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Evaluation of energy efficiency on an urban scale using the TRACE and LEED models for sustainable development case study: Velenjak neighbourhood of Tehran city

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Abstract

This research is an attempt to plan land use and its relationship with energy efficiency optimization for urban sustainability development. In this regard, first, by focusing on identifying different energy efficiency assessment models and methods, the TRACE and LEED models were used to evaluate energy efficiency in Tehran and Velenjak neighbourhood of Tehran. This study is an applied research and its method is descriptive-analytic. Data were gathered using library information, organization data and data of detailed plan of the region 1 of Tehran's municipality. Analysis of data was conducted using TRACE and LEED models and EXCEL and GIS software. The research findings indicate that there is a direct relationship between land use planning and energy consumption, and two sections of building and transportation are the main components that affect energy consumption and efficiency. By policy making and planning, as well as by reviewing suggestions, we can change our cities to higher-quality, energy-efficient spaces.

Keywords: *Energy efficiency; sustainable development; TRACE model; LEED model; Tehran; Velenjak neighbourhood*

Problem Statement

One of the most important contemporary viewpoints about urban planning is sustainable development which has been developed since Brudtland's commission report and is currently used as an integral part in social, economic, and environmental areas (Cameron, 1991; Bajura, 2002). According to this definition, the issue of energy sustainability, as one of the necessities of urban life, has always been present which highlights the importance of paying attention to energy sustainability in cities. Generally, with regard to the vital role of energy in sustainability development, due to economic growth and worldwide climate change, taking optimizing energy consumption policies into consideration gains more importance every day. Cities are the major consumers (two third) of energy in the world (Bose, 2002) and the growing development of urbanization leads to a remarkable increase in energy consumption (Kamal-Chaoui & Alexis, 2009). Therefore, such a trend reflects realizing the pressing need for dealing with energy problems in cities (Keirstead et al, 2010).

On the other hand, one of the most critical and effective factors in urban planning is the issue of land-use planning. Hence, due to its direct relationship with urban activities, urban land-use planning is closely linked to the issue of energy and efficiency. Therefore, one of the most critical goals of urban planning and land-use planning is creating cities with optimal energy use. In this regard, land-use planning plays an important role in decreasing energy consumption by enhancing the sustainability of the current and future urban regions (Bose, 2010). This is so because it can affect trip behaviors positively and ultimately contribute to increasing optimal energy consumption via influencing different aspect of the forms and structures of cities, such as, urban designing, land-use distribution, building patterns, density, and infrastructure of transportation (Banister & Hickman, 2007). Considering these issues, the circumstances of the country with regard to the amount of energy consumption, there is a need to analyze and evaluate urban land-use based on energy efficiency approach. In this study, after stating the research methodology, the concept of energy efficiency and its models (i.e. TRACE and LEED) will be investigated and finally, some relevant case studies will be discusses.

Theoretical Framework

The growth in demand and energy consumption in recent decades has had major effects, especially on the environment, such as air pollution (Raydan & Steemers, 2005); ozone depletion (Thomas, 1999), deforestation, desertification, global warming and climate change. Since then, a wide range of researchers from different fields, concerned about the environmental issue, the future of mankind and the future of the planet, emphasized on the research institutes' focus on environmental problems. Such a comprehensive endeavour has contributed to the formation of various ideas and movements such as sustainable urban development, new urbanism, and smart growth as an obvious paradigm. With regard to sustainable development, the issue of sustainability in the field of energy has been one of the main principles of sustainable urban development which highlights the need for taking into consideration the sustainability of energy in cities due to the excessive amount of energy consumption in them. In its ideal sense, energy sustainability means using and exploiting resources which: (a). Usually are not finished as a result of constant use; (b) Do not cause the emission of significant pollutant or do not pose any other threats to the environment and; (c) Do not contain any persistent health hazards or social inequality. Nevertheless, the production and consumption of energy with renewable technologies such as wind,

