Comparing the Microclimatic Role of Horizontal and Vertical Vegetation to Improving the Thermal Comfort of Outdoor Spaces Between Buildings: A Case study (Faculty of Agriculture, I.K.I University), Qazvin.

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Abstract

Vegetation moderates a microclimate by casting shadows, increasing solar reflection and evapotranspiration, and modifying wind patterns. The present study aims to investigate the microclimatic role of vegetated surfaces and structures in improving thermal comfort in outdoor spaces between buildings. The main research question is which green system—horizontal vegetation (green floor) or vertical vegetation (green façade)—is more effective in moderating a microclimate and improving thermal comfort in outdoor spaces? To find the answer, an academic building with vertical and horizontal walls facing an outdoor space (yard) was selected for the case study. Data were analyzed via numerical modeling (ENVI-met) and the RayMan software model. The Indices of PMV (predicted mean vote), PET (physiological equivalent temperature), Tmrt (total mean radiant temperature), and RH (relative humidity) were computed and analyzed to identify and analyze thermal comfort levels in outdoor spaces. The analysis results indicate that vegetation significantly affects thermal comfort in outdoor spaces between buildings in warm seasons by reducing PMV, PET, and Tmrt, while increasing RH. In all analytical models based on the indices of thermal comfort in outdoor spaces, the green floor performed better than the green façade due to a more extensive tree coverage on horizontal surfaces. The trees planted on horizontal surfaces and the ground improve thermal comfort in outdoor spaces by shading and blocking direct sunlight. Further, the results indicate that compared to vegetation, blocking direct solar radiation and providing shading on surfaces are much more effective in improving thermal comfort in outdoor spaces.

Keywords: Horizontal greenery, Vertical greenery, Green cover, Thermal comfort, Spaces between building, ENVI-met software

1. Introduction

Buildings significantly contribute to global and local climate change (Lassandro & Di Turi, 2017:183). Studies show that increasing the ratio of vegetation and high-albedo materials in urban areas can potentially reduce UHI (urban heat island) effects in cities (Imran et al., 2018: 2). Thermal comfort analysis, especially for outdoor spaces, is a great challenge due to a large number of environmental and personal (physiological and psychological) factors influencing it (Ahmadpour Kolahrodi et al., 2017: 60-63). Such analysis requires understanding the microclimate of an environment. Studying urban microclimates has heightened our knowledge about the thermal behavior of such environments, which, if incorporated in sound design strategies, can contribute greatly to improving living conditions in urban areas (Hatami, 2016: 3). Vegetation reduces the temperature of a microclimate by shading, increased reflection and evapotranspiration, and changing wind patterns (Karimian et al., 2014: 682). The façade of a building is one of the most influential components of the building's energy consumption (Mohamed Farid et al., 2016: 174). The material used in the façade of a building greatly affects the consumption of non-renewable energies. Therefore, increased UHI not only increases urban temperature, but it also reduces the thermal comfort of persons and users of urban outdoor spaces. Consequently, vertical and horizontal vegetation systems can significantly improve thermal comfort in outdoor spaces. The study aims to investigate the microclimatic role of vegetated surfaces and structures in improving thermal comfort in the outdoor spaces between buildings. The main research question is which of the vegetation systems, including horizontal (green floor) and vertical (green façade), will more effectively moderate a microclimate and improve thermal comfort outdoors. Accordingly, an academic building in the Imam Khomeini International University of Qazvin, Iran, which features a central yard with vertical and horizontal walls facing outdoors, was used as the case for modeling and analysis. Numerical modeling (ENVI-met) and software modeling (RayMan) were used to identify and analyze thermal comfort and the respective affecting factors of the studied case.

2. Literature Review

There have been numerous studies on vegetation in recent years. Herath et al., 2018 In a study in Colombo, Sri Lanka, the impact of vegetation on urban facades have been investigated by using ENVI software. The results indicate that vegetation can affect the weather conditions in a city and be used as a strategy to reduce the UHI

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(Herath et al: 2018). Besir et al. analyzed green rooftops and facades via a comprehensive method. Their paper extensively studied the benefits of green roofs and facades (e.g. considering evaporation, perspiration, wind-blocking, and the cooling effect of green spaces on reduced demand for cooling in buildings). The results indicate that green rooftops and facades are key strategies for reduced energy consumption and lower emission of greenhouse gases (Besir et al: 2018). In another study, Paschaolino et al. the thermal behavior of a green wall and a simple wall without vegetation were tested in the center of Madrid, Spain. A comparison of the experimental results on the green wall and the simple wall shows that green facades can have the potential to reduce the temperature around a microclimate (Paschaolino et al:2017). Ridzwan Othman et al,2016 In a study, two office buildings in Jakarta, Indonesia have been investigated. One of the buildings has a green wall while the other is without a green wall. The results show that the temperature reduced in the building with a green wall system more than the other building which had ordinary walls. This study shows the benefits of a vertical green system in an office building in tropical climates (Ridzwan Othman et al:2016). Sajjadzade et al,2015 introduced green walls, their benefits and problems and their use for reducing building energy consumption. The results indicate that as a new school of sustainable architecture, green architecture is a new solution for mitigating air pollution and enhancing the percapita of urban green space. Green walls are a key component of sustainable architecture and will gain increasing importance in our cities in the upcoming years (Sajadzadeh et al:2015). Khanzadeh Natanzi,2009 modeled a site in three conditions (status quo, increased density, and green rooftops) and obtained the effects of a green rooftop, especially on ambient temperature and wind. Their results indicate that in small scales, the benefits of a green rooftop in improving the thermal comfort of the outdoor space are limited to the proximity of the vegetated rooftop, while in locations where it is possible to create roof gardens such benefits may further increase (Khanzadeh Natanzi: 2009). Erdem Cuce,2016 In experimental and numerical research, a green wall system located at the Nottingham University Jubilee Campus has been tested. The tested green wall is a direct green view system on which plant growth has occurred naturally. The green wall is constructed by red bricks and covered by a hydra plant, which is an evergreen and liana vegetation. Experiments were carried out during three weeks in different environmental conditions, temperature, and humidity along with wind speed measurements for a reliable and realistic way to determine the effect of green wall systems on thermal adjustment. The results show that the thermal adjustment properties of green wall systems are highly dependent on vegetation type and growth angle. An average of 2.5 centigrade degrees of temperature reduction in the internal wall is achieved through green walls with 10cm-thick vegetation, which is very promising (Erdem Cuce:2016). [Table 1] is a list of some other studies on the subject.

Based on the research background and to the best of our knowledge, there are no other studies on the comparison of the performance of vertical (green floor) and horizontal (green façade) vegetation in moderating microclimates and improving thermal comfort outdoors. The current study aims to bridge this research gap. According to the research background and research gap, the main research question is which green system, which is horizontal vegetation (green floor) or vertical vegetation (green façade), more effectively moderates microclimates and improves thermal comfort outdoors.

2.1. Vertical greenery system

A common, widespread approach to increasing green infrastructures is integrating vegetation in vertical structures, known as green walls (Collins et al., 2017:114). The greening of building envelope is a new field that has expanded in the ecology, cultural and built environment quickly (Fallahi & Ayvazian,2016:35). The vertical green system is defined as a vertical green layer (façade, wall, slanted walls, separating walls), the main purpose of which is to grow plants on a wall. This system is known as a vertical garden, green wall, vertical vegetation, green view, biowall, and the living wall (Besir et al,2018:918). Vertical green surfaces have the potential to cool building surfaces (Sheweka & Magdy Mohamed,2012: 507). A green façade performs better in reducing building temperature. Therefore, a vertical green façade is a suitable passive solution in sustainable design (Ridzwan Othman & Sahidin, 2016: 845). The recent studies on the implementation of vertical green systems indicate four key factors in their performance as passive systems for energy conservation in buildings: system structure, climate impact (on both the thermal performance of the building and the selection of plant species and their growth), plant species, and mechanisms (how a system is used passively to reduce energy consumption in buildings by means of shading, insulation, evapotranspiration, and wind-blocking)(Coma et al., 2017: 226-228). Many studies have found that green walls improve thermal comfort in outdoor spaces (Olivieri et al., 2017:2). In general, vertical green systems are divided into two categories: green façade (ground systems), and the green wall (wall systems) (Medl et al., 2017: 7). The difference between the green façade and living wall is that the former uses vegetation planted in the ground, which keeps growing on a building facade (green wall), while the latter uses vegetation planted on a building wall (green façade) (Besir et al., 2018: 918). Green façade consists of direct and two-layer types (M. Hunter et al., 2014: 103). the green wall consists of continuous, modular, and linear types (Medl et al., 2017: 7) [Table2]. Structure-wise, the green façade consists of two systems: hydroponic and soil cells (Riley, 2017: 5). Figure 1 shows the types of the green wall according to their structure.

Table1
Previous Study on The Greenery Systems [Vertical Green System(VGS)/ Green Roof(GR)/ Green Frosting(GF)]

Authors	**Year**	**Location**	**climate**	**Period of study**	**Type of study**	**System of Study**	**Source**
Ghazalli et al	2018	Australian / Canberra	Warm temperate	All year	Case study Simulation	VGS	[28]
Feitosa & Wilkinson	2018	Rio de Janeiro &Brazil Sydney & Australian	Subtropical Hot Mediterranean	All year	Experiment Simulation	VGS / GR	[25]
Daemei et al	2018	Tehran / Si-e-Tir Street	Warm and dry	S / W	Experiment	VGS	[18]
Morakinyo et al	2017	Hong Kong	tropical	S / W	field study Simulation	VGS	[66]
Chatzidimitriou et al	2017	Greece / Thessaloniki	Temperate / Mediterranean	S / W	Experiment Simulation	GF	[14]
Morille & Musy	2017	France / Lyon	Mediterranean & Western oceanic	S	Simulation	VGS / GR	[68]
Saito et al	2017	Malaysia / Malacca	tropical	S	Simulation	GF	[87]
Coma et al	2017	Spain / Catalonia	Mediterranean continental	S / W	Experiment	VGS	[17]
Perez et al	2017	Spain / Lleida	Mediterranean	S	Experiment	VGS	[78]
Moren & Korjenic	2017	Austria / Vienna	overheated	All year	Experiment	VGS	[67]
Mitterboeck & Korjenic	2017	Karlsplatz / Vienna	overheated	S	Experiment	VGS	[62]
Razzaghmanesh & Razzaghmanesh	2017	Australian	hot Mediterranean	S / W	Experiment	VGS	[83]
Charoenkit et al	2017	Thailand	tropical	S/ W	Experiment	VGS	[12]
Safikhani & Baharvand	2017	Malaysia / Skudai	hot and humid	Sp	Experiment	VGS	[86]
Olivieri et al	2017	Spain / Colmenar	continental Mediterranean	S	Experiment	VGS	[74]
Ottelé et al	2017	Spain / Catalonia	Nothing is mentioned Hot and cold box	S / W	Experiment	VGS	[76]
Razzaghmanesh et al	2016	Australian / Adelaide	Hot Mediterranean	S / W	Experiment Simulation	GR	[82]
Tsitoura et al	2016	Greece / Crete	Mediterranean	S	Case study Simulation	GF	[93]
Gros et al	2016	France / Lyon	Mediterranean & Western oceanic	S	Simulation	VGS/GF/GR	[29]
Gusson et al	2016	Brazil / Sao Paulo	Subtropical	S / A	field study Simulation	GF	[30]
Karimian	2016	Yazd	Warm and dry	S	Simulation	GR	[46]
Davis et al	2016	Ecuador	Nm	Nm	Experiment	VGS	[19]
Suklje et al	2016	Slovenia / Ljubljana	Nm	S	Experiment	VGS	[91]
Manso et al	2016	Portugal / Covilha	dry mesomediterranean	S / W	Experiment	VGS	[56]
Djedjig et al	2016	France	Mediterranean	S	Experiment	VGS	[21]
Lobaccaro & Acero	2015	Spain / Bilbao	humid temperate with no dry season	S	Simulation	GF	[51]
Chatzidimitriou & Yannas	2015	Greece / Thessaloniki	Mediterranean	S	Simulation	GF	[13]
Zabeti Targhi & Van Dessel	2015	Massachusetts/Worcester	humid continental	S	Simulation	VGS/GR/GF	[92]
Koulivand	2015	Isfahan	Warm and dry	S / W	Simulation	GF	[49]
Mahdian Mahfrozi et al	2015	Tehran	Warm and dry	S / W	field study Simulation	GF	[53]
Ahmadpour Kolahrodi et al	2015	Kashan	Warm and dry	All year	Simulation	GF	[01]

Explanation: S: Summer/ W: Winter/ A: Autumn/ Sp: Spring/ Nm: Nothing is mentioned
(Source: Authors).

