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Urban energy system and climate indicators for urban energy planning

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ABSTRACT

BACKGROUND AND OBJECTIVES: Cities are the main energy consumers; they can be a critical solution to threats to energy resources, the environment, and climate change. Knowing the effective indicators in urban planning and design in the energy field is one of the priorities of urban planners and designers. In this regard, Current research in the first step has tried to define a conceptual framework of urban system indicators influential to energy planning in cities. And in the second step, since climatic characteristics could be as fundamental factors in urban energy planning, the relationship between climatic indicators and urban energy planning indicators has been identified.

METHODS: This study is basic research in terms of purpose and presents a new conceptual framework for the urban energy system. It also aimed to analyses the relationship between the urban energy system indicators and local climate indicators. Its methodology is descriptive-analytical, conducted by library method and survey. Data analysis was done through a combination of quantitative and quantitative methods and descriptive statistical analysis. To do the survey questionnaire and interview experts in the energy field in different countries by using the Delphi method has been done.

FINDINGS: The urban energy system conceptual framework was identified, and it has been divided into seven sub-systems (physical, land use, infrastructure, and transportation, movement/accessibility, cultural and technological), 15 components, and 61 indicators. Also, by analyzing the relationship between urban energy and climate indicators, "Air temperature" is the most related climate indicator from the experts' view with 682 total scores, followed by "Solar radiation and sunny days", "greenery" and "wind" indicators respectively with the sum points of 624, 596 and 594 scores in the seven defined urban energy system indicators.

CONCLUSION: A theoretical framework of urban energy systems has been defined based on previous studies and experts' ideas in a comprehensive framework. And by analyzing the relationship between the defined urban energy system and climate indicators, the important indicators were recognized in each group. That could be academic knowledge and a practical source for future urban plans. For future studies, the institutional and economic dimensions of urban energy systems have to be conducted to complete the theoretical framework.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
67	2	11

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INTRODUCTION

Currently, many environmental and social challenges related to urban development are linked to inadequate and high energy consumption due to the growing population in cities (Akcin *et al*.; De Lotto *et al*., 2022). These include greenhouse gas emissions, over-consumption of resources (land, fossil fuels, water, food), overall environmental footprint, infrastructure costs due to urban sprawl, etc. (De Lotto *et al*., 2022). In other words, how urban areas are built significantly impacts the performance of urban energy now and in the future (Oliveria and Silva, 2013). In recent years, urban energy studies focused more on the intermediate scale between the city scale and the building scale, namely the district or neighborhood scale. Urban design and sometimes urban planning work on this scale in the process of urban development (Shi *et al*., 2017). The transition from fossil fuel-based urban energy systems to 100% renewable energy systems is expected to be achieved within a few decades. To reach this goal, it is essential to upscale planning from net-zero buildings to energy-sustainable neighborhoods, which are more cost-effective than optimizing each building separately (Perera *et al*., 2018). To this end, developing a holistic computational platform that bridges urban climate and energy systems will be immensely helpful in this context. This research will discuss the crucial indicators of the urban energy system and climate situation. Urban Energy is consumed in five main sectors of industry, transport, building, service, and agriculture. Esmaeilpour Zanjani *et al*. (2021); Madlener and Sunak (2011) divided the impacts of urbanization on urban structures and energy demand into four main components, urban production, mobility/transportation, infrastructure/urban density, and private households. Moreover, moving toward energy efficiency and sustainability in the urban context depends on five leverages, i.e., urban morphology, technology, building form, occupant behavior, and energy system, and the contribution of all these leverages is subject to the urban climate (Perera *et al*., 2018). Moreover, some scientists have dealt with the issue with a broader perspective and found energy and urban planning in different parameters, such as physical (UN, 2021; Gul, Patidar, 2015;) and historical, socio-economic, institutional/political, and natural environments, resources, and the location of cities (De Almeida Collaco *et al*., 2019). According to the United Nations, the urban form significantly impacts energy consumption (Marique and Reiter, 2012). From a morphological view, characteristics like density, land-use mix, and public transport network affect energy consumption (Pan *et al*., 2009; Ferguson, 2014; Urquizo *et al*., 2017). The effects of land use (Roshan *et al*., 2022; Zhang, and Zhao, 2017; Ursula Eicker *et al*., 2018) and the built environment on travel behavior and travel energy use have been a title of longstanding research interest. Policymakers and planners have known mixed land use, as a critical planning parameter, is considered energy efficient (Zhang and Zhao, 2017). Energy consumption inconspicuously is like a bridge between nature and culture (Horta *et al*., 2014). Energy efficiency can be increased by raising residents' awareness (De Almeida Collaco, *et al*., 2019) and guiding stakeholders in improving the city's infrastructure (Perera *et al*., 2018; UN, 2020; Gul and Patidar, 2015; Sharifia and Yamagatab, 2015), systems, and building performance (Hukkalainen, 2017). And the modes of energy production and consumption also reflect the relations that any society establishes with humans and non-humans (Horta *et al*., 2014). On the other hand, people's lifestyles affect energy consumption. They have a significant role in cultural and social variables (Eyre *et al*., 2012). "Culture" can be defined as a diversity of values, beliefs, knowledge, practice, technology (Popp, 2001), and other cultural determinants within a given society (Stephenson *et al*., 2010). The research of Ishak (2017) shows that "five factors from the energy culture framework contribute to energy consumption behavior, namely, building regulation, environmental concern, education, social marketing and direct factors (device and activities)." Cities that have higher urban density consume less energy per person. This matter is mainly because of the increased travel distance inherent to a sprawling city structure (Le Néchet, 2012; Riera Perez and Rey, 2013). However, Banister (1992) found conflicting results that energy consumption is not only influenced by urban density but also by land use and socio-economic parameters. The other essential criteria in urban energy planning are technology. New technologies have a significant effect on energy consumption and its policy implications. Many environmental solutions and policies can be expected to develop new technologies (Popp, 2001). Therefore, access to related facilities is essential in using this part. Mobility in urban areas represents an essential part of the consumption energy sector. There is much research that has studied transport energy consumption (Esmaeilpour Zanjani *et al*., 2021; Roshan, *et al*., 2020; Elliot *et al*., 2022). Poudenx (2008) mentioned that greenhouse gas emissions and energy use are related to different transportation policies. And Ogilvie *et al.* (2004), represented that a sustainable transportation policy should ease the development of the most energy-efficient modes or non-motorized modes of transport (soft mobility), such as walking, cycling, and public transport. The density of buildings and changes in the features of underlying surfaces in urban areas, like artificial surfaces, caused higher temperatures in the urban than its surrounding areas, which have been known as urban heat islands (Du *et al*., 2017). One significant effect of urban heat islands is the increase in energy consumption (Alghannam and Al-Qahtnai, 2012; Ng *et al.,* 2012), and greening is a proper mitigation strategy to help cool the air and provide shade, and lower building energy consumption (Ng *et al*., 2012), along with other influential factors in reducing energy consumption. Accordingly, urban planning should be linked narrowly to energy planning and the process of urban planning as energy consumption and potential local energy sources are highly connected to urban plans (Zanon and Verones, 2013). Moreover, close collaboration between urban planning and energy planning can also provide an innovative local energy policy (Gabillet, 2015). In this regard, a comprehensive look at energy planning and design indicators in cities and climate indicators and recognizing how they are linked would help planners to better decide. For example, the Climate Index should be based on natural ventilation, taking advantage of the physical features of the urban area to reduce urban thermal environmental problems effectively (City air conditioning assistance) (Yang *et al*., 2021). The aim of this research is to identify the urban energy system indicators by reviewing related studies and using experts' ideas to reach a comprehensive theoretical framework and then find the relation between its indicators and local climate indicators which plays a significant role in urban energy planning. The current study has been carried out in Tehran and Italy in 2022.

