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Investigating the relation between built area, occupant number and energy consumption in first modern residential buildings (Case study: 1970s houses in the semi-arid climate of Shiraz, Iran)

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Abstract

Energy consumption in the residential sector is a complex socio-technical problem that can be explained using a combination of physical, demographic and behavioural characteristics of a house and its occupants. In this paper, by using the energy consumption data for the residential sector of Shiraz in Iran, the effect of built area (BA) and occupant number (Occ) on annual energy consumption (Ec) was investigated. Ten houses from the first modern period of the city were selected randomly from 1971 up to 1991. It was found that the built area and Occ did not have a direct impact on energy consumption in Shiraz's residential buildings; however, the household behaviours and houses' building construction directly affected energy saving. Houses with maximum BA or maximum annual energy consumption were not the same; the same held for Occ. The average annual energy consumption per capita of 1 m^2 built area of the case studies was 0.087, and for each occupant it was 2.487.

Keywords: Desert climate; Energy consumption; Residential building; Occupant number (Occ); Built area (BA)

1. Introduction

The existing building stock in European countries accounts for over 40 % of final energy consumption in the European Union (EU) member states, of which residential use represents 63 % of total energy consumption in the building sector. Consequently, an increase in buildings' energy performance can constitute an important instrument in efforts to alleviate the EU's energy import dependency (currently at about 48 %) and comply with the Kyoto Protocol to reduce carbon dioxide emissions (Balaras *et al*., 2007).

To investigate the energy performance in a building, two types of characteristics were discussed, which are, firstly, socio-economic and behavioural aspects of occupants, and secondly, climatic and physical building characteristics. Given the great importance of the subject, many researches have been carried out about the effect of residential buildings' construction characteristics on energy saving (Ashrae, 2005; Clarke, 2001; ISO 13790, 2004; ISO 13790, 2008). The impact of the building's thermal characteristics on space heating demand has been well studied (Santin *et al*., 2009).

As mentioned, another group of parameters affecting energy use in residential buildings are occupant behaviour and consumption culture. Some studies have shown that occupant behaviour might have an influence on energy consumption in different households, but the extent of such influence is unknown (Santin *et al*., 2009). Therefore, the energy consumption per capita of each person differs due to various parameters, such as building construction, occupant number and climate.

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From the current survey of each of the mentioned parameters, two detailed parameters were chosen, which were building area (BA) and occupant number (Occ). The role of Occ is not clear, because some studies derived it as an effective (Kelly, 2011) or non-effective factor (Vringer and Blok, 2007). The impact of BA on household energy consumption has been studied in some countries (Bartusch *et al*., 2012; Kelly, 2011).

As in European countries, Iran has huge energy consumption in the residential sector. Due to Iran having the highest electricity consumption growth among 10 countries (7.6 %) (Fig. 1), these buildings' consumption should be investigated and improved.

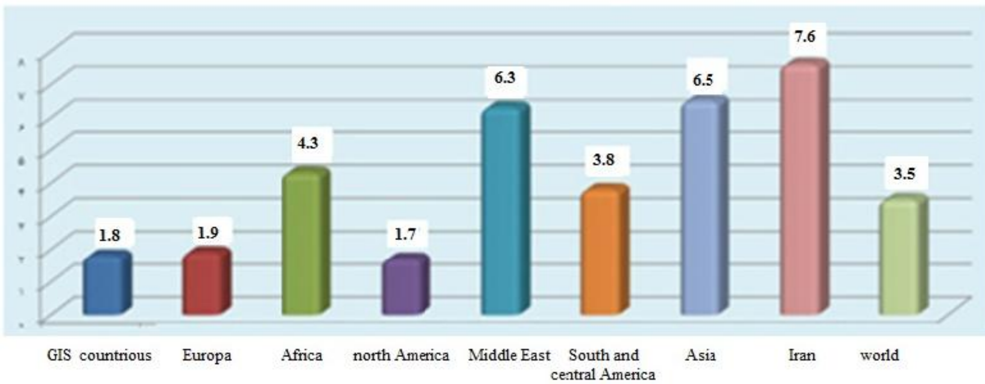

Fig. 1. Iran's energy consumption growth among 10 countries (Fars Regional Electric Co., 2011)

