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# Courtyards as solutions in green architecture to reduce environmental pollution

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**Abstract**

After the industrial revolution, men intended-more than ever-to use energy, specifically the fossil fuels. In spite of providing comfort conditions for human life, too much use of these energy resources can cause the pollution and destruction of environment. The result is the threatening of the environment and the continuity of life on the planet Earth. Hence, the environmental concerns in the 1970s caused the emergence of a new concept entitled as sustainability in all sciences and industries. Therefore, construction sectors -as one of the main consumers of energy- are required to follow sustainability principles, as other disciplines do. One of the techniques in planning green architecture to reach the optimal usage of clean energies and, subsequently, to reduce environmental pollution is to have central courtyards around buildings. This research considers the effect of different parts of a courtyard building on the operative temperature and solar gain per square meter in Isfahan. Therefore, three traditional houses have been chosen and simulated in DesignBuilder as case studies.

*Keywords*: Environment; Sustainable development; Sustainable energies; Green architecture; Courtyard


## 1. Introduction

The quick growth of population and also the increasing usage of the fossil fuels nowadays have added considerably the speed of the critical status of environmental affairs.

The shortage in natural resources, the increase of polluting levels in surroundings, and the environmental dangers due to the above mentioned problems require appropriate management, sustainable utilization and the use of clean and renewable energies. There is considerable

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attention to the declining energy resources such as the fossil fuels in recent decades; Such as resources that have developed during centuries are not recoverable in comparison with the consumption rate. Hence, it's essential to have multidirectional consideration to the related industries along with sustainable development. It has been clear based upon a research in Europe that 50% of energy consumption in countries is allocated to building construction industry. Transportation consumes 25% of the energy [1]. Thus, replacing and substituting a proportion of these energies with clean energies and planning and constructing based on green architecture can be considered as important steps along with better usage of accessible resources. The present research is a attempt to primarily introduce the existent environmental problems in accord with green architecture principles. Therefore, it also introduces concepts of sustainable development and green architecture. Ultimately, one of the traditional architectural procedures, that is, using courtyards is dealt with. Courtyards are along with green architecture adjectives and are under investigation in three case studies at three traditional houses.

## 2. Research method

The combined research method and simulation in case studies are used in the present research. This Paper is an attempt to review the environmental problems, energy crisis, and the necessity of using clean energies. Meanwhile, it takes into consideration the role of courtyards as a procedure in accord with green architecture objectives. Hence, after some documental studies, there traditional houses in Isfahan with Charmi, Kahkashan and Karimi names are simulated on the basis of Design Builder software. The results obtained from the simulation of the three samples are different with regard to their arrangements around the courtyards (namely two sided, three sided, and four sided arrangements). They are under investigation in the present research as well.

### *2. 1. Sustainable development*

The approval of Stockholm Declaration in Environmental Conference of United Nations Organization is a turning point in formal human attitude during history towards natural resources and the utilization systems of ground. The mentioned declaration and 1974 Declaration of KOKOIK have confirmed the complexity and seriousness of social- environmental crises. Furthermore, they have emphasized upon the necessity of devising and demonstrating healthy environmental strategies in order to upgrade socio-economic and fair environmental developments. Also these affairs led to the "earth Commission" in 1992. During the mentioned commission, the 21 Declaration and Rio Declaration about environmental and development were approved. The 21 Declaration consists of four chapters which are stated in four main parts and includes socio-economic dimensions, the necessary recourses based upon development, strengthening the main groups, and the demonstrative styles, based upon the 21 Declaration and Rio declaration, all countries are obliged to adapt and regulate sustainable development strategies in accord with their geographic, climatic, social, cultural, political, and economic conditions with regard to their existent facilities and limitations [2].

A definition of sustainable development which is generally accepted is the definition written in Brutland report wherein it is stated that "sustainable development is the development that fulfils the needs of present generation ability to satisfy their needs" [3] and "upgrade the quality of Life within the ecosystem capacity and natural- resources boundaries" [4].

