A novel spatial based approach for estimation of space heating demand saving potential and CO_2 emissions reduction in urban areas

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Abstract

Space heating accounts for the most significant share of final energy demand in buildings in colder climatic regions contributing to greenhouse gas emission. In addition, there is a lack of data available to assess spatially the potential of space heating demand reduction in different buildings when considering typical building refurbishment measures. Hence, in this paper, a robust information socket for urban building stock is developed to assess the impact of energy efficiency measures on space heating demand savings and CO_2 emission reduction potential in the existing buildings based on a Geographical Information System tool. The model considers the topology and thermal performance of different building categories; houses with and without thermal insulation, apartments, commercial, public, office, and industrial buildings. Three scenarios, a reference and two additional scenarios using Prishtina city as a case study, have been created for standard (scenario 1), and advanced energy efficiency (scenario 2) measures based on the government's proposed policies. The findings show that space heat demand saving potential for scenario 1 and 2 in comparison to the reference scenario was 50 % and 68.5% respectively. Moreover, the CO_2 emissions are reduced significantly from 502.3 mil $kgCO_2$/year in reference scenario to 249.8 mil $kgCO_2$/year for scenario 1 and 158.7 mil $kgCO_2$/year in scenario 2 respectively.

Keywords: Space heating demand, energy efficiency measures, buildings, GIS, developing nations

Highlights

- Analysis of space heating demand for different building categories
- A novel method for robust information socket for urban building stock is developed
- A spatial based method for potential savings in space heating demand is proposed
- Spatial analysis of 23384 buildings for Prishtina is performed
- Space heating demand savings potential with energy efficiency measures is calculated

NOMENCLATURE

$A^{b}_{n.h}$, m^2 – the total net space heated area of a building

A^{b}_{f}, m^2 –the building footprint area

n_f – the number of floors

c_r – the calibration ratio between net and gross area of a particular building

$Q_{building}$, kWh/year – the space heating demand for the building

e_a, kWh/m^{2}year – specific space heating demand

$Q_{grid,}$ kWh/year – the actual space heating demand in a grid with 200 m × 200 m

Q_{grid}^{EEs}, kWh/year – the space heating demand with standard energy efficiency measures in a grid with 200 m × 200 m

Q_{grid}^{EEa}, kWh/year – the space heating demand with advanced energy efficiency measures in a grid with 200 m × 200 m

$Q_{SH,city}$, kWh/year – the total annual space heating demand of the city

e_i, % – the share of primary energy supply source to cover final energy demand in buildings

Q_{PES}, kWh/year – the useful space heating demand produced from different primary energy supply (PES) sources

Q_{coal}, kWh/year – the useful heat produced from coal

Q_{oil}, kWh/year – the useful heat produced from oil

$Q_{biomass}$, kWh/year – the useful heat produced from biomass

Q_{elec}, kWh/year – the useful heat produced from electricity

Q_{solar}, kWh/year – the useful heat produced from solar thermal collectors

Q_{DH}, kWh/year – the useful heat produced from district heating

η_{coal} – the efficiency of conversion of coal into heat

η_{oil} – the efficiency of conversion of oil into heat

$\eta_{biomass}$ – the efficiency of conversion of biomass into heat

η_{solar} – the efficiency of solar thermal collectors

$\eta_{ele.production}$ – the efficiency of conversion of PES mix into electricity

$\eta_{DH,production}$– the efficiency of district heat production

$gCO_{2(fuel,mix)}$ – kg/kWh carbon dioxide emission factor

λ, W/m°C – layer thermal conductivity

U, W/m^2°C – Overall heat transfer coefficient

ABBREVIATIONS

GHG Greenhouse Gas Emissions
EU European Union
DH District Heating
4GDH Fourth Generation of District Heating

GIS Geographical Information System
EE Energy Efficiency
CO_2 Carbon Dioxide
QGIS Quantum Geographical Information System
EEs Standard Energy Efficiency
EEa Advanced Energy Efficiency

1 INTRODUCTION

The demand for space heating in buildings accounts for a significant share in the total global final energy use [1]. Depending on the country's primary energy mix and climate, it is found that buildings cause 19% of the total greenhouse gas emissions (GHG) [2]. Half of the final energy demand in the European Union (EU) is consumed for heating and cooling purposes [3]. In addition, the study [3] highlights that about 25-30% of total final energy demand (depending on the country and geospatial location in EU) takes the form of heat that is consumed for space heating in buildings. Fig. 1 shows the final energy demand for Kosovo, a country located in the southeastern part of Europe. The graph shows that the building sector is the largest one and hence the space heating demand in buildings accounts for 33% of total final energy demand of the country. In comparison to other sectors (transport, industry, agriculture and others) the space heating demand accounts for the highest share of final energy demand of the country.

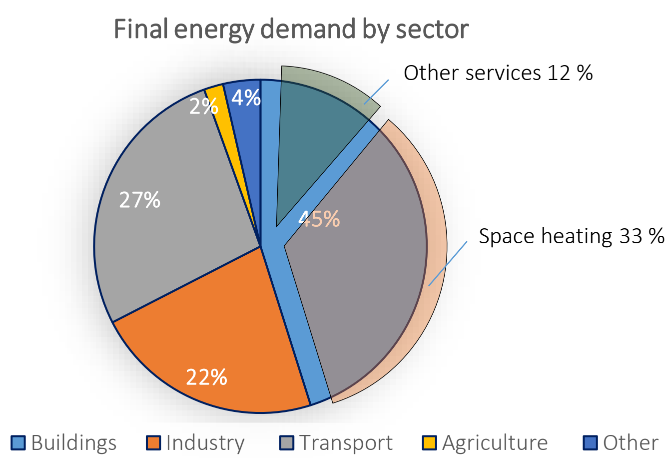


Fig. 1. Final energy demand by sector [1], [4]

The European Commission in its Heating and Cooling Strategy [5] focuses on the heating and cooling sectors of Europe, which accounts for more than 50% of the total final energy demand in Europe [6]. Very few countries have developed policies on how to decarbonize the heating sector. Research has shown that the modern district heating (DH) system is one of the vital technology that is critical for decarbonizing the heating sector [7]. 4thGeneration of District Heating (4GDH) will supply existing, renovated and new buildings with low-temperature district heat for space heating and domestic hot water demand, distribute heat in networks with very low heat losses, recycle heat from low-temperature sources, integrate renewable heat, aid in the integration of variable renewables, ensure suitable planning cost and effective structures for a transformation toward sustainable energy systems [7]. Research in DH requires data on the built environment for planning sustainable heating infrastructure. For instance [8] develops a spatial-temporal method for assessing the feasible expansion potential of DH considering both space heating and hot water demand in buildings.

Renewable supply heating and energy efficiency measures are the main pillars for decarbonizing the space heating in buildings. The main emphasis has been placed on thermal performance improvement through deep renovations in buildings or the replacement of existing building stock with nearly zero energy buildings [9]. However, spatial approaches for assessing the heat saving potential based on the built environment are lacking behind even for EU. There are very few countries like Denmark, that has a detailed geospatial building dataset, and are able to assess the bottom-up heat mapping at the national level. The other countries may have detailed data for certain cities but not for the entire country. Research [10] develops a Pan-European Thermal Atlas to improve the knowledge base for the geographical distribution of heating and cooling demands across Europe. The main objectives were to develop a comprehensive model, which can be used to quantify heat demands by density, group coherent areas with demands into perspective supply zones, and produce supply curves for these zones among others. The authors used both bottom-up and top-down modelling approaches. They concluded that at this time however, it is far-fetched yet to expect databases for other European countries, which would allow for bottom-up modelling of the heating sector. Research [11] presents a heat demand mapping and DH viability assessment method in data poor areas using data sources mostly from public databases. The developed method consists of three key steps: assessment of the aggregated heating demand, bottom-up mapping used for validation and top-down mapping of the entire observed area.

Space heating demand for buildings is calculated using the recorded heating demand data as well as the geometrical characteristics of the buildings. Different models are developed by researchers for assessing the heat demand spatially with a Geographical Information System (GIS) tool both at the local and regional level. Research [12] estimated spatially the heat demand of buildings in the Lombardy region (Italy) using the available building data and energy audits for building samples. It was concluded that the integration of energy and building data in a GIS platform allows for a more comprehensive framework of heating performance in buildings. Authors in [13] developed a model for estimating spatially end-use thermal and electric energy demand for building stock in the Newcastle Upon Tyne. They concluded that unless spatial heat model estimation is available at an appropriate level, future local energy planning infrastructure would not be effective. Research [14] assessed spatially the space heating demand of heritage buildings for an old town in Italy depending on age and building geometrical features. The results of the space heating demand of buildings were shown spatially, with a GIS tool, to suggest a zone energy indicator. Research [15] presented a comparative method between two buildings' heat demand model applications. The method was used for diagnosing and modelling precisely, the actual heat demand at an urban scale. Both models were combined in a new multi-scale framework for improved prediction of heat demand and energy savings potential of building stock at the several scales within the city. A simplified model that characterized the heating demand of the built environment at a territorial scale using a GIS tool was developed in [16]. The model took into account the data regarding the energy certificate of buildings, building age and the energy reference data available in an official statistical database. Authors in [17] developed a model for estimation and analysis of thermal energy performance gap of the occupied main Portuguese residential building stock, using a GIS tool with a high-resolution scale. A building topology approach was applied to estimate the theoretical final heating demand for thermal comfort, while an energy demand statistics-based approach was used to estimate the real heating demand.