Shiraz, one of the big cities in Iran, has latitude 29°33'N and longitude 52°36'E, with a semi-arid climate (climate-charts). Arid climate is identified by two substantial characteristics: high temperature and low humidity (Kasmai, 2005). In these types of region, direct solar radiation on the horizontal surface is 700-800 kcal/h/m^2 (Moradia *et al*., 2011); therefore, controlling the climate for thermal comfort in buildings is necessary. On the other hand, the population of Shiraz in 1956 was 170,659, while in 2006 it was 1,351,181 (General Population and Housing Census, 2006, 1996). This means that it has grown about eight times from 1956 to 2006. In addition, changes in different land uses in the Shiraz Plain during the mentioned period, because of rapid urbanization were very extensive (21-fold) (Esfandiari Baiat and Barzegar, 2012). According to Shiraz's electricity consumption records from 1968 to 2006, the consumption growth was about 70-fold (Esfandiari Baiat and Barzegar, 2012). Fars Regional Electric Co. (2011) has announced that Shiraz's residential building sector had the highest electricity energy consumption over the last three decades. Therefore, given the need to control the climate, rapid growth of population and urbanism, and energy need growth, investigating and determining the issues and solutions for buildings could be very beneficial.

In this paper, by determining annual[2] and primary energy consumption[3] (include the electricity and gas consumption) of 20 randomly selected houses in Shiraz, divided into sections of cooling energy consumption[4], heating energy consumption[5], lighting energy consumption[6], and equipment energy consumption[7], the relations between number of occupants[8], built area[9] and residential energy consumption were investigated and compared.

2. Background

2.1. Background: building characteristics and occupant behaviour

Energy use is determined by buildings' technical and architectural characteristics, and also by the residents' behaviour (Papakostas and Sotiropoulos, 1997). People and building performance are intimately linked (Li and Lim, 2013). The thermal quality of the building, building type, occupant behaviour and climate are the parameters influencing energy demand (Santin *et al*., 2009). The energy required for space heating has been significantly reduced in

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[2] E_c
[3] $E_{primary}$
[4] $E_{cooling}$
[5] $E_{heating}$
[6] $E_{Lighting}$
[7] E_{Equip}
[8] Occ
[9] BA

recent decades by making use of insulation and more efficient heating and ventilation systems (Santin *et al*., 2009). Steemers and Young (2009) investigated the relation between actual energy consumption, detailed energy characteristics and occupants in the residential sector. Results reveal that apart from climate, occupant behavioural and socio-economic aspects are critical, partly directly and also, significantly, indirectly through their influence on choices and decisions about the physical characteristics of buildings and systems.

Li and Lim (2013) produced a chapter focused on the issue of occupant behaviour; principally, its impact, and the influence of building performance on occupants. The early sections looked at how energy is consumed in buildings and identifies a range of occupant-interactive opportunities (Li and Lim, 2013).

Kelly (2011) introduced a structural equation model (SEM) to calculate the magnitude and significance of explanatory variables on residential energy consumption. The main drivers behind residential energy consumption are found to be the number of household occupants, floor area, household income, dwelling efficiency (SAP), household heating patterns and living room temperature.

Furthermore, Virote and Neves-Silva (2013) described a model for occupant behaviour within the building in relation to energy consumption, and a building energy consumption model (ECM) was proposed based on stochastic Markov models.

Santin *et al*. (2009) gained greater insights into the effect of occupant behaviour on energy consumption for space heating by determining its effect on the variation of energy consumption in dwellings while controlling for building characteristics in Dutch residential stock. This study showed that occupant characteristics and behaviour significantly affect energy use (4.2 %), but building characteristics still determine a large part of the energy use in a dwelling (42 %).

Santin *et al*. (2009) statistically examined differences in occupant behaviour in relation to the building characteristics of the housing stock in the Netherlands, and explored the possible existence of a rebound effect on the consumption of energy for space heating. They found that although energy consumption is lower in energy-efficient dwellings, analysis of the behavioural variables indicates that their occupants tend to prefer higher indoor temperatures and to ventilate less. This finding might be related to a rebound effect on occupant behaviour. However, the improvement of the efficiency of thermal properties and systems still leads to a reduction in energy consumption for heating.

