The Impacts of Demographic Transition on Embodied Energy Consumption and Typology of Residential Buildings: the Case Study of Tehran's Region 5

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The Impacts of Demographic Transition on Embodied Energy Consumption and Typology of Residential Buildings: The Case Study of Tehran's Region 5

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Abstract

Changes in the structural characteristics of the population, such as age structure, household size, and number of households indicate shifts in the population age structure, moving from the younger towards the older populations and result in the reduction of household size. Former extended families have turned into a nuclear and even one-person household. Shifts in household status, both household composition, and household size lead to the formation of a new housing typology. It can affect the type, number, and floor area of residential units as well as the amount of embodied energy used in the wet zones (kitchen, bathroom, and toilet), which are fixed, inflexible and costly areas of a residential unit. This study attempts to investigate the effect of demographic transition on the housing typology and embodied energy consumption of wet zones. The research is based on a case study: first, the changes in the population characteristics were examined by referring to the data published by the statistics Center of Iran. Then a field survey of residential buildings was started, to identify the number of floors, and the number of residential units. Then interviews with 15 developers have be conducted to investigate the significant changes in the housing typology and the common plan of the area. The common plan of residential units was then examined to assess the floor areas of wet zones and to compare their ratios to dry zones. In the next step, the amount of materials and embodied energy in each wet zone were calculated. The analysis of the reports by the statistics Center of Iran on the case study showed an age transition from the younger to the older, a decrease in the household size, and a change in the housing typology in the case study. The interview with developers and field survey on 831 land plots indicated three periods of changes in the housing typology in the case study between 1987 and 2018. During each period, in each plot of land, more residential units with fewer floor areas were built and the amount of embodied energy used by the wet zones increased.

Keywords: embodied energy, population, household composition, household size, housing typology.

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Introduction

Most developing countries are experiencing demographic "transition" and changes in the population age structure, moving from the younger towards the older populations (Reza Zadeh & Outadi, 2008). Iran is also one of the countries undergoing the process of population transition. According to the reported statistics, from 1956 to 2016, the household size dropped from 5.2 to 3.3 and the number of family members shrunk to one, two, three, and four. Although this distribution has been on the rise in each decade, the number of households of five and more has decreased (Table 1) (SCI, 2016).

Table 1

A Comparison of the relative distribution of households based on the census report of 2006, 2011, and 2016 (SCI, 2016)

Household size (%) / Census report(year)	One member	Two members	Three members	Four members	Five members
2006	5.2	15.3	22.9	24.4	32.3
2011	7.1	18.4	27.1	26.3	21
2016	8.5	20.7	28.5	27.6	14.7

Changes in the household status affect the housing typology. In the past, houses used to serve as units for living of extended households and several dependent families, and sometimes 2 or 3 generations used to live together. In this housing typology, the required number of houses per person and per living space was less than what is needed today. Nowadays, the housing typology has been influenced by the nuclear family structure. The results of SCI[1] in 2016 showed an increase of 4.59% in the number of residential units with a floor area of 51 to 100 square meters compared to 2006 (SCI, 2016).

Each residential unit consists of wet and dry zones. The zones are named based on the main activities or functions. According to the Iranian National Building Regulations No.4, wet zone includes toilets, bathrooms, and kitchens, and each residential unit has to provide this zone for its residents (INBR, 2013). The wet zones of a building do not have much flexibility due to its relatively stable and often expensive structure. The wet zones need to be equipped with amenities to serve their proper functions. To this purpose, hard, stable, durable, and washable materials are needed for covering walls and floors, at least up to the wall shelves or up to 1.50 meters of the finished floor. The materials need to be resistant to scratches or abrasion such as ceramic tiles. The required amenities include insulation, finishing, installation of shelves, and mechanical and electrical appliances. The dry zone of a residential unit such as a living room and bedroom has flexibility because it does not have a fixed structure and changing the arrangement of furniture and their spaces depend on the taste of the family (Susanka, 1998). In contrast, in wet zones, such changes are not impossible but is very difficult, and not economical, because there are various connections and installations (Ghasem Zadeh, 2012).

