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Increasing the Energy Performance of Existing Buildings in Cold Climate Regions

A Social Housing Case in Erzurum

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Abstract

High energy consumption in regions with harsh climatic conditions makes it difficult to reach energy consumption targets. This study considers design decisions affecting energy consumption for cold climate regions; the position of the building, its orientation, building envelope elements and building materials were examined. In line with these decisions, a field study was conducted by researching the energy-efficient renovation of existing social housing structures in cold climate regions. For the field study, social housing in Erzurum was selected, and the current heating energy consumption of the building was simulated using the Design Builder program. By creating energy-efficient renewal scenarios that can be economically and physically enacted, the U-values and thicknesses of the building envelope elements were changed, and 14 renewal simulations were carried out for five scenarios. The effects of each renovation scenario on the current heating energy consumption were examined, and the results were compared. With the most efficient replacement scenario, it was observed that the heating energy consumption decreased by an average of 31%. The data obtained informed decisions for building envelope element selection within the scope of energy-efficient renewal studies in cold climate regions and their impact on energy consumption.

Keywords

energy performance, renovation in existing buildings, cold climate zones

1 Introduction

Today, energy is a critical input of the economy and a compass for world political policy, although it first entered the world agenda with the energy crisis in 1973 (EIA, 2013). The concept of reducing energy consumption and improving energy efficiency is a worldwide issue that needs to be continually addressed.

Between 1971 and 2017, total primary world energy demand (TPES) increased more than 2.5 times (from 5,519 Mtoe to 13,972 Mtoe) (IEA, 2019b). Among the regions with the highest demand in 1971-2018, the Organization for Economic Cooperation and Development (OECD) and non-OECD Asia stand out. Most of the OECD countries are located in the cold climate areas.

According to OECD data, when the change in energy consumption values according to sectors between 1990-2017 is examined, the transportation and building sectors have constantly increased and remained in the same band since 2015 (IEA, 2019b). According to the 2017 IEA data, the transportation sector constituted the highest share of consumption at 36%. Following transportation is the manufacturing industry at 23% and the housing sector at 20% (IEA, 2019a). At EU level, residential buildings consume about two-thirds of the building energy. In countries with cold climates, such as Denmark, Latvia, Poland, and Austria, energy use of residences is over 70% and even reaches 80% in Romania (Gynther et al., 2015), making it increasingly significant in countries with cold climates.

When the energy consumption in EU residences is examined, overall, the energy consumed for space heating has decreased by 0.7% per year from 2000 to 2017, based on 2017 data. While the rate of space heating in energy consumption was 71% in 2000, it decreased to 67% in 2017. However, this value is still very high. Based on the same climate, heating consumption of residential

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buildings is the highest in countries such as Luxembourg, Belgium, Italy, Hungary, and France. Compared to the European average, regions with colder climates consume more energy. Despite advances in using more efficient devices in building design and construction, the overall energy demand in residences continues to increase (Odyssee-Mure, 2021b).

Energy efficiency in Europe increased by 1.2% between 2000 and 2017. There has been a slowdown in energy efficiency growth since 2010 (Odyssee-Mure, 2021a). According to IEA data, energy consumed for space heating within the scope of energy efficient improvements. In EU countries, it has decreased significantly, mostly due to better insulation of buildings, renovation of old buildings and improvements in heating equipment. For example, France, Germany, and the United Kingdom have reduced energy consumption for space heating by over 30% since 2000 (IEA, 2019a). The IEA's Efficient World Scenario (EWS) shows that in 2040 average energy use will decrease by 1.3% from current levels (IEA, 2018). Although an increase in population and energy demand is expected in 2040, consumption is predicted to remain stagnant due to the high energy efficiency potential.

The main goal of this research, within the framework of the investigations carried out, is to examine the energy-efficient renewal of existing social housing structures in cold climate zones in terms of building envelope elements and the effects on energy consumption. Consequently, the energy consumed for space heating in residences was investigated; renovated social housing examples in Central Europe and Northern European regions were examined, and the results of this examination were compared with the social housing structure for which energy analysis and improvement scenarios were made using the Design Builder simulation program. This research provides a perspective for the energy-efficient renewal of a building in cold climatic regions, aiding decision-makers and planners of the renovation process.

The energy performance analysis of a TOKI social housing structure in the Narman district of Erzurum province, which was completed in 2016, was used for the research. The building envelope elements, their U-values and the HVAC system elements of the building were used with the Design Builder program for the energy simulation.

The building was modelled using Design Builder and from the building shell elements; existing parameters in the program analysis such as insulation thickness, U-values, thermal conductivity value, HVAC system of shell elements such as walls, doors/windows, roof, foundation/floor were used and simulated in terms of energy performance. Later, this model was simulated again following changes made in the building envelope elements. The study was completed with an evaluation of the energy values.

2 Energy consumption and energy-efficient renewal of social housing structures in Europe's cold climate regions

Cold climate regions undoubtedly have higher energy consumption compared to other areas. Due to the wide range of temperature differences between the indoor and outdoor environments in these regions, trying to provide indoor comfort makes an inevitable increase in energy consumption, and the importance of greater energy efficiency. The amount of energy consumed by a building is related to the climate zone in which the building is located, its use, the thermal comfort conditions envisaged by the users (indoor temperature, lighting), the building envelope (structural elements that separate the heated interior from the unheated exterior; foundation, roof, walls, doors and windows) (Manioğlu and Yılmaz, 2006), and the properties of the building envelope. In energy terms, the quality of the envelope is mainly determined by the thickness of the insulation material and the orientation, size, and type of the windows (sun protection, glass type) and other environmental and physical factors of the building (Richarz and Schulz, 2013).