In many European countries, buildings were built-up between 1950 and 1975, hence they need to be renovated [18]. There are many studies carried out so far regarding the building energy renovation and retrofitting process. For instance, [19] estimated the economic and societal challenge of renovating and energy retrofitting the ageing building stock in multi-family dwellings in Gothenburg. Research [20] developed a detailed model for determining heat demand, possible heat savings and associated costs in the Danish building stock. The highly detailed GIS-based heat atlas for Denmark is used as a container for storing data about physical properties for 2.5 million buildings in Denmark. A bottom-up statistical methodology based on GIS to estimate the heat demand and the saving potential of residential building stock across the entire city of Rotterdam was developed in [21]. The heat demand was apportioned to different end-uses and corrected for the weather, and then the heat savings potential was estimated by accounting for the implementation of typical refurbishment measures. Research [22] presents an energy-economic model that combines General Algebraic Modelling System coupled with the GIS-based tool for decision support in developing strategies aimed at reduction of air pollutant emissions from the residential sector. The main findings show that emission reduction could be achieved with negative costs due to investments in thermomodernization of energy-intensive buildings. Research [23] presented a bottom-up method for modelling the heating demand of a multi-family residential building sector built before 2012 in the city of Kragujevac. Firstly, the criteria for the identification of a multi-family residential building sector of the city was described and building types were defined. Secondly, the selection of the real buildings, their modelling, and heating demand simulation was performed. In addition, the simulation of different thicknesses of polystyrene thermal insulation added to external walls and simulation of the new windows installation is done for identifying the reductions of the total annual space heating demand. It was observed that the savings potential varies based on the year of construction. Apart from the contribution of energy efficiency (EE) measures to reduce GHG emission, they can additionally contribute to renewable energy technology integration. Authors in [24] developed an optimization procedure of renewable energy technology integration and building renovation, selected for a Swiss village as a case study. The main conclusion shows that retrofitting of all buildings according to the Minergie standard [25] reduces the space heating demand by 70-85% and reduces the fluctuations in energy demand, thereby allowing more renewable energy integration. Research [26] presents two bottom-up statistical extrapolation models for the estimation of the geo-dependent heat and electricity demand of the Swiss building stock. The main finding shows that for the application of the heat demand model, a realistic saving potential is estimated for the existing building stock; this potential could be achieved through by a deep retrofit program.

The literature review shows that there is a lack of available data needed to assess spatially the heat-saving potential based on a bottom-up heating approach even in EU countries. Thus, this paper concentrates on developing a robust information socket of an incomplete urban building stock by combining different data sources (open sources) to assess the impact of energy efficiency measures in space heating demand reduction and carbon dioxide emission saving potential using a GIS tool. The method presented in this paper is of high relevance for developing policies that are related to emission reduction potential analysis in the building sector through the introduction of the building envelop retrofitting measures. The method is based on spatial and statistical data analysis and is replicable, such that it can be used for study of other areas. The processes of data collection, model building, energy efficiency measure utilization within the model and environmental impact assessment are discussed in the following sections.

2 METHOD

The method applied in this research is based on the four main steps: data collection, bottom-up heat demand mapping, mapping of energy efficiency measures and CO_2 emission reduction potential analysis. The current methodology is highly relevant for developing countries which lack building topography data. The results obtained with this method are of high importance for the local authorities for developing policies that are related to impact assessments of energy efficiency measures in reduction of CO_2 emissions, especially in the residential sector. A detailed description of each undertaken step is explained in the following subsections from 2.1 to 2.5.

2.1 Data

Data needed for developing a method for bottom-up mapping of both actual and reduced space heating demand of the buildings was collected from spatial and statistical energy datasets. The data available from online data sources was not enough for the proposed methodology, hence additional data was created manually. A systematic description of data collection and post-processing is provided in the following section.

2.1.1 Spatial data

Data sources like Eurostat [27] and Open Street Map [28] provide information regarding the topography of buildings. Such type of available data is limited for developing nations but available mostly for the developed countries. Research [10] concluded that even for developed countries in EU such data provided by Open Street Map deliver an incomplete and occasionally erroneous cartographical representation of building footprints. They concluded that apart from statistical sources on national levels, no data exist, which contain concise, local information on physical building properties such as floor area, number of floors, height, age etc. At this time however, it is far-fetched yet to expect databases for other European countries, which would allow for bottom-up modelling of the heating sector.

In contrast, for the considered case study shown in fig. 2, such data (building polygon areas) was available partially, hence the missing data was created manually with the use of open layer plugin (Google hybrid) in Quantum Geographical Information System tool (QGIS) [29]. In other cases, this data can be obtained from the municipality cadaster office, if available. Another needed spatial information for bottom-up mapping was the identification of different building categories. Fig. 3 shows an urban built-up environment in a three-dimensional view. Since, the Eurostat and Open Street Map, provided only limited information regarding the building classification, Google Earth Pro [30] was used for visual identification of different building categories, like public, apartment, house, office, school etc. Apart from that, Google Earth Pro was also used for the identification of building floors.

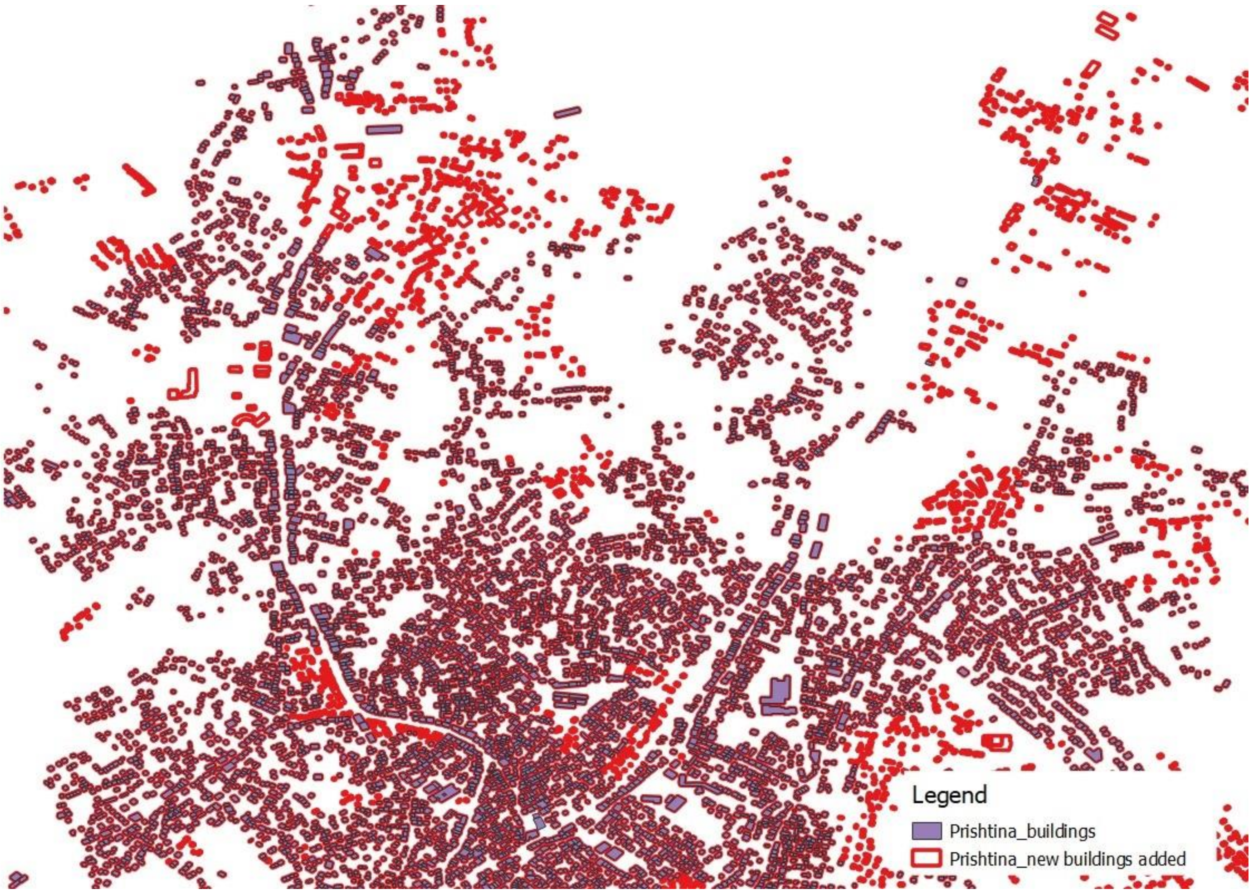
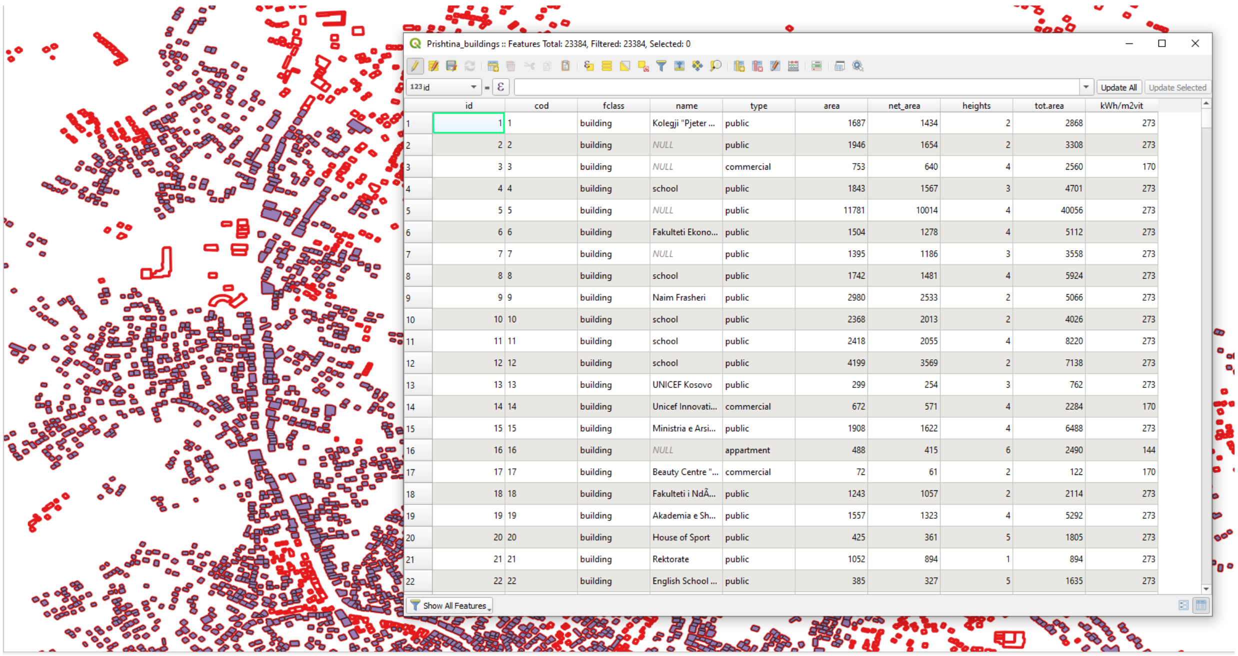


Fig. 2. Existing and new added building's footprint

Fig. 3 Three-dimensional (3D) building view (Google Earth Pro)