The construction industry is one of the largest consumers of energy and the most important producer of carbon dioxide in the world. The energy consumption of buildings and the carbon dioxide produced by them can be examined from three perspectives: production, operation, and demolition of buildings, which are inevitably related to each other (Monahan & Powell, 2011). The energy consumption in the production stages of buildings is usually measured by embodied energy (Mohammad Moradi, Hosseini & Yazdani, 2012). In general, the embodied energy of a building is 1/3 to 1/5 of the total energy consumed by the building during its life cycle (Foroozan, Hajipour & Soltani, 2016). The importance of embodied energy as part of the total energy consumption can be examined on a macro scale of the national economy or a smaller scale such as urban areas or individual buildings. Since global standards for new construction are moving towards "Zero-energy or low carbon buildings", the importance of embodied energy has increased (Mohammad Moradi, Hosseini & Yazdani, 2012). If a residential unit assumed to be a product affected by household developments and housing typologies, a significant amount of energy from renewable or non-renewable sources

1 Statistical center of Iran

will be consumed for its production. This amount of energy consumption is likely to have negative environmental consequences. The question is if reducing the household size and the floor area of residential units on one hand, and increasing the number of small residential units, on the other hand, will raise the amount of embodied energy consumed in the wet zones of residential units? This study attempts to investigate the effect of the demographic transition on the housing typology and the amount of embodied energy consumption of the wet zones in the residential unit. Due to the lack of studies in developing countries (such as Turkey, Iraq, Egypt...) about the relationship between three variables (demographic transition, housing typology and embodied energy), The authors had to refer to studies in developed countries (Canada, Australia and USA). Although there are major difference between developed and developing countries in case of demographic changes, housing typology and related technologies; as few research has been conducted in this topic, the authors decided to review the results of those studies with the focus on the methodology.

In the following sections, the literature review on population, housing typology, and embodied energy are examined in developed countries (Canada, Australia and USA) and Iran. To evaluate the amount of embodied energy consumption in the wet zones of the residential unit caused by household changes and housing typology, a case study in the city of Tehran is reviewed and at the end, a conclusion is presented.

A. Changes in Population Characteristics

The most important characteristics of the population which greatly influence the housing sector are the population growth rate, age structure, household formation rate, household composition, and changes in the household size (Parhizkar, Amakchi & Roknaddin Eftekhari, 2009). The age structure transition is an output of the demographic transition process. The results of SCI dating back to 2016 indicate that the age of the majority of Iran's population (44.8%) falls between 30 to 64 In which providing a house is their most important need (Abbasi Shavazi, 2017). At the same time, the household formation rate of this age group has changed. From 1956 to 2016, the number of households in Iran surged from 3.9 to 24.19 million. According to Fig. 1, both the average growth rate of population and households had undergone almost the same changes between 1956 and 1986, but from 1986 onwards, the average growth rate differed dramatically from the household number (Fathi, 2019; SCI, 2016).

Household composition shows the number of family members and their relationship with each other (Fathi, 2014). Based on Fig. 2, during the years 1996-2016, the number of households with one to four members was on the rise. However, the number of households with five or more members decreased. The situation indicates the tendency of Iranian families to live in smaller nuclear families (Fathi, 2014; Fathi, 2019; Rezaei Ghahroodi Firozi & Harandi, 2011).

