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URBAN FEATURES AND ENERGY CONSUMPTION AT LOCAL LEVEL

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Abstract: There has been a growing interest in discovering human effects on the environment and energy consumption in the recent decades. It is estimated that the shares of energy consumed in transportation and housing systems are around 20 and 30 percent of the total energy consumption. Furthermore, it is believed that the residential greenhouse emissions depend on urban form and structure. This paper explores the effects of urban features on residential energy consumption at neighborhood level using data collected through household questionnaires (n = 140). Two residential districts in the metropolitan Shiraz, located in the south of Iran, were selected as case study areas. Different features of the two areas including building density, typology, housing location, parcel size, floor area and construction materials were compared. Ordinary linear regression was used to discover the impact of explanatory variables on energy consumption. It was found that some physical variables such as parcel size, setback, and the number of floors played significant roles in explaining the variances existing in energy use level. The results can be considered by governmental agencies in order to modify land use policies and subdivision rules in hope of saving energy and achieving a sustainable community.

Keywords: Urban planning; building form; energy consumption; Shiraz

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1. INTRODUCTION

The world energy crisis and the magnificent growth in energy consumption have made energy optimization a mandatory task around the world. On the other hand, the quality of urban life is dependent on energy sources and supplies. Evidence shows that the energy consumption of Iranian big cities is significantly higher than that of international norms. In fact, Iran has plentiful energy resources and it has been one of the major exporters of oil in the Middle East since the 1910s. It also owns about 15 percent of the world's gas resources. However, Iran has to import 2.4 million tons of fuel each year. Iranian total energy consumption is estimated to be 3.5 times bigger than that of Turkey, 0.75 times bigger than that of China, 14.5 times bigger than that of Japan and 5 times greater than that of the global average (EIA, 2011). The high inefficient energy consumption is now an important matter for the Iranian government as an obstacle to achieving sustainability. Policies such as '*subsidy reform*' as well as '*petrol quota*' have been recently applied to overcome a part of this growing concern.

The term 'energy' is used to describe 'the state of a particle, object or system that is attributed as the power to define the ability to work' (Ness, 1998). Energy can be classified into different categories based on its' release and impacts. Therefore, it has various forms such as heat energy, electrical energy, chemical energy, nuclear energy, and radiation. In this study, only one type of energy consumption, which is household gas consumption as the chemical potential energy, has been studied.

While warnings regarding global energy resources ending date back to the late 1920s, conservation strategies have only appeared since the 1970s after soaring oil prices. The bulk of research in this area has increased significantly since the 1980s, with a main focus on the impacts of urban development on energy use. Some of them are at household level (e.g. Norman, 2006; Perkins, 2003), although research at this level is still limited. This is mainly due to the lack of relevant and precise data available for different locations, densities and housing types (Holloway & Bunker, 2003; Lefèvre, 2012). The popular work of Newman & Kenworthy (1989) indicated a curvilinear association between urban density and energy use (per capita) through an analysis of 32 cities world-wide. High-density Asian cities are the most efficient energy users whereas low density cities such as North American and Australian cities are the least efficient.

Moriarty (2002) investigated the energy use in inner and outer suburbs of five Australian capital cities. According to his study, inner city residents used less per capita energy than their outer suburban counterparts provided that the income level is considered as a control variable. This study recommended that a shift towards walking/cycling and public transport could have a significant potential in reducing energy usage. Ewing & Rong (2008) studied the relationship between urban form and residential energy use in the major cities of the United States. Their study indicated that compact development is correlated with lower residential energy consumption as compared to sprawling counties.

Aden *et al*. (2010) analyzed building operational energy use, as well as the embodied energy related to personal consumption and building in *LuJing Development* in China. The lifecycle assessment showed that the operational phase of building energy comprised more than three quarters of the lifecycle energy use and emissions. This suggests that buildings operational energy use is a significant subject when trying to reach efficiency improvement. Additionally, *LuJing* residents' personal energy use was higher than their direct energy use and the embodied energy of the buildings they live in. The results of this study indicated that the modal change to private vehicles accounts for the largest portion of personal transport energy use among high-income households.

