Original Article

The Effect of Garden Pit on the Surface and Peripheral Temperature and Energy Consumption in Arid and Hot Climate

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Abstract

The building is enumerated amongst the factors having a great deal of effect on the environment change; it accounts for 41% of energy consumption in Iran. Thus, in order to acquire a part of applied knowledge and also to respond to the essential environmental needs of the human beings, the present article tries analyzing the effect of garden pit in the traditional climate of the hot and arid climates so that the values of the past architecture can be continued and simultaneously elaborate the extent to which it is useful. The present study has been conducted based on a quantitative-qualitative and descriptive-analytical method. Using Thermovision (thermal camera), model DT-982, it was concluded that the traditional building of Khajeh Khidr in Yazd features such conditions as surface temperatures up to 10°C for its possession of the garden pit; based on the analysis of findings and simulation in Design Builder Program, two buildings one with garden pit and the other without garden pit, it was proved that energy consumption can be reduced up to 14% when using electricity for lighting, cooling, and heating by means of garden pit.

Keywords: garden pit, energy, hot and arid climate, temperature

INTRODUCTION

Traditional architecture is subtly dependent on its environmental context and, due to the same reason, it is influenced by the changes and metamorphoses therein. Vernacular architecture possesses important environmental properties that enable stability and sustainability and make it offer comfort to mankind such as low-energy methods, form-related approaches, orientation and masonries that are obtained from the local resources [1].

Subsurface spaces like garden pits are envisioned as the oldest types of shelter. The use of the subsurface spaces dates back in Dezful to the initial formation of the city, i.e. 1500 years ago. Although the subsurface spaces have not been introduced in some of the prior studies as a dwelling place and basement is realized as a modern invention, the existence of several types of houses as old as 3000BC and with sunken yards and garden pits in the vernacular architecture of Matma Village in the south of Tunisia confirms the application of subsurface spaces [2].

Earth is a nearly endless thermal source that its high thermal capacity enables the seasonal storage of heat. The temperature of the soil in depths below 6m is nearly more stable and equal to the average annual temperature of the surface and it is usually two or three degrees hotter than the average annual temperature of the air due to the sun's irradiation and the very high temperature of the earth's deep core. In the shallow depths, the increase in the depth brings about fluctuations in the annual temperature of the soil with a sort of temporal delay occurring in the temperatures. The soil's thermal features differ depending on the soil type (fixed), its compactness (relatively fixed) and moisture (changeable under the rainfall and groundwater vicinity conditions). The soil's increased thermal mass in the subsurface buildings provides relatively stable temperatures during the year that leads to seasonal heat storage. Therefore, the heat absorbed in the earth's surface during summer lasts several months and the subsurface space's temperature is consequently balanced during the other seasons. In summer,

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as well, the cool soil with temperature below the air is a suitable source of cooling [3].

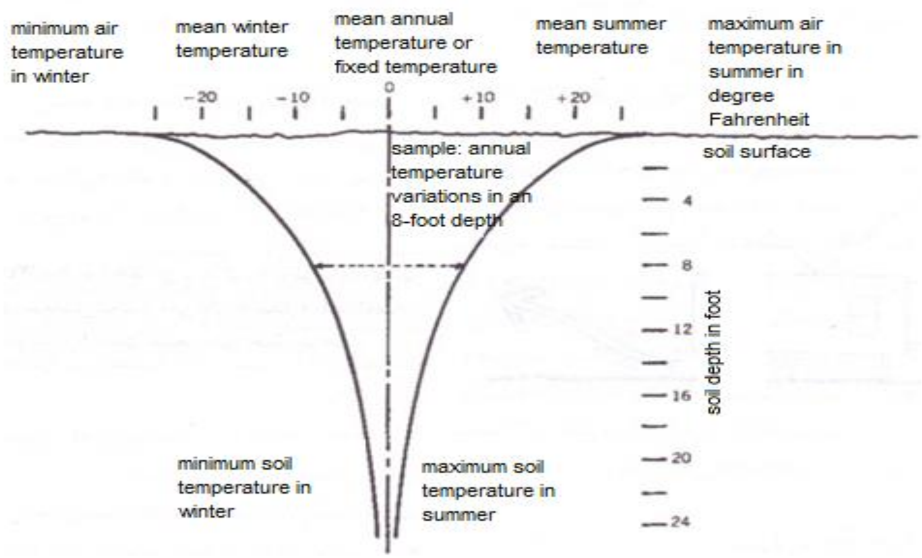


Image 1: earth temperature variations with the changes in the depth (Source: Lankar, 2006) [4]

