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Performance of Building Energy Efficiency by Orientation with Regression
(Case Study: Semi Desert in Iran)

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ABSTRACT: In this research multiple-regression analysis with stepwise selection method was employed for investigating the effect of vertical building envelopes solar radiation (Evr) on cooling energy consumption (E cooling) in residential sector. The high capacity of solar energy in semi-arid climate (Shiraz) can provide a part of buildings required energy. Depends on house orientations in two directions of SE and SW and by using statistical data, E cooling in urban residences was analyzed. The autocorrelation in the residuals, checked by Durbin- Watson test, was not existed. By investigating the relations between average Evr and E Cooling in each group, it can be proved that climatic orientated houses can achieve lower E Cooling, owing to SE desirable orientation. The percentage of Evr in SW houses is 28.89 % and in SE it is 15.72 %, so choosing the building orientation is important to reduce energy consumption. Finally, the concluding remarks were indicated.

Keywords: *Energy consumption, Solar radiation, Residential sector, Building orientation, Cooling need, Regression.*

INTRODUCTION

There is a growing concern about energy use and its implications for the environment (Wan et al., 2011). The energy consumption in Iran is extraordinarily higher than international standards. Iran recycles 28% of its used oil and gas where as the figure for certain countries stand at 60%. With an economy which is expected to maintain a rate of growth of 2 to 5% for decades, Iran's role in the world energy market becomes increasingly influential (Gudarzi Farahani et al., 2012, 12). Besides, buildings account for 45% of worldwide energy use, 80% of portable water use, and 50% of the timber harvest in North America. They also account for about 40% of municipal solid waste and 30% of U.S. greenhouse gas emissions that contribute to global warming and acid rain (Zhai & Previtali, 2010).

A significant proportion of energy consumption was due to the ever growing demand for better thermal comfort in terms of space heating in winter and space cooling during the hot summer months (Lam et al., 2005; 2008). The residential sector is a substantial consumer of energy in every country (Barzegar et al., 2012, 51), and therefore a focus for energy consumption efforts. Climate of a region effects strongly on the residential energy consumption (Zhang, 2004). Arid climate (in desert and semi desert regions) has two substantial characteristics: high temperature and low humidity (Kasmai, 2005). In these regions type's solar direct radiation on horizontal surface is high (Moradia et al., 2011). Tabari and Hosseinzadeh Talaee. (2011) calculated trends in maximum and minimum air temperatures in the arid and semi-arid regions of Iran during 1966-2005. Results indicate that the majority of the trends in temperature time series show increasing tendency during the last decades. If the energy consumption does not optimize, its dangerous environmental impact changes semi arid climate to arid one and green textures become desert (Zarei, 2013, 35). In addition deserts and semi desert regions depend on its high solar radiation have huge efficiency to get its beneficial impact for energy use. Therefore it is essential to restraining the mentioned climate solar radiation.

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Shiraz as one of Iran semi arid climate cities is located on 29° 33′ Latitude and 52° 33′ Longitude. With the increasing of population (1749926 in 2010) and family number (644195 in 2006), Shiraz has high amount of residential buildings (Fars meteorological organization report, 2011). Due to so many residential buildings, obtaining control policies in such ones is required.

Jafarpur and Yaghoubi (1989) in calculating solar radiation for Shiraz indicate that this area possesses a relatively high abundance of sunshine. The average cumulative annual irradiation and the average daily irradiation are 7250 MJ/m2 and 19.9 MJ/m2. A decrease in solar radiation on horizontal surface in the 1960s and 1970s for Shiraz is demonstrated by Yaghoubi and Sabzevari (1993). Simultaneous City Ariel photo from 1800 up to now shows reducing green texture and maximizing building ones. The statistics reveals the accuracy of high solar energy capacity utilization and the temperature increasing in Shiraz. Also to provide greater thermal comfort and to decrease energy consumption due to its growing cost in Iran, the need to control the radiant energy is evident.

Huge amounts of efforts by many researchers have been directed into modelling, analyzing, and investigating through energy consumption in residential sector. Swan and Ugursal (2009) provided a review of the various modelling techniques used for modelling residential sector energy consumption. Dong et al. (2005) forecasted building energy consumption in the tropical region by support vector machines (SVM). Lee and Kung (2011) used climate classification and data envelopment analysis (DEA) to propose an adjustment to the traditional approach. By using statistical data, Zhang (2004) analyzed the annual consumption of electricity, coal gas, LPG, natural gas, and coal as well as energy for district heating in urban residences of different regions. Kaza (2010) used quintile regression analysis to appear the effects of various factors on entire distribution on the energy consumption spectrum instead of focusing on the conditional average by using residential energy consumption survey data from the Energy Information Administration (EIA Report, 2011).