Perkins (2003) compared the delivered energy use by the households of an urban fringe suburb and an inner city neighborhood in Adelaide, South Australia. Delivered energy includes both the operational energy and the embodied energy consumed in housing and transport sectors. A significant difference in the delivered energy consumption between the two areas was observed. Energy consumption of all kinds was slightly higher in the outer suburbs. Further statistical analysis indicated that, among the urban form factors used, location, number of shared walls, site area, and the dwelling structure were the most important in affecting the delivered energy use. On the other hand, physical features were more important in explaining the variations in the household's use of operational energy rather than the embodied energy, while the latter was still important. This study showed no constant impact of household socio-economic characteristics on energy usage.

Ratti *et al*. (2005) believe that while building design, system design, and occupant behavior account for variations in energy performance, little is clear about the role urban form/geometry play in building stock energy performance. Ratti *et al*. (2005) also analyzed the relationships between urban geometry and energy consumption for the non-form variables of London, Toulouse and Berlin. The 'geometric variables' included distance from the façade, façade orientation, urban horizon angle, and obstruction of the sky view. The association between urban geometry and energy consumption was analyzed in details.

Reviewing literature generally confirms that modifying the attributes of urban form/structure may improve the efficient performance of cities and their environmental functioning. However, the relationship between the variables is complicated and non-linear. Therefore caution is required in drawing detailed causal conclusions (Buxton, 2006).

METHODOLOGY

The Conceptual Model

This study investigates the impacts of urban features on energy consumption at household level. A large set of factors can be found which are of importance in explaining energy usage. These include: socio-economic characteristics, urban physical attributes, and building characteristics. However, a limited number of variables were considered because of the lack of sufficient data. The conceptual model of the study is depicted in **Fig. 1**.

Study Area

Shiraz, the capital of Fars Province in Iran, with a population of 1.4 million people, is the sixth most populous city of the country. Two districts have been chosen based on their different locations, development history, and urban density. *Eram* is an inner suburb located in the network distance of 2.6 km from CBD (*Emam Hosein* Square). Its area is 35.5 ha. *Maaliabad* is an outer suburb in the north-west of the city which is13.7 km from CBD. It has an area of 30.1 ha (**Fig.2**).

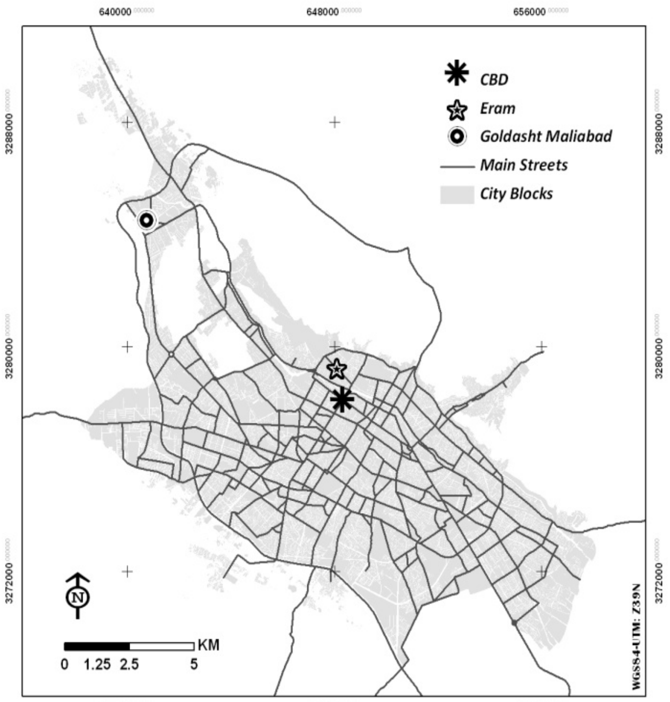

Fig 2. The location of the two case studies.