Study Background:

Since the present study aims at the analysis and investigation of the garden pit's effect on the energy consumption and the peripheral and surface temperature moderation, the books and works published on the energy stability in hot and arid climate have been explored; the plants' ability in moderating the temperature which is amongst the important factors for controlling the solar energy has also been examined. The ground located in shade can absorb a lot of heat but the humidity caused by the plants will decrease the heat so the cold will remain for a longer period of time during a day in the surfaces and parts of the building that contain greeneries [5].

Data and Study Method:

In the present study, the library documents, including the books and articles related to the study's topics, and the sample spaces studied in similar research in regard of the present project's functioning and approach were investigated, if available, and computer sciences were employed to investigate the data and analyze them.

The most important data required in the present study is atmospheric information, ground surface characteristics and applied maps of the ground surface. The atmospheric data included the sunny hours' information, the sky's cloudiness amount and the wind's speed, direction, and frequency; all these data were procured from the meteorology organization with the general sun irradiation's data being acquired from the radiometric stations (in Yazd, Na'ein and Kashan).

These data have been recorded within the format of fixed parameters in Design Builder Software following which the energy consumption was simulated and determined in two residential units in Yazd which has an arid and hot climate.

Definition of the Problem and Study Goals:

The present study aims at the investigation of the garden pit's role in the vernacular architecture; an answer will be found to the question that what is the role played by the garden pit in the buildings' energy consumption?

Thus, the garden pit is evaluated in the present study as one of the basic elements in terms of stability and its role will be elucidated in the reduction of energy consumption. According to the existing statistics, Iran's residential buildings are the largest consumers of energy countrywide. There are numerous factors influencing the energy consumption behavior in the residential buildings and they have caused the energy consumption prediction and auditing to an important challenge in the consumption optimization institutions. The world's energy needs are considerably increased and fossil energy resources cannot respond to the world's energy need for survival, development, and perfection in the upcoming centuries. Here, it is necessary to state that the present study aims at determining the usefulness of garden pit in energy consumption and environmental temperature moderation.

Definitions:

Energy: it is the measurable quantity of a mass; it can be transmitted to other objects or transformed into various states and forms. Energy is a fundamental quantity attributed to a particle, object or system for describing them [6].

Hot and Arid Climate:

In regions under the influence of the arid climate, the evaporation and transpiration of the surfaces of waters and the soil and vegetative cover are more than rainfall. Thus, the environment's water needs cannot be supplied through rainfall. The perpetual storage of groundwater does not also suffice water requirements [7].

Temperature: it is a sign of the average speed of molecules constituting an object. It can be actually stated that temperature is a quantity that its difference between two connected objects and/or two points of a single object causes the spontaneous transferring of heat from the one with higher temperature to the other with lower temperature [8].

Garden Pit:

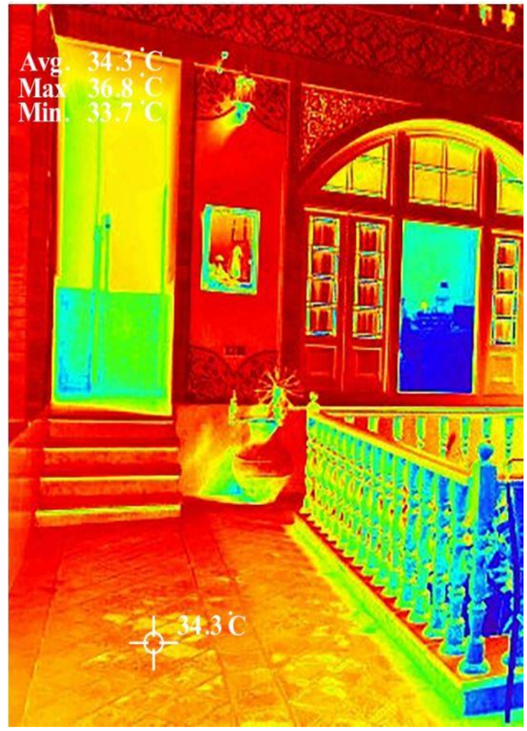
In the vernacular architecture of Iran's hot and arid regions and in most of the buildings therein, the yards are situated in a level lower than the passageway. Besides contributing to the space's cooling, such sunken yard causes the dissipation of the forces causing the building's subsidence; conformation of the building with the ground motion and ease of access to the routes of flowing waters; in addition, the extracted soil is used in place as constructional materials [9].