During the life cycle of a building, 80 to 85% of the total energy consumption occurs during the usage phase (Sharma et al., 2011). This includes the energy costs of building heating, cooling, ventilation, lighting, equipment operation, water supply, water heating and wastewater treatment (Scheuer et al., 2003). Fig. 1 illustrates the approximately 50% heating losses in residential buildings through the walls, foundations and roof (U.S. Department of Energy, 2015). The design criteria that affect the building's energy saving and indoor comfort conditions are the optical and thermophysical properties of the building envelope elements, the orientation and shape.

Within the design criteria, the heat transfer coefficient (U-value) allows us to measure energy performance. The U-value determines the heat loss per unit area of the components of the building envelope (Pacheco et al., 2012).

The wall is the largest and most important element in contact with the external environment. It should be high performing and well-insulated (Dehlin et al., 2018). The economic optimum for exterior wall and roof insulation is typically around 24 cm, assuming a thermal conductivity

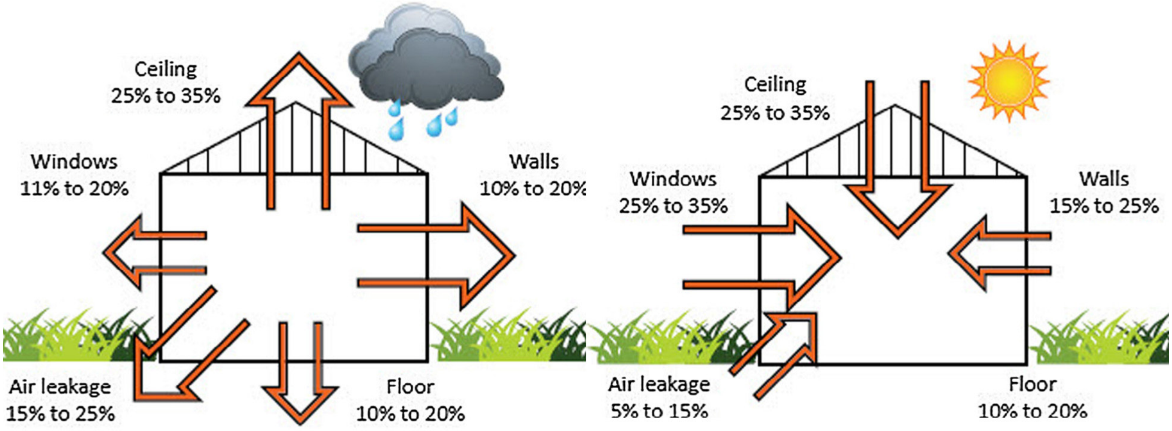


Fig. 1 Heat flow in uninsulated buildings in a cold climate (adapted from CCS, 2015, cited in El-Darwish and Gomaa, 2017:p.581)

of 0.036 W/m^{2}K. Insulation thickness of 32 cm are equally cost-effective, resulting in more significant energy savings (IPHA, 2014). Fibrous materials like glass wool, rock wool and rigid foams such as polystyrene-based XPS and EPS are generally used as insulation materials.

For a material to be considered a thermal insulation material, the thermal conductivity coefficient (λ) must be less than 0.065 W/m^{2}K according to ISO and CEN standards (Yaman et al., 2015). The lower the thermal conductivity value (u) of an insulation material, the higher its resistance to heat transmission.

The windows, the transparent components of the building envelope, have many functions, such as providing daylight, ventilation, and heat flow to the building. Heat flow depends on the season, the type of building and the performance of the building (El-Darwish and Gomaa, 2017). Windows are considered the weakest part of the building envelope, and 10–20% of all heat loss in a standard residence occurs through windows (Roos and Karlsson, 1994). That's why window design should be considered in terms of performance, heat transfer, thermal comfort, light transmission, and appearance (Chaiyapinunt et al., 2005).

Windows are evaluated regarding frame and glass ratio; frames constitute 30–40% of windows. However, because the thermal performance of the glass is better than the frame, smaller frame areas are preferred. Thus, the higher glass aspect ratio allows for higher solar gains. In cold climates, highly insulated frames and triple glazing are required which refers to U-values of less than 0.85 W/m^{2}K for an installed window (IPHA, 2014). In addition to high insulation and triple glazing, low-e coatings improve efficiency in preventing heat loss (Lechner, 2015). Low-e coatings can control 70% of the heat escape, improving the insulation value by 36% compared to insulating glass with a 12 mm gap (Bektaş and Aksoy, 2005). In addition to the U-values, their apparent transmittance and solar heat gain should be considered (Rodriguez-Urbinas et al., 2014).

It is surprising that there are still poorly insulated double-glazed or even single-glazed windows in many parts of the world, posing significant energy consumption problems, especially for cold climatic regions. The thermal performance of the frames used in windows is as important as the U-value of the glass. Windows with wooden frames have a lower U-value than windows with aluminium and plastic frames, providing savings between 1% and 18%. triple-glazed airtight windows with wooden frames are the most efficient solutions for cold climate regions (Bektaş and Aksoy, 2005).

Examples from European countries with cold climate type is examined in this part of the study. Building features such as building envelope elements, U-values, changes made, building identity information, and energy consumption values of the samples were evaluated. Koniklecova social housing, one of the important buildings, is explained in more detail (Table 1).