MATERIALS AND METHODS

This study is basic research in terms of purpose and seeks to promote knowledge (Palys, 2008). In this regard, this research introduces a new conceptual framework of the urban energy system for the first time and, secondly, analyzes the relationship between obtained urban energy system indicators and related climate indicators. Its methodology is descriptive-analytical, conducted by library method and survey (questionnaire and interview). For data analysis, a combination of qualitative and quantitative methods were applied. More precisely, Google Docs was used for building and descriptive analysis of the questionnaire, and Microsoft Excel for descriptive statistical analysis. An extensive study has been performed on urban planning and design related literature and its relation with the field of energy use to identify and extract the Urban Energy System (UES) relevant indicators. The indicators were categorized using the expert's interviews and questionnaires. To complete and build the conceptual framework of UES, experts who work specifically in the field of urban planning related to the field of energy from different countries (France, Germany, Italy, and Iran) were identified by non-probability and judgment sampling methods (The survey has been done in these countries based on the availability of the experts). The reliability of the questionnaire was calculated through Cronbach's alpha test, and its validity was verified using the content validity ratio (CVR). The process of conducting the present study is shown in Fig. 1.

In this research, the postulates that could lead to new advancements in efficacy and efficiency in urban energy use have been analyzed. As explained, the urban energy system components, variables, and indicators were identified and collected based on a literature review, interviewing, and filling questionnaires by experts in this sector (Table 1), and It concluded in a conceptual framework (Fig. 2) presented and classified in the following. Also, the same processes have been done for identifying and collecting the climate variables related to urban energy planning (Table 2). The Delphi method was used to fill questionnaires, which is one of the best methods with reliable results using experts. And to do that, we analyzed the questionnaires in 4 rounds

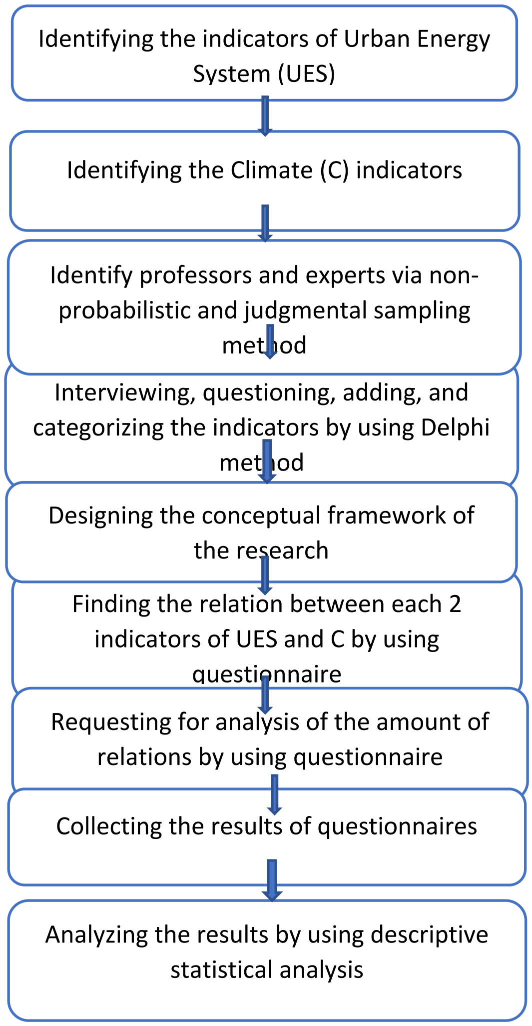

Fig.1: Methodology process

with 31 experts from different countries in the field of urban energy. In the conceptual framework, the UES is categorized into seven sub-systems. It should be noted that two components of economic and institutional were eliminated based on the distance of the concept of the next step.