The standard of the garden pit in the residential setting has been specified under the topic 4 of the national building regulations, paragraph 1-4-8-5-4: if the garden pit has been designed for supplying light and ventilation in the residential spaces and workplaces, it has to be at least 20 square meters in area and at least 5.4 meters wide.

Records Made in Eco-Touristic Khajeh Khidr Domicile in Yazd:

Using Thermovision Camera, Model DT-982, three different levels of this building were subjected to the thermal recording during May.

Image (2): the environment in the periphery of the garden pit which is in a negative elevation code in respect to the passageway



Image(3): the building's ground floor with one story on the garden pit (building's ground floor)

Image (4): heat recording in a part of the building's roof in the closest distance to the garden pit

The following table summarizes the results obtained by the use of the thermovision camera.

Table 1: temperatures recorded using a thermal camera in Khajeh Khidr Building (Source: the author)

Recorded level (May 2017)	Camera's target temperature	Highest temperature rate	Lowest temperature rate	Type of masonry extracted from the excavated surface
Basement	28.1°C	29.8°C	The temperature of water in the pond: 18.2°C	Stone
Ground floor	34.3°C	36.8°C	33.7°C	Stone
Roof	38°C	42.2°C	37.7°C	Brick

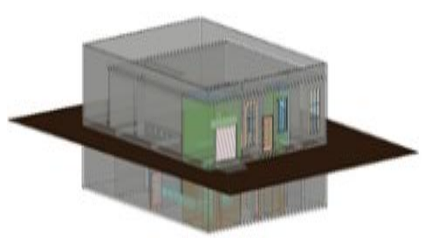
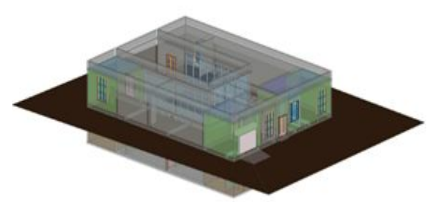
Based on the above table, the temperatures of the surfaces of the basement in the periphery of the garden pit are 10°C lower than the temperature recorded in a part of roof in the closest distance to the garden pit for such a reason as no direct irradiation of sun and air circulation in the garden pit and larger coefficient of the soil's cooling in the underlying beds of the ground surface. Of course, this amount of temperature decrease is variable for every building depending on the sun's angle of irradiation (temperature recording hour), building's geographical position and type of masonry (thermal capacity) targeted by the camera. Efforts were made in the present study to record temperature for congruent constructional materials.

Simulation in the Design-Builder Program:

Design Builder Software is a specialized energy simulation software package and one of the most frequently applied software packages existent for energy calculations. Amongst the important characteristics of this software is the use of such a computational engine as energy plus developed by American energy department and it is viewed as one of the most credible energy modeling software packages (international energy association, IEA); it is possible by the use of this software to model the thermal and cooling loads of the building, various energy consumptions, including heating and cooling, lighting, electrical home appliances and so forth in a dynamic manner. In order to investigate the effect of the garden pit on the energy consumption reduction, Design Builder Program creates the best and the most accurate output via considering the irradiation angle, direction, and power of the favorable wind and the peripheral temperature on every day of the year. In the present study, the residential buildings with and without garden pit are subjected to analysis for thermal energy through the use of this program. The model of the intended buildings has been simulated under the real climatic conditions so that it can become clear that how the aforementioned building acts. Moreover, the effects of the designing elements can be investigated on the key parameters, including the annual energy consumption, very hot hours and amount of carbon dioxide production.

The following table specifies the simulated residential units with and without garden pit as well as the characteristics of each.

