ITU A|Z • Vol 17 No 3 • November 2020 • 89-101

Relation between urban form and heating energy consumption

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Received: November 2017 • Final Acceptance: December 2019

Abstract

The climate change and accompanying environmental problems have led different disciplines to think about that the natural resources soon start to run out. Rapid urbanization and industrialization and increasing pressure on natural resources have brought the concept of sustainability in urban planning discipline. Rapidly depleted energy sources threatened by uncontrolled growth have led to the emergence of new planning strategies and urbanization trends in urban energy efficiency and sustainable planning. There are many multidimensional studies in the context of urban parameters aims to provide sustainable settlements. One of those parameters is urban form, which comprises the spatial composition of buildings and open spaces in a physical texture. Theoretically, it is already known that there is a strong relation between urban form and energy consumption; but there is a lack of examination on existing settlements. This paper examines the relationship between urban form and heating energy consumption in different urban textures from Istanbul using the actual values of heating energy consumption to show up if the practical results are compatible with theoretical assumptions. It focuses on energy performance of urban textures and takes human behaviours and socioeconomic factors into account as another layer. Case study clearly underlines that the urban form of settlements creates a significant difference about the consumption of heating energy, while human behaviours and socioeconomic factors also have apparent impacts on it.

Keywords
Energy planning, Heating energy, Energy efficient urban form, Sustainable urban morphology.

doi: 10.5505/itujfa.2020.09787

1. Introduction

Irreversible damage of natural resources and global environmental problems has led to the emergence of the concept of sustainability especially in urban planning discipline, while the urbanization has been considered as the main responsible of energy consumption. The emergence of the concept of sustainability, which aims the balance between the economic, environmental and social dimensions of development is an important point that has led to changes in the form of modern cities after the industrial revolution.

In general meaning, sustainable urban planning refers to a mixed form of land use, aiming the efficient use of land in urban spaces, energy efficiency in residential areas, environmental facilities, transportation etc. (Mikaeili and Memlük, 2013). The management of the energy consumed in the urban area is the basis of sustainable urbanization and the effect of urban form on energy demand is a major challenge for achieving more sustainable urban environment.

As it is widely accepted that there is a direct relationship between urban morphology and energy consumption. Studies in the literature focusing on urban form and energy consumption are primarily from the perspective of individual buildings.

Olgyay's studies (1963) and Martin's studies (1967) as the first studies in literature, estimates the energy demand at micro scale by calibrating geometric approaches of building form and basic scientific principles with experimental results. Donovan and others (1976) attempts to identify and measure the factors that affect the energy consumed for residential heating energy in the UK using statistical models, examining the impact of price and analyzing behavioral changes. Gupta's study in 1984 is another macro scale study after Martin's as it shows that the distance between buildings, orientation and form are important factors in thermal performance. Newton et al. (2000) found that in terms of operational energy consumption, apartment buildings consume less energy than detached houses, according to a study based on the energy performance of two different types of dwellings, including detached houses and apartments throughout several climate zones in Australia.

Many of these studies take solar gain as an indicator of thermal performance and analyze a cluster of buildings using the simulation tools referring to hypothetical calculations and theoretical assumptions. Yet, there is no evident study derives from actual energy consumption values of an existing urban area that real human behaviors are effective.

In this study, relation between urban form and heating energy demand is examined by use of actual heating energy consumption values of existing settlements. The aim of this study, first of all to test the theoretical and practical assumptions of the relation between urban form and heating energy in residential areas using actual consumption values and to bring out the common morphological characters of similar heating energy consumption in living areas which have different morphologic and socioeconomic characters in neighborhood scale. It highlights the crucial morphological parameters of urban design to decrease the heating energy demand and provides spot benchmarks for urban design and management policies of new and existing settlements.

The method of this study bases on comparative analysis technique of a large amount of raw data set accumulated via surveys and computable inputs in order to explore the differences in heating energy consumptions in selected areas. Relational research methods are used in order to make the comparisons of parameters. Comparisons are visualized with matrixes and graphics. Relations of parameters were analyzed by use of non-parametric statistical methods.

The criteria for the selection of the cases is all of them are chosen from most settled residential regions of Istanbul that reflects the general housing typologies of Istanbul with homogenous urban forms. They have distinct morphologic parameters that are asserted in the literature as the most effective in heating energy performance of settlements in macro scale.

Neighborhoods with similar typology have different social and economic conditions that widen the range of the study and help to explore how much other parameters affects the consumption values. The morphologic parameters that effect heating energy performance of settlements in macro scale are determined based on the literature.

This study is comprised of 3 parts. In section 2, relation between urban form and heating energy consumption is examined introducing the parameters of urban form affecting heating energy consumption in macro scale. In section 3, aim of case study is declared, method of data collection and processing are explained. Morphological parameters are analyzed in study areas and compared with actual natural gas consumption values. Conflicts and constraints of results are rendered while findings are discussed. In the last section, conclusions derived from this study are revealed.

2. Factors affecting energy consumption of settlements

In urban scale, different researchers have classified factors that play significant role in energy consumption of settlements in different ways. However, it is possible to group them under 3 main classes; natural factors, socioeconomic factors and physical factors.