So, based on the in-depth literature review and interviews about identifying indicators of urban energy systems, the conceptual framework was obtained (Fig. 2).

By approaching the earth's surface, the environmental effects on the climate become more tangible, and the general climatic conditions of the region change. The changes caused by the ecological conditions in the climate state are called climate subsets or climate layers. In general, four main climatic layers can be identified in each region. The status of these layers changes based on the topographical position and the nature of the earth's surface. These four climate layers are macro, middle, local, and microclimate based on Table 2 (Tahbaz and Djalilian, 2016). In this research, climate indicators of the local climate layer have been chosen.

Analysis of the climatic conditions of a site due to evaluate the most suitable strategy for comfortable outdoor and public space, mostly includes,

Table 1: Identifying the components, variables, and indicators of urban energy system from literature and other data collection sources.

	Components	Variables	Sources
Urban energy system	Physical	Building deployment and orientation	Esmaeilpour Zanjani *et al*., (2021); Madlener and Sunak, (2011); Bahrainy, (2014)
		Building form and size	Perera *et al*., (2018); Bahrainy, (2014); Yanxue Li *et al.,* (2021)
		Building openings	Bahrainy, (2014); Yanxue Li *et al.,* (2021)
		The ratio of mass and space on the site	Regina de Casas and Marins, (2014); Banister, (2007); Mosteiro-Romero *et al*., (2020)
		Blocking	Faroughi *et al*., (2020); Sudprasert, (2019); Palme and Salvati, (2016)
		Urban form	Marique and Reiter, (2012); Regina de Casas and Marins, (2014); Sudprasert, (2019);
		Site orientation	Karamouzian *et al*., (2021); Faroughi *et al*., (2020)
		Building density and compact form	Ferguson, (2014); Owens, (2005); Du *et al*., (2017);
		Geographical location	Sharifia and Yamagatab, (2015); Adolphe, (2001)
		Construction technology	Ursula Eicker *et al*., (2018); Yanxue Li *et al.,* (2021)
		Type of material	Sudprasert, (2019); Palme and Salvati, (2016)
		Building life	Yanxue Li *et al*., (2021); Ursula Eicker *et al*., (2018)
		Building quality	Regina de Casas and Marins, (2014)
		Building height	Bahrainy, (2014); Yanxue Li *et al.,* (2021)
	Land- use	Land-use types Mixed land use The ratio of land use rate to a population growth rate Green space distribution Distribution of public spaces Active neighborhood center	Van Wee, (2002); Pan *et al*., (2009); Zhang and Zhao, (2017)
	Infrastructure	Amount of energy transmission system	Rezaie Jahormi and Barakpur, (2016)
		The population proportion that has electricity access	van Leeuwen *et al*., (2017)
		The population proportion that primarily relies on fuel and clean technology	Rezaie Jahormi and Barakpur, (2016)
		Energy intensity indicators in terms of primary energy and GDP Installed renewable energy production capacity in developing countries (in watts per capita) Smart networks	van Leeuwen *et al*., (2017); Bulkeley and Betsill, (2005)
		Heating systems Streets and highway lights Car refueling services The extent of the road network Energy-saving Amount of energy for landscaping and traffic signs	Rezaie Jahormi and Barakpur, (2016)
	Transportation	The amount and easy access to shared vehicles Number of electric and hybrid cars and other new technology of cars.	Ogilvie *et al*., (2004); van Leeuwen *et al*., (2017)
		Amount of non-motorized transport with soft mobility (mobility with human power)	Poudenx, (2008); Berkpour and Masnanzadeh, (2011)
		The population proportion with easy access to public transportation	Ogilvie *et al*., (2004); Bulkeley and Betsill, (2005)
		Number of bus stops/subway stations and terminals Number of railway stations Transportation and freight terminals Public transportation coverage	Ferguson, (2014); Urquizo *et al*., (2017); Owens, (2005)
		The number of pedestrian paths Number of bike lanes The rate of traffic signs for pedestrian and cycling routes The amount of bicycle parking The number of parking lots and marginal parking lots	Ogilvie *et al*., (2004); Berkpour and Masnanzadeh, (2011); Bulkeley and Betsill, (2005)

Continued Table 1: Identifying the components, variables, and indicators of urban energy system from literature and other data collection sources.

