A novel spatial-temporal space heating and hot water demand method for expansion analysis of district heating systems

Drilon Meha[1, 2]*, Jagruti Thakur[3], Tomislav Novosel[4], Tomislav Pukšec[1], Neven Duić[1]

[1]Faculty of Mechanical Engineering and Naval Architecture
University of Zagreb, Zagreb, Croatia

[2]Faculty of Mechanical Engineering,
University of Prishtina, Hasan Prishtina, Pristina, Kosovo
e–mail: drilon.meha@uni-pr.edu

[3]Department of Energy Technology, KTH,
Royal Institute of Technology, Sweden

[4]North-West Croatia Regional Energy Agency
Zagreb, Croatia

ABSTRACT

The fourth generation of district heating will play a significant role in the decarbonization of energy systems. In general, only space heating demand is considered when assessing the district heating potential, excluding hot water. In contrast, the hot water demand accounts for up to 18% of total final energy demand in buildings. Hence, in this paper, a spatial-temporal method for annual hot water demand is considered in conjunction with space heating demand while technically and economically assessing the expansion potential of the district heating. A bottom-up heat demand mapping process was carried out for Pristina city to identify the space heating demand of buildings, while a top-down approach was used for spatial mapping of hot water demand. Hourly, daily, weekly and seasonal hot water demand profiles, besides heating degree-day method used for space heating, were considered when estimating the temporal operation of district heating. The findings show that the existing district heating can be increased four times when excluding hot water and five times when considering both space heating and hot water demand of buildings. Moreover, the heat supply capacities needed in district heating to cover space heating and hot water demand would be 600 MW and 70 MW respectively.

KEYWORDS

District heating, heat demand mapping, space heating, domestic hot water, GIS, urban planning

HIGHLIGHT

- Spatial-temporal method for assessing district heating expansion in cities
- Spatial analysis consider domestic hot water besides space heating demand
- Hourly intervals of hot water and space heating demand are modelled in the analysis
- Hourly, daily, weekly and seasonal variations of hot water demand are considered
- The results show that hot water contributes significantly to the district heating

NOMENCLATURE

A_f^b building floor area, m^2

n_f number of building floor

c_r calibration ratio between net and gross building heated area, %

$A_{n.h}^b$ net building heated area, m^2

$A_{g.h}^b$ gross building heated area, m^2

$A_{p.h}^b$ partially heated area of a building, m^2

$Q_{s.h}^b$ space heating demand per building, $kWh/year$

e_{sh}^b annual specific space heating demand per building category, $kWh/m^2 year$

$Q_{s.h}^{grid}$ total space heating demand in a cell with 250 m x 250 m, kWh/year

$Q_{s.h}^{city}$ overall city space heating demand, kWh/year

c_{pw} specific heat capacity at constant pressure, Wh/kg˚C

m_{wi} domestic hot water flow rate, l/day

t_{hw} hot water supply temperature, ˚C

t_{cw} cold water temperature, ˚C

$A_{n.a}^b$ net area of a building, m^2

$A_{t.n.a}^{grid}$ total net area of the buildings in a grid with 250 m x 250 m, m^2

P_c^{grid} number of people in a grid with 250 m x 250 m, number of occupants

$a_{a.n.a}^c$ average net building area per occupant, $m^2/occupant$

$Q_{h.w}^{grid}$ domestic hot water demand per grid, kWh/day

$e_{h.w}^c$ specific hot water demand per occupant, $kWh/occupant \cdot day$

$Q_{t.h}^{grid}$ total aggregated heat demand in a grid with 250 m x 250 m, MWh/year

DH_p district heating potential, euro/year

C_{heat} price of heat, euro/MWh

LCOH levelized cost of heat, euro/MWh

$l_{g.e}$ specific equivalent network length within a grid size with 250 m x 250 m, m/m^2

$C_{g.e}$ cost of distribution network installation length in a grid with 250 m x 250 m for inner cities, euro/m

$l_{eg.DH}$ existing district network length, m

A_{nDH} net area of buildings connected to district heating (DH), m^2

$A_{p.DH}$ potential net building areas for connection to expanded DH, m^2

A_{grid} area of the ground distributed network, m^2

T_{am} ambient dry air temperature, ˚C

T_{in} building design air temperature, ˚C

ABBREVIATIONS

EU European countries

DH District Heating

CO_2 Carbon Dioxide

4GDH fourth generation of district heating

DHW Domestic Hot Water

GIS Geographical Information System

RES Renewable Energy Sources

PV Photovoltaics

COP Coefficient of Performance

HDD Heating Degree Day

QGIS Quantum Geographical Information System

LCOH Levelized Cost of Heat

1. INTRODUCTION

The building sector is responsible for about 40% of the overall final energy consumption, mostly due to space heating and domestic hot water (DHW) heating [1]. In the majority of countries worldwide, the second-largest energy consumption (after space heating) in building energy balance accounts for DHW heating. For instance, the DHW in Europe accounts for 14% of total final energy consumption in buildings, while in the USA this share is even higher up to 18% [2]. The share of DHW in final energy consumption will increase as opposed to space heating which is expected to decrease because of building refurbishment measures and better energy management systems [3]. Many studies are focusing on the reduction of energy consumption for DHW production using heat pumps and renewable heating solutions [4], [5], [6].

According to [7] the useful heat demand of residential and commercial buildings for European Countries (EU) in 2010 was estimated at approximately 13.1 EJ. In addition, around 66% of the total heat demand of buildings in the EU is supplied by fossil fuels, while only 12% of heat demand is covered by district heating (DH) [7]. In Kosovo, the share of energy consumption in the building sector in 2015 accounted for 44.3% of total energy consumption [8]. Out of this, around 80% of total energy consumption in buildings is consumed for space heating and DHW heating [9]. This means that 1/3 of the total final energy consumption of the country takes the form of heat that is consumed for space heating and DHW heating. The DH share in Kosovo is around 8.5% of total heat demand [8], which is a bit lower in comparison with EU countries and hence the DH is only used to supply buildings with space heating.

In general, DH systems supply building with space heating (excluding DHW), however research [10] shows that the fourth generation of district heating (4GDH) that supplies buildings with space heating and DHW is one of the vital technology that is critical for a sustainable energy transition towards low carbon energy systems [11], [12]. In this regard, the developments of 4GDH involve the sustainable energy supply and addressing the challenge of meeting the space heating and DHW demand for increased energy-efficient buildings [13]. 4GDH will supply existing, renovated and new buildings with low-temperature district heat for space heating and DHW heating, 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 transition toward sustainable energy systems [13]. Therefore, DH will play a critical role for sustainable space heating and DHW supply in buildings hence it needs to be expanded up to the economically feasible level. However, research focusing on DH potential assessments have neglected the contribution of DHW by considering only the space heating demand of buildings. As major refurbishment measures are expected to take place in buildings for reducing space heating demand in the future, the share of DHW in final energy consumption in buildings will continue increasing. Considering the fact that DH is undergoing towards the conversion to low supply temperature 55°C or even ultralow supply temperature (35 - 45°C) district heating, there are more studies on how to produce DHW in such cases [14], [15].

Bottom-up and top-down heat demand mapping methods are used for assessing the economically viable DH potential locally and regionally. In general, DH potential assessments consider the economic analysis of heat supply technologies, district heat prices and network distribution expansion costs. However, the study [16] suggests that not only these indicators should be taken into account when assessing future DH potential in urban areas, but also to consider for the DH potential from an energy systems perspective. The potential for expansion of the DH system in the EU between 1990 and 2050 is identified based on extensive and detailed mapping of the EU heat demand and various heat supply options [16]. The results indicate that with DH, the EU energy system will be able to achieve the same reductions in primary energy supply and CO_2 emissions as the existing alternatives proposed, but with reduced cost by approximately 15%. Spatial analysis of renewable energy sources (RES) using Geographical Information System (GIS) is important for detailed modelling and planning of renewable-based DH systems. For instance research [17] uses GIS-based information for the estimation of solar resources in Vietnam. Research [18] uses GIS for identifying economically viable wind power utilization potential in Sweden and research [19] uses GIS for techno-economic and environmental analysis of heating supply technologies for buildings in China.

GIS analysis has also proved to be a useful tool for assessing the potential for expansion of DH systems in cities. For instance, authors in [20] developed a Danish heat atlas as a supporting tool for energy system modelling analysis. The heat atlas provided highly detailed information for more than 2.5 million buildings in Denmark. The research concluded that heat atlas will be a crucial tool for planning the capital-intensive infrastructure investments, such as the expansion of DH networks and the introduction of heat-saving measures. In terms of DH potential assessments, research [21] concluded that the penetration of DH systems into the Danish energy system at 55% to 57% of heat demand would be economically justified. Another research carried out for Denmark [22] analysed different heat supplying options including DH, individual heat pump and micro combined heat and power plants from the perspective of fuel demand, CO_2 emissions and cost in renewable-based energy systems. It was concluded that the optimal heat supply solution for the DH expansion for the whole of Denmark is somewhere between 63 and 70% while the rest of the heat is to be covered by individual heat pumps.