Koniklecova social housing flat blocks are a typical 80s structure built using reinforced concrete panels. There is a basement in the building (Sedlák et al., 2015). It has been renovated with a low-energy building concept. The main goals included increasing the indoor comfort conditions, reducing the energy consumption of the building and general modernization of the building. Information of the building is given in Table 1.

Kapfenberg social housing was a typical building from the 1960s made of prefabricated sandwich concrete elements without additional insulation. The energy concept is built on insulation, mechanical ventilation, solar energy and PV system (Höfler et al., 2014; Romano et al., 2022) (changes in building envelope and energy consumption values are given in Tables 2 and 3).

Table 1 Building information of *Koniklecova* social housing sample

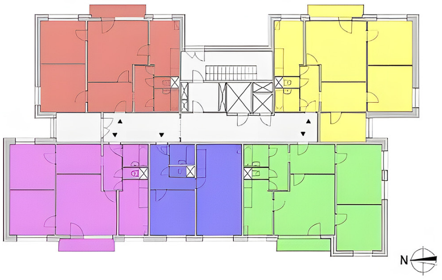
Building credentials		Plan and photo
Production year / Place	1983 / Brno-Nový Lískovec	
Land condition	Gently sloping terrain	
Building orientation	North-South	
Number of floors / Number of dwellings	12 floors / 60 dwellings	
Number of buildings / Settlements	1 blocks	
Renovation year / Architect	2009-2010 / MENHIR Project	
Annual energy requirement	466.50 MJ/m^{2}a (129.58 kWh)	

Table 2 Renovation studies of European examples (Almeida and Ferreira, 2017; Hastings, 2010; Herkel and Kagerer, 2011; Höfler et al., 2014; Kaufmann et al., 2010; Romano et al., 2022)

Renovation works		U-value W/m^{2}K		TR-U-value W/m^{2}K	Total thickness	
		Before	After	Cold climate region	Before	After
Czech Republic - Koniklecova social housing example	Wall	0.78–0.80	0.17–0.24	0.19	26–33	46.53
	Window / Door	1.20–5.65	1.05–1.70	1.10	–	triple glass
	Ground flooring	1.13	0.33	0.28	–	+14 cm
	Roof	0.50	0.15	0.13	concrete + 12 cm	concrete+ 24 cm EPS
Austria - Kapfenberg social housing example	Wall	0.87	0.17	0.19	24.5	64.5
	Window / Door	2.50	0.90	1.10	double glass	triple glass
	Ground flooring	0.39	0.30	0.28	14	27
	Roof	0.74	0.10	0.13	20	55
Switzerland - Staufen social housing example	Wall	1.32	0.17	0.19	26.3	47.3
	Window / Door	1.62	1.62	1.10	–	–
	Ground flooring	2.27	0.20	0.28	16	26
	Roof	0.32	0.15	0.13	27	42.6
Belgium - Wezembeek social housing example	Wall	1.78	0.41	0.19	19	29
	Window / Door	5.10	1.19	1.10	–	double glass
	Ground flooring	6.66	0.26	0.28	19	38
	Roof	0.77	0.28	0.13	17	33

Staufen social housing, from 1967, suffered from mould and thermal bridges. The main goals of the renovation are a sustainable and energy-efficient building, improved comfort, and retirement income from the photovoltaic roof (Hastings and Enz, 2007) (changes in building envelope and energy consumption values are given in Tables 2 and 3).

Table 3 Energy consumption data of European samples (Almeida and Ferreira, 2017; Hastings, 2010; Herkel and Kagerer, 2011; Höfler et al., 2014; Kaufmann et al., 2010; Romano et al., 2022)

Energy consumption (kWh)	Before renewal	After renovation	Recovery %
Czech Republic- Koniklecova social housing example	129.58 kWh/m²·year	50.71 kWh/m²·year	78.87 kWh/m²·year
Austria-Kapfenberg social housing example	146.5 kWh/m²·year	46.5 kWh/m²·year	100 kWh/m²·year
Switzerland-Staufen social housing example	154 kWh/m²·year heating+hot water	54 kWh/year heating+hot water	100 kWh/m²·year heating+hot water
Belgium-Wezembeek social housing example	150 mWh/year	75 mWh/year	75 mWh/year

Wezembeek social housing, part of the Ban Eik garden city project, was the winning design of an architectural competition in 1959. After 30 years, the apartment blocks were dilapidated and became obsolete. They were built from cheap construction materials and were poorly maintained. The blocks were a problem "hotspot". Energy loss was minimized with insulation, heat recovery and thermal bridge alleviation. This was complemented with solar collectors and PV panels (Herkel and Kagerer, 2011) (changes in building envelope and energy consumption values are given in Tables 2 and 3).

A compact form with a rectangular plan was preferred. The land is slightly inclined, and the structure is positioned on the southern slope. It is known that before the renovation, the walls consisted of 60 mm EPS and 200–270 mm reinforced concrete panels, and the U-value was between 0.78–0.80 W/m²K. It has a flat roof consisting of slabs and was insulated with 120 mm mineral wool before refurbishment. The doors/windows in the building are single or double-glazed and are inadequate, especially air tightness. Considering the consumption values, the building consumes the most energy for the heating of the building.

Regarding the heating, ventilation, cooling and lighting systems before the renovation, heating is supplied from a nearby district heating facility connected to the central heat exchanger. There is no cooling installed in the structure. The building is mainly ventilated by natural ventilation. There are ventilation shafts in the kitchen, toilet and bathrooms, exhausting to the roof. Manually controllable light bulbs and fluorescents were used in the building (Sponar, 2011; Sedlák et al., 2015).