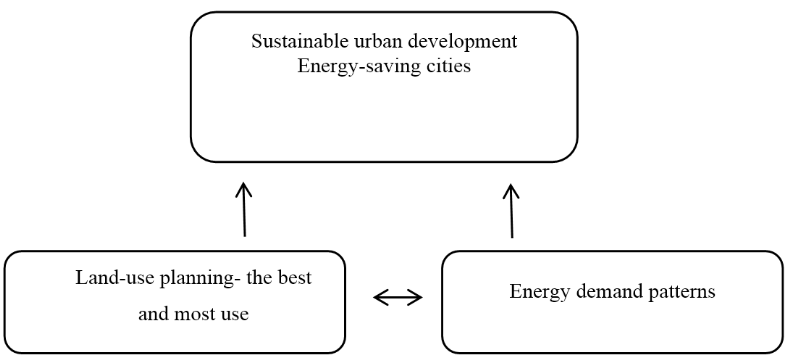

Fig. 1: The Relationship between Energy, Urban Sustainability and Land-Use Planning
Source: (Siong Ho, 2005)

sun, geothermal energy, and biofuels, which need industrial infrastructures and life cycle energy input, do not come without any environmental costs. Therefore, energy sustainability is a relative concept, not an absolute one (Lantsberg, 2005). In general, using renewable energy resources and making energy consumption efficient are two main solutions for achieving sustainable energy development in cities. These advantages, indeed, reflect the significance of taking energy evaluation into consideration (Department of energy and climate change, 2012). Paying attention to this principle in 2016 has also helped many families to save their money from 10 to 30 percent in their annual costs of energy (IEA, 2017). Energy efficiency is critical in changing and orienting the country's development path towards low-carbon economic growth. Specifically, in developing countries and in transition economies there have not been any great potential for saving energy so far (Taylor et al, 2008). There are many different components that affect the extent of energy consumption in cities and clarify the importance of energy efficiency. These components include city form (Newman & Kenworthy, 1999; Breheny, 1996), compactness of urban forms (IGES, 2004), buildings (Sunikka, 2006), the spatial structure of the city (Burby, 2008) and urban land-use (Zhao et al, 2017). In the literature of urban planning, there are different perspectives which define urban land-use planning, for instance, according to the definition provided by Farmer and Gibb (1979), urban land-use planning is a management process which is conducted on the basis of general and detailed objectives and the components of land-use include activities, places, and people which operate in relation to each other (Farmer & Gibbo, 1979).

Methodology

Research Method

The present study is within the area of applied research and has a descriptive-analytic research method. This study aimed to evaluate energy efficiency of land-use in Velenjak neighbourhood of Tehran based on energy evaluation in line with sustainable development. Therefore, after evaluating various models and methods in this field, two superior scale-based models- TRACE[1] and LEED[2] Models- were chosen for the evaluation of energy efficiency in Velenjak neighbourhood of Tehran. Based on the variety of different models for evaluating energy efficiency, TRACE Model on the scale of Tehran and LEED Model on the scale of neighbourhood were selected.

TRACE Model is a tool designed as a decision-making support system for the quick evaluation of city energy (ESMP, 2013). The indices of TRACE Model include general and background information of the city, urban building, water and wastewater, public lighting, waste materials, and transportation (ECA, 2013).

The purpose of LEED Model is converting the construction and designing methods of societies' performance into a responsible community which is compatible with a healthy and rich environment; thereby improving the quality of life (US Green Building Council, 2007). Focusing on new constructions and land-use, and urban planning, LEED Model, in general, increases efficacy and efficiency of energy and water consumption, while improving the quality of air in the city (Aburbach, 2009).

1 Tool for Rapid Assessment of City Energy
2 Leadership in Energy and Environmental Design

The Geographical Realm of Research

From a geographical point of view, the city of Tehran (Iran's capital city) is located in 51° and 17' to 51° and 33' in the east and 35° and 36' to 35° and 44' width in the north. This city is about 720 km^2 and has 22 municipal regions.

Velenjak is one of the neighbourhoods of Tehran in Shemiran region. This neighbourhood is located in Tochal foothills and in region 1 of Tehran's municipality (Figure 2). This neighbourhood is located in district 2 of Tehran's municipality in region 1 and according to the latest census, its population is 22742 (Tehran Province Water and Wastewater Company, 2016).