The research amounts that have been conducted to study the effect of building orientation on energy consumption is so rare. Yu et al. (2008) employed EQUEST software to analyze the effects of energy saving strategies on air conditioner electric consumption of different orientation rooms in hot summer and cold winter zone in China. The results indicate that envelopes condition decrease the AC electric consumption 11.31 to 11.55%. Jaber and Ajib (2011) discussed an assessment of best orientation of the building, windows size, and thermal insulation thickness from energetic, economic and environmental point of view for typical residential building located in Mediterranean region. The results showed that about 27.59% of annual energy consumption can be saved by choosing best orientation, optimum size of windows and shading device, and optimum insulation thickness.

This study presents an approach to reach the aim by determination the effect of building orientation (BO) on electricity cooling energy consumption (E Electricity) in middle- life urban residence annually and monthly in semi-arid climate (Shiraz).

MATERIALS AND METHODS

The study involved experimental and analytical activities divided into the following phases:

Data selection: depend on random house selection, data categorized into two type, NE- SW (group 1) and NW-SE (group 2). Then sample characteristics investigated.

Evr: Solar radiation on vertical building envelope measured in hourly, daily, monthly intervals by Olgyay method (as mentioned below).

E electricity: the samples electricity energy consumption was derived by the bills from Shiraz power distribution co.

E cooling: cooling energy consumption of the building was calculated based upon summation of the electricity bills of the sample houses in different time intervals, by means of source-site ratio (EIA Report, 2011).

Parametric analyzing of relation between E vr and Ecooling.

For the process, different statistical and experimental methods are used. Regression analysis as a popular modelling technique is used by many researchers for building energy consumption (Hirst et al., 1982; Kaza, 2010; Lee & Kung 2011; Tso Geoffrey & Kelvin, 2007; Wan et al., 2011). Ease of use is one of the popularity of the regression models use reasons (Wan et al., 2011). In present paper, multiple-regression analysis was deployed to determine the effect of building envelopes solar radiation on cooling energy consumptions. Moreover for prediction errors, Durbin- Watson test was used. As a result, regression analysis can be employed for this research.

For measuring E Electricity, firstly electricity energy consumptions in hot seasons, including E Cooling, E Lighting, E Equip.(equation 1).

$$E_{\text{Electricity}} = E_{\text{Cooling}} + E_{\text{Lighting}} + E_{\text{Equip}} \qquad \text{(It is a fact) (1)}$$

Next cooling energy consumption (E Cooling) of the proposed case studies derives only from electricity, as the sample houses were not equipped with gas-cooling devices. As mentioned before, the purpose of this study is to investigate the effect of BO on E cooling; thus, in this survey, E Lighting and E Equip. have been supposed fixed in a yearly period. Operation months of space cooling in summer (warm and hot; high temperature months) depend upon the sample houses behaviours in periods for heating or cooling need. Depend on higher electricity consumption in operation months (hot months), the average of consumption in non operation months show the average electricity usage without cooling (E w-cooling). Then, E Cooling was calculated as below for the operation month and the monthly and yearly cooling consumption was derived:

$$E_{\text{Cooling}} = \text{Monthly } E_{\text{Electricity}} - E_{\text{w-cooling}} \qquad \text{(It is a fact) (2)}$$

The solar energy calculation was obtained by Victor Olgyay method. Victor Olgyay by using computing methods, presented conveyer charts which could calculate the direct, reflected and diffuse solar radiation on a building surface with different situations and latitudes (Kasmai, 2005, 29). This chart is a cycle shape which divided into two parts; the upper part shows the solar radiation on horizontal surfaces and the below part shows the one on walls and vertical surfaces. This chart is the same size as sun chart of distinguished latitude; then by synchronization of both mentioned chart, the solar radiation on both horizontal and vertical surfaces with different directions to north calculate (Olgyay & Olgyay, 1963).