Components	Variables	Sources
Movement and accessibility	Amount of parking near public transportation stations	
	Pedestrian access to basic services	
	Access to public spaces	
	Access to green spaces	
Culture and human behavior	Education	Hukkalainen, (2017); Ishak, (2017); van Leeuwen *et al*., (2017);
	Household energy consumption Cities Suitability with direct participation structure of civil society (in urban planning and management) Amount of green workplace practices recycling programs, reuse Suitability of collected urban solid waste and related facilities The amount of energy consumption The rate of water consumption	Ishak, (2017); Rezaie Jahormi and Barakpur, (2016) Dabir and Azarpira, 2017; Eyre *et al*., (2012), Van Leeuwen *et al*., (2017);
	The amount of carbon dioxide production	Poudenx,(2008);
	The extent of environmental impact	Zhang, and Zhao, (2017); Stephenson *et al*., (2010)
Technology	Information technology connection Internet access and services Computer access and smart devices	Ishak, (2017); Popp, (2001)

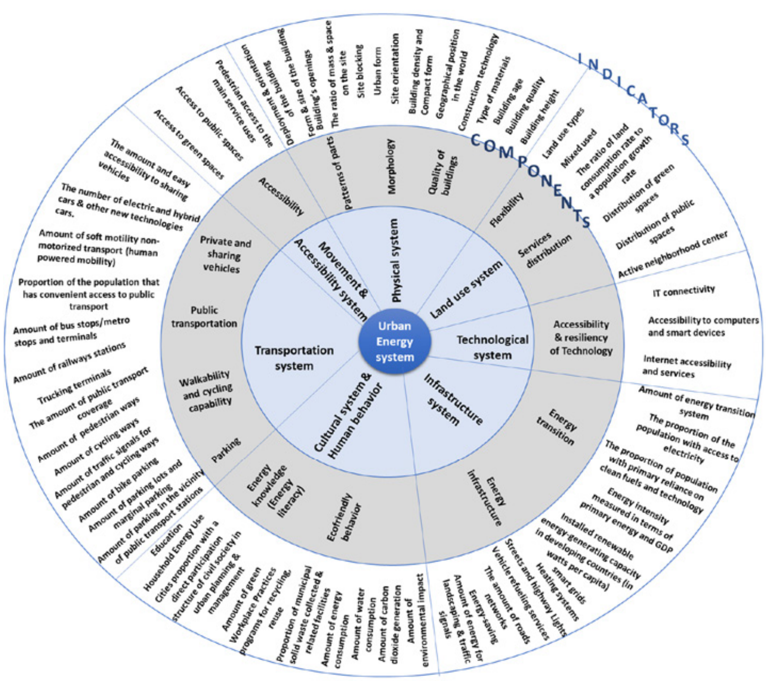

Fig. 2: Conceptual framework of the Urban Energy System (UES)

Table 2: Four climate layers (Tahbaz and Djalilian, 2016)

Climate subsets/layers	Characteristics
Macroclimate	Large areas at a distance of one hundred to one hundred thousand kilometers - with these data, one can understand the methods of assimilation with the environment in that climatic zone.
Middle climate	They are determined according to the general variations of the region's topography - sub-climates are under the set of macro-climates and separate areas at a distance of 10 to 200 km, and each of these areas has a particular climate.
local climate	Topographic features are determined in more detail - areas at a distance of 100 meters to 50 kilometers - a type of construction, the orientation of streets, the ratio of empty and full spaces, the area of green surfaces, land slope, and topography, etc., which are creating special local climate conditions.
microclimate	Very small scale from a distance of one centimeter to one kilometer - it depends on land details such as land surface cover, land slope, vegetation, soil moisture, weather conditions such as shade and sun, wind flow or air stagnation, and so on. The area of influence of microclimate in the vertical direction is estimated up to two meters from the earth's surface

Table 3: Effective climate indicators on local scale

Components	Indicators
Temperature	- Different seasons' minimum and maximum temperature -Average temperature -Existence of micro-climate -Number of urban heat islands
Wind	-Wind flow pressure -Dominant wind direction -Wind speed
Sunshine and sunny days	-Amount of radiation received and the loss of SVF sky vision -Number of sunny days -The amount of shading -Sunbeam angle -Sunlight absorption and reflection by surfaces
Humidity, water, and hydrology	-Humidity level -Number of rivers, canals and waterways -Distance from sea, lake or waterways -The amount of groundwater -Rainfall in different seasons
Sea level	-Topography and slope -Slope direction
Greenery	-Area of greenery -Location of greenery -Type of greenery -Amount of trees

temperature range, relative humidity, solar radiation, prevailing wind direction, and greenery that, based on many researches (Brozovsky *et al*., 2021; Nasrollahi, 2014; Huang *et al*., 2011; Pioppi *et al*., 2020; Manni *et al*., 2019) could be divided into different indicators as it shows in Table 3.

RESULTS AND DISCUSSION

Table 4 demonstrates the relationship between physical system indicators and effective climate indicators in the UES, the "urban form" indicator with the highest overall score (90) and an average of 15 points ranks first in coordination with climatic conditions and indicators. Then the "geographical location," "deployment and orientation of the building," and the "type of material" are in the following ranks. Finally, it should be noted that the "blocking" has the lowest score compared to other physical system indicators.