Research [23] demonstrates the opportunities for expansions of DH network in the city of Sheffield through GIS software modelling for an in-depth analysis of the space heating demand within the city. Six zones were identified as possible areas for expansion of the existing DH system. Authors in [24] analyzed the utilization of a bottom-up space heating demand mapping method for modelling and simulation of an energy system with a high share of variable RES. Data obtained from the heat mapping process was used to create scenarios for the development of a city's energy system with high penetration of DH, wind, and solar PV. Another study carried out in [25] showed the contribution of power to heat (compression heat pump with thermal energy storage) technologies in DH for increasing the variable RES integration in a coal-powered energy system. The application of heat pumps in DH can bring additional benefits for enhancing the RES integration. In this regard, research [26] develops an air source heat pump prototype for producing hot water with high temperature capable of industrial and commercial use in coal to electricity-based energy systems. The finding shows that these heat pumps have a coefficient of performance (COP) around 1.69, where the ambient temperature is -20°C, while at higher ambient temperatures around 5°C the COP increases up to 2.1, which indicates that such heat pump has a significant energy saving potential.

For analyzing the impact of DH in energy systems, besides the spatial distribution, the temporal distribution of space heating and DHW demand is needed as well. The majority of DH systems operate only during the heating season and they cover only the demand for space heating. In contrast, 4GDH should also provide DHW to buildings hence their demand profile is an important parameter for planning and designing sustainable heat supply solutions. Different factors which influence the DHW consumption profile were compared for different types of buildings in [27]. In addition, research [28] presents the monthly and hourly DHW consumption for residential buildings in Finland, while research [29] and [30] investigate the DHW consumption for residential buildings in Canada and Switzerland respectively.

Limited studies are focusing on DHW demand profile both spatially and temporally in DH as opposed to space heating. For instance, research [31] provided an innovative method for displaying hourly real-time space heating demand profiles to support municipalities toward producing renewable heating and sustainable planning solutions. The method showed the calculation procedure for displaying the real-time hourly heat demand for each building in a district based on the basic cartography, cadaster, and heating degree-day (HDD) values. Another study in [32] analyzed space heat demand of DH for a medium-sized DH network in a city in southern Germany in a spatially explicit approach excluding hot water. Initially, buildings were geo-located and attributes were obtained from various sources including the building category, ground floor area, and numbers of floors that were merged. Research [33] presents a space heat demand mapping and DH viability assessment method in data pour areas using data sources 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. The spatial analyses were not only useful when addressing the current space heating demand, but also while considering the future demand of a refurbished building. Research [34] presented a bottom-up approach for the calculation of the useful heat demand for space heating and hot water preparation using geo-referenced datasets of buildings for the city of Krakow. The results obtained have shown potential areas that have sufficient heat demand density for developing the DH system. A similar study was carried out in [35] for developing a method for assessing the space heating demand spatially in developing cities considering building geometrical features, climate and the share of partially heated areas. Research [36] provided a new statistical model based on the census data to assess the energy demand, heat demand for space heating and hot water preparation as well as electricity, of buildings in Great Britain. Based on the data available, heat atlases were created around a spatial database using a GIS tool. Heat atlases obtained from heat mapping process in [37] were used for analyzing the impacts of expanding DH and implementing end-use energy savings at the municipality level in relation to an existing local energy system. In terms of DH expansion analysis research [38] and [39] show that the economic viability of DH in larger cities and inner-city areas can be favorable for implementing DH, by showing that even the reduction of space heating demand in the future, in high heat density areas will not be a barrier for future DH networks. Feasibility studies on different DH schemes based on GIS mapping are presented in [40]. It was observed that current published reports have underestimated the potential of DH utilization for the city of Bowmore. Research [41] identified the heat sources and sinks, potential suppliers and end-users, key locations to where a connection should be expanded in the DH system, sourced by the waste-to-energy facility, would be feasible. Authors in [42] determined the space heat demand mapping and areas where it may be beneficial to expand the DH system based on the EU directive 2012/27/EU, using the Salaspils municipality as a case study. The study results emphasize the identification of thermal end-users and methods for their mapping and assessing possibilities of DH potential utilization in a respective region. Research [43] developed a novel method for assessing the costs associated with supplying buildings with DH in Denmark. It is concluded that it is economically feasible to expand DH in certain areas, but others would require reductions in production costs and distribution losses for DH expansions to be economically feasible. A method for assessing the costs of DH expansions has been developed in [44]. The method was applied in a GIS model that consists of three parts and assesses the costs of heat production, distribution, and transmission. The results showed the improvement in the method to assess the distribution costs based on geographical properties of each area and transmission costs based on an iterative process that took into account the expansion of DH potentials gradually.

The majority of bottom-up spatial research studies focus on the expansion assessments of DH systems considering solely the space heat demand of buildings excluding DHW. In contrast, for developed countries with a high standard of living, the DHW demand can account for up to 18% of final energy demand in buildings and up to 30% of total heat demand in buildings [2], [27]. The research reviewed also show that DHW is continually increasing in the final energy consumption of buildings as opposed to space heating which is expected to decrease because of the building refurbishment measures. Thus, this research concentrates on developing a spatial method for assessing the economically feasible expansion potential of DH systems that consider both space heating and DHW demand of buildings using a GIS tool.

Moreover, the temporal modelling of space heating demand in DH on hourly intervals, excluding DHW, is generally carried out by using the HDD method. In terms of the temporal modelling of DHW demand in DH, an identified research gap, is a study that considers the comprehensive analysis of daily, weekly, and seasonal variations. In general, the daily distribution profile of DHW demand in DH within a year is modelled as a constant feature. To solve this issue, this research focuses on hourly modelling of DHW demand in a DH considering daily, weekly and seasonal fluctuations. The profile of space heating and DHW heating demand in DH is particularly important for planning sustainable thermal networks that supply buildings with district heat.

Hence, in this paper, a spatial method was developed to show that domestic hot water demand in buildings has a significant impact on the feasibility of DH system expansion potential in urban areas besides space heating, while temporally modelling total DH demand in hourly intervals. The method consists of main four steps: bottom-up mapping of space heating demand, top-down mapping of hot water demand, temporal modelling of hot water demand considering daily, weekly and seasonal fluctuations as well as temporal modelling of space heating demand using the HDD method. The paper is organised as follows: section 2 discusses method, section 3 discusses results and discussion and section 4 discusses conclusions respectively.

2. METHOD

Spatial and temporal quantification of aggregated space heating and DHW demand in an urban area is important for analyzing the expansion potential of DH systems, estimating the capacities of heating supply technologies in DH, creating daily and hourly heat demand profiles that can be used for detailed and comprehensive energy system analysis. Moreover, the method is also important for assessing the process of switching from seasonal to the annual operation of DH systems. The spatial-temporal method developed in this research consists of the following main steps:

- The quantification of space heating demand of the city using a bottom-up approach
- Annual modelling of DHW demand in hourly intervals in DH systems
- Spatial quantification of DHW demand using a top-down approach
- Spatial quantification of total aggregated space heating and DHW demand in 250m x250m grid
- An assessment for quantifying economically feasible expansion potential of the DH system
- Annual modelling of space heating demand in hourly intervals using HDD method

2.1 Bottom-up heat demand mapping

The bottom-up mapping approach is used for assessing spatially the space heating demand of buildings in urban area locations, especially cities. The same depends on building characteristics and weather dependencies. For a comprehensive presentation of buildings in the model, seven different building categories are considered and divided according to their purpose of use and construction materials. For instance, house (single-family house = insulated), nhouse (single-family house = non-insulated), apartment, commercial, public, office and industrial buildings. The building category is considered in the model, as different buildings have different energy needs, when assessing spatially the space heating demand of buildings. Moreover, as some buildings in the city are partially heated, two bottom-up scenarios have been developed in the model to consider that buildings are heated up to their net heated area (fully heated) and partially heated. The mathematical description used for spatial quantification of space heating demand is provided bellow. The comparison and model calibration between bottom-up and top-down space heating demand mapping methods is carried out in detail in [35].

2.1.1 Space heating demand

For replication of the method in both developed and developing locations, two scenarios that consider for the net space heated areas of buildings partially and fully were investigated in this research. The space heating demand of buildings is dependent on the climatic regions as well as rural and urban settings. Other than this, based on developed or developing region, partial heating of buildings can also be considered in the model.

2.1.1.1 Buildings fully heated

The total net space heated area of a building is calculated with the equation:

$$A^b_{n.h} = A^b_f \times n_f \times c_r \tag{1}$$

where: A_f^b - is the building floor area, n_f - is the number of building floor [-], c_r - is the calibration ratio between net and gross building heated area and is calculated with:

$$c_r = \frac{A_{n.h}^b}{A_{g,h}^b} \tag{2}$$

$A_{n.h}^b -$ is the net building heated area, $A_{g.h}^b$ - is the gross building heated area.