By the term development, the continual changes during centuries and eras are meant particularly in technical, social, and economical conditions of human civilization. Sustainable means steady and efficient process (Fig. 1). Besides that, the suggested solutions presented therein are in contrast with social-economic temporary frame patterns of developments so that to block the way for such affairs as the destruction of natural recourses, the demolishing of bio-lives, the pollution of the earth, climate changes, injustice and decline of quality of life [5].

In other words, sustainable development causes the continuity of "utility of resources", in economical surrounding conditions and also "adaptation and qualification of social-economical utilization of resources. With regard to the above definition, sustainable development possesses three important dimensions: human, environment, and future. Along with it, human is propounded as one of the axes of sustainable development. Hence, human development and his fulfilment are prior to the materialistic and economical development .

### *2. 2. Green architecture*

Sustainable development propounds new discussions with terms such as green architecture, sustainable architecture, and/or ecologic architecture.

**Green architecture objectives are:** caring the quality of human life at present and in the future, using the materials that are adaptive with surrounding environment while producing, building and even destroying them. Minimum use of fossil fuels, maximum utilization of clean and renewable energies, and the protection of native culture of each region are important points of consideration [5].

Williams [6] has summed up the above objectives in the three viewpoints as environmental, technical, and cultural ones:

**Environmental aspect:** Designers should consider the characteristics of site, specially the potentials which their buildings can use to have less fossil fuel consumption.

**Cultural aspect:** From the cultural aspect, designers should embed traditional values in their designs. In this regard, including traditional solutions has passive and low cost architectural strategies in themselves.

**Technical aspect:** this aspect uses measuring data and technological facts in the design of a building such as lighting, heating and cooling.

**The proportion of housing energy consumption to national energy consumption:**

Regarding the matters presented in the present research, policy makers have made up their minds in many countries to focus on renewable energy resources and to substitute them with hydrocarbonic energy resources [7]. As it is observed in the picture, housing energy consumption consists of 16 to 50% of total energy consumption in fourteen countries in the world. Average world energy consumption is 30% [8].

As it was argued elsewhere, buildings consume one third of national energy budget. The housing buildings have the key role in the mentioned amount of consumption. Therefore, housing energy consumption must be reduced (Fig. 2). This is why the present paper is an attempt to introduce the utility of courtyards as an effective procedure in order to reduce energy consumption.

## 3. Courtyard

In hot and dry climate that consists two thirds of Iran, yards are considered as heats of

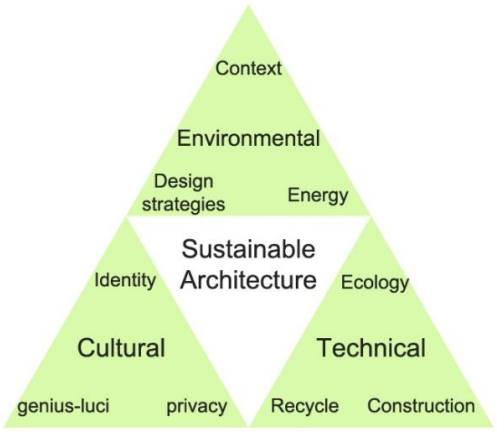


Fig. 1. Sustainable development pattern. *Source*: the writers of the present research.

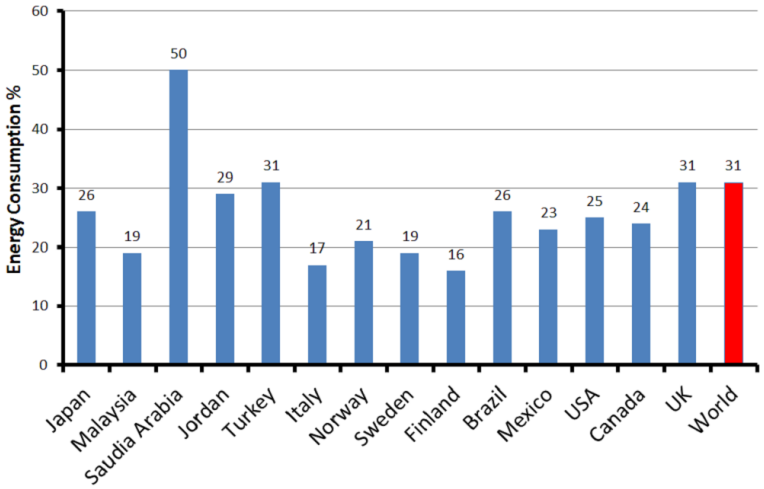


Fig. 2. Housing consumption as a percentage of national energy consumption and its percentage of national energy consumption and its average in the world [9].