Climate, topography and orientation are the main natural factors in macro scale. Climate is especially the key determinant of heating energy need in residential areas. However, the increase or decrease of energy consumption in residential areas is not directly related to climate conditions. Due to the changes in heating and cooling services, the effect of climate on energy consumption is negligible when compared to other variables.

The topographic settling and the orientation of buildings affects the impact of weather conditions, such as the amount of solar gain, wind etc. and it changes the need of energy. Sustainable urban design policies are the key of utilizing the weather conditions.

Social behaviors and economic situations are certainly effective on the use of residents and in parallel the consumption of energy in settlements. Household size, user behaviors and habits, life cycles, income rates etc. are socioeconomic factors that may affect the energy consumption trends.

The most significant physical factor that causes energy consumption in urban scale is undoubtedly the urban form. Studies show that the composition of buildings and open spaces in a physical texture can have serious changes in energy consumption.

2.1. Urban form and energy efficiency

The idea of creating sustainable cities where the urban energy is protected has led to many new urban morphology concepts in the literature and many of these concepts agree that a physically more intensive urban forms are more sustainable. The density of a settlement plays a crucial role in energy conservation and the physical density of a settlement appears with the concept of compactness.

There are numerous literatures describing the compact city concept, but the basic approaches are the same. According to the Green Paper (2005), the compact city strategy focuses on compact, mixed-use and dense settlement patterns that minimize the need for vehicles and mobility while enabling public transport to be used effectively, while focusing on the city's form and the effectiveness of the distribution of human activities within it.

Dumreicher et al. (2000) argues that a sustainable city must be compact, dense, diversified, and at a high level of integration.

According to Wheeler (2004), compactness also refers to the urban adjacency and connection that future urban development must take place alongside existing urban structures.

According to EU, the compact city approach aims to succeed these goals:

(1) Saving resources and energy (such as land use, transportation, pollutant emission, wastes etc.)

(2) Revitalization inner city, to control the expansion of city (KAJI at all, 2003)

As it is being a critical determinant of energy efficiency, sustainability and the cost of infrastructure; urban form has a strong effect on how people interact, consume and create value within cities (www.urbanmorphologyinstitute.org).

2.2. Parameters of urban form affecting heating energy consumption

In today's cities, US Department of Energy (DOE) declares that almost 39% of the energy consumed in the urban area is spent by the residents. It is followed by transportation and industry, while the world's residential energy consumption is expected to increase by 48% from 2012 to 2040 (World Energy Demand and Economic Outlook, 2016). Besides, researches show that most consumed energy in residential areas is heating energy. This rate is 20% in Japan, 35% in China, 45% in the US and 70% in European cities (WBCSD, 2009). This shows that controlling the consumption of heat energy in residential areas is very crucial to achieve the sustainability in settlements.

The heat consumption in the residential areas has been covered in theory many times, the factors affecting the heat consumption are listed and many researchers, theorists and academicians have revealed the general bases that can be a reference to the design of the new settlement patterns. However, there is no macroscale study bases on the real consumption quantities that shows how these theories working in reality.

There are many natural, physical and socioeconomic factors mentioned in literature affecting the consumption of heating energy in residents. Urban form is the major physical factor including many aspects in different urban scales.

Components of urban form that affect the heating energy consumption depending on the urban scale; some of them creates major effects and some creates minor effects.

2.2.1. Typology of buildings

Studies on settlements have shown that there is a close relationship between typology of buildings and energy consumption for heating. Different configurations of buildings such as detached housing, high-rise apartments, slab housing and compact urban blocks etc. perform different when the heating energy consumptions are compared. They create different density of settlements and receives different number of inhabitants.

Geometrical characteristics of the buildings such as height, wall-to-volume ratio and the orientation of the buildings affect the solar gain and heating energy demand. According to the simulations based on experimental models shows that, height of buildings has a parabolic graphic when the heating energy demand is calculated in settlement; when low height buildings consume more heating energy compared to the middle height ones, very high buildings cause an over-shading effect on surrounding buildings and prevent the accessibility of sunlight (Shang et al., 2013). Type of dwellings changes the consequences of consumption of energy, materials, land for housing, transportation and urban infrastructure based on sustainability (Walker and Rees 1997).

2.2.2. Land use density of settlements

Density is a multidimensional concept in urban planning and design, and it refers to dwellings or people per unit area. Land use density of a settlement is the ratio of the total standing area of all buildings to the total area of the interest area (Pan et al, 2008). This ratio corresponds to the rate we accept as "building coverage ratio" (BCR) and shows the land use density ratio of total structured area. Since it is already accepted that, a more compact urban form provides a more efficient heating system (Owens, 1992), it is also critical that how dense should a settlement be, for an ideal life quality. A certain percentage of the available lot space need to be reserved for parking, setback and green area. However, sprawling on the land use means more soil pollution so the built environment has to be limited. According to Jabareen, (2006), high density and integrated land use not only conserve resources but also provide for compactness that encourages social interaction.

Building coverage ratio does not directly determine the density of the settlement; because it does not provide any information about the number of people or amount of construction in a proper size of settlement. However, the density of land use allows the interpretation of the urban fabric as sprawled or compact in the settlements that have similar construction area and population.