The largest area in the neighbourhood under study has been specified for residential use (0/56). Green space use (5%) and military use (5%) come next. A remarkable point about this neighbourhood's land-use is its high percentage vacant land of around 12 percent (Figure 5)

Findings

Energy Efficiency in Tehran (TRACE Model)

From a general characteristics point of view, Tehran has a special geographical location (height from the sea level and altitude difference in north and south) and there are a lot of means of transportation which are constantly being used in it and western

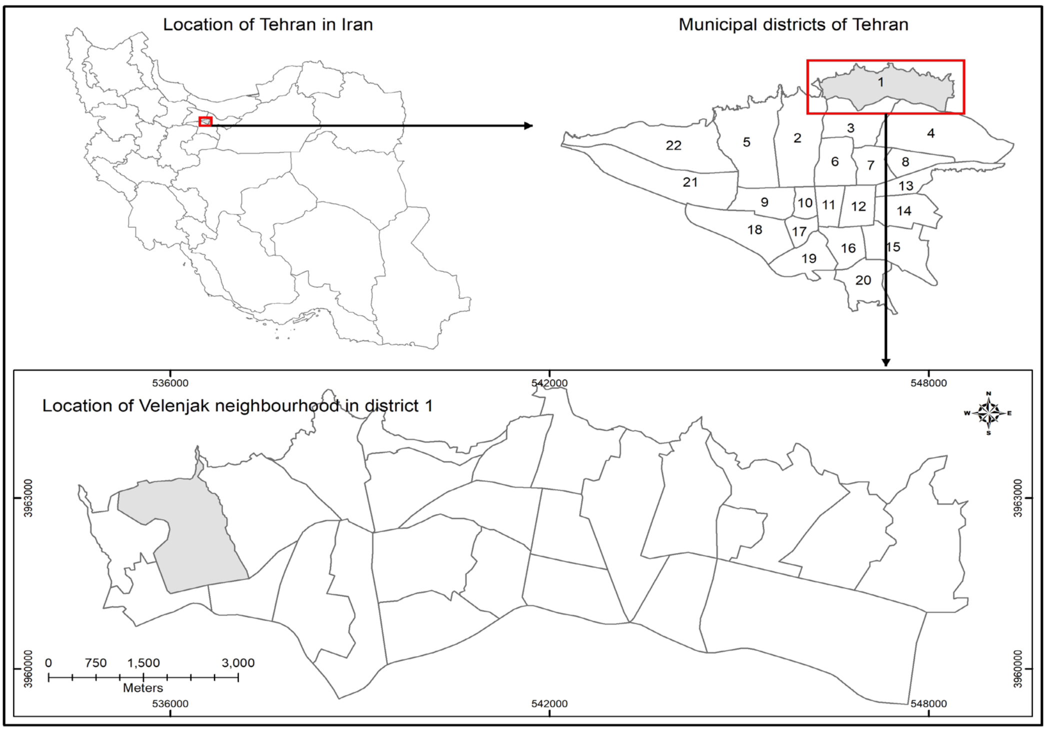

Fig. 2: Lacation of Velenjak in Region 1 of Tehran Municipality, Tehran, Iran
Source: Authors

winds bring the smoke of factories and other pollutants to the city (Portal of Tehran's Municipality, Region 1, 2016). According to the census conducted in 2016, Tehran's population was 8737510 (Municipality of Tehran, 2012). The increasing population has caused high energy consumption in Tehran. Based on energy balance sheet, Tehran metropolitan city consumes 15 percent of the total energy in the whole country. In order to identify high energy consumer indices in Tehran, each one of the indices and measures of TRACE Model were analyzed for the year 2016 (Table 1).

TRACE Model consists of three sub-models. The first sub-model, energy consumption criterion model, investigates the indices and compares the tools of the model in Tehran and other cities around the world. From among 90 cities presented in the model, 36 cities which were more similar to Tehran, were chosen. After considering the graphs and tables of the model (see figure 2 and 3) it was found that the index of building and transportation had the highest number of energy consumers in comparison to other similar cities which are the default of the features and criteria information. In general, energy consumption in different sections is above average, but these two sections have the highest number of energy consumers in Tehran.