Data regarding the building floor areas (building topography) is available in some countries through various agencies like Eurostat [46] and if needed, can also be created manually using open layer plugin in Quantum Geographical Information System (QGIS) which is considered in this research. The data for building number of floors can be given by cadastre or can be identified by visual inspection of buildings using tools like Google Earth Pro [47]. Data regarding building categories is also country-specific and for example in EU it is provided by Eurostat and for the missing data, it can be also visually collected using Google Earth Pro. This data is important for spatial space heat demand mapping process in a QGIS tool [48] as already explained in [35].

2.1.1.2 Buildings partially heated

In general, not all buildings in developing countries are fully heated. Buildings heated partially are especially encountered to individual houses and nhouse[1] categories among others. The only difference between house and nhouse is the application of thermal insulation in external walls, influencing their thermal performance. The share of heated rooms in individual houses and the average surface heated area per room is reflected in equation (3) through correction factor f_h [-]. In addition, the total heated area of a building partially heated is calculated with:

$$A_{p.h}^b = A_{n.h}^b \times f_h \tag{3}$$

where: $A_{p.h}^b$ is the partially heated area of a building, n_f is the number of building floor [-]

The total space heating demand per building is calculated with:

$$Q_{s.h}^b = A_{n.h}^b \times e_h^b \text{ and } Q_{s.h}^b = A_{p.h}^b \times e_h^b \tag{4}$$

where: $Q_{s.h}^b$ is the space heating demand per building, e_{sh}^b is annual specific space heating demand per building category.

Specific space heating demand for different building categories can be taken from local energy auditing reports and other building energy certificates. The quality of the space heat mapping results can be further increased with additional data regarding the age of the building and the actual thermal energy performance of each particular building. In the proposed methodology, the age of the building is neglected as it is difficult to obtain such detailed data. To account for the majority of city building categories in the model, data regarding the thermal energy performance of sample buildings are considered and summarized in Table 1.

[1] **nhouse-** houses without any layer in external walls. These houses are made of blocks with 25cm width and plastered with gypsum on inner wall side.

Table 1. Building categories and their specific space heating demand [49]

CATEGORY	Specific heating demand, kWh/m^{2}year
Apartment	161
Commercial	160
House	153
Industry	94
Nhouse	272
Office	135
Public	272

Once, the space heating demand of each particular building in the city is estimated, a grid with adjustable resolution can be added to quantify the spatial distribution of the space heating demand. Total aggregated space heating demand in a cell with 250 m x 250 m (grid) $Q_{s.h}^{grid}$ was the sum of zth buildings intersecting the boundary cell:

$$Q_{s.h}^{grid} = \sum_{x=1}^{z} Q_{s.h\,x}^{b} \tag{5}$$

By summing up the total space heating demand of all buildings in the city, the overall city space heating demand $Q_{s.h}^{city}$ is calculated:

$$Q_{s.h}^{city} = \sum_{i=1}^{n} Q_{s.h\ \ x}^{grid} = \sum_{i=1}^{n} \left(\sum_{x=1}^{z} Q_{s.h\,x}^{b} \right)_i \tag{6}$$

2.1.2 Temporal modelling of domestic hot water

Hot water demand per occupant depends on standards defined by the country as well as the type of use in the building. Research conducted in [27] investigated DHW profiles in residential buildings for EU member states, Canada and the USA and their results are shown in Fig. 1. It can be seen that there is a significant difference between daily DHW demands in different countries. For instance, in Canada average daily DHW demand is 94 l/day/occupant, while in other countries like Spain this value is significantly lower 30 l/day/occupant. Besides DHW demand per occupant, the increase in the water temperature difference is another critical parameter when quantifying spatially and modelling temporally the DHW. For instance, hot water supply temperature in EU is 55°C, in Canada is 57.3°C, Japan is less than 65°C and the USA is 57.3 °C [27].

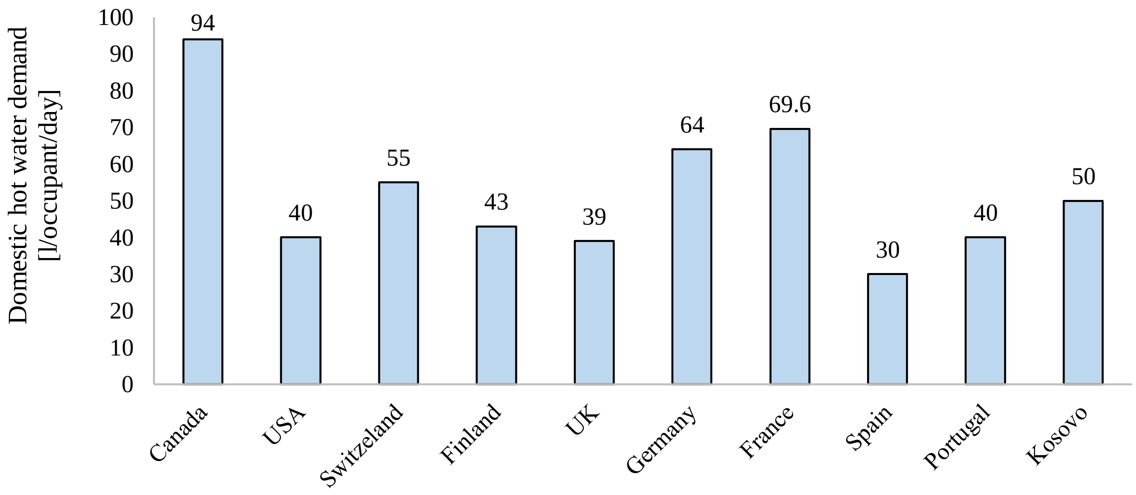

Figure 1. Daily hot water demand per residential occupant by country [27], [50]

Hourly modelling of DHW demand profiles in a DH can contribute in developing control strategies, where demand follows supply, hence in-depth knowledge of the features of demand profiles on an hourly basis will allow the energy modellers and planners to design sustainable heating solutions among other. The hourly DHW demand profile changes in different building categories. DHW demand profile is complicated and strongly fluctuates over time. Among others, lifestyle, weather conditions, occupant behaviour toward DHW usages, occupant number, social and economic condition were found the most significant variables in DHW consumption. A comparison between daily DHW profiles for different building categories is shown in fig. 2. It can be seen that restaurant buildings have the highest peak load demand during the mid-day, which is not the case with residential buildings where the peak loads appear in the morning and evening. The same can be used for spatial quantification and hourly modelling of DHW demand in DH systems using spatial and temporal heat demand mapping approach developed in this paper.

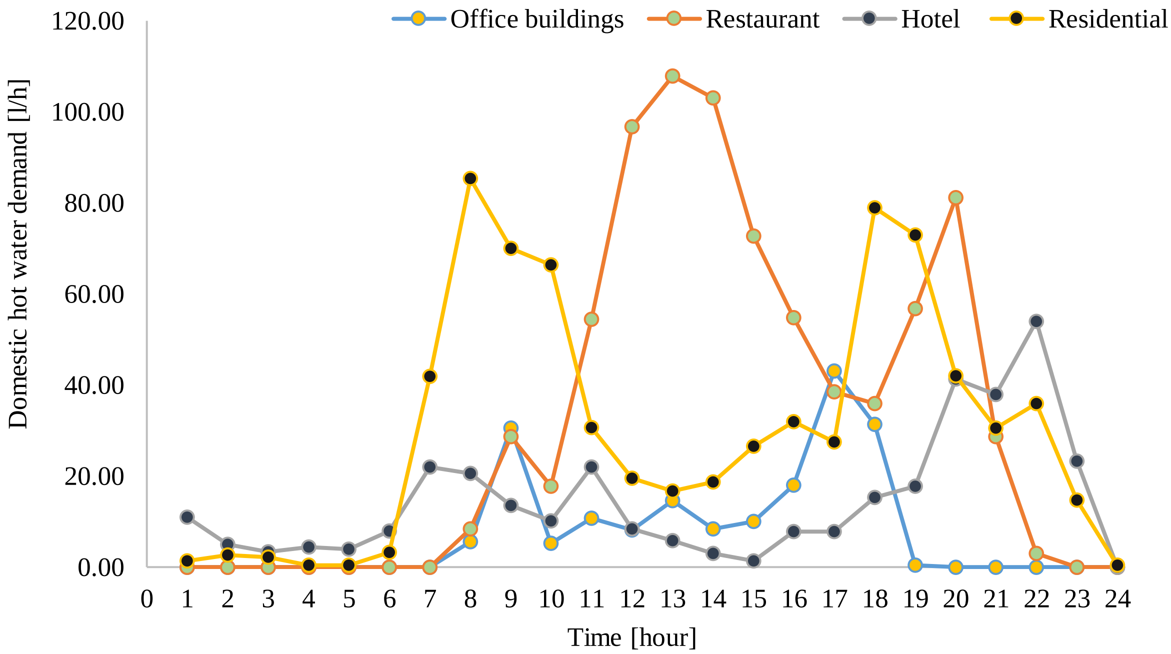

Figure 2. Comparison of average daily DHW profiles for different building types [27],[51] [52] [53] [54]

As over 95% of the assessed city[2] is occupied with residential buildings, for further analysis only residential DHW profile is considered. Fig. 3 shows the relative distribution of DHW demand profile for a residential consumer. Relative values of this profile were considered for modelling hourly DHW demand profile for residential consumers. The reason for such an assumption is that the DHW demand profile is approximately similar for residential consumers, and it is sparsely dependent on geographical locations [27].