2.2. Building characteristics and area (BA)

The important impact of the building's thermal characteristics on energy demand has been well studied (Ashrae, 2005; Clarke, 2001; ISO 13790, 2004; ISO 13790, 2008; Santin *et al*., 2009). Leth-Petersen and Togeby (2001) found that building regulations have been important in reducing energy consumption in new buildings. Ultimately, overall energy use associated with building characteristics is decreasing, making the role of the occupant even more important (Groot et al., 2008; Haas *et al*., 1998; Papakostas and Sotiropoulos, 1997). In the Netherlands, Beerepoot and Beerepoot (2007) found that regulations for conserving energy performance have been successful. As a detailed example, Balaras *et al*. (2007) presented an overview of the EU's residential building stock. Accordingly, the most effective ECMs are the insulation of external walls (33–60 % energy savings), weather proofing of openings (16–21 %), the installation of double-glazed windows (14–20 %), the regular maintenance of central heating boilers (10–12 %), and the installation of solar collectors for sanitary hot water production (50–80 %). From these researches, the way to improve buildings' energy performance by construction can be determined.

Although the role of building area in energy consumption (as a building characteristic) is considered to be obvious, different studies have ignored it.

However, using the traditional method of using energy consumption per unit, it is very difficult to confirm reasonable ranges, such as power per unit area, because these indexes generally vary in a large range for most sorts of buildings (Zhao *et al*., 2013).

Bartusch *et al*. (2012) investigated the impact of household features and building properties on electricity consumption associated with statistically significant variances, such as number of family members, family composition, year of construction and area. The overall result of the analyses is nevertheless that variance in residential electricity consumption cannot be fully explained by independent variables related to household and building characteristics alone.

Zhu and Cai (2014) selected population, urbanization, construction area and level of urban consumption as the key factors driving the growth of urban residential building energy consumption. According to the results of their regression analysis, it is concluded that firstly, the level of urban consumption has much more influence on the growth of urban residential buildings' energy consumption than other factors, secondly, that the increase of urban construction area directly drives the growth of urban residential buildings' energy consumption, and thirdly, that the structure of population has much more influence on the growth of urban residential buildings' energy consumption.

2.3. Occupant behaviour and occupant number (Occ)

Among the previously described parameters, occupant behaviour and consumption culture have a distinct effect on energy usage. Studies have shown that occupant behaviour might play a prominent role in the variation in energy consumption in different households, but the extent of such influence is unknown (Santin *et al*., 2009). According to Haas *et al.*, (1998), energy savings due to conservation measures will be lower in practice than those calculated, because the impact of consumer behaviour is neglected. Yu *et al.*, (2011) reported the development of a methodology for identifying and improving occupant behaviour in existing residential buildings in Japan. For a given dwelling, electricity consumption peaks are strongly influenced by occupancy and activity patterns within a particular household (Yohanis *et al*., 2008).

According to several authors, age is an important characteristic determining energy use. In general, older households tend to consume more energy than younger households, especially for space heating (Liao and Chang, 2002; Linde *et al*., 2006). The number of occupants in the dwelling is also an important parameter for energy use. Linear correlations between household size and energy use have been found in several international studies. Vringer and Blok (2007) stated that there are differences in energy use that are not explained by occupant characteristics such as household size, level of education and age distribution. In another survey, Hong Kong Polytechnic University surveyed the energy consumption expenditure of 16 hotel buildings in 1998, and analysed the relationship of building energy to age of building, outdoor temperature, hotel grade, floor area and occupancy rate (Deng and Burnett, 2000; Zhao *et al*., 2013).

