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Renovation wave of the residential building stock targets for the carbon-neutral: Evaluation by Finland and Türkiye case studies for energy demand

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ABSTRACT

The recent EU energy efficiency goals and renovation wave have called attention to the building stock's energy-demand-saving potential. Finland and Türkiye, with two contrasting perspectives on climate zones and building typologies in the EU, were chosen to analyse energy-demand potential. The study's scope was restricted to the residential building stock, a significant portion of the overall building stock. The latest residential building stock data and regulations history was gathered via a bottom-up approach. Then three representative buildings for each typology were energy demand simulated for climatic regions and periods. Thirdly, the area-weighted energy needs difference values for each decade (1960–2020) and climatic zone were multiplied with the building stock data to predict saving potential. Fourth, the impact of factors on energy demand was assessed using full-factorial analysis. Lastly, the main factors were parametrically simulated and compared with mandatory limits. The substantial energy-demand-saving potential existed in both countries. The findings highlighted the following: (1) the energy demand saving potential for the Finnish and Turkish building stocks were calculated as 10,176.9 GWh/year (30 %) and 124,889.3 GWh/year (50 %), respectively; (2) energy demand in Finland is dependent strongly on the climatic zone; (3) the optimum thermal insulation thickness for Finnish buildings is likely to be at the current level or even below it, while Türkiye's insulation limits are climatic zone based but not sufficient for carbon neutral; (4) Surprisingly for both countries, the most important factors to consider when renovating buildings were the thermal insulation level of the walls and roof in single-family buildings and the thermal insulation level of the walls in multi-family buildings and the airtightness of the building envelope. It should be noted that for Finland, building energy efficiency regulations will differ on the climate zone. Türkiye's newly published NZEB values should become mandatory lower limits for all residences because current legislative limits are insufficient and date back to the 2000s.

Introduction

General

Following discussions to mitigate the effects of climate change, the United Nations Framework Convention on Climate Change (https://unfccc.int/process-and-meetings/the-convention/what-is-the-united-nations-framework-convention-on-climate-change, n.d.) (UNFCCC) decided to reduce greenhouse gas (GHG) emissions to 1990 levels, and this year has been used as a reference emission year in continuing meetings (https://unfccc.int/kyoto_protocol, n.d.; https://unfccc.int/resource/docs/2007/cop13/eng/06a01.pdf, n.d.; https://unfccc.int/files/kyoto_protocol/application/pdf/costarica050609.pdf, n.d.) (21 March 1994). With the Paris Agreement (https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement, n.d.), legal obligations were introduced as a continuation of the UNFCCC (November 4, 2016).

According to the report of the Intergovernmental Panel on Climate Change (https://unfccc.int/news/unfccc-secretariat-welcomes-ipcc-s-global-warming-of-15degc-report, n.d.) (IPCC), reducing the use of fossil fuels and carbon emissions in order to limit global warming to 1.5 °C has targeted the building sector, where energy is consumed intensively. As explained in both the IPCC (https://www.ipcc.ch/report/ar5/wg3/buildings/, n.d.) and International Energy Agency

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(https://www.iea.org/topics/buildings, n.d.) (IEA) reports, one-third of the final energy is used to meet the comfort user requirements of buildings in the world. Furthermore, according to the European Union's (EU) Energy Performance of Buildings Directive (EPBD), which was first published in 2002, buildings in Europe account for approximately 40 % of total energy consumption and 36 % of GHG emissions.

In October 2020, the EU Commission published the Renovation Wave strategy (https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en, n.d.), which aims for decarbonized buildings, job opportunities, and improved life quality. EU Renovation Wave strategy indicates that buildings representing 85 % of the EU building stock were built before 2001, and 85–95 % will be in use by 2050. A revised EPBD (https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en?redir=1, n.d.) proposal was published, with targets aligned with the Renovation wave strategy in December 2021. A building renovation passport was defined in this new proposal, which is aimed at deep renovation of the building stock. One of the key actions identified by the EU Commission for 2023 is the proposal on Building Renovation Passports and the introduction of a single digital tool unifying them with Digital Building Logbooks, from which a variety of data can be accessed by beneficiaries from various sectors. Static data such as Energy Performance Certificates (EPC), renovation passports, and dynamic data such as smart meter data will be stored in the EU's building digital logbook. The revised directive establishes guidelines for achieving zero-emission building stock in Europe by 2050.

Depending on the demographic structures of the countries, new buildings are included in the stocks every year. On the other hand, renovation strategies and action plans have focused on improving the existing building stock. Existing buildings will need to be renovated to meet future demand. The residential building stocks of Finland and Türkiye, which differ in terms of demographics, climatic conditions, and building typologies, were studied. The potential for reducing the energy demand of the two countries was assessed.

To date, there is no study in the literature in which, weighted areas and weighted energy demand were defined for each typology, climatic zone and decade in Finland and Türkiye. Energy demand results were verified with top-down energy consumption and EPC values. The study filled this gap. In simulations, country-specific occupancy rates, indoor temperatures, and infiltration rates were included. The energy-saving potential has been analysed at the national level and the main parameters of renovation in building typologies were analysed with the full-factorial method, and the parametric runs were done for the insulation thickness in relation to energy demand. Finland and Türkiye were chosen for this study because of the different climatic regions and regulations can give two various aspects to the study.

Similar studies in previous literature

The building sector has a high energy efficiency potential, which has led researchers to improve and explore different perspectives. Studies aimed at reducing energy demand focus on finding the optimum insulation thicknesses or glazing rates that affect cooling and heating loads. Energy consumption-saving studies are examined according to different mechanical systems and renewable energy scenarios. However, these studies give accurate results for the individual building, but not a proper approximation in nationwide extrapolation without a detailed study of building stocks, weather data, and decades.

Ugursal (Swan & Ugursal, 2009) reviewed bottom-up and top-down approaches in terms of defining building models and methods for simulating energy efficiency in the residential sector. Results show that researchers should include a detailed bottom-up approach. Gulotta et al. (n.d.) studied the building stock of 28 EU countries using the BOHEEME methodology, which is based on a bottom-up approach. They suggested that weather conditions and geographic locations should always be accounted for in studies. In Typology Approach for Building Stock Energy Assessment (https://episcope.eu/building-typology/tabula-structure/concept/, n.d.) (TABULA) funded by the Intelligent Energy Europe Programme, residential building stock data was developed for 21 countries (https://episcope.eu/building-typology/country/, n.d.), such as Denmark, Norway, Sweden, Spain, Italy, and Greece. The bottom-up approach was used in that project to build residential typology data, and renovation targets were investigated. MortenBrøgger et al. (2019) used a bottom-up hybrid building energy model. The approach combined building physics-based modelling with a statistical method to evaluate the energy demand of the Danish housing stock. It was found that incorporating the building physics energy model into a statistical model improves accuracy. N. Mustaffa et al. (2021) show different ways of using a bottom-up approach. Research conducted 54 building stakeholder surveys and bottom-up studies, consisting of six case studies, to improve and change the behavior of the Malaysian construction industry and greening practices. Kavgic et al. (2010) reviewed bottom-up building models, including one of the residential building models researched by Snäkin (2000) for North Karelia in Finland. The model produced annual energy consumption and energy costs based on 1996 prices. It is a numeric model that covers 19 municipalities out of 303. Snäkin suggested using woodfuels in district heating to decrease emissions. Another bottom-up model is used in Finnish building stock by Vihola et al. (2015) the study focused on heat loss rate and used the 2012 reference year to calculate 2010 heat loss with two reference buildings. Results showed that peak load was 25 GW.

The regulations were included in studies that limited energy demand or consumption. Regulations classify with standards, legislation, and laws. The regulations' limits are based on studies because building compliance with legislation is checked by local administrations in order to obtain construction and use permits. Evans et al. (2017) analysed the diversity of enforcement practices between countries and how these practices affect global and emphasized the need for stronger control arrangements by policymakers to implement regulations. Adly et al. simulated the effect of using an integrated approach to energy efficiency retrofitting techniques based on the requirements of the Egyptian Energy Code for Residential Buildings in Cairo. Ece Kalaycioglu and Yilmaz (2017) analysed district-level heating and cooling comparisons with reference buildings and NZEB-targeted buildings with cost-effectiveness. As a result of the study, primary energy factors have a significant impact on renewable energy use incentives, national energy efficiency policies, and the country's financial stability. The identification and calculation of primary energy conversion factors should reflect the country's energy policy objectives. Hirvoenen et al. (2021) studied the Finnish building stock's emission-saving potential with five renewable energy scenarios by calculating final energy consumption. As a result, compared to the business-as-usual development scenario, district heating demand was reduced by 25–63 %..

Manni et al. (2020) studied parametric control the building's shape, by maximizing the solar irradiation and minimizing the embodied emissions with Grasshopper software. The result showed optimizing the algorithm can increase solar irradiation equal to 35 % in the Mediterranean area and 20 % in the Nordic climate. Kyrö et al. (2011) studied the occupancy effect on overall energy consumption in district-heated residential buildings in Finland. Results show that the occupants cannot influence or adjust room temperatures in multi-family buildings connected to a district heating system. Mattinenet al (2014). studied energy consumption in residential buildings via visualization. In their study, the Kaukajarvi area visualized e district energy consumption and GHG emissions Meijer et al. (2009) studied the comparison of the European building stock in 7 countries with basic data. According to their statistical survey, the gap in physical building stock data differs in energy use breakdown and definition of building typology. In Finland and Türkiye cases, second summer homes are common for temporary usage, which isn't included in this study. The country-specific, detailed study supports the elimination of these criteria.

Methods and materials

General

The study began with an examination of both countries' building stock using national statistical databases. A bottom-up approach is used to classify existing building typologies, the number of buildings in each province, the construction date, and envelope features. In the Finnish statistical database (https://www.stat.fi/meta/kas/talotyyppi_en.html, n.d.), residential building typologies are grouped as detached, attached, and blocks of flats (multi-family houses). In the Turkish statistical database, residential buildings are classified as one-dwelling buildings, two-dwelling buildings, and three and more dwelling buildings. In this study, one or two dwelling buildings are named single-family houses (SFH) and three and more dwelling buildings are called multi-family houses (MFH) for Türkiye. For each typology, three model buildings with different geometries were simulated based on their climatic zones and the construction period, which determined the way they were constructed. Both countries have four distinct climatic zones based on heating degree days, as shown in Table 8. However, due to HDD differences in Finland's coldest region, Rovaniemi and Sodankyla are represented by two main locations. Helsinki, Tampere, Jyväskylä, Rovaniemi, and Sodankyla cities' hourly weather data were chosen to represent the climatic regions in Finland, and Istanbul, Izmir, Ankara, and Erzurum cities hourly weather data were chosen to represent the climatic regions in Türkiye. The 1st and 2nd climatic regions, which included Helsinki and Tampere in Finland, and Istanbul and Izmir in Türkiye cover more than half of the populations of both countries. Fig. 1 depicts the steps of the study.

IDA-ICE (https://www.equa.se/en/ida-ice, n.d.) is dynamic energy simulation software that has hourly climate data (typical meteorological year) for both countries and internal gains, time schedules, ventilation, infiltration, and heating and cooling parameters that can be adjusted to the country-specific regulations for simulations. In terms of the construction period, building envelope features, such as opaque and transparent surfaces, and buildings in various locations were simulated. Internal gains from people and equipment were included in the simulations' internal gains. IDA-ICE software calculation methodology is validated with EN 15265-15255-13971 (https://www.equa.se/en/ida-ice/validation-certifications, n.d.) (EN 15265:2007, Energy performance of buildings — Calculation of energy needs for space heating and cooling using dynamic methods — General criteria and validation procedures). In both countries, energy needs calculations have been adapted to their countries according to the EN ISO 13790 (Updated version EN ISO 52016-1) standard. The formulas for the energy needs given to the relevant standard are the same for both countries.

The first three equations (Eqs. (1)–(3)) show the general formulation of heating and cooling energy demand annually in both countries.

$$Q_{\mathrm{H,C;nd;}ztc\mathrm{;an}} = \sum\nolimits_{m=1}^{12} Q_{\mathrm{H,C;nd;}ztc\mathrm{;m}} \tag{1}$$

where

$Q_{\mathrm{H,C;nd;}ztc\mathrm{;m}}$ is the monthly energy needs for heating and cooling for the thermally conditioned zone ztc and month m,

$$Q_{\mathrm{H,C;nd;}ztc\mathrm{;m}} = Q_{\mathrm{H,C;tr;}ztc\mathrm{;m}} + Q_{\mathrm{H,C;ve;}ztc\mathrm{;m}} \tag{2}$$

where

$Q_{\mathrm{H,C;tr;}ztc\mathrm{;m}}$ is the total heat transfer by transmission for heating, and cooling, in kWh;

$Q_{\mathrm{H,C;ve;}ztc\mathrm{;m}}$ is the total heat transfer by ventilation for heating, and

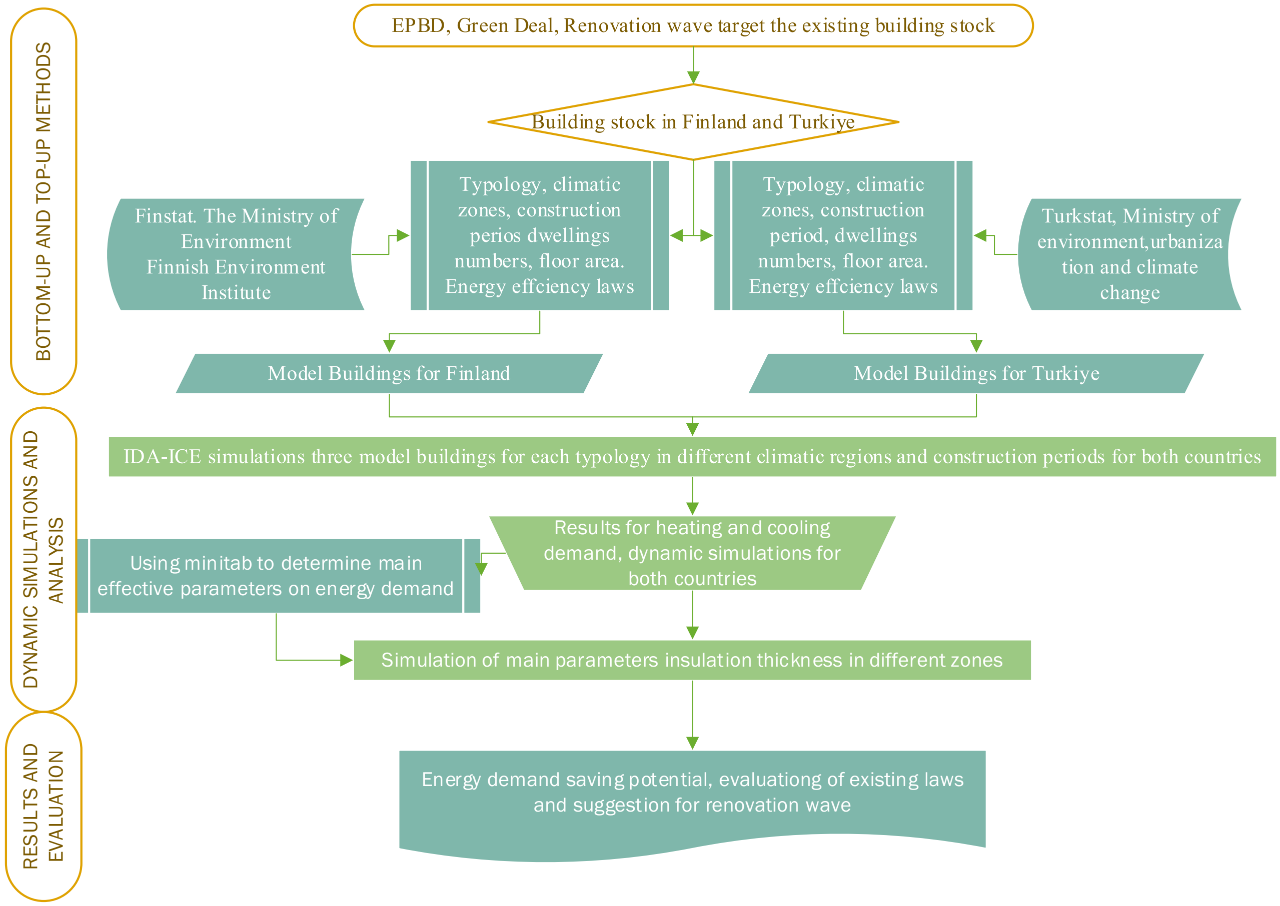


Fig. 1. Flow chart of the methodology.

cooling, in kWh;

$$Q_{\mathrm{H,C;gn;}ztc\mathrm{;m}} = Q_{\mathrm{H,C;}int\mathrm{;}ztc\mathrm{;m}} + Q_{\mathrm{H,C;sol;}ztc\mathrm{;m}} \tag{3}$$

where

$Q_{\mathrm{H,C;}int\mathrm{;}ztc\mathrm{;m}}$ is the sum of internal heat gains for heating or cooling in kWh;

$Q_{\mathrm{H,C;sol;}ztc\mathrm{;m}}$ is the sum of solar heat gains for heating or cooling in kWh;

Ventilation heat loss calculation in Finland

In Finland, there are no differentiated U values for different climatic zones. However, the values of the walls, roof, floor, and windows in Türkiye vary according to the climatic zones. In Finland, facade insulation values have increased, resulting in lower infiltration values, and mechanical exhaust systems have been installed in multi-story apartments.