2.2.3. Construction density and building height of settlements

Construction density is the common measurement that directly refers to the compactness of a settlement. It is generally calculated by "floor area ratio" (FAR) which means the ratio of the sum of the areas of all building floors. FAR is one of the most common measurement systems used to regulate the density of settlements and to control the bulk sizes.

In urban areas, construction density is very crucial for sustainable urban development policies. Low construction density that means lower height and larger urban area, while high construction density means higher buildings and denser urban form. Energy expenditure per square meter in multi-storey residential structures is much lower than discrete single-house dwellings (Næss et al., 1996). However, Doherty et all (no date), states that the high buildings do not always mean higher density or greater energy efficiency. High buildings may affect each other's accessibility to sun and may cause over-shading. When the vertical densities exceed the bearing capacity of the urban area, other energy consumptions per unit begin to increase. Here the point is what the ideal density of a settlement should be.

2.3. Socioeconomic factors affecting heating energy consumption

Income rates, lifestyles, life cycles, cultural habits, educational level, household size and other socioeconomic factors are also effective on the consumption of heating energy in settlements.

Herring and Roy, (2007) determine the socioeconomic effects in 3 different ways; first is the price effect that means more efficient energy usage reduces the costs. Second is indirect effect or income effect, which means the reduction of energy costs leads higher income share for other goods and services. And the third is economy wide effect (or macroeconomic effect) that leads energy consumption increase in other sectors, while the economic gains of energy consumption spend in other interests.

Educational level creates a general decrease in energy consumption habits since the awareness level is very high and the consciousness about environment and sustainability is highly developed.

Life cycle and household size is also effective on energy consumption. In the neighborhoods which larger families are living, consumption increases in parallel.

3. Case study

This study attempts to determine and quantify the factors affecting heating gas consumption. The report focuses on 20 neighborhoods selected from 6 neighborhoods in Istanbul were compared according to their forms and heating energy consumptions while evaluated with their socioeconomic status in order to understand the effect of human behavior. Selected neighborhoods reflect the typology of buildings where patterns are similar to those in all of İstanbul.

The major data series used in this study come from IGDAS natural gas consumption data. Consumption data on individual homes-gas delivery records for some 18000 building in 20 neighborhoods which are listed in Table 1.

Consumption amounts were degraded to unit consumption values and calculated per building, per square meter and per dwelling unit in order to explain the consumption differences of settlements with similar typologies. Comparisons have made by correlation analysis; scatter graphs, matrixes and column graphs inserted in tables have been used. All data

Table 1. *Case Study Areas.*

Beşiktaş	Sarıyer	Bakırköy	Üsküdar	Kadıköy	Ataşehir
Dikilitaş	Yeniköy	Ataköy 3-4-11	İcadiye	Osmanağa	Barbaros
Ulus	Reşitpaşa	Ataköy 2-5-6	Kuzguncuk	Caferağa	Kayışdağı
Levent	Emirgan	Ataköy 7-8-9-10	Salacak	Fenerbahçe	
Etiler	Pınar			Suadiye	

were evaluated over the same year so that the data can be compared fairly.

3.1. Morphologic parameters

Morphologic parameters that are considered in this study are calculated for every study area and categorized with their major values in order to draw some general rules in macro scale.

The morphologic parameters that effect heating energy performance of settlements in macro scale are considered as below:

- Building typology
- Land use density
- Building height
- Construction density

During the study, effects of orientation, green spaces, waterways etc. are not considered while non-morphological factors that have impact on heat energy demand kept constant.

3.1.1. Building typology

In the first stage, dominant building typologies of the selected neighborhoods were classified under 7 typologies in order to compare their thermal performance. Typologies are considered as the main building typologies of Istanbul emerged within years and have created the urban pattern of Istanbul over centuries. These are; detached, high rise, compact and row apartment blocks, villa type single residences, mansions and squatters. Aerial photos of urban textures in each neighborhood are showed in Figure 1.

General housing typology of Istanbul predominantly consists of apartment blocks. Apartment blocks are a group that warrants this study that over 80 percent of all housing units in Istanbul apartment blocks. However, there are different types of apartments that typologically behaves different from each other. In every neighborhood, homogeneity of building stock has calculated according to typological classifications as shown in Table 2.

Detached apartment blocks

It is a residential typology with a general character of discrete order, predominantly 3 to 6 storey building stock and multiple dwellings.

In this study, typology of Fenerbahçe, Dikilitaş, Pınar and Kayışdağı neighborhoods are considered as detached apartment blocks since more than %71 of building stock has detached character in average.

High-rise apartment blocks

It refers to single apartment blocks with 5 and more storeys and multiple dwellings. Typology of Ataköy 2-5-6 and Suadiye neighborhoods are considered as high-rise apartment blocks since more than %65 of building stock has 5 and more storeys.

Compact apartment blocks

Apartment type typology with a general character of adjacent order, predominantly having 3 to 6 storey building stock and multiple dwellings. Typology of Osmanağa, Caferağa, İcadiye and Salacak neighborhoods are considered as compact apartment blocks since more than %85 of building stock has adjacent order.

Row apartment blocks

It is an apartment type typology, which consists of several attached blocks with 5 and more storeys and multiple dwellings.

Typology of Ataköy 3-4-11 and

Figure 1. *Aerial Photos of Urban Textures in Each Neighborhood.*

Ataköy 7-8-9-10 are considered as row apartment blocks since more than %74,8 of building stock consists of row apartments.