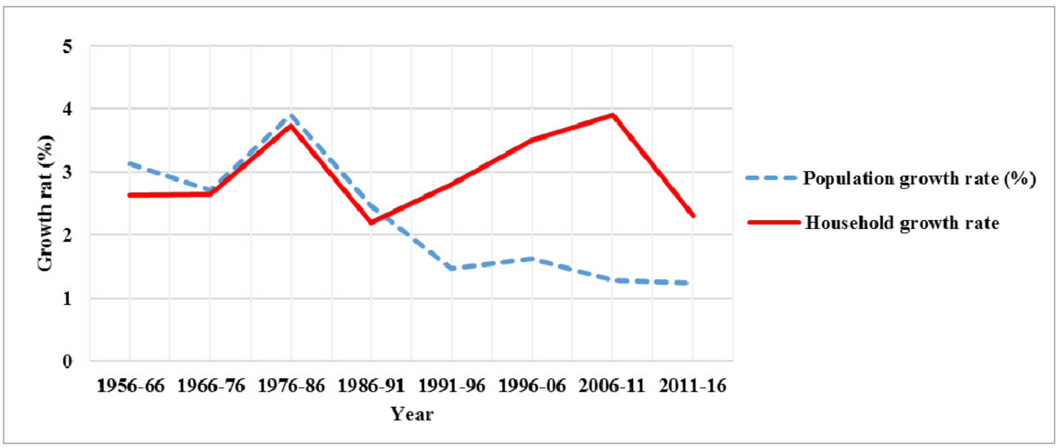
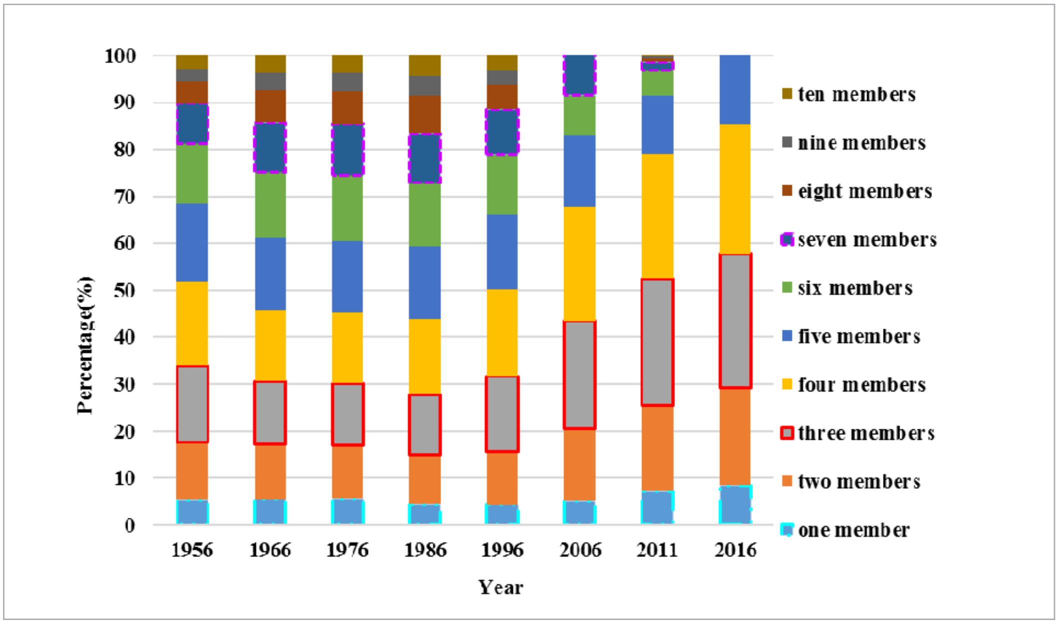


Fig. 1

A Comparison between the average growth rate of population and household (1956-2016) (Fathi, 2019; SCI, 2016)

Fig. 2

Relative distribution of households in the country according to the number of members in 1956 to 2016 (Fathi, 2019; SCI, 2016)



As can be seen inTable 2, in all three countries, the household changes include a reduction in the size and a transition in household composition.

Table 2

A study of household changes in Australia, Canada and USA

Changes in Population Characteristics	
Australia	_ The most common household composition in Australia in 2003-04 included couple families with dependent children which accounted for 27% of all number of households and showed a decrease of 3% compared to 1994-95(Linacre, 2007). _ In contrast to the decrease in this household composition, there was an increase in couple-only and lone-person households (Linacre, 2007). _ The composition of couple-only and lone-person households reached 26% and 25%. In 2003-04, the values were24%, and 23% respectively in 1994–95 (Linacre, 2007).
Canada	_ Since the beginning of the 20th century, the average size of households in Canada has decreased, from 5.0 persons in 1901 to 2.4 persons in 2016 (Tang, Galbraith, And Truong, 2019). _ The number of couples without children households raised from 21% to 29% between 2006 and 2011. This increase was quite significant compared to the number of households with children (QFREB, 2012). _ The number of persons living alone (between the ages 25 to 64) in Canada more than doubled over the last 35 years, from 1.7 million in 1981 to 4.0 million in 2016 (Tang, Galbraith, And Truong, 2019).
USA	_ In 1963, household and house characteristics data from 1940 were collected and recorded. The results of the collected data showed a decrease in the average household size from 3.67 in 1940 to 2.62 in 2002 (Wilson & Boehland, 2005).

B. Housing Typology

Examining the reports of the SCI during the years 1986 to 2016 shows that the shifts in the housing sector were in line with demographic transition. The growth of the number of residential units was influenced by the culture and behavior of households and factors such as population growth rate, marriage, divorce, and lifestyle changes (SCI, 2018). This means that changes in households and population influence the housing typology over time. The average floor area of residential units in Tehran from 2011 to 2018 had a decreasing trend and fluctuated between 74 to 93 square meters (SCI, 2018). Examination of the data of the SCI in the years 2006, 2011, and 2016 shows the increase in the number of residential units with a floor area of 51 to 100 square meters Fig. 3.