[2] The city assessed for the proposed method is Pristina in Kosovo.

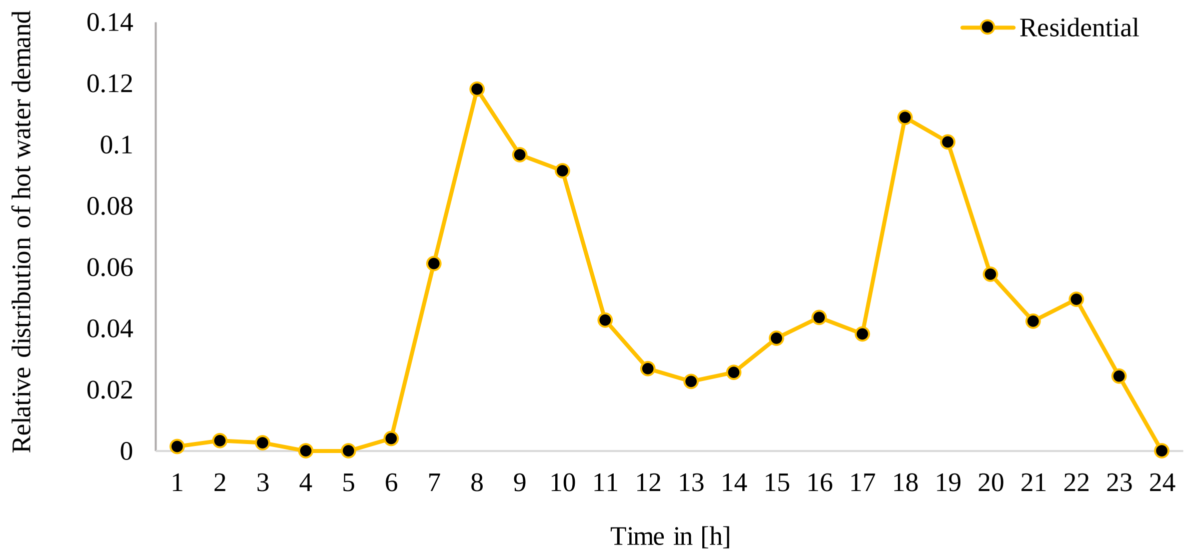

Figure 3. Relative distribution of DHW demand profile for residential end-user in the winter season [27], [54]

Different seasons also affect the DHW profile, shown in fig. 4, as the DHW needs of the residential consumer changes based on activities during a particular season. Based on this, the hourly demand profiles between four seasons are considered in the proposed approach. It is observed that DHW demand during the spring season is the smallest and the largest demand is observed for the winter season.

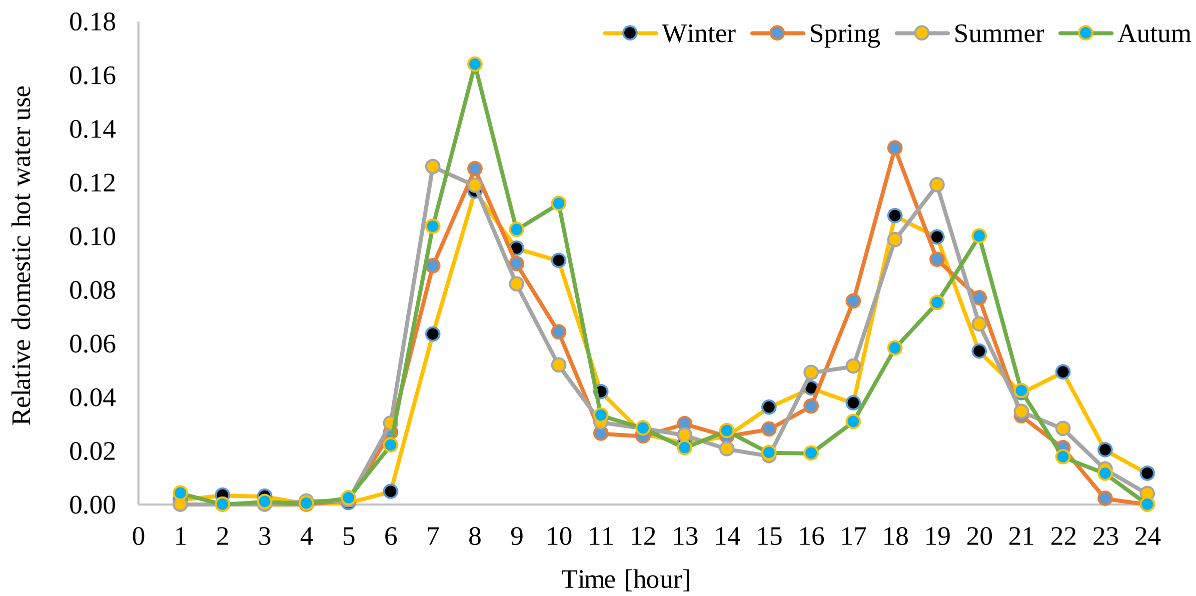

Figure 4. Relative seasonal influence on the daily DHW profile for residential buildings [54]

Research has also shown weekly DHW demand profiles variations besides hourly, daily and seasonal variations. Fig. 5 shows DHW for the residential consumers estimated by different researchers. Krippelova et al. weekly DHW relative profile was considered in this research.

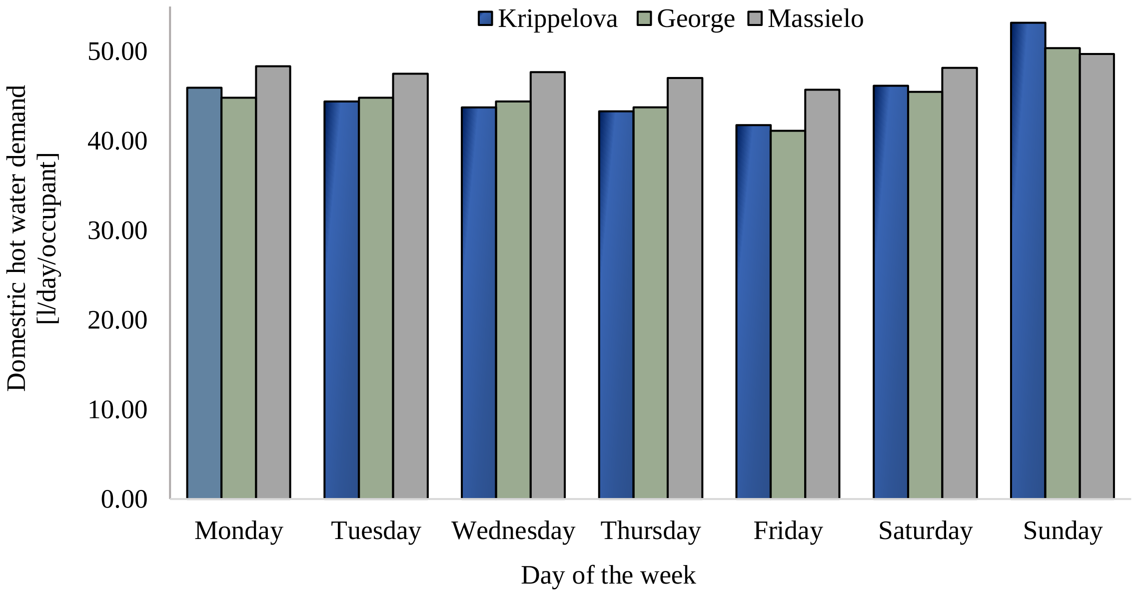

Figure 5. Daily average DHW demand per occupant according to different studies on residential buildings for a week [55], [56], [57]

Using the results of DHW modelling per day and the hourly DHW profiles in the four seasons, hourly hot water flow rate ($\boldsymbol{m_{wi}}$) in [l/h] during one year is calculated. Then, the increase of DHW water temperature difference (the difference between hot and cold water temperatures) is needed. The hot water supply temperature ($\boldsymbol{t_{hw}}$) is considered the same as in EU countries which is 55˚C. The cold water temperature ($\boldsymbol{t_{cw}}$) during the heating season (between 15.Oct - 15.April) is considered as 5˚C, while for the remaining time of the year it is considered to be 15˚C. Specific water heat capacity at constant pressure ($\boldsymbol{c_{pw}}$) is 1.1667 Wh/kg ˚C. Then using the equation number (7), the hourly DHW heating demand is estimated:

$$\boldsymbol{Q_{wi} = m_{wi} \cdot c_{pw} \cdot (t_{hw} - t_{cw})} \tag{7}$$

<u>2.1.3 Spatial distribution of domestic hot water</u>

For spatial distribution of DHW a relation between net areas of buildings and occupants was found. As residential consumers are considered in the model, it is found that the daily heating demand is 2.10 kWh/year/occupant according to standard EN 16147:2011 [17]. This approach can be used for calculating hourly heat demand curves.