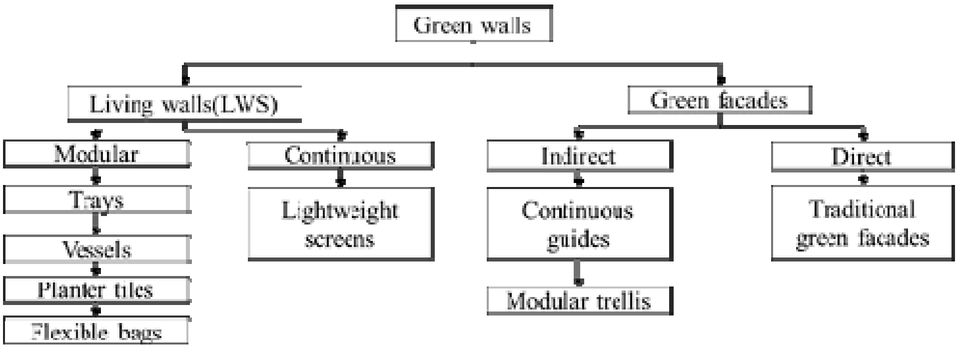
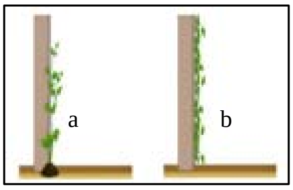
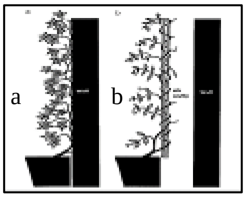
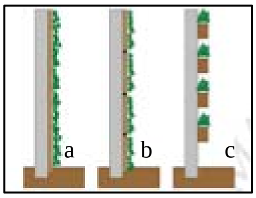
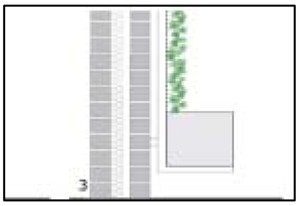
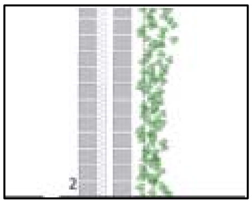
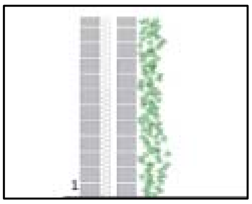
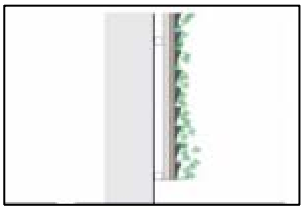
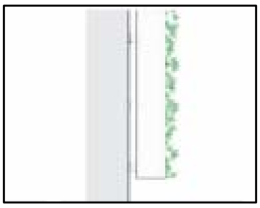
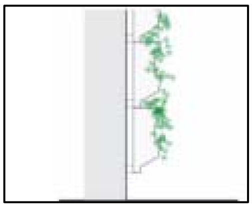


Fig. 1. Classification of green walls according to their construction characteristic
(Source: Manso& Castro-Gomes,2015:856)

Table 2
Type of Vertical Greenery Systems

Type of vertical greenery systems	(a)Green façade (b)Green wall	(a) Direct green facade (b) Double-skin green facade	(a)Continous (b)Modular (c) Liner (green wall)
Image			
Type of green facade	Indirect green façade combined with planter boxes	Indirect green façade (double-skin)	Direct green façade (traditional)
Image			
Type of green wall	Living wall (Modular system)	Living wall (felt layer)	Living wall (Planter boxes)
Image			

(Source: Authors, Retrieved from; Besir et al:2018, Medl et al: 2017, Perini &Rosasco:2013, Koliaie: 2016, M. Hunter et al: 2014, Perini et al: 2011)

2.2. Thermal comfort

The quality of public spaces depends on various aspects, among which thermal comfort is of significant importance. A public space without comfort will be in low usage or even avoided. Thermal comfort is a mental condition indicating satisfaction with ambient temperature based on mental judgments (Ashrae standard 55, 2017: 3). According to ISO 7730 (2005), thermal comfort is the condition where an individual is satisfied with the ambient temperature (Ridzwan Othman et al., 2016: 847).

2.3. Thermal comfort in outdoor spaces

as long as the residents demand thermal comfort in their living spaces in order to raise their capabilities , analysing the thermal comfort and the impact of climatic factors on thermal comfort in the outdoor spaces from the viewpoint of different climatic indices are indispensable(Moradi et al,2018:35).The outdoor thermal comfort is generally impacted by the built environment e.g., anthropogenic heat, coverage material of ground surfaces, and shading by both green spaces and man - made objects (Ojaghlou & Khakzand ,2017:9). Outdoor spaces facilitate urban light, air, and respiration. They are more influential than other components on forming and linking different regions and views, the implementation of urban projects, the creation of landscapes, pleasantness of activities and spaces, citizens' perception of the city, and development of recreational and leisure places (Mohammadzadeh, 2011: 31). In addition to the physical attributes of a building, environmental parameters also significantly affect thermal comfort in outdoor spaces. For instance, vegetation (trees, lawn, and such), water, shading elements, flooring materials, etc. are among the parameters that can significantly help resolve thermal comfort issues for the users of outdoor spaces (Maghsoudi & Jamshidi, 2014:6). Most recent studies on thermal comfort in outdoor and indoor spaces have used PMV, SET, and PET indices to predict comfort temperature outdoors (Ahmadpour Kolahrodi et al., 2015: 63). In addition, the UTCI index has also been used in some studies. [Table 3] shows some of the indices for evaluating thermal comfort in outdoor spaces while [Table 4] shows the selected indices and their evaluated comfort range. According to the introduced indices of thermal comfort in outdoor spaces and the research question, the most applicable, comprehensive indices (PMV and PET) were used in the model to evaluate thermal comfort in outdoor spaces.

Table 3

Categorization Outdoor Thermal Comfort Indicators.

Index	Complete phrase	Index	Complete phrase	Index	Complete phrase
CFD	Computational fluid dynamics	**VIF**	Variance Inflationary Factor	**TCI**	Tourism Climate Index
LSE	Linear stochastic estimate	**TSV**	Thermal sensation votes	**CID**	Comfort Index daily
UHI	Urban Heat Island	**LAD**	Leaf Area Density	**ASV**	Actual Sensation Vote
UCL	Urban Canopy Layer	**LAI**	Leaf Area Index	**OUT_SET**	Out. Stand. Eff. Temp
PMV	Predicted Mean Vote	**ET**	Effective temperature	**PCI**	park cool island
TMRT	Mean Radiant Temperature	**WVF**	Wall view factor	**WCI**	Wind Chill Index
NDVI	Normalized Difference Index Vegetation	**UTCI**	Universal Thermal Climate Index	**HIS**	Heat Stress Index
LST	Land surface temperature	**TSP**	Thermal Sensation Perception	**RH**	Relative Humidity
LIDAR	Light detection and ranging	**PPD**	Percentage People Dissatisfied	**MET**	Metabolic rate
ISA	Impervious surface area	**PAQ**	People's perceived air quality	**PT**	Perceived Temp
SVF	Sky view factor	**APD**	Actual Percentage of Dissatisfied	**ITS**	Index of Thermal Stress
SET	Standard effective temperature	**aPMV**	Adaptive Predicted Mean Vote	**DI**	Discomfort Index
PET	Physiologically equivalent temperature	**ETU**	Effective Universal Temperature	**HL**	Heat Load Index
ERT	Radiation Effective Temperature	**PSI**	Physiological Strain Index	**CPI**	Cool Power Index
TS	Sensation-Ginovi method Thermal	**THI**	Temperature-Humidity Index	**TPV**	Thermal Perception Vote
WCET	Wind Chill Equivalent Temperature	**GHSI**	General Heat Stress Index	**PHS**	Predicted Heat Strain
PST	Physiological Subjective Temperature	**GOCI**	Global Outdoor Comfort Index	**AMV**	Actual Mean Vote

(Source: Authors, Retrieved from; Wong et al: 2017, Rodriguez et al: 2018, Ghani et al: 2017, Nazarian et al: 2017, Kong et al. : 2017, Nasrollahi et al: 2017, Jamei et al: 2017, Aligani & Razavi: 2017, Mohammadi: 2017, Chen et al: 2016, Heydari: 2016, Bardisy et al: 2016, Calis: 2016, Nadim et al: 2016, Hedayati rad et al: 2016, Mokhtari:2016, Ansarimanesh & Nasrollahi: 2014, Karimian: 2014,Baaghideh et al: 2014, Farajzadeh et al: 2014, Heydari & Monam: 2013, Calautit et al: 2013, Mahdinasab & Naserzadeh: 2013, Sallal & Rais: 2011, Hassaan & Mahmoud: 2011, Oliveira et al: 2011, Ismaeili et al: 2011, yao et al: 2009)

2.4. PMV index (predicted mean vote)

First introduced by Fanger, PMV is a thermophysiological index obtained from the energy balance equation of the human body. This index consists of four variables: ambient temperature, mean radiant temperature, relative humidity, and a fourth variable consisting of the two sub-variables of clothing insulation and activity level (Mahdinasab & Naserzadeh,2013: 92). PMV index is defined based on the opinions of a sample including individuals staying in a room with controlled climatic variables (Mohammadi: 2017; Gandomkar & Moradmand: 2013). The index determines ratios that are measured according to the ASHRAE (American Society of Heating, Refrigerating and Air) thermal sensation scale (Hedayati rad et al., 2016: 30). PMV index is one of the primary physiological indices of temperature and is widely used in urban and regional planning, especially for determining the thermal parameters of urban microclimates, in addition to tourism climatology (Najafi & Najafi, 2012:62).

2.5 PET index (physiological equivalent temperature)

The PET index, similar to PMV, is a conventional thermophysiological index obtained from the equation of human body energy balance (Baaghideh et al: 2015; Ataee & Hasheminasab: 2013; Kamyabi & Ahmadi: 2014). It is also one of the most comprehensive, applied indices for evaluating biometeorological conditions and identifying tourism climates (Nadim et al., 2017:51). PET index can be described as the temperature where a human body is in thermal balance when positioned in an indoor environment and in seated position (without wind or solar radiation), with a metabolic rate of 80 W and clothing insulation of 0.9 against skin temperature and core body temperature (Mahdinasab & Naserzadeh:2013; Ataee & Hasheminasab: 2013; Ismaeili & Montazeri: 2014; Zolfaghari:2008). The difference between PMV and PET is that PET uses actual skin temperature and evapotranspiration values while PMV is a function of mean skin temperature and core body temperature (Karimian, 2014: 43-44).

Table 4
Categorization of (PMV/PET/SET/UTCI) for Different Levels of Thermal Perception and Physiological Stress.

Physiological Stress	**Thermal sensation**	**PET**	**PMV**	**Physiological Stress**	**SET**	**Physiological Stress**	**UTCI**
Extreme cold stress	Very cold	4 >	-3 >	Extreme warm	30 <	extreme heat stress	46 <
Strong cold stress	Cold	4	-3	Sultry	27.5-30	very strong heat stress	38-46
Moderate cold stress	Cool	8	-2	Very warm	25.6-27.5	strong heat stress	32-38
Slight cold stress	Slightly cool	13	-1	Warm	22.2-25.6	moderate heat stress	26-32
No thermal stress	Comfortable	18	0	Comfortable	17.8-22.2	no thermal stress	9-26
Slight heat stress	Slightly warm	23	1	Cool	15.5-17.8	slight cold stress	0-9
Moderate heat stress	Warm	29	2	Very cool	(-1.67)-15.5	moderate cold stress	0-(-13)
Strong heat stress	Hot	35	3	Cold	(-10)-(-1.67)	strong cold stress	(-13)-(-27)
Extreme heat stress	Very hot	41	3 <	Very cold	(-20)-(-10)	very strong cold stress	(-27)-(-40)
				Extreme cold	-20 >	extreme cold stress	-40 >

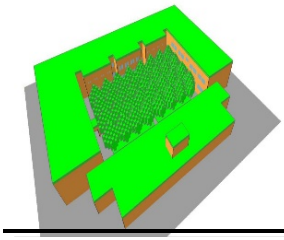
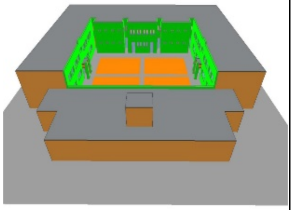
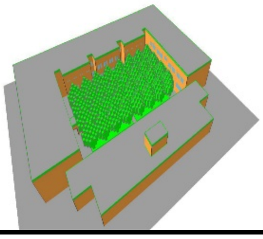
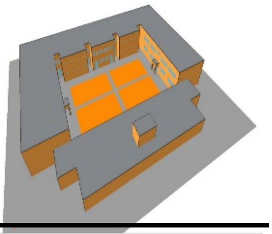
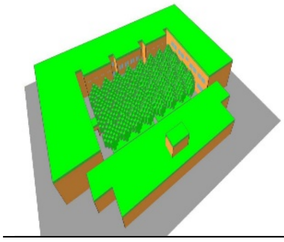
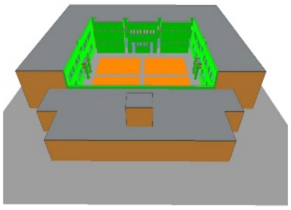
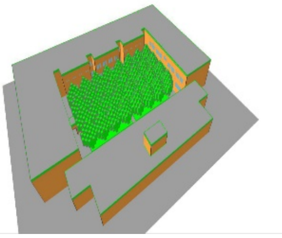
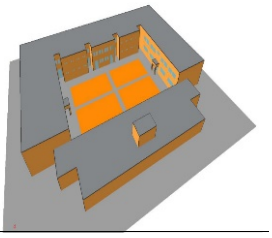
(Source: Zarei et al: 2018, Ashrae standard 55: 2017, Iso 7730: 2005, Nadim et al: 2016, Mokhtari: 2015, Koulivand: 2015, Peyman rad: 2015, Baaghideh et al: 2014, Ismaeili & Montazeri: 2013, Ataee: 2012, Ismaeili et al: 2011, Zolfaghari: 2007)