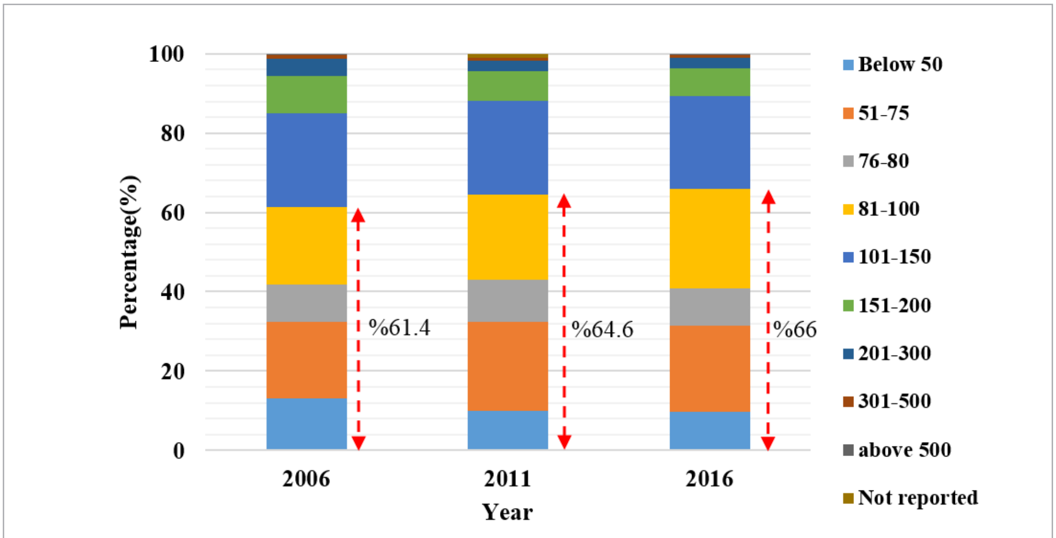


Figure 3

Frequency of residential units in terms of floor area based on the census reports in 2006, 2011 and 2016 (percentage) (SCI, 2016)

Table 3 presents the literature and examines the relationship between the two variables of household and housing typology in three countries.

Table 3

The relationship between household and housing typology in Australia, Canada and USA

	Housing typology
Australia	_ In 2003-04, about 92% of Couple families with dependent children lived in separate units. 41% of a lone person household under the age of 35 lived in apartment units while 17% in row houses. 88% of couple households aged 65-55 lived in separate houses and only 5% living in apartments (Linacre, 2007). _ The average living space in Australia increased from 163 to 241 square meters between 1984 and 2012. This significantly increased the average floor area. This value per capita in a residential unit raised from 57 to 94 square meters between 1984 to 2012 (65% increase) (Stephan & Crawford, 2016).
Canada	_ Trends in building permits indicate that the construction pace of apartments, and especially condominium units (Condominiums consisted primarily of low-rise and high-rise apartment buildings, and row houses) has accelerated since the early 2000s, and that this has surpassed the number of single-detached houses constructed since 2012 (Statistics Canada, 2017) (Statistics Canada, 2011). _ Non-family households (45.5%) and Couple-family households (with or without children) (42.3%) accounted for the highest proportion of households in condominium ownership (Statistics Canada, 2011). _ condominium apartments built after 1990 tending to have an increasingly smaller living area. In Ontario, the median living area of a condominium apartment built in 2016 and 2017 is 61.78 square meters, a decline of more than 30% in square meters compared with condominium apartments constructed in the 1980s and 1990s (Statistics Canada, 2019).
USA	_ The average size of houses increased from about 100 square meter in the 1940s and 1950s to 217 square meter in 2002. Factoring together the family size and house size statistics, we find that in 1950 houses were built with about 27 square meter per family member, whereas in 2003 houses provided 83 square meter per family member (NAHB 2003)—a factor of 3 increase (Wilson & Boehland, 2005).

C. Embodied Energy

Embodied energy represents the sum of all energy inputs for the production of building materials across their supply chains, as well as energy for non-material inputs, such as services supporting material production. Embodied energy can be broken down into two components: initial and recurrent embodied energy. The first represents the total embodied energy of the house as-built, prior to its occupation. The second takes into account the embodied energy associated with the replacement of building materials across the life of the house (Stephan & Crawford, 2016).

Changes in the floor area of residential units following the transformation in household changes and housing typology affect the amount of embodied energy used both during production and operation process (Stephan & Crawford, 2016). For instance, in Australia a mismatch between household composition and residential units has increased embodied energy (Table 4).