buildings. The proportions and dimensions are determined based on geographical latitude, the extend of need to shades, and the extend of solar energy absorption relatively. Besides that, green surrounding and water ponds inside yards cause the increase of relative moisture and mildness of weather [10]. Furthermore, courtyards in Williamson's sustainability viewpoint related to green architecture would be under study.

1) Environmental aspect:

One of the main reasons that courtyards have survived for more than 5000 years, is their potential to provide a thermally comfortable area for living. Courtyards can be a source of fresh air, light and heat. They have been generally referred to as a microclimate modifier in the house due to their ability to reduce peak temperatures, to channel breezes and to adjust the degree of humidity.

Courtyards have been used in hot, temperate, tropical and snow climates with different characteristics.

The simple idea of including an open space (like a courtyard) in a building comes to mind when we need natural lighting, heating, cooling and ventilating in a solid building. Wadah (2006) numbers three main factors in the climatic function of a courtyard building; sun, wind and humidity.

Sun: It is discussed that courtyard buildings somewhere are sun collector and somewhere sun protector. In this regard, it is important to consider sunlight in addition to the thermal effect of the sun. Therefore, the correct orientation of the buildings and its court and the proper position of the void (court) in a solid mass (building) should be taken into account.

Wind: wind has two effects on a courtyard building. First it circulates between exterior space and inside the court; second it ventilates the interior building by the court air. In this regard, in hot areas during the night, warm air rises and exits from the court. Then, the cooler air will enter to replace the existing air. Hence, during the hot day, cool air is circulated to the rooms and the court can be a source of fresh and cool air [11]. In snow regions there is limited circulation between the court and the building. Moreover, in tropical regions where the temperatures of outside and inside the building are close to each other, the court is used for refreshing the interior air.

Humidity: different natural elements can be utilised in the courtyard to increase the humidity. Humidity is needed in arid areas to achieve comfort by increasing the relative humidity of the air. Plants and water elements are the major elements used in hot and arid areas. The evaporation and corresponding increase of humidity are a result of sun and wind [12]. Obviously, in other climates in which humidity is not required, fewer natural elements are seen.

2) Cultural aspect:

One of the biggest advantages of courtyards is the privacy caused by surrounding elements (buildings, rooms or walls) [13-15]. This characteristic provides a safe place for rest, play with children, worship (meditation), women activities and exercise. In this regard, different courtyard shapes are suitable for kindergartens, schools, ritual spaces (great mosques, basilicas), hospitals (places which are supposed to provide a quiet area for treating patients) and even prisons. In courtyard houses, the court acts as an outdoor room. This room can be used as an extension of the kitchen during mornings or as an extension of the living room during evenings for instance to entertain guests [16]. Moreover, visual privacy in a courtyard is an important item in Islamic and Middle Eastern countries. Furthermore, the buildings or rooms around a courtyard attenuate noises from surrounding buildings or from the street.

From a long time ago, the protection of private limits has been one of the primary principles in constructing any buildings. It's because private limits should be protected from the non-intimates. Thus, courtyards are suitable responses as a design strategy for Iranians. This type of culture has dominated in Iran since pre-Islam era. The proof for this claim is the design of Takht-e-Jamshid, palaces and many other magnificent architectural works of our ancestors. Furthermore, the buildings and rooms around the courtyard cause the reduction of sound pollution around the building and also next to streets.

Ultimately, since many of the openings and entrances of this form of building is located in the courtyard, the security and safe feeling increases. Thus, courtyards are in accordance with sustainable architectural objectives in cultural points of view.

1) Formal aspect:

Among all the spaces of a courtyard building (Fig. 3), the courtyard has the best view and access to the other spaces. On an urban scale, we can see that a central courtyard can be

developed to an arena (or a stadium), a city centre, an urban block or a university campus [17, 18].