3. Material and methods

For evaluating the main issue of this research (the comparison of energy consumption with occupant number and built area in the residential sector of Shiraz), the following procedure was applied as a combination of statistical and experimental methods. Firstly, due to the non-existence of any household energy consumption survey in the region, the residential case studies were randomly chosen from 1971 for the whole of the modern part of the city. The specifications, such as material, structure, heating devices and cooling devices were the same, and the buildings' orientation was NE-SW. Characteristics such as Occ, occupant culture and courtyard existence differed. Based on Shiraz's energy portfolio, which is divided into electricity and gas, to evaluate energy consumption in the case studies, electricity energy was classified into four sectors including cooling ($E_{Cooling}$), lighting ($E_{Lighting}$), heating ($E_{Heating}$) and equipment (E_{Equip}). In addition, gas energy is classified into heating ($E_{Heating}$) and equipment (E_{Equip}). Actual energy consumption, which is divided into gas and electricity, was gathered through bills from gas organizations and electricity power distribution companies, as the reports of companies were issued monthly. The monthly and annual data were prepared and investigated for all case studies.

Domestic electricity (and gas) load profiles for individual dwellings are highly variable, with typical consumption patterns often changing considerably across a 24-hour period. Electricity consumption varies as a function of time and is influenced by various factors. A daily pattern is usually apparent, with a peak in the morning and evening. For a given dwelling, electricity consumption peaks occur at roughly the same time of day, and are strongly influenced by occupancy and activity patterns within a particular household (Yohanis *et al.*, 2008). To evaluate the energy consumption, it was necessary to convert both kinds of energy into a single one. Therefore, both energy types (electricity and gas) were converted to primary energy ($E_{Primary}$), to be added as the same type of consumption, using a source-site ratio (EIA, 2011). Then, a local questionnaire survey was performed to collect the Occ and BA of case studies. Finally, the primary energy consumption was compared with Occ and BA by statistical software (Excel and SPSS). With regard to measurement procedures, some points should be mentioned. There are four different energy consumptions for both electricity and natural gas, which are:

$E_{Cooling} + E_{Heating} + E_{Lighting} + E_{Equip.} = E_{Total} = E_{Primary}$

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. Heating energy consumption ($E_{Heating}$) of the proposed case studies derives only from natural gas, because no electrical thermal equipment is used. As mentioned before, the purpose of this study is to investigate the relations between built area, occupant number and residential energy consumption ($E_{primary}$); thus, in this survey, $E_{Lighting}$ and $E_{Equip.}$, $E_{Heating}$ and $E_{Cooling}$ would be measured as total primary energy consumption.

The residential energy consumption depends strongly on the climate of a region (Zhang, 2004). The Shiraz climate is a semi-arid one with hot and dry weather (Kasmai, 2005), and therefore more energy consumption is needed to control the climate (Table 1). In addition, with the increase of population (1,749,926 in 2010) and number of families (644,195 in 2006), Shiraz has a high number of residential buildings (Amar, 2011). According to statistics released by Shiraz Electronic Power Distribution Company in October 2010, building energy consumption is up to 49.6 % of total electricity consumption (Shiraz Power Distribution Co., 2011). Due to the great number of subscribers in the residential sector (35.79 %), establishing control policies in such buildings is required.

Table 1. Shiraz temperature and humidity data

Statistic	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Temperature Mean Value	C	5.3	7.7	11.8	16.2	22.5	27.7	29.8	28.7	24.5	18.4	11.7	6.8	17.59
High Temperature Mean Daily Value	C	12.1	14.7	18.9	23.8	30.6	36.1	37.8	37.0	33.7	27.8	20.5	14.4	25.62
Low Temperature Mean Daily Value	C	-0.4	1.2	4.8	8.5	13.2	17.1	19.9	18.8	14.1	8.8	3.8	0.5	9.19
Precipitation Mean Monthly Value	mm	79.8	49.8	48.4	30.6	6.6	0.2	1.0	0.1	0.0	5.2	20.7	63.2	25.47
Relative Humidity Mean Value	%	65.0	58.0	51.0	46.0	32.0	22.0	24.0	24.0	26.0	34.0	48.0	61.0	40.92

Source: www.shirazedc.co.ir/22/9/2011

However, the Shiraz houses come in completely different types, and due to new buildings' characteristics, the climate consideration has almost disappeared, although traditional houses are climatic. The building parameters such as age, material and orientation differ totally in Shiraz houses. In 2006, Shiraz's size became 19.074 hectares (Esfandiari Baiat and Barzegar, 2012); therefore, the situation and local climate of houses was no longer the same. From 1971, a new change in building specifications came to the city, and therefore the architectural characteristics differed in some ways, but unfortunately, most of these type of buildings were destroyed and few were renovated. Nowadays, few of these houses remain in their original state, and so the number of samples could not be large.