As the shadow account was so important in exploring the impact of orientation, in this research the selected house did not have any shadow from other buildings and things around itself. But about self shadow of houses, this kind of shadow affected more in group 1 because of western courtyard wall shadow on façade after about 10 o'clock and all shadow is in the time of disturbing noon and afternoon radiation which cause less cooling need. In group 2 this shadow was happened in morning up to about 2 o'clock and all of this shadow was in the morning pleasant radiation which omitting radiation is not suitable. Therefore the self shadow calculation shows that the effect of self shadow on cooling need depend on orientation and the SE orientation had more shadow than SW facades in the samples.

As the condition of windows and curtains were important, the same condition was chosen. All of the houses used thick cloth curtains inside the rooms beside their windows. The other important item was occupant behaviours in the houses. The cooling method only had daily usage in all samples, but the heating one was depended on climate condition. In addition, the occupant no. and old range were different. The construction material and building age was as the same in all samples. At all, the habitant behaviours were not completely the same, but the condition of building and climate was same.

It is important to select the house samples and investigate them for approaching the purpose. Among all the houses owned 40 years ago in the city, selected houses have been investigating. The importance of this period is the transition architecture from traditional to modern. Almost all house parts differed, also oil use ended by gas and electricity use. In quite accidental selection only two high percent house orientations were chosen; North East- South West, and North West- South East (NE-SW, and NW-SE) (Fig. 1).

All the samples investigated through three characters, building characters and energy consumption and solar absorbed radiation on envelopes. In the first category the specification of building was obtained as occupant no., land area, built area, orientation, step no., longevity, length to width ratio, proximity degree, window to wall ratio and side (Table 1). The second characters were about the type of energy that was consumed; electricity and gas consumption. In addition, the amount of solar absorbed radiation to the vertical envelopes was calculated through discovering the areas and the orientations of facades.

H4 had building specifications like a SW-NE orientation, 5 occupants, 312.5 m2 land area, 160 m2 built area, in 2 steps, 1.02 length to width ratio, 174 m2 proximity, 0.36 SW and 0.15 NE window to wall ratio and 2 facades (Fig. 1). The SW, NE, roof envelope area were 83.125, 83.135 and 160 m2 respectively. The SW envelope includes 6.89 m2 door and 30.2 m2 window. The building used 1 water cooler and 1 gas heater. H4 cooling need was about for 6 months and heating need was about for 5 months in 2009. The house consumed 1928 MW electricity and 3981.5 m3 natural gas in 2009 (Table 2). The house did not have any surrounding shadow or terrace or balcony or external shutter. The occupant used thick textile curtain for windows, keep windows closed in sunny days and no night cooling. The building material was consisted of brick for walls and walls for structure (no columns) in a common traditional method.

Table 1. Case study building characteristics

Cluster	Row	Occupants	Land area (m2)
1 : NE-SW	H1	3	128
	H2	4	102
	H3	5	221.9
	H4	5	312.5
2 : NW-SE	H5	5	200
	H6	5	209
	H7	4	118.53
	H8	7	213.9

Table 2. H4 energy consumption, the colored cells was cooling period

Month	E Gas (m3)	E Electricity (MW)
Apr	349	105
May	170	216
June	159	219
July	100	293
Aug	98.5	313
Sep	90	204
Oct	87	195
Nov	507	99
Dec	669	96
Jan	859	94
Feb	893	94
Mar	714	89
Annual	3981.5	1928

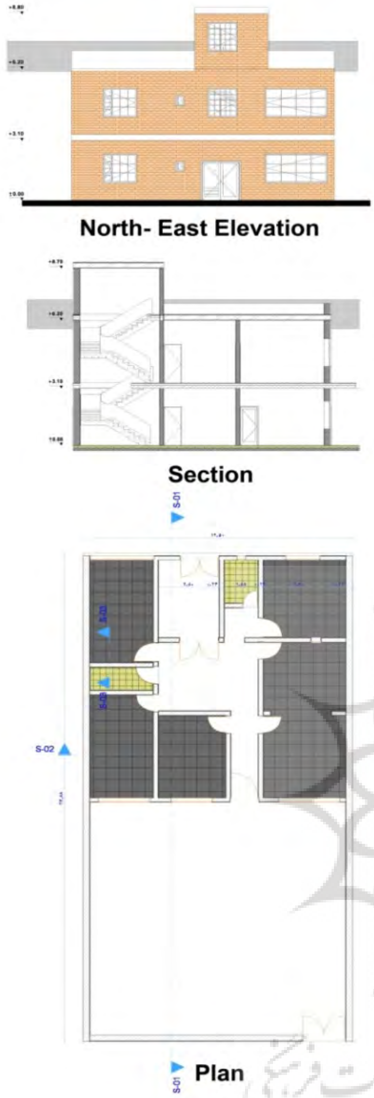

Fig. 1: H4 Plan (SW-NE oriented)