In Finland, heat losses from ventilation are calculated using Eqs. (4)–(7).

$$\mathrm{H}_{\mathrm{iv}} = \rho_i c_{pi} q_{v,exhaust} t_d t_w (1-\eta_a) \tag{4}$$

where

H_{iv} is the specific heat loss of the ventilation, W/K

ρ_i is the air density, 1,2 kg/m^3

c_{pi} is the specific heat capacity of air, 1000 J/(kg K)

$q_{v,exhaust}$ is the calculated exhaust airflow according to standard use, m^3/s

t_{d} is the average daily operating time ratio of the ventilation system, h/24 h

t_{w} is the weekly operating time ratio of the ventilation system, days/7 days;

η_a is the annual heat recovery efficiency of the ventilation exhaust air, –

$$H_{leakage} = \rho_i c_{pi} q_{leakage\ air} \tag{5}$$

$$q_{leakage\ air} = \frac{q_{50}}{3600.x} A_{enveleope\ area} \tag{6}$$

$$q_{50} = \frac{n_{50}}{A_{area}}\ V \tag{7}$$

where

q_{50} is the building envelope leakage rate, m^3/(h m^2)

n_{50} is the building leakage rate with a pressure difference of 50 Pa, 1/h

V is the air volume of the building, m^3

$\mathrm{A}_{\mathrm{area}}$ is the building envelope area (including subfloor), m^2.

x is a coefficient that depends on the number of floors in the building, –.

In Türkiye the natural ventilation and infiltration are calculated together using Eq. (8), and there the n50 value at regulatory calculations is set at 0,8 h^{-1}.

$$\mathrm{H}_{\mathrm{v=}}\ \mathrm{r.c.V^{\prime}} = \mathrm{r.c.n_h\ V_h} = 0.33\ \mathrm{n_h.V_h} \tag{8}$$

r density 1.184 (kg/m^3),

c specific heat capacity of the air 1006 (J/kgK),

$\mathrm{V}^{\prime}$ air exchange rate by volume (m^3/h),

n_{h} air change ratio (h^{-1}),

V_{h} ventilated volume ($\mathrm{V_h} = 0{,}7 \times \mathrm{V_{total}}$) (m^3)

r density 1.184 (kg/m^3),

"r" ve "c" change slightly depending on temperature and pressure, values are for 20 °C ve 100 kPa.

0,33 = (r.c/3600) = (1184. 1006/3600) = 0,33 Jh/m^{3}Ks = Wh/m^{3}K.

The ventilation "nh" value is taken as 0,8 (h^{-1}) in the calculation of heat loss through ventilation in buildings with natural ventilation.

In general, two approaches are used in evaluating building stocks: bottom-up and top-down approaches. The top-down method is used to establish a relationship between the major sectors; and includes national and historical information, such as an assessment of residential energy consumption in relation to the industry sector. The bottom-up approach begins with the creation of building typology data based on location and construction period and progresses to the creation of model buildings that will be used to analyse the typologies that comprise the building stock.

The data from these two approaches should be compared in studies. The compatibility of the obtained results with the two approaches improves the reliability of the research results. In this study, the results of the energy demand saving potential are compatible with the energy consumption values.

In the full factorial design, the key values are P, S, and R-squared and these values give an idea about the accuracy of the analyse. In the first step, the p-value can compare with the significance level of 0.05 which indicates the association of factors with the response. In this analysis, 7 factors' P values are less than the significance level <0.05 and it concludes that a statistically significant association is established between these factors and the response. If the value is higher than 0.05, it means, there will be a risk that the factors don't associate with the response. In the second step, the S value indicates how well the defined model responds to the results. The R-square value is between 0 and 100 %, and a high value indicates that the model is compatible with the data and the correlations between factors are strongly linear. As a summary of one analysis, our model has approximately 99,46 % variation in the response. In this case, the R^2 value proves the model fits the data.

Model buildings

Model buildings are defined with weighted areas obtained via a bottom-up approach. However, building stock's different geometries and glazing ratios affect energy demand. If the weighted area can multiply with the weighted energy demand, realistic results can be obtained. Therefore, the weighted energy demand (kWh/m^2/year) was calculated using the average of three different model-building geometries for each typology to account for the effect of different geometries and window ratios.

To provide a precise result in the study, the building stock is divided into three typologies for Finland (SFH, MFH, and Attached) and two typologies in Türkiye (SFH, MFH). The number of buildings of the typologies' weighted areas were calculated according to the building occupancy permits of the municipalities located in the climate zones.

Three buildings with different geometry, area, and glazing ratio were dynamically simulated for climate zones and construction periods and the results were averaged for each typology. The weighted energy demand results per square meter; allowed us to average the effect of different window/wall ratios and floor and ceiling areas. The total energy demand was found by multiplying the number of buildings, the weighted area and the weighted energy demand/square meter for climate zones and periods.

The buildings were selected from constructed buildings representing the building stock's general geometry properties such as L shape, square, and rectangular geometries with an open indoor balcony. Duplex SFH and, a two-floor attached house model was included for Türkiye and Finland respectively which are more specific to country typology except for the general geometries. The model results were verified with their own EPC certificate.

In Table 1, the model buildings' floor area and wall/windows ratios were given. After that, the weighted area, building number, and weighted energy demand/m^{2}year were used to calculate the results for national energy demand. Buildings cover general architectural designs such as L shape, rectangular, and square which are given in Annex 1.

Hourly data is used to simulate model buildings, and internal gains such as daily usage intensity, lighting, and equipment are factored in. The internal (comfort) temperature ranges were specified as between 21 °C and 27 °C for Finland, and between 20 °C and 26 °C for Türkiye.

Table 1
Model buildings for each typology for weighted energy demand calculations.

Building models	SFH-1	SFH-2	SFH-3
floor area	170 m2	150 m2	110 m2
wall-window ratios	13.5 %,	14.8 %	15.5 %
Building Models	Attached-1	Attached-2	Attached-3
floor area	924 m2	435 m2	380 m2
wall-window ratios	19 %	22 %	12.5 %
Building Models	MFH-1	MFH-2	MFH-3
floor area	4061 m2	2872 m2	1411 m2
wall-window ratios	21 %	15 %	26 %

While the U-values have improved over time, the comfort temperatures have largely remained the same.

In the evaluation between periods, interior comfort temperatures less affect the results as a variable. In Table 2, the simulation results are given for different climatic regions and periods, and two temperature set points. The difference decreases toward hot climatic regions where the energy demand is low.

The demand for cooling in Finland's southern regions is increasing. On the other hand, in Türkiye, cooling is as important as heating in the south.

Regulations

The first step of energy efficiency begins with improving the building envelope, infiltration, and ventilation while maintaining comfort levels. The building envelope has opaque and transparent parts are walls, roof, floor, and window. The mandatory regulations of the heat transfer coefficients and ventilation were started in Finland in 1976, however, they became mandatory in Türkiye, not until the 2000s.

In Finland, the heat transfer coefficient and infiltration values arranged by the regulations have been improved as needed in time. Regulation updates are taken into account in the assessment of energy demand in the residential building stock. Insulation regulation has been defined by the Finnish Building Code Part C3 Thermal Insulation and C4 Guidelines. Part C3 thermal insulation code was updated in 1976 (https://ymparisto.fi/download/noname/%7B02831F23-08E6-4B9E-9E39-A923CA8DD37A%7D/100663, n.d.),1985 (https://ymparisto.fi/download/noname/%7BCA9A3363-CC70-48E3-8AAB-C04A8ED9BCF0%7D/100665, n.d.),2003 (https://ymparisto.fi/download/noname/%7B926E23F8-D52D-4129-98AB-7A21693D8B14%7D/101088, n.d.),2007 (https://ymparisto.fi/download/noname/%7BD6B713D7-B1DB-4A1E-BCA6-B611D8DB4589%7D/101089, n.d.), and 2010 (https://ymparisto.fi/download/noname/%7B7BF051A7-6436-4724-A1FD-7688A56FB09B%7D/102966, n.d.) and this study was based on the updated values. In addition, Building Code Part D3 energy efficiency regulation codes (1978,2007,2010,2012 (https://ym.fi/documents/1410903/0/37188-D3-2012_Suomi.pdf/3072837e-928a-424c-f7dc-b6b61f7b8da6/37188-D3-2012_Suomi.pdf?t=1622704540584, n.d.)) and Part D5 guidelines have also been published.

U-values started to be improved in the 1970s due to Finnish climatic conditions. As of 2017, it has been brought to the current NZEB levels. These different values of model-building simulations are handled according to the period, which is shown in Table 3.

The Act on the Energy Certificate for a Building (https://www.ymparistoosaava.fi/rakennusala/index.php?k=22802, n.d.), enacted in 2013, mandates EPC for new buildings; existing buildings also had a transition period for EPC certificates. The Energy Performance of Buildings Directive includes the 2020–2050 Long-term Renovation Construction Strategy that member states must submit. Due to the necessity of the EPBD, the strategy was submitted to the EU on 10.3.2020.

In Finland total EPC numbers (https://www.energiatodistusrekisteri.fi/tilastot?kayttotarkoitus=3, n.d.) according to building typologies are given in Table 4. The primary energy conversion factors in Finnish EPC are electricity 1.2, district heating 0.5, district cooling 0.28, fossil fuels 1.0, and renewable fuels 0.5. The government supports a financial mechanism for elderly and disabled people to renovate their homes (https://www.ara.fi/fi-FI/Lainat_ja_avustukset/Korjausavustukset/Korjausavustus_iakkaiden_ja_vammaisten_henkiloiden_asuntoihin, n.d.), and owners and housing companies get a grant to improve energy efficiency in residential buildings (https://www.ara.fi/fi-FI/Lainat_ja_avustukset/Energiaavustus, n.d.).

In Türkiye the “Regulation on Thermal Insulation in Buildings” published on 08.05.2000 is accepted as the first main regulation that deals with the energy performance of buildings. This regulation obliges buildings to be insulated according to the rules explained in the national standard “TS 825: Thermal Insulation Conditions in Buildings”. This standard only regulates the space heating demand of the building.

Since the mandatory thermal insulation regulation did not come into force before 2000 in Türkiye, the building material usage percentages in periods and climatic regions were used to calculate weighted U values, which are shown in Table 5. The primary materials for the exterior walls are brick and hollow concrete brick.

In Türkiye, U-values were calculated according to the building physics before 2000, and the values determined in the legislation were used between 2000 and 2020. The level at which the existing building stock should be improved by renovation was determined according to the NZEB guideline's (https://meslekihizmetler.csb.gov.tr/neredeyse-sifir-enerjili-binalar-nseb-icin-rehber-i-99831, n.d.) and the NZEB definition. In Table 6, SFH and MFH U-values were given for Türkiye.

“Building Energy Performance Regulation (https://www.resmigazete.gov.tr/eskiler/2008/12/20081205-9.htm, n.d.)” (BEP) was published on 05.12.2008. It has been prepared in accordance with the 2002/91/EC European Directive in parallel with its compatibility with the EU. The regulation entered into force on 05.12.2009. Official “Building Energy Performance National Calculation Methodology (https://www.resmigazete.gov.tr/eskiler/2017/11/20171101M1-1.htm, n.d.)” was published on 07.12.2010 and amended on 01.11.2017. The methodology describes the calculation of a building's heating and cooling energy demand, lighting and domestic hot water demand, renewable energy contribution, and the overall performance of the building. It was developed mainly based on the EN ISO 13790:2008 but the standard was revised to EN ISO 52016-1 in 2017. Building energy performance class is determined by comparison with a reference building, as detailed in the national calculation methodology. BEPTR software was developed based on methodology and after 2011 EPC became mandatory for new buildings.

In Türkiye 92 % of EPC data belongs to new or renovated buildings. EPC is a necessary document for getting a building occupancy permit. The average primary energy (kWh/m^{2}year) represented mostly

Table 2
Comparison of energy demand differences from different heating and cooling setpoints according to climatic regions and periods.

Heating and Cooling energy demand	According to current regulations		Difference	According to updated regulations 2023		Difference
Location	21–27 °C	20–26 °C	kWh/m^{2}year	21–27 °C	20–26 °C	kWh/m^{2}year
TUR_ERZURUM	268,9	252,8	16,1	148,4	139,6	8,8
TUR_ANKARA	158,4	147,6	10,8	93,63	87,71	5,92
TUR_ISTANBUL	110,7	102,6	8,1	85,81	80,03	5,7
TUR_IZMIR	106	101,2	4,8	71,58	69,21	2,37

Table 3

Heat transfer coefficient and natural ventilation values for detached, attached, and MFH in Finland (https://finlex.fi/data/sdliite/liite/6822.pdf, n.d.).

		1940–1959	1960–1969	1970–1979	1980–1989	1990–1999	2000–2009	2010–2020
U wall	(W/m^{2}K)	0,81	0,81	0,4	0,3	0,3	0,25	0,17
U roof	(W/m^{2}K)	0,47	0,47	0,35	0,22	0,22	0,16	0,09
U ground	(W/m^{2}K)	0,48	0,48	0,4	0,35	0,35	0,25	0,16
U window	(W/m^{2}K)	2,8	2,8	2,1	2,1	2,1	1,4	1
U door	(W/m^{2}K)	2,1	2,1	1,4	1,4	1,4	1,4	1
Mech. exhaust inc. airleakage	1/h	0,3(only natural vent.)	0,55	0,55	0,55	0,55	$q_{50} = 4$	$q_{50} = 2$

Table 4

EPC number and average primary energy in Finland by 2022.

Building typology	EPC number (ACT 2018)	Average primary energy	EPC number (ACT 2013)	Average primary energy
Detached	76,771	170 kWh/m^{2}year	37,680	210 kWh/m^{2}year
Attached	14,052	166 kWh/m^{2}year	10,768	247 kWh/m^{2}year
MFH	10,476	133 kWh/m^{2}year	9475	185 kWh/m^{2}year

constructed new buildings in 1st and 2nd climatic regions. Table 7 shows the number of EPCs issued and the average primary energy consumption in Türkiye.