Also, according to the results of the climate indicators (shown in the columns), it can be concluded that "wind", based on the score obtained (198) is the first and most crucial climate indicator in the physical system. This system includes the

Table 4: Relation between the and climate indicators

Components and Variables		Indicator	Air temperature	Wind	Solar radiation and sunny days	Humidity, water and hydrology	Above sea level	greenery	Sum	Average	Max	Min	Mode
Physical system	patterns of parts	**Deployment and orientation of the building**	14	16	20	8	8	8	74	12.3	20	8	8
		Form and size of the building	10	14	14	10	6	8	62	10.3	14	6	10
		Building openings	16	18	14	4	6	10	68	11.3	18	4	#N/A
		The ratio of mass and space on the site	10	10	10	6	8	14	58	9.7	14	6	10
	morphology	**The ratio of mass and space on the site**	10	16	10	2	2	4	44	7.3	16	2	10
		Urban form	18	18	18	10	14	12	90	15.0	18	10	18
		Site orientation	12	16	16	8	6	10	68	11.3	16	6	16
		Building density and compact form	16	16	14	6	6	14	72	12.0	16	6	16
	quality and location of the building	**Geographical location**	16	16	16	12	12	14	86	14.3	16	12	16
		Construction technology	12	12	10	12	6	6	58	9.7	12	6	12
		Type of material	16	12	14	12	10	10	74	12.3	16	10	12
		Building life	6	6	10	10	12	6	50	8.3	12	6	6
		Building quality	12	12	16	12	10	10	72	12.0	16	10	12
		Building height	14	16	8	8	4	10	60	10.0	16	4	8
		Sum	**182**	**198**	**190**	**120**	**110**	**136**					
		Average	**13**	**14**	**13.57**	**8.57**	**7.86**	**9.71**					
		Max	**18**	**18**	**20**	**12**	**14**	**14**					
		Min	**6**	**6**	**8**	**2**	**2**	**4**					
		Mode	**16**	**16**	**14**	**12**	**6**	**10**					

"patterns of parts," "morphology," and "quality and location of the building." In second place was "sun and sunny days," with 190 points and in third place was "air temperature," with 182 points. We can therefore conclude that "wind," "Solar radiation and sunny days," and "air temperature" with a slight difference are three clear climatic indicators among the final indicators of the physical system and play an essential role in energy planning and design in cities. Of these, "above sea level" has the lowest score among the climatic indicators associated with the physical system of the site and the building. This means in the physical system of EUS, the focus should be more on the wind, the number of sunny days, the amount of solar radiation, and the air temperature which can help to increase the energy efficiency and effectiveness of urban areas. This matter could be done by establishing some urban energy rules for both existing and future settlements.

Table 5 illustrates the relationship between land use system indicators and climate indicators. In the flexibility category "land use types" scored 68

Table 5: Relation between Land-use system and climate indicators

Components and Variables		Indicator	Air temperature	Wind	Solar radiation and sunny days	Humidity water, and hydrology	Above sea level	greenery	Sum	Average	Max	Min	Mode
Land-use system	Flexibility	Land-use types	10	10	10	14	8	16	68	11.3	16	8	10
		Mixed land use	8	6	8	6	6	8	42	7.0	8	6	8
	Services distribution	Ratio of land use rate to a population growth rate	8	8	12	4	8	8	48	8.0	12	4	8
		Green space distribution	14	10	10	12	6	14	66	11.0	14	6	14
		Distribution of public spaces	12	8	4	10	2	12	48	8.0	12	2	12
		Active neighborhood center	12	8	10	8	4	12	54	9.0	12	4	12
		Sum	64	50	54	54	34	70					
		Average	11	8	9	9	6	12					
		Max	14	10	12	14	8	16					
		Min	8	6	4	4	2	8					
		Mode	8	8	10	#N/A	8	8					

points, and "distribution of green spaces" scored 66 points in the service distribution category. These two indicators obtained the highest score among other land use system indicators with climate indicators which means in the time of energy planning, the type of land use (residential, commercial, medical, etc.) and the place and distribution of green spaces are two sensitive indicators to climate indicator especially greenery, air temperature and the number of sunny days as well as the amount of solar radiation. Conversely, the "mixed land use," with a value of 42, shows the weakest correlation between the land use system indices and the climatic indices. Among the climate indicators, "greenery" with a total score of 70, a maximum of 16 points, and an average score of 12 are the most important indicator in the field of the land-use system. The "Air temperature" indicator, with 64 in the second rank, and the indices of "Solar radiation days" and "water and hydrology," with an equal score of 54, are both in the third rank. It means land use planning by energy efficiency approach needs a great focus on these three indicators.

According to Table 6, which shows the category of infrastructure systems related to the UES, the index of heating systems from the class of energy infrastructure has the highest score with a total of 72 which is similar to the result of many other studies (Esmaeilpour Zanjani *et al*., 2021). It followed by "Amount of energy transmission system," with 66 points which ranked second. "Energy intensity indicators in terms of primary energy and GDP," and "energy-saving "indicators are in the third rank, with 64 points. It has to be noted that there is a zero point in each of the indicators "streets and highway lights," "car refueling services," and "the extent of the road network," which means that there is no relation to any of the climate indicators from an expert perspective. For example, no correlation has been found between the street indicator, highway lights, and the greenery indicator, which means, although mentioned indicators play roles to decrease energy consumption, this issue could not be solved by using some strategies and rules related to climate indicators. From climate indicators, the air temperature index, (136 points), the solar radiation and sunny day's index (126 points), and the wind index (110 points) have been recognized as the most effective indicators of the energy efficiency of infrastructure system.