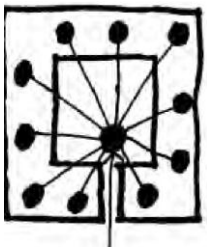

Fig. 3. Courtyard house in terms of access [19].

*3. 1. The simulation of three sample cases by design builder software*

**Design builder software:** The simulative motor of the mentioned software is energy plus (7) which is confirmed by Energy Department of United States of America (http://apps1.eere. energy.g.v/buildings/energyplus/en-interface.cfm). This software is nowadays used in many countries including America, England, Japan, France, Holland, etc (refer samples in sources [20-24].

Wherein selected printed Papers from 2008 to 2012 are in them. (This software has been applied for housing, educational, office buildings in the mentioned selected Papers). Despite other common softwares that try to respond to all reigns of physic of buildings including sound, light, temperature, ventilation, etc; this software is allocated to merely temperature/heating simulation.

The outputs of the software are as follows:

1. Consumptive energy on the basis of energy and fuel units,
2. Internal, reflective, effective air temperature and its relative moisture,
3. Curves of heating comfort width,
4. (Via the site) City climate information,
5. Transferred energy from external layers of the buildings (through walls, ceilings, and around openers),
6. Three dimensional and two-dimensional curves of flowing dynamic of internal ventilation of buildings,
7. Heating and cooling load.

Such information is accessible through curves and graphs. The numerical results (diagrams) are also accessible and the transfer is possible through statistical software such as Excel.

**Isfahan climate:** Isfahan city in the north and east is under the influence of desert regain. This city has a cooler weather in the south part due to the existence of Saffeh Mountain. Generally, Isfahan city is dry and moderate. Since this software should have the capability of building simulation for Iran cities, America's Energy Department provides the climate information of Iran cities to the users. This climate information includes: highest, lowest recorded average temperature per each month, average of rainy days, rain rate, moisture percentage, and sunny hours. Situated at 1,590 meters above sea level on the eastern side of the Zagros Mountains, Isfahan has an arid climate (Köppen BWk). Despite its altitude, Isfahan remains very hot during the summer with maxima typically around 36 °C (97 °F). However, with low humidity and

moderate temperatures at night, the climate can be very pleasant. During the winter, days are mild but nights can be very cold and snow has occurred at least once every winter except 1986/1987 and 1989/1990. However, on the whole Isfahan's climate is extremely cold in winter.

*3. 2. Three sample cases*

**A) Kahkeshan's House:** The spaces of this house are situated in three fronts of the courtyards. The northern front has two stories. It has two with three doors and a corridor between the rooms. In western fronts the courtyard penetrates within the midst of spaces. The entrance to the yard is also from this part. The eastern front of the yard consists of a five-door room in the middle and two rooms in the two directions (Fig. 4).

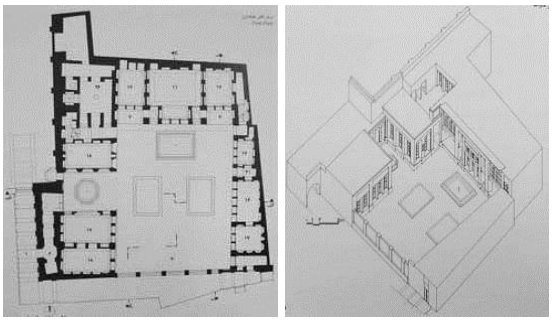

Fig. 4. three-dimensional picture cut and plan of Kahkeshan's house in Isfahan [25].

Regarding the results of the simulation of internal temperature of this building can be observed in the below graph (Fig. 5). In winter (December, January, February) the internal temperature in the three fronts of the house is much higher than the minimum external temperature. In the three months of summer, the temperature of eastern front id higher than the rest of parts (northern and western parts). Also, in winters the temperature of this part (eastern front) is lower than the other parts. This point is opposite in the northern front of the yard.

Thus, this spaces specifies to itself the least=lowest internal temperature in summer and the most highest external temperature in winter.