Table 2: simulated residential units and their specifications (source: the author)

	a)	b)
A) Unit without the garden pit **B) Unit with garden pit**		
Meterage	Ground floor 44×30 Basement 22.5×23	Ground floor 44×30 Basement 44×30
Spatial position	54° eastern longitude and 32° northern latitude (Yazd)	54° eastern longitude and 32° northern latitude (Yazd)
Area of the yard and garden pit	Southern yard: 145m	Garden pit: 179m

Calculation type	Electricity consumption for lighting, cooling, and heating	Electricity consumption for lighting, cooling, and heating

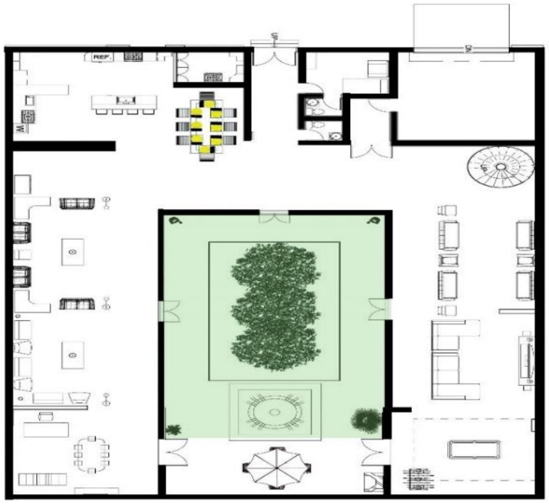
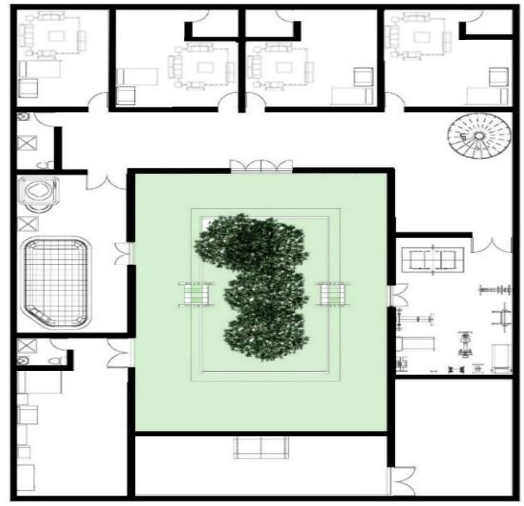
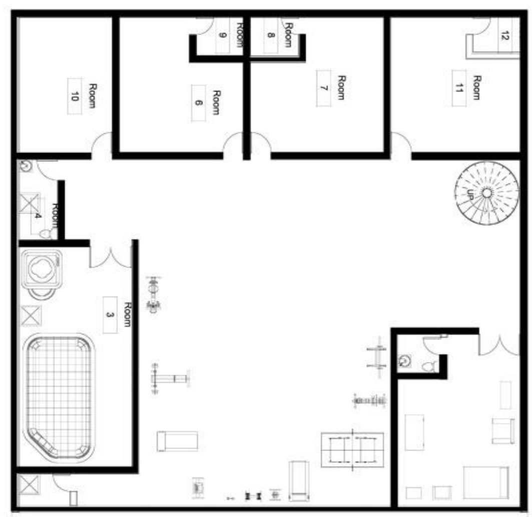


Image (5):Plan of the unit with the garden pit in the ground floor



Image(7):Plan of the unit with the garden pit in the basement

Image(6):Plan of the basement in the unit without the garden pit



Image(8):Plan of the ground floor in the unit without the garden pit

Data in Design Builder Program:

In both of the residential units, use has been made of one type of constructional materials and they both feature similar site plans. The amounts of such parameters as the activity[1], construction[2], opening[3] , and lighting[4] have been identically determined for both of the building units.

[1] Section on the activities related to the project
[2] Masonry and type of structure in the project
[3] Openings, including glass types and amount of shutters
[4] Number and type of the lighting elements

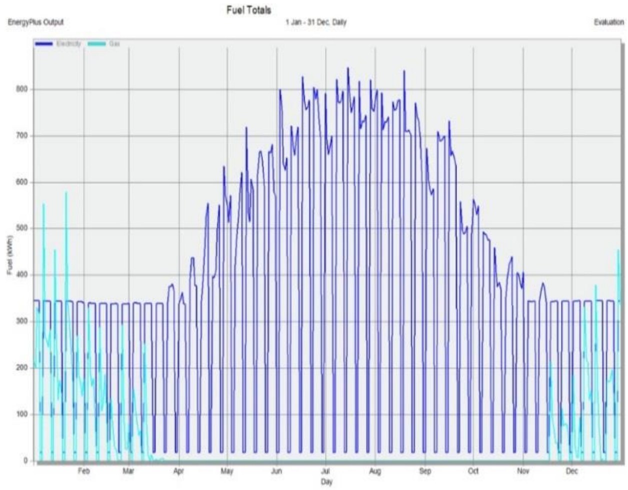


Image 6: the amount of energy use during a year in the plaque with the garden pit (electricity and gas) (Source: Design Builder Program)