Table 4

The effect of the household changes on the embodied energy in literature

	Embodied Energy
Australia	_ An increase in the floor area per capita results in the rise of consumable materials, and the amount of embodied energy needed for the life cycle of the building. The average embodied energy per square meter was between 10 and 19 GJ, and each Australian was responsible for 370–703 GJ in 2012 (Stephan & Crawford, 2015).
Canada	_ Four different alternatives of residential buildings in Vancouver (BC, Canada) have been evaluated, including High Rise Apartment (HRA), Low Rise Apartment (LRA), Single family Attached House (SAH), and Single family Detached House (SDH) (Kumar, Hewage, and Sadiq, 2015). _ The total embodied energy of each residential units is about 2700MJ, 1750MJ, 2000MJ, and 2170MJ for HRA (no. of floor:8, area of unit(m^2):520), LRA (no. of floor:3, area of unit(m^2):520), SAH (no. of floor:2, area of unit(m^2):260), and SDH (no. of floor:1, area of unit(m^2):130) respectively (Kumar, Hewage, and Sadiq, 2015). _ This clearly indicates that HRA has high-embodied energy than other residential buildings. But each residential unit of HRA and LRA has lower embodied energy than SAH and SDH(Kumar, Hewage, and Sadiq, 2015).
USA	_ The U.S. National Association of Home Builders (NAHB) reported, larger residential units consume more materials due to more space. A newly built residential unit with 463.2 square meter consumes materials three times more than a 193 square meter residential unit modeled in the NAHB, although its floor area is 2.4 times larger (Ahluwalia, 1998)

Research Method

The main research question of the paper is: "if reducing the household size and the floor area of residential units on one hand, and increasing the number of small residential units, on the other hand, will raise the amount of embodied energy consumed in the wet zones of residential units?", To find an answer for the research question, first the research variables relationship were investigated in the literature review (Iran and other developed countries), then a case study has been done to observe the changes of these three variables and the effect of them on the embodied energy consumption in the wet zones. Two features were considered for selecting the case study; a) The area should have a young age structure or experiencing a transition from the younger to older, and b) the area needed to have ongoing construction of residential units.

To evaluate an area based on these features first the authors referred to the SCI to identify the changes in the population characteristics such as age structure, household composition, and household size, and then started a field survey to find the changes in housing typology. In the field survey, the residential buildings in the area were examined based on the number of floors and the number of residential units. The next step was to conduct interviews with 15 local developers. These interviews included questions about the significant changes in the housing typology which caused the changes in the common plan of the area. Analyzing the results of SCI, the field survey, and interviews, identified the significant period of changes in housing typology. Each period had its own characteristics and plan. Due to the high number of residential unit plans, one typical plan for each period has been chosen and the ratio of the wet and dry zones was compared. The amount of used materials and the embodied energy consumption in wet zones were calculated. Due to the lack of information on the mechanical parts of wet zones, this part has not been calculated. Fig. 4 shows the research method in brief.

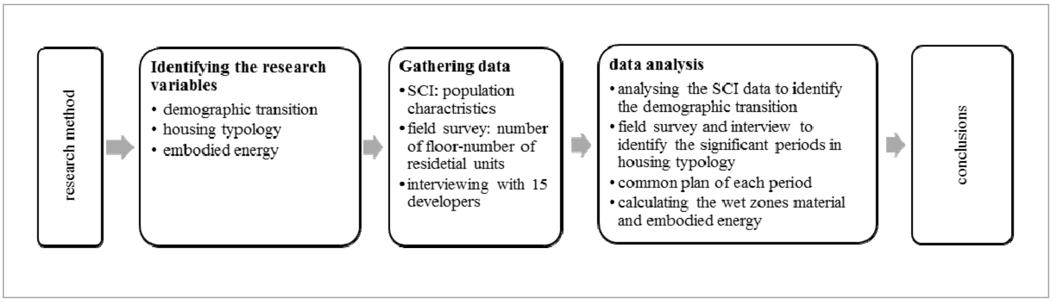


Fig. 4

Research method (authors)

A Case Study in Region 5 of Tehran

Tehran, the capital of Iran, has 22 regions. Region 5, which is located in the Western part of Tehran, includes the young age structure and has the highest amount of construction compared to other regions. The selected area is located in district 7 of region 5, and, from the north, it goes to Ansar Al-Mahdi Street from the south, it stretches to Iranpars, from the east to Sattari Street, and from the west to Iranshahr Street. Development of the selected area has started in 1987 (Fig. 5) (Sharmand consultants, 2002).