Case studies solar radiation and energy consumption: In principle, building energy consumption relates to the notion of climate-responsive design. For example, the placement of a window in a building is of the greatest importance as it could provide effective natural light, comfort cooling and ventilation (Taleb & Sharples, 2011). Envelope construction, roof material, building shape, building story, window, infiltration, relationship to ground and etc. are different architectural characteristics influences on energy consumption in a building. As a result of major affect of building envelope on reducing cooling and heating need, case studies categorized depend on building orientation (NE-SW and NW-SE). Other characters have been considered including consumer behaviour, envelope thermal transfer value, occupants, window to wall ratio, step no., equipment, lighting, length to width ratio, and longevity.

Solar radiation (direct, diffuse or reflected radiation) has important effect on building thermal comfort both in cold winter by absorbing and in hot summer by preventing deal with building envelopes. To avoid solar radiation in hot summers, shading and thermal insulation are important considerations in vernacular house design (Borong et al., 2004). Also in vernacular house construction method, to absorb solar radiation in cold winter, window ratio and thermal mass have main role. Shen et al. (2011) concluded that solar radiation influences interior and exterior surface temperatures, heat flow entering the building, and hence indoor thermal environment. Parker et al. (1994) monitored six homes in Florida, before and after coatings on their roofs. Reduction in air-conditioning electricity consumption was reported between 11% and 43%.

Shiraz vertical surfaces solar radiation with different angles, which is more beneficial in architecture, does not have yet been considered in the researches. In computational method for current purpose, some software have employed as Energy plus, Eco tech, Transys, Radiation on solar collectors, Ret screen, etc., but the Shiraz climate characteristics no exist in the mentioned software. Solar radiation was calculated on vertical surfaces (2 type houses) according to Victor Olgyay method (Kasmai, 2005).

Shiraz energy portfolio divided into electricity and gas, in addition in mid-life houses and selected houses, the primary and common cooling system is water cooler, and the additional system is fan, so to evaluate cooling energy consumption in the case studies, electricity energy was classified into sectors. The main Shiraz electricity consumption is for cooling in hot season.

RESULTS AND DISSCUSSION

Cooling Energy Consumption

The two direction houses were investigated to determine the effect of Evr on E Cooling. Houses electricity energy is used for cooling from April to November. The trend of cooling energy consumption in all houses was almost similar; the maximum cooling consumption is in July and August. In group1, the minimum E Cooling is for H1; on the other hand, H4 has the highest consumption. E Primary is the greatest one in H3, although E Cooling is low. So this high usage is related to other electricity sectors that are not in the field of this research (e.g. high energy consumption due to over lighting, equipments, etc.) (Fig. 2). In group 2, the minimum ECooling was for H8, and H7 has the highest one, Along with the high ECooling in H7, the primary energy consumption is also great. Although ECooling in H5 and H6 is normal, EPrimary is high as H3 (Fig. 2). At all, the average ECooling in group 1 is more than group 2 (Fig. 3). The maximum average monthly ECooling was for July in both groups (Table 3).

Table 3. The amounts of cooling load and operation months

Group	House no.	Apr	may	June	July	Aug	sep	Oct	Nov
1 : NE-SW	H1	-	41.67	49.67	111.67	117.67	49.67	49.67	-
	H2	18.266	65.266	50.606	46.266	46.566	35.626	14.756	-
	H3	-	-	129.84	195.09	166.84	126.09	122.09	-
	H4	-	119.83	122.83	196.83	216.83	107.83	98.83	-
	Average	4.57	56.69	88.24	137.46	136.98	79.80	71.34	-
2 : NW-SE	H5	-		193.87	256.37	188.37	119.37	47.97	-
	H6	-	176.27	210.27	308.27	239.27	52.27	-	-
	H7		119.66	129.66	149.66	134.66	169.26	131.66	108.66
	H8	-	-	58.07	180.57	156.57	61.57	49.57	-
	Average		73.98	147.97	223.72	179.72	100.62	57.3	27.16