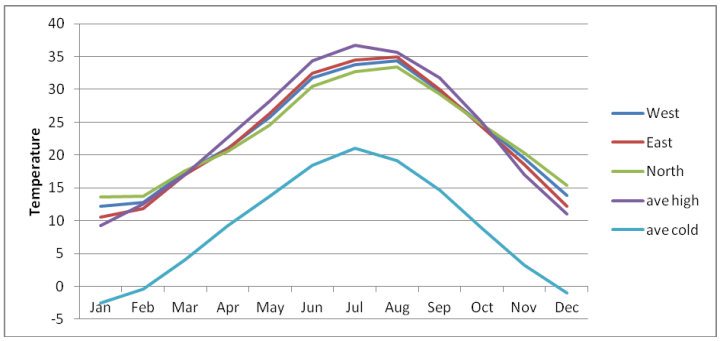


Fig. 5. The internal Temperature in the three directions of the court along with the maximum and the minimum city temperature.

This graph and its results illustrates clearly that this building provides the temperature between 10 to 25 degrees for its residents through three aren't any heating and cooling systems- except the natural ventilation due to the fact that the building is now just a museum. The important point in this graph is the location of wide interval time during each year within heating comfort without consuming energy. In spring (between middle of March to middle of May- and also from the middle of September to the middle of October it is possible to clearly observe this time interval.

**B) Karimi's house:** The mentioned house is in the northern and eastern front. The more important space series of the house is located in the northern front. The house consists of a cross-shaped corridor in all middle and two-rooms with three doors at each side. The western and eastern parts of the yard-like the front facade. They are made by short depth false arches (Fig. 6).

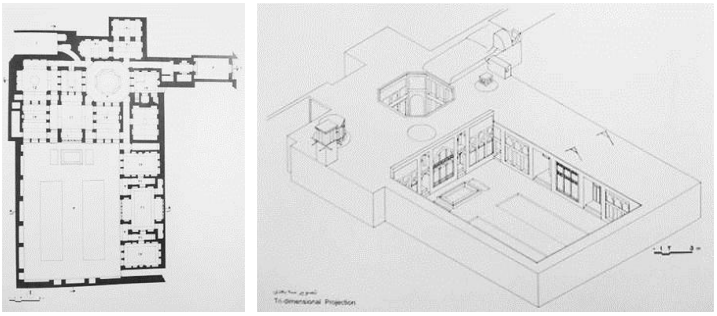

Fig. 6. three dimensional picture, cut and plan of Karimi's house in Isfahan [25].

In the following graphs (Figs. 7 and 8), the results obtained from the simulation of the house can be observed for the internal temperature and the solar gains.

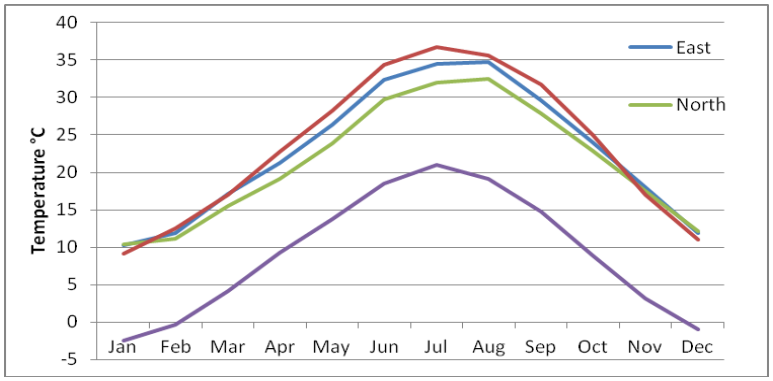


Fig. 7. The internal temperature in the two sides of the yard accompanied with maximum and minimum of city temperature.

As it is expected from the location of openers in northern and eastern fronts, the northern front has the least warmth in summer. It (northern front) has higher temperature than the eastern front. In other words, the average internal temperature in the three months of summer is 31.1 degree centigrade in the northern front, whereas during the same months the average is 33.8 degree

centigrade in the eastern front. The following graph (Fig. 8) illustrates a more important point for the use of the two mentioned fronts- regarding the solar gains).