Electricity's primary energy conversion factor was 1826 (https://meslekihizmetler.csb.gov.tr/elektrik-enerjisinin-birincil-enerji-ve-sera-gazi-salimi-katsayilari-2021-yilindan-itibaren-kullanilmak-uzere-guncellenmistir-duyuru-411795, n.d.), and in August 2022 the updated new conversion factor is 1788 (https://webdosya.csb.gov.tr/db/meslekihizmetler/icerikler/elektrik-enerjisinin-birincil-enerji-ve-sera-gazi-salimi-katsayilari-agustos-2022den-sonra-20220825085911.pdf, n.d.). Residential building typologies are classified as single-family houses (SFH) and multi-family houses (MFH). SFH covers detached and attached buildings. In Türkiye, green credits are given for buildings that meet the EPC requirement after renovation.

Structure of the building stock

The estimate of housing demand is linked to population growth and urbanization. Population and migration to urban centres should be taken into account when assessing the renovation of the building stock. Finnish and Turkish urban population ratios are 72 % and 93.2 %, respectively. The rural population was more numerous than the urban population in the 1930s. Türkiye and Finland differ not only in terms of geography but also in terms of population and building stock, allowing the study to be seen from different perspectives.

The population of Finland is 5,525,292. The entire building stock includes 1,536,650 buildings, of which 85 % are residential, 8 % are commercial and public buildings and the rest are industrial and warehouse buildings. The residential floor area is 62 % of the building stock. The total number of residential buildings is 1,319,404 and the total gross area is 313,754,014 m^2. The number of detached houses is 1,169,903 and the number of multi-story buildings is 65,479. The total number of households is 3,124,268, of which 1,178,861 are in detached houses, 1,467,617 are located in apartments and a total of 2,776,679 are continuously occupied (http://www.tilastokeskus.fi/til/asas/2019/01/asas_2019_01_2020-10-14_kat_001_fi.html, n.d.). As can be seen from Fig. 2, even though the number of multi-story buildings is lower in comparison to the detached buildings, the number of dwellings in both building typologies is close together. A total of 1,450,861 dwellings were built between 1970 and 1999 and constitute half of the building stock, and these flats will be in use in 2050 (https://data.tuik.gov.tr/Bulten/Index?p=Nufus-ve-Konut-Arastirmasi-2011-15843, n.d.-a).

A total of 309 municipalities in Finland were divided into four climatic zones, and the coldest zone was further subdivided into two subregions in this study in terms of Heating Degree Days (HDD). In the Finnish building stock, the number of detached, attached, and MFH building typologies, and their square meters, were classified in each climatic region based on decades since 1960, given in Tables 9 and 11. The number of MFH is <50 in 199 municipalities out of 309. And there are 508,289 summer cottages used for vacations that are not included in the calculations. 473,000 studios (single rooms with kitchens) make up 15 % of all housing stock. The most common dwelling type is a two-room and kitchen dwelling, which accounts for 925,000 units and accounts for 30 % of the housing stock (https://pxnet2.stat.fi/PXWeb/pxweb/en/StatFin/StatFin_asu_asas/, n.d.). 55.2 % of the population lives in their own houses and 37.2 % live in rental houses including government-subsidized housing. In Finland, there are an average of 2.5 occupants in a detached house, 1.9 in an attached house, and 1.6 in an apartment (https://www.stat.fi/tup/suoluk/suoluk_asuminen_en.html, n.d.). These values were used for internal gain input in IDA-ICE simulations.

The population of Türkiye is 83,614,362. The residential building stock includes 7,146,804 buildings, of which 86 % of the whole building stock. Occupancy permits were taken into account in the study. In Türkiye, the closest census was held in 2011 (https://data.tuik.gov.tr/Bulten/Index?p=Nufus-ve-Konut-Arastirmasi-2011-15843, n.d.-b), which gives detailed results about the characteristics of the housing stock in Türkiye. According to the results of this census, 20 % of the households reside in dwellings located in one-floor buildings, 19.5 % of the households live in two floors buildings, 11.9 % of the households reside in three floors building, and 23.1 % of the households reside in the six or more floors building.

The first three provinces with the highest number of buildings with six or more floors are Istanbul at 41.7 %, Ankara at 39.5 %, and Kayseri at 38.8 %. In 2011, 67.3 % of households were owners, this figure dropped to 58.8 % (https://data.tuik.gov.tr/Bulten/Index?p=Istatistiklerle-Aile-2020-37251, n.d.). Ankara (30.2 %), Istanbul (31.5 %) and Antalya (29.9 %) provinces have the highest number of tenants.

According to the results of the Address Based Population Registration System in 2021, residential buildings constitute 85 % of the whole building stock. 23.4 % of the buildings were constructed before 1980. While 43.5 % of the households live in the buildings built between 1981 and 2000, 21.8 % of them reside in the buildings constructed in 2001 and after. Statistics are rapidly changing, with an average of 600,000 new dwellings added each year after 2011, as shown in Fig. 3. The increasing population and lack of construction area are alleviated by demolishing detached buildings and constructing multi-story apartments, particularly in city centres. The average household size has decreased from four people in 2008 to three people in 2020 in Türkiye.

Heating and cooling degree days

According to the World Meteorological Organization (WMO), 2011–2020 was the warmest decade on record, indicating a long-term climate change trend, with the warmest years being 2016, 2019, and 2020, the top three since 2015 (https://public.wmo.int/en/media/press-release/2020-was-one-of-three-warmest-years-record, n.d.). Türkiye and Finland both have four distinct climatic zones. Simulated

Table 5
SFH and MFH outer wall materials according to climatic regions and construction periods in Türkiye.

Materials	–	1st climatic region				2nd climatic region				3rd climatic region				4th climatic region			
		1960–69	1970–79	1980–89	1990–00	1960–69	1970–79	1980–89	1990–00	1960–69	1970–79	1980–89	1990–00	1960–69	1970–79	1980–89	1990–00
brick	%	0,42	0,46	0,55	0,72	0,44	0,38	0,65	0,62	0,22	0,40	0,61	0,80	0,24	0,33	0,42	0,42
CalSi brick	%	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
stone	%	0,18	0,07	0,02	0,01	0,15	0,06	0,05	0,02	0,21	0,14	0,11	0,09	0,34	0,25	0,20	0,14
concrete block	%	0,00	0,01	0,01	0,01	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
wood	%	0,02	0,01	0,00	0,00	0,06	0,02	0,01	0,00	0,05	0,03	0,01	0,01	0,06	0,03	0,02	0,01
hollow concrete brick	%	0,29	0,42	0,41	0,25	0,19	0,19	0,26	0,33	0,14	0,20	0,11	0,04	0,15	0,24	0,27	0,39
sun-dried brick	%	0,07	0,02	0,01	0,00	0,14	0,34	0,02	0,01	0,37	0,22	0,13	0,05	0,19	0,13	0,07	0,03
others	%	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,01	0,01	0,01	0,01	0,01	0,01
total		1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

cities represent the climate zones listed in Table 8. Finland's coldest climatic zone is divided into two sub-regions, represented by the cities of Rovaniemi and Sodankylä.

The definition of Heating Degree Days (HDD) is: If Tm ≤ 15 °C Then [HDD = ∑i(Tref - Tim)] Else [HDD = 0], where Tim is the mean air temperature of day i. Tref is 18 °C for the EU Statistical Institute (Eurostat) and it is the same in the Turkish Meteorological Institute but for Finland it is 17 °C and in Finnish Meteorological Institute called this calculation heating demand figure (Previously named heating degree days). Cooling degree days are calculated with the same formula; If Tm ≥ 24 °C Then [CDD = ∑i(Tim - 21 °C)], Else [CDD = 0] where Tim is the mean air temperature of the day in EU statistical institute, Tm value is 22 °C for Türkiye (https://mgm.gov.tr/veridegerlendirme/gun-derece.aspx, n.d.) and the formula is: If Tm ≥ 22 °C Then [CDD = ∑iTim - 22 °C)]. Finland has not typically calculated the cooling degree days because of their small number, but from IEA statistics there is an increase in CDD in both Finland (https://www.iea.org/data-and-statistics/charts/cooling-degree-days-in-Türkiye-2000-2020, n.d.-a) and Türkiye (https://www.iea.org/data-and-statistics/charts/cooling-degree-days-in-Türkiye-2000-2020, n.d.-b) 2000–2020 periods.

As the effects of climate change have begun to increase cooling days in Finland in the last decade, cooling-degree days can be published by the Finnish Meteorological Institute (https://en.ilmatieteenlaitos.fi/heating-degree-days, n.d.) to make the analysis. Fig. 4 shows 81 cities of Türkiye and 309 municipalities of Finland illustrated on the map according to HDD.

Energy consumption in residential sector

Due to the changing technology and regulations, a building in the 'A' energy performance certificate (EPC) class will likely be in a lower class in the future. This is supported by the fact that a large portion of the current building stock is in the lower EPC classes, and as new buildings are built and existing ones renovated, the old EPC class definition will not properly separate the energy performance properties of individual buildings anymore.

Another topic related to energy performance certificates is that the technical properties of building materials and HVAC equipment might not stay constant throughout the building's life span. Some materials, such as modern mineral wool insulation products in favourable conditions, are likely to maintain their original thermal conductivity for a long time. However, it is experienced increases in effective thermal conductivity due to deformations, moisture uptake, and diffusion of air into closed-cell structures. As the energy performance certificates are valid for ten years at a time, the EPC experts should try to consider the various changes that have occurred in buildings during that time and try to use as updated properties of the building in the EPC as possible.

In Finland, out of 1,139,404 residential buildings, 1,169,903 are SFH (detached) houses, of which 504,342 are heated with electricity and 505,101 with oil or wood, and 60 % of attached houses are connected to the district heating system. Furthermore, district heating is used to heat 89 % of the apartments. It demonstrates how critical it is to reduce the energy demand of buildings. According to 2020 statistics, the market share of air and ground source heat pumps has increased from 81 GWh/y to 1181 GWh/y, and sales have increased from 5000 units to 100.000 units in the last 20 years. As shown in Fig. 5, Finland's total energy consumption in residential buildings in 2020 reached 64,000 GWh, of which 49,000 GWh were used for heating and domestic hot water supply, nearly the same as in previous years. Heating energy consumption accounts for 75 % of the total final energy consumption (energy used at building site). The long-term renovation strategy targets for 2020–2050 aim to keep 70 % of the existing building stock in use by 2050 and reduce CO2 emissions from buildings by 90 % by 2050 compared to the beginning of 2020. The average heating energy consumption by a dwelling is 205 kWh/m^{2}year (according to an average dwelling area and energy consumption by the year 2020).

Table 6
Heat transfer coefficient and natural ventilation values for SFH and MFH in Türkiye.

		SFH				MFH			
	Construction periods	1st climatic region	2nd climatic region	3rd climatic region	4th climatic region	1st climatic region	2nd climatic region	3rd climatic region	4th climatic region
U wall (W/m^2K)	1929–2000	1,12	1,14	1,1	1,15	1,09	1,02	0,96	1,04
	2001–2020	0,7	0,6	0,5	0,4	0,7	0,6	0,5	0,4
	2023-	0,41	0,33	0,3	0,28	0,41	0,33	0,3	0,28
U ground (W/m^2K)	1929–2000	1	1	1	1	1	1	1	1
	2001–2020	0,7	0,6	0,45	0,4	0,7	0,6	0,45	0,4
	2023-	0,45	0,39	0,35	0,32	0,45	0,39	0,35	0,32
U roof (W/m^2K)	1929–2000	1	1	1	1	1	1	1	1
	2001–2020	0,45	0,4	0,3	0,25	0,45	0,4	0,3	0,25
	2023-	0,3	0,26	0,22	0,2	0,4	0,35	0,3	0,2
U window (W/m^2K)	1929–2000	5	5	5	5	5	5	5	5
	2001–2020	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4
	2023-	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2
Natural ventilation ($h{-}1$)	1929–2000	1	1	1	1	1	1	1	1
	2001–2020	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8
	2023-	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5

Table 7
EPC number and average energy in Türkiye by 2022.

Building typology	EPC number [BEPTR-1(01/2011) + BEPTR-2 (10/2017)]	Average primary energy
SFH (Detached + Attached)	235,133	151,37 kWh/ m^2year
MFH	1,029,676	143,45 kWh/ m^2year

According to Turkstat data, between 1929 and 2000, 97 % of SFH buildings and 60 % of MFH buildings were heated with stoves. The fuels were, 55 % biomass and 40 % coal in the first climate zone, 26 % biomass and 70 % coal in the second climate zone, 11 % biomass and 87 % coal in the third climate zone, and 21 % biomass and 78 % coal in the fourth climate zone. In the first and second climatic zones, half of the MFH built after 2000 are heated with stoves; in other climatic zones and high-rise buildings, central heating systems are used by nearly 90 %. Biomass is primarily used in the first and second climatic zones (sea sides), whereas coal is used in the third and fourth climatic zones (inner parts of Anatolia).

The installation of natural gas distribution lines in the 2000s drastically altered the heating system and fuel type of building stock. Natural gas distribution in Ankara (The capital) began in 1988. Later that year, in 1992, Istanbul and Bursa converted coal to natural gas, and in 1996, Eskişehir and Kocaeli followed suit. The use of natural gas reduced air pollution. On the other hand, natural gas is imported from other countries, such as Russia and the Caspian region, and the energy security risk has greatly increased.

In 2020, 17,5 million residential subscribers in Türkiye consumed 15,4 billion m^3 of natural gas for heating, domestic hot water, and cooking. The average consumption of natural gas per dwelling is 964 Sm^3/year (the equivalent of 10,256 kWh/year). Residences account for 32.2 % of total natural gas consumption (https://www.stat.fi/til/asen/2019/asen_2019_2020-11-19_tau_001_en.html, n.d.), and approximately 35,5 million electricity household subscribers' usage is 60,13 TWh. The proportion of total electricity consumption consumed by residences is 25,76 % (https://www.gazbir.org.tr/uploads/page/2020_Yili_Dogal_Gaz_Sektoor_Raporu.pdf, n.d.). The average consumption of electricity per dwelling is 1576 kWh/year.

The blue and green columns in Fig. 6 represent the years 2019 and 2020, respectively. The consumption increases with new subscribers. The lines in Fig. 6 represent the average temperature.

The simulation results were obtained in three steps for both countries in Results and discussion section:

1. The energy demand was simulated for three building typologies in/with
   a. four climatic regions,
   b. three different geometries for each building typology
   c. U-values (wall, roof, floor, window), and natural ventilation (including infiltration and mechanical exhaust) according to decades.

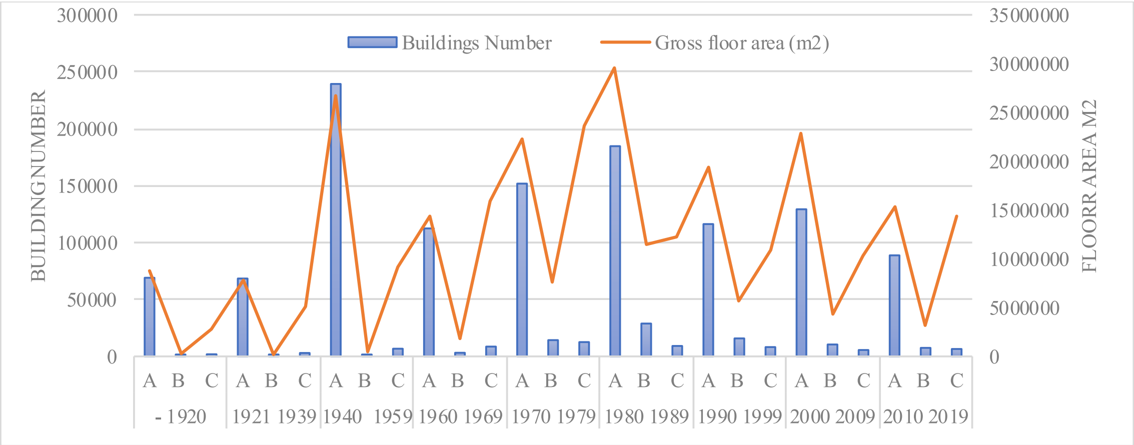


Fig. 2. The number of buildings and Gross floor area in Finland. (A: Detached house B: Attached house C: Multi-Family house).