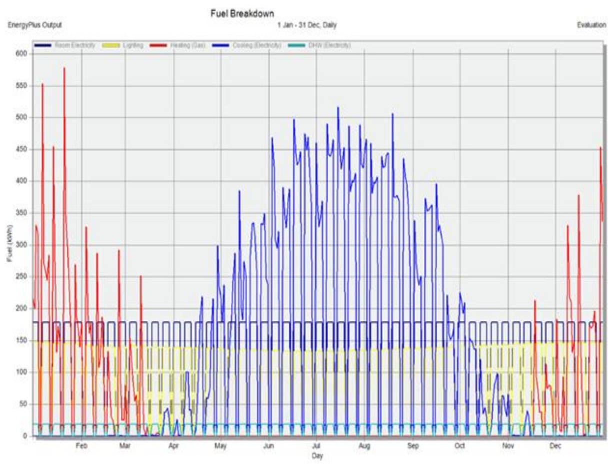


Image 7: the amount of energy use in one year in the plaque with the garden pit (electricity consumed for rooms' lighting, cooling and heating water and gas used for heating) (Source: Design Builder Program)

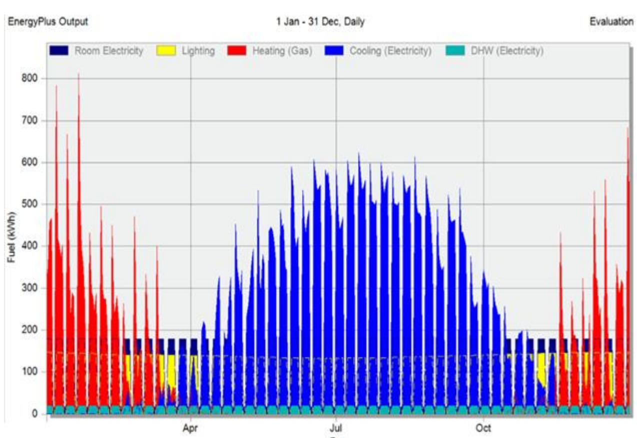


Image 8: the amount of energy used in one year in the plaque without garden pit (electricity consumed for the rooms' lighting, cooling and heating water and gas used for heating) (Source: Design Builder Program)

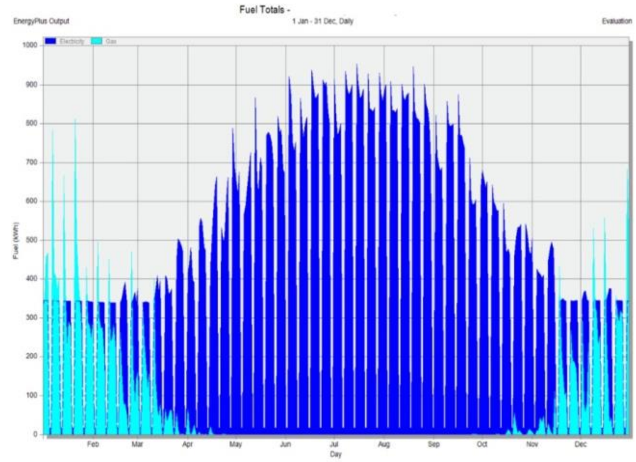


Image 9: the amount of energy used in one year in the plaque without garden pit (electricity and gas) (Source: Design Builder Program)

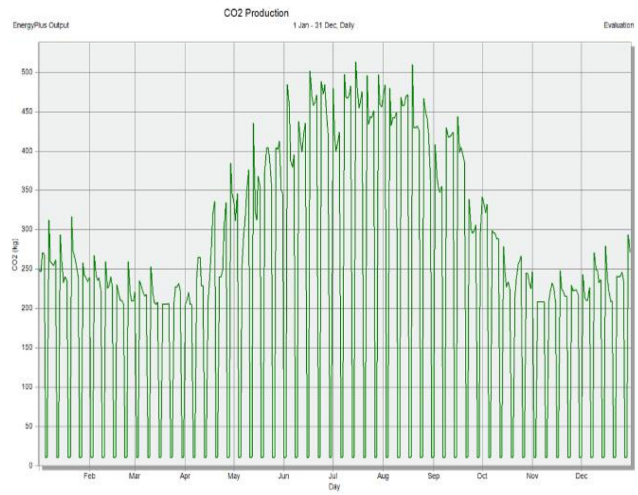


Image 10: CO2 produced in one year in plaque with the garden pit (kg_ (source: design builder program)