The total net area $A_{t.n.a}^{grid}$ in a grid size with 250 m x 250 m is calculated as the sum of zth building net areas intersecting the boundary of the grid:

$$A_{t.n.a}^{grid} = \sum_{x=1}^{z} \left(A_{n.a}^{b}\right)_x \tag{8}$$

The number of people in a grid P_c^{grid}, is determined using the approach for an average net building area per occupant $a_{a.n.a}^{c}$:

$$P_c^{grid} = A_{t.n.a}^{grid} / a_{a.n.a}^{c} \tag{9}$$

In this way, the DHW heating demand per grid $Q_{h.w}^{grid}$ is calculated by multiplying the number of occupants of the corresponding cell with specific hot water demand per occupant $e_{h.w}^{c}$, which is calculated according to standard EN 16147:2011 [17].

$$Q_{h.w}^{grid} = P_{c}^{grid} \times e_{h.w}^{c} \tag{10}$$

<u>*3.1.4 Total aggregated heat demand*</u>

Space heating and DHW heating demands are summed up for defining the total aggregated heat demand of a corresponding cell $\boldsymbol{Q_{t.h}^{grid}}$ with 250 m x 250 m using equation (11).

$$Q_{t.h}^{grid} = Q_{h.w}^{grid} + Q_{s.h}^{grid} \tag{11}$$

where: $Q_{h.w}^{grid}$ is annual DHW heating demand and $Q_{s.h}^{grid}$ is the annual space heating demand.

The results of total aggregated heat demand in a grid with 250 m x 250 m, are further used for analysing economically viable DH expansion potential.

2.2 District heating expansion potential analysis

Feasibility analysis for expansion of DH up to the economically viable level was carried out in 250 m x 250 m aggregated total annual heat demand grid w equation (12). It takes into account the actual specific price of heat for final end-users. The price of district heat is paid both in [euro/MWh] and [euro/m^2] and it includes the price of the connection fee. Apart from that, equation (12) includes the cost of installation and operation of heating technologies reflected by Levelized Cost of Heat (LCOH) as well as the cost of expansion of the DH network. Grid areas with $DH_p \geq 0$ were considered as economically feasible area locations for expansion of DH system:

$$DH_p \geq Q_{t.h}^{grid} \times c_{heat} - Q_{t.h}^{grid} \times LCOH - 65200 \times l_{g.e} \times c_{g.e} \tag{12}$$

where: $Q_{t.h}^{grid}$ is the total aggregated heat demand in a single grid with 250 m x 250 m, C_{heat} is the price of heat, LCOH is the levelized cost of heat, $l_{g.e}$ is the specific equivalent network length within a grid size with 250 m x 250 m, $C_{g.e}$ is the cost of distribution network installation length in a grid with 250 m x 250 m for inner cities [58].

The levelized cost of heat was calculated using the LCOH from [59] for a DH based on large scale heat pump. Data regarding the capital expenditure, discount rate, tax rate and present value of deprecation are considered from [59], while other remaining data regarding the capital, fixed and variable cost of technologies and lifetime of investment for large scale heat pumps in DH are taken from Danish technology report [60].

The specific equivalent length of the DH network within a grid with 250 m x 250 m is calculated by:

$$l_{g.e} = \left(l_{eg.DH} / A_{n.DH}\right) / \left(l_{p.DH} / A_{grid}\right) \tag{13}$$

where: $l_{eg.DH,}$ is the existing district network length, A_{nDH} is the net area of buildings connected to DH, $A_{p.DH}$ is the potential net building areas for connection to expanded DH, A_{grid} is the area of the ground distributed network.

2.3 Heating Degree-Day Method

Heating degree days are used to quantify temporally the space heating demand of buildings in DH. HDD's are depended on outdoor air temperatures and can be expressed in daily and hourly intervals by showing the amount of heat needed to heat the buildings up to the comfort level. The more detailed recorded outdoor air temperature data, the more accurate is the HDD calculation. Weather data was taken from the Meteonorm software for the city [61]. HDD's vary significantly in the geographical location of buildings, but since the application of the current method is applied at a city level, the outdoor air temperature is assumed to be same for all the buildings. The definition of HDD's is based on the German norm DIN 4701 [50].

$$T_{am} \leq 12°\text{C and } T_{in} = 20°\text{C} \tag{14}$$

Daily dry air temperature over the year is considered for the model, while the internal design air temperature in buildings is considered to be 20˚C and the HDD threshold to be 12˚C. HDD's are calculated between 15 October and 15 April. Degree days counted out of this interval equal zero. A result of sample HDD calculation is described in table 2.

Table 2. Heating degree-day evaluation

Day of the month	Daily mean outside air temperature [62]	HDD threshold 12˚C	HDD
15 November	5	12	15
15 January	-3	12	23
15 March	7	12	13

According to equation (15) the space heating demand is linear to ambient dry air temperature T_{am} as well as indoor air temperature T_{in}. The total (grid) hourly space heating demand Q_{sh}^{grid} is then a sum of space heating demand annually Q_{sh}^{grid} over all the buildings contained in a boundary grid divided by all $\sum_{i=1}^{8760} HDD\ s$ during the year times hourly heating degrees HDD:

$$Q_{s.h.d}^{grid} = \frac{Q_{s.h}^{grid} \times HDD}{\sum_{i=1}^{8760} HDD} \tag{15}$$

DHW demand is not dependent on outside air temperature variations as in HDD's, even though during the summer months there is a slightly low or little demand for DHW [27], which was considered while modelling DHW temporally in subsection 2.1.1.

3. RESULTS AND DISCUSSION

3.1. District heating system of Pristina

As a case study for testing the method, existing DH system of Pristina was selected. The city has already established a DH system since 2014, which is based on cogeneration coal-based thermal power plant Kosova B [63]. However, only a small part of the city around 19% of total heat demand is already connected to DH. Figure 6 shows the actual DH network respectively buildings that are being supplied with district heat. The model contained detailed information for 23384 buildings regarding their thermal energy performance and building topography. For validation of the bottom-up space heat demand mapping approach with recorded annual DH data from the local heat distribution company, two factors have been taken into consideration; the net area of buildings already connected to DH and the space heating demand of these buildings. The calibration ratio c_r, around 0.7 - 0.8 for different building categories, was considered for the estimation of net area of buildings in the GIS model. Apart from this, the local DH distribution company provided data regarding the net building areas of consumers already connected to existing DH. Similar numbers of net heated areas for identified buildings connected to DH were obtained when running calculations in the GIS model and the results of modelling are summarized in table 3. In addition of using the data for net heated areas of buildings and specific heat demand for building category (shown in table 1), the space heating demand of buildings already connected to DH was also calulated. The comparative results between building space heat demand recorded and modelled with GIS show a good agreement. The difference between modelled and recorded data is less than 5%, which indicates the accuracy of the model. The GIS model used for validation purpose, considers only the space heat demand of buildings, excluding DHW, because existing DH is used only for covering space heating demand of buildings. The space heat demand of buildings reported from DH distribution company and calculated in GIS were 230 and 235 GWh/year respectively. In contrast, the validation results can be further improved with the use of different calibration ratio (ratio between net and a gross area of the building), the share of heated areas in buildings, space heating demand of buildings and hot water demand among others.

Table 3. Validation of the GIS model with recorded data from existing DH [63].

	GIS model	Actual DH	Difference in [%]
Surface net heated area of buildings connected to existing DH, m^2	641005	620798	3.2
Space heat demand of buildings connected to existing DH, GWh/year	235	230	2.2

Polygon areas with red colour, shown in figure 6, are buildings that are being supplied by the existing DH system. The analysis shows that not all buildings that are close to DH grid are connected. When classifying the building categories that are connected to the DH system, it was found that the main heat consumers are apartment, public and commercial buildings, with only a few houses. In total, 411 thermal substations in existing DH are used for exchanging heat. Plate heat exchangers are the most widely used in these thermal substations [63].