After analyzing the graphs that compare Tehran to other cities in the world, there is a need to analyze the priority sub-model which considers the priorities of energy indices from three aspects. The first criterion, potential of energy saving, automatically considers the potential of saving in each index of energy in the city from 0 to 0.40 and in this study, the model hypothesis was used. The second criterion is prioritizing the cost of energy in each index. Since there were no precise values for these data in Tehran, they were roughly gathered from documents and organizations. Finally, the third criterion is the issue of organizational management and control. From an organizational control point of view, most of the indices are controlled by the government or government agencies in Tehran. With regard to the prioritization of the model, the index of urban buildings has the highest amount of energy consumption in Tehran. The relative energy intensity of this index is about 63 percent and the score that it gets based on the prioritization of the data is higher than other indices. Other indices such as lighting of passageways, transportation and waste and wastewater come next. Therefore, based on all the sub-models of TRACE Model, the indices of building and transportation have the highest number of energy consumers.

The model offered some recommendations for the indices that overuse energy according to the analysis of energy consumption in Tehran. The solutions and suggestions that the model presents intend to cover physical and managerial aspects and propose several action plans and methodologies as well as executed samples in different cities. Energy consumption can be reduced through considering the model recommendation that aims at enhancing energy efficiency in Tehran via introducing various policies in the sections that overuse energy. The content of these policies include general methods of reducing energy consumption, such as, decreasing urban trips, intrinsic development, using renewable resources in the form of existing or new documents, planning by using such solutions as user integration, redevelopment in previously developed land, hierarchical distribution of services in the main centers of activity, transport-oriented development, creation of continuous and integrated passageways, management and pricing of parking lots, and increasing the accessibility of pedestrian, bicycle and public transportation.

Table 1: Indices and Measures of TRACE Model

Index	Measure	Estimate
General information	Population in the urban area	8737510
	Types of climate (dry, continental, temperate, tropical)	dry
	Human development index	0/829
	Primary power consumption per capita (kWh per person)	298
	Primary consumption in GDP [kWh / Gross Domestic Product]	0/225
	Per capita primary energy consumption [equivalent to crude oil barrels per person]	5/32
	Primary energy consumption in GDP [equivalent to crude oil barrels per person / GDP]	2/8
Transportation	Total per capita energy use in the transportation section [equivalent to crude oil barrels per person]	7252
	Energy consumption in public transportation [equivalent to barrels of crude oil per trip]	0/32
	Non-motorized transport percentage [%]	0/5
	Public transportation percentage [%]	22/39
	Private energy consumption [equivalent to barrels of crude oil per trip]	0/37
Waste materials	Per capita waste [kg per person]	800
	Percentage of recycled waste [%]	96/5
	Percentage of waste that is buried [%]	3/5
Water	Per capita water consumption per day [liters per person]	356
	The amount of energy to produce drinking water [kWh per cubic meter]	1/02
	Percentage of water without income [%]	26/9
	The cost of energy for treatment of water (drinking and sewage) as a percentage of the total water cost [%]	18/4
	Amount of energy for wastewater treatment [kWh / m3]	0/55
Lighting	Electricity consumption per km of roads for lighting [kWh per kilometer]	16660
	Urban lighting percentage [%]	82
Building	Power consumption of urban buildings [kWh / m]	312
	Heat consumption in urban buildings [kWh / m]	265

Sources: Authors; according to TRACE Model; Tehran Province Water and Wastewater company, 2016; Statistical Center of Iran 2016; ESMP, The World Bank, 2013; The Urban Planning and Research Center of Tehran, Assistance of Urban Planning and Research of Infrastructure and Comprehensive Plan, 2011; Tehran Waste Management Organization, 2016; Tehran Regional Electric Company, 2016.