According to Table 7, on movement and accessibility system indicators and their relationship with the climate indicators, the "access to public spaces," indicator receives 60 points, which means is closely related to climatic indicators. Two other indicators in the second position, namely pedestrian access to essential services and green spaces, totaling 56 points. These three indicators' average and maximum values are very close, showing a slight difference in their ranking. In climate indicators

Table 6: Relation between infrastructure system and climate indicators

Components and Variables		Indicator	Air temperature	Wind	Solar radiation and sunny days	Humidity, water and hydrology	Above sea level	greenery	Sum	Average	Max	Min	Mode
Infrastructure system	Energy transition	Amount of energy transmission system	12	10	16	10	8	10	66	11.0	16	8	10
		The proportion of the population that has access to electricity	6	2	6	6	4	12	36	6.0	12	2	6
		The proportion of the population that primarily relies on fuel and clean technology	12	10	12	8	6	12	60	10.0	12	6	12
		Energy intensity indicators in terms of primary energy and GDP	18	12	14	6	6	8	64	10.7	18	6	6
		Installed renewable energy production capacity in developing countries (in watts per capita)	12	12	12	6	6	10	58	9.7	12	6	12
	Energy infrastructure	Smart networks	8	12	8	6	10	12	56	9.3	12	6	8
		Heating systems	16	12	12	8	12	12	72	12.0	16	8	12
		Streets and highway lights	8	8	6	2	2	0	26	4.3	8	0	8
		Car refueling services	12	4	4	0	8	6	34	5.7	12	0	4
		The extent of the road network	8	10	8	0	8	8	42	7.0	10	0	8
		Energy-saving	14	10	16	10	8	6	64	10.7	16	6	10
		Amount of energy for landscaping and traffic signs	10	8	12	8	4	6	48	8.0	12	4	8
		Sum	**136**	**110**	**126**	**70**	**82**	**102**					
		Average	**11**	**9**	**11**	**6**	**7**	**9**					
		Max	**18**	**12**	**16**	**10**	**12**	**12**					
		Min	**6**	**2**	**4**	**0**	**2**	**0**					
		Mode	**12**	**10**	**12**	**6**	**8**	**12**					

Table 7: Relation between movement and accessibility system and climate indicators

Components and Variables		Indicator	Air temperature	Wind	Solar radiation and sunny days	Humidity, waterand hydrology	Above sea level	greenery	Sum	Average	Max	Min	Mode
Movement and accessibility system	Accessibility	Pedestrian access to basic services	12	10	8	4	8	14	56	9.3	14	4	8
		Access to public spaces	16	10	10	6	8	10	60	10.0	16	6	10
		Access to green spaces	12	12	10	8	6	8	56	9.3	12	6	12
		Sum	40	32	28	18	22	32					
		Average	13	11	9	6	7	11					
		Max	16	12	10	8	8	14					
		Min	12	10	8	4	6	8					
		Mode	12	10	10	#N/A	8	#N/A					

Table 8: Relation between transportation system and climate indicators

		Indicator	Air temperature	Wind	Solar radiation And sunny days	Humidity, water and hydrology	sea level	greenery	Sum	Average	Max	Min	Mode
Transportation system	Personal and common vehicles	The amount and easy access to shared vehicles	12	6	4	2	8	4	36	6.0	12	2	4
		Number of electric and hybrid cars and other new technology cars.	8	6	8	8	4	6	40	6.7	8	4	8
		Amount of non-motorized transport with soft mobility (mobility with human power)	16	10	14	10	6	12	68	11.3	16	6	10
	Public transportation	The proportion of the population that has easy access to public transportation	14	12	8	10	8	10	62	10.3	14	8	8
		Number of bus stops / subway stations and terminals	12	8	8	6	4	12	50	8.3	12	4	12
		Number of railway stations	6	10	8	8	8	8	48	8.0	10	6	8
		Transportation and freight terminals	8	8	6	6	8	12	48	8.0	12	6	8
		Public transportation coverage	16	10	8	4	8	14	60	10.0	16	4	8
	Pedestrian and cycling capability	The number of pedestrian paths	14	14	18	14	2	18	80	13.3	18	2	14
		Number of bike lanes	10	14	14	10	2	16	66	11.0	16	2	10
		The rate of traffic signs for pedestrian and cycling routes	6	2	2	6	0	2	18	3.0	6	0	2
	Parking	The amount of bicycle parking	4	2	2	8	0	2	18	3.0	8	0	2
		The number of parking lots and marginal parking lots	4	6	8	8	2	12	40	6.7	12	2	8
		Amount of parking near public transportation stations	8	4	10	10	2	10	44	7.3	10	2	10
		Sum	**138**	**112**	**118**	**110**	**62**	**138**					
		Average	**10**	**8**	**8**	**8**	**4**	**10**					
		Max	**16**	**14**	**18**	**14**	**8**	**18**					
		Min	**4**	**2**	**2**	**2**	**0**	**2**					
		Mode	**8**	**6**	**8**	**8**	**8**	**12**					

parts, "air temperature" has the highest total score (40) in this category, which shows the importance of this indicator in designing and planning for public and green spaces and also accessibility of basic services. And then, the wind and greenery indicators are in the second and third rows which are identified as other significant climate indicators in terms of increasing energy efficiency in experts' view.