Fig. 4 shows the building attribute table with input data regarding the building footprints, building type, number of height, specific space heating demand for building category using attribute table for building features. The quality of input data can continually be improved with additional data in the future as building age and energy certificate for each building. The process of data classification, identification and post-processing in a GIS tool was performed to collect the requisite data for the model. These spatial data was used for mapping the net area of buildings.



	id	cod	fclass	name	type	area	net_area	heights	tot.area	kWh/m2vit
1	1	1	building	Kolegji "Pjeter ...	public	1687	1434	2	2868	273
2	2	2	building	NULL	public	1946	1654	2	3308	273
3	3	3	building	NULL	commercial	753	640	4	2560	170
4	4	4	building	school	public	1843	1567	3	4701	273
5	5	5	building	NULL	public	11781	10014	4	40056	273
6	6	6	building	Fakulteti Ekono...	public	1504	1278	4	5112	273
7	7	7	building	NULL	public	1395	1186	3	3558	273
8	8	8	building	school	public	1742	1481	4	5924	273
9	9	9	building	Naim Frasheri	public	2980	2533	2	5066	273
10	10	10	building	school	public	2368	2013	2	4026	273
11	11	11	building	school	public	2418	2055	4	8220	273
12	12	12	building	school	public	4199	3569	2	7138	273
13	13	13	building	UNICEF Kosovo	public	299	254	3	762	273
14	14	14	building	Unicef Innovati...	commercial	672	571	4	2284	170
15	15	15	building	Ministria e Arsi...	public	1908	1622	4	6488	273
16	16	16	building	NULL	appartment	488	415	6	2490	144
17	17	17	building	Beauty Centre "...	commercial	72	61	2	122	170
18	18	18	building	Fakulteti i NdÃ...	public	1243	1057	2	2114	273
19	19	19	building	Akademia e Sh...	public	1557	1323	4	5292	273
20	20	20	building	House of Sport	public	425	361	5	1805	273
21	21	21	building	Rektorate	public	1052	894	1	894	273
22	22	22	building	English School ...	public	385	327	5	1635	273

Fig. 4 Attribute table including input data for building type, building footprint, number of floors, and building form of use.

2.1.2 Statistical energy-based data

Another critical information required for the bottom-up mapping is the specific heat demand per square meter for different building categories. This data was available only for residential buildings, however, for other building categories like public, office and industrial buildings, the data was collected from the energy auditors and other internal discussions with energy auditors of buildings in Kosovo and other reports (see tab. 1 and 2). The heat demand in residential buildings is based on the seasonal method of the EN 13790 for calculation of energy demand [31]. The method takes into account the internal and solar heat gains, ventilation losses and thermal inertia of buildings. The method used implies the classification of the typology and evaluation of energy efficiency measures in residential buildings in the EU as explained in section 2.3. Data on specific heat demand for public, office and industrial buildings was collected from different building energy auditing reports. The method used for calculation of heat demand in these energy auditing reports, considers building envelope and ventilation heat losses [32], internal heat gains of buildings, excluding solar heat gains. The calculations are carried out in Excel sheet tables. The reviewing results of specific heat demand for different buildings are summarized in tab. 1. The description of how this data was utilized in the model is discussed in the energy efficiency subsection (section 2.3).

2.2 Bottom-up heat demand mapping

The bottom-up method is used for assessing the heat demand densities in small urban areas. The process of heating demand mapping is elaborated in [33], [34], [35], [36], [37], [38], [39], [40]. The process of mapping consists of the following steps: mapping of building area locations, mapping of building floors and mapping of building categories. With the multiplication of building floor areas and the number of the floors, the total gross area per building can be estimated. In addition, the total net space heated area of a building was calculated with the equation below:

$$A_{n.h}^{b} = A_{f}^{b} \times n_f \times c_r \tag{1}$$

where: $A_{n.h}^{b}$, m^2 – is the total net space heated area of a building, A_{f}^{b}, m^2 – is the building footprint area, n_f – is the number of floors, c_r – is the calibration ratio between net and gross area of a particular building. The calibration ratio 0.75 is considered for single-family houses, while for other building categories the calibration ratio 0.8 is considered.

Space heating demand for each building was calculated using the specific space heating demand (from tab. 1) and net heated area of a particular building

$$Q_{building} = A_{n.h}^{b} \times e_a \tag{2}$$

where: $Q_{building}$, kWh/year – is the space heating demand for the building, e_a, kWh/m^2year – is specific space heating demand

The actual space heating demand of buildings was aggregated and distributed spatially in a grid with 200 m × 200 m.

$$Q_{grid} = \sum_{i=1}^{n} Q_{building.i} \tag{3}$$

where: Q_{grid}, kWh/year – is the actual space heating demand in a grid with 200 m × 200 m.

The bottom-up heat demand mapping is used for assessing spatially the actual heating demand of the city, which in terms is named as reference scenario for further analysis. The next step includes the integration of typical energy efficiency measures in the model.

2.3 Energy Efficiency measures

The method proposed for evaluating the impact of energy efficiency measures in buildings was in accordance with TABULA EU project [31], which takes into account the classification of typology and evaluation of energy efficiency measures of the residential and commercial buildings. The same is applied also for EU countries, thus the proposed method can be utilized in these countries as well. The method of TABULA is based on the standard EN 13790 for the calculation of heat demand in residential and commercial buildings. This methodology proposes two scenarios for improving energy performance in the existing building stock.

- Standard energy efficiency measures (Scenario 1)
- Advanced energy efficiency measures (Scenario 2)

Both scenarios consider the refurbishment of the building envelopes, replacement of windows and doors, utilization of thermal insulation in external walls, roofs among others. The only difference between the standard (EEs) and advanced energy efficiency (EEa) scenario is the application of higher thermal performance components.

Similar refurbishment measures are proposed for other building categories rather than residential and commercial buildings. A review of energy auditing reports for office, public (schools, hospitals) and industrial building categories was carried out for identifying typical renovation measures in those buildings. These measures were also divided into two scenarios like for residential and commercial buildings. The proposed typical building envelope measures for these building categories are summarized in tab 2. Energy efficiency measures are taken into account in the spatial analysis with the reduced specific space heating demand e_a per floor area of the buildings.

2.4 Mapping of heating demand saving potential

The bottom-up head demand mapping approach mainly is used for identifying the spatial allocation of heat demand. For the proposed research, the results of calculated heat demand in reference scenario were additionally used to identify the spatial distribution of space heating demand within a city to locate the hotspots. Based on considered energy efficiency scenarios that were considered from both residential topography and the auditing processes, the spatial distribution of heat demand savings potential was calculated. Such a process is calculated by multiplying the net heated areas of buildings with reduced space heating demand in refurbishment buildings.

The results of the space heat demand saving potential spatially with EEs measures in existing building stock are shown as a percentage of reduced and actual space heating demand of building contained in a 200m× 200m grid as follow:

$$\%EEs = \frac{Q_{grid}^{EEs}}{Q_{grid}} \times 100 \quad (4)$$

Similarly, the reduction potential of space heat demand with EEa measures for grid and district is calculated as below:

$$\%EEa = \frac{Q_{grid}^{EEa}}{Q_{grid}} \times 100 \quad (5)$$

2.5 Energy and environment impact assessment

Based on the bottom-up heat modelling, the annual space heating of buildings for the entire city was estimated. Useful space heating demand and primary energy supply mix in buildings were used for assessing the effects of energy efficiency measures in CO_2 emission reduction potential within the city.

The useful space heating in buildings is obtained by summing up the total heat demand of buildings in the city as shown in equation (6):

$$Q_{SH,city} = \sum_{i=1}^{n} Q_{buildings,i} \tag{6}$$

where: $Q_{SH,city}$, kWh/year – is the total annual space heating demand of the city.

The primary energy supply mix for covering space heating demand is assumed the same as the primary energy supply mix to cover the total final energy demand in buildings. We undertake this process, when the primary energy carriers that supply space heating in buildings are not known, however, the energy carriers that supply total final energy demand in respective buildings are known. Based on the aggregated value of total space heating demand in buildings and the share factors (e_i), the useful space heat demand for different shares of primary energy carriers can be estimated using the following equation:

$$Q_{PES,i} = Q_{SH,city} \cdot e_i \tag{7}$$

where: $e_{i,}$ % – is the share of primary energy supply source to cover final energy demand in buildings, $Q_{PES,i}$, kWh/year – is the useful space heating demand produced from different i^{th} primary energy supply source.

The primary energy supply carrier used for covering space heating demand in different buildings consists of coal, oil, and biomass among others. The share of primary energy supply source that covers final energy demand for both residential and public buildings can be found from local energy balances.

Considering the same share of primary energy supply mix as for final energy demand in buildings, the useful space heating demand is calculated with the following equation:

$$Q_{SH,city} = Q_{coal} + Q_{oil} + Q_{biomass} + Q_{elec} + Q_{solar} + Q_{DH} \tag{8}$$

where: Q_{coal}, kWh/year – is the useful heat produced from coal, Q_{oil}, kWh/year – is the useful heat produced from oil, $Q_{biomass}$, kWh/year – is the useful heat produced from biomass, Q_{elec}, kWh/year – is the useful heat produced from electricity, Q_{solar}, kWh/year - is the useful heat produced from solar thermal collectors, Q_{DH}, kWh/year – is the useful heat produced from district heating.

The conversion efficiencies were used for the estimation of primary energy supply sources utilized for covering useful space heating demand in buildings. The primary energy supply (PES) can be estimated using the conversion efficiencies for different heat production technologies as follow:

$$\begin{aligned} E_{PES} = Q_{coal}/\eta_{coal} + Q_{oil}/\eta_{oil} + Q_{biomass}/\eta_{biomass} + Q_{elec}/\eta_{ele.production} \\ +Q_{solar}/\eta_{solar} + Q_{DH}/\eta_{DH,production} = \textstyle\sum_{i}^{n}(Q_{PES}/\eta)_i \end{aligned} \tag{9}$$

where: η_{coal} - is the efficiency of conversion of coal into heat, η_{oil} - is the efficiency of conversion of oil into heat, $\eta_{biomass}$ - is the efficiency of conversion of biomass into heat, η_{solar}- is the efficiency of solar thermal collectors, $\eta_{ele.production}$ - is the efficiency of conversion of PES mix into electricity, $\eta_{DH,production}$- is the efficiency of district heat production.