Data

Urban data were extracted from the 2006 Shiraz GIS database. Some 140 questionnaires were completed by the residents of the case study areas who were asked about the socio-economic status (SES) and lifestyle, as well as the characteristics of the buildings. The data regarding the gas consumption by the chosen households were obtained from Shiraz Gas Administration Office.

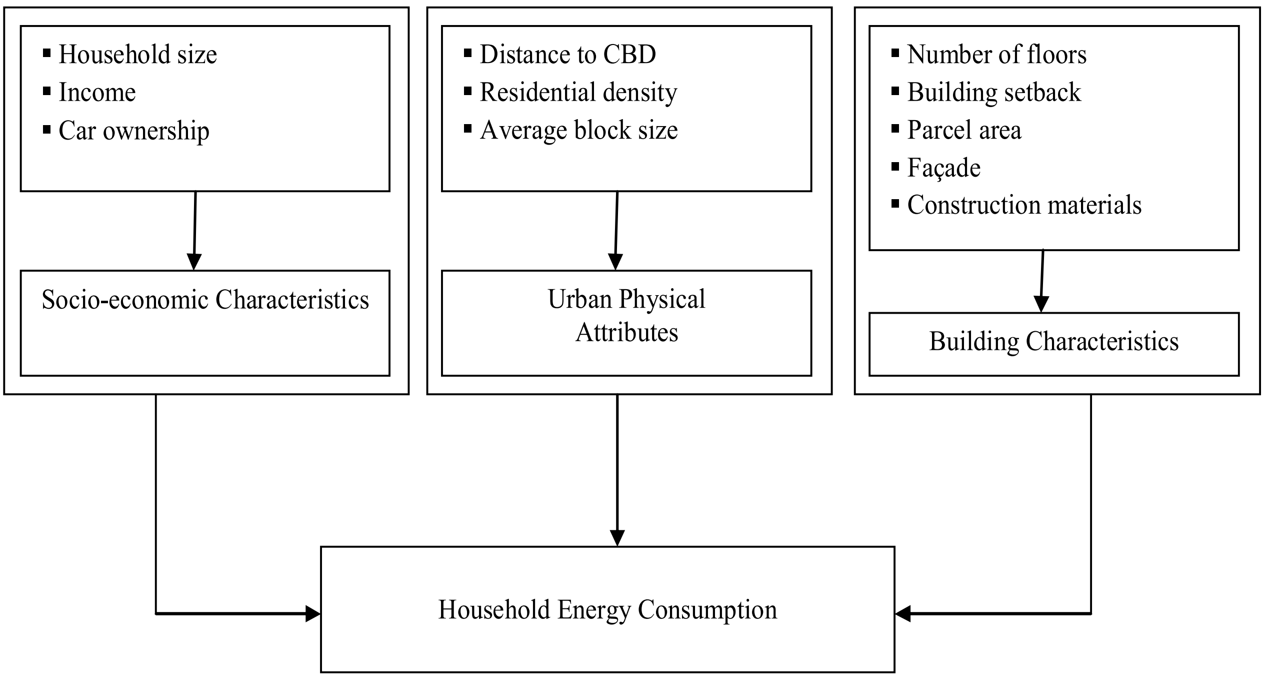

Fig.1. The conceptual model.

Table1. Travel modes in Eram and Maaliabad

Trip purpose	Mode	Eram (percent)	Maaliabad (percent)
Work trips	Car	63	75
	Bus	8	11
	Others	29	17
Non-work trips	Car	83	80
	Bus	6	7
	Others	11	13

Table 2. The regression results for Eram

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	427.932	111.893		3.824	.000
Household size	9.112	1.684	.144	5.411	.000
Number of floors	-24.051	10.474	-.661	-2.296	.041
Setback (m)	-2.681	1.071	-.076	-2.503	.021

Dependent Variable: Energy(household gas) consumption (m³); N=80; Alpha=0.05; R^2= 0.634

ANALYSIS

Comparative Description

According to the data collected through the questionnaire survey, the average household size of Maaliabad (3.8) was higher than that of Eram (3.5).The monthly income level of Eram was 1.2 times higher than that of Maaliabad. The average travel time of the people in Maaliabad (46.3 min) was longer than that of Eram (29.7 min). The monthly average gas consumption figures for Eram and Maaliabad were 431 and 390 m³, respectively. This difference was partly due to the lower density level and larger parcel size in Eram which call for higher energy use.