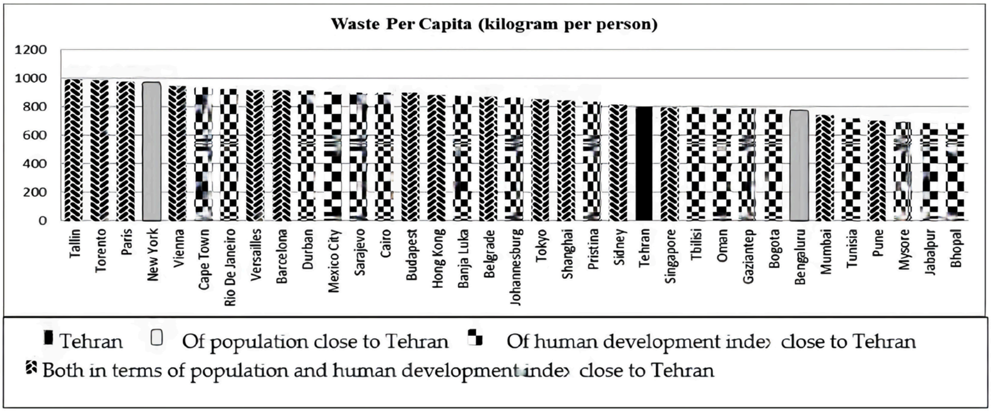

Fig. 3: Comparison of Tehran's Waste Per Capita with Other Cities based on TRACE Model;
Source: Authors

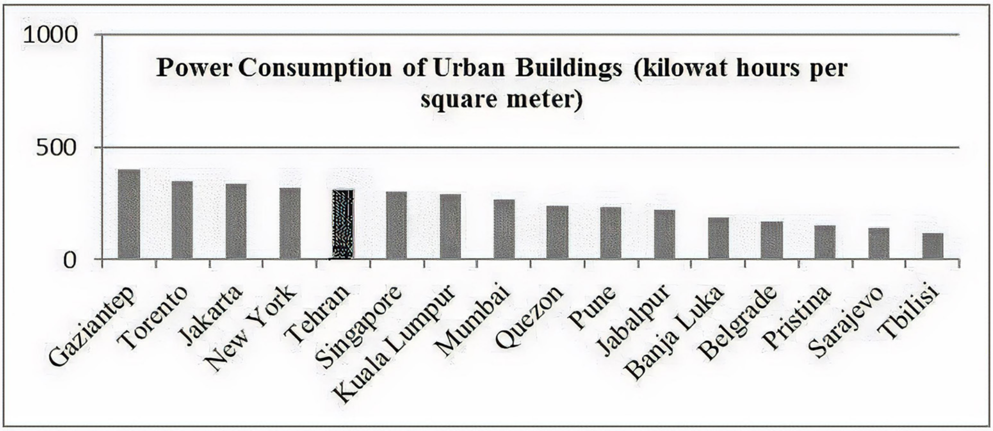

Fig. 4: Comparison of Tehran's Urban Building Power Consumption with Other Cities
Source: Authors

Energy Efficiency in Velenjak Neighbourhood (LEED Model)

After considering the conditions of Velenjak neighbourhood and also having access to the required data, three criterion of location and smart connection (with 4 indices), neighbourhood pattern and design (with 6 indices) and construction and green technology (with 4 indices) were selected from among LEED Model indices. In all, 14 indices (Table 2.) were employed in the area under study. The selected indices were scored in such a way that first, the purpose of indices were mentioned based on which the needs and the scoring criteria of the index were presented. Finally, each one of the indices was analyzed in the neighbourhood and the scores were calculated for each index in the neighbourhood.