The actual carbon dioxide emissions were estimated using the primary energy supply mix and different CO_2 emission factors for fuel types as shown in equation (10)

$$CO_2 emissions = gCO_{2(fuel,mix)} \cdot E_{PES} = gCO_{2(fuel)i} \cdot \sum_i^n (Q_{PES}/\eta)_i \tag{10}$$

The country's primary electricity production mix was considered for the estimation of CO_2 emission factor $gCO_{2(fuel,mix)}$. District heating system is based on the cogeneration plant, which uses lignite coal for electricity and heat production. In addition, the CO_2 emission factor was considered the same as for individual coal boilers.

The same procedure, as described above, was undertaken for calculating the total CO_2 emissions from the refurbished buildings in scenarios 1 and 2 respectively.

3 CASE STUDY

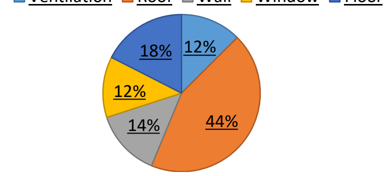
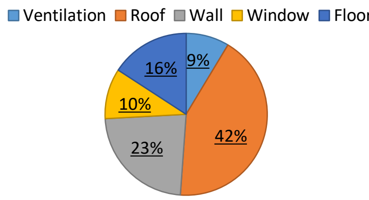
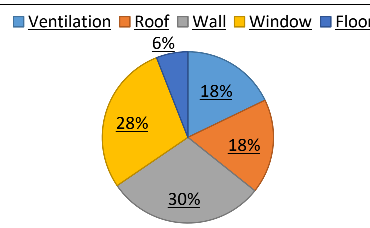
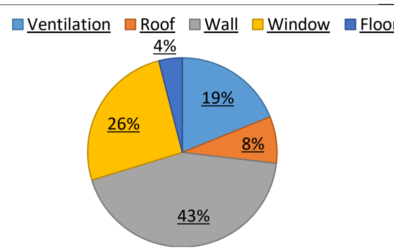
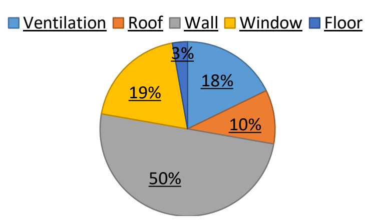
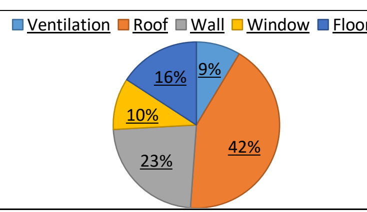
A case study of Prishtina, Kosovo is conducted to assess the potential of space heating demand savings and CO_2 emission reduction based on the proposed method. The building stock of Prishtina city consisted of about 23384 buildings. Buildings were categorized into 7 different categories according to their purpose of use and construction materials like a house (single-family house), nhouse (single-family house), apartment, commercial, public, office and industrial buildings. These categories were considered in the model to have a better representation of existing building stock as they describe the majority of the existing buildings. The input data in the GIS model can continually be improved in terms of data regarding the energy certificate for every single building. There is no data regarding the building age spatially, however buildings were divided in a way to consider for the majority of buildings built in a certain period. For instance, half of the individual houses in Kosovo, are built after the 2000 year [41]. To consider the building age in the model the individual houses have been divided into two categories. Sample buildings considered in this research are summarized in tab. 1.

House represents a single-family individual house with one, two or three floors, which is thermally insulated and plastered from both inside and outside. Nhouse are single-family individual houses which do not have thermal insulation in external walls and not plastered from outside. Apartments are considered as residential buildings occupied with many residential consumers. Commercial buildings include buildings that are used for commercial purposes like shopping mall centres, convenience stores and other buildings with multiuse purposes. Public buildings included school, hospital, universities, and libraries. Thermal performances for different building categories, that are shown in tab. 1, are reviewed from local sources and energy auditing reports. Residential buildings (house, nhouse, apartment) are the most important as they cover over 90% of buildings in the city.

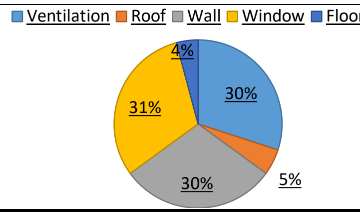
Tab. 2 shows the typical building envelope refurbishment measures according to European standard EN 13790 for residential building. The tab. 2 also shows the refurbishment measures for other building categories rather than residential provided by local energy auditors. The reviewed refurbishment measures include thermal properties for both buildings thermal insulation materials and new window installation. The building refurbishment measures are considered within the model with standard and advanced specific

heating demand, however they are not calculated by authors but they are considered from different sources labelled in the tab.2.
Based on the described method and input data, a simulation was performed to calculate space heating saving potential for Prishtina. The results are discussed in section 4.

Tab. 1. Building block description and actual space heating demand per different building category.

Actual building stock description[1]	Percentage of actual heat loss	Actual specific heat demand in kWh/m²year
House 		153 [31], [42]
N.house 		272 [31], [42]
Apartment 		144 [31], [42]
Office 		151 [42]
Commercial 		169 [31], [42]
Public 		272 [42], [43], [44]

[1] Building sample's images are made by authors

Industrial 		94 [45]

Tab. 2. Proposed energy efficiency measures in the actual building stock [31], [31], [32], [44], [45].

Building type	Proposed EEs measures	Proposed EEa measures	EEs. specific heating demand in kWh/m²year	EEa. specific heating demand in kWh/m²year
House	• Insulation of external walls with 10 cm and λ= 0.04 W/m℃. • Insulation on the roof slab with 10 cm thermal insulation layer (λ=0.04 W/m℃). • Replacement of windows with new low E-double glazing window with U=1.6 W/m²℃	• Insulation of walls with 20cm thermal insulation layer (λ= 0.04W/m℃). • Insulation on the roof slab with 20cm thermal insulation layer (λ = 0.04 W/ m℃) and insulation on the floor slab with 10 cm thermal insulation layer (λ= 0.04 W/m℃). • Replacement of windows, with new low-E triple glazing windows with U=1.0 W/m²℃	93	55
N.house	• Insulation of walls with 10 cm thermal insulation layer (λ= 0.04 W/m℃). • Insulation on the roof slab with 10 cm thermal insulation layer (λ= 0.04 W/m℃). • Replacement of windows with new low E-double glazing window with U=1.4W/m2℃	• Insulation of walls with 20 cm thermal insulation layer (λ= 0.04 W/m℃). • Insulation on the roof slab with 20 cm thermal insulation layer (λ= 0.04W / m℃) and insulation on the floor slab with 10 cm thermal insulation layer (λ = 0.04 W/m℃ . • Replacement of windows with new low E triple glazing windows with U=1.0 W/m2℃	125	55
Apartment	• Insulation of walls with 10cm thermal insulation layer (λ= 0.04 W/m℃). • Insulation on the slab above unheated space and Insulation on the roof slab with 10 cm thermal insulation layer (λ= 0.04 W/m℃). • Replacement of windows, with new windows with two layers of low-E glass with U=1.6 W/m2℃	• Insulation of walls with 20cm thermal insulation layer (λ= 0.04 W/m℃). • Insulation on the slab above unheated space and insulation on the roof slab with 20 cm thermal insulation layer (λ= 0.04 W/m℃). • Replacement of windows, with new windows two layers of low-e glass with U=1.0 W/m2℃	50	40
Office	• Insulation of walls with 10cm thermal insulation layer (λ= 0.04W/m℃) and the attic walls with 5 cm thermal insulation layer (λ= 0.04W/m℃). • Insulation of the roof with 10 cm of thermal insulation (λ=0.04W/m℃). • Floor slab above the unheated space without any changes. • Replacement of windows, with new double glazed windows with low-E with U=1.60W/m2℃	• Insulation of walls with 20 cm thermal insulation layer (λ= 0.04W/m℃) and the attic walls with 15cm thermal insulation layer (λ= 0.04W/m℃). • Insulation of roof with 20cm of thermal insulation (λ=0.04W/m℃). Insulation on the floor slab above the unheated space with 10cm thermal insulation layer (λ= 0.04W/m℃). • Replacement of windows with new triple glazed windows with low-E with U=1.0W/m2℃	84	64
Commercial	• Insulation of walls with 10cm thermal insulation layer (λ= 0.04W/m℃). • No interventions on the roof and floor. • Replacement of windows, with new double-glazed windows with low E to achieve U=1.60W/m2℃	• Insulation of walls with 20 cm thermal insulation layer (λ= 0.04W/m℃). • Insulation of construction towards unheated attic with 15 cm of thermal insulation (λ =0.04W/m℃). • Insulation on the ground slab with 15 cm thermal insulation layer (λ= 0.04W/m℃). • Replacement of windows, with new triple glazed windows with low-E to achieve U=1.0W/m2℃	96	65
Public	• Insulation of walls with 10cm thermal insulation layer (λ= 0.04 W/m℃). • Insulation on the roof slab with 10cm thermal insulation layer (λ= 0.04 W/m℃). • Replacement of windows with new low e double glazing windows with U=1.4W/m2℃	• Insulation of walls with 20cm thermal insulation layer (λ= 0.04 W/m℃). • Insulation on the roof slab with 20cm thermal insulation layer (λ= 0.04 W/ m℃) and insulation on the floor slab with 10cm thermal insulation layer (λ= 0.04W/m℃). • Replacement of windows with new low-E triple glazing window with U=1.0W/m2℃	125	55
Industrial	• Equipment heat gains, un-comfort conditions, and small space heating demand reviled with no EE measured proposed for buildings of this category.	• Equipment heat gains, un-comfort conditions, and small space heating demand reviled with no EE measured proposed for buildings of this category.	94	94

4 RESULTS AND DISCUSSION

The 3D modelling result for actual building stock of Prishtina is calculated based on discussed method is shown in fig. 5. A colour code was used for the visualization of building heights. Red geometry codes in fig. 5, expresses the tallest buildings in the city up to 18 floors, while blue ones are buildings with one to two floor.