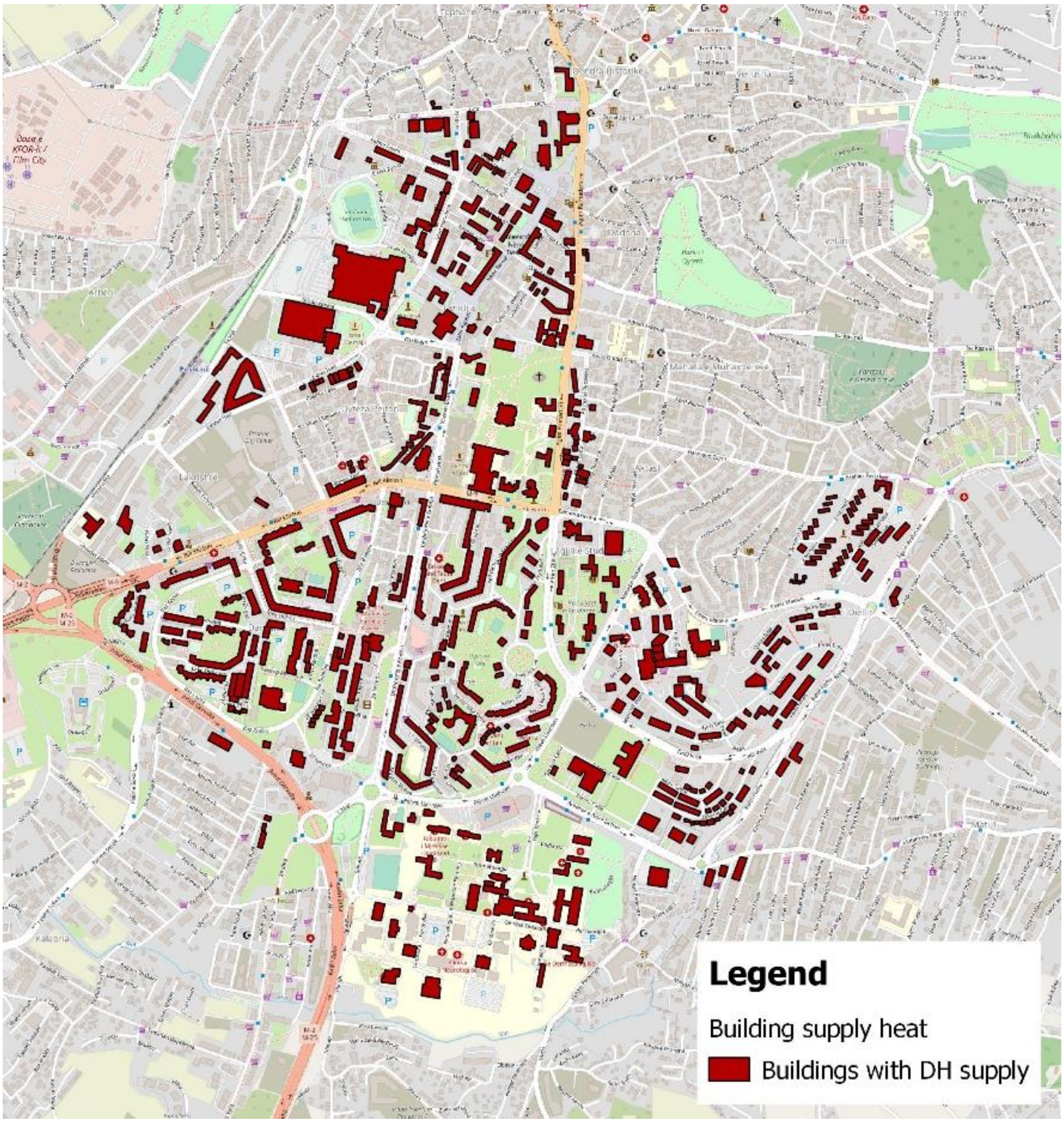

Figure 6. Buildings being supplied by the actual district heating network in Pristina

The actual installed thermal capacity of the cogeneration system in Pristina is 140 MW_{th}. Annual thermal energy production recorded in 2018 was 250 GWh_{th}/year and the maximum utilized capacity was 70 MW_{th}, which means that there is a significant potential for the expansion of existing DH system using actual thermal capacities. There are plans for increasing the cogeneration capacities from actual and new thermal power plants (if built) up to 280 MW_{th}. The main objectives of DH Company is the maximum utilization of available heat supply capacities, increasing the reliability of heating supply, plan the expansion of DH and integrate renewable heating solutions. For the integration of renewable technologies and expansion analysis of DH system, spatial and temporal analysis of space heating and DHW demand are crucial. Figure 7 shows the ambient air temperature fluctuations and actual space heating demand of buildings Q_{SH} that are connected to existing DH distributed on hourly intervals during one year using the HDD method. The total annual aggregated heat demand of buildings in DH was 230 GWh/year. The heat supplied by existing DH is used only for covering the space heating of buildings. The heating season in Kosovo is in between 15 October and 15 April, because in this interval the air temperature is lower than HDD threshold 12°C. Annual HDD in Pristina account for 2830 degree days/year.

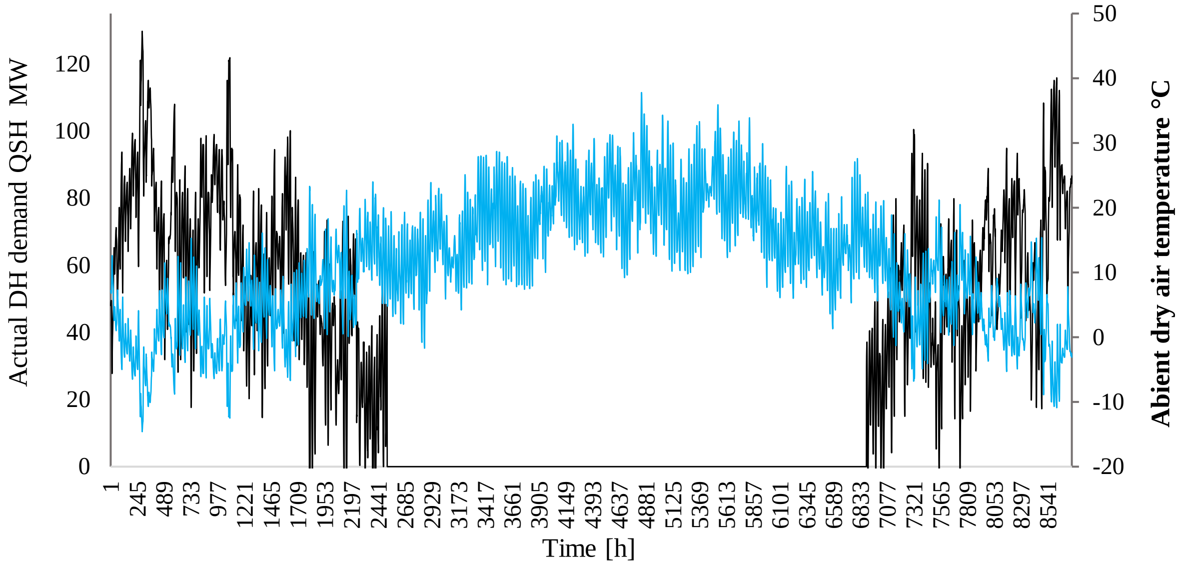

Figure 7. Q_{SH} Actual space heating demand curve of Pristina DH for one-hour resolution (in black), local Pristina ambient dry air temperature (in blue)

3.2 Space heating and domestic hot water heating demand in existing district heating system

Using a bottom-up heat demand mapping approach described in method section 2.1, the space heating demand spatially distributed over a grid with 250 m x 250 m in existing DH is quantified. The results of space heating demand spatially are shown in Figure 8.