3. Material and Methods of Research

According to the introduction section, the present study aims to investigate the microclimatic role of building structures and walls in improving thermal comfort in outdoor spaces between buildings. The main question is which green system, including horizontal (green floor or green rooftop) and vertical (green façade), performs better in microclimatic moderation and thermal comfort improvement in outdoor spaces. The research used a qualitative-quantitative method and the data were gathered via field studies and library research. Quantitative data analysis was performed via the microclimatic modeling tool of ENVI-met and RayMan software; in addition, numerical modeling was performed to evaluate the effectiveness of the green system in reducing the ambient temperature on the hottest summer day (Jul 7, 2018)[1] in Qazvin, Iran. The modeling was performed to compare and analyze thermal comfort indices in outdoor spaces and influencing factors. The research steps were as follows:

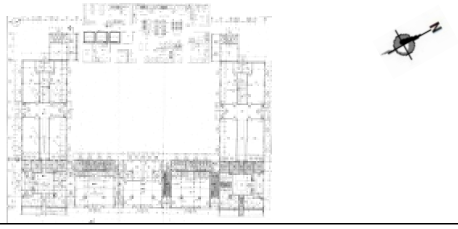
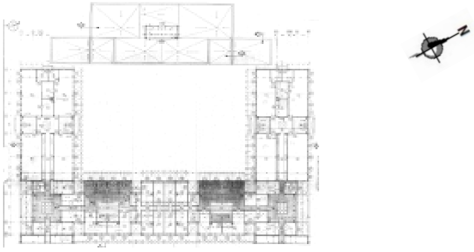
In the first step, the faculty of agriculture building of the Imam Khomeini International University of Qazvin was selected as the studied case. The said building features a central yard with vertical and horizontal surfaces facing an outdoor space (the central yard). In the second step, four different modes were used for numerical modeling [Table 5]. In the third step, the raw weather data required by the software were collected from Qazvin's synoptic weather station for the year 2018 (July/7/2018). According to the synoptic data, July was the hottest month in the studied period with Jul 7 as the hottest day of the month. The results of modeling the four modes in [Table 5] based on evaluating thermal comfort indices in outdoor spaces can answer the research question. PMV, PET, Tmrt, and RH indices were used to evaluate thermal comfort for each mode.

Table 5
Simulated Models in The Envi-met Software.

			
H&V.Green	V.Green	H.Green	W.O.Green.
			
H&V.Green	V.Green	H.Green	W.O.Green.

Explanation: V: vertical Greenery system / H. Horizontal Greenery system / W. without Greenery system

Table 6
Architectural Specifications of Faculty of Agriculture, Imam Khomeini International University of Qazvin

Ground floor plan	Site plan
	
First-floor plan	Elevations
	

(Source: Authors)

3.1. *Study area*

The studied case was the faculty of agriculture building in Imam Khomeini International University of Qazvin. The town’s longitude, latitude, and altitude from sea level are50, 36.19, and 1374 (WeatherTool Software), respectively, and the city has a warm and dry climate (Sarhadi &Moradi: 2018). The other climatic attributes of Qazvin include high variations in daily and annual temperature, low precipitation, short freezing period, sunny weather most of the year, cold winter winds and warm summer winds (Tahbaz:2017,135). The floor of the studied case was modeled as a horizontal green floor while the walls facing the central yard were modeled as vertical green walls [Table 5]. [Table 6] shows the site plan and architectural plan of the building. The meteorological data of year 2018 (Mar 21, 2018–Mar 20, 2019) from the synoptic weather station of Qazvin (obtained from National Meteorological Organization), were used for numerical modeling.

3.2. *Introducing envi-met software*

ENVI-met is a non-hydrostatic 3D microclimatic model comprising a simple 1D soil model, radiation transfer model, and vegetation model (Huttner et al: 2008; Bruse & Huttner: 2008; Ozkeresteci et al: 2003; Karimian: 2013; Morakinoy et al: 2017). The model is designed with a spatial resolution of 0.5-10 meters and intervals of 10 seconds to simulate the interactions between the surface, plants, and air in urban areas. The model is normally used for the analysis of urban climates, urban planning, and building and environmental designs (Huttner et al: 2008; Bruse & Huttner: 2009; Ozkeresteci et al: 2003; Karimian: 2016; Morakinoy et al: 2017; Jamei et al: 2017; Ahmadpour Kolahrodi et al: 2015). This model approaches vegetation not only as a porous obstacle to the wind and solar radiation but also as a living object with the biological processes of evapotranspiration and photosynthesis. It features various types of vegetation with specific attributes and offers an extensible vegetation database with the ability to add new plants with respective attributes (Karimian, 2016: 683). ENVI-met can model microclimates via five computation models:

- The atmospheric model: computes airflow, 3D turbulence, temperature, and relative humidity by factoring obstacles such as vegetation and buildings.
- Surface model: computes the long waves absorbed and short waves reflected by different surfaces in order to obtain long- and short-wavelength radiation in the model.
- Vegetation model: computes foliage and branch temperature and the thermal balance of leaves via physiological and meteorological parameters. Vegetation is described via the normalized indicators LAD (leaf area density) and RAD (root area density). The evaporation rate and airflow are computed based on the airflow around plants.
- Soil model: computes the thermal and thermodynamic processes of the soil and factors the composition of artificial and natural urban surfaces in the model.
- Bioeteorological model: computes PMV index using meteorological data (Bruse & Fleer, 1998: 374-378).

Quantitative evaluations have proven that ENVI-met is able to accurately predict microclimates with different variables. There are small differences in the surface temperature of materials at some points of the day; however, such differences do not exceed two degrees Celsius and are mostly equal to the surface temperature. In other words, ENVI-met predictions are usually acceptable for surface and ambient temperature (Marie, 2014: 31-32). ENVI-met is the only software able to integrate and model all parameters influencing thermal comfort (e.g. wind speed and direction, mean radiant temperature, ambient temperature, etc)

3.3. Input data to the Envi-met software

Table7
Physical-Thermal Characteristics of Materials Used in The Model. (Source: Authors)

Element	Explanation	Thickness	Albedo	Thermal Radiation emission capability
Wall	0.3 meter brick wall with internal plastering*	33cm	0.4	0.9
Roof	Concrete roof with old asphalt outer layer	30cm	0.2	0.9
Soil	Soil Flooring	………..	** ----	0.98
	Concrete Brick Flooring***	………..	0.3	0.9

Explanation: * The thermal conductivity for brick and plaster is 0.90 and 0.57 w/mk, respectively.
** The amount of soil moisture is calculated according to the amount of moisture present at the soil surface for each time frame by the software.
*** Concrete flooring consists of a concrete layer of 10 cm thick, a sandstone layer of 6 cm thick, and lower than normal clay.

Table 8
Entry File Settings. (source: Authors)

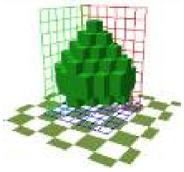
Parameter	Explanation	Amounts
Base model geometry	Mesh Size	240*203*29 / dx, dy= 0.50 m, / Base dz= 0.50 m
	Model size	120*101.5*23.53 m^3
Vertical model	Telescopic mode	2
Marginal mesh		Base grid= 0.5 m / Start telescoping after height = 9.0 m / Telescoping factor = 20.0%

Table 9
Meteorological Configuration Data File. (Source: State Synoptic Meteorological Organization: 2018)

Parameter	Explanation	Amounts
Meteorology data	Air temperature (minimum and maximum daily)	22.5, 40.90 (°C)
	Relative humidity (minimum and maximum daily)	10.0, 26.0(%)
	The dominant wind speed and direction	3.0 m/s, 135.0 (deg)
	Adjustable Coefficient for Solar Radiation	0.5
Model Soil	Temperature and relative humidity of the soil *	Upper Layer (0-20 cm) =30.0 (°C), 50 (%) Middle Layer (20-50 cm) = 31.85 (°C),50 (%) Deep Layer (50-200 cm)=28.6.0 (°C),60 (%)

*The values of relative temperature and relative humidity of the soil are the values of the beginning of the simulation and during simulation, these values are calculated based on the energy consumption/loss of energy by the software. These values are extracted from the climatic file of Qazvin.

Table10
Physical and Geometric Characteristics of the Trees Used. (Source: Authors)

	Information	
	Tree height	10m
	The height of the crown of the tree	0.2m
	Diameter of the crown of the tree	7m
	Leaf Density Index (LAD)	$2m^2/m^3$
	Amount of Albedo leaves	0.2

4. Analysis of the Findings

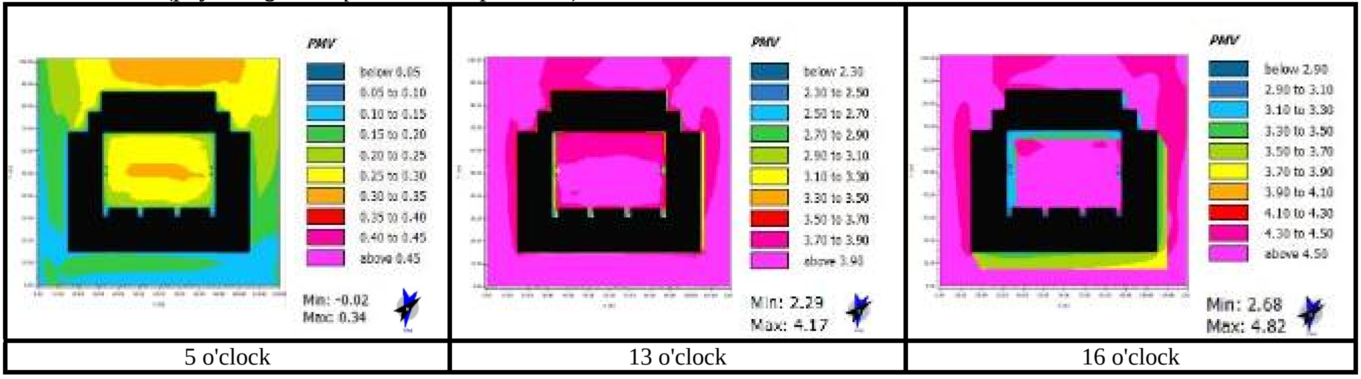
Model outputs are presented as graphical zoning maps for the date Jul 7, 2018 (hours 5, 13, and 16); in addition to numeric results in an excel spreadsheet for a 24-hour period on the same day, in order to facilitate a more accurate analysis of research indices. The colored region in the figures indicates the comfort zone of each analysis index.

4.1. PMV index (predicted mean vote)

The resulting diagram and zoning maps [2–6] of the quantitative PMV Index modeling in [Fig 6] indicate that each mode (H, V, W.O, H&V. Green) is in the thermal comfort zone only from 23 to 6 o’clock. The four modes have no significant performance difference in the said hours, implying that in hours without solar radiation, the vegetation shows no difference in the thermal comfort of outdoor spaces. [Fig 6] shows that from 6 a.m. and at sunrise, PMV index increases for all four modes; however, the horizontal vegetation (H), and high vegetation (H&V) modes are closer to the comfort zone. From 11 to 14 when solar radiation is perpendicular to horizontal surfaces, PMV index is equal for all modes. From 14 o’clock when there is shading on the yard, PMV index is the same as the before-noon modes (6-11 o’clock) the modes: without vegetation (W.O), vertical vegetation (V), horizontal vegetation (H) and high vegetation (H&V); perform similarly. Here horizontal vegetation (H) is closer to the comfort zone compared to vertical vegetation (V); which shows that horizontal vegetation performs better than green walls in improving thermal comfort in outdoor spaces. The consistent changes in all four modes between sunset and sunrise (19–6 o’clock) confirm that the four modes produce different results only when there is solar radiation. The figure shows no significant effect on thermal comfort by vertical vegetation compared to no vegetation; however, we should not disregard the effect of vertical vegetation in improving thermal comfort for indoor spaces. This topic (the effect of vertical vegetation on the thermal comfort of indoor spaces) sheds light on future works.