Villa type single residences

This typology simply refers to single detached houses with 2-3 storey and single dwelling unit. Etiler, Levent and Emirgan neighborhoods are considered as villa type single residences since more than %65 of building stock consists of villas.

Mansions

Mansions are buildings with single or double dwelling units that has a high construction area than village type houses. Kuzguncuk, Yeniköy and Ulus neighborhoods are considered as mansion type housings since more than %50 of building stock consists of mansions.

Table 2. *Typological Homogeneity Ratio.*

Building Typology	Neighborhoods	Typological Homogeneity Ratio
Detached Apartment	Kayişdaği Fenerbahçe Pinar Dikilitaş	71.0%
High Rise	Suadiye Ataköy 2-5-6	65.0%
Compact Apartment	Osmanağa Icadiye Caferağa Salacak	85.0%
Row Apartment	Ataköy 7-8-9-10 Ataköy 3-4-11	74.8%
Villa Type	Levent Emirgan Etiler	65.0%
Mansion Type	Yeniköy Kuzguncuk Ulus	50.0%
Squatters	Barbaros Reşitpaşa	80.0%

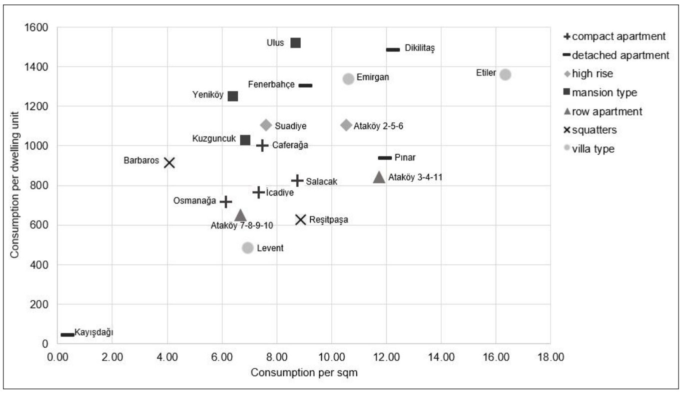

Figure 2. *Natural Gas Consumption Values of Selected Building Typologies.*

Squatters

Squatters are 2-3 storey unlicensed buildings that has low quality construction and infrastructural conditions. Barbaros and Reşitpaşa neighborhoods are considered as squatters (slums) since %80 of building typology consists of squatters.

In each neighborhood, it is expected that there will be differences in natural gas consumption between the urban forms which assemble contiguously or discretely. Different building typologies are also expected to have different consumption values. Annual natural gas consumptions of all typologies were calculated as per square meter, per dwelling unit and per building.

In comparison of 20 selected neighborhood, it is seen that there is no dominant typology that has lower or higher natural gas consumption.

However, when average consumption values of typologies per square meter are examined, it is seen that the highest consumption values belong to villa type single residences while lowest values belong to squatters, row and compact apartment blocks.

All the areas that the consumption per dwelling unit and per square meter is lowest, building textures are adjacent; vice versa, highest consumptions belongs to discrete building textures. When we compared the dwelling unit consumptions, highest values belong to mansion types since they have highest dwelling unit size. Figure 2 shows the natural gas consumption values of selected building typologies.

As a general tendency, more compact and dense building typologies have lower consumption values such as compact apartment blocks, high rise apartment blocks and row apartment blocks, but it is not possible to claim that the specific building typologies have lower or higher consumption trends apparently since they have also have different building quality, usage, population, social and economic structure.

3.1.2. Land use density ratio

Land use density refers to the building coverage ratio (BCR) which means buildings' floor space covered in the land. BCR ratios in the area. At the neighborhood scale, the average occupancy rate was calculated for each neighborhood as land use ratio. Land use density does not have a decisive value directly related to the density of the settlement; because the unit does not provide information about the number of people in the settlement or the construction site. However, it enables the interpretation of the compactness of urban texture in settlements with similar land use density, construction site and population.

Differences in land use density can change the heating energy demand and cause less or more natural gas consumption in the settlements. The approach used in this section is formulated around spearman correlation method draws from two data series; building coverage ratio and consumption per sqm that attempts to determine whether there is a relation between heating energy consumption and land use density.

Since the variables are not normally distributed, spearman correlation test is applied to find out if there is any relation between variables as shown in Figure 3. Correlation value of these two variables is calculated as -0.45 that means there is a reasonable correlation between them; negative correlation value shows that there is an inverse relationship between them; while consumption per square meter increases, land use density (BCR) tends to decrease. This decreasing tendency is more evident in the neighborhoods where the building mass also increases vertically.

Neighborhoods that have same land use density levels have no similar consumption trends, however, in same typologies, it is clearly observed that while land use density increases, natural gas consumption tends to decrease.