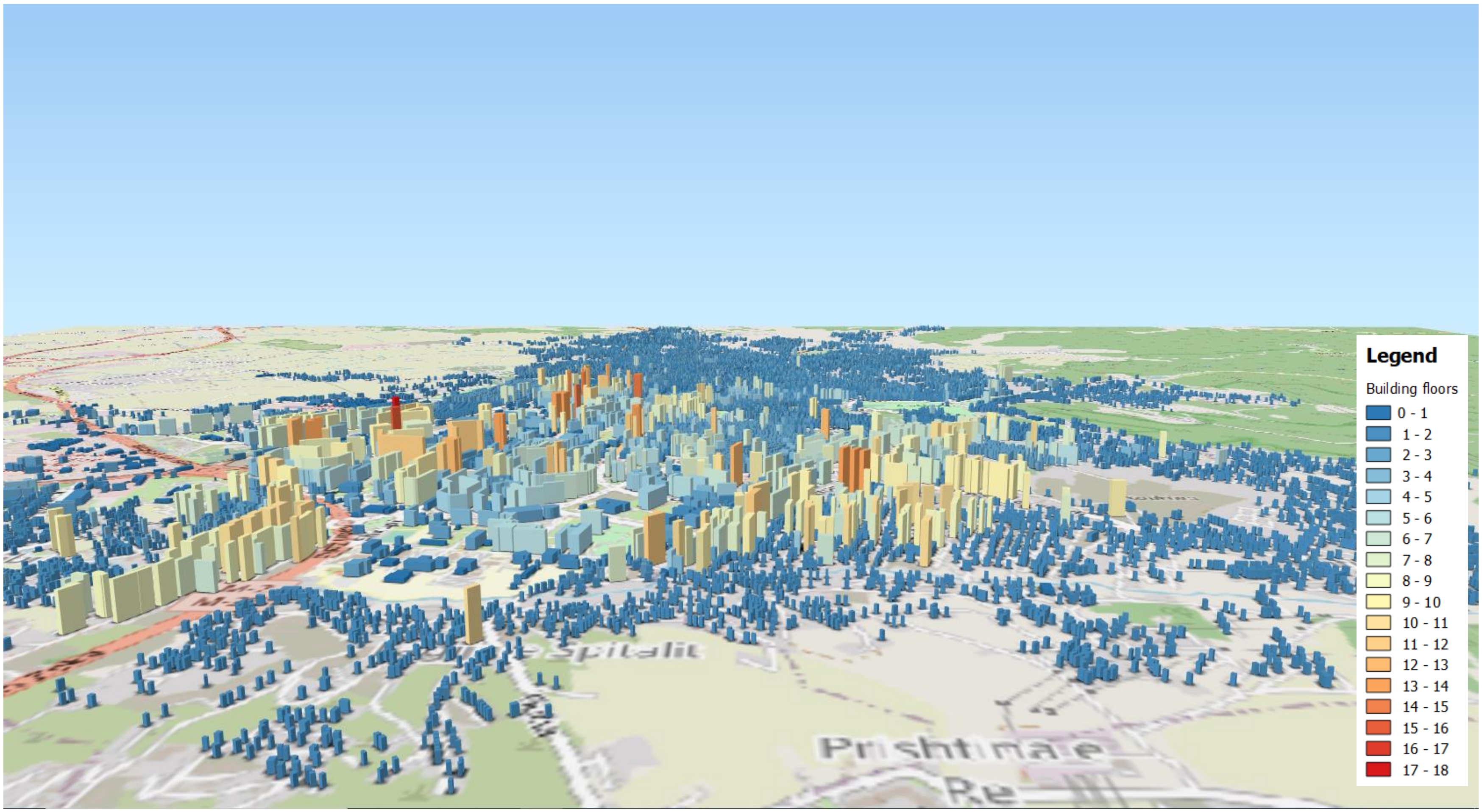


Fig. 5 Prishtina building stock presented in 3D view

The actual space heating demand for buildings is given in tab. 3 while its aggregated values which are distributed spatially in a 200 m × 200 m grid are presented in fig. 6. It is found out that the total actual heat demand of buildings in Prishtina city is 968.8 GWh/year for houses, 752.2 GWh/year for apartments, 38.54 GWh/year for nhouse, 106.7 GWh/year for commercial buildings, 2.23 GWh/year for offices, 377.5 GWh/year for public buildings and 30.02 GWh for industrial buildings. It can be shown that the heat demand is spatially concentrated in the apartment building areas, which is shown with a dark red colour code (fig. 6). Other building features like building footprint area, net areas and their actual and reduced heat demand for each category are given in the tab. 3.

Tab. 3 Buildings net area and their heat demand saving results

CATEGORY	Number of buildings	Building footprint area m^2	Total net building heated area m^2	Actual heat demand GWh/year	Heat demand after applying EEs GWh/year	Heat demand after applying EEa GWh/year
Apartment	1024	862,542.0	5,223,644.0	752.2	261.2	208.9
Commercial	225	301,284.0	627,632.0	106.6	60.2	40.7
House	20450	3,406,174.0	6,331,997.0	968.8	588.7	348.2
Industry	272	330,838.0	319,245.0	30.0	30.0	30.0
Nhouse	477	75,974.0	141,700.0	38.5	17.7	7.8
Office	13	10,398.0	14,641.0	2.2	1.2	0.9
Public	301	459,833.0	1,236,230.0	337.4	154.5	68.0
Not heated area[2]	622	76,454.0	73,134.0	0.00	0.00	0.0
TOTAL	**23384**	**5,523,497.0**	**13,968,223.0**	**2,235.9**	**1,118.3**	**704.7**

[2] Not heated area= include areas like parking slots, garage, depot.. etc, which are not being heated and hence are excluded in the model.

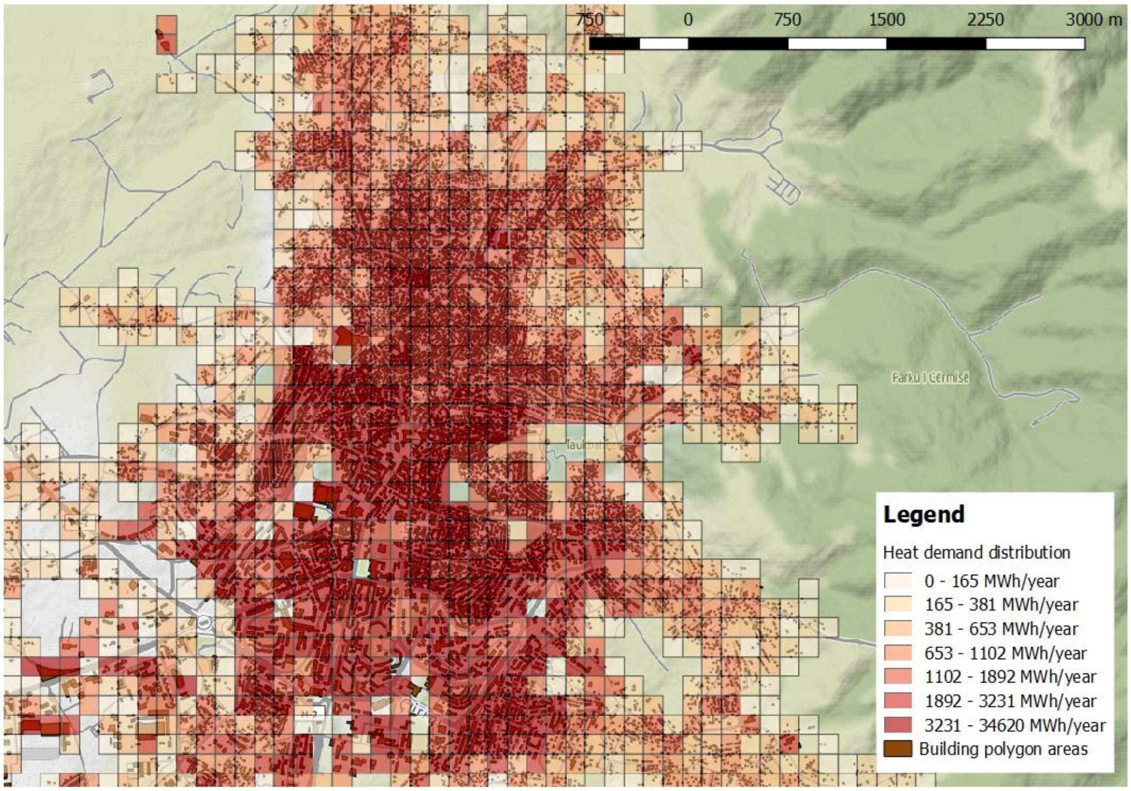


Fig. 6 The actual space heating demand for buildings aggregated in a 200m × 200m grid.

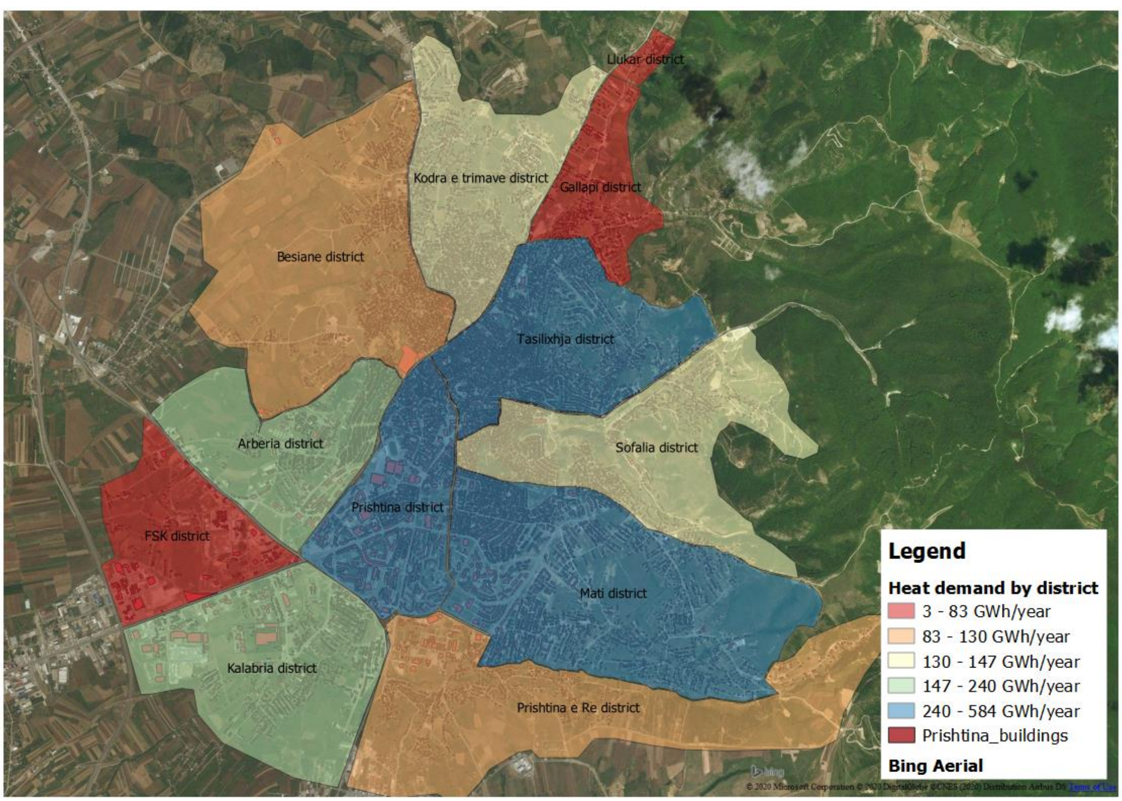


Fig. 7 Actual space heating demand for buildings aggregated in Prishtina city districts.