For the purposes of this research, the selected case studies' specifications, such as material, structure, heating devices and cooling devices, were the same, and the houses which could have this similarity were few. In addition, the main building orientation in Shiraz urban land use is NE-SW, so from the mentioned statistical group of houses, only a small number could be selected with the proposed orientation. The 20 selected case studies in this article were new modern residential buildings with NE-SW orientation (as mentioned), and selected by random classification which situated them in different parts of city (Fig. 2). Other building characteristics such as Occ, occupant culture and courtyard existence differed (Table 2). Therefore the study, by offering positive or negative observations, can provide new models and will improve residential buildings' energy situation.

Table 2. Case studies' BA and Occ

Type	unit	H_1	H_2	H_3	H_4	H_5	H_6	H_7	H_8	H_9	H_{10}	H_{11}	H_{12}	H_{13}	H_{14}	H_{15}	H_{16}	H_{17}	H_{18}	H_{19}	H_{20}
Area	m^2	90	80	108	176	125	126	170	200	151	123	129	123	123	121	166	171	152	134	133	118
Occ	person	5	4	5	5	5	3	5	5	5	4	4	5	5	4	6	5	4	4	7	5

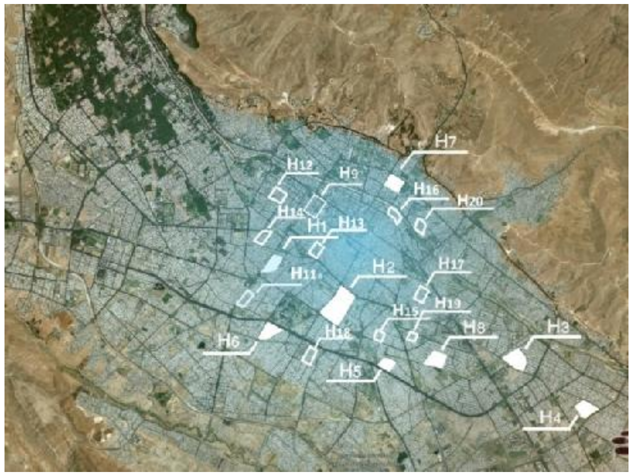


Fig. 2. Case studies' situation in Shiraz city

One of the case studies, with 90 m^2 area and five-person Occ was constructed 10 years before in the central part of the city (Fig. 3). This house's materials were brick for walls, joist and block for roof and ceramics for floor.

The building was 10.70 m * 8.40 m * 2.60 m in one floor that was oriented to the south in a local alley. The house had a courtyard in the south part and two bedrooms, a kitchen, a bathroom and a living room. In the questionnaire survey, it was determined that the occupants' economy was high and their culture accentuated the reduction of energy consumption. The household's members are a father and mother with three children, one of whom was a university student. The H_1 primary energy consumption was evaluated monthly as described above (Fig. 4).