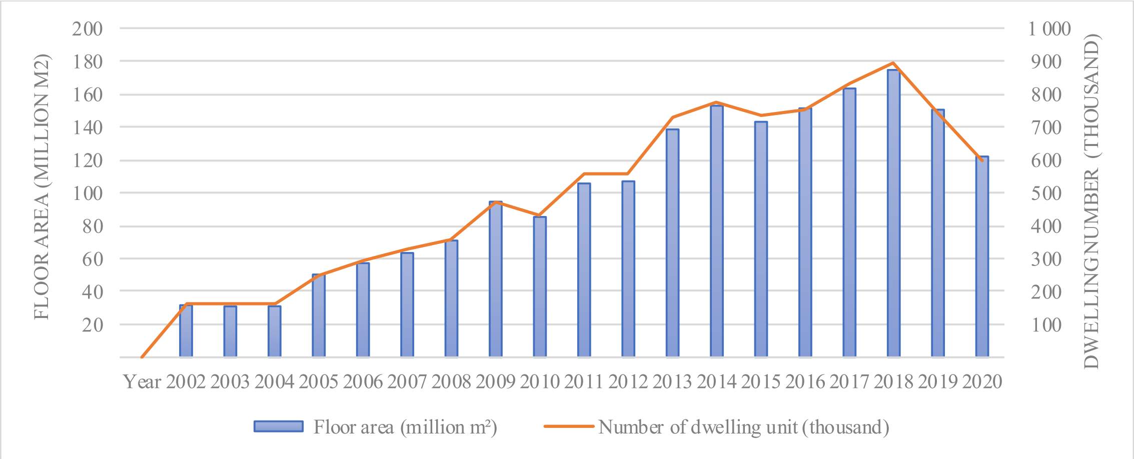


Fig. 3. Annual floor area and the number of dwellings in Türkiye.

Table 8
Heating Degree Days between 2007 and 2022 for Finland and Türkiye for simulated locations.

Finland climatic zones (https://www.finlex.fi/data/sdliite/liite/6800.pdf, n.d.)	Representing city	HDD Finland (17 °C)	Türkiye climatic zones (https://www.resmigazete.gov.tr/eskiler/2008/10/20081009-2.htm, n.d.)	Representing city	HDD Türkiye (18 °C)	CDD Türkiye (22 °C)
1. Climatic Zone	Helsinki	3803	1. Climatic Zone	İzmir	948	693
2.Climatic Zone	Tampere	4117	2.Climatic Zone	İstanbul	1431	317
3.Climatic Zone	Jyväskylä	4479	3.Climatic Zone	Ankara	2335	254
4a. Climatic Zone	Rovaniemi	4909	4. Climatic Zone	Erzurum	4444	13
4b. Climatic Zone	Sodankylä	5759				

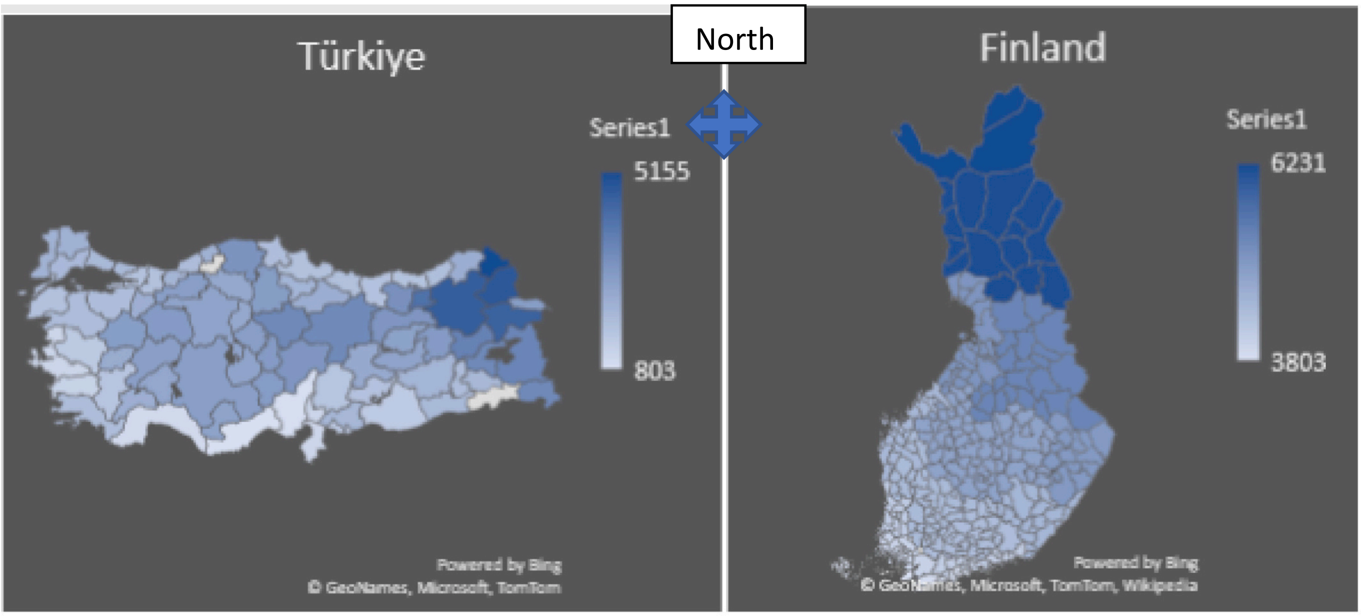


Fig. 4. Türkiye and Finland Heating Degree Days maps.

2. The full-factorial design factors with initial (lower value) and renovated (higher value)
   a. U-values (wall, roof, floor, window)
   b. natural ventilation
   c. orientation
   d. 1st and 4th climatic regions (cold and hot climates)
   e. building typologies (SFH and MFH)
3. Limits of the most effective factors in regulations were searched via parametric runs
   a. U-values (wall and roof)
   b. four climatic regions
   c. building typologies (SFH and MFH).

Results and discussion

Model building simulations and average results

Structural and technical characteristics of the existing building stock

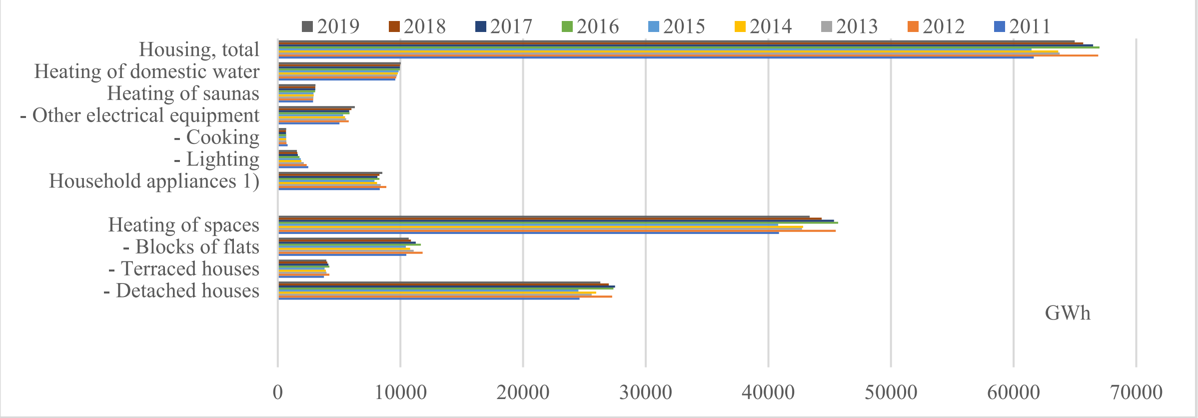


Fig. 5. Energy consumption and heating of spaces in the residential sector in Finland (http://pxnet2.stat.fi/PXWeb/pxweb/en/StatFin/StatFin_ene_asen/statfin_asen_pxt_11zr.px/chart/chartViewColumn/, n.d.).

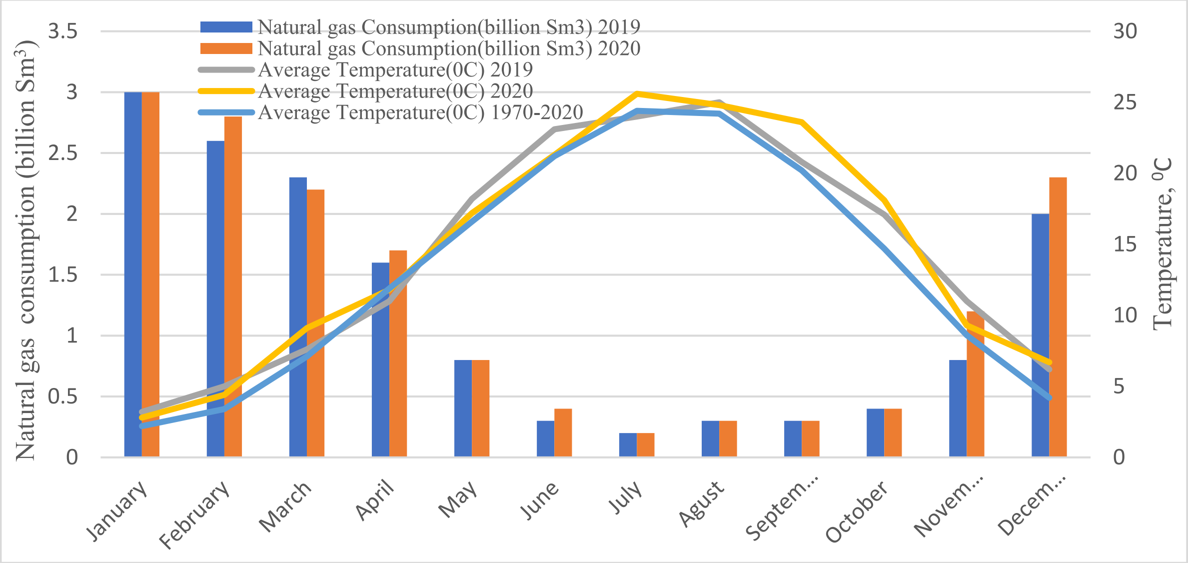


Fig. 6. Dwelling Natural Gas consumption with an average temperature in 2019 and 2020 in Türkiye (https://www.epdk.gov.tr/Detay/Icerik/3-0-24/elektrikyillik-sektor-raporu, n.d.).

in Türkiye and Finland were investigated. The building stock of the two countries is evaluated in accordance with their respective energy demands because the building technical systems, the energy sources used for the final energy, and the primary energy conversion factors all vary. The energy demand saving potential has been calculated as if the existing residential building stock would be brought to the revised regulation levels.

The average of the simulation results of the three model buildings according to the periods and climatic areas was calculated for each typology. The areas of the detached model buildings are 170, 150 and 110 square meters, with external wall-window ratios of 13.5 %, 14.8 %, and 15.5 %, respectively. Geometry and exterior wall/window ratios were accounted for in the calculations by taking the average of the results of the three model buildings for each typology.

Detached, attached, and MFH residential building results for Finland are given in Figs. 7, 8 and 9, respectively.

The attached house's dimensions and geometries are similar to those of the model buildings chosen from the existing building stock. While some row houses' outer walls are not completely adjacent, some of their inner walls are. In terms of area, the glazing rates for 924 m^2, 435 m^2, and 380 m^2 model buildings are 19 %, 22 %, and 12.5 %, respectively. Fig. 8 shows the energy demand and the average energy demand for attached buildings.

The number of multi-story buildings is lower than the number of detached buildings and in 200 municipalities out of 309, the number of multi-story buildings is under 50. The number of flats in multi-storey buildings, however, is 1,294,260, while the number of detached flats is 1,055,778. Although the building has a large footprint, the flat areas are small. The total area of the buildings used to calculate the average energy consumption was 1411 m^2, 2872, m^2 and 4061 m^2 with glazing ratios of 26 %, 15 %, and 21 %, respectively. The results for multi-family houses are shown in Fig. 9.

The average kWh/(m^2, year) results for MFH, detached, and attached buildings show that energy demand for heating and cooling is decreasing in all building typologies in Finland in Fig. 8, as a result of energy efficiency regulations (Fig. 10). The difference in energy demand between climatic zones is also visible, which could assist in renovation strategies by comparing the dwelling numbers in zones.

Heating and cooling total energy demand and average building areas and number of MFH, detached, and attached buildings are given in Table 9. According to climatic zones and building typologies, the energy-saving potential of a building built in the 1960s is 37–44 % if it is renovated according to the current regulatory limits. In the 1960s, the U wall value was 0,81 W/m^{2}K) and in current regulations, it is increased

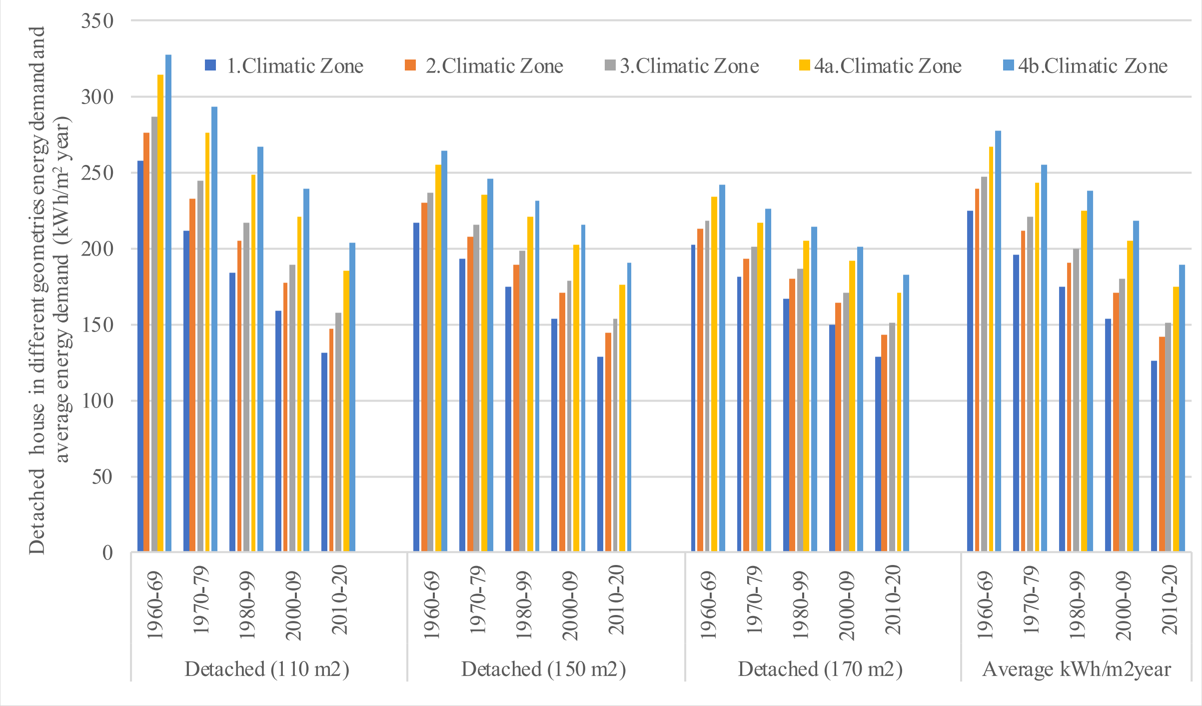


Fig. 7. Detached house average energy demand results (kWh/m^{2}year) for each period and climatic region.