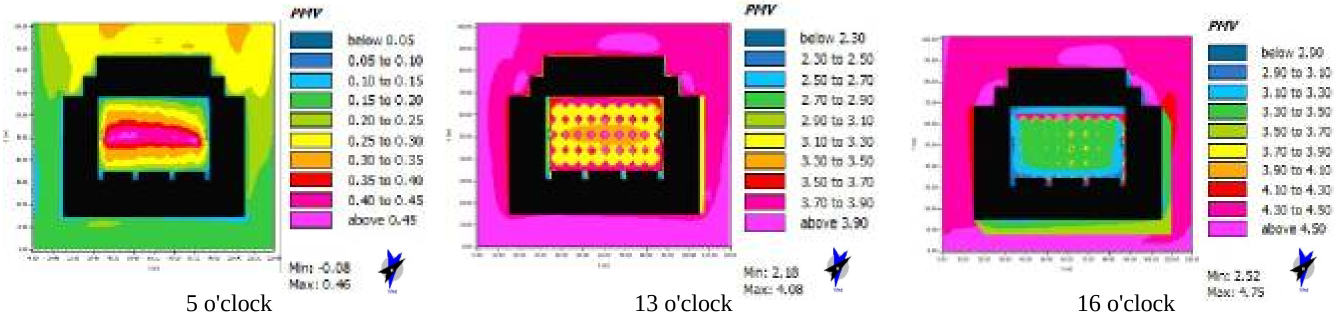
4.2 PET index (physiological equivalent temperature)

According to [Fig 11], PET index variations approximately follow PMV index variations. Same as for PMV index, in PET index variations, the two modes (W.O) and (V) perform similarly while the two modes (H) and (H&V) also show identical performance. The PET index variations show that from 24 until 4 o'clock all four (H&V, V, H, W.O) are in the thermal comfort zone



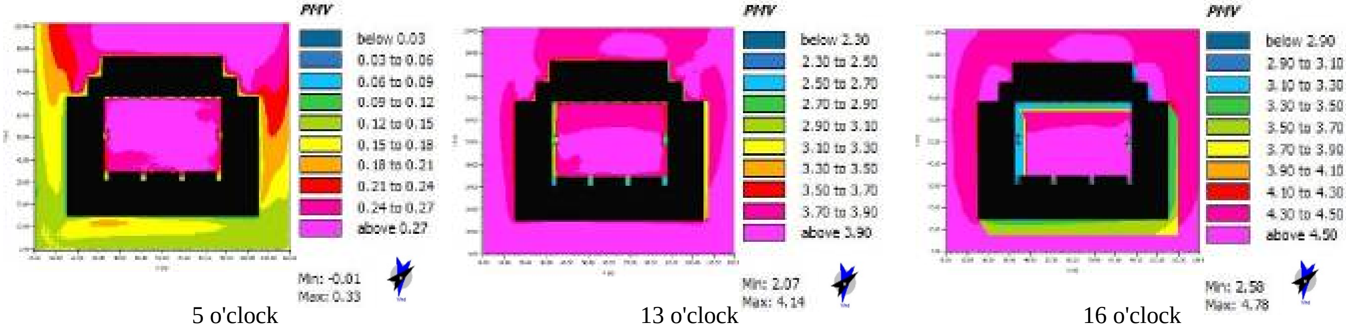
5 o'clock 13 o'clock 16 o'clock

Fig. 2. Graphical zoning, results of the simulation of the PMV index (Without Greenery system) in the Summer, July 7th



5 o'clock 13 o'clock 16 o'clock

Fig. 3. Graphical zoning, results of the simulation of the PMV index (Horizontal Greenery system) in the Summer, July 7th



5 o'clock 13 o'clock 16 o'clock

Fig. 4. Graphical zoning, results of the simulation of the PMV index (vertical Greenery system) in the Summer, July 7th

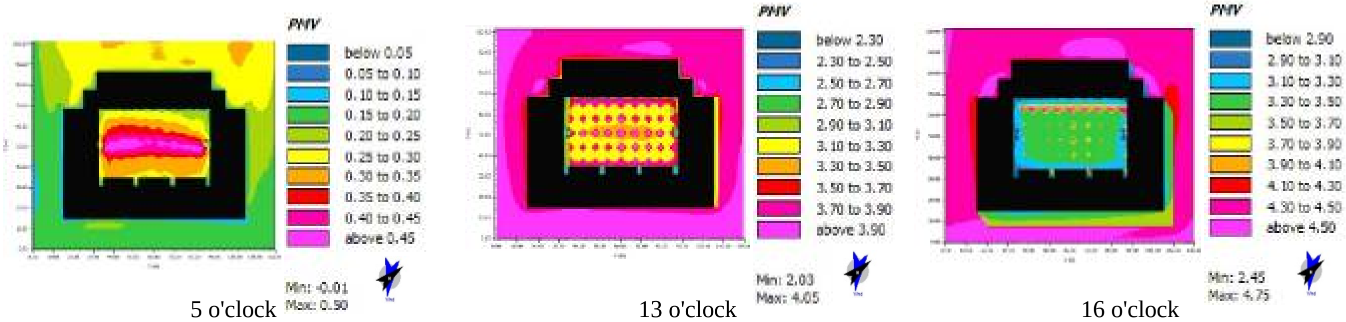


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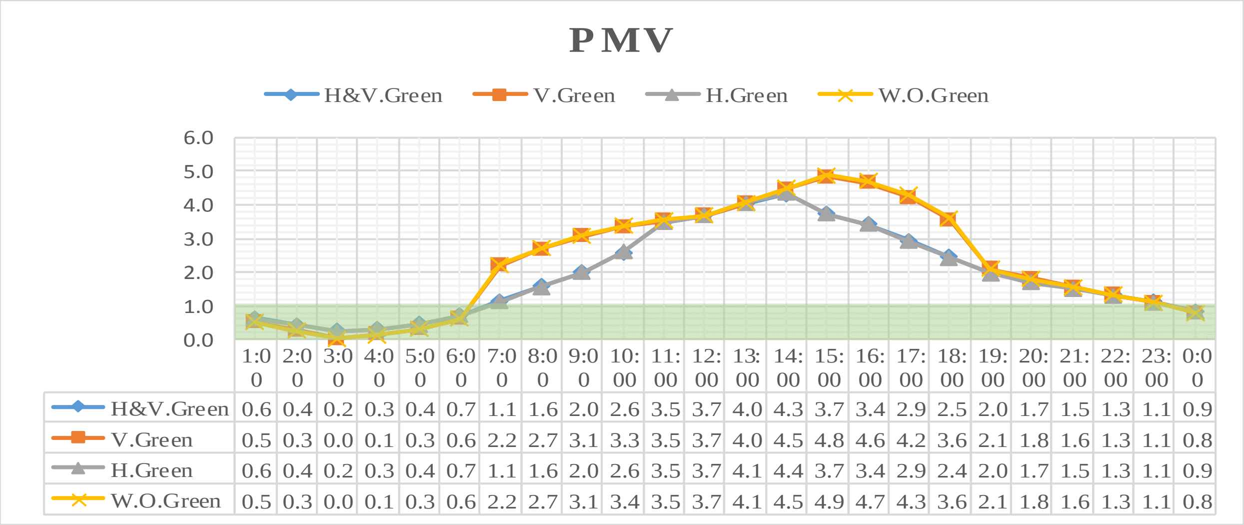
Fig. 5. Graphical zoning, results of the simulation of the PMV index (vertical& Horizontal Greenery system) in the Summer, July 7th



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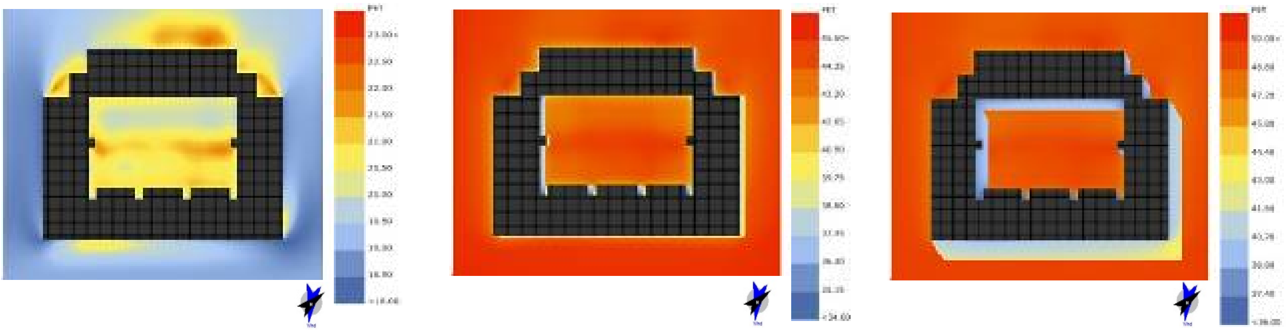
H&V.Green	0.6	0.4	0.2	0.3	0.4	0.7	1.1	1.6	2.0	2.6	3.5	3.7	4.0	4.3	3.7	3.4	2.9	2.5	2.0	1.7	1.5	1.3	1.1	0.9
V.Green	0.5	0.3	0.0	0.1	0.3	0.6	2.2	2.7	3.1	3.3	3.5	3.7	4.0	4.5	4.8	4.6	4.2	3.6	2.1	1.8	1.6	1.3	1.1	0.8
H.Green	0.6	0.4	0.2	0.3	0.4	0.7	1.1	1.6	2.0	2.6	3.5	3.7	4.1	4.4	3.7	3.4	2.9	2.4	2.0	1.7	1.5	1.3	1.1	0.9
W.O.Green	0.5	0.3	0.0	0.1	0.3	0.6	2.2	2.7	3.1	3.4	3.5	3.7	4.1	4.5	4.9	4.7	4.3	3.6	2.1	1.8	1.6	1.3	1.1	0.8

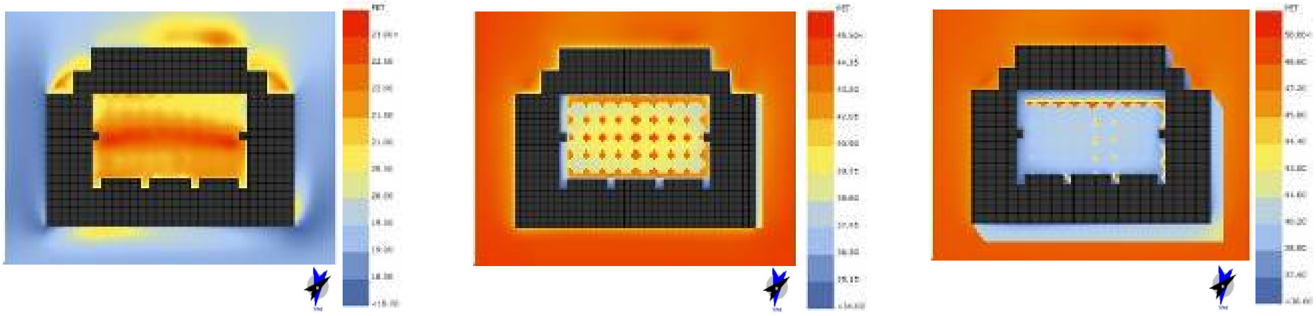
Fig. 6. The 24-hour changes of PMV index in the Summer, July 7th (H&V/ V/ H/W.O. Green).

and there is no performance difference between the modes with and without vegetation at the said nigh hours. This confirms the decisive role of solar radiation in PET index variations. At the hottest hours of the day, the horizontal vegetation (H) is 8 ℃ closer to the thermal comfort zone compared to vertical vegetation (V). The said difference remains from 15 until 19 o'clock. Generally speaking, without perpendicular solar radiation, the wide shadows on the yard floor causes horizontal vegetation (H) to perform much better in cooling the outdoor space. We can conclude that blocking solar radiation and shading on surfaces are much more effective in improving thermal comfort in outdoor spaces in comparison with green surfaces. Notwithstanding, incorporating green surfaces in addition to shading can further improve the thermal comfort of outdoor spaces in hot seasons.