Improvements to Koniklecová 4 social housing included additional thermal insulation using expanded (EPS) or extruded (XPS) polystyrene or mineral wool installed on the outer walls, ground floor and roof. The roof was converted from a cold roof (ventilated with an air gap) to a warm roof (air gap not ventilated). In addition, the roof was waterproofed with a new bituminous membrane. All wooden and metal doors/windows in the building's envelope have been replaced, and the new doors/windows feature triple-glazed aluminium or plastic frames. The counterflow heating system on the ground floor of the building was used for heating, and radiators were installed throughout the building. During the renovation, the measuring and regulating equipment was changed. Existing shafts in the ventilation system have been preserved, and noise silencers and outlets on the roof have been replaced. The fans in the kitchen, toilet and bathroom and the roads connecting them to the central channels have been changed. With the modified system, they can be operated manually by the occupants (Höfler et al., 2014; Sponar, 2011; Sedlák et al., 2015).

More than 20% of energy savings were achieved by replacing the thermal heating and hot water system (DHW). The total energy consumption was 466.50 MJ/m^{2}a, with 350.03 MJ/m^{2}a for heating energy before renewal. After the renewal, 89.62 MJ/m^{2}a of energy is used up for heating, while the total consumption is 182.56 MJ/m^{2}a. With the renewals and the replacement of the DHW system, energy consumption was decreased by 60.9%.

When the improvements made in Northern Europe and Central Europe examples were examined, it was observed that renovations were made on the building envelope elements of the buildings in general (using materials with low U-value), HVAC systems were renewed, and significant savings were achieved as a result of these renovations. With the renovation of the Austria- Kapfenberg social housing sample, 68%, Germany- BIG Heimbau housing sample, 62%, Switzerland-Staufen housing sample, 65%, and with the Belgium-Wezembeek housing sample, 50% savings were achieved. These data demonstrate the benefits resulting from energy-efficient renewal/remediation.

3 Materials and method

In regions with cold climates, specific climate data shape architectural designs. These data are specific events directly affecting human life, such as low-temperature averages, frost and ice events, high rate of snowfall, and strong winds. The difficulties created by the cold climate present specific parameters for building design and building processes. In terms of parameters examined in the literature section of the study, a TOKI (Turkish Social Housing Administration) residence in Erzurum, one of the coldest provinces in Turkey, was analyzed. Mainly since 2003, TOKI's investments in the mass production of residential buildings, which have been responsible for rapidly meeting the housing demand, have played an important role in the improvement of the energy efficiency level of the construction sector in Turkey (Mangan and Oral, 2014). Therefore, energy-efficient improvement/production of TOKI houses is significant.

The building whose detailed information is listed in Table 4 is in Narman district of Erzurum province and was built with a tunnel formwork system. The social housing structure was completed in 2016 and consists of five blocks and one mosque. While positioning the buildings, the distances between them (min. 15 m) were considered, and they were placed so that they do not block each other's daylight. There are 120 residences in total in this social housing structure. In the block examined within the scope of this study, there are 24 2+1 residences, four on each floor. The block marked in the chart below was selected and analyzed.

There are two types of housing in this social housing structure, one of the TOKI type projects, B1 type and C type. Since four blocks are B1 type and one block is C type, the block type chosen for analysis is B1. The square plan, a compact typology, was used as the building form. The width and length of the building are approximately 20 meters, and its height is 22 meters. Each residence has a gross area of 75 m².

The type of each material used in the project implemented by TOKI was defined with detailed project and technical specifications.

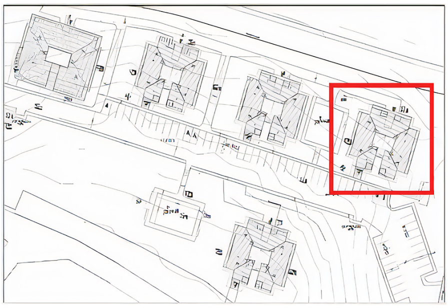
Walls (from inside to outside): Plastic paint + satin plaster coating + interior plaster + brick wall + exterior plaster + heat insulation (EPS) + silicone-added acrylic exterior paint. The total thickness is 31 cm. The inner walls are 20 cm reinforced concrete, a structure made with a tunnel formwork system.

Windows/Doors: double glazed windows of 140 cm/130 cm have been fitted, with floor hall windows of 90 cm/130 cm in size. The same type of windows was used systematically in the building. There is a lobby at the entrance, and the building is entered through two aluminum doors: 260 cm/277 cm.

Roof: The building has a hipped roof due to snowfall and snow load. Roof (from top to bottom): It consists of 0.70 mm trapezoidal sheet + thin membrane + wooden seated roof + glass wool thermal insulation + reinforced concrete flooring + satin plaster + top coat decorative paint.

Foundation slab (from top to bottom): Mosaic tiles + levelling layer + foundation concrete + 5 cm of lean concrete + 2 layers of waterproofing + 10 cm of lean concrete + compacted soil which results in a total of 75 cm of

Table 4 Building identity information of Erzurum social housing sample (TOKI)

Building credentials		Plan and photo
Production year / Place	2016 / Narman	
Land condition	Flat land	
Building orientation	North-South-East-West	
Number of floors / Number of houses	5 floors / 120 houses (24)	
Number of buildings / Settlements	5 blocks / Separated order	
Renovation year / Architect	- / TOKI	
Annual energy requirement	26,000 kWh (average value)	

thickness. Floor coverings (from top to bottom): laminate flooring + screed + levelling layer + reinforced concrete flooring + satin plaster coating + top coat decorative paint, with a total thickness of 25 cm.

