environmental sciences proceedings

MDPI

Proceeding Paper

Investigating the Relative Importance of Spatial and Environmental Factors on Energy Consumption in the Residential Sectors Using GIS (Case Study: Kerman) †

Atefeh Sajadian [1], Saeid Niazmardi [1,*], Meysam Argany [2], Reza Arababadi [3] and Gloria Pignatta [4]

[1] Department of Surveying Engineering, Faculty of Civil and Surveying Engineering, Graduate University of Advanced Technology, Kerman 7631885356, Iran; atefeh.sajadian222@gmail.com
[2] Faculty of Geography, University of Tehran, Tehran 1417853933, Iran; argany@ut.ac.ir
[3] Department of Energy Management and Optimization, Institute of Science and High Technology and Environmental Sciences, Graduate University of Advanced Technology, Kerman 7631885356, Iran; reza.arababadi@asu.edu
[4] School of Built Environment, Faculty of Arts, Design, and Architecture, University of New South Wales (UNSW) Sydney, Kensington, NSW 2052, Australia; g.pignatta@unsw.edu.au
* Correspondence: s.niazmardi@kgut.ac.ir; Tel.: +98-3431623382
† Presented at the 3rd Built Environment Research Forum, Sydney, Australia, 1 December 2021.

Abstract: A large number of factors affect the energy consumption of a building. These factors can be categorized into building-related and space-related factors. The purpose of this study was to use the geospatial information system (GIS) to estimate and analyze the relative importance of factors within either group to model the gas and electricity consumption of several randomly selected residential buildings in the city of Kerman, Iran. The considered building-related factors were age, area, and price of the building, and the space-related factors were elevation, vegetation cover, and land surface temperature. The results showed that the area, elevation, and vegetation cover were the most important factors for gas consumption, while the age of the building and the land surface temperature affected the electricity consumption more than others.

Keywords: building energy; GIS; spatial parameters; artificial neural network; relative importance

Citation: Sajadian, A.; Niazmardi, S.; Argany, M.; Arababadi, R.; Pignatta, G. Investigating the Relative Importance of Spatial and Environmental Factors on Energy Consumption in the Residential Sectors Using GIS (Case Study: Kerman). *Environ. Sci. Proc.* **2021**, *12*, 6. https://doi.org/10.3390/environsciproc2021012006

Academic Editor: Khan Rahmat Ullah

Published: 18 February 2022

1. Introduction

The energy consumption of buildings accounts for a significant share of global energy demand. Monthly electricity data released in January 2018 by the United States Department of Energy (DOE) showed that electricity consumed by commercial and residential buildings accounted for 77.5% of the total energy consumption in the United States [1]. As a result of the continuous development of urbanization, the energy consumption in the residential sectors has grown exponentially, which has raised many environmental and economic concerns. Accordingly, understanding these energy consumption patterns is of the utmost importance to the decision-makers and the city planners.

Existing literature has found several factors that affect the energy consumption pattern of a building. These factors can be categorized into three categories. The first category, named building-related factors, includes factors such as age and area (e.g., [2]). The second category includes occupant-related factors. The last category, which is the least-studied one and is called space-related factors, consists of factors that model the spatial relationships between buildings and the characteristics of the urban environment [3]. Studies have shown that urban morphology plays a decisive role in the energy consumption of buildings by changing the pattern of airflow and wind speed around the building [4]. In another study, the height changes and urban morphology in 150 m buffers around each building were considered as spatial factors [5]. The amount of vegetation around each building [6],

the presence of shadows [7], and the density of the urban environment [8] are among the most important spatial factors that affect the energy consumption of a building.

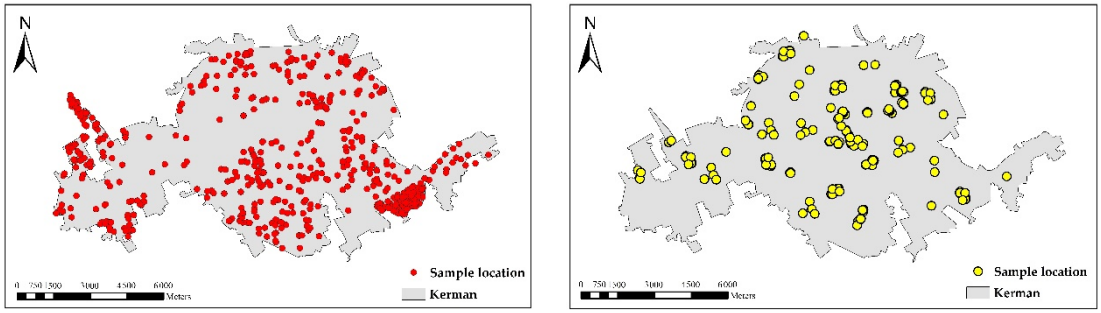
The purpose of this study was to investigate the primary affecting factors on the energy consumption of buildings using Geospatial Information System (GIS) techniques. The novelty of this paper was in separately modeling, analyzing, and comparing the same set of building-related and space-related factors on the gas and electricity consumptions in a residential area of Kerman.