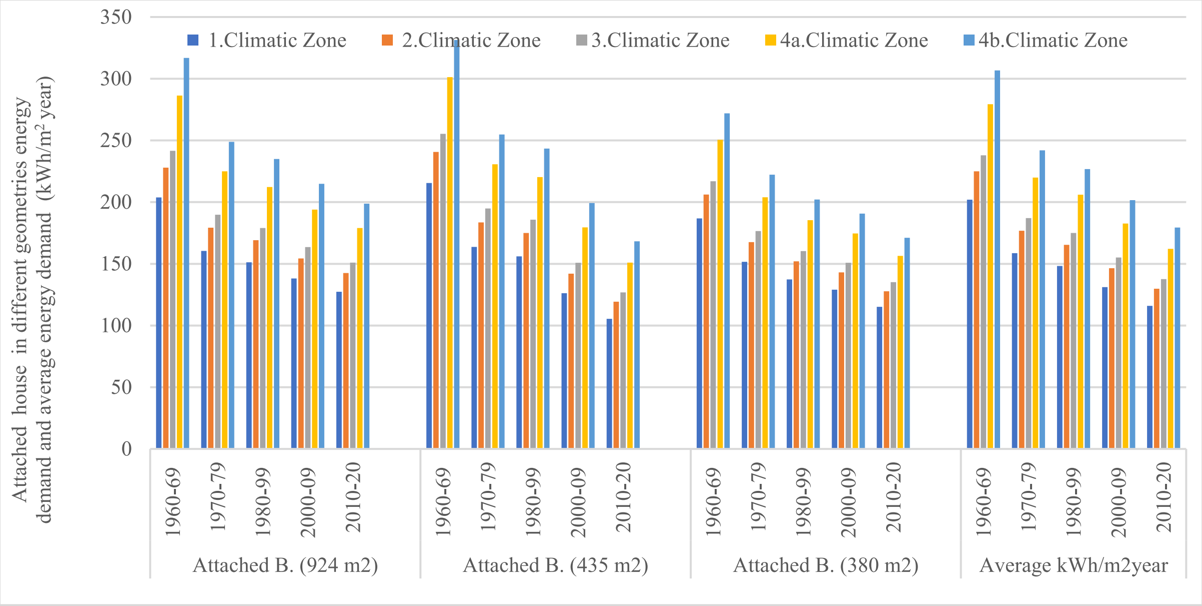


Fig. 8. Attached house average energy demand results (kWh/m^{2}year) for each period and climatic region.

by 0,17 W/m^{2}K and the U roof value is increased from 0,47 to 0,09 W/m^{2}K. These improved regulation limits help to decrease the average energy demand reduction potential, which is 44 % in detached houses, 42 % in attached houses, and 37 % in MFH buildings.

The simulations were done according to building typologies and climatic regions. In Table 10 the average areas and numbers for building typologies in climatic regions are given.

The energy demand saving potential in Finland according to the building typology, period, and climatic region is given in Fig. 11. There are 1,169,903 detached, 84,022 attached, and 65,479 multi-story buildings in Finnish residential building stock. Since 2050 long-term improvement strategies are taken into account in the residential building stock, the number of residential buildings built before 1960 was not considered in the energy demand saving potential calculation.

Finland's energy demand saving potential of the residential building stock is 10.200 GWh/year, and when the efficiency of building technical systems is considered, the final energy to be spent to meet this energy demand corresponds to 13.000 GWh. The building sector consumes approximately 64.000 GWh of energy in total, with approximately 42.000 GWh consumed solely for heating purposes, as shown in Fig. 5.

Improving the existing building stock will result in a 30 % savings. The U-values specified in the legislation can be reduced during renovation works, as shown in the parametric simulation figures for the U-wall and U-roof. The first and second climatic regions, which have a

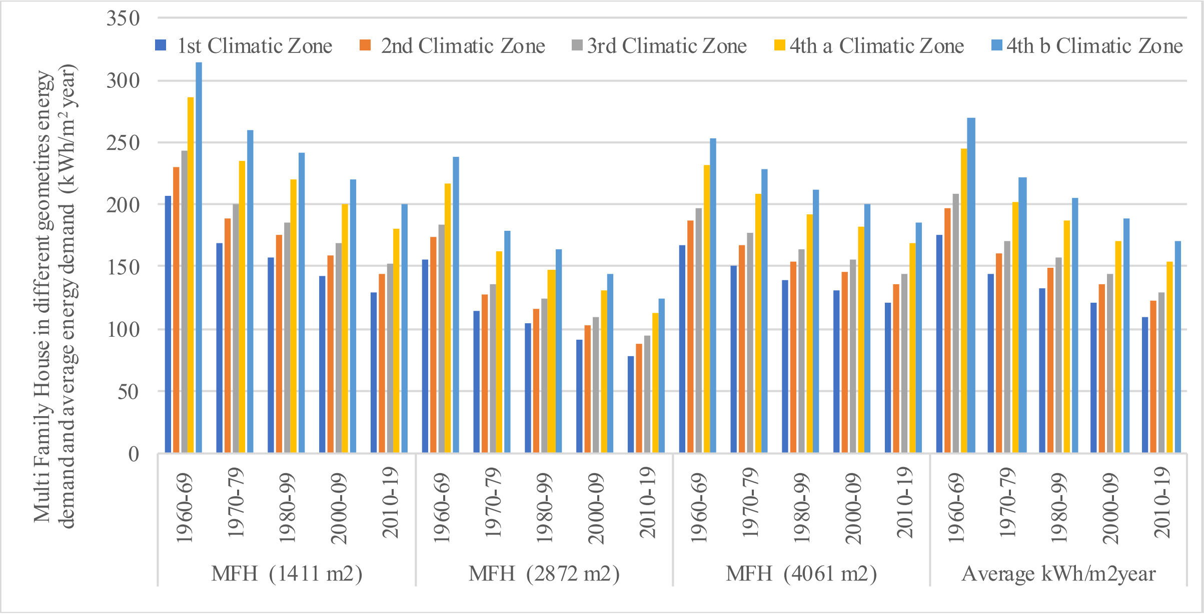


Fig. 9. Multi-Family House in different geometries energy demand and average energy demand (kWh/m^2year) in terms of periods and building typology in Finland.

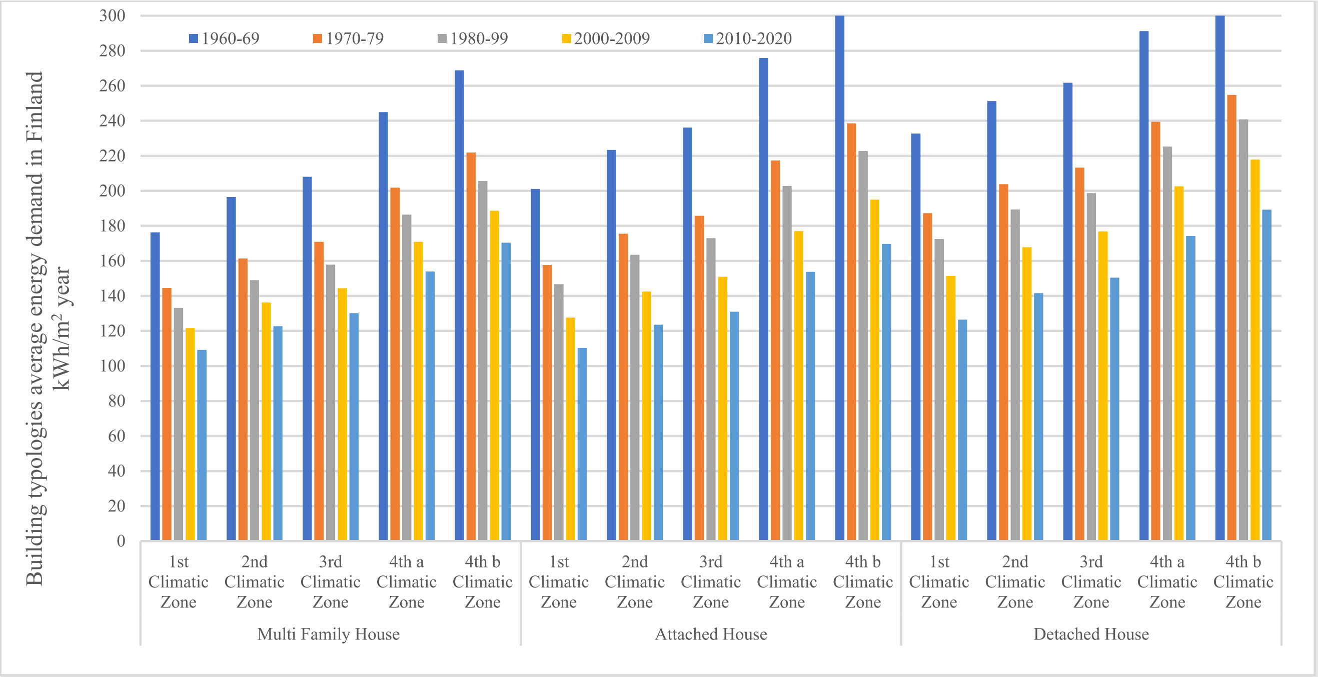


Fig. 10. Model buildings' average energy demand results in terms of period and building typology in Finland.

dense population, have a milder climate than other regions, and the majority of the building stock is located in these regions. For this study, when the insulation thickness exceeds 15 cm, the effect of U-wall and U-roof values, which are the most key factors in the building envelope, decreases. However, the insulation thickness required by regulation is 25 cm for the wall (U_{wall} 0,17 W/m^2K) and 50 cm for the roof (U_{roof} 0,09 W/m^2K). With the improvement in insulation values in Finland, also the building airtightness has improved, and the use of mechanical ventilation with heat recovery has increased.

When detached dwellings are studied according to their construction time and region, the building stock in the first three regions from 1960 to 1989 has significant potential. The decrease in energy demand through building renovations is a higher potential in the fourth region, as seen in Fig. 7, where climatic conditions are more severe, but the limited number of buildings decreases the potential in this region. MFH's potential energy demand savings are higher in the Helsinki region. The buildings erected to comply with current standards during the 2000–2009 era have the lowest potential.

In the 2010–2020 period, the buildings were built according to the latest regulations. The limitations of the regulation have reached the maximum level of building physics. Therefore, buildings built in this decade have no potential for energy demand savings.

These limits are simulated in parametric runs to show a relation with energy demand in Parametric simulation results section. Graphs 17 and

Table 9
Average simulation results for MFH, Detached, and Attached building energy demand in Finland.

MFH Simulation Results in FINLAND kWh/m^{2}annual

Climatic Regions	1960–1969	1970–1979	1980–1999	2000–2009	2010–2020
1st Climatic Region	176.3	144.5	133.1	121.6	109.2
2nd Climatic Region	196.5	161.3	149.0	136.3	122.8
3rd Climatic Region	208.0	170.9	157.8	144.4	130.1
4th a Climatic Region	244.9	201.8	186.5	170.9	153.9
4th b Climatic Region	268.8	221.9	205.6	188.7	170.4

Detached House Simulation Results in FINLAND kWh/m^{2}annual

Climatic Regions	1960–1969	1970–1979	1980–1999	2000–2009	2010–2020
1st Climatic Region	232.7	187.3	172.5	151.4	126.5
2nd Climatic Region	251.3	203.8	189.3	167.8	160.4
3rd Climatic Region	261.7	213.2	198.7	176.8	159.8
4th a Climatic Region	291.2	239.4	225.3	202.6	161.9
4th b Climatic Region	308.2	254.8	240.9	217.9	173.5

Attached House Simulation Results in FINLAND kWh/m^{2}annual

Climatic Regions	1960–1969	1970–1979	1980–1999	2000–2009	2010–2020
1st Climatic Region	201.2	157.7	146.7	127.7	110.3
2nd Climatic Region	223.4	175.6	163.5	142.5	123.6
3rd Climatic Region	236.1	185.8	173.1	150.9	131.0
4th a Climatic Region	275.9	217.4	202.9	177.1	153.7
4th b Climatic Region	301.7	238.5	222.8	195.0	169.7

18 illustrated the thickness of wall insulation is >15 cm (with 0.036 W/mK) not a substantial decrease in energy demand, especially in 1st and 2nd climatic zones. However, the limit of thickness increased to 20 cm (with 0.036 W/mK) in the latest regulation. These wall and roof parametric results vary for typology and climatic regions. With the possible climate change scenarios, these limits will have adverse effects such as overheating risk in 1st and 2nd climatic regions.

The potential for energy demand savings is greater for the 1980–1989 timeframe compared to the 1960–1969 decade, due to the higher number of attached buildings developed during that time. However, because the potential for energy demand savings is proportional to the number of buildings and construction periods, policymakers should consider this when renovation policies are revised. Such as the attached house constructed between 1970 and 1989, the MFH buildings constructed between 1960 and 1980, and the SFH building constructed between 1960 and 1989 could be forced for renovation. and financial support can be expanded starting from the first climate zone with high energy savings.

The current Turkish thermal insulation standard was published in 2000 and was revised in 2008 and 2013. The revised version, released in 2013, tightened U-values by 10 %, but the new values were not officially published by the responsible ministry, and the previous values are still in use. Although a new revision of the standard is currently underway, the U-values have not been changed officially in the last 20 years and have not been improved as frequently as those in Finland. The values for 2023 were calculated using the officially published NZEB (https://www.gazbir.org.tr/2019-NATURAL-GAS-DISTRIBUTION-SECTOR-REPORT/files/downloads/2019-Eng-Rapor.pdf, n.d.) guidebook. For that reason, three regulations limiting U-values and natural ventilation were considered in simulations.

In the coastal region, cooling is required in addition to heating due to climatic conditions. The average simulation results of the model buildings for the four regions are shown in Fig. 12.

The attached house definition is not defined separately in the Turkish statistical database. For this reason, one-storey and two-storey buildings are gathered under the typology of SFH. The energy demand of buildings is shown in Table 11, based on the legislation in effect during the construction periods. The same aspects were used for calculating the average energy demand in Turkish residential building stock.

The total average heating and cooling energy demand of MFH and SFH (detached and attached) buildings are given in Table 12 by climatic zone. In Türkiye, before the 2000s, there weren't any mandatory limits for buildings, U values were calculated for building opaque and transparent material properties in climatic regions. Mainly local materials were used in buildings. and the U wall values around 1,12 W/m2K in each climatic zone, and the latest NZEB guide limits are increased to 0,41in 1st climatic zone and 0,28 in the fourth climatic zone.

By renovating a 1960s-era SFH building by new limits, it is possible to reduce energy demand by 46 % in 1st climatic region and 32 % in 4th climatic region. The energy demand saving potential in MFH by 23 % in 1st climatic region and 38 % in 4th climatic region. The differences in the 1st climatic regions are related to the SFH floor area, which helps to decrease cooling loads. However, in MFH buildings, cooling loads didn't lower with improved limits.

Table 12 shows the average area and the number of building typologies of the building stock, which are handled bottom-up according to climatic zones and periods. The attached house is not common in Türkiye, so there is no separate classification in the statistical database. The total number of residences in Türkiye's 81 provinces was grouped according to the climatic zones in where the provinces are located, and the average SFH and MFH building areas were calculated for the climatic zones. In the pre-2000 building data of TURKSTAT, only floor area and floor number information are available, and the total building area is correlated and calculated. The average area of the buildings and especially the number of MFH increased post-2000′. And similar to Finland, building density is in coastal areas.

The suggested U-values for the climatic zones were used in the legislation of the period. As a result of the calculation made by spreading the results throughout the country, the energy demand potential was found to be 124,889.3 GWh/(m^{2}year), as shown in Fig. 13.