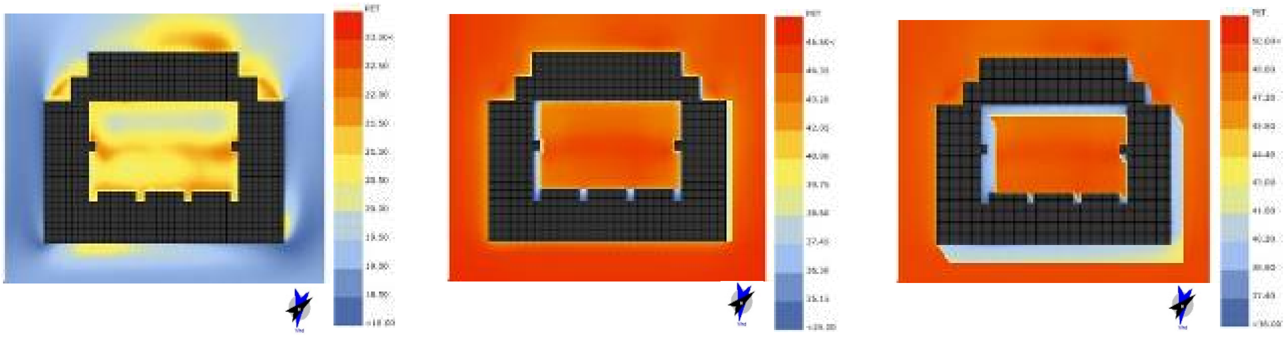
5 o'clock 13 o'clock 16 o'clock

Fig. 7. Graphical zoning, results of the simulation of the PET index (Without Greenery system) in the Summer, July 7th



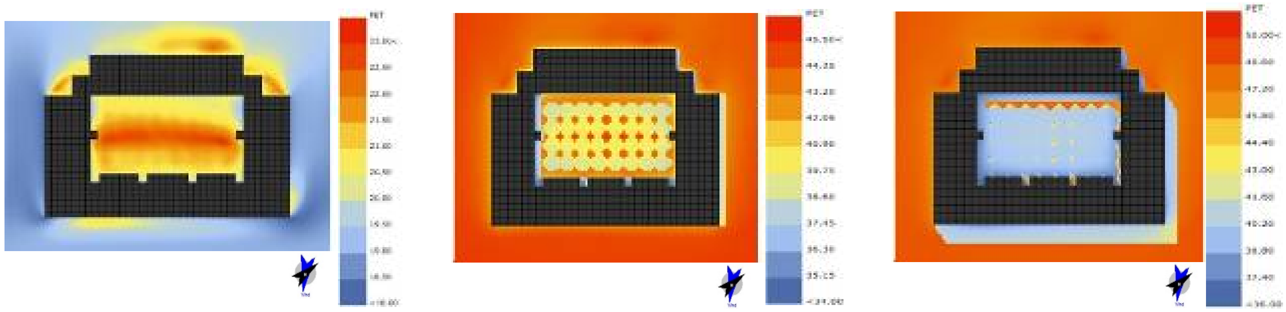
5 o'clock 13 o'clock 16 o'clock

Fig. 8. Graphical zoning, results of the simulation of the PET index (Horizontal Greenery system) in the Summer, July 7th



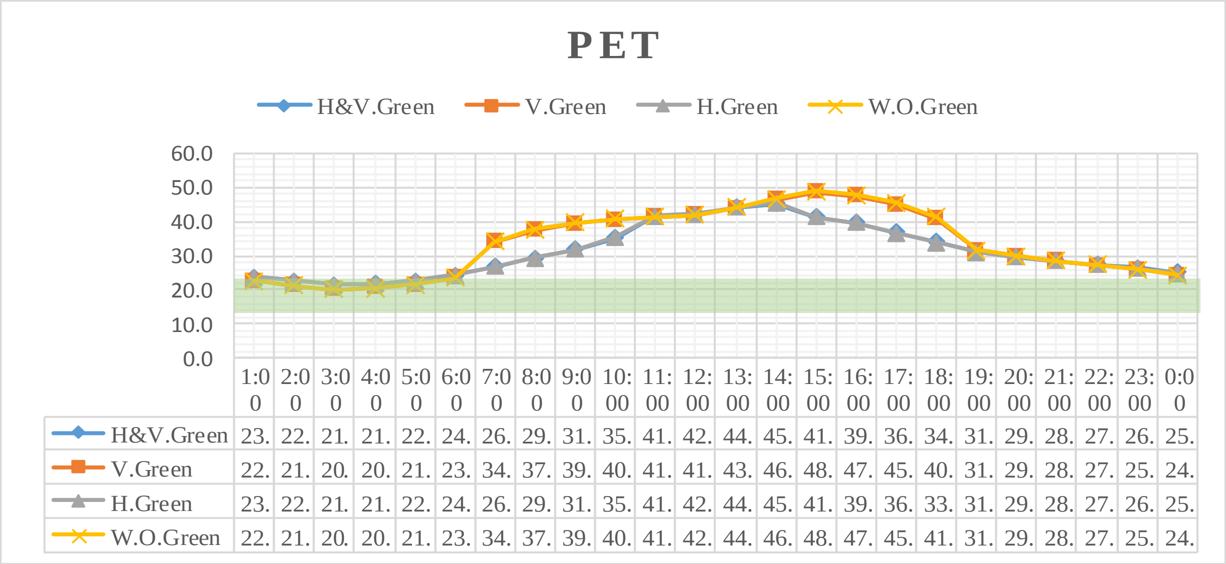
5 o'clock 13 o'clock 16 o'clock

Fig. 9. Graphical zoning, results of the simulation of the PET^2 index (vertical Greenery system) in the Summer, July 7th



5 o'clock 13 o'clock 16 o'clock

Fig. 10. Graphical zoning, results of the simulation of the PET index (vertical & Horizontal Greenery system) in the Summer, July 7th



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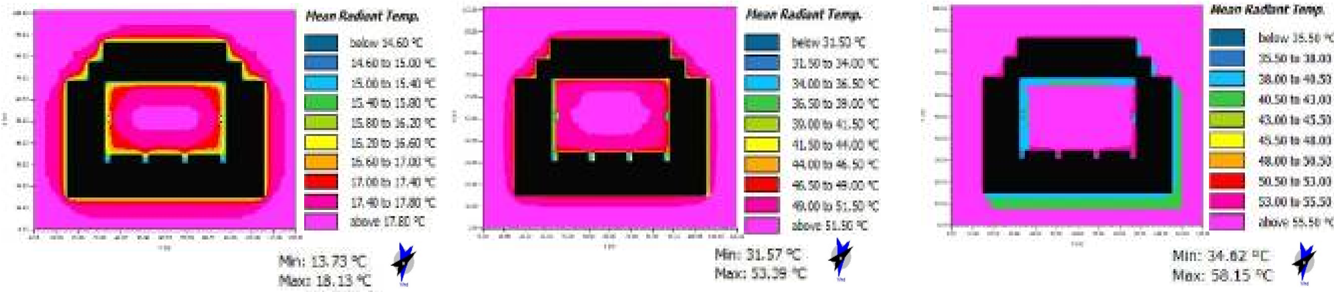
H&V.Green	23.	22.	21.	21.	22.	24.	26.	29.	31.	35.	41.	42.	44.	45.	41.	39.	36.	34.	31.	29.	28.	27.	26.	25.
V.Green	22.	21.	20.	20.	21.	23.	34.	37.	39.	40.	41.	41.	43.	46.	48.	47.	45.	40.	31.	29.	28.	27.	25.	24.
H.Green	23.	22.	21.	21.	22.	24.	26.	29.	31.	35.	41.	42.	44.	45.	41.	39.	36.	33.	31.	29.	28.	27.	26.	25.
W.O.Green	22.	21.	20.	20.	21.	23.	34.	37.	39.	40.	41.	42.	44.	46.	48.	47.	45.	41.	31.	29.	28.	27.	25.	24.

Fig. 11. The 24-hour changes of PET index in the Summer, July 7th (H&V/ V/ H/ W.O. Green).

4.3. *Tmrt (total mean radiant temperature)*

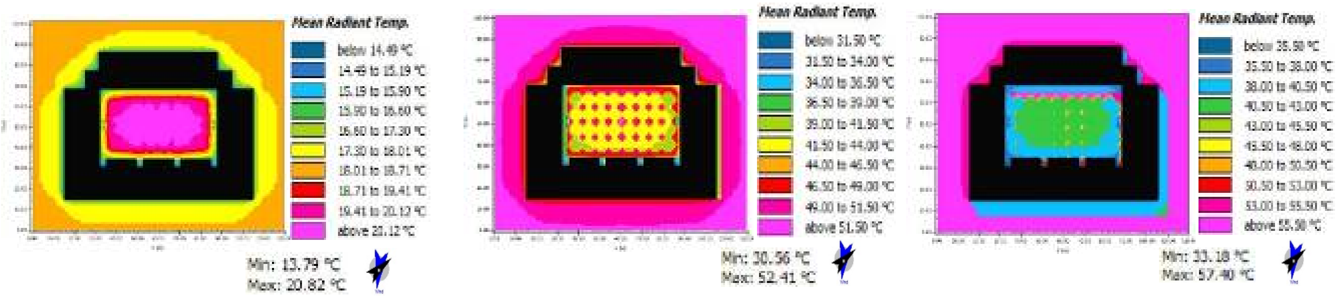
As Tmrt directly affects thermal comfort in outdoor spaces, we can see that Tmrt index variations [Fig 16] and PMV index variations [Fig 6] are similar to relatively identical variation trends. [Fig 16] and graphical zoning maps [12-15] show that the variations in (V) and (W.O) modes and the (V) mode are similar; while variations in the modes (H) and (H&V) are consistent with that of (H); showing that vertical vegetation performs similarly to no vegetation while horizontal vegetation performs similarly to high vegetation. Therefore, Tmrt index is significantly affected by horizontal vegetation in outdoor spaces. The consistent, close variations in the four modes from sunset to sunrise (19–6 o’clock) show that during hours without solar radiation, Tmrt index variations are relatively similar in the four modes, but at sunrise Tmrt index changes among the four modes and increases for the (V) and (W.O) modes compared to (H) and (H&V) modes; peaking to 50℃ at 10 o’clock in the morning. From 6 to

12 o’clock (when solar radiation is perpendicular), Tmrt index is 16℃ lower for (H) and (H&V) modes compared to (W.O) and (V) modes; indicating that horizontal green surface reduces Tmrt index by 16°C compared to no vegetation mode, thus improving thermal comfort in outdoor spaces in hot seasons. The maximum Tmrt index value was recorded for the no vegetation mode, peaking to 58°C at the hottest time of day (15 o’clock). At that time, Tmrt index value for the high vegetation mode was 44 °C; in other words, this mode could reduce Tmrt index by 14°C at the hottest time of day and cool the environment. [Fig 16] shows that compared to the no vegetation mode, the high vegetation mode reduced Tmrt index by 16°C in before-noon hours and improved the thermal comfort of the outdoor space. As suggested by numerical data, diagrams, and zoning maps, the mode (V) performs equally to mode (W.O) while mode (H) performs the same as (H)and (H&V) modes; Therefore, we can deduce that the horizontal green surfaces reduced Tmrt index by 15°C further compared to the vertical green surfaces. [Fig 16] shows that, in the summertime, Tmrt index had no significant variation during the day between the no vegetation mode and vertical green wall, indicating the negligible effect of vertical green surfaces on microclimatic conditions in the studied outdoor space in hot seasons.



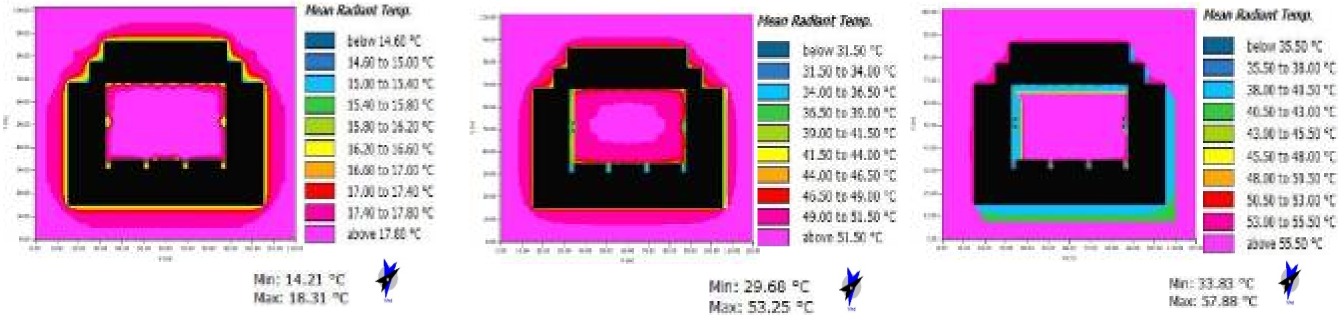
5 o'clock 13 o'clock 16 o'clock

Fig. 12. Graphical zoning, results of the simulation of the Tmrt index (Without Greenery system) in the Summer, July 7th



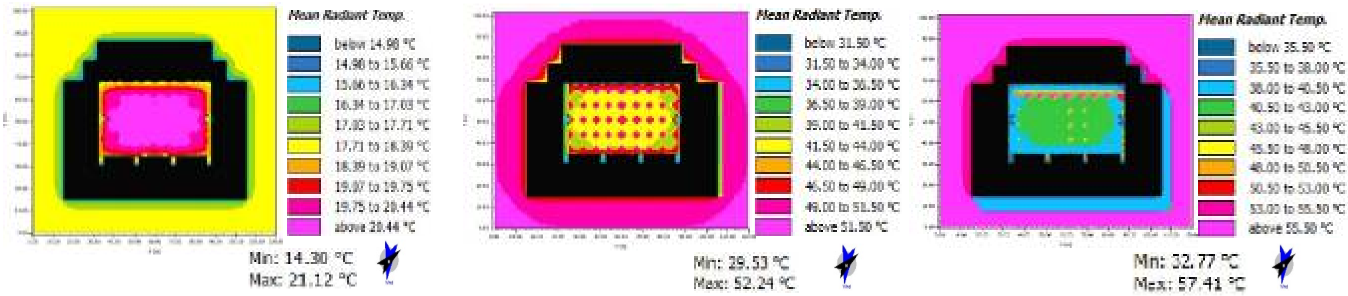
5 o'clock 13 o'clock 16 o'clock

Fig. 13. Graphical zoning, results of the simulation of the Tmrt index (Horizontal Greenery system) in the Summer, July 7th