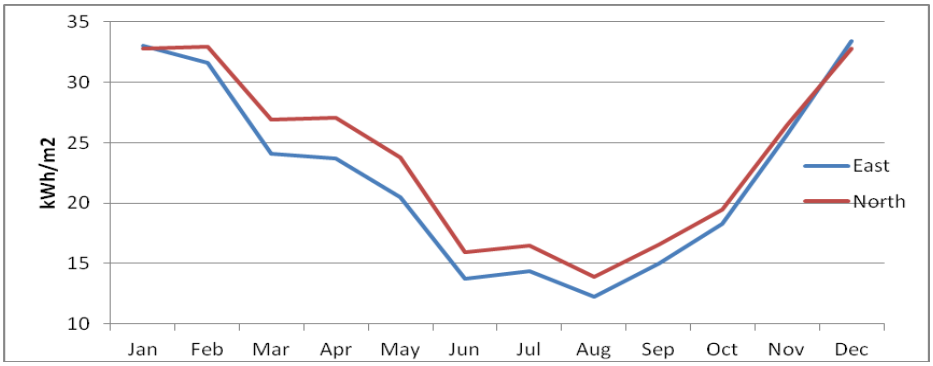


Fig. 8. The solar gains in the two sides of the court.

On the basis of those graph, the solar energy and, subsequently, the extent of natural light is more in the northern front. Simultaneously lower temperature is felt in comparison with the eastern front. Hence, this front possesses the highest solar energy (KWh/m2/yr 22.1) and highest internal temperature.

**C) Chami's house:** This yard is surrounded from four sides with the house spaces. Among them, the northern front with about three. Stories are the most important part of the house. This front consists of a corridor in the middle and four rooms each with three doors in the two stories in the sides. For the simulation purpose, the house is considered without residents and also regardless of heating and cooling systems. It means that the building merely uses the natural ventilation (Fig. 9).

The main necessary materials for this type of buildings are bricks. The coefficient of heat non-conductors in external walls is 1.254W/m2k. Also, the coefficient of heat transmission is 0.797m2k/w. Furthermore, the percentage of windows areas to the walls would be 30%.

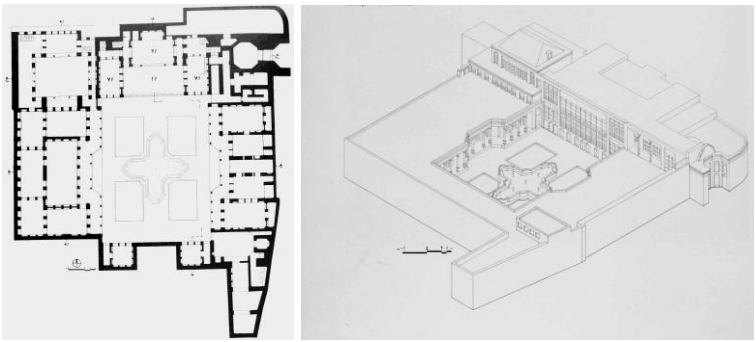

Fig. 9. three-dimensional picture, cut and plan of Charmi's House in Isfahan [25].

Due to the gained results from the simulation of this building- as for the two previous buildings-it is observed that the northern front has the highest temperature in winter. Also, the northern front, among other parts of the building, has the lowest temperature (Fig. 10).

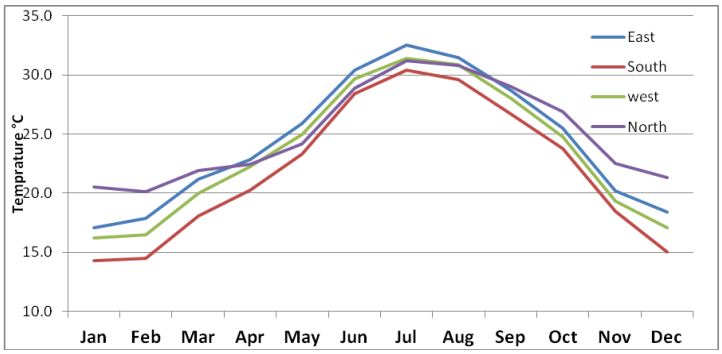


Fig. 10. the indoor temperature of four sides of the house.