The actual space heat demand of buildings was aggregated in Prishtina districts (fig. 7) in order to identify which districts have larger heat demands and which ones have a higher potential for space heating demand reduction when applying standard and advanced EE measures, which was demonstrated in details in the tab. 2. It can be shown that districts of Prishtina, Mati and Talixhje have higher heat demand compared to the other districts in the city. This is due to the fact, that most of the high rise buildings are located in these districts, especially in the Prishtina district where more than 80% of the district area is occupied with apartments and other high rise buildings. Higher demand districts are shown with green polygon code, while the ones with lesser heat demand (Kodra e Trimave, Besiane, Gallap, Prishtina e Re, Kalabria and Arberia district) are shown with red colours, and light brown color in fig 7.

In fig. 8, the city's space heat demand reduction potential with EEs measures is presented. Significant reduction of actual space heating demand potential of around 55-65% was identified in the locations occupied with high rise buildings specifically apartments (green grids). Similarly, a high reduction potential was identified in high-density built-up areas with mixed buildings (apartments and individual houses) accounting for a reduction potential of around 45-53%. In contrast, smaller reduction potential was identified in red grid areas accounting for 37-41%, which is almost entirely occupied by single-family buildings or individual houses as compared to their actual heating demand.

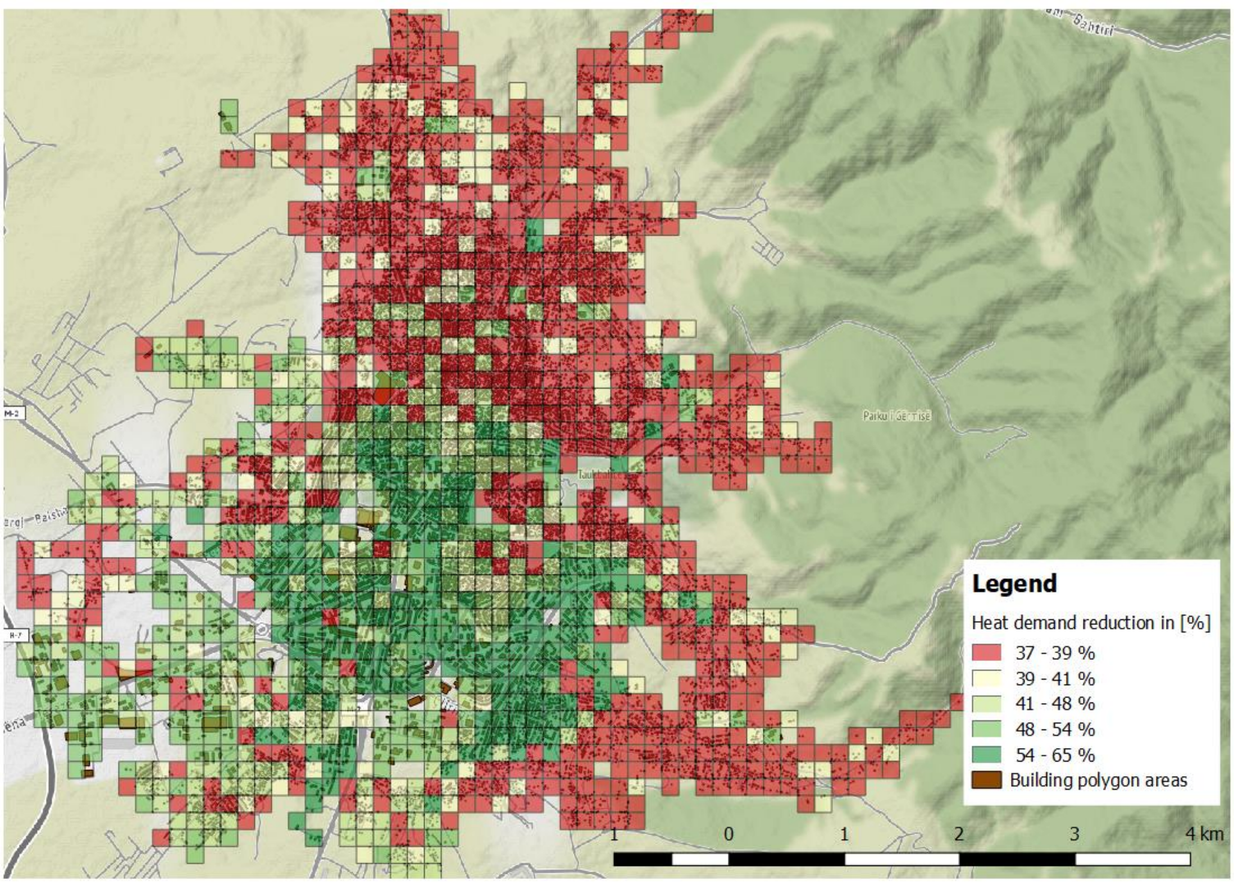


Fig. 8 Space heating demand saving potential in a 200 m × 200 m grid for scenario 1 (EEs measures in buildings)

The space heating demand reduction by districts when applying EEs measures in actual building stock is shown in fig 9. Similarly, in districts of Prishtina and Mati significant heat demand reduction potential was identified accounting for a reduction 329 and 284 GWh/year respectively. Furthermore, by following the same procedure for the estimation of space heating demand reduction potential with EEa measures (as discussed for scenario 1), the space heating demand saving potential can be estimated spatially for different levels of details and the results for a district-level are shown in figures 10 and 11 respectively. In fig. 10, a significant heat-saving potential is obtained for locations occupied with high rise building, dark green colored grids accounting for 80% of the reduction, while the least potential with red colored grids is around 58%.

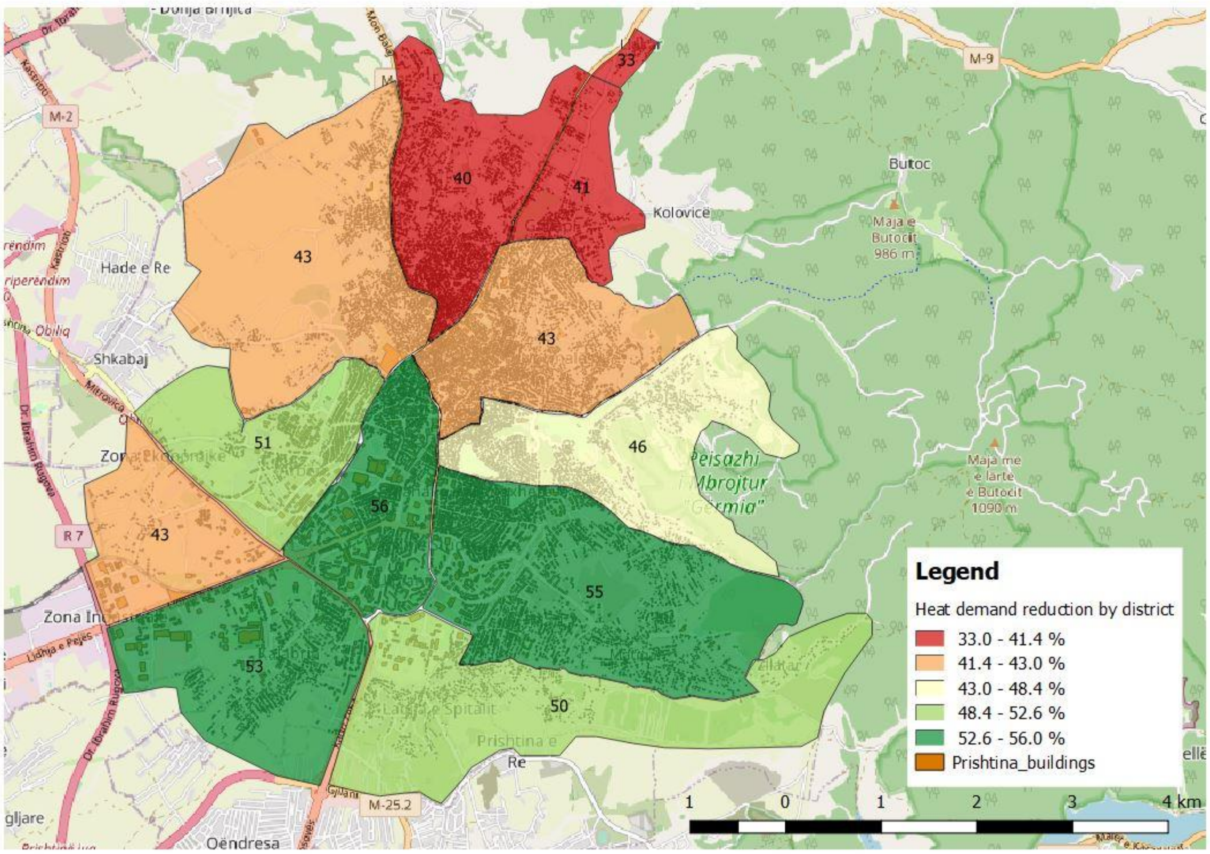


Fig. 9 Space heat demand saving potential by districts for scenario 1, (EEs measures in buildings)

While observing each space heat demand building category, it was found that the space heat demand reduction when applying EEa measures for houses, nhouses, apartments, commercial, public, office, and industrial buildings accounted for 348.2 GWh/year, 7.81 GWh/year, 208.9 GWh/year, 40.8 GWh/year, 68 GWh/year, 0.94 GWh/year and 11.17 GWh/year respectively (see tab. 2). The space heating demand reduction potential for districts while applying EEa meausres is shown in fig.10. In addition, in districts with high density of high rise buildings, significant space heat demand reduction potential was identified especially for the district of Prishtina, Mati and Taslixhja leading to a reduction of 421, 360 and 169 GWh/year respectively (fig. 11).