Turkish residential building stock's energy demand saving potential is 125.000 GWh/year. In 2020, Türkiye's residential natural gas consumption was 15.4 billion m^3 (164.000 GWh/year). Considering the amount of natural gas consumed in residences the saving potential to be

Table 10
Average building area (m^2) and number of Detached, Attached, and Multifamily Houses in Finland.

Detached average building area	1960–1969	1970–1979	1980–1989	1990–1999	2000–2009	2010–2020
1st Climatic Region	135	157	168	177	185	179
2nd Climatic Region	129	148	160	168	179	177
3rd Climatic Region	124	142	155	160	171	168
4th a Climatic Region	116	134	155	159	174	167
4th b Climatic Region	117	129	139	139	148	145

Detached total building number	1960–1969	1970–1979	1980–1989	1990–1999	2000–2009	2010–2020
1st Climatic Region	40,305	51,654	64,001	44,054	55,616	39,556
2nd Climatic Region	34,552	48,308	56,470	35,189	39,039	29,296
3rd Climatic Region	28,449	41,235	51,243	28,889	29,966	22,338
4th a Climatic Region	3768	5056	7439	3994	3800	2785
4th b Climatic Region	4107	4799	6331	3256	1865	1595

Attached average building area	1960–1969	1970–1979	1980–1989	1990–1999	2000–2009	2010–2020
1st Climatic Region	640	541	428	400	454	450
2nd Climatic Region	528	531	407	351	421	426
3rd Climatic Region	589	541	365	338	384	407
4th a Climatic Region	592	502	390	333	392	404
4th b Climatic Region	449	527	345	299	345	370

Attached total building number	1960–1969	1970–1979	1980–1989	1990–1999	2000–2009	2010–2020
1st Climatic Region	1497	6019	11,641	6716	4803	3537
2nd Climatic Region	790	3813	8822	4499	3164	2542
3rd Climatic Region	770	3851	7176	3947	2291	1775
4th a Climatic Region	139	412	714	414	197	150
4th b Climatic Region	98	255	642	340	96	109

MFH average building area	1960–1969	1970–1979	1980–1989	1990–1999	2000–2009	2010–2020
1st Climatic Region	2001	2021	1427	1509	2078	2432
2nd Climatic Region	1639	1809	1309	1182	1693	2115
3rd Climatic Region	1650	1679	1169	1152	1472	1992
4th a Climatic Region	1652	1646	1329	1077	1485	2072
4th b Climatic Region	1236	1361	1072	788	735	1076

MFH total building number	1960–1969	1970–1979	1980–1989	1990–1999	2000–2009	2010–2020
1st Climatic Region	4521	6433	4623	4158	2678	3988
2nd Climatic Region	2782	3749	2742	2354	1691	1872
3rd Climatic Region	1278	1992	1608	1432	1158	1182
4th a Climatic Region	248	388	281	277	144	150
4th b Climatic Region	71	108	76	80	31	41

achieved is an important ratio that should be evaluated in terms of energy supply security. Multi-story buildings built after 1990 have the greatest potential for energy demand saving. In the renovation of the building stock of Türkiye, earthquake risk, should be taken into consideration as well as energy, particularly after 1990. The two most important factors influencing the energy demand savings potential in Türkiye's building stock, after U-wall values in SFH building typologies, are U-ground and infiltration. Infiltration and window systems are effective in reducing energy demand in multi-story buildings. Improving glass-window systems will reduce infiltration as well. In multi-story building improvement projects, U-wall and window systems must be addressed first.

Both building typologies have high energy-demand-saving potential, constructed between 1970 and 2020. The energy demand savings potential in SFH decreased after 2000 due to the number of buildings. The high potential in MFH buildings between 1990 and 2000 is due to energy inefficiency and their number. Even if the buildings built after 2010 are built according to the energy performance regulation, they still need to be improved according to the 2050 carbon zero targets. Because the existing regulatory limits are not meet the lower energy demand. The NZEB guide values should lower the limit for all buildings.

Pareto results

Pareto figures show which factors affect the energy demand most in Finnish and Turkish SFH and MFH building renovations. In the design of the factorial analysis, seven factors were used with two levels, which were the former regulation limits and the latest legislation limits. The U-wall, U-roof, U-window, U-ground (floor), infiltration, orientation, and climatic region are the factors of the building. The factors differ across typologies because of the building envelope areas, for that reason, SFH and MFH building simulation results are separately analysed to see the impact of factors in reducing energy demand in buildings. In Türkiye, specific U-values have been assigned to each climatic zone. In Finland, U-values are the same for all climatic regions. As a result, using full factor analysis in Pareto charts, it was determined which factor had the greatest effect on energy demand. The bar graphs show which factors most contribute to the response and the red dot line shows the limit of

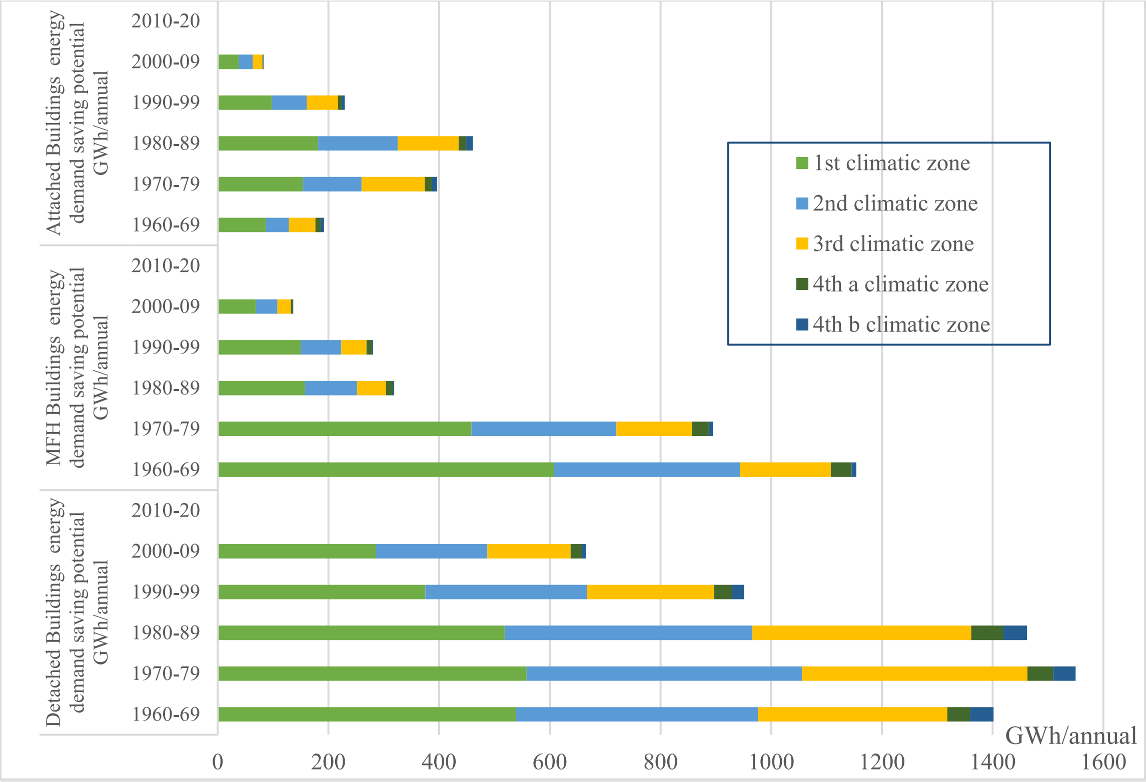


Fig. 11. Energy demand saving potential for residential buildings in Finland.

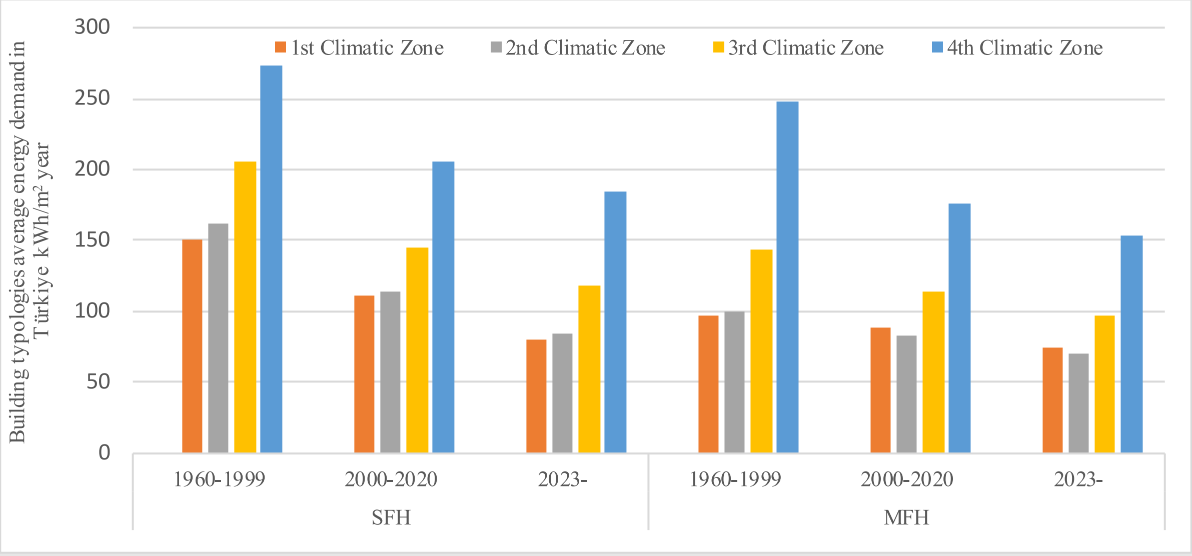


Fig. 12. Average energy demand simulation results in Türkiye by climatic region and period.

statistically significant effects to respond.

Fig. 14 shows the effects of factors in hot and cold climatic regions for SFH in Türkiye because the limits vary in climatic regions. The bar length is related to the factor's effect. The most influential factors were the U-wall, U-roof, and infiltration (n50 value).

In SFH and MFH typologies, the factors' effects were different due to the building areas. Exterior walls and glazing areas, as well as building volumes, are becoming more important in multi-family buildings in terms of energy demand than other factors. The ranking of the most effective factors in cold and hot climatic regions did not change, but the factor's size changed with climatic regions.

In a warm climate, the building orientation and floor insulation had the smallest impact on energy needs in both SFH and MFH. In a cold climate, the ground insulation had some effect on energy needs at SFH but not at MFH (Fig. 15).

The U-values defined in Finnish legislation are the same for all climatic zones. As a result, the climatic zone is counted as the seventh factor. The effect of the factors on the total building energy requirement was investigated using 2^7 (= 128) simulations. The results of the analysis of detached and multi-story buildings are shown in Fig. 16 below.

The factors' lower and upper limits were determined using the 1960 and 2020 time periods. The fact that the climatic region has the greatest

Table 11
SFH and MFH average energy need results for climatic regions and construction periods in Türkiye.

SFH	1960–1999			2000–2020			2023 (NZEB guidebook)		
	Total kWh/m^{2}year	Heating need	Cooling need	Total kWh/m^{2}year	Heating need	Cooling need	Total kWh/m^{2}year	Heating need	Cooling need
1st climatic zone	150,6	130,3	20,3	111,9	96,2	15,6	80,3	67,3	13,0
2nd climatic zone	162,6	157,4	5,3	113,4	109,7	3,8	85,1	81,6	3,5
3rd climatic zone	205,4	201,3	4,1	144,7	142,1	2,6	117,9	115,7	2,2
4th climatic zone	272,7	272,7	0,0	205,2	205,2	0,0	184,1	184,1	0,0

MFH	1960–1999			2000–2020			2023 (NZEB guidebook)		
	Total kWh/m^{2}year	Heating need	Cooling need	Total kWh/m^{2}year	Heating need	Cooling need	Total kWh/m^{2}year	Heating need	Cooling need
1st climatic zone	97,1	75,3	21,7	88,4	67,7	20,7	74,8	55,3	19,5
2nd climatic zone	99,7	91,9	7,7	83,7	76,0	7,7	70,0	62,3	7,7
3rd climatic zone	144,3	138,9	5,5	114,5	109,2	5,3	97,7	92,7	5,1
4th climatic zone	248,3	248,0	0,3	176,3	175,9	0,4	154,2	153,9	0,3

Table 12
Single-Family House, and Multi-family House average building area (m^2) and the number of buildings in Türkiye.

SFH average building area	1960–1969	1970–1979	1980–1989	1990–2000	2001–2010	2011–2020
1st Climatic Region	111,0	124,6	128,4	116,9	138,4	182,7
2nd Climatic Region	114,2	125,6	142,0	139,5	255,7	251,4
3rd Climatic Region	117,7	121,5	129,6	137,1	253,4	217,5
4th Climatic Region	118,8	128,8	138,5	141,5	229,4	245,2

MFH average building area	1960–1969	1970–1979	1980–1989	1990–2000	2001–2010	2011–2020
1st Climatic Region	512,4	670,3	843,4	938,9	1382,7	1500,9
2nd Climatic Region	600,5	682,5	726,3	854,0	3353,2	1856,0
3rd Climatic Region	983,7	993,9	975,2	1210,0	2325,6	2274,5
4th Climatic Region	465,7	661,4	879,6	1098,3	2565,2	2568,8

SFH number of buildings	1960–1969	1970–1979	1980–1989	1990–2000	2001–2010	2011–2020
1st Climatic Region	119,708	231,779	352,210	379,364	74,310	87,654
2nd Climatic Region	210,470	522,248	477,713	610,766	72,232	81,702
3rd Climatic Region	194,316	333,808	297,175	217,998	32,991	50,823
4th Climatic Region	66,793	124,243	143,037	129,971	9355	14,004

MFH number of buildings	1960–1969	1970–1979	1980–1989	1990–2000	2001–2010	2011–2020
1st Climatic Region	11,990	46,577	97,532	126,424	95,508	103,085
2nd Climatic Region	46,596	163,946	314,757	421,436	83,735	252,006
3rd Climatic Region	14,911	43,704	76,269	111,764	73,081	113,158
4th Climatic Region	3142	12,822	24,935	32,853	15,292	26,611

influence on energy demand backs up the analysis. After the climatic region, the main factors in detached buildings are the U-wall and U-roof. U-ground, U-window, and infiltration all have nearly identical effects. Infiltration occurs after the main factor U-wall in multi-story buildings. The orientation has the least impact on the overall energy demand of the detached building. While the U-ground effect is more effective than U-window and leakage in a detached building, it has the least effect in a multi-story building. Based on the Pareto results for Finland, the U-values could be defined depending on the climatic region.

Since the legislative limits of each climate zone are the same in Finland, the climate zone was also added to the analysis as a factor and according to the results, it is the most important parameter in detached and multi-storey buildings. In northern countries, these values need to be differentiated according to climatic zones. In Sweden, U wall is 1.5 (W/m^{2}K) and U roof is 1.2(W/m^{2}K), in Denmark, U wall is 1.2(W/m^{2}K) and U roof is 1(W/m^{2}K), in Norway U wall is 0.22(W/m^{2}K) and U roof is 0.18 (W/m^{2}K).

Parametric simulation results

The three main factors influencing energy demand are U-wall, U-roof, and infiltration, as discussed in Pareto results section. The main parameters, according to the Pareto figures, are U-wall and U-roof, which can be applied in different thicknesses depending on the application, along with other building components in the building envelope. In the market, glass-frame systems are manufactured with a more consistent U-window value. The increase in U-values is examined to see if the energy demand decreases continuously.