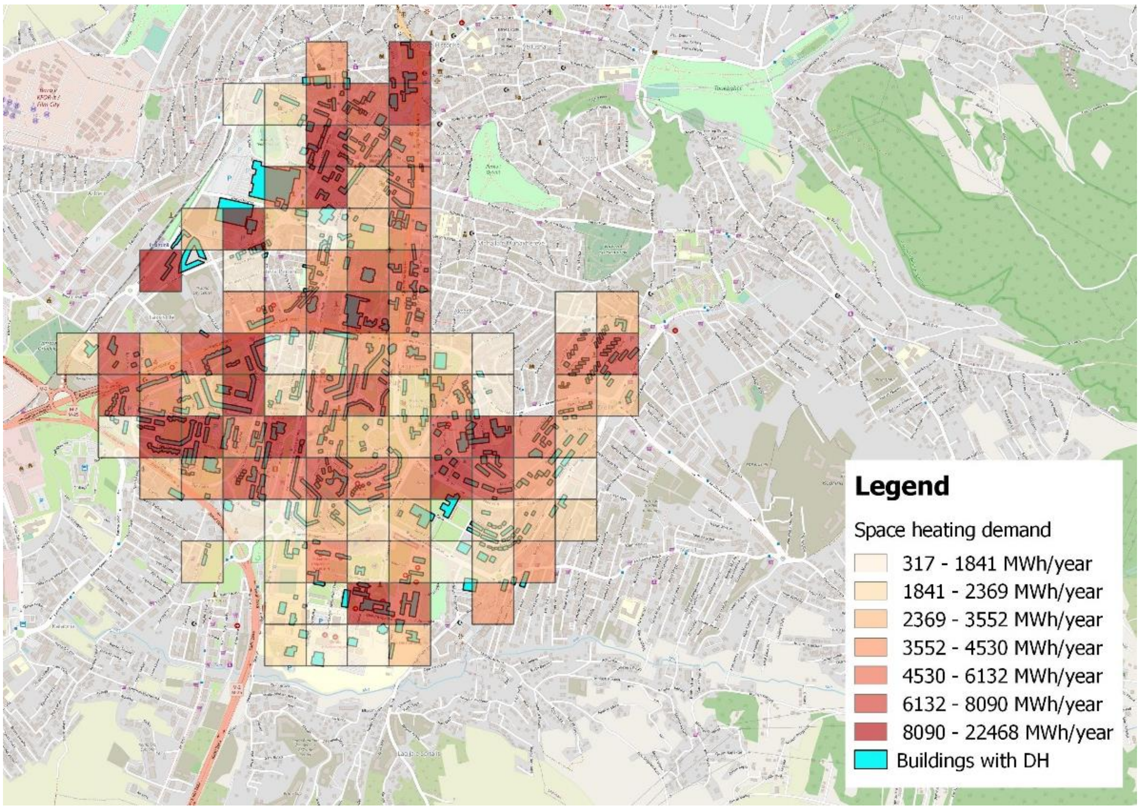

Figure 8. Actual space heating demand for the buildings connected to DH

As the existing DH supplies only the space heating demand of buildings, the spatial analysis proposed in this research for quantifying DHW focuses firstly on buildings that are already connected to DH. The description of the method is given subsection 2.1.3. The average net area of building per occupant in Pristina varies from 20-80 m^2/ occupant, so a net area of 60 m^2 per occupant was assumed and used for the analysis of DHW demand mapping spatially. Using the attributes for buildings distributed in a grid (250 m x 250 m) respectively by dividing the net build-up areas in a grid with assumed net surface building area per occupant, a density population grid was estimated which was then validated using the actual number of consumers connected to DH. A hot water temperature increase of 40˚C and a hot water demand of 50 l/d/occupant during the heating season was considered for estimation of DHW heating demand per occupant. DHW heating demand during the winter is the largest in comparison to other seasons, hence it is considered in spatial mapping.

In contrast, daily DHW demand during the summer months is a bit smaller compared to other months and different countries apply different increase in hot water temperature [27]. Also, the profile of hot water demand is different for different building categories, but as more than 95% of the consumers are residential for the considered case study, their distribution profile was considered.

The calculated DHW demand per occupant was multiplied with the number of people in a respective cell. In this way, the DHW heating demand spatially was estimated and the results of modelling are shown in Figure 9. It was estimated that the total DHW heating demand for existing buildings that are already connected to the DH of Pristina would be 57.67 MWh_{th}/year. In this regard, the space heating and DHW demand would account for 97.7 and 2.3% of total heat demand in existing DH.

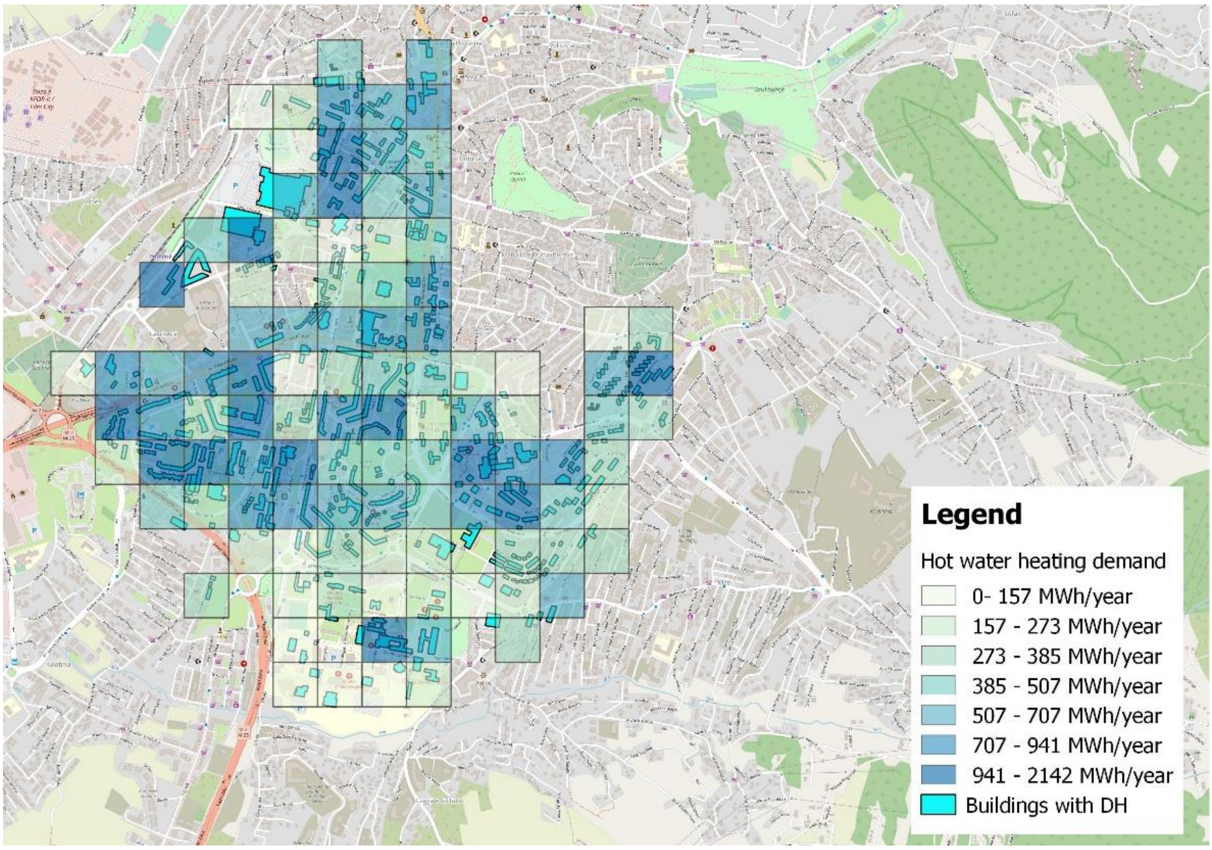

Figure 9. Spatial distribution of DHW heating demand for building already connected to DH

Besides the estimation of DHW heating demand spatially, its hourly demand profile is another critical parameter that should be taken into account when planning and modelling of modern DH systems. Figure 10 shows the modelling of space heating and DHW demand for the existing DH of Pristina over the year in hourly intervals. Hot water modelling was based on the actual number of residential buildings connected to DH.

Figure 11 shows the results of DHW modelling for one week during four seasons. A week in January, April, July and September was considered for comparative analysis of DHW demand profiles in DH. Significant differences in DHW demand profiles can be observed especially between spring and winter seasons. The largest heating demand for DHW account for winter, then autumn, summer and spring respectively. It reveals that hourly DHW demand profile, for actual residential end-users that are connected to DH, would change in hourly, daily, and seasonal intervals. For instance, the maximum DHW demand during the winter and spring seasons would be 93 m^3/h and 50 m^3/h respectively.

Moreover, significant differences in hot water heating demand during the days of the week in a particular season can be observed. The results show that weekends have a higher demand in comparison to weekdays, and the same trend was observed in four seasons. Moreover, the maximum DHW heating demand around 5.2 MWh/h was observed during the winter season on Sundays. This means that an additional 5.2 MW capacity would be needed by the heat distribution company in Pristina to cover both space and DHW heating demand.

The existing DH system in Pristina is not operating annually, hence the DHW demand of buildings is entirely being supplied by electric heaters which electricity production is based on lignite coal. This study would be beneficial for assessing the feasibility of DH to switch to annual operation. In addition, the operation of DH annually may lead to substantial benefits such as building’s supply with space heating and DHW, recycle heat from waste sources, integrate renewable heat, ensure sustainable transformation towards clean energy systems among other [13].