In the research, the building envelope elements of the selected building, the U-values of these elements and the HVAC system elements of the building were used, and energy simulation was made with the Design Builder program. Building modelling was done in the Design Builder program with the building envelope elements. Factors existing in the program analysis, such as insulation thickness, U-values, thermal conductivity value, HVAC system of envelope elements such as walls, doors/windows, roof, and foundation/floor, were used and simulated in terms of energy performance. Later, this model was simulated again by making changes to the building envelope elements and HVAC system elements, and the analysis was made on the energy values. The steps followed during the simulation were as follows; The "As Built" data of the building was transferred to the program, defining the assumptions in the program and determining the energy consumption by starting the simulation. In Design Builder program, the simulation of the structure and the definition of the assumptions developed as follows:

- Design Builder program uses climate data in simulation in accordance with ASHRAE standards. Since the climate data of the Erzurum region is not available in the program, according to the Koppen climate classification, the climate data of the Stockholm region, which is included in the Dfb classification and the same climate category, were used for Erzurum.
- The building envelope elements of the existing building were defined separately for each space in the program. The building envelope elements not included in the program are material layers created and defined by entering their thickness and technical information into the program.
- For modelling energy consumption within the scope of the study, it was assumed that four people live in a house in the social housing structure in Erzurum.
- Within the scope of the program, the hipped roof form was evaluated over the form assigned by the program, and since there are no roof space parameters, the roof slab has been evaluated and simulated.
- Since the building is in a cold climate zone, there is no cooling system. As a result of the examinations made in the literature, since the amount of energy consumed for space heating constitutes the largest share for cold climate regions, the energy used for space heating in terms of building envelope elements was evaluated within the scope of this simulation and the use of cooling, lighting, and electrical appliances was ignored.
- The central system for heating all the spaces in the building (except the basement and halls) was provided with a hot water radiator system, and natural gas is used as fuel. There is no mechanical ventilation in the building. It is assumed that there is natural ventilation for each space (except the corridor), and central ventilation is activated when the building temperature rises above +24 °C.
- According to the Design Builder template, the indoor temperature value used is 21 °C for the living area and 18 °C for other areas such as rooms, halls, and bathrooms. The metabolic factor for each place was defined as 0.90.

After transferring data such as climate data, application project data, and user profiles to the program, a building model was created and simulated in terms of the heating load.

As can be seen in the normal floor plan (Fig. 2), the spaces for each floor have been determined and the necessary data has been entered into the program. The calculation of the heating load as a result of the data entered into the program, and the simulation results are given in Fig. 3.

When the heat losses of the current situation are examined, the heat lost from the walls is 36.12 kWh/m²·year, from the windows 7.86 kWh/m²·year, and from the roof is 3.47 kWh/m²·year. The energy consumed by the building for space heating is shown in Fig. 4.

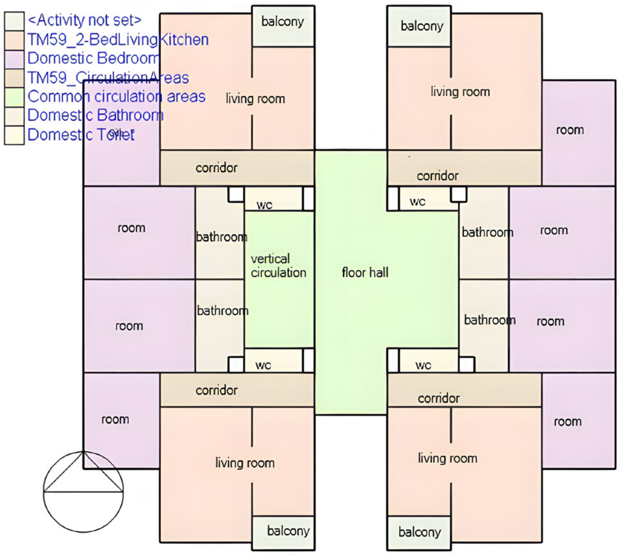
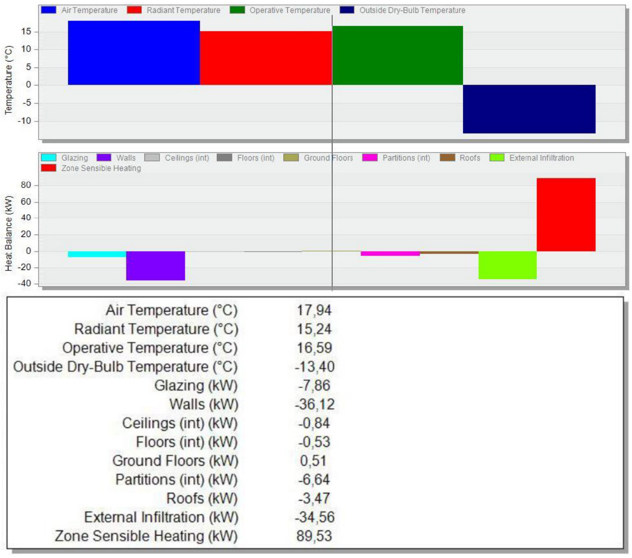