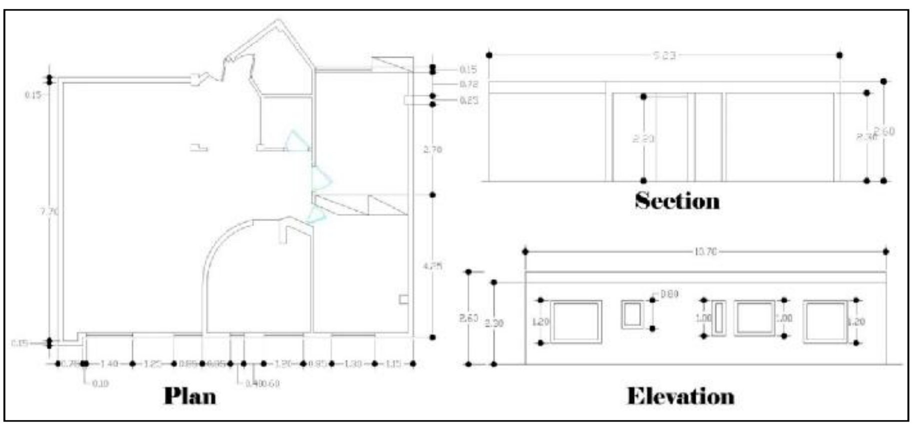
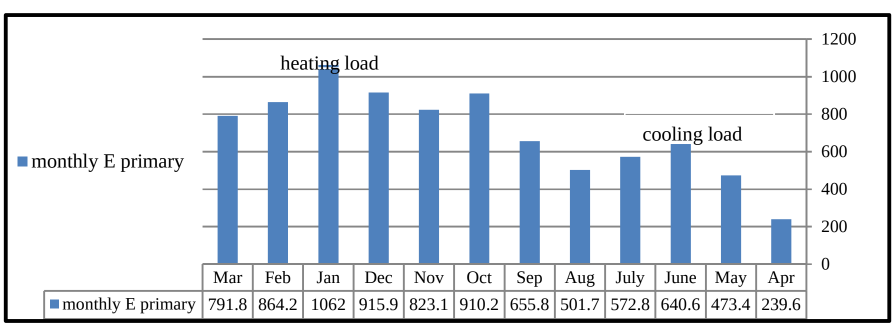


Fig. 3. H_1 case study plan, elevation and section



	Mar	Feb	Jan	Dec	Nov	Oct	Sep	Aug	July	June	May	Apr
monthly E primary	791.8	864.2	1062	915.9	823.1	910.2	655.8	501.7	572.8	640.6	473.4	239.6

Fig. 4. H_1 case study monthly Ec

4. Results and Discussion

4.1. Primary energy consumption

Based on Shiraz's energy portfolio, which is divided into electricity and gas, to evaluate energy consumption in the case studies, electricity energy is classified into four sectors including cooling ($E_{Cooling}$), lighting ($E_{Lighting}$), heating ($E_{Heating}$) and equipment (E_{Equip}). The majority of Shiraz's electricity consumption is for cooling in the hot season. In mid-life houses and certain other houses, the primary and common cooling system is the water cooler, and the additional system is the fan. In addition, gas energy is classified into heating ($E_{Heating}$) and equipment (E_{Equip}). The main gas consumption is related to the heating sector in the cold season. In mid-life houses and certain other kinds of houses, the primary and common heating system is the gas heater. For measuring energy consumption monthly, seasonally and annually, gas and electricity bills were used. But for evaluating gas and electricity consumption in comparison with each other, converting these kinds of energy into a primary one by means of a source-site ratio (EIA, 2011) was obligatory (Table 3).

Table 3. Case studies' Ec

Consumption type	unit	H_1	H_2	H_3	H_4	H_5	H_6	H_7	H_8	H_9	H_{10}	H_{11}	H_{12}	H_{13}	H_{14}	H_{15}	H_{16}	H_{17}	H_{18}	H_{19}	H_{20}
Annual electricity	kw	1530	1679	3703	2459	5802	3703	1547	2937.5	1290	1510	4004	4218	3714.9	3297	2800	1547	5517	4218	2899.5	2862.8
Annual gas	m^3	3189	1318	1713	1637	2690	1713	1204.9	1041.64	1237	2559	3810.2	2012.2	1681.6	1883.7	0	1204.9	2920	2012.2	2089.56	2108
Ec	Kprimary	8.45	6.98	14.16	9.93	22.19	14.16	5.64	10.90	5.60	7.72	17.36	16.19	14.16	12.98	9.35	6.43	21.48	16.19	11.87	4.58

Due to different building and household characteristics, primary energy consumption accounts were completely different. For example, H_5 consumes 4.85 times more than H_{20} (Table 4). Therefore, ranking could help to show the role of parameters.

Table 4. Case studies' Ec

Type	unit	H_{20}	H_9	H_7	H_{16}	H_2	H_{10}	H_1	H_{15}	H_4	H_8	H_{19}	h_{14}	H_3	H_6	H_{13}	H_{12}	H_{18}	H_{11}	H_{17}	3
Ec	Kprimary	4.58	5.60	5.64	6.43	6.99	7.72	8.45	9.35	9.93	10.90	11.87	12.98	14.16	14.16	14.17	16.19	16.19	17.36	21.48	22.19

4.2. Comparison between Ec and BA

We considered that each metre of BA affected energy consumption as a rule, because each metre of extension needs extra cooling and heating load. To investigate the role of BA in increasing or decreasing energy consumption in residential buildings, firstly case studies were employed, and then the energy consumptions were compared based on BA. The case study houses have different built space, ranging from 80 to 200 m^2, and as mentioned different energy consumption.