Table 9: Relation between cultural system and climate indicators

		Indicator	Air temperature	Wind	Solar radiation and sunny days	Humidity, water and hydrology	Above sea level	greenery	Sum	Average	Max	Min	Mode
cultural system and human behavior	Energy knowledge	Eeducation	10	2	4	6	6	10	38	6.3	10	2	10
		Household energy consumption	14	12	14	10	8	10	68	11.3	14	8	14
		Suitability of cities with the structure of direct participation of civil society in urban planning and management	6	6	6	6	4	8	36	6.0	8	4	6
	environmentally friendly behavior in organizations and cities	Amount of green workplace practices recycling programs, reuse	8	6	6	6	8	10	44	7.3	10	6	6
		Suitability of collected urban solid waste and related facilities	8	4	8	6	8	8	42	7.0	8	4	8
		The amount of energy consumption	16	16	14	12	12	14	84	14.0	16	12	16
		The rate of water consumption	12	12	8	14	10	14	70	11.7	14	8	12
		The amount of carbon dioxide production	14	10	12	12	10	10	68	11.3	14	10	10
		The extent of environmental impact	16	14	16	8	8	10	72	12.0	16	8	16
		Sum	104	82	88	80	74	94					
		Average	12	9	10	9	8	10					
		Max	16	16	16	14	12	14					
		Min	6	2	4	6	4	8					
		Mode	14	12	14	6	8	10					

According to Table 8, the number of pedestrian routes has the most significant relationship with climate indicators scoring 80 and with the highest average and maximum efficiency. According to this, the share of non-motorized transport and soft mobility (mobility with manpower) ranks second among the indicators for personal and shared vehicles component. And then, the number of cycle routes with a score close to the previous indicator (2 points less) is in third place with the strongest correlation of climate indicators. The optioned results in the columns prove that two climatic indicators, air temperature, and greenery, with the same score of 138, are in first place for the most connection with the transportation system in terms of less energy consumption and increasing energy efficiency. Then the three indicators of “sunlight and sunny days,” “wind,” and “humidity, water, and hydrology” are in the second, third, and fourth ranks. In contrast, the “above sea level “indicator with zero points for two indicators has the least connection with the transportation system in urban energy planning. This analysis means, the number of pedestrian and cycle routes and also, the amount of soft mobility have a direct relation to the air temperature indicators (Minimum and maximum air temperature in different seasons, average temperature, the existence of micro-climate, and the number of urban heat islands), wind indicators (Wind flow pressure, dominant wind direction and

Table 10: Relation between technological system and climate indicators

		Indicator	Air temperature	Wind	Solar radiation and sunny days	Humidity, water and hydrology	Above sea level	greenery	Sum	Average	Max	Min	Mode
Technology system	Access	Information technology connection	6	2	8	6	6	6	34	5.7	8	2	6
		Internet access and services	4	2	6	4	8	8	32	5.3	8	2	4
		Computer access and smart devices	8	6	6	6	6	10	42	7.0	10	6	6
		Sum	18	10	20	16	20	24					
		Average	6	3	7	5	7	8					
		Max	8	6	8	6	8	10					
		Min	4	2	6	4	6	6					
		Mode	#N/A	2	6	6	6	#N/A					

wind speed) and greenery indicators such as the number of trees and green areas. It means the higher quality of each of these indicators could significantly impact attracting people and general view, it effects on decreasing energy consumption.

Table 9 demonstrates the links between the “cultural system and human behavior “and climate indicators. The indicators of “the amount of energy consumption,” “the extent of environmental impact,” and “the rate of water consumption” in the category of “environmentally friendly behavior in organizations and cities” were 84, 72, and 70, respectively first, second and third points. in the energy knowledge category, the indicator of “Household energy consumption” ranked first. In climate indicators results “air temperature” indicator has the most significant influence on the cultural system and human behavior, with 104 points and the highest average score of 12, followed by two indicators of “solar radiation and sunny days” and “greenery” which are in second (94 points) and third place (88 points). According to the numbers obtained from the expert’s view, “air temperature,” “greenery,” and “solar radiation and sunny days” indicators play a significant role in the amount of energy and water consumption(in public and household categories) and the extent of environmental impact, in the other hand these three climate indicators could influence on the cultural system and human behavior. So, it is essential to consider these indicators in times of the cultural part of urban energy planning.

According to Table 10, the “Computer access and smart devices” indicator ranks first with 42 points in technological system indicators. Followed by two indicators of “information technology connection” with a score of 34 and “Internet access and services” with a score of 32. Concerning climatic indicators, the “greenery” indicator has the highest score (24 points) in this section, followed by the indicator of “Solar radiation and sunny days” and “Above sea level” with a score equal to 20. Finally, the “air temperature” indicator is third-ranked with 18 points. It has to be said that there is no visible relation between the technological system indicators and climate indicators but due to the numbers obtained from experts’ view, there is a link between the accessibility of technology and greenery. Compared to the other UESs, the score of climate indicators in relation to technology accessibility is less than other categories.

In general, the relation between each system of the defined UES indicators and local climate indicators could be summarized as follow Table 11:

- Concerning the physical system indicators, “wind”, “Solar radiation and sunny days,” and “air temperature” are three influential climatic indicators with 198, 190, and 182 points respectively. So, to reduce energy consumption through climate characteristics in the physical system of the city, the three mentioned indicators are the most significant indexes.
- In the land-use system, “greenery” has been found to be the most important indicator (70 points),

Table 11: A general view of the relationship between UESs and climate indicators

Total points of each system	Air temperature	Wind	Solar radiation and sunny days	Humidity ,water and hydrology	Above sea level	greenery
Physical system	182	198	190	120	110	136
Land-use system	64	50	54	54	34	70
Infrastructure system	136	110	126	70	82	102
Movement and accessibility system	40	32	28	18	22	32
Transportation system	138	112	118	110	62	138
cultural system and human behavior	104	82	88	80	74	94
Technology system	18	10	20	16	20	24
SUM	682	594	624	468	404	596

and "Air temperature" is the second rank (64 points), followed by "Solar radiation and sunny days" and "water and hydrology" indicators in the third rank (54 points). So, in order to increase energy efficiency in land-use planning special attention should be on "greenery "and "Air temperature" linked to the land-use system indicators.