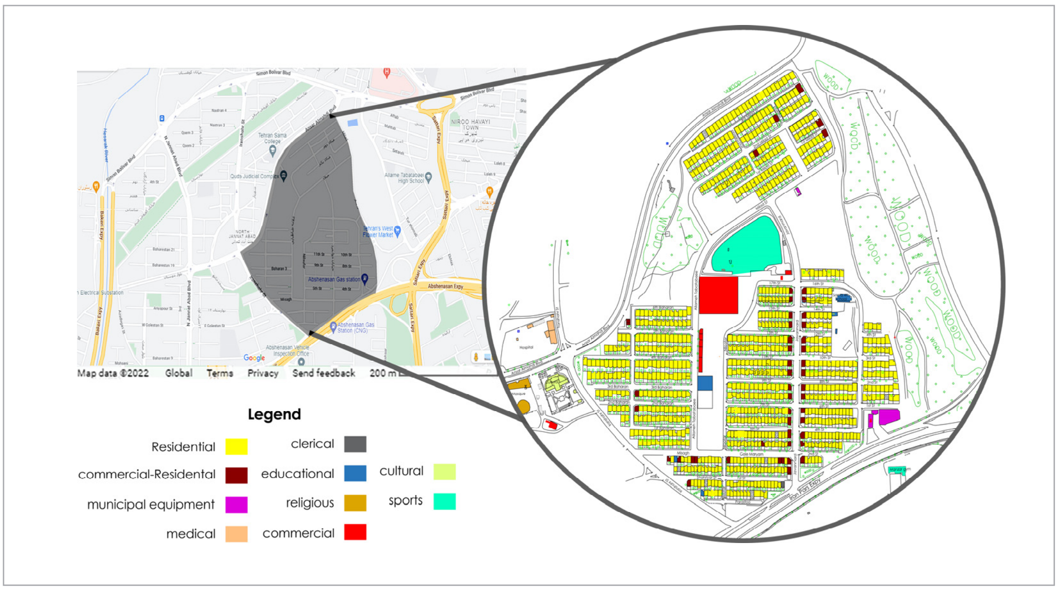


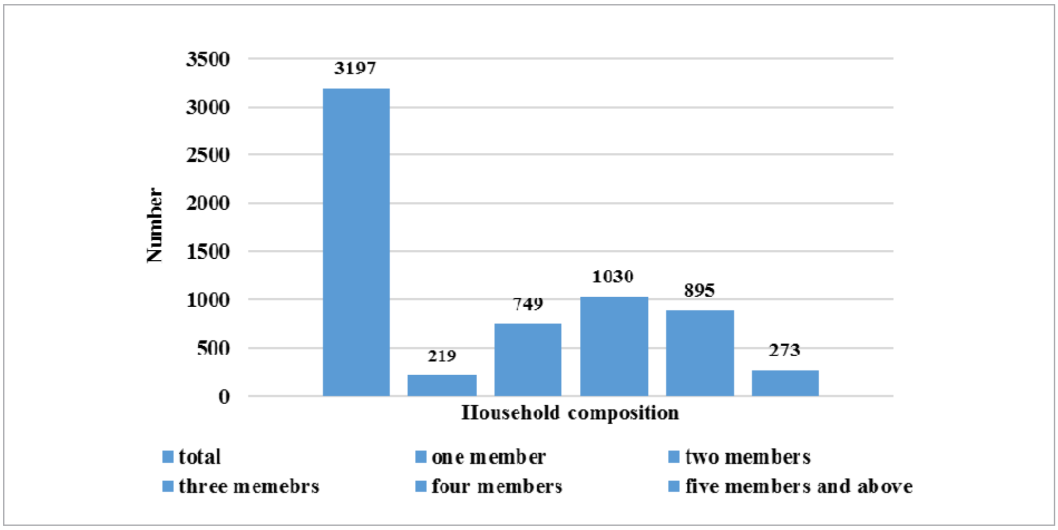
Fig. 5

The boundary of the selected area in district 7, region 5 of Tehran and its land use map (Author)

This area had 9841 population, of which 4922 were men and 4919 were women (SCI, 2016). two age groups have the majority: middle aged people aged between 30 to 64 and younger ones aged between 15 to 29 (SCI, 2016). According to the last results of the SCI in 2016, the number of households in this area was 3197. Most of the households were composed of three and four members (Fig. 6). The number of residents in apartments increased in 2016 and approximately 3101 households lived in these residential units (SCI, 2016).