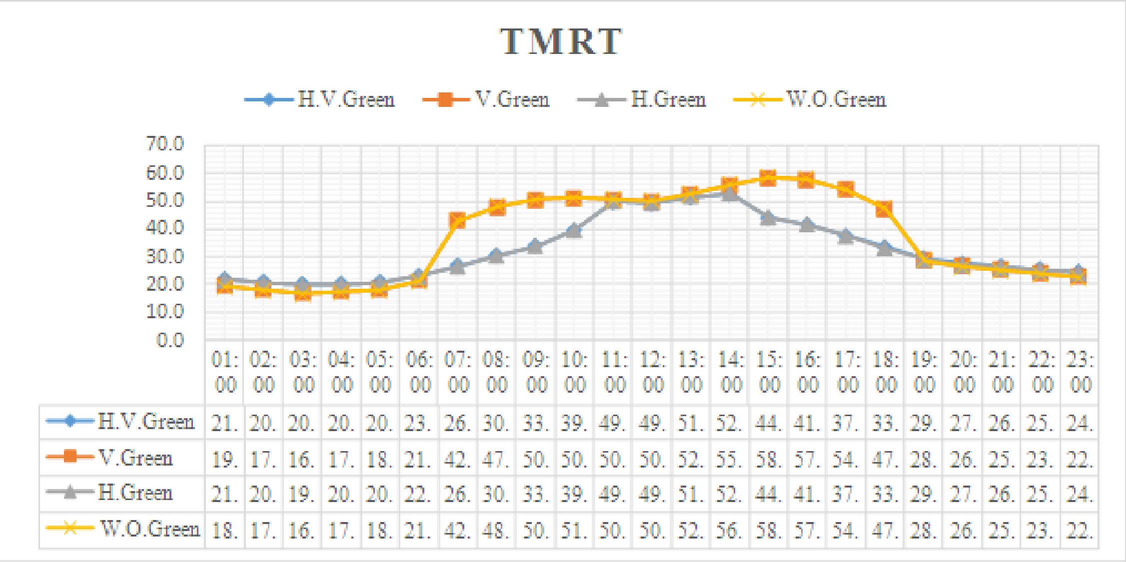
5 o'clock 13 o'clock 16 o'clock

Fig. 14. Graphical zoning, results of the simulation of the Tmrt index (vertical Greenery system) in the Summer, July 7th



5 o'clock 13 o'clock 16 o'clock

Fig. 15. Graphical zoning, results of the simulation of the Tmrt index (vertical& Horizontal Greenery system) in the Summer, July 7th

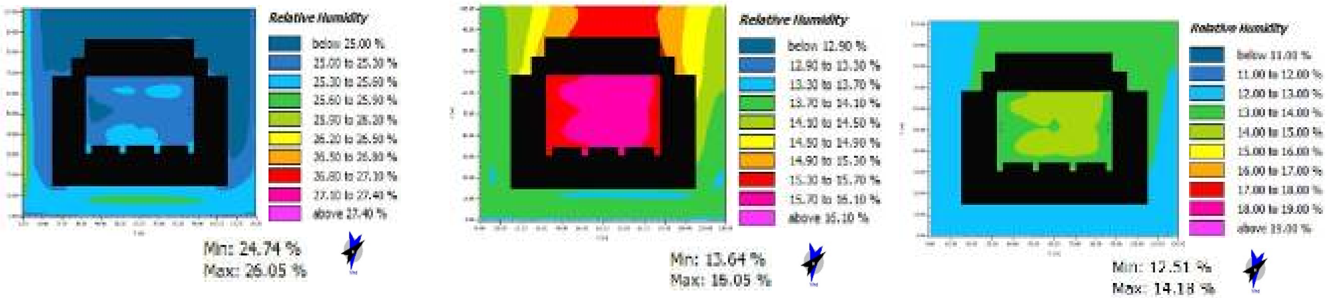


	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
H.V.Green	21.	20.	20.	20.	20.	23.	26.	30.	33.	39.	49.	49.	51.	52.	44.	41.	37.	33.	29.	27.	26.	25.	24.
V.Green	19.	17.	16.	17.	18.	21.	42.	47.	50.	50.	50.	50.	52.	55.	58.	57.	54.	47.	28.	26.	25.	23.	22.
H.Green	21.	20.	19.	20.	20.	22.	26.	30.	33.	39.	49.	49.	51.	52.	44.	41.	37.	33.	29.	27.	26.	25.	24.
W.O.Green	18.	17.	16.	17.	18.	21.	42.	48.	50.	51.	50.	50.	52.	56.	58.	57.	54.	47.	28.	26.	25.	23.	22.

Fig. 16. The 24-hour changes of Tmrt index in the Summer, July 7th (H&V/ V/ H/ W.O. Green).

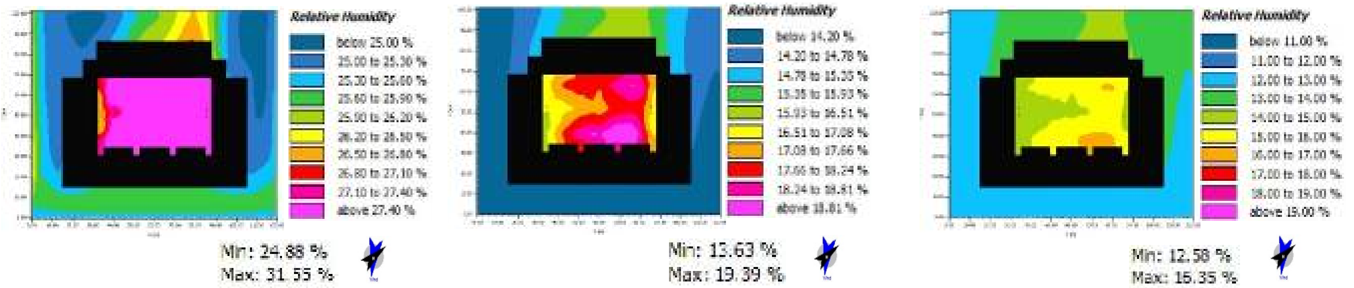
4.4. RH (relative humidity)

According to [Fig 21], the variations of RH index in the four simulation modes indicate that the minimum RH index was recorded at 15 o’clock (the hottest time of day with maximum ambient temperature). The diagram shows that RH index in the four converged for the four modes at 15 o’clock, reaching 12.5% which is 17.5% below the minimum permissible RH (the minimum RH index for comfort), however, the index rose after 15 o’clock with the reduction in ambient temperature, peaking at 24 o’clock. After 24 o’clock, the RH index for (H) and (H&V) modes was 26%, which is 2.5% more than that of (W.O) and (V) modes. Overall, at nighttime, the RH index for the horizontal green surfaces mode was 2.5% higher than that of the vertical green surfaces mode. The 2.5% difference in RH index between horizontal and vertical green surfaces held through the night and remained constant at 2.5% until after sunrise at 9 o’clock. However, the difference reduced by increased ambient temperature and at 15 o’clock, the RH index of the four modes became almost identical. In general, at 3 o’clock on Jul 7, 2018 is the time the earth is losing its heat due to negative radiation and when the maximum RH index occurs. At 3 o’clock the RH index for (H) and (H&V) modes reached 30% (maximum permissible RH for thermal comfort). The (H) and (H&V) modes result in an RH index of outdoor spaces which was 2.5% higher than that of (V) and (W.O) modes. The results presented in [Fig 21] and graphical zoning maps [17-20] show that during the day, the variations in (V) and (W.O) modes matched the variations in (V) mode while variations in the (H) and (H&V) modes were consistent with the variations in (H) mode. Therefore, horizontal vegetation produces a higher RH index compared to vertical vegetation which results in better thermal comfort in outdoor spaces.



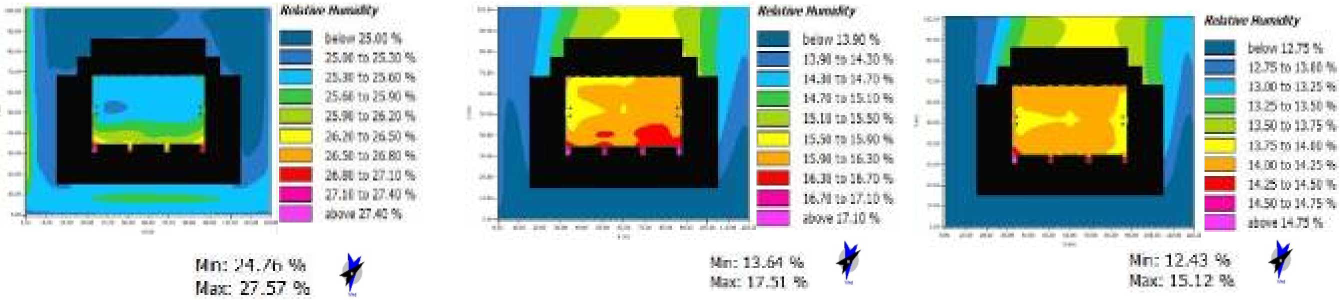
5 o'clock 13 o'clock 16 o'clock

Fig. 17. Graphical zoning, results of the simulation of the RH index (Without Greenery system) in the Summer, July 7th



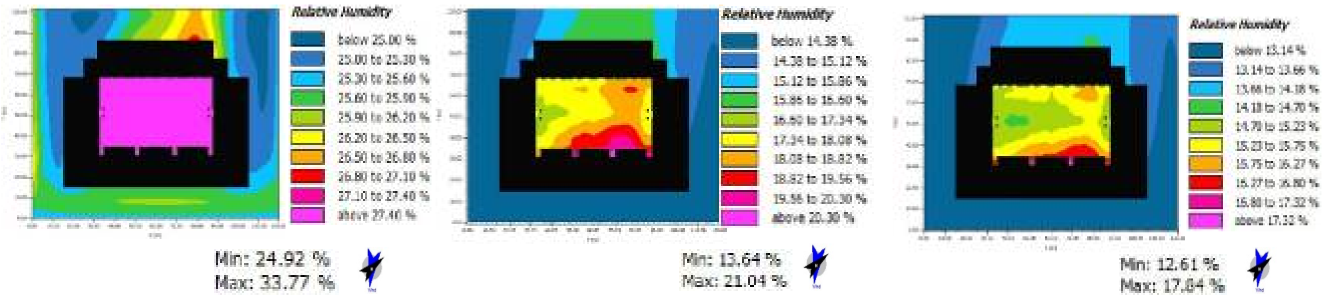
5 o'clock 13 o'clock 16 o'clock

Fig. 18. Graphical zoning, results of the simulation of the RH index (Horizontal Greenery system) in the Summer, July 7th



5 o'clock 13 o'clock 16 o'clock

Fig. 19. Graphical zoning, results of the simulation of the RH index (vertical Greenery system) in the Summer, July 7th



5 o'clock 13 o'clock 16 o'clock

Fig. 20. Graphical zoning, results of the simulation of the RH index (vertical& Horizontal Greenery system) in the Summer, July 7th

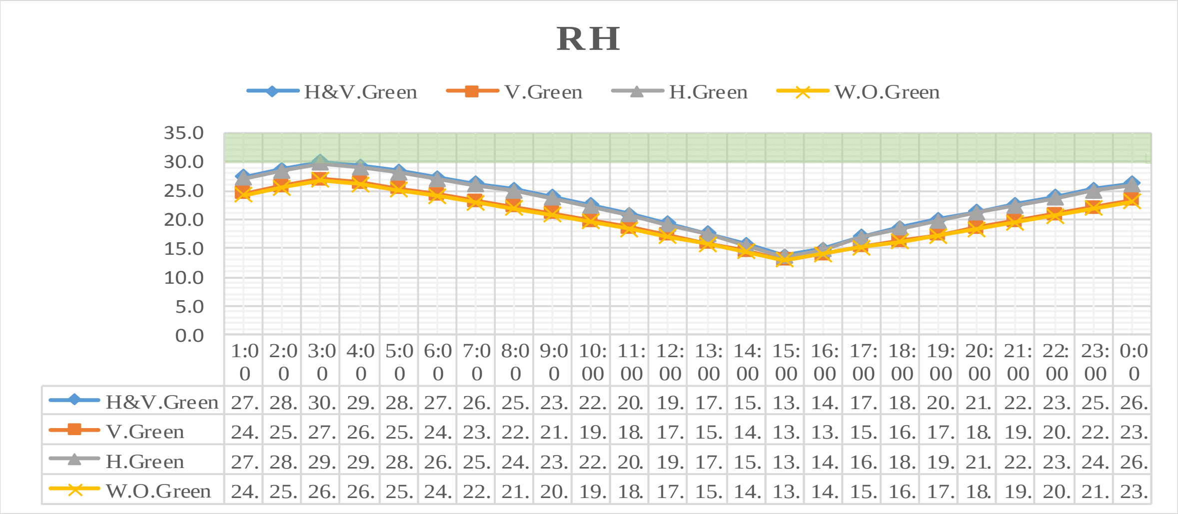


Fig. 21. The 24-hour changes of RH index in the Summer, July 7th (H&V/ V/ H/ W.O. Green).