Based on the LEED Model analysis conducted in Velenjak neighbourhood, a major section of the neighbourhood (about 56

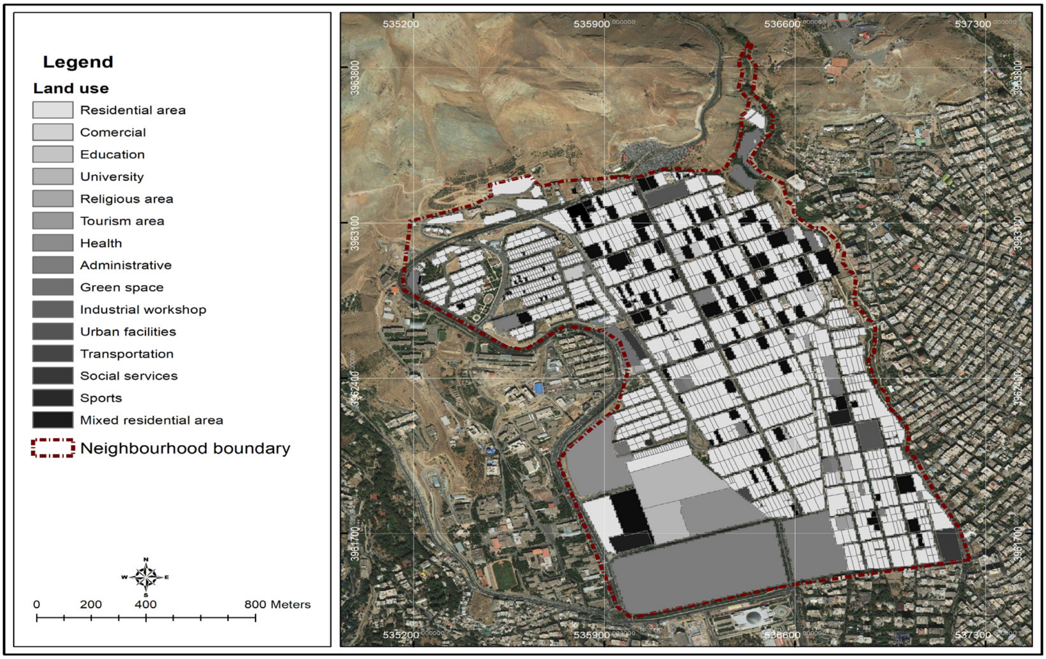

Fig. 5: Land-use in Velenjak
Source: Authors

percent) has been specified for residential use. As for the index of reducing car dependency, many sections in the neighbourhood do not have access to bus stations. The number of buses that transport people in the neighbourhood during the week has been considered in the good service category. Therefore, this neighbourhood gains 4 scores from the index of reducing car dependency criterion (Figure. 4)

Since there are no bicycle connections, Velenjak neighbourhood does not gain any scores from this index. As for the jobs and housing proximity, the workplaces of most of the inhabitants were located in a distance within more than the required standard and the neighbourhood does not gain the score related to this index. With regard to school access, the neighbourhood gains 1 score because it has good access to many schools in different grades. Concerning the intensive development index, based on the density model index, the neighbourhood should have at least 7 or more residential units per 4,000 square meters of buildable lands. The neighbourhood does not gain any scores from this index either. In addition, most of the residential units have access to four different uses. Hence, the neighbourhood gains 2 scores from this index (table 3).

With regard to the index of walkable streets, based on the standards, at least 30 percent of the neighbourhood's residential units should have access to appropriate access connections, public spaces, and sidewalks. After conducting field studies and considering the current condition of the neighbourhood, it only gains 4 scores in this index. Since the neighbourhood has suitable bus stations and traffic signs, it gains all the scores related to the index of transit facilities.