The share of work trips made by cars in Eram and Maaliabad are 63 percent and 75 percent, respectively, showing higher dependence of Maaliabad workers on cars (**Table 1**).This can be because of its distance from CBD, since Shiraz is a mono-centric city in which jobs are concentrated in the central area. Maaliabad has a higher figure in public transport usage than Eram, probably due to travel cost saving. In terms of modal choice for non-work trips, the share of car use for Eram (83) was higher than that of Maaliabad (80), while both areas are significantly dependent on cars for non-work destinations. There was a moderate difference between bus usages although bus is not a major mode for the two suburbs. The reason could be the lack of a reliable access to an efficient public transport system.

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Generally, Eram buildings are older than Maaliabad ones, thus making the quality of the built environments different. While Maaliabad possesses 24 percent newly built houses, this figure for Eram is only 8%. The numbers of entrances for the buildings in the two areas are similar. On the other hand, the average floor area ratio (FAR) for the two areas is 60 and 300 percent respectively, showing compactness in Maaliabad.

Statistical Analysis

Linear regression analyses were applied to discover the effects of the factors influencing energy consumption. A summary of the results are detailed in **Table 2**. The value of R-square confirms achieving a reasonable model. The following equation describes the relationship between the explanatory variables and the dependent variable for Eram:

$$\text{Energy consumption} = 427.932 - 24.051*(\text{Number of floors}) - 2.681*(\text{Setback}) + 9.112*(\text{Household size}) \quad (1)$$

According to these results, the number of floors and building setback are the two main physical variables influencing energy consumption. The parcel with a longer setback will attract more sun exposure so the energy consumption is expected to be lower.

Similarly, linear regression was applied on the Maaliabad data. A summary of the results are below (**Table 3**). The following equation describes the relationship between the explanatory variables and the dependent variable in Maaliabad:

$$\text{Energy consumption} = 330.927 - 117.117*(\text{Number of floor}) - 11.954*(\text{Setback}) + 1.803*(\text{Parcel area}) + 8.638*(\text{Household size}) \quad (2)$$

Table 3. The regression results for Maaliabad

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	330.927	126.563		2.615	.047
Household size	8.638	4.081	.144	2.117	.035
Number of floors	-117.117	55.239	-3.397	-2.120	.028
Setback (m)	-11.954	5.563	-.358	-2.149	.015
Parcel area (m²)	1.803	.568	2.795	3.174	.002

Dependent Variable: Energy (household gas) consumption (m³), N = 60, Alpha = 0.05, $R^2 = 0.481$

The most important factors explaining the variances in energy consumption change are household size, the number of floors, setback and parcel area. The number of floors and building setback are inversely related to energy consumption, confirming the idea of a compact city as a model for a sustainable city.

CONCLUSION

This study tried to highlight the basic knowledge of urban energy consumption at neighborhood scale in a developing country. Urban features of two sampled areas of Shiraz metropolitan with different levels of density and distances from the city center have been analyzed against their role in energy consumption. According to the regression results, the most effective urban factors on energy consumption were the number of floors (building height), setback distance, and parcel area.

The results generally confirm the role of compactness (high density) in reducing energy consumption which is consistent with sustainable urban form advocates (Williams *et al*., 2000; Newman & Kenworthy, 1989; Howard *et al*., 2012; Zhang, *et al*., 2011). It was found that no significant association exists between energy consumption and several other aspects of urban form including building age, building façade type, and construction materials. This study can be extended by choosing more urban districts located in other geographical areas. Furthermore, using more advanced statistical methods could help improve the quality of the findings. The results can be used by governmental agencies in order to modify land use policies and subdivision rules in hope of saving energy and achieving a sustainable community.

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