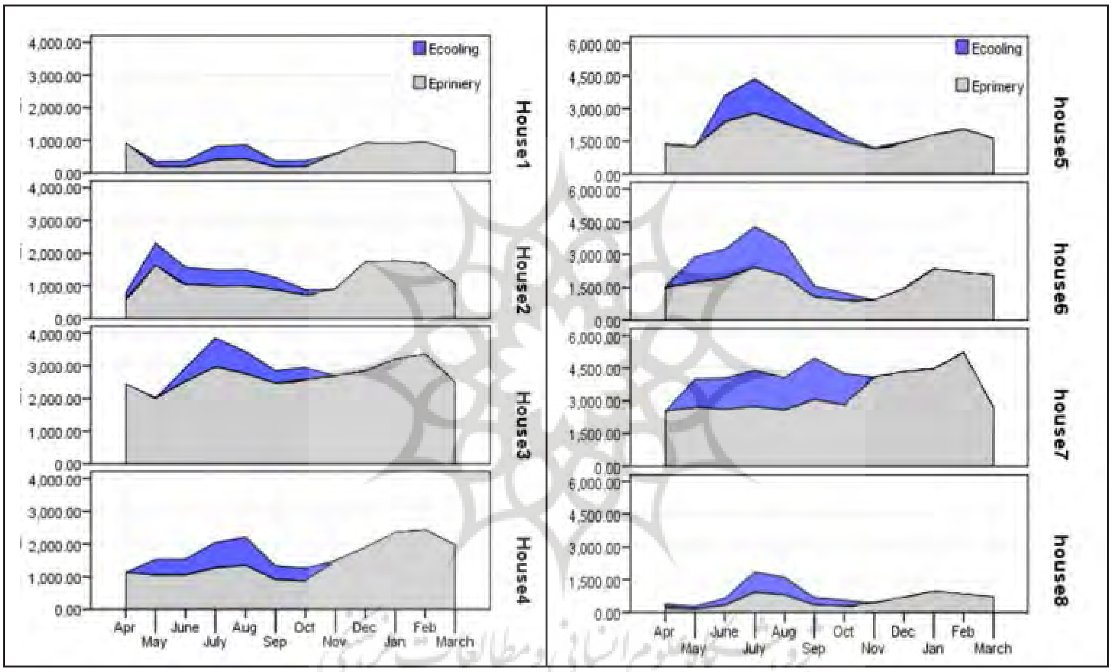

Fig. 2: Cooling and primary energy consumption in groups 1 and 2

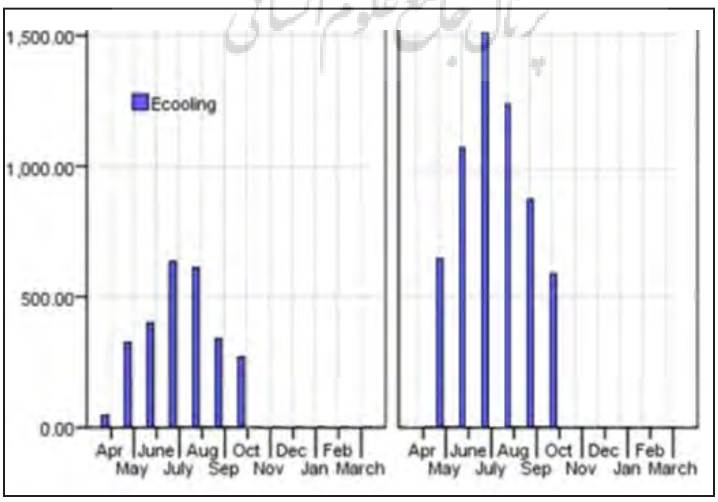

Fig. 3: Average cooling energy consumption in groups 1 and 2, right: group 1, left: group 2

Relation of Evr and E Cooling

One of the building envelopes for receiving climatic solar radiations is vertical one. Energy demands of lighting, cooling and heating could be fulfilled and building energy efficiency is improved by absorbing solar radiation in the mentioned surfaces, provided that a proper building orientation (BO) exists. The main envelope of group 1 and 2 are south-west and south-east. In this part, the mentioned points are investigated:
The trend of annual main vertical envelope solar radiation in each group for cold seasons was maximum amount and for warm ones was minimum one. Due to the mentioned rule, the E Cooling in summer and therefore E Primary decreased.