Fig. 17 below shows that these values were at their highest in Finland's most recent legislative update. According to the most recent legislation, insulation thickness needs to be approximately 25 cm. This varies depending on the insulation material's thermal conductivity (W/mK). The insulation material used in this simulation (mineral wool) has a thermal conductivity of 0.045 W/mK and a total U-wall value of 0.17 W/m^{2}K when applied at a thickness of 25 cm. The conditions specified in

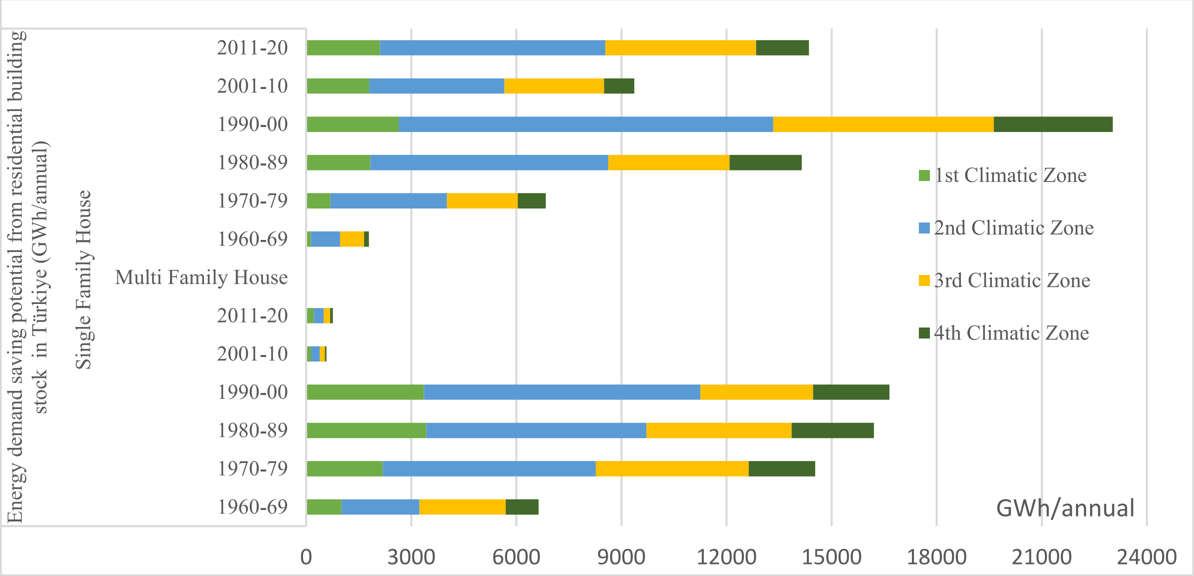


Fig. 13. Energy demand saving potential in Türkiye (GWh/year).

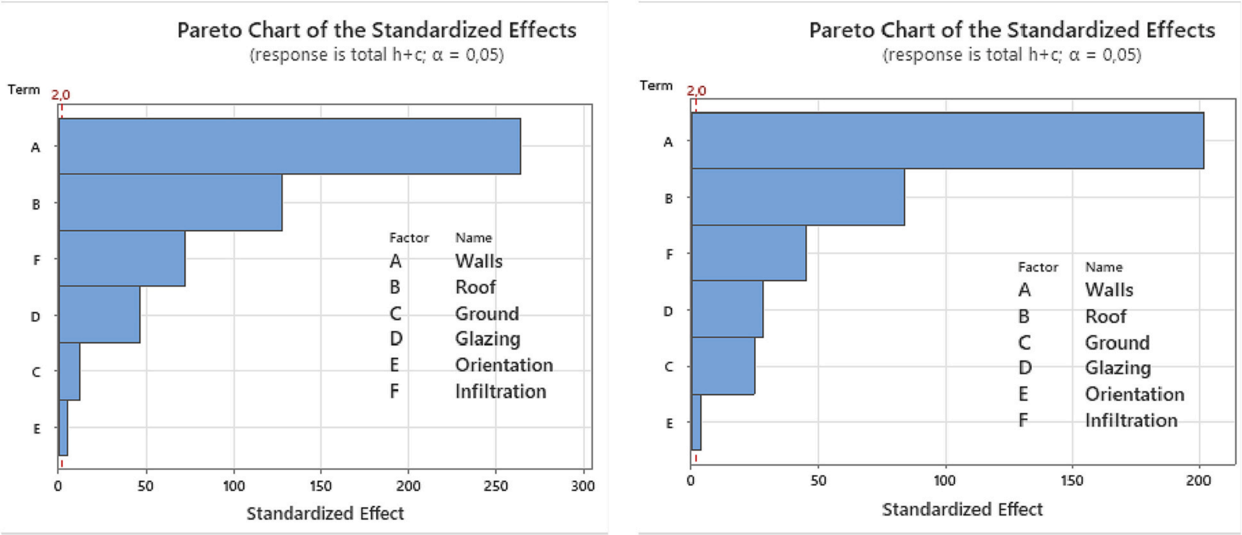


Fig. 14. Pareto figures for the six factors at SFH building in the 1st and 4th climatic regions in Türkiye.

the legislation are depicted in red points in the figures below. To meet the requirements of the current legislation (U-roof ≤ $0.09\ W/(m^2K)$), a 50 cm thickness must be installed. However, as shown in Figs. 17 and 18, after 25 cm, the energy demand reduces very slowly for any additional thermal insulation.

The calculation of the average energy demand is simulated in various climatic regions and periods of model buildings. Parametric simulations of U-wall and U-floor thicknesses ranging from 0 to 25 cm were performed to investigate the decrease in energy demand as the average insulation thickness increased (Fig. 17). The MFH model buildings had areas of 4061 m^2, 2872 m^2 and 1411 m^2, and are depicted in Annex 1.

Fig. 18 below depicts the reduction in energy demand on the x-axis due to improvements in U-roof and U-wall values on the y-axis with insulation thickness in four different climatic zones for detached houses. When compared to multi-story buildings, U-roof values provide the same slope reduction as U-wall values.

The red dots show the insulation values recommended in the current legislation in Türkiye in Figs. 19 and 20.

The red dots on the parabolic curve clearly show that Türkiye still needs to improve its current U-values. A typical wall model includes brick (19 cm), interior and exterior plaster (1 cm + 1 cm) and insulating material with thermal conductivity of 0.036 W/mK. The current regulation requires 7, 5, 4 and 3 cm of thick insulation to be applied from the cold climatic zone to the warm climatic zone, respectively. To meet requirements, 13, 11, 8 and 7 cm of thick ceiling (roof) insulation should be used, per climatic zone. The energy demand is reduced up the parabolic curve to a point when the insulation thickness is increased, but after that, it is not remarkably effective later. The insulation values for NZEB buildings in Türkiye are determined from the cold climatic zone to the warm climatic zone, with the thickness of the wall insulation material (λ 0,036 W/mk) being 12, 11, 9 and 8 cm and the thickness of the roof insulation material being 17, 15, 13 and 11 cm. The insulation thicknesses have been increased by 4 cm, and the values for the insulation have been brought to a good insulation value, as seen in Fig. 20. NZEB limits are mandatory to apply as of 2023 in new buildings with a total construction area of 2000 m^2.

Following these four figures, the main question is determining the insulation thickness level based on energy demand or cost-effectiveness.

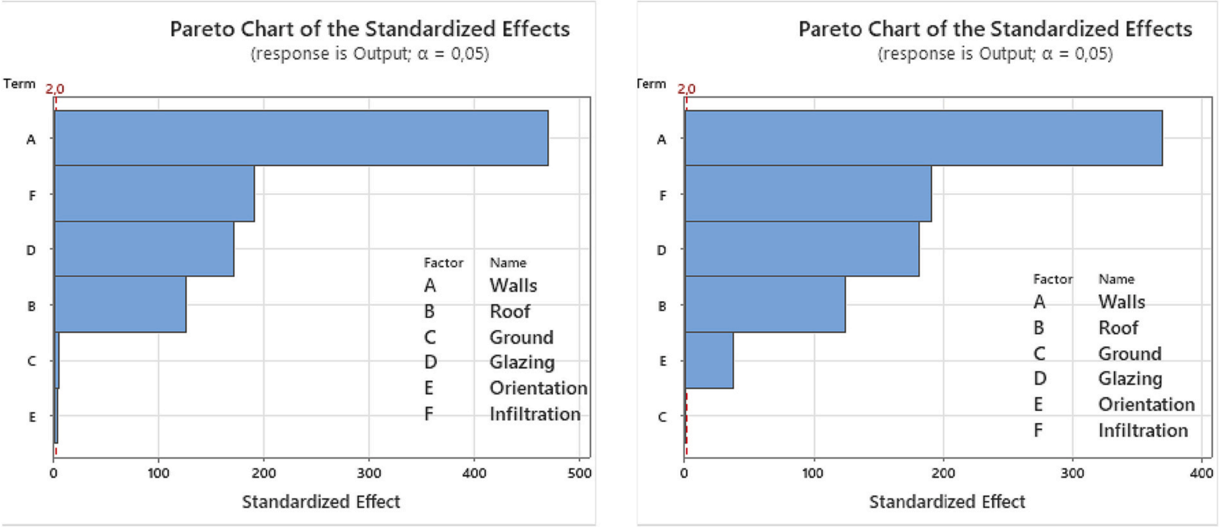


Fig. 15. Pareto figures for the six factors at MFH buildings in the 1st and 4th climatic regions of Türkiye.

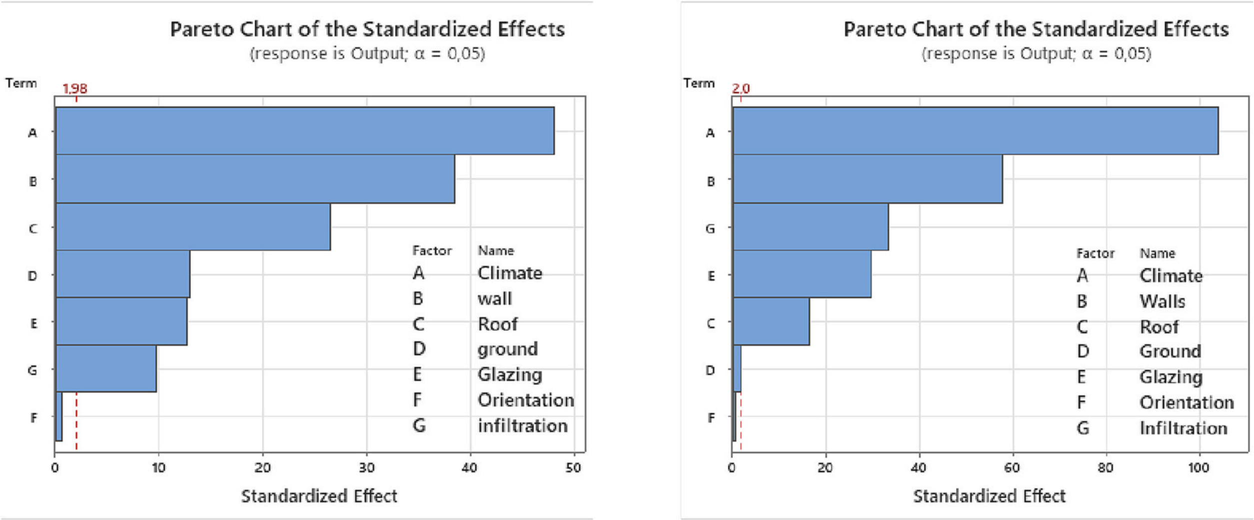


Fig. 16. Pareto figures of seven factors of SFH and MFH buildings in Finland.

Establishing a link between the environmental impact of insulation material production and its contribution to CO2 mitigation is necessary. This correlation must be evaluated in conjunction with the insulation material's contribution factors of energy demand, cost, carbon footprint, and CO2 mitigation.

Due to the lack of literature, it has not been possible to conduct a comprehensive discussion to provide information on the similarities and differences between this study with other studies. The main suggested approaches were applied to the study mentioned in Similar studies in previous literature section.

Conclusion

This study revealed the number and average areas of building stocks in two different countries according to typology and climate regions. Using these results, the energy demand savings of the building stocks of the two countries were calculated on the basis of legal limits of potential savings. In the renovation phase, the analysis of the most influential factors on energy needs and their boundaries in the legal regulations of the two countries has been studied through parametric simulations.

The findings highlighted that (1) The U values were calculated before 2000 for Turkish building stock in line with the climatic regions (2) The weighted areas were calculated in climatic zones and decades (3) Indoor environment temperature differences effects are decreasing with the improvement of building physic limits (4) Energy demand saving potential for typology climate regions and decades were presented (5) Main factors analysed affected to the energy demand (6) Parametric runs simulated the parameters in relation to energy demand.

Based on this study, the thermal insulation level in Finnish legislation has reached the highest level in terms of limiting energy demand, and next other measures should be evaluated, such as the utilization of renewable energy sources, intelligent control of HVAC systems, and reducing peak power demands. Limiting U-values for renovated buildings based on climatic zones reduces implementation costs and can help finance renewable energy systems. Türkiye should develop legal regulations to reduce building energy demand and evaluate renewable energy sources, particularly solar energy potential, due to its geographical location.

The findings will guide renovation activities at the national and individual levels. Policymakers should consider the results of this study when revising regulations and renovation wave targets against climate change. Financial support and promotions can be prioritized according

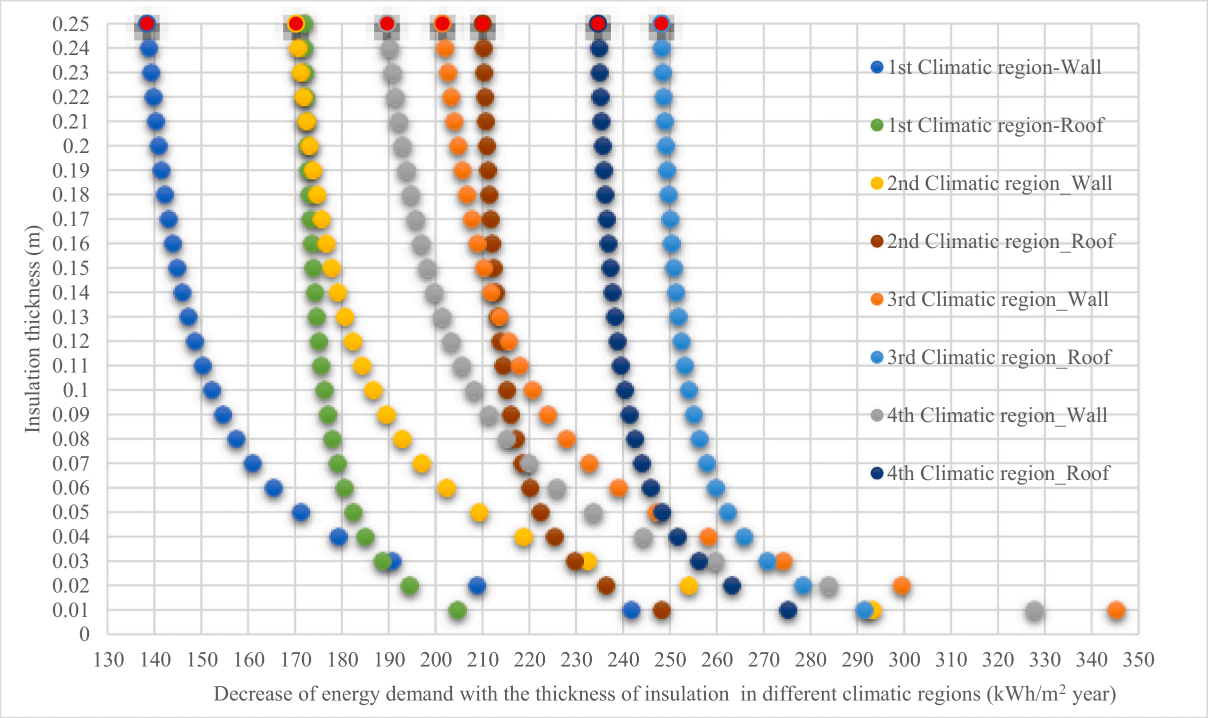


Fig. 17. MFH buildings energy demand changes (kWh/m^{2}year) with U wall and U roof insulation thickness in Finland.