Fig. 6

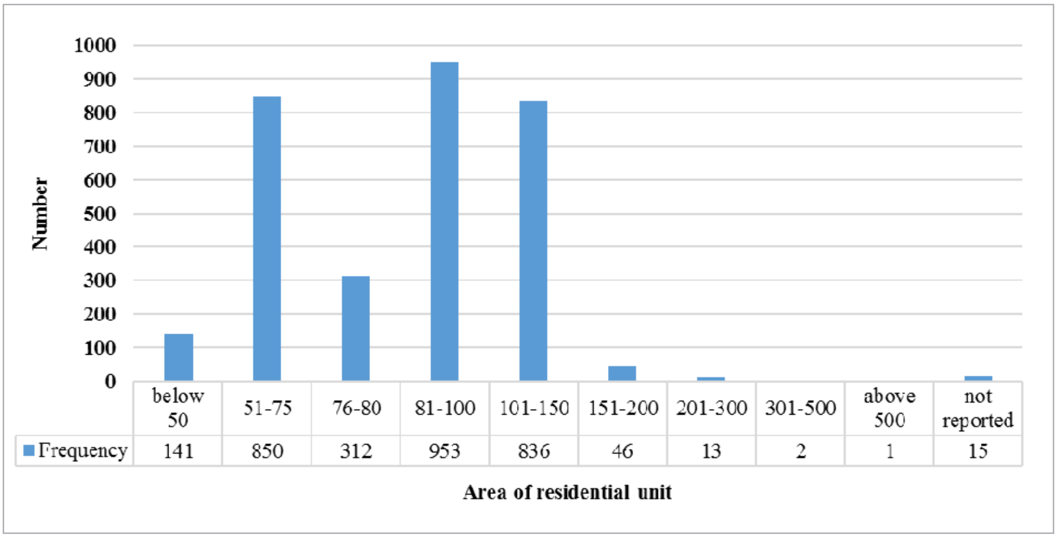
Number and composition of households in the case study (Authors based on data from SCI, 2016)



As can be seen in Fig. 7, residential units with a floor area of 51 to 75; 81 to 100, and 101 to 150 square meters had the highest frequency. The total number of units under 100 square meters in the region was 2256. This value was much more than the total number of units above 100 square meters which was 913(SCI, 2016).

Fig. 7

Frequency of floor area of residential units in the case study (authors based on data from the SCI, 2016)



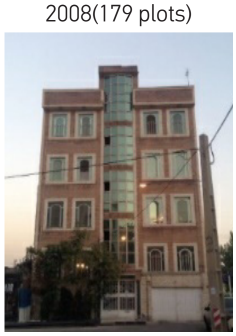
A. Field survey

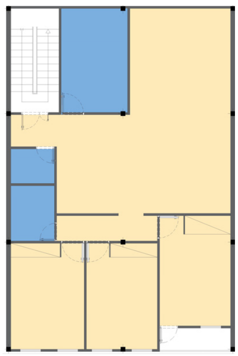
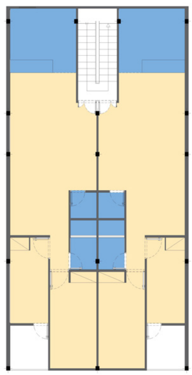
Field studies included the examination of the residential buildings in the area to understand the changes in the housing typology from 1987 to 2018 in terms of the number of floors and the number of residential units. The next part of data collection related to field studies included interviews with 15 local developers. The interview included questions about the significant changes to the residential buildings in the area such as floor area and plan design. The results of the survey on 831 plot of land in the case study showed three periods of construction changes which means three periods of housing typology, each period had its special characteristics. The common plan for each period was prepared with the help of the developers and the municipality. Fig. 8 shows the distribution of the three common periods of housing typology in the area. Table 5 presents the characteristics, the common plans, and the dry and wet zones of these three common periods of housing typology in the area per square meters.