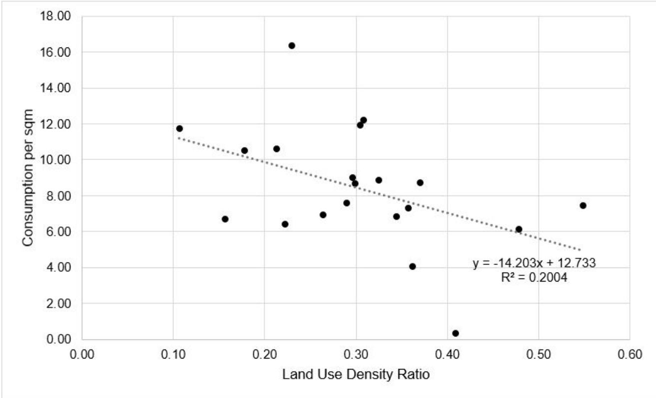

Figure 3. *Comparison of Consumption per sqm and Building Coverage Ratio.*

3.1.3. Building height

Building height, that creates vertical density in urban form expected to affect heating energy consumption. Study areas are clustered according to their average heights to be able to compare in neighborhood scale. Four different height ranges are specified as 2-3 floors, 3-5 floors, 4-6 floors and 5-10 floors. Neighborhoods that have similar consumption per square meter do not properly have similar building heights. However, consumption difference of typologies, land use ratio or construction ratio in neighborhoods that have similar building heights can be easily noticed.

Except for the neighborhoods which have 2-3 floors, lowest consumptions in every height cluster belongs to adjacent building forms.

It is observed that neighborhoods that have less than average consumptions per square meter are villa types, mansions and detached houses that also have lower land use density.

In the neighborhoods that have 3-5 or 4-6 floors, population density is also in optimum levels when compared to the others. When study areas are

Table 3. *Morphologic Parameters of Selected Neighborhoods and Average Natural Gas Consumption Values per Sqm.*

Neighborhoods	Building Typology	Structural Layout	Number of Floors	Land Use Density Ratio	Construction Density Ratio	Average Consumption per m²
Barbaros	squatters	adjacent	2-3	0.36	2.68	4.07
Emirgan	villa type	discrete	2-3	0.21	2.95	10.62
Etiler	villa type	discrete	2-3	0.23	3.79	16.35
Kayışdağı	detached apartment	discrete	2-3	0.41	3.60	0.34
Kuzguncuk	mansion type	discrete	2-3	0.34	2.74	6.86
Levent	villa type	discrete	2-3	0.26	2.31	6.95
Reşitpaşa	squatters	adjacent	2-3	0.33	2.48	8.87
Yeniköy	mansion type	discrete	2-3	0.22	1.69	6.41
Fenerbahçe	detached apartment	discrete	3-5	0.30	5.34	9.02
İcadiye	compact apartment	adjacent	3-5	0.36	4.41	7.33
Pınar	detached apartment	discrete	3-5	0.30	2.48	11.93
Salacak	compact apartment	adjacent	3-5	0.37	3.66	8.74
Ataköy 3-4-11	row apartment	adjacent	4-6	0.11	5.32	11.73
Caferağa	compact apartment	adjacent	4-6	0.55	5.03	7.46
Dikilitaş	detached apartment	discrete	4-6	0.31	5.86	12.22
Osmanağa	compact apartment	adjacent	4-6	0.48	4.79	6.13
Ulus	mansion type	discrete	4-6	0.30	5.10	8.69
Ataköy 2-5-6	high rise	discrete	5-10	0.18	7.66	10.52
Ataköy 7-8-9-10	row apartment	adjacent	5-10	0.16	7.60	6.69
Suadiye	high rise	discrete	5-10	0.29	5.84	7.61

clustered according to their dominant number of floors and average consumptions per square meter are compared, in every height shows us that the highest consumption average belongs to 2-3 storey and lowest consumption average belongs to 3-5 storey neighborhoods as a general conclusion.

3.1.4. Construction density

Construction density indicates both horizontal and vertical density of a settlement. Common way to understand the construction density in that scale is to calculate the floor area ratio (FAR). This ratio gives us information about how many times the mass of the area of land used is building mass, but also refers to average building height in the settlement.

In the study, construction density is calculated in two different ways; first floor area ratios (FAR) of every neighborhood are calculated. Average construction area of the buildings in selected neighborhoods are also calculated in order to determine the building masses for each.

Average construction area of buildings in neighborhoods and the consumption values have a strong correlation value which is -0,53, means that while construction area per building increases, natural gas consumption decreases as shown in Figure 4.

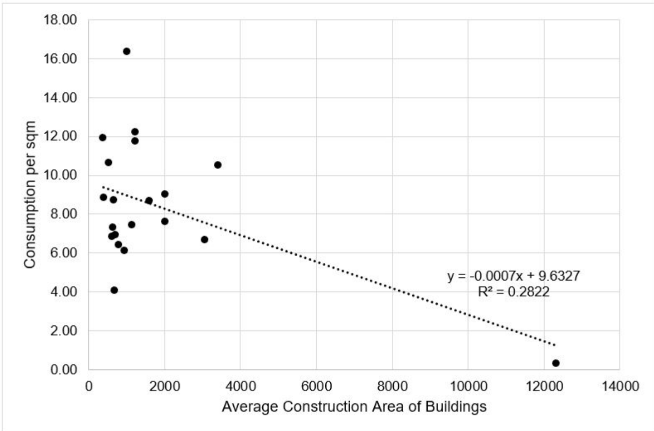

Figure 4. *Average Construction Area of Buildings in Each Neighborhood and Consumption Values.*