5. Conclusions

The present study aimed to investigate the microclimatic role of vegetated surfaces and structures in improving thermal comfort in the outdoor spaces in different buildings. The main research question was which green system, including horizontal (green floor) and vertical (green façade), are more effective in moderating a microclimate and improving thermal comfort in outdoor spaces.

- The PMV and PET indices show that each of the four studied modes (H&V, V, H, W.O) were in the thermal comfort zone only in the 23–6 o'clock period. In the said hours the surfaces with and without vegetation showed no significant difference in their performance, indicating that during hours without solar radiation the surfaces with and without vegetation do not perform differently in regards to thermal comfort in outdoor spaces.
- Tmrt index analysis shows that horizontal green surface reduced Tmrt by 16°C compared to no vegetation mode, thus improving thermal comfort in the studied outdoor spaces. The index also reveals that, in the summertime, there is no significant difference in the mean radiating temperature between the vertical green wall and no vegetation modes, which shows the negligible effect of vertical green surfaces on the microclimatic conditions of the studied outdoor spaces in hot seasons.
- RH index analysis shows that compared to vertical vegetation, horizontal vegetation is more effective in enhancing relative humidity and thermal comfort in outdoor spaces.
- The analysis of respective indices shows that when solar radiation is not perpendicular, the extensive shading on the yard floor causes vertical green surfaces to be more effective in cooling the outdoor space. In the end, it can be concluded that compared to horizontal green surfaces, blocking solar radiation and shading on the surfaces are much more effective in improving thermal comfort in outdoor spaces. Nevertheless, adding green surfaces to shading can further improve the thermal comfort of outdoor spaces in hot seasons.
- Vegetation reduces PMV, PET, and Tmrt while increasing RH, and thus contributes greatly to improving thermal comfort in outdoor spaces between buildings in hot seasons.
- In all analyses based on the indices of thermal comfort in outdoor spaces, the green floor performed better than the vertical green wall. This better performance can be attributed to denser, more extensive tree coverage on the floor, which is not possible on a green façade. The trees on a horizontal surface and yard floor block direct solar radiation and cast shadows, which improve thermal comfort in outdoor spaces. The results of the study show that green walls do not noticeably improve thermal comfort in outdoor spaces; however, the role of vertical vegetation in improving thermal comfort in indoor spaces cannot be disregarded. We hope the present research addressing the effect of vertical vegetation on thermal comfort in indoor spaces will serve as a base for future studies.

According to the final results of the present study, in all buildings and during warmer seasons, the effect that adjacent buildings' shadow has on the thermal comfort conditions in the open spaces is more than the effect of the green walls. In this situation, the horizontal green surface is more efficient than vertical green surfaces. This can be generalized to all buildings with vertical green walls. The effect that horizontal and vertical green walls (as microclimate conditions) have on the other types of buildings will be investigated in future studies. However, the results of the present study can be generalized to all open space buildings.

References

1) Ahmadpour Kolahrodi, N., Pour Jafar, M. Mahdavi Nejad, M. Yousefian S. (2017) ‘The role and effect of design elements on the thermal comfort of urban open spaces (Case study: Designing the pedestrian paths Tamghachs in Kashan)’, Art University Journal (18): 79-59. (In persian)
2) Aligani, B. Razavi, Z. (2017). ‘Comparison of Comfort Indicators for Climatic Comfort Assessment in Tehran’, Geographical View of University of Zanjan 9(16): 169-145. (In persian)
3) Al-Sallal, K. & Al-Rais, L. (2011) ‘Outdoor airflow analysis and potential for passive cooling in the traditional urban context of Dubai’, Renewable energy 36(9): 2494-2501. (In persian)
4) Ansarimanesh, M. Nasrollahi, N. (2014) ‘Determination of the thermal comfort of residents in order to improve the quality of the indoor environment in administrative buildings of Kermanshah’, The Role of the World 4 (2): 27-17. (In persian)
5) ANSI/ASHRAE Standard 55. (2017)‘Thermal Environmental Conditions for Human Occupancy.
6) Ataee, H. Hasheminasab, S. (2012) ‘Comparative evaluation of human bioclimate of Isfahan city using Terjong, TCI, PET, PMV’, Urban and Regional Studies and Research 4(14): 82-63. (In persian)
7) Baaghideh, M. Asgari, A. Shojaa, F. Jamalabadi, J. (2014) ‘Reviewing and comparing the performance of the Rayman model parameters in determining the appropriate tourism calendar. Case study: Esfahan Shahr’, Geography and Development (36). (In persian)
8) Besir, A. & Cuce, E. (2018) ‘Green roofs and facades: A comprehensive review’, Renewable and Sustainable Energy Reviews (82): 915-939.
9) Bruse, M. & Fleer, H. (1998) ‘Simulating surface–plant–air interactions inside urban environments with a three-dimensional numerical model’, Environmental modeling & software 13(3-4): 373-384.
10) Calautit, J. Hughes, B. Chaudhry, H. & Ghani, S. (2013) ‘CFD analysis of a heat transfer device integrated wind tower system for hot and dry climate’, Applied Energy (112): 576-591.
11) Calis, G. & Kuru, M. (2017) ‘Assessing user thermal sensation in the Aegean region against standards’, Sustainable Cities and Society (29): 77-85.
12) Charoenkit, S. & Yiemwattana, S. (2017) ‘Role of specific plant characteristics on thermal and carbon sequestration properties of living walls in tropical climate’, Building and Environment (115): 67-79.
13) Chatzidimitriou, A. & Axarli, K. (2017) ‘Street canyon geometry effects on microclimate and comfort; a case study in Thessaloniki’, Procedia environmental sciences (38):643-650.
14) Chatzidimitriou, A. & Yannas, S. (2015) ‘Microclimate development in open urban spaces: The influence of form and materials’, Energy and Buildings (108): 156-174
15) Chen, Y. Chen, C. Matzarakis, A. Liu, J. & Lin, T. (2016) ‘Modeling of mean radiant temperature based on comparison of airborne remote sensing data with surface measured data’, Atmospheric Research (174): 151-159.
16) Collins, R. Schaafsma, M. & Hudson, M. (2017) ‘
17) Coma, J. Pérez, G. de Gracia, A. Burés, S. Urrestarazu, M. & Cabeza, L. (2017) ‘Vertical greenery systems for energy savings in buildings: A comparative study between green walls and green facades’, Building and environment (111): 228-237.
18) Daemei, A. Azmoodeh, M. Zamani, Z. & Khotbehsara, E. (2018) ‘Experimental and simulation studies on the thermal behavior of vertical greenery system for temperature mitigation in urban spaces’, Journal of Building Engineering (20): 277-284. (In persian)
19) Davis, M. Ramirez, F. & Pérez, M. (2016) ‘More than just a Green Façade: vertical gardens as active air conditioning units’, Procedia Engineering (145): 1250-1257.
20) De Jesus, M. Lourenço, J. Arce, R. & Macias, M. (2017) ‘Green façades and in situ measurements of outdoor building thermal behaviour’, Building and Environment (119):11-19.
21) Djedjig, R. Bozonnet, E. & Belarbi, R. (2016) ‘Modeling green wall interactions with street canyons for building energy simulation in urban context’, Urban Climate (16): 75-85.
22) El-Bardisy, W. Fahmy, M. & El-Gohary, G. (2016) ‘Climatic sensitive landscape design: Towards a better microclimate through plantation in public schools, Cairo, Egypt’, Procedia-Social and Behavioral Sciences (216): 206-216.
23) Fallahi, S., & Ayvazian, S. (2016). The Analysis of the Role of Green Walls in Reduction of Heat Islands in Tehran’, Space Ontology International Journal, 5 Issue 1 Winter 2016, 31 – 44. (In persian)
24) Farajzadeh, M. Mohammad pour, M. Porbar, Z. Moghani, B. Social, B. (2014) ‘Design of the Climate Calendar of Workers of the Parsian Gas Refinery in Mehr City’, Scientific-Research Journal of New Attitudes in Human Geography 6(3): 37-23. (In persian)
25) Farid, F. Ahmad, S. Raub, A& Shaari, M. (2016) ‘Green “Breathing Facades” for Occupants’ Improved Quality of Life’, Procedia-Social and Behavioral Sciences (234) :173-184.
26) Feitosa, R. & Wilkinson, S. (2018) ‘Attenuating heat stress through green roof and green wall retrofit’, Building and Environment (140): 11-22.
27) Gandomkar, A. Moradmand, S. (2013) ‘Investigating Changes in Climate Change of Tourism Comfort of Chaharmahal Bakhtiari Province Using PMV Index’, Seasonal Tourism 2(8): 14-1. (In persian)
28) Ghani, S. ElBialy, E. Bakochristou, F. Gamaledin, S. & Rashwan, M. (2017) ‘The effect of forced convection and PCM on helmets’ thermal

performance in hot and arid environments', Applied Thermal Engineering (111) :624-637.

29) Ghazalli, A. Brack, C. Bai, X. & Said, I. (2018) 'Alterations in use of space, air quality, temperature and humidity by the presence of vertical greenery system in a building corridor', Urban Forestry & Urban Greening (32): 177-184.
30) Gros, A. Bozonnet, E. Inard, C. & Musy, M. (2016) 'A new performance indicator to assess building and district cooling strategies', Procedia engineering (169): 117-124.
31) Gusson, C. & Duarte, D. (2016) 'Effects of Built Density and Urban Morphology on Urban Microclimate-Calibration of the Model ENVI-met V4 for the Subtropical Sao Paulo, Brazil', Procedia engineering (169): 2-10.
32) Hatami, Mojtaba. (2016) 'Modeling of comfort and thermal behavior in the central suburbs of the central courtyard in order to achieve an optimal architectural model; Case study: Shiraz City', Master's Degree in Architectural Engineering, Ilam University. (In persian)
33) Hedayati Rad, F. Shabankari, M. Zarghamiyan, M. Abarghou'i, p. (2016) 'Evaluation of Bio-Climate Indicators Affecting Human Comfort (Case Study: Arvand Free Zone)', Environmental Science and Technology 18(3): 41-22. (In persian)
34) Herath, H. Halwatura, R. & Jayasinghe, G. (2018) 'Evaluation of green infrastructure effects on tropical Sri Lankan urban context as an urban heat island adaptation strategy', Urban Forestry & Urban Greening (29): 212-222.
35) Heydari, Sh. Balaam, AS. (2013) 'Evaluation of Indoor Thermal Comfort Indicators', Geography and Regional Development Magazine (20) :216-197. (In persian)
36) Heydari, Shahin. (2014) Thermal Compatibility in Architecture. Tehran: Tehran University Press. (In persian)
37) Hunter, A. Williams, N. Rayner, J. Aye, L. Hes, D. & Livesley, S. (2014) 'Quantifying the thermal performance of green façades: a critical review', Ecological Engineering (63): 102-113.
38) Huttner, S. Bruse, M. & Dostal, P. (2008) 'Using ENVI-met to simulate the impact of global warming on the microclimate in central European cities', In 5th Japanese-German Meeting on Urban Climatology 18(18): 307-312.
39) Imran, H. Kala, J. Ng, A. & Muthukumaran, S. (2018) 'Effectiveness of green and cool roofs in mitigating urban heat island effects during a heatwave event in the city of Melbourne in southeast Australia', Journal of Cleaner Production.
40) International Organization for Standardization. (2005). Ergonomics of the thermal environment: analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria: International Organization for Standardization.
41) Ismaili, R. Gandomkar, A. Nohandan, M. (2011) 'Evaluating the comfort climate of several major Iranian tourism cities using physiological equivalent temperature (PET)', Natural Geography Research (75): 18-1. (In persian)
42) Ismaili, R. Montazeri, M. (2013) 'Determination of the Bioclimatic Clock Range in Mashhad', Geography and Environmental Planning 24(49) (1): 230-215. (In persian)
43) Jamei, E. Ossen, D. & Rajagopalan, P. (2017) 'Investigating the effect of urban configurations on the variation of air temperature', International Journal of Sustainable Built Environment 6(2):389-399.
44) Kamyabi, S. Ahmadi, A. (2014) 'Study of thermal comfort indexes in Mashhad city', Contemporary Architecture & Urban Development & Sustainable Development from Native Architecture to Sustainable City: Khavaran Higher Education Institution, Mashhad, December 5. (In persian)
45) Karimian, Z. (2013) 'Optimization of urban green space in order to comfort the warmest period of the year using modeling methods', Doctoral dissertation: Faculty of Agriculture, Ferdowsi University of Mashhad. (In persian)
46) Karimian, Z. (2016) 'Simulation of the environmental impact of widespread and compact green roofs in Yazd', Iranian Horticultural Science 47(4). (In persian)
47) Khakzand, M. (2017) Cooling Effect of Shaded Open Spaces on Long-term Outdoor Comfort by Evaluation of UTCI Index in two Universities of Tehran', Space Ontology International Journal, Vol.6, Issue 2, 9-26. (In persian)
48) Khanzadeh Natanzi, Coral. (2009) 'Green Roof; An Approach to Promoting Qualitative Thickness and Sustainable City Tourism Attraction', Human and Environment 7(1): 87-80. (In persian)
49) Koliaie Mahyar. (2016) 'Upgrading and revising the guidelines in the Tehran municipality regarding green walls for use in high altitudes', Master's degree in Architecture, Department of Art and Architecture: Payame Noor University of Tehran, Center for East Tehran. (In persian)
50) Kong, L. Lau, K. Yuan, C. Chen, Y. Xu, Y. Ren, C. & Ng, E. (2017) 'Regulation of outdoor thermal comfort by trees in Hong Kong', Sustainable Cities and Society (31): 12-25.
51) Koulivand, Tahereh. (2015) 'Evaluation of thermal performance of green spaces in urban valleys and its effect on thermal comfort in warm and dry climate', Master's Degree in Architecture-Energy: Faculty of Engineering, Ilam University. (In persian)
52) Lassandro, P. & Di Turi, S. (2017) 'Façade retrofitting: from energy efficiency to climate change mitigation', Energy Procedia (140):182-193.
53) Lobaccaro, G. & Acero, J. (2015) 'Comparative analysis of green actions to improve outdoor thermal comfort inside typical urban street canyons', Urban Climate (14): 251-267.