Fig. 8
Distribution of the three common periods of housing typology in the area (authors)

As can be seen in **Table 5**, by reducing the floor area of a residential unit (second and third period), the floor area of wet and dry zones decreases. Thus, the used material and the embodied energy

Table 5
Characteristics of the three common periods of housing typology in the area (authors)

Significant Characteristics of each period			
Period (examples of buildings) / **Features**	First period (1987-1997) (612 plots)  Fig. 9. The example building picture of first period(authors)	Second period 1998-2008(179 plots)  Fig. 10. The example building picture of second period(authors)	Third period (2009-2018) (40 plots)  Fig. 11. The example building picture of third period(authors)
Land plot(m^2)	250	250	500
Number of floors	2 or 3 floors	4 floors	5 or 6 floors
Number of residential units on each floor	1	2	4

Significant Characteristics of each period			
Floor area of one unit(m^2)	150	80.5	75
Examples buildings floor plan wet zones dry zones	 Fig. 12. Common plan of first period(authors)	 Fig. 13. Common plan of second period(authors)	 Fig. 14. Common plan of third period(authors)
The floor area of wet zones in a residential unit (m^2)	**20.46**	**15.55**	**11.28**
The floor area of dry zones in a residential unit (m^2)	**119.54**	**64.95**	**63.72**
The ratio of wet zones to dry zones in a residential unit(%)	**%17.1**	**%24**	**%17.7**

of the wet zones decreases. **Table 6** shows the calculation of embodied energy of wet zones in each period. However, the amount of embodied energy consumption in a small residential unit decreases, in a same plot of land such as 250, the opposite happens, by increasing the number of residential units on a floor, the amount of embodied energy consumption of the wet zones increases. **Table 6** also shows that the amount of embodied energy consumption of wet zones in a residential building by each period increases. Due to the scarcity of research on embodied energy and the lack of necessary attention to this topic in Iran, the embodied energy of the materials and components used in this paper was calculated based on the data published by the University of Melbourne in Australia. (Crawford & Treloar, 2010)

Table 6

The calculation of embodied energy for wet zones in each period (authors)

Each period / Embodied energy(GJ/m2)	First period (1987-1997)	Second period (1998-2008)	Third period (2009-2018)
The amount of embodied energy for the wet zones of a residential unit (GJ/m^2)	192.46	158.49	150.52
The amount of embodied energy for the wet zones on a floor (GJ/m^2)	192.46	316.98	602.11
The total amount of embodied energy for wet zones in a residential building (GJ/m^2)	577.38	1267.95	3612.69

Conclusions

Examining the data from the Statistical Center of Iran shows changes in population characteristics such as decreasing in household size, changing the process of household composition, and the age structure transition from the younger to elderly. The results of field survey of 831 plots of land identify three periods of housing typology. Each period had its specific characteristics. The characteristics of each period show a reduction in the average floor area of residential units and wet zones, but the number of residential units in 250(m^2) plots of land increased. Examining the common plan of each period showed by increasing the number of residential units in the same plot of land (for example 250 square meters) the amount of embodied energy consumption in the wet zones increased. Reviewing the literature and results of this study indicate that embodied energy consumption of buildings is not only affected by their design, construction, and operation, but also by demographic transition of the residents. This factor is important to consider by people who are in charge of providing houses for people such as architects, civil engineers, and developers. these are different design and construction strategies focusing on reducing the embodied energy that authors offer:

- Providing the list of materials embodied energy in Iran is one of the most important things that need to be considered. it helps civil engineers, architects and developers choose the material with lower embodied energy.
- flexibility of a residential unit: flexibility not only plays a key role in the quality of the residential space but also adapts the residential unit to changes in household composition. This reduces the need to build new residential buildings and thus decreases embodied energy. The flexibility of a residential unit can be improved during the household changes by developing its capability of being integrated, separated, and developed. For instance, the service zones, including the entrance, kitchen, and bathroom, need to be flexible enough to joint to or detach from other parts. The adjustable walls and a suitable partition space can be useful for the integration or separation of the two residential units. Also, using semi-open space like terrace brings vitality to the residential space and also promotes the potentiality of space for future development.
- Due to the changes in family composition, the number of people living alone, such as young people who have been separated from their parents or single-parent families and retirees, is increasing. These households are looking for safe and cheap places and Co-living can be the best option for them. Co-living includes people who do not know each other but use shared spaces. In Co-living, in addition to the kitchen, living room, and library, bathrooms and toilets may even be shared.

The present study has some limitations. First, the access to data on the status and developments of residential units was limited. Second, this study was conducted in a small area of Tehran. Third, the number of interviewees was limited to 15. These limitations make it difficult to generalize the data to a wider scope. In addition, there was a lack of access to data on the embodied energy of construction materials and products in Iran, and the authors had to use the literature on other countries. Despite these limitations, this study provides insights into the impact of demographic variables and components on energy consumption in the building sector. These results can be fortified by conducting more studies and the availability of more data.

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