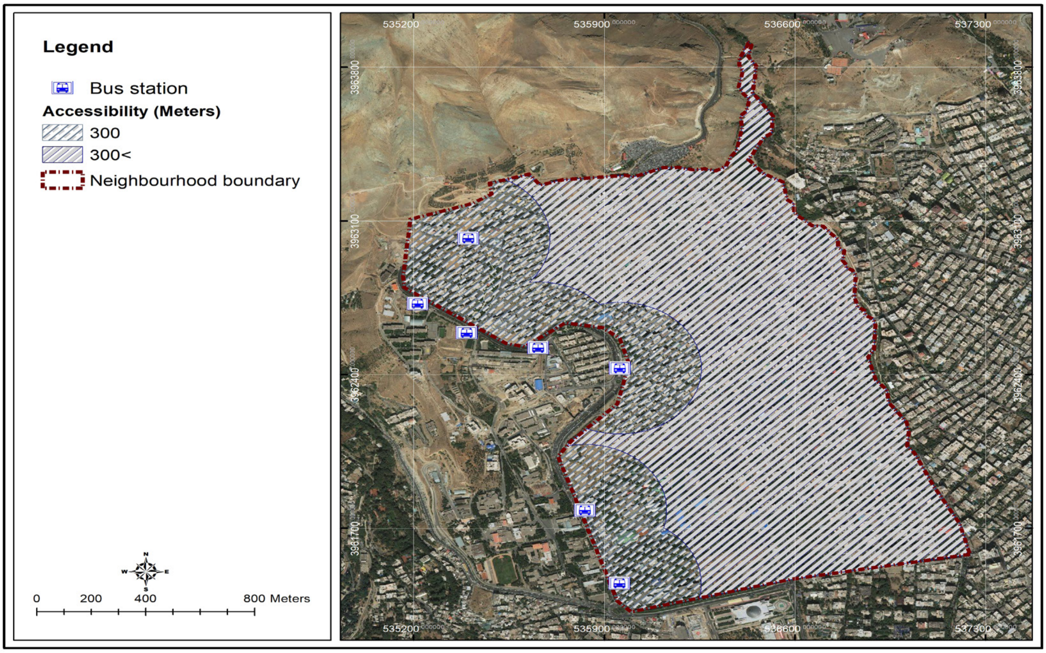

Fig. 6: Residential Units' Access to Bus Stations
Source: Authors

Table 2: Scoring Criteria for Variety of Uses

Number of uses	Percentage of land occupancy
2 uses (1 score)	0/20
4 uses (2 scores)	0/30
7 uses (3 scores)	0/40
10 uses (4 scores)	0/50

Sources: (King, 2011)

The index of access to public spaces which represents residential units' pedestrian access to public places, does not gain any scores due to the neighbourhood's lack of suitable spaces based on the standards. Concerning the position of the neighbourhood's variety of types of housing, based on the required standards in the model, Velenjak neighbourhood gains 3 out of 4 scores. For the index of heat islands reduction, according to the factors specified in the model such as roofed spaces, green roofs, green spaces in the yard, light reflective materials, the neighbourhood only gains 0/35 scores. Also, from the point of view of buildings' energy efficiency, considering the purpose of the model which is compliance with construction standards and building regulations, as well as the age of the buildings, it cannot be precisely determined whether residential buildings

Table 3: Selected indices of LEED Model in Velenjak neighbourhood

Criterion	Index	Scoring	Score	Score of Neighbour-hood
location and smart connection	Reducing car dependency	At least 50% of the residential units should be located within 300 meters of bus stations and their service levels during the week	1-8	4
	Bicycle connections	The existence of a bicycle station or bicycle connections as part of the transportation connection	1	0
	Jobs and housing proximity	At least 25% of residential units should be within 1.9 km of businesses	3	0
	School access	At least 50% of residential units should be located within 400-meter of schools (kindergarten, elementary school, middle school, and high school).	1	1
Pattern and design of neighbourhood	Compact development	The existence of residential units in a neighbourhood with a density of at least 7 residential units or more than 4000 square meters of buildable land	1-7	3
	Diversity of uses	Access to at least 50% of residential use for a variety of uses	1-4	2
	Walkable streets	Access of at least 30% of residential buildings to access connections and public spaces such as suitable streets, squares, parks and walkways	4-8	4
	Transit facilities	Suitable furniture for bus stations, traffic signs	1	1
	Access to public spaces	Pedestrian access of at least 90% of residential units to parks, squares, open spaces and green areas	1	0/025
	Variety of type of housing	Access to different types of housing (in terms of area) for different categories of citizens	1-3	1
Construction and green technology	Heat islands reduction	The presence of roofed parking lots, the use of sunlight reflective materials in floor coverings, green roofs	1	0/25
	Energy efficiency in buildings	Compliance with construction standards to reduce air pollution and energy consumption	1-3	2
	Energy Efficiency Infrastructure	The use of renewable energy in infrastructures such as street lights, solar cells, etc.	1	0/25
	Wastewater and Waste Management	Reuse of at least 50% of wastewater and sprawls	1	0/45