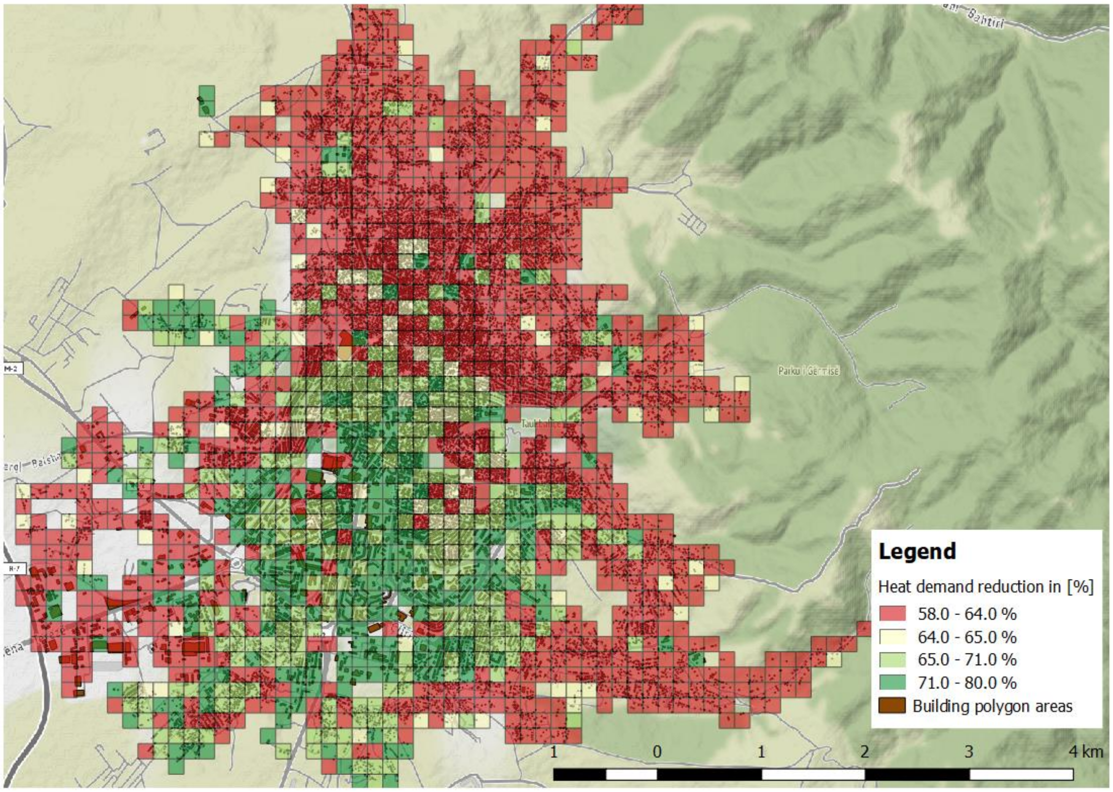


Fig. 10 Space heating demand saving potential in a 200 m × 200 m grid, scenario 2 (EEa measures in buildings)

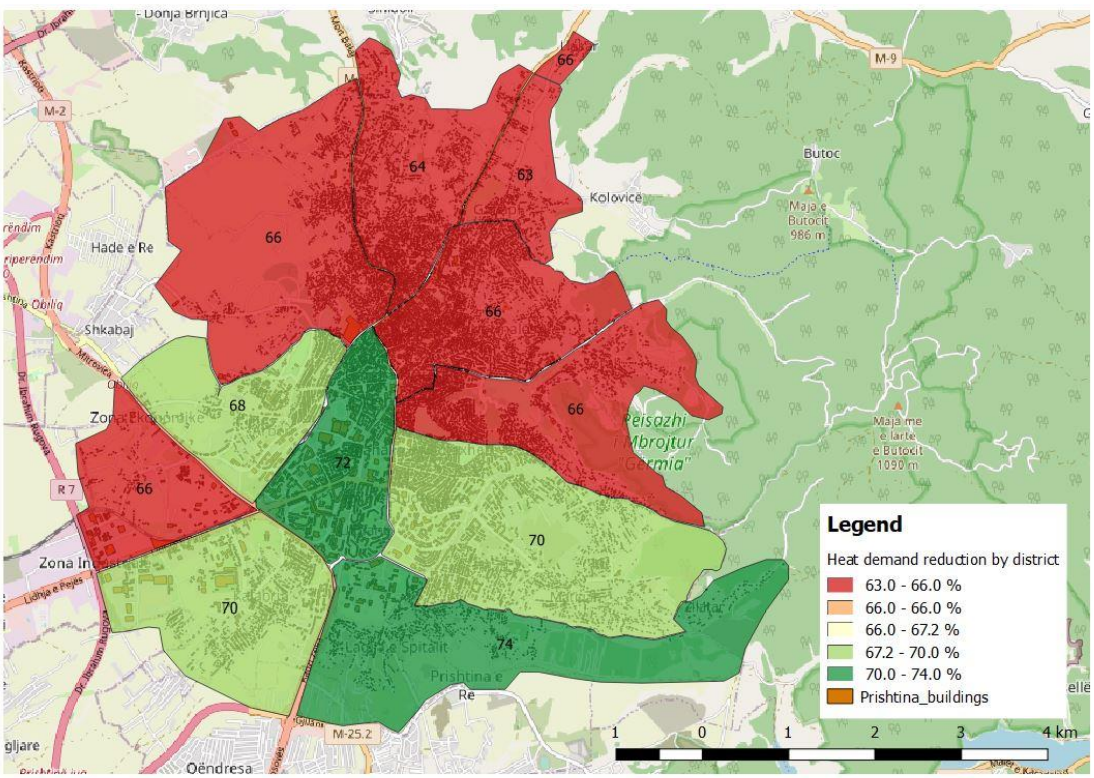


Fig. 11 Space heat demand saving potential by districts, scenario 2 (EEa measures in buildings)

Fig. 12 shows the heat demand duration curve over the heating season in Prishtina for three different cases (reference case with actual heat demand, scenario 1 for heat demand with EEs and Scenario 2 for heat demand with EEa). The load curves are generated using the hourly heating degree day method [8]. Load heat curves are created using hourly air temperature data, for ten years, downloaded from the Meteonorm [46] for the climate conditions in Prishtina. For the actual space heating demand estimated, the maximal needed thermal capacity from heat providers is around 1115 MW_{th}. Such capacity is needed only for a short period when the external dry air temperatures reach maximal minus values around -15°C. In Prishtina the heating season lasts for six months, accounting for 4230 h/year demand to be heated. In contrast, such heat demand capacity can be significantly reduced to around 50% and 68% of the actual maximum capacity when applying standard and advanced EE measures in the actual building envelope components.

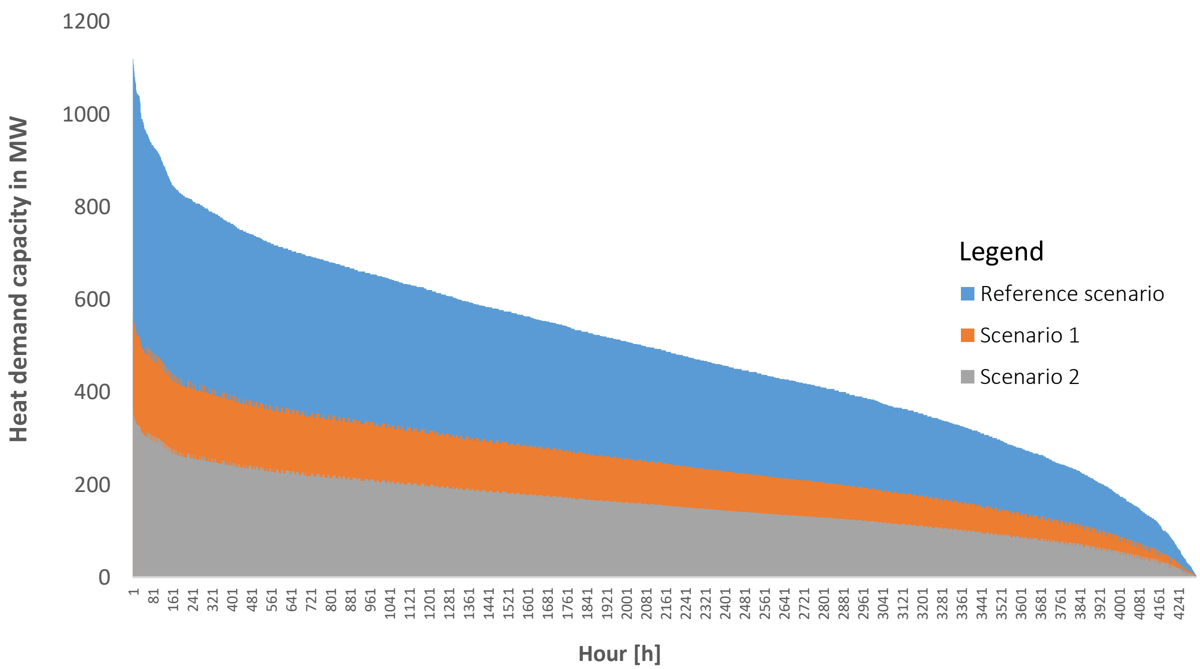


Fig. 12 Actual and reduced space heating demand capacity in [MW]

Fig. 13 shows the actual and reduced space heating demand for building categories in a district. It can be seen that the different building heat demand varies, considering the share and overall heat demand for different building categories in a district. The largest heat demand is identified in Prishtina, Mati, and Tasligjia districts. In other districts, the overall share of the heat demand is less significant because the main heat consumers in such districts are houses. This is not the case, for Prishtina e re[3] and Kalabria districts, where public and apartment buildings still are the main heat consumers, but the overall heat demand is not that significant compared to previously discussed districts. In Prishtina district, apartments are the main heat consumers accounting for an actual heat demand of 275 GWh/year (blue column), public buildings 160 GWh/year and commercial and public buildings almost the same share accounting for 68 GWh/year. The share of other building categories (industrial, office) in this district is very small compared to the other heat consumers. The second bar (red in the bar chart in fig. 13) shows the reduced space heating demand

[3] Prishtina e re, Kalabria, Tasligjia, Mati, Kodra e trimave are original Albanian names of Prishtina city districts

after applying EEs measures accounting for 95 GWh/year, public buildings 75GWh/year, commercial and house categories 40 GWh/year. Similarly, the third bar (green) shows the reduced space heating demand after applying EEa measures. It can be seen that there is not a significant difference between standard and advanced EE measures in the overall heat demand reduction especially in the apartment, commercial and industrial buildings. Similar conclusions can be observed for the other districts shown in fig. 13.