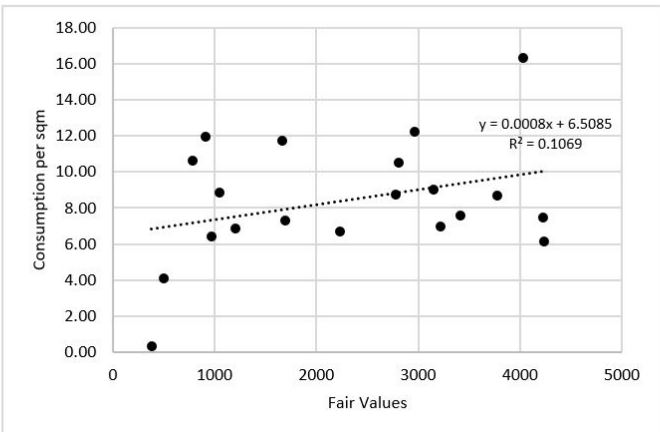

Figure 5. *Comparison of Consumption per sqm and Fair Values.*

3.2. Socioeconomic conditions

All case study areas have different socioeconomic levels that may affect heating energy demand. Although habits, life cycle, household size etc. are all effective on heating energy consumption. In order to measure that, fair values are taken as an indicator of income level. Correlation value between fair values and consumptions is calculated as 0.33 as shown in Figure 5. It means there is a medium level positive correlation showing that while income level increases, heating energy consumptions increases in parallel.

3.3. Comparisons and findings

The results of morphological comparisons are tried to be combined and meaningful similarities are tried to be interpreted Table 3 shows morphologic parameters of selected neighborhoods and average natural gas consumption values per sqm.

In the neighborhoods consists of compact apartment blocks, as a general tendency consumption per square meter is in medium levels.

In the typology of detached apartments, when land use density is high, consumption levels are observed medium, when land use density is medium, consumption levels observed high. This means in detached building texture; land use density affects the consumption tendency inversely. Similar situation is also observed in the neighborhoods that have high rise building typology.

In the neighborhoods consists of villa type houses, there is no low consumption tendency as expected. In squatters, income level seems to be effective on consumption values.

All morphological comparisons show that the physical dynamics affecting heating energy consumption in settlements are dependent to each other's and needed to be evaluated together. Besides, unit consumption values help to explain different physical and social characteristics of related neighborhoods. Since every neighborhood has its physical and social dynamics, similar morphologies needed to be evaluated with all aspects of unit consumption values Table 4 shows natural gas consumption trends in similar morphologies.

The highest consumption per person belongs to Etiler, followed by Levent. Etiler and Levent neighborhoods are formed with villa type single residences with 2-3 floors and have lower population per building while income level is high. The neighborhood with the lowest consumption per person is Kayışdağı and it is also the most populated area among the selected neighborhoods. Plus, in Kayışdağı neighborhood, use of stove is still very common and natural gas consumption is calculated too lower than expected.

When the natural gas consumption per building is examined, it is seen that there is a high negative correlation coefficient between consumption per building and land use density which means while land use density gets higher, consumption per building decreases. Highest consumption per building is observed in Ataköy neighborhoods of Bakırköy, which has the highest number of floors and construction area per building. Ataköy neighborhoods are followed by Fenerbahçe, Suadiye and Dikilitaş respectively and those neighborhoods also have 4-6 number of floors. Although Etiler neighborhood consists of low-rise and villa type single residences, it has been ranked high according to the consumption values per building. This shows that the individual and relatively old residential texture of Etiler neighborhood needs more energy for heating while high income level is also a factor.

When the natural gas consumption per dwelling unit is compared, highest consumption value is calculated in Ulus and lowest is calculated in Kayışdağı. In terms of the size of households, highest consumption per dwelling unit in Ulus is a reasonable result since it has the largest dwelling size among neighborhoods. Following neighborhoods such as Etiler, Emirgan, Fenerbahçe and Yeniköy all have villa type or mansion type of buildings with large dwelling units. All the neighborhoods where the consumption per dwelling unit is highest, building textures are discrete. Figure 7 shows unit consumption values of neighborhoods.

In the neighborhoods that have same building typology and similar building heights, the neighborhood with higher