● The "air temperature" indicator in the infrastructure system obtained the highest score with 136 scores, followed by the "Solar radiation and sunny days" as second rank (126 scores) and the "wind" indicator at the next level with 110 scores. It means, to reduce the energy consumption of energy transition and energy infrastructure components in relation to climate indicators, the focus has to be on "air temperature", "Solar radiation and sunny days" and "wind" indicators.

● "Air temperature" has the highest influence on movement and accessibility system indicators with total score of 40, which shows the importance of this indicator in the energy design and planning toward accessibility of green and public spaces and also main services in a city. And then the wind and greenery indicators are in the second rank with 32 scores.

● In the transportation system, two climatic indicators of "air temperature" and "greenery," are in first place with 138 points. And then "Solar radiation and sunny days" and "wind" are in the second and third ranks with 118 and 112 scores. This section of the descriptive analysis shows the importance of mentioned climate indicators in planning and designing pedestrian and cycling paths to increase energy efficiency.

● The "Air temperature" indicator impacts the cultural system and human behavior the most (104 scores). And then "greenery" and "Solar radiation and sunny days" are in the second and third ranks with 94 and 88 scores. It means environmentally friendly behaviors and energy literacy could be affected by mentioned climate indicators.

● In the technological system, the "greenery" indicators has been recognized as the most important climate indicators with the highest score of 24, followed by the indicator of "Solar radiation and sunny days" and "Above sea level" with a score equal to 20. Totally in this system, the number shows less relation with climate indicators compared with previous systems and it mean independency of defined technological system of UES to climate indicators.

As a result, "air temperature" is the most important climate indicator in the defined UES as Ching, *et al.*, 2005 and De Felice *et al.*, 2015 identified it as an influential indicator of electricity demand which is one of the two most energy usages in cities. It is followed by "Solar radiation and sunny days" and "wind," as the second and third important indicators which confirmed the study that has been done by Lam *et al.*, 2008. After mentioned climate indicators, "greenery" has been recognized as the 4th significant indicator. From experts' view "greenery" could also play a remarkable role in cooling areas and less energy consumption (Zhang *et al.*, 2014). Analyzing each of the indicators of local climate variables in a comprehensive view and its effect on the urban energy system has been the innovation of this study compared to previous ones. More importantly, defining the new master urban energy system which includes different variables and indicators was the main result of the research.

CONCLUSION

International concerns about climate change and environmental impacts linked to nonrenewable energies have pushed up urban designers and planners to identify the influential urban indicators to reduce energy consumption as well as increase energy efficiency in cities. One of the main factors which can play a significant role in moving toward natural base solutions is climate. The first theoretical achievement of this research is in line with other studies on energy planning and completing their theoretical topics through basic research to promote knowledge. In previous inquiries in the field of urban energy planning or design, only one component or dimension has been investigated. Either in the field of physical (construction) and transportation, or a descriptive analysis of a case study with different components. Given the importance of increasing the efficiency and effectiveness of energy in cities that can have long-term effects on humans, settlements, and the environment. The present study was conducted to identify the indicators of planning and designing the urban energy system indicators by introducing a new conceptual framework. It has been done through an extensive study of literature, expert interviews, and questionnaires. Then analyzes of the relationship between obtained UES conceptual framework and related climate indicators have been done by questionnaires (They were identified by non-probability and judgment sampling methods). After identifying the indicators of the urban energy system (divided into seven components or systems) shown in Fig.1, and effective climatic indicators (divided into six components) in the energy discussion, the level of relationship with these two groups of indicators was measured by experts, and the results demonstrate "air temperature" variable as the most related climate indicator from the experts' view with seven analyzed urban energy systems, as guessed, followed by "Solar radiation and sunny days," "wind," and "greenery." And "Sea level" ranked the minimum score in four systems (Physical, Land-use, Transportation, and cultural systems) which shows a less relationship between these indicators with urban energy system indicators. Then "Humidity, water and hydrological" indicator obtained the second rank with less connection with urban energy system indicators. Findings taken from this research are expected to be an academic knowledge and practical source for getting a better understanding of indicators and variables that has to be noted during urban energy planning and design. Future researchers could investigate the same research by using different analysis methods to find relations and correlations between all mentioned indicators. Additionally, future studies should take into the institutional and economic dimensions to complete the theoretical framework of urban energy systems which has been obtained to fix the theoretical lack of this subject which was one of the limitations of this research. Also, the indicators could be used for the evaluation of a project. Globally, this study also contributes to the literature on the foundations for successful urban energy planning applied on local scales.

AUTHOR CONTRIBUTIONS

N. Esmaeilpour Zanjani performed the literature review, analyzed and interpreted the data, prepared the manuscript text, and manuscript edition. Y.A. Ziyari, helped in the literature review, doing survey and manuscript preparation Z.S. Zarabadi consulted in research analysis. H.R. Sabbaghi helped in manuscript preparation. R. De Lotto aided in defining the concepts of the subject and filling out the questionnaires.

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CONFLICT OF INTEREST

The authors have no conflict of interest to be declared concerning this review paper. Also, the authors have checked all the ethical affairs comprising duplicates, misconduct, data making, informed consent, and plagiarism.

PUBLISHER'S NOTE

ABBREVIATION

C	Climate
CVR	Content Validity Ratio
UES	Urban Energy System

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