54) Maghsoudi, M. Jamshidi, M. (2014) ‘Improvement of thermal comfort in open spaces of residential complexes’, Fourth International Conference on Modern Approaches to Energy Conservation: Permanent Secretariat of the Conference, Tehran, Feb. 29. (In persian)
55) Mahdian Mahfrozi, M. Shamsipour, A. Azizi, Gh. (2015) ‘The Effects of Green Spread on the Pattern of Urban Heat Islet (Case Study: Boostan Province)’, Urban Planning Geography 3(1): 99-85. (In persian)
56) Mahdinasab, M. Naserzadeh, M. (2013) ‘Determining tourism time calendar in Gahar Lake based on MEMI model’, Journal of Applied Geosciences Research 13 (30): 109-91. (In persian)
57) Mahmoud, A. (2011) ‘An analysis of bioclimatic zones and implications for design of outdoor built environments in Egypt’, Building and Environment 46(3): 605-620. (In persian)
58) Manso, M. & Castro-Gomes, J. (2015) ‘Green wall systems: a review of their characteristics’, Renewable and Sustainable Energy Reviews (41): 863-871.
59) Manso, M. & Castro-Gomes, J. (2016) ‘Thermal analysis of a new modular system for green walls’, Journal of Building Engineering (7):53-62.
60) Marie, Elahe. (2014) ‘The Role of Urban Shell Materials in Building Design Based on Temperature Changes (Tehran Case Study)’, Master’s Degree in Energy and Architecture: Art University.
61) Medl, A. Mayr, S. Rauch, H. P. Weihs, P. & Florineth, F. (2017) ‘Microclimatic conditions of ‘Green Walls’, a new restoration technique for steep slopes based on a steel grid construction’, Ecological engineering (101): 39-45.
62) Medl, A. Stangl, R. & Florineth, F. (2017) ‘Vertical greening systems–A review on recent technologies and research advancement’, Building and Environment (125):227-239.
63) Medl, A. Stangl, R. Kikuta, S. & Florineth, F. (2017) ‘Vegetation establishment on ‘Green Walls’: Integrating shotcrete walls from road construction into the landscape’, Urban forestry & urban greening (25): 26-35.
64) Mitterboeck, M. & Korjenic, A. (2017) ‘Analysis for improving the passive cooling of building’s surroundings through the creation of green spaces in the urban built-up area’, Energy and Buildings (148): 166-181.
65) Mohammadi B. Mohammad Khani, P. Gholizadeh M. (2017) ‘Preparation of Iran's biochemical map using the averagely measured average score’, Geographic Survey Chapter 32(2): 39-21. (In persian)
66) Mohammadzadeh, Rahmat. (2011) ‘Surveying the quality of spatial and physical factors of open spaces of residential complexes in Sahand new city’, Journal of Fine Arts, Architecture and Urban Development (47): 38-29. (In persian)
67) Mokhtari, Mahnoosh. (2015) ‘An Invaluable Assessment of Human Thermal Comfort in Yazd City Using Several Thermal-Biochemical Indicators’, Master’s Degree in Meteorology, Faculty of Physics: Department of Meteorology, Yazd University. (In persian)
68) Moradi, S., Matin, M., & FAYAZ, R. (2018). Analysing The Climatic Impact of Central Courtyards in Traditional Houses of Tabriz’, Space Ontology International Journal, Vol. 7, Issue 1, Winter 2018, 29-49. (In persian)
69) Morakinyo, T. Lai, A. Lau, K. & Ng, E. (2017) ‘Thermal benefits of vertical greening in a high-density city: Case study of Hong Kong’, Urban Forestry & Urban Greening.
70) Moren, M. & Korjenic, A. (2017) ‘Hotter and colder–How Do Photovoltaics and Greening Impact Exterior Facade Temperatures: The synergies of a Multifunctional System’, Energy and Buildings (147): 123-141.
71) Morille, B. & Musy, M. (2017) ‘Comparison of the impact of three climate adaptation strategies on summer thermal comfort–Cases study in Lyon France’, Procedia environmental sciences (38): 619-626.
72) Nadim, Z. Gandomkar, A. Abbasi, AS. (2016) ‘Comparison of quantitative tourism climate indicators to measure the thermal comfort of the environment’, Tourism Room 5(18): 58-43. (In persian)
73) Najafi, M. Najafi, N. (2012) ‘Thermal comfort study using PMV and PPD (Case study: Shiraz Lawyer's Market)’, Seven Fence1(1): 70-61. (In persian)
74) Nasrollahi, N. Hatami, M. Khastar, S. & Taleghani, M. (2017) ‘Numerical evaluation of thermal comfort in traditional courtyards to develop new microclimate design in a hot and dry climate’, Sustainable Cities and Society (35): 449-467. (In persian)
75) Nazarian, N. Fan, J. Sin, T. Norford, L. & Kleissl, J. (2017) ‘Predicting outdoor thermal comfort in urban environments: A 3D numerical model for standard effective temperature’, Urban climate (20): 251-267.
76) Oliveira, S. Andrade, H. & Vaz, T. (2011) ‘The cooling effect of green spaces as a contribution to the mitigation of urban heat: A case study in Lisbon’, Building and Environment 46(11): 2186-2194.
77) Olivieri, F. Grifoni, R. Redondas, D. Sánchez-Reséndiz, J. & Tascini, S. (2017) ‘An experimental method to quantitatively analyse the effect of thermal insulation thickness on the summer performance of a vertical green wall’, Energy and Buildings (150): 132-148.
78) Othman, A. & Sahidin, N. (2016) ‘Vertical greening façade as passive approach in sustainable design’, Procedia-Social and Behavioral Sciences (222): 845-854.
79) Ottelé, M. & Perini, K. (2017) ‘Comparative experimental approach to investigate the thermal behaviour of vertical greened façades of buildings’, Ecological Engineering (108):152-161.
80) Ozkeresteci, I. Crewe, K. Brazel, A. & Bruse, M. (2003) ‘Use and evaluation of the ENVI-met model for environmental design and planning: an

experiment on linear parks', In Proceedings of the 21st International Cartographic Conference (ICC) Durban South Africa: 10-16.

81) Pérez, G. Coma, J. Sol, S. & Cabeza, L. F. (2017) 'Green facade for energy savings in buildings: The influence of leaf area index and facade orientation on the shadow effect', Applied Energy (187):424-437.
82) Perini, K. & Rosasco, P. (2013) 'Cost–benefit analysis for green façades and living wall systems', Building and Environment (70):110-121.
83) Perini, K. Ottelé, M. Fraaij, A. Haas, E. M. & Raiteri, R. (2011) 'Vertical greening systems and the effect on air flow and temperature on the building envelope', Building and Environment 46(11): 2287-2294.
84) Peyman Rad, Amir Hossein. (2015) 'Review Urban Blocks Formation with External Thermal Comfort Approach in Tehran', Master's Degree in Architectural Energy: Ilam University. (In persian)
85) Razzaghmanesh, M. & Razzaghmanesh, M. (2017) 'Thermal performance investigation of a living wall in a dry climate of Australia', Building and Environment (112): 45-62.
86) Razzaghmanesh, M. Beecham, S. & Salemi, T. (2016) 'The role of green roofs in mitigating Urban Heat Island effects in the metropolitan area of Adelaide, South Australia', Urban Forestry & Urban Greening (15): 89-102.
87) Riley, B. (2017) 'The state of the art of living walls: Lessons learned', Building and Environment (114): 219-232.
88) Rodríguez-Algeciras, J. Tablada, A. Chaos-Yeras, M. De la Paz, G. & Matzarakis, A. (2018) 'Influence of aspect ratio and orientation on large courtyard thermal conditions in the historical centre of Camagüey-Cuba', Renewable Energy (125): 840-856.
89) Safikhani, T. & Baharvand, M. (2017) 'Evaluating the effective distance between living walls and wall surfaces', Energy and Buildings (150):498-506.
90) Saito, K. Said, I. & Shinozaki, M. (2017) 'Evidence-based neighborhood greening and concomitant improvement of urban heat environment in the context of a world heritage Site-Malacca, Malaysia', Computers Environment and Urban Systems (64): 356-372. (In persian)
91) Sajadzadeh, H. Gholami, F. Golbzadeh. (2015) 'Recognition and examination of green walls to reduce energy loss of buildings', National Conference on Civil Engineering and Architecture with an approach to sustainable development, August.
92) Sarhadi, F. Moradi, S. (2018) 'Qazvin climatic zoning with bioclimatic architecture approach', Iranian Architecture & Urban Planning Conference on the Transition of Works and Ideas: Islamic Azad University Qazvin: October 26. (In persian)
93) Sheweka, S. & Mohamed, N. (2012) 'Green facades as a new sustainable approach towards climate change', Energy Procedia (18): 507-520.
94) Šuklje, T. Medved, S. & Arkar, C. (2016) 'On detailed thermal response modeling of vertical greenery systems as cooling measure for buildings and cities in summer conditions', Energy (115): 1055-1068.
95) Targhi, M. & Van Dessel, S. (2015) 'Potential contribution of urban developments to outdoor thermal comfort conditions: The influence of urban geometry and form in Worcester, Massachusetts, USA', Procedia engineering (118): 1153-1161.
The value of green walls to urban biodiversity', Land
96) Tsitoura, M. Michailidou, M. & Tsoutsos, T. (2016) 'Achieving sustainability through the management of microclimate parameters in Mediterranean urban environments during summer', Sustainable Cities and Society (26): 48-64.
Use Policy (64):114-123.
97) Wong, L. Alias, H. Aghamohammadi, N. Aghazadeh, S. & Sulaiman, N. (2017) 'Urban heat island experience, control measures and health impact: A survey among working community in the city of Kuala Lumpur', Sustainable Cities and Society (35): 660-668.
98) Yao, R. Li, B. & Liu, J. (2009) 'A theoretical adaptive model of thermal comfort–Adaptive Predicted Mean Vote (aPMV)', Building and environment 44(10): 2089-2096.
99) Zarei, Qasim. (2017) 'Structural Challenge of Greenhouses in Iran', Journal of Strategic Research in Agricultural Sciences and Natural Resources 2(2): 162-149. (In persian)
100) Zolfaghari, Hassan. (2010) 'Considerations about available indicators and models to determine the timetable for tourism in Tabriz', Journal of the Faculty of Humanities and Social Sciences of Tabriz University. (In persian)

Online Resources:

1) *https://www.irimo.ir*

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[1] The purpose of creating green walls is to use their cooling function. Therefore, it is necessary to evaluate the efficiency of these walls in critical conditions
(warmest days of the year). Therefore, July 7th of the day as the hottest day of 2018 (as the closest and most up-to-date statistic) was selected as the reference and raw data input source of the software.

[2] As the trial version of ENVI-met did not allow performing PET calculations, this index was obtained via RayMan.