Table 4. *Natural Gas Consumption Trends in Similar Morphologies.*

Neighborhoods	Building Typology	Structural Layout	Number of Floors	Construction Density Ratio	Land Use Density Ratio	Average Consumption per building	Average Consumption per dwelling unit	Average Consumption per sqm
Levent	villa type	detached	2-3	2.31	0.26	4851.51	485.31	6.95
Emirgan	villa type	detached	2-3	2.95	0.21	5698.91	1337.65	10.62
Etiler	villa type	detached	2-3	3.79	0.23	16642.10	1360.33	16.35
Kuzguncuk	mansion type	detached	2-3	2.74	0.34	4244.25	1026.86	6.86
Ulus	mansion type	detached	4-6	5.10	0.30	13818.91	1517.89	8.69
Yeniköy	mansion type	detached	2-3	1.69	0.22	5129.42	1249.33	6.41
Reşitpaşa	squatters	attached	2-3	2.48	0.33	3456.75	624.82	8.87
Barbaros	squatters	attached	2-3	2.68	0.36	2802.16	916.28	4.07
İcadiye	compact apartment	attached	3-5	4.41	0.36	4744.30	765.64	7.33
Salacak	compact apartment	attached	3-5	3.66	0.37	5792.08	824.74	8.74
Fenerbahçe	detached apartment	detached	3-5	5.34	0.30	18127.85	1301.72	9.02
Dikilitaş	detached apartment	detached	4-6	5.86	0.31	14985.20	1482.90	12.22
Kayışdağı	detached apartment	detached	2-3	3.60	0.41	4172.36	42.00	0.34
Pınar	detached apartment	detached	3-5	2.48	0.30	4529.98	937.30	11.93
Caferağa	compact apartment	attached	4-6	5.03	0.55	8558.69	1001.40	7.46
Osmanağa	compact apartment	attached	4-6	4.79	0.48	5746.63	715.73	6.13
Ataköy 7-8-9-10	row apartment	attached	5-10	7.60	0.16	20468.78	652.06	6.69
Ataköy 3-4-11	row apartment	attached	4-6	5.32	0.11	14284.11	843.72	11.73
Ataköy 2-5-6	high rise	detached	5-10	7.66	0.18	35816.57	1103.28	10.52
Suadiye	high rise	detached	5-10	5.84	0.29	15371.93	1103.92	7.61

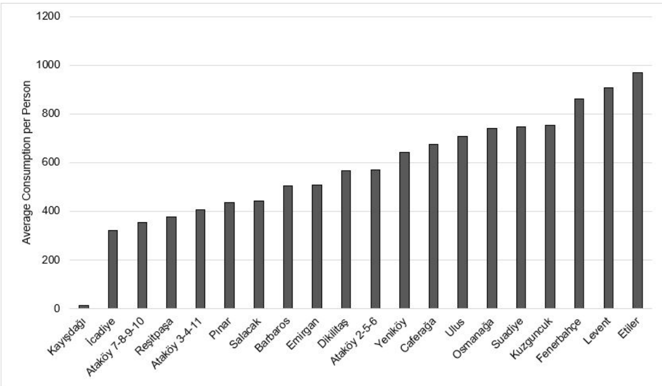

Figure 6. *Average Consumption Values per Person in Neighborhoods.*

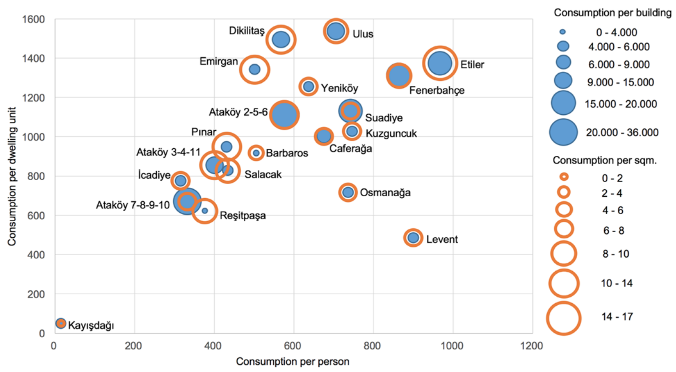

Figure 7. *Unit Consumption Values of Neighborhoods.*

construction density always consumes less than other. Barbaros and Reşitpaşa are squatters and their relatively lower consumption is caused by their socioeconomic structure. In 3-5 floors neighborhoods, İcadiye and Salacak has lower consumption in comparison with Pınar and Fenerbahçe neighborhoods. Although İcadiye and Salacak have same land use density and same socioeconomic conditions, İcadiye has higher construction density and as a result consumes less than Salacak.

Construction density ratios, land use ratios consumption per square meter and per dwelling unit are compared in settlements in order to observe the similarities of areal, volumatic and demographic densities at the same time.

According to this; it is seen that Suadiye and Fenerbahçe neighborhoods which have similar land use density and the number of people per square meter. In Fenerbahçe and Suadiye, while the amount of consumption per dwelling unit is close to each other, it is seen that the consumption amount per square meter is higher in Suadiye. Fenerbahçe, which has a lower amount of natural gas consumption, has a more compact settlement pattern than Suadiye, while Suadiye has higher income level.