Sources: (Authors citing Welch et al, 2010) have strictly complied with the regulations or not. Therefore, the neighbourhood gains 2 scores in this index. For the infrastructure performance index, this uses renewable energy infrastructures, the neighbourhood gains 0/5 points for using solar lights in parks and etc. Finally, for the wastewater and wastewater management index, which relates to the reuse of wastewater and sprawl, based on the district's sewage system and the way the neighbourhood reuses wastewater, it gains 0/5 scores. In sum, the neighbourhood under study gained 20 out of 43 scores which reflects its average (and not so desirable) condition and highlights the fact that based on LEED Model, energy efficiency can be enhanced in the neighbourhood after some changes are applied.

There are various recommendations that can be offered in order to improve Velenjak neighbourhood through reducing energy consumption and improving energy efficiency. These suggestions are listed in Table 4. Once the changes and suggestions are applied, the neighbourhood's score can rise to 30 out of 43. Hence, with regard to the current score of the neighbourhood, there can be a 60 percent growth in its score. As for calculating the amount of reduction in energy consumption, after applying the suggestions, based on the diverse impacts of the mentioned indices in LEED Model, it can be said that

Table 4: Suggestions of the Selected Index of LEED Model for Velenjak Neighbourhood

Index	Suggestions	Score	Neighbourhood Score	Score
Car dependency reduction	Insertion and adding of other stations according to the map of the district bus access based on the conditions of the neighbourhood and improving the service of the buses	1-8	4	8
Diversity of uses	User mixing and their variety	1-4	2	4
Compact development	By changing the zoning and changes in the detailed design of the future, it is possible to implement this index	1-7	3	5
Energy efficiency in buildings	Increasing the energy efficiency of buildings by planning, setting up and monitoring of national building regulations of the country (energy savings)	1-3	2	3
Reduction of heat islands	Planning and creating factors such as green roof, installing cold ceilings, cold plowing, increasing the reflection of street surfaces, etc.	1	0/25	1
Energy Efficiency Infrastructure	Planning for the use of more renewable energy such as increasing solar panel lights	1	0/25	1
Wastewater and Waste Management	Planning for a better coverage of the sewage system in the neighbourhood, separation of household water consumption (such as gray water), quality control of surface runoff ,etc.	1	0/45	1
Walkable streets	Adopting measures and solutions that provide access to public spaces, squares, parks for residential buildings through the optimization of pedestrians	4-8	4	6

Sources: Authors

there can be a 40 to 50 percent reduction in energy consumption.

Conclusion

The present study focused on achieving energy efficiency in different sections through actions such as promoting user mixing, increasing density and compactness, hierarchical distributing of the service in the centers of activity, transport-oriented development, creating a continuous and integrated transit connection, providing pedestrian access and public transportation, and changing the energy consumption pattern. In so doing, on the first level, the scale of city was directly investigated and the amount of energy consumption in Tehran was evaluated based on the indices and criteria of TRACE Model which demonstrated that the indices of building and transportation had the highest amount of consumption in Tehran. On the second level, in order to analyze the amount of energy efficiency in Velenjak neighbourhood of Tehran with regard to district divisions in the city, LEED Model was adopted which focused on high consumer indices on the first level (i.e. building and construction). The evaluation through LEED Model revealed that the neighbourhood under study has an almost average condition based on the gained scores and applying various changes can enhance energy efficiency in this neighbourhood.

Therefore, research solutions and suggestions in the scale of neighbourhood were proposed after the analysis of data based on the mentioned models. The findings highlighted the fact that energy efficiency can be improved through policy making and employing different plans. In general, it can be mentioned that taking the importance of urban efficiency into consideration is essential due to the fact that the shortage of global energy has not only become a problem, but considering such an issue would enhance the quality of our cities. In this way, it is necessary to carry out particular energy-related action plans to reduce energy consumption and ultimately achieve energy efficiency.

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