In the related diagram of the received solar energy, it is clearly observed that the process of receiving energy in northern front is opposite to the other parts. In this respect that in winter, because of the sun's inclined angle, light can penetrate deeper to the depth of this front. Whereas, in summer that sun nearly radiates vertically, this front is preserved of severe radiation of the sun. Also, other fronts receive much radiation due to long and consistent duration of radiation during days in the morning and afternoons.

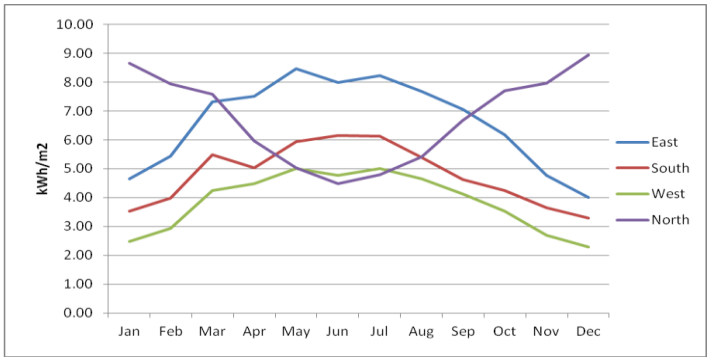


Fig. 11. The amount of solar gains energy of the four sides of the yard.

As it is clear in the following diagram (Fig. 12), the northern front has the most efficiency in receiving the solar energy. In other words, in cold seasons, heat energy is more whereas in warm months, it (the northern front) receives less heat energy.

## 4. Results and conclusions

Nowadays, man has encountered with dangers like the destruction of the ozone layer, the increase of heating of the Earth, acid rain, etc. More emphasis upon applying polluting environmental technologies and non-renewal energies in different industries are the most important damaging factors to the environment. So it is necessary that all the human activities and developments in all fields would be managed in a way that be along with sustainable development objectives and compensating the incurred losses. Hence, the subject of green architecture approach has gained a lot of importance as a matter related to environment.

In this research, the courtyard has been introduced as an architectural procedure in sustainable

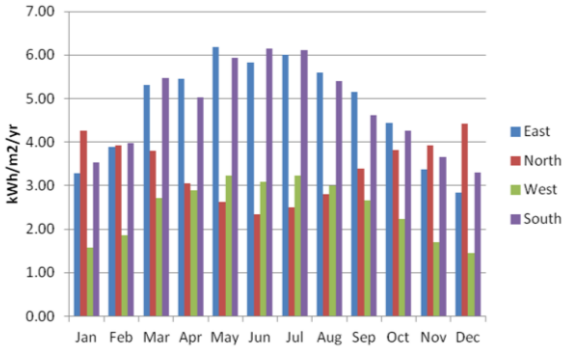


Fig. 12. The average heat energy of the three houses per square meter in four dimensions.

development. It (courtyard) is under investigation in three aspects; namely, technical, cultural and environmental ones. (The three mentioned aspects are the three conditions required to be taken into consideration in sustainable development in Williamson's theory). One can reach to the conclusion that courtyards-as architectural procedures- can fulfill the three mentioned conditions. In this research, after the simulation of the three traditional houses, the extent of received heat energy and the effective internal heat were taken into consideration, wherein the following results were obtained:

The building simulations showed that the northern front -among the other parts- always has received the highest radiation and the lowest cinternal temperature. Totally in the three houses, the eastern and western front show the highest received solar gains per year (relatively 23.4 and 23.8 kilowatt per hour in square meter for Isfahan city). While the northern front with 23.2 kilowatt per hour in each square meter always shows the most ideal climatic condition. This matter creates ideal concepts and innovative procedures in the choice of the types of planning and constructions around the courtyard for architectures. Furthermore, it is clear that if the construction length is eastern to western side and also if less width is allocated to the eastern and western sides, the most efficiency would be gained from the courtyard.

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