In group 1, the more climatic vertical radiation was belonged to H1 which also has the minimum energy consumption in its group. In group 2, it also was belonged to H6 (Fig. 4).
By the comparison of the relation between Evr and E Cooling, it can be concluded that better relationship were belonged to H1 in group 1 and H8 in group 2; moreover, these houses have the minimum energy consumption in groups (Fig. 5).

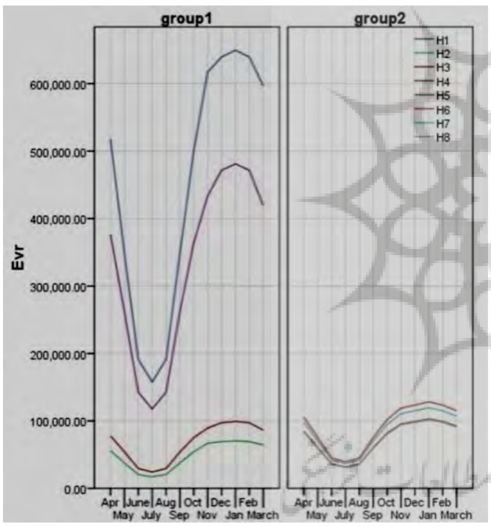

Fig. 4: Solar energy on vertical building envelope in groups

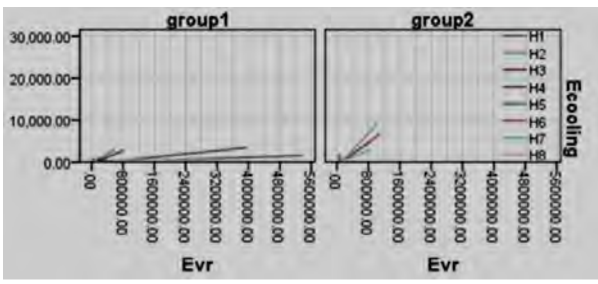

Fig. 5: Relation between with Evr and E Cooling in groups

The average summer Evr of group 2 is lower than its group 1, which caused reduction in E cooling. Generally, the vertical radiation in group 1 is higher than group 2 (Fig. 6); however, by the relationship between average Evr and ECooling and EPrimary in each group, it was indicated the relation of group 2 with NW-SE direction is better (Fig. 7). In addition group 2, optimal morning radiation had a large contribution of solar radiation in, but in group 1undesirable afternoon radiation has a large contribution of solar radiation.

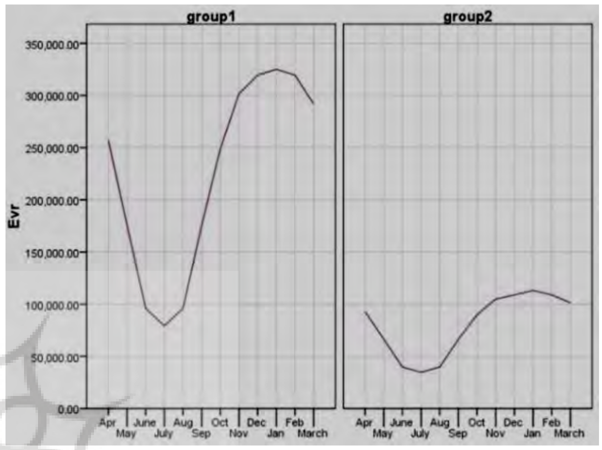

Fig. 6: Average solar energy on vertical envelope in groups

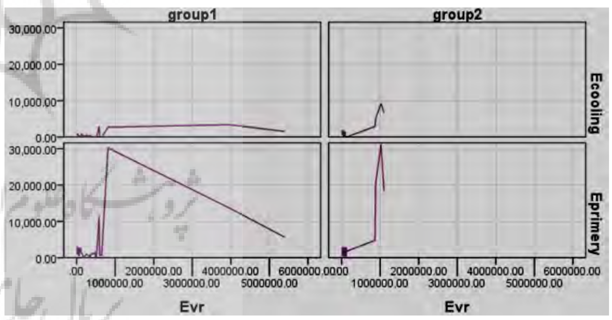

Fig. 7: Average relation between Cooling and primary energy consumption with solar energy on vertical envelope in groups

CONCLUSION

By high energy and water consumption, human kinds let the climate change to growth regionally and worldly. Shiraz city as a semi desert climate in Iran, change their green urban textures to building ones. But without conservation, by omitting green parts and high energy consumption, regional climate change from semi arid to arid is not so far. Considering the limited sources of energy, high energy efficiency buildings have became a main strategy in recent years. With the increasing of population, this city has high amount of residential buildings and high energy consumption per capita house. This city like other semi desert ones possesses a relatively high abundance of sunshine. This radiation could reduce or increase the building thermal comfort due to its climatic design. Therefore a high capacity of solar energy utilization exists which can provide some part of the required energy in residential sector.