By drawing comparative charts for BA and Ec, it was found that:

- The highest consumption was related to H_5 and the lowest was for H_{20} (Fig. 5).
- The maximum BA was for H_8 and the minimum was for H_2 (Fig. 4).
- The maximum energy consumption was not for the biggest house, and likewise the minimum energy consumption was not for the smallest house (Fig. 6).
- The slopes of the BA chart and the Ec chart were not the same; they differed completely (Fig. 6).
- The local maximum points in each chart were not found in the same houses (Fig. 5).

4.3. Comparison between energy consumption and occupancy number

Each person had a per capita energy usage, for example, for warm water and equipment needs.

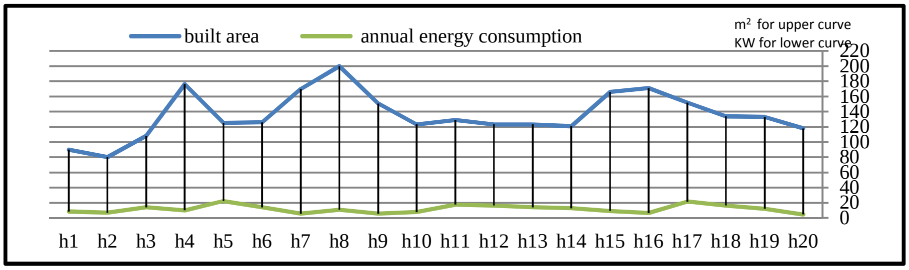


Fig. 5. Comparison of houses' BA and Ec

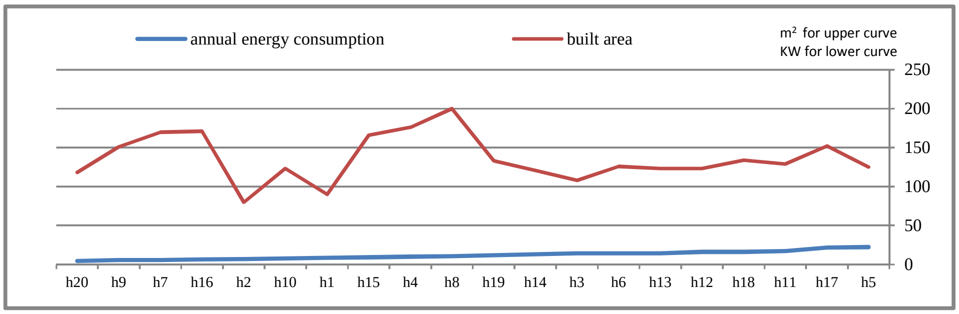


Fig. 6. Comparison of houses' BA and ranked Ec

But if a number of persons leave together, it seems that consumption is increased. In this article, the houses' occupants differed from three to seven persons. According to the Occ and Ec charts, it can be stated that:

- The highest consumption was related to H_5 and the lowest was related to H_{20} (Fig. 7).
- The maximum Occ belonged to H_{19} and the minimum one belonged to H_6 (Fig. 7).
- The maximum energy consumption was not for the busiest house, and the minimum was not for the quietest.
- The slopes of the Occ chart and Ec chart were not the same, and differed completely (Fig. 8).
- The local maximum points of each chart were not found in the same houses (Fig. 8).