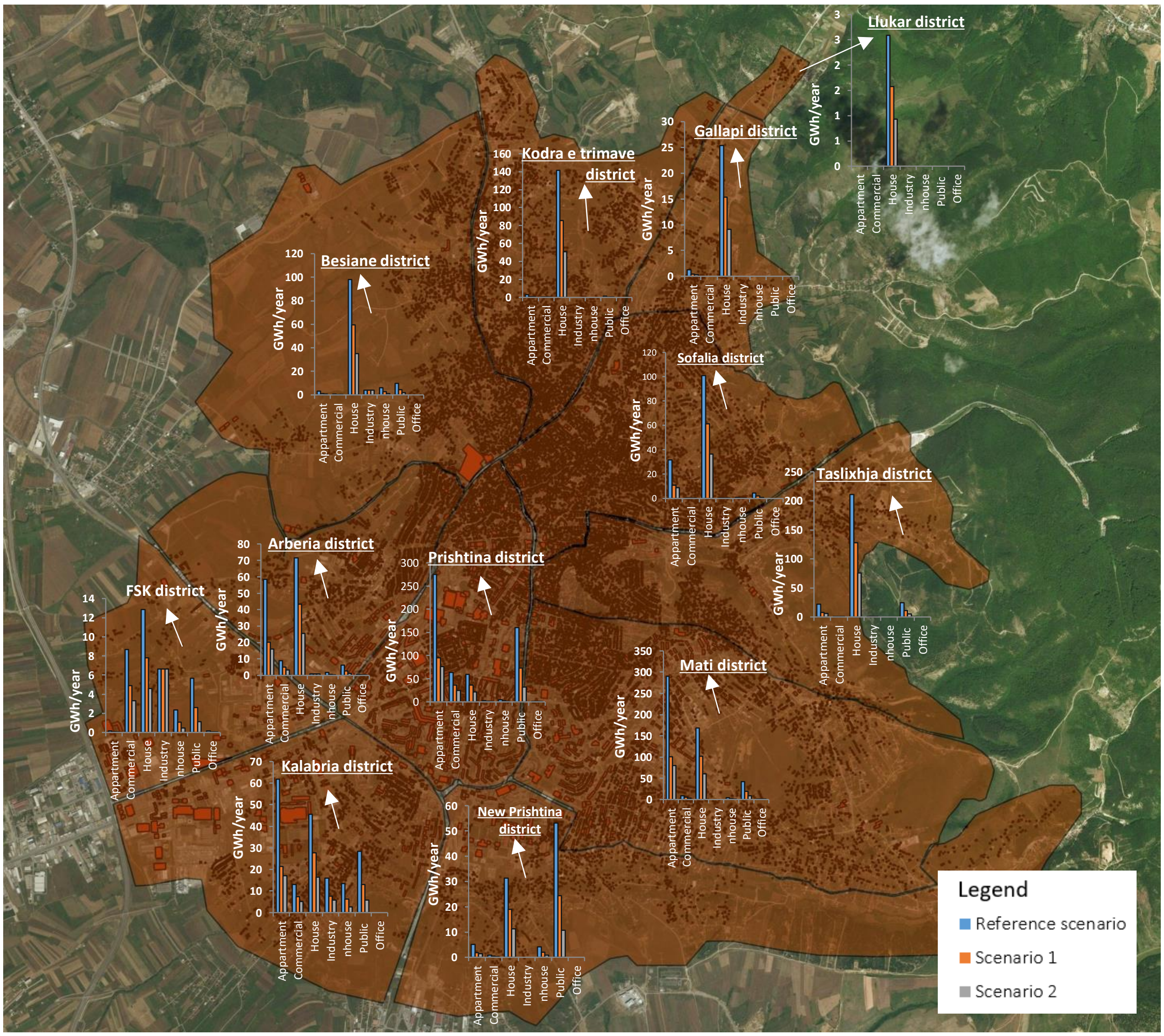


Fig. 13 Actual and reduced space heating demand for different building categories distributed spatially in districts. Blue bar shows the actual heat demand of buildings, red bar shows the reduced space heating demand for buildings after applying EEs measures, and grey bar shows the reduced space heating demand for buildings after applying EEa measures.

Fig. 14 shows the actual and reduced CO_2 emissions from space heating of buildings. The emissions were calculated for different cases, considering the actual and reduced space heating demand of public and residential buildings with energy efficiency measures. The results have shown that actual CO_2 emission's from public and residential buildings account for 90.1 Million kgCO_2/year and 412.1 Million kgCO_2/year respectively. With standard energy efficiency measures, the overall CO_2 emission was reduced significantly compared to the reference scenario (actual heat demand) accounting for a decrease of 50%. Even higher CO_2 emission reduction potential was observed with the utilization of advanced energy efficiency measures in buildings. Current research is of high importance for developing future policies that are related to emission reduction potential in residential buildings. So far, most of the energy efficiency projects are focused on public buildings, but future targets of the ministry are to support energy efficiency measures in residential buildings as well. In addition, the potential for reducing CO_2 emission in residential buildings is significant.

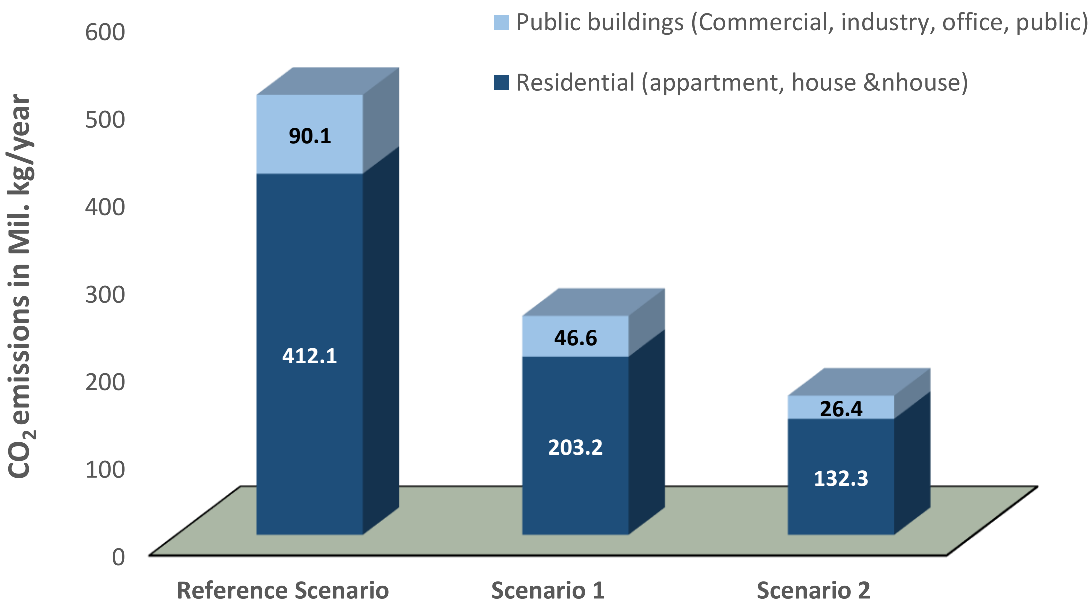


Fig. 14 Total actual and reduced CO_2 emissions due to energy efficiency measures in buildings.

5. CONCLUSION

In this research, a method for spatial evaluation of space heating demand and CO_2 emission saving potential based on energy efficiency measures in buildings was developed and investigated. The method has been applied for a municipality in Kosovo. Two energy efficiency scenarios have been proposed and the results show that there is a significant potential for both space heating demand and CO_2 emission reduction within the city. For the first and second scenario, the space heat demand savings accounted for 1.12 TWh/year and 1.53 TWh/year respectively, when compared with actual space heating demand of the existing buildings stock (reference scenario). The results of the simulation were shown in layer grid map with 200 m × 200 m as well as districts based map of the city. Higher space heating demand saving potential was identified in districts with high rise buildings and apartments while less saving potential in areas populated by individual houses as the main building category.

When observing the building level, the results of scenario 1 have shown that applying EEs, apartments can save up to 65.2% of their actual space heat demand, commercial 43.5%, houses 39.2%, public 54.2%, nhouse 53% and office buildings 44.8% respectively. In the second scenario, compared to actual space heat demand, apartments can save 72.2%, commercial 61.7%, houses 64.1%, public 79.8%, nhouse 79.5% and office buildings 57.8%. Apart from the analysis of space heating demand distribution spatially, it was further shown that the required capacity of heat can be reduced significantly with proposed EEs and EEa measures accounting for 50% and 68% as compared with the actual needed capacity. Furthermore, it was shown that with the application of energy efficiency measures in buildings, the CO_2 emissions can be reduced significantly accounting for a decrease of 49.7% in scenario 1 and 68.3% for scenario 2, when compared with reference scenario.

The approach elaborated in this research can be applied in data scarce areas for bottom-up modelling of the heating sector. The proposed method contributes towards the application of GIS based research for space heat savings' studies and is replicable as it can be used for rural and urban areas equally. The results from this approach can be continually improved and updated with new information regarding the building energy certificates, energy efficiency measures proposed by energy audits for buildings among others. The application of this approach at the national level still lacks, as there is no complete spatial data regarding the building geometries (footprints areas and number of floors), building energy certificate, energy audits, building age and building form of use. Moreover, the data sources used in this approach for identifying building's form of use and building categories in other urban areas is lacking.

A spatial based survey that gathers information for buildings would be a reliable method for creating a regional heat atlas (considering hot water and space heating demand) based on bottom-up modelling which would give detailed insights into the demand for heating. Future work of this research besides regional mapping might be the impact of spatial space heating demand savings in the fourth generation of district heating systems especially in pressure drop and heat loss analysis.

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