Fig. 2 Design Builder simulation plan of Erzurum sample



Air Temperature (°C)	17,94
Radiant Temperature (°C)	15,24
Operative Temperature (°C)	16,59
Outside Dry-Bulb Temperature (°C)	-13,40
Glazing (kW)	-7,86
Walls (kW)	-36,12
Ceilings (int) (kW)	-0,84
Floors (int) (kW)	-0,53
Ground Floors (kW)	0,51
Partitions (int) (kW)	-6,64
Roofs (kW)	-3,47
External Infiltration (kW)	-34,56
Zone Sensible Heating (kW)	89,53

Fig. 3 Current heating design of the Erzurum example

Building 1 Total Design Heating Capacity = 111,920 (kW)
+ BodrumKt Total Design Heating Capacity = 0,000 (kW)
+ Zemin kat Total Design Heating Capacity = 21,370 (kW)
+ 2. Kat Total Design Heating Capacity = 16,900 (kW)
+ 5.Kat Total Design Heating Capacity = 22,630 (kW)
+ 3. Kat Total Design Heating Capacity = 16,960 (kW)
+ 4. Kat Total Design Heating Capacity = 17,210 (kW)
+ 1. Kat Total Design Heating Capacity = 16,850 (kW)

Fig. 4 The energy consumed for the current space heating of the Erzurum example

The floors with the highest energy consumption are the ground floor (the ground floor is unheated), the 5th floor, and the top floor. The total annual heating energy consumption of the building is 111.92 kWh/m²·year.

4 Findings and evaluation

Within the scope of the study, the improvement scenarios of B1 type TOKI housing were to reduce the energy consumed for space heating. These scenarios were handled through the building envelope elements and evaluated in the five categories listed below:

- Improvement of external walls (S1, S1A, S1B, S1C),
- Improvement of windows (S2),
- Improvement of roofing (S3, S3A, S3B, S3C),
- Foundation/Ground improvement (S4, S4A, S4B, S4C),
- Improvement of S1C-S2-S3C-S4C scenarios as a whole (S5).

When examining the scenarios carried out for the improvement of external walls, it can be seen that 5 cm EPS is currently used as external wall insulation. Instead of 5 cm EPS, 10 cm stone wool was used for S1 scenario, 20 cm stone wool was used for S1A scenario, 30 cm stone wool was used for S1B scenario and 40 cm stone wool was used for S1C scenario. The results are given in Table 5.

In the results given in Table 5, the values on the heating energy consumption of the scenarios were examined, and it was shown that S1, S1A, S1B, S1C improved by 10.52%, 17.16%, 19.67%, and 21.08% respectively.

In the scenario realized for the improvement of the windows, instead of the 4+12+4 double-glazed PVC frame windows in the current situation, S2 scenario and triple-glazed PVC frames windows with heat control coating (Low-E) were used.

Table 6 analyses the data on the heating energy consumption of the S2 scenario. This analysis shows that an improvement of 5.01% was achieved by saving 5.61 kWh/m²·year of energy in total.

In the scenarios carried out for the improvement of the roof flooring, which is the 3rd type scenario, instead of the 5 cm glass wool in the current situation, 10 cm stone wool for S3 scenario, 20 cm stone wool for S3A scenario, 30 cm stone wool for S3B scenario, 40 cm stone wool for S3C scenario which all were carried out using stone wool.

Table 5 Analysis of S1, S1A, S1B, S1C scenarios

Improvement of exterior walls	Material used	Heat loss	Total heating load	Recovery percentage (%)
Current situation	5 cm EPS	36.12 kWh/m²·year	111.920	–
S1 scenario	10 cm rock wool	26.88 kWh/m²·year	100.14	10.52
S1A scenario	20 cm rock wool	21.09 kWh/m²·year	92.71	17.16
S1B scenario	30 cm rock wool	18.83 kWh/m²·year	89.9	19.67
S1C scenario	40 cm rock wool	17.63 kWh/m²·year	88.32	21.08

Table 6 S2 scenario analysis

Improvement of windows	Material used	Heat loss	Total heating load	Recovery percentage (%)
Current situation	4+12+4 double glazing	7.86 kWh/m²·year	111.92 kWh/m²·year	–
S2 scenario	Low-E triple glass	3.08 kWh/m²·year	106.31 kWh/m²·year	5.01

The results of the scenarios for improving the roof covering are analyzed in Table 7. As a result of the S3, S3A, S3B, S3C scenarios, it was observed that there was an improvement of 1.07%, 1.42%, 1.71% and 2.12%, respectively.

An improvement was considered for the ground floor slab (basement ceiling) in the S4 scenario, and it was assumed that 3 cm XPS was applied to the ground floor slab for the S4 scenario, 5 cm XPS for the S4A scenario, 10 cm XPS for the S4B scenario, and 15 cm XPS for the S4C scenario.

In the results of Type 4 scenarios given in Table 8, it was observed that there would be an improvement of 0.89%, 1.17%, 1.4%, and 1.57% for S4, S4A, S4B, S4C scenarios, respectively.

In the S5 scenario, it was assumed that the external wall, window, floor and roofing improvements, which were considered separately in the first four scenarios (S1C, S2, S3C, S4C), would be carried out together, and it was noted that the results of the heating load obtained would be as follows.

It has been determined that the annual total heating load per square meter, which is 111.92 kWh/m²·year in the current situation, will be 77.79 kWh/m²·year with an improvement of approximately 30.49% as a result of the S5 scenario, where S1C, S2, S3C, S4C improvements are applied simultaneously (Table 9).

