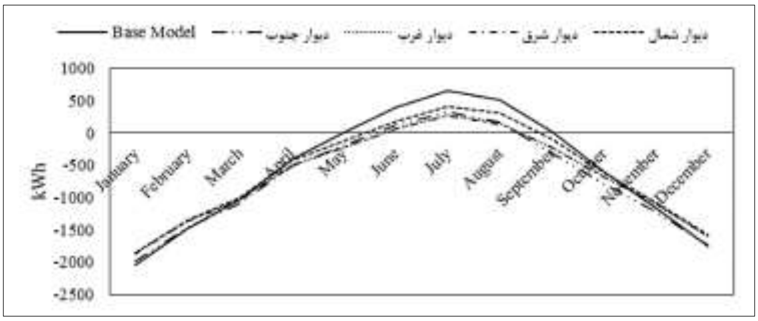



Figure 5. Heat Loss through the Wall (Source: Authors, 2

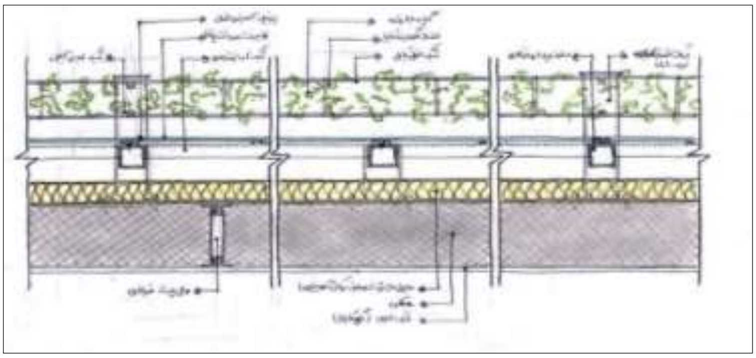
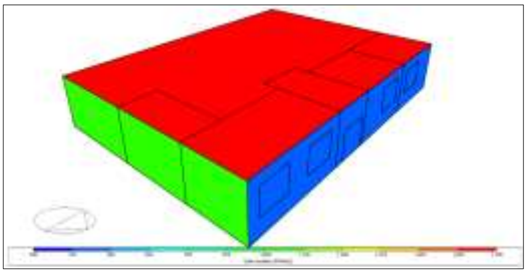
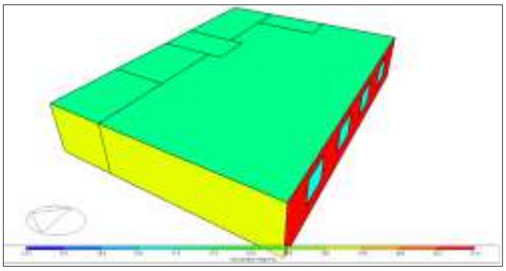


Figure 6. Green Wall Section (Source: Authors, 2018)

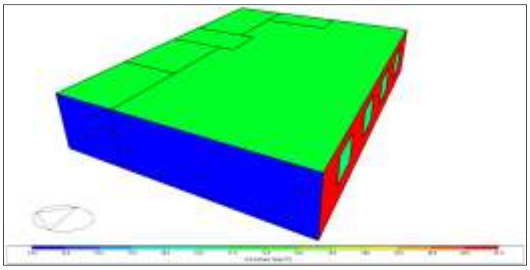

Figure 7. Annual Energy Consumption of Heating and Cooling Systems (Source: Authors, 2018)



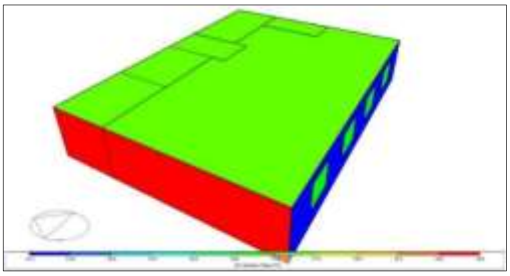
Surfaces' temperature in basic mode



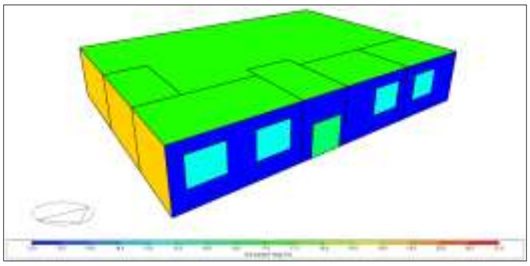
Surfaces' temperature in basic mode



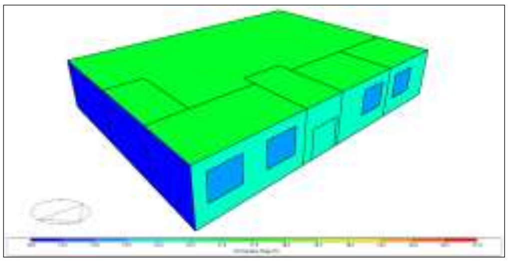
The West Green



The South Green



The North Green Wall



The East Green Wall

Figure 8. The Surfaces' Temperature in the Case Study (Source: Authors, 2018)

Table 5. Annual Average Temperature (Source: Authors, 2018)

| **Temperature of the green mode (°c)** | **Temperature of basic mode(°c)** | **Surface** |
|---|---|---|
| 14 | 18/5 | roof |
| 14 | 16/5 | North wall |
| 14/5 | 21 | South wall |
| 15 | 19/5 | Eastern wall |
| 15 | 19/5 | Western Wall |

Table 6. Reducing the Energy Consumption (Source: Authors, 2018)

| Total reduction percent | Cooling energy reduction percent | Heating energy reduction percent | Total energy (kWh) | Cooling System Energy (kWh) | Heating System Energy (kWh) | |
|---|---|---|---|---|---|---|
| - | - | - | 11341 | 5913 | 5428 | Basic mode |
| 26/6% | 41/5% | 10/3% | 8325 | 3457 | 4868 | Green roof with the thickness of 15 cm |
| 27/6% | 39/3% | 14/9% | 8205 | 3588 | 4617 | Green roof with the thickness of 30 cm |
| 6/6% | 8/4% | 4/7% | 10588 | 5415 | 5174 | North wall |
| 6/9% | 13/3% | 0/1-% | 10558 | 5126 | 5432 | South wall |
| 8/8% | 13/5% | 3/7% | 10343 | 5115 | 5228 | West wall |
| 8/8% | 13/6% | 3/6% | 10342 | 5107 | 5235 | East wall |

## 5. Conclusion

Considering the benefits of green coverage in the exterior walls of buildings, in order to reduce energy consumption which is one of the important goals of sustainable architecture, in the present study, the effect of green walls on the thermal performance of the building shell in different fronts in the climate of Mashhad has been analyzed. The results of Table 6 show that the need for cooling and heating the building was reduced by an average of 26%, using a green roof, and such changes, in warm seasons and in green roof system with a thickness of 15 cm, reached to 41/5%. Also, the building shell temperature had a reduction of 5 °c in warmer seasons. Finally, by reviewing the graphs of heat loss from the building shell after adding green walls and roofs, it was observed that in hot seasons this rate has had a significant reduction. The percentage of total energy reduction for cooling and heating the building is 26/6% in green roof system, 8/8% in the east and west walls, 6/9% in the south wall and 6/6% in the north wall.

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