In residential energy consumption different parameters were effected which can be divided to building characteristics, occupants specification and public strategies. In this paper only one of building parameters was investigated. For investigating the role of building orientation on cooling energy consumption, houses are divided to SW-NE and SE-NW directions (groups 1 and 2). According to results, annually primary and cooling energy consumption in group 2 is lower. The main envelopes that receive solar radiation are divided into three main parts; horizontal envelope (roof), main vertical envelope (south elevation) and other envelopes. The percentage of each envelope received solar radiation showed its effective role in annually and monthly energy consumption house behaviour. The effect of horizontal absorbed radiation on buildings is so higher than vertical ones and it could be controlled easily (for example by reducing the horizontal surfaces, making shadow or thermal insulation). But the orientation of buildings and the facades in urban small lands could not be changed and was fixed; therefore having controlling techniques was good but not sufficient. Although the impact of all surfaces was derived by research because of the importance in this paper only the radiation on vertical envelopes were discussed which was depend on orientation.

In group 2 the annually vertical surface radiation had 28.89 % of whole and in group one 15.72 % (Table 4). In monthly Evr, it indicated that the less heat transfer from outside made the building cooler due to less Evr in summer, therefore cooling energy use reduces. In winter, the more heat transfer from outside made the building warmer due to more Evr, therefore heating energy use reduces. At all, the annually heat gain trends from south elevation is climatic.

By investigating each house, it was shown that closer correlation between Evr and E Cooling is owned to two types of house: the houses with low energy consumption and climatic Er, and those with high energy consumption and high non-climatic Er. In calculating the correlation between annually average Evr and E Cooling in groups, it was determined that (if other variables assumed to be constant) this relation is direct and close. It indicates in group1, Ecooling changes 0.891 per unit change in Er, while it is 0.758 units in group2. Again, the change in group 1 is more.

Table 4. Evr, percentages in both groups

	Group2	Group1
Evr	28.89	15.72

Table 5. Standardized Coefficients (Beta) value respect to the Evr

Dependent Variable (Evr)	E cooling
Beta (type = group1)	0.891
Beta (type = group2)	0.758

a. Independent Variable = Evr

In this case, the energy change in group 2 is less than group 1. The dependency value between Evr and E Cooling in group 1 is more; for each unit change of Evr in summer, cooling energy consumption increases more (Table 5).

Reduction of E cooling in group 2 is the result of the lower average summer Evr in group 2 than group 1. Group 2 eastern radiations are much better than group 1 that has high western radiation, although the Evr of group 2 in winter is often less. Generally, the vertical radiation in group 1 is higher than group 2 (Fig. 5); however, the initiative hypothesis (climatic orientated houses can achieve lower ECooling, and E Primary) achieved by the relationship between average Evr and E Cooling and E Primary in each group. The reasons are SE desirable orientation with its required solar radiation, and meanwhile closer relation between Evr and ECooling and E Primary (Fig. 6).

Therefore it can be stated that the more climatic and energy efficiency house is the one that has the more climatic radiation on its vertical envelopes, if the radiation from roof omitted by insulation and shading technique; finally, building vertical envelopes are the best ones for receiving climatic solar radiations (Fig. 4). Energy demands of lighting, cooling and heating are fulfilled and building energy efficiency, by absorbing solar radiation in the mentioned surfaces, is improved provided that a proper building orientation (BO) exists.

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Nomenclature	
NE-SW	North East -South West
NW-SE	North West-South East
BO	Building Orientation
$E_{cooling}$	Cooling energy consumption
$E_{Electricity}$	Electricity energy consumption
$E_{Lighting}$	lighting energy consumption
E_{Equip}	Equipment energy consumption
E_{hr}	Radiation on horizontal envelope
E_{or}	Radiation on other envelopes
$E\ w\text{-}_{cooling}$	The average electricity usage without cooling

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