The U-values calculated in the program of the building envelope elements used in the S5 scenario are in Table 10.

According to the S5 scenario in Table 7, when the U-values of the building envelope elements before and after the renovation of the building are examined, the U-value of the walls changes from 0.559 to 0.091, the windows from 1.440 to 0.966, the floor slab from 2.17 to 0.183, and the U-value of the roof was reduced from 0.606 to 0.096.

Table 11 gives the simulation results obtained after applying the current situations and scenarios. S1 scenarios resulted in improvements of 10.52-17.16-19.67-21.08%, respectively; S2 scenario resulted in a 5.01% improvement; S3 scenarios resulted in 1.07-1.42-1.71-2%, respectively; S4 scenarios resulted in 0.89-1.17-1.40-1.57% improvement respectively. As a result of the S5 scenario, in which 12 improvement scenarios were applied together and 30.49% improvement was achieved. According to these results, the highest savings were obtained from the S5 scenario (30.49%), in which all scenarios were applied together.

Of course, assessing based on m² while evaluating the improvement rates will be helpful. Accordingly, the wall renovation carries the most m²; therefore, the highest value among the S1-S2-S3-S4 scenarios belongs to the walls. It was observed that the results were higher as the thickness or number of layers applied increased.

Table 7 Analysis of 3 S3, S3A, S3B, S3C scenarios

Improvement of roofing	Material used	Heat loss	Total heating load	Recovery percentage (%)
Current situation	5 cm EPS	3.47 kWh/m²·year	111.92 kWh/m²·year	–
S3 scenario	10 cm rock wool	2.63 kWh/m²·year	110.91 kWh/m²·year	1.07
S3A scenario	20 cm rock wool	2.18 kWh/m²·year	110.33 kWh/m²·year	1.42
S3B scenario	30 cm rock wool	1.87 kWh/m²·year	110 kWh/m²·year	1.71
S3C scenario	40 cm rock wool	1.47 kWh/m²·year	109.54 kWh/m²·year	2.12

Table 8 Analysis of S4, S4A, S4B, S4C scenarios

Improvement of the ground floor slab (basement ceiling)	Material used	Heat loss	Total heating load	Recovery percentage (%)
Current situation	3 cm EPS	0.53 kWh/m²·year	111.92 kWh/m²·year	–
S4 scenario	3 cm XPS	0.52 kWh/m²·year	110.82 kWh/m²·year	0.89
S4A scenario	5 cm XPS	0.76 kWh/m²·year	110.6 kWh/m²·year	1.17
S4B scenario	10 cm XPS	0.99 kWh/m²·year	110.32 kWh/m²·year	1.4
S4C scenario	15 cm XPS	1.12 kWh/m²·year	110.16 kWh/m²·year	1.57

Table 9 Comparison of scenarios

Comparison of scenarios	Material used	Total heating load	Recovery percentage (%)
Current situation	–	111.92 kWh/m²·year	–
S1C	40 cm rock wool	88.32 kWh/m²·year	21.08
S2	Low-E triple glass	106.31 kWh/m²·year	5.01
S3C	40 cm rock wool	109.54 kWh/m²·year	2.12
S4C	15 cm XPS	110.16 kWh/m²·year	1.57
S5	S1C, S2, S3C, S4C	77.79 kWh/m²·year	30.49

Table 10 Building element information of Erzurum social housing sample (calculated in the program)

		Erzurum TOKI social housing sample				
Renovation works		U-value $\text{W/m}^2\text{K}$		Total thickness		The changes that have been made
		Before	After	Before	After	Total (S5)
Building envelope elements	Wall	0.559	0.091	31 cm	66 cm	40 cm rock wool thermal insulation
	Window / Door	1.440	0.966	4 + 16 + 4 cm double glass	Low-E triple glass	Replacing with triple Low-E glass
	Ground flooring	2.17	0.183	25 cm	40 cm	15 cm XPS
	Roof	0.606	0.096	28 cm + hipped roof	65 cm + hipped roof	40 cm rock wool

Table 11 Building energy performance information of Erzurum social housing sample

Energy consumption (kW)	Before renewal	After renovation	Recovery percentage (%)
S1	111.92	100.1014	10.52
S1A	111.92	92.71	17.16
S1B	111.92	89.9	19.67
S1C	111.92	88.32	21.08
S2	111.92	106.31	5.01
S3	111.92	110.91	1.07
S3A	111.92	110.33	1.42
S3B	111.92	110	1.71
S3C	111.92	109.54	2.12
S4	111.92	110.82	0.89
S4A	111.92	110.6	1.17
S4B	111.92	111.32	1.40
S4C	111.92	110.16	1.57
S5	111.92	77.79	30.49

Since a change in the area of the windows would be a big size change, this was ignored and only double-glazed windows were converted to triple-glazed windows. However, not as much as triple-glazed windows in terms of energy performance, windows with 4+12+4 (4 mm + 12 mm space + 4 mm glass) features are also considered to be in good condition in terms of energy performance. Therefore, it is foreseen that greater energy savings can be achieved when single-glazed windows are renewed.

Since the roof parameters are not defined in the simulation program, the S3 improvement scenario is limited to the roof covering. However, while defining the roof covering in the program, flooring + 10 cm rock wool + 2 meters space + 10 cm rock wool + membrane + sheet metal was evaluated as an unheated roof space. Since the load on the heating area to be affected by this scenario is limited to the last floor, it is considered normal that the recovery percentage is low when evaluated in m^2.