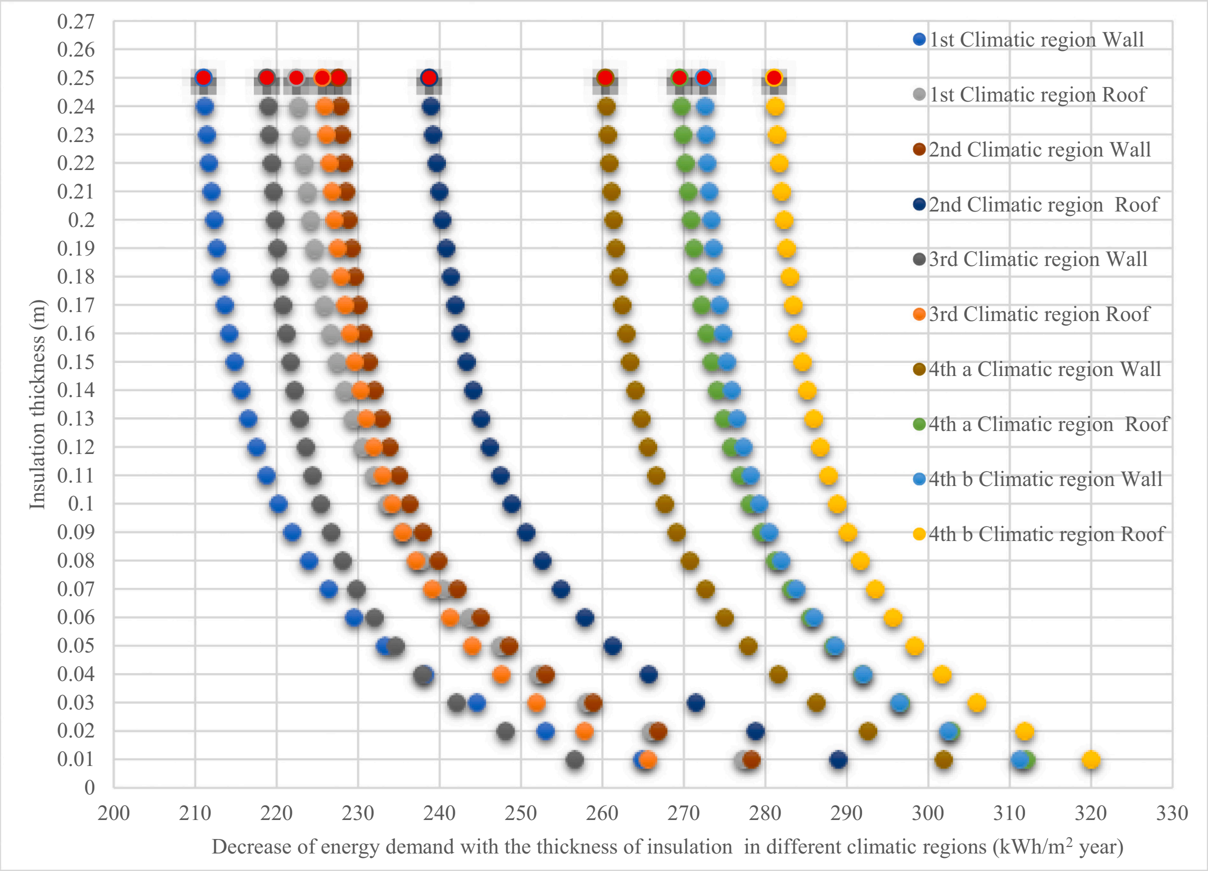


Fig. 18. SFH buildings energy demand changes (kWh/m^{2}year) with U-wall and U-roof insulation thickness in Finland.

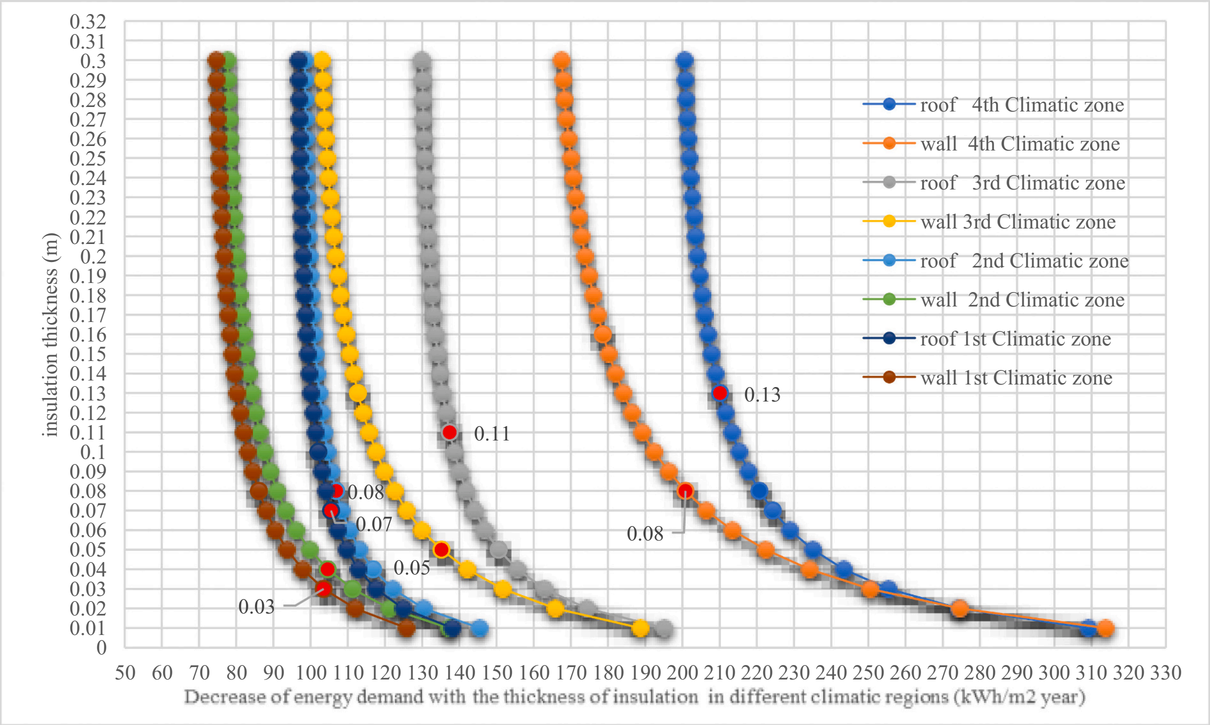


Fig. 19. Total SFH energy demand (kWh/m^{2}year) change with (U wall and U roof) insulation thickness in each climatic region in Türkiye.

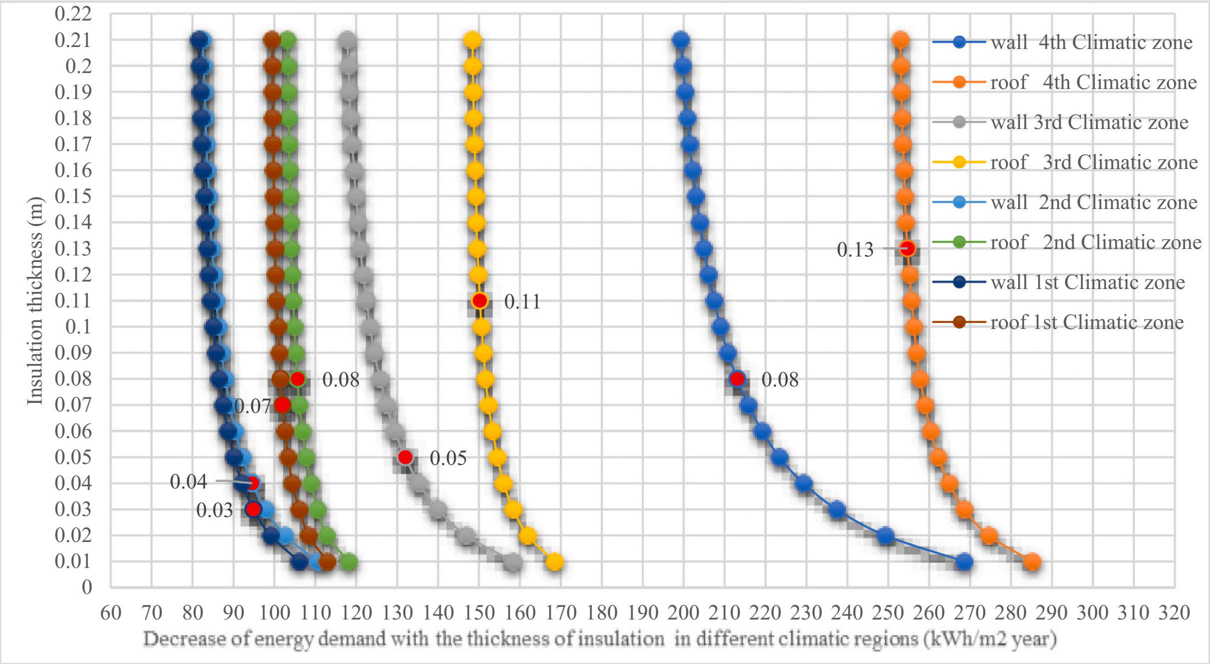


Fig. 20. Total MFH energy demand (kWh/m^{2}year) change with (U wall and U roof) insulation thickness in each climatic region in Türkiye.

to the savings potential of variables such as climate zones, building typologies, and periods. Users with limited budgets can start renovating with the most influential factors, such as walls and windows, which improve infiltration rates too.

Suggestions for future studies include a) configuring a cost and energy-efficient correlation between the cost of renewable energy systems and the costs of insulation in buildings to be renovated. This would allow optimal targeting of financing between structural solutions and building systems. And b) SFH and MFH model-building methodology could be developed further and used to simulate all EU countries' climatic regions and compare results in three energy stages energy demand, delivered energy, primary energy, and other possible performance indicators. Results will help to show whether and how the EU renovation wave targets by 2050 will be achieved.

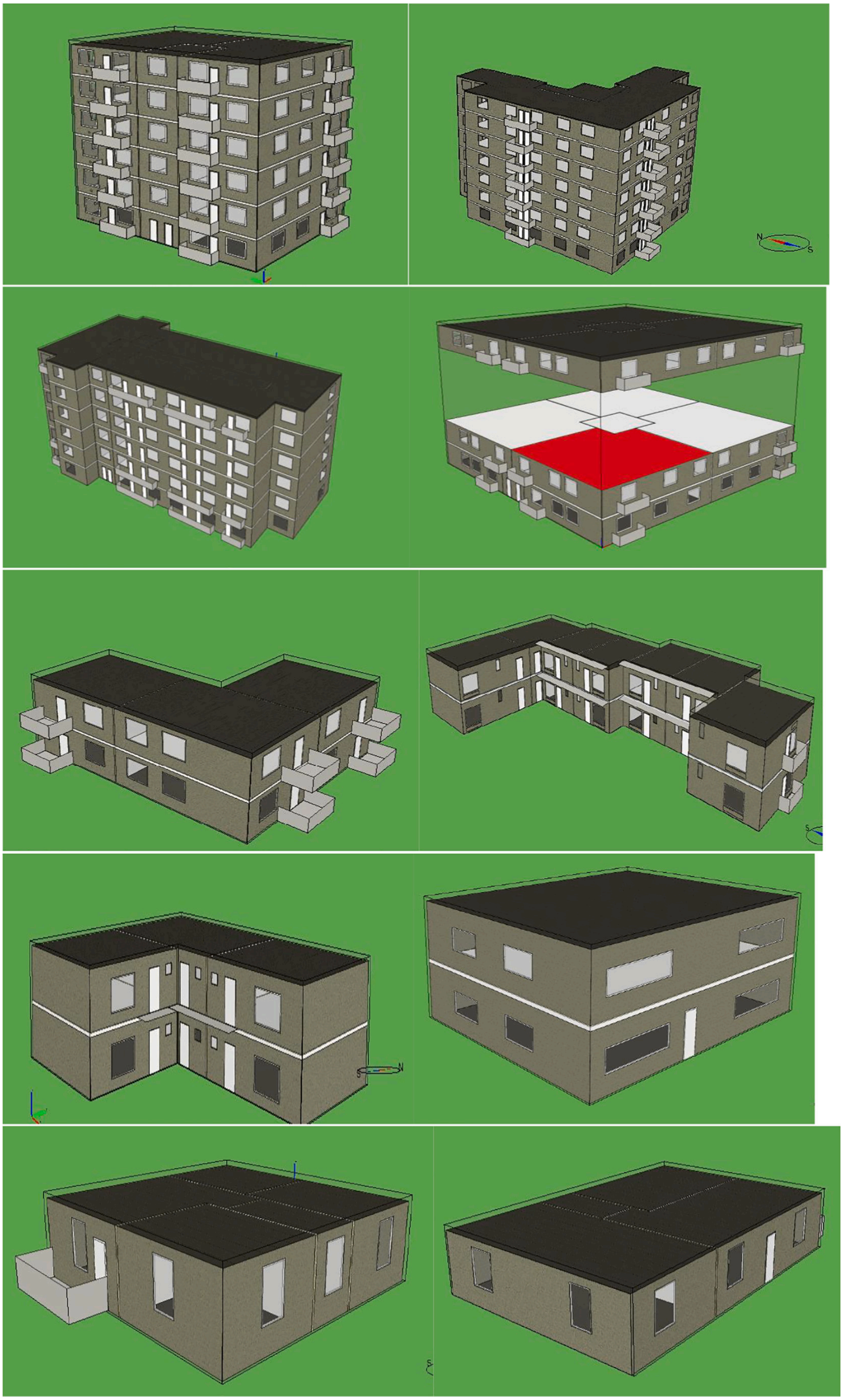
CRediT authorship contribution statement

Uygur KINAY: Conceptualization, Methodology, Data Collection, Simulation, Writing - Original Draft, Visualization. Anssi LAUKKARINEN: Conceptualization, Methodology, Simulation, Writing - Review & Editing, Visualization, Supervision. Juha VINHA: Conceptualization, Methodology, Review & Editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Annex 1. Model buildings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Annex The # cities # selected for simulation in Finland (most populated cities were given in the table).

	All dwellings in Finland			
	Detached house	Terraced house	Block of flats	Population
	Number of dwellings	Number of dwellings	Number of dwellings	
WHOLE COUNTRY	1,159,516	408,514	1,378,785	5,533,793
# Helsinki #	27,872	20,162	309,440	656,920
Espoo	34,131	18,363	77,866	292,796
# Tampere #	18,972	13,731	100,424	241,009
Vantaa	26,106	13,708	71,366	237,231
Oulu	31,718	16,369	56,560	207,327
Turku	15,040	14,270	84,164	194,391
# Jyväskylä #	18,841	10,195	49,518	143,420
Kuopio	19,555	9020	37,482	120,210
Lahti	16,422	5549	46,947	119,984
Pori	21,852	5513	22,379	83,684
Kouvola	22,476	6585	18,175	81,187
Joensuu	14,683	7823	21,099	76,935
Lappeenranta	15,503	3563	22,274	72,662
Hämeenlinna	14,412	6344	17,588	67,848
Vaasa	10,783	3275	25,385	67,551
Seinäjoki	13,927	7680	12,159	64,130
# Rovaniemi #	12,962	4540	17,152	63,528
Mikkeli	12,846	4360	13,555	52,583
Kotka	10,128	3225	17,812	51,668
Salo	15,258	5587	8197	51,562
Porvoo	12,252	2487	10,361	50,619
# Sodankylä #	2929	1206	639	8266
TOTAL	385,739	182,349	1,039,903	2,997,245
Percentage of whole country	***33 %***	***45 %***	***75 %***	***54 %***

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