2. Materials and Methods

2.1. Data

The study area was the city of Kerman, located in the southeast of Iran, with an area of around 240 km^2. According to the 2016 census, the population of this city is 738,724 people. For this study, gas and electricity consumption records from 620 and 410, respectively, from randomly selected residential buildings for the solar year of 1397 (March 2018 to March 2019) were used as the data set. Figure 1 shows the location of the sample buildings.

Seven different factors were selected to model both gas and electricity consumption of the selected buildings. The building age, building area (conditioned area), and the property prices were considered as the building-related factors. The space-related factors included the horizontal density of buildings, land elevation, normalized difference vegetation index (NDVI) and land surface temperature (LST). Energy consumption was measured and recorded every other month; thus, for every 60 days an NDVI and an LST map were prepared using Landsat8-OLI satellite imagery. Since access to the household income and economic conditions of the samples was not possible, property prices were used as the representative of the socio-economic characteristics of the buildings. The property price map was extracted from the real estate transaction information in different areas of the city. The normalized area of buildings that fell into a 200 m buffer around each selected building was considered as the horizontal density.



(**a**) (**b**)

Figure 1. Locations of selected residential buildings: (**a**) gas consumption samples; (**b**) electricity consumption samples.

2.2. Method

In this study, a single-layer perceptron neural network was used to model the relation between affecting factors and energy consumption. In total, 70% of the data were considered as the training data, the remaining 30% of the data were used for validation. The relative importance of each factor (or input variables) was the share of each independent variable in predicting the dependent variable (i.e., energy consumption). In this study, the connection weights method was used to determine the relative importance of independent variables in predicting the output variable. This method uses interlayer weights, so that the relative importance is obtained from the sum of the absolute values of the weights of each parameter [9].

3. Results and Discussion

Due to the different weather conditions during the year, the model was run separately for each period. The results are presented in Tables 1 and 2. Natural gas is often used in domestic applications for cooking, preparing hot water, and space heating. In autumn and winter (the second three periods), due to the drop in temperature, natural gas consumption was higher than in the first three periods.

The results showed that the building area has the highest relative importance among the considered factors to the model of gas consumption. As the building area increased, more energy was required for heating. The importance of the building area was higher in the second half of the year (September to March) than in the first half. The elevation (DEM) was the second important factor affecting gas consumption (18% in the first six months and 14% in the second six months). The vegetation cover (NDVI) increased gas consumption to heat the space, by reducing the thermal load in the second half of the year. Thus, the importance of vegetation cover on gas consumption in the second half of the year was twice what it was in the first half of the year. According to the results, the effects of the horizontal density of buildings, property prices, building age, and land surface temperature (LST) was low.

Table 1. The relative importance of the effect of variables on gas energy consumption.

Parameters/Period	1	2	3	4	5	6
Age	5.3	6.97	10.31	6.43	6.70	12.16
Area	22.59	46.02	24.64	14.51	39.83	64.03
Property Prices	10.76	1.67	17.14	15.98	11.86	3.15
Density	16.5	17.79	9.95	15.9	6.86	4.69
DEM	17.17	14.88	23.29	21.86	13.6	6.21
NDVI	8.36	3.21	9.89	16.98	17.89	7.78
LST	19.28	9.43	4.75	8.31	3.22	1.95

Table 2. The relative importance of the effect of variables on electricity consumption.