In the improvement scenario applied for the ground floor slab, 3-5-10-15 cm XPS was applied to the basement ceiling, and the area it would most affect was the ground floor, limited to one floor, as in the S3 scenario. When considered in m^2, the results of this scenario are so effective that it cannot be underestimated. Due to the 1% energy saving difference, S3 and S4 scenarios can be evaluated at the same level.

5 Conclusion and recommendations

The issue of energy has been on the priority agenda of all countries in recent years. The limited resources make every work, initiative and effort on energy even more important. The building sector is responsible for 40% of energy consumption on a global scale is an indication that architects should approach the issue more sensitively. Studies on energy conservation and reduction of energy consumption in architecture continue to increase. Architects' relations with the subject are in the initial stages of design within the scope of determining the design principles of heating, cooling, lighting and ventilation in relation to energy consumption. Design principles affect the basic needs of houses and play a major role in energy consumption.

New buildings in Turkey comply with thermal insulation and energy performance regulations. However, many existing buildings were built before the regulations came into force. The energy consumed by these structures is significant. Therefore, studies on improving the energy efficiency of existing building stock with renovations are critical.

This study was motivated by the question "How much can the energy consumption of existing social housing structures in the cold climate zone be reduced?". "The energy consumed for space heating in cold climate regions can be reduced by improvements to the building envelope." A research plan was prepared with the hypothesis.

Within the framework of this plan and the scope of this study, only the factors affecting the building envelope are discussed; factors such as design criteria (factors that cannot be changed after the building is built, such as site selection, orientation, climatic conditions) and the addition of systems for energy recovery are excluded from the scope of this study.

To evaluate the energy-efficient renewal of existing housing structures from European countries, previously renovated social housing examples from the Czech Republic, Austria, Germany, Switzerland and Belgium were examined, and the possible renovations made in the building envelope elements. Attention was paid to the improvements made as the first step in the examined examples was to the building envelope, and this area was focused on within the scope of the study. In this context, replacement of existing window material was excluded as it is a comprehensive change. Restored building samples in Europe which are in the scope of this study were not renovated only for space heating. Comparisons could have been more effective if these buildings were also renovated for space heating purposes.

In the field study, Erzurum was selected for the sample study and a house built by TOKI, an institution that has met a large part of the housing need in recent years, has been evaluated. Within the framework of this evaluation, the amount of energy required for space heating in the current situation was calculated with the Design Builder simulation program. Then, a total of 14 scenarios were determined, with five different scenarios applied to walls, windows, floors, and roofs and the type of scenario where they were all applied together; For four scenario types, improvements are made on individual building envelope elements by using different thicknesses, and a scenario in which all improvements are made together is designed in 1 scenario. The material (rock wool, XPS) types have not been changed for the scenarios where the thicknesses are evaluated/compared. In these scenarios, it was noted that the highest improvement rate was in the S5 scenario, where all of them were applied together, and 30.49% improvement could be achieved in total in space heating. This value shows that a 30.49% improvement in space heating energy can be achieved by renewing the building envelope in cold climates. This result answered the research question and the study's hypothesis was confirmed.

Erzurum TOKI social housing is compared with European social housing examples and it has the lowest level of energy saved which is listed in Table 12. However, it also has the lowest rate in total energy consumption before renovation. The building chosen as an example was not built to low qualities in terms of energy performance, as in the European examples. Of course, when evaluating this, the legislation which they are subject to when they were constructed should also be considered.

During the study process, natural gas invoices for 2020 which spans through 3 months were taken into account. The inability to compare the data obtained from the simulation program with the invoices of at least three years is among the limitations of this study.

It is clear that there is a gap, especially for cold climate regions, to reduce the energy consumed for space heating in Turkish buildings. Considering the work done, evaluating the existing building stock in cold climate regions in the context of the building envelope and taking the necessary renewal steps is essential.

It is foreseen that greater savings will be achieved with the improvements made to older housing stock.

The results of this study, which was carried out on a completed project, show that it is possible to reduce a significant part of the heating loads of buildings in cold climate regions by improving the building envelope. In the proposed improvement scenarios, opaque and transparent components can be renewed by considering the efficiency of the building envelope elements based on the square meterage of the building.

Table 12 Comparison of the energy performance change of the examined social houses

Examples	Before renewal	After renovation	Saving	Recovery percentage (%)
Czech Republic - Koniklecova social housing example	129.58 kWh/m²·year	50.71 kWh/m²·year	78.87 kWh/m²·year	74.4
Austria - Kapfenberg social housing example	146.5 kWh/m²·year	46 kWh/m²·year	100 kWh/m²·year	68
Switzerland - Staufen social housing example	154 kWh/m²·year	54 kWh/m²·year	100 kWh/m²·year	65
Belgium - Wezembeek social housing example	150 kWh/m²·year	75 kWh/m²·year	75 kWh/m²·year	50
Erzurum TOKI example (S5)	111.92 kWh/m²·year	77.79 kWh/m²·year	34.13 kWh/m²·year	30.49

Topics such as the renovation efficiency per m² of the building envelope elements, the renovation of the HVAC systems of the building, the renovation of the building envelope according to the cost, as well as the addition of energy generating systems and the evaluation of which scenario will be more efficient in terms of cost and performance may be a new research question for researchers.

Although residential energy consumption is a world issue, the Erzurum example is locally significant as Turkey imports most of the energy used. In addition, considering that the number of new constructions is less than the number of existing buildings, the renewal of the existing housing stock to use energy more effectively has great value in today's conditions.

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