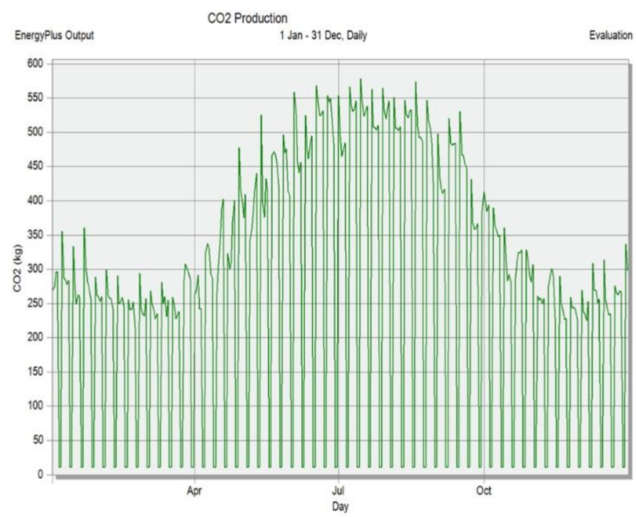


Image 11: CO2 produced in one year in plaque without garden pit (kilogram) (source: design builder program)

Analysis of the Data Obtained from Design Builder:

Table 3: energy consumption in the simulated units (source: the author)

	The highest amount of electricity consumption in one month for lighting	The highest amount of electricity consumption in one month for cooling in July	The highest amount of gas consumed by the heating system in January	Amount of CO2 produced in one year
Building with garden pit	120kWh	530 kWh	570m^3	530kg
Building without the garden pit	150kWh	630kWh	610m^3	560kg

Sum of energy consumed in one year (residential unit with garden pit): 3637.8 kWh

Program Version:**EnergyPlus, Version 8.3.0-6d97d074ea, YMD=2019.04.28 18:47**

Tabular Output Report in Format: **HTML**

Building: **Building**

Environment: **HOME WITH COURTYARD ** Yazd - IRN ITMY WMO#=408210**

Simulation Timestamp: **2019-04-28 18:47:52**

Report: **Annual Building Utility Performance Summary**

For: **Entire Facility**

Timestamp: **2019-04-28 18:47:52**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]
Total Site Energy	3637.8	136.38
Net Site Energy	3637.8	136.38

Image 12: Source-Design Builder Program

Sum of energy consumed in one year (residential unit without garden pit): 4230.4 kWh

Program Version:**EnergyPlus, Version 8.3.0-6d97d074ea, YMD=2019.04.28 19:04**

Tabular Output Report in Format: **HTML**

Building: **Building**

Environment: **WITHOUT COURTYARD ** Yazd - IRN ITMY WMO#=408210**

Simulation Timestamp: **2019-04-28 19:04:19**

Report: **Annual Building Utility Performance Summary**

For: **Entire Facility**

Timestamp: **2019-04-28 19:04:19**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]
Total Site Energy	4230.4	191.92
Net Site Energy	4230.4	191.92

Image 13: Source-Design Builder Program

Conclusion:

Vernacular and introvert architecture of the traditional buildings in the hot and arid climates provide the people with comfortable conditions through introducing garden pit element and by the use of renewable energies and also via receiving more solar energy during winter and providing maximum shade in summer and also by enabling natural ventilation and lighting through the use of vernacular masonry and by creating sunken parts excavated to the heart of the ground for ventilation and creation of humidity by the assistance of the plants and water ponds and additionally by the use of the locally found constructional materials. The economic effects of the garden pits such as the lower need for electricity and fossil fuels, more application and use of renewable energies (sun and wind) and employment of the vernacular masonry. It was concluded in this article that the residential unit enjoying the garden pit in its design uses electricity for lighting, cooling, and heating 14% lower than the residential unit that has a yard and is positioned southward. So, the garden pit has been very effective in the surface temperature reduction which has been varying up to 10C between the three building levels in the Eco-Touristic Khajeh Khidr Building; such a reduction in the surface temperature causes the moderation of the environmental temperature.

It is hereby declared by the writers that there has been no interest conflict for them in performing the present research.

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