Parameters/Period	1	2	3	4	5	6
Age	24.53	35.43	26.21	60.94	44.86	12.01
Property Prices	6.54	16.45	0.57	0.61	4.26	6.39
Density	21.1	3.21	27.67	3.61	9.52	32.63
DEM	13.14	14.27	14.29	2.66	6.82	21.34
NDVI	8.18	7.37	2.6	10.32	25.73	26.46
LST	26.48	23.25	28.63	21.83	8.8	1.15

Regarding electricity consumption, the age of the building was the most important factor in all periods, probably as a result of using heat insulation materials in new buildings. The second important factor was LST for the first four periods of the year, due to the extensive use of air conditioners during these periods. The third factor affecting electricity consumption was the horizontal density of buildings throughout the year. These findings were broadly in line with previous researches, which indicated that floor area [5,10], year of construction [10–12], vegetation [6], and density of buildings [12] influenced the energy usage of a building. The low percentage of LST on gas consumption could be due to the fact that in the second half of the year in Kerman there was no significant temperature difference between different periods.

4. Conclusions

Studies have shown that in addition to building-related factors, such as age and area, space-related and occupant-related factors significantly affect the overall energy consumption of the building. This indicates the need for further analysis to determine to what extent each factor affects the energy consumption of the building. In this study, by collecting and combining a large set of data using GIS, the relative importance of several

factors was investigated, among which building area, height, and vegetation had a great effect on gas consumption, while building age, LST, and horizontal density had a great effect on electricity consumption. Given the complexity of the energy consumption pattern, we plan to exploit more factors as the input to the model in future studies. Moreover, different models and data from different cities should be further studied to obtain a clearer understanding of the energy consumption patterns in the residential sector of Iran, and the rule of different energy efficiency factors on the energy consumption should be studied further, as well.

Author Contributions: A.S., S.N. and M.A. gathered and processed the data set, and performed the experiments. R.A. and G.P. supervised the experiments. All the authors contributed in analyzing the results and writing the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data is available upon request from the corresponding author.

Acknowledgments: The authors would like to thank the research division of Kerman's Gas and Electricity companies for providing the used data sets.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. U.S. Energy Information Administration. *Electric Power Monthly with Data for December 2017*; US Energy Information Administration: Washington, DC, USA, 2018.
2. Arababadi, R.; Naganathan, H.; Saffari Pour, M.; Dadvar, A.; Parrish, K.; Chong, O. Building stock energy modeling: Feasibility study on selection of important input parameters using stepwise regression. *Energy Sci. Eng.* **2021**, *9*, 284–296. [CrossRef]
3. Silva, M.; Oliveira, V.; Leal, V. Urban form and energy demand: A review of energy-relevant urban attributes. *J. Plan. Lit.* **2017**, *32*, 346–365. [CrossRef]
4. Asfour, O.S.; Alshawaf, E.S. Effect of housing density on energy efficiency of buildings located in hot climates. *Energy Build.* **2015**, *91*, 131–138. [CrossRef]
5. Ahn, Y.; Sohn, D.-W. The effect of neighbourhood-level urban form on residential building energy use: A GIS-based model using building energy benchmarking data in Seattle. *Energy Build.* **2019**, *196*, 124–133. [CrossRef]
6. Douthat, T.; Morgan, J.D.; Alibašić, H.; Grant, A. Passive building characteristics, and summertime residential energy use: A spatial analysis of energy efficiency in Gainesville, FL. *Build. Environ.* **2020**, *169*, 106542. [CrossRef]
7. Chatzipoulka, C.; Compagnon, R.; Nikolopoulou, M. Urban geometry and solar availability on façades and ground of real urban forms: Using London as a case study. *Sol. Energy* **2016**, *138*, 53–66. [CrossRef]
8. Santamouris, M.; Papanikolaou, N.; Livada, I.; Koronakis, I.; Georgakis, C.; Argiriou, A.; Assimakopoulos, D. On the impact of urban climate on the energy consumption of buildings. *Sol. Energy* **2001**, *70*, 201–216. [CrossRef]
9. Ibrahim, O. A comparison of methods for assessing the relative importance of input variables in artificial neural networks. *J. Appl. Sci. Res.* **2013**, *9*, 5692–5700.
10. Huebner, G.M.; Hamilton, I.; Chalabi, Z.; Shipworth, D.; Oreszczyn, T. Explaining domestic energy consumption–the comparative contribution of building factors, socio-demographics, behaviours and attitudes. *Appl. Energy* **2015**, *159*, 589–600. [CrossRef]
11. Liao, H.-C.; Chang, T.-F. Space-heating and water-heating energy demands of the aged in the US. *Energy Econ.* **2002**, *24*, 267–284. [CrossRef]
12. Ewing, R.; Rong, F. The impact of urban form on US residential energy use. *Hous. Policy Debate* **2008**, *19*, 1–30. [CrossRef]