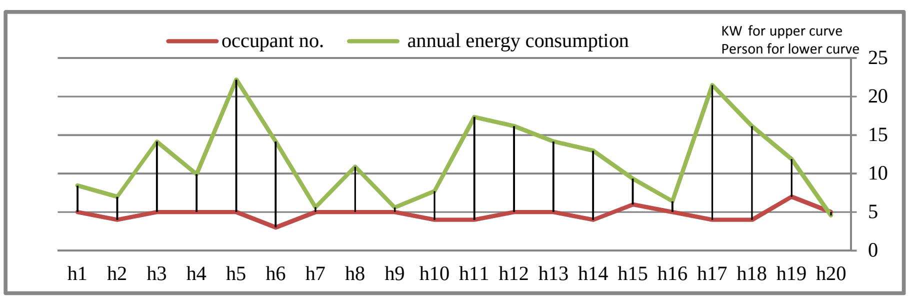


Fig. 7. Comparison of houses' Occ and Ec

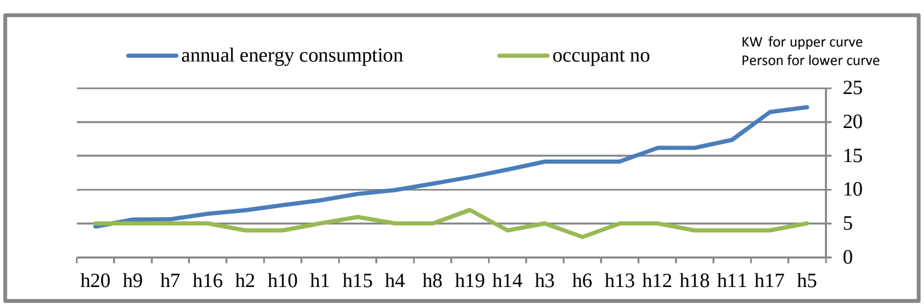


Fig. 8. Comparison of houses' Occ and ranked Ec

4.4. Comparison of average amount of BA, Occ and Ec

In this step, the average amounts of BA, Occ and Ec were calculated and analysed (Table 5). The average amounts of $E_{Primary,}$ Occ and BA were 11.816 K primary, 4.75 person and 135.95, respectively. The average energy consumption in Shiraz houses is higher than the standards in the same climate. The houses with energy consumption above the average amount did not have Occ or BA above average overall (like H_3), and did not have either Occ or BA alone above average (like H_{11}). In relation to low consumption houses, the below average consumption was not associated with Occ or BA below average overall (like H_7). Some houses had the same situation in all three parameters, either below or above the average amounts (like H_2 and H_{10}) (Table 6).

Table 5. Ec, Occ and BA average amounts

Type	Ec (k primary)	Occ (person)	Area (m2)
Total amount	236.32	95	2719
Average amount	11.816	4.75	135.95

Table 6. Case studies' Ec, Occ and BA less or more than average amount

Type	Ec (k primary)	Occ (person)	Area (m2)
H7	less	more	more
H1	less	more	less
H3	more	more	less
H11	more	less	less
H2	less	less	less
H10	less	less	less

4.5. Ec per capita amount of BA and Occ

By a 2.49 person increase or decrease of Occ or a 0.09 m^2 BA, Ec is changed by 1 K primary. This showed that the effect of BA is higher than Occ in energy consumption. Therefore, designing houses with smaller area could strongly affect the energy efficiency of the residential sector of Shiraz.

Table 7. Case studies' Ec per capita amount of Occ and BA

Type	Occ (person)	Area (m^2)
Ec (k primary) Per capita amount	2.487	0.087

5. Conclusion

By using residential energy consumption survey data from the energy information in bills, this research used Shiraz houses' BA and Occ data to tease out the effects of these two factors on energy consumption. Results showed that while housing size for conditioning, heating and cooling living space is important, the effect of the mentioned parameter was less distinct in the case studies. Furthermore, household density did not seem to have a significant impact on energy use, although the warm water and equipment use depended on the household number. The results indicate that controls of other parameters (possibly building construction methods and household behaviour) are better strategies to decrease energy consumption. The first strategy could be achieved by techniques such as envelope shading and exterior wall thermal insulation. The second strategy is related to the culture that has arisen due to low energy prices in Iran and high consumption by people. These behaviours could be controlled by educational support and energy prices. The highlights of this paper were:

- Cooling and heating needs are more related to space than person number.
- Warm water and equipment needs are more related to household number.
- The BA and Occ did not have an apparent direct impact on energy consumption in Shiraz residential buildings.
- Other parameters such as the household behaviours and building construction may have important effects.

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