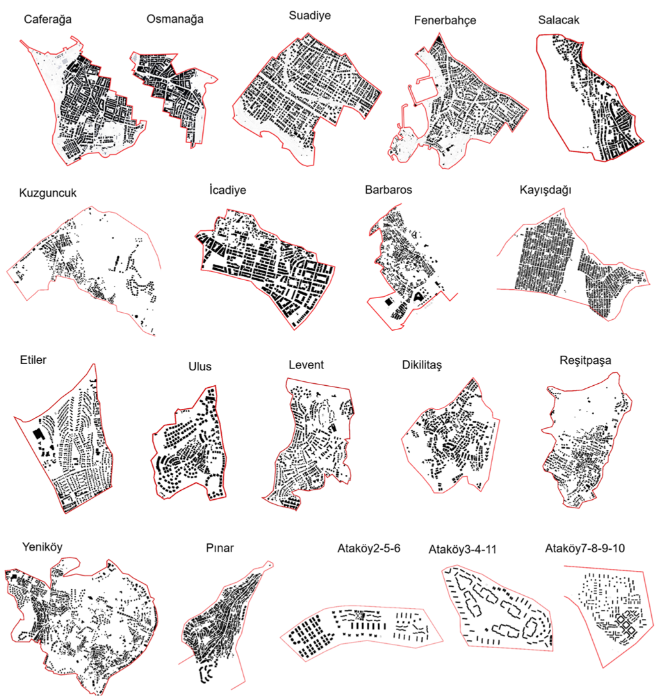

***Figure 8.** Morphological Textures of Neighborhoods.*

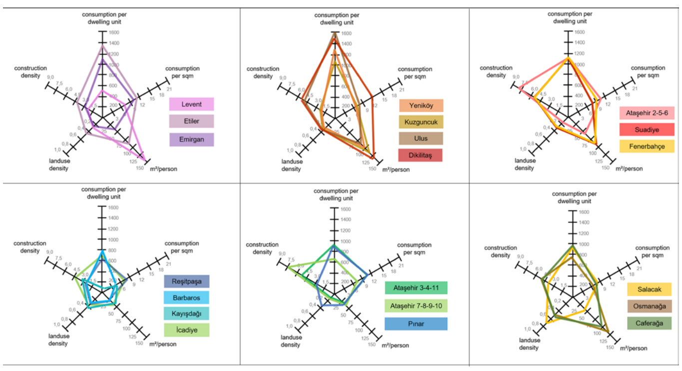

***Figure 9.** Comparison of densities and consumptions.*

Among Etiler, Levent and Emirgan neighborhoods, Etiler has the highest consumption amount per square meter and per dwelling unit. Dwelling unit area per person is higher in Levent, which shows that the population is lower. While Emirgan and Levent have similar land use density and construction density, consumption per dwelling unit is higher in Emirgan, which means the dwelling units in Emirgan is higher among these neighborhoods. Consumption per sqm is also higher than Levent which proofs that, although both neighborhoods have villa type typologies, Emirgan has larger building sizes and population density than Levent. Figure 6 shows average consumption values per person in neighborhoods.

Kuzguncuk and Yeniköy have similar density in terms of land use, construction and population so their consumption values are calculated very similar. Osmanağa and Caferağa again have similar density in terms of land use and construction. Consumption per dwelling unit is lower in Osmanağa while sqm per person is higher; which means Osmanağa has a higher population density and lower size dwelling units. This difference makes them have similar consumption per sqm. Figure 9 shows the comparison of densities and consumptions.

Ataköy 7-8-9-10 and Ataköy 3-4-11 neighborhoods have similar typologies while construction density is higher in Ataköy 7-8-9-10 and consumption per sqm is lower in parallel.

The results of the study show that the morphologic parameters do not always causes the same energy demand in the settlements and have not similar effects on consumption values. Building typology is not a single dominant factor for the settlements, however if the typology is more compact and denser, consumption per sqm and per dwelling unit is lower. Land use density has a reasonable effect on the heating energy consumption levels of settlements and in the neighborhoods that have more dense land use, natural gas consumption tends to decrease. Building height is not an independent parameter that can be measured and evaluated separately. It is highly related with the construction density. When settlements with same typology and similar building height are compared, consumption differences are generally caused by land use and construction density. Relation between construction density and the heating energy demand is calculated as the strongest relation compared to the other morphologic parameters discussed in this study. Since the social and economic structures are hard to measure and compare as quantitative values in such a study, different economic levels are tried to be compared over the fair values. However, results show that it is hard to mention about the effect of income levels to heating energy demand in this scale.

In brief, results indicate that dense settlements within case study areas have much higher energy efficiency lower heating energy consumption, which means the urban form has a significant impact on energy demand for space heating.

4. Conclusion

Energy consumption in settlements is a product of many interacting factors. Understanding the impacts of each component is key to determine the best urban planning and land use configuration.

In this study, the relationship between urban form and heating energy consumption is determined over the real heating energy consumption values in neighborhood scale. This relation is quite complex that there is no one certain formula that fits every kind of settlement but as a general tendency, it is observed that more compact urban forms means less heating energy consumption in macroscale although there are many micro and macro factors that change the consumptions individually. However, the social and qualitative factors also have quite strong effects.

By analysing the real values of heating energy consumptions in different urban forms, hypothesis of the study is proofed as there is a strong relation between urban form and energy consumption; different urban forms have distinct thermal performances and the practical results are compatible with theoretical assumptions.

Results of the study should be interpreted as observations of general trends rather than absolute conclusions. The current model needs further development to reduce uncertainties and include other urban energy components related to density. It is limited to chosen both morphological parameter values and number of study areas because of the scale of the study. However it helps to inferring general conclusions. The study can be expanded to evaluate the impacts of more study areas and a broader range of parameters in that scale. As a conclusion, this study is aimed to show the energy consumption trends of settlements with real consumption values to measure the potential for energy saving approaches of planning studies.

Findings of this study provide a possible way to develop new urban design criterias in new settlements for a more sustainable development. Urban planners, local authorities and policy makers of urban area could also benefit from this study while improving new housing development policies and urban plans. It is also a useful guide for natural gas providers for their macro scale projects.

Results of this study proves that urban form has a crucial position for energy efficiency and sustainability. However, the ideal housing pattern is still a question mark for academics and researchers since the city is a dynamic and living organism including many major and minor factors that causes difficulty in calculating the heating energy consumption of different urban forms in real life.

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