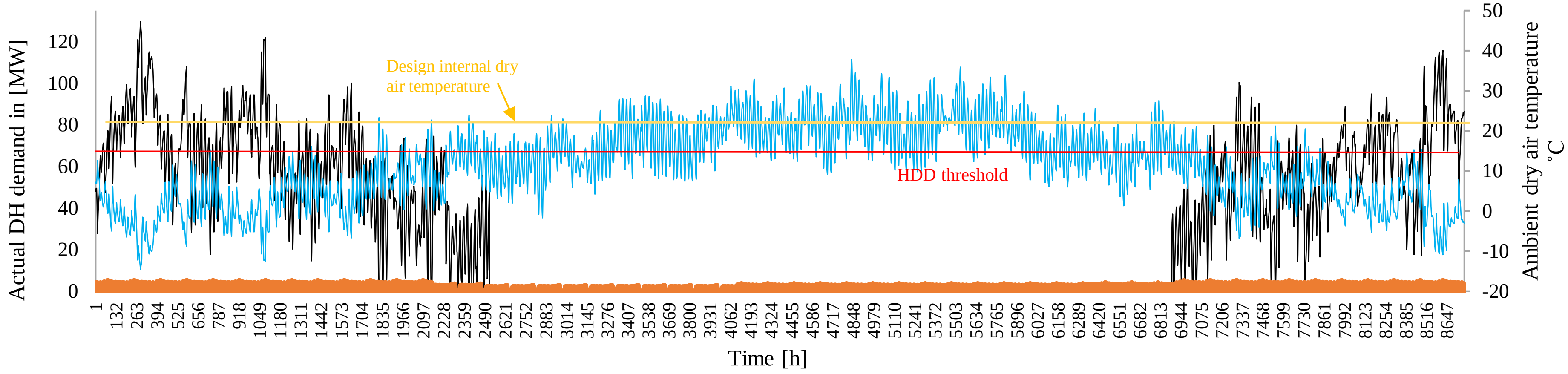

Figure 10. Q_{SH} Actual space heating demand curve of Pristina DH for one- hour resolution (in black), local Pristina ambient dry air temperature (in blue), T_{in} internal desired dry air temperature (in yellow) and the definition of HDD threshold with 12˚C (in red), Q_{HW} hot water heating demand (in orange).

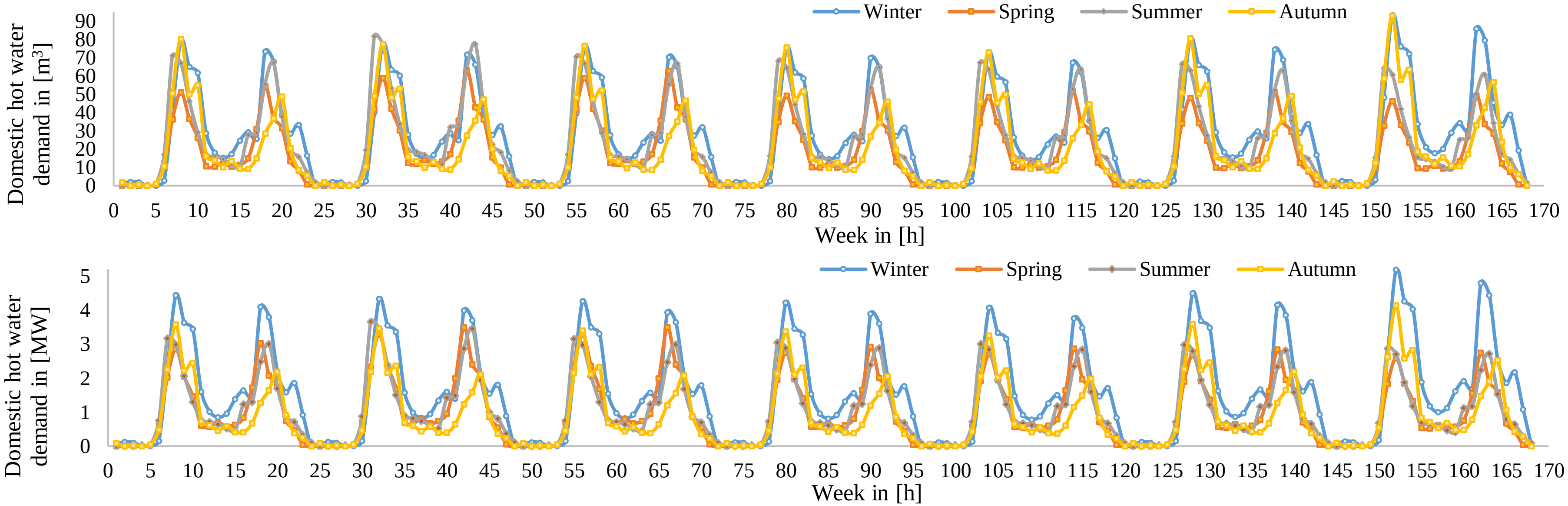

Figure 11. Hourly hot water demand in [m^3] and residential hot water heating demand Q_{HW} in existing DH [MW]

3.3 Space heating and domestic hot water heating demand in expanded district heating system

The following section shows the spatial results of space heating demand, DHW heating demand as well as the spatial analysis for expansion of DH in Pristina. Furthermore, is also shows the temporal modelling of space heating and DHW demand in potential DH system. The results of space heat demand of buildings distributed spatially in a grid with 250 m x 250 m are presented in Figure 12. In this scenario, it was considered that the houses are being heated to their net area, which is not reflecting the real scenario for assessed area locations. Another scenario, where houses are heated partially was considered in this research and the results are shown in Figure 16.

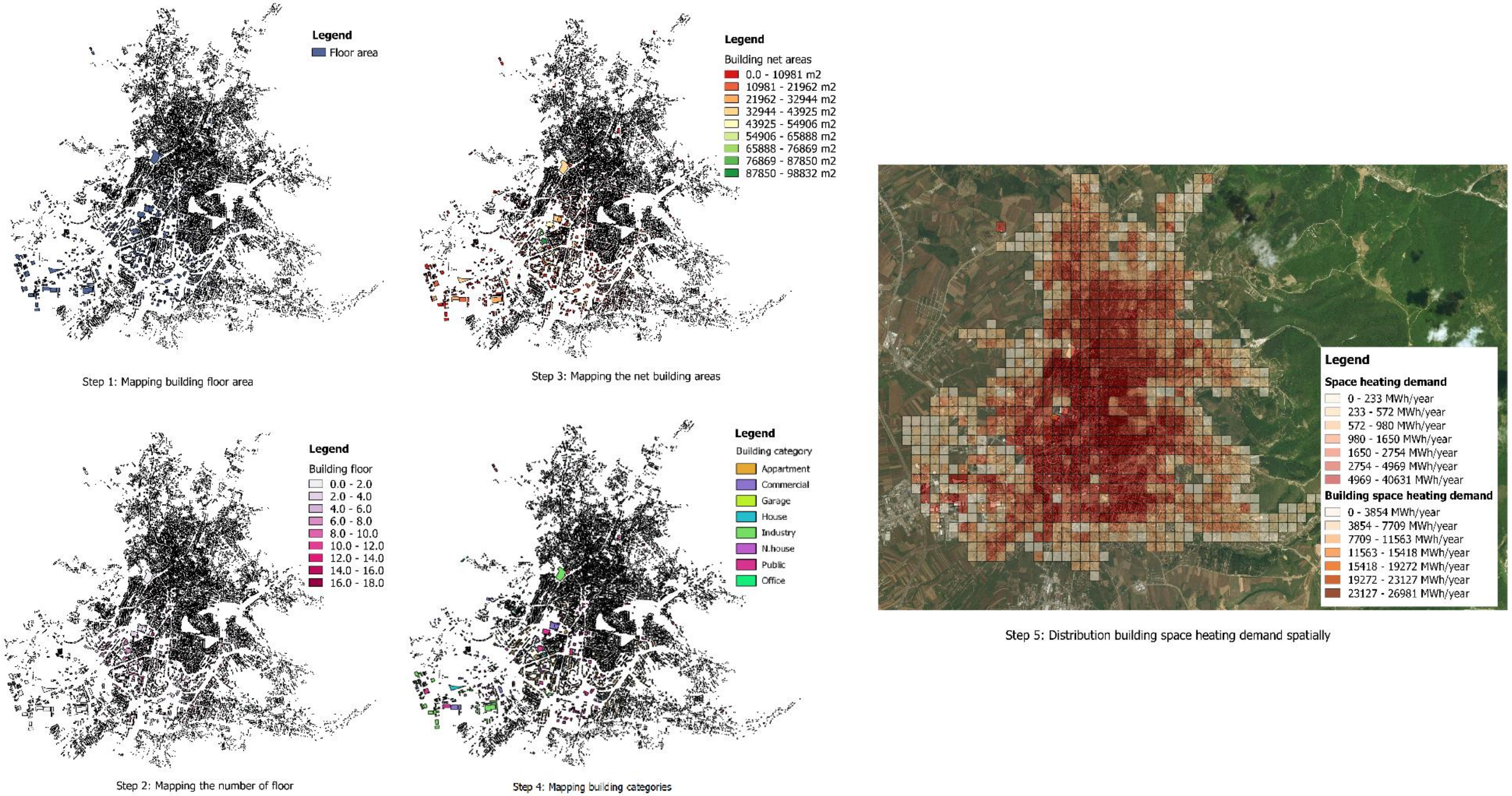

Figure 12. Bottom-up mapping approach for estimation of actual building space heating demand

Using the same approach presented schematically in Figure 9, the DHW demand for the entire city spatially was estimated (Figure 13). The first step (left top picture) shows the net building area, the second step (left bottom picture) shows the number of population in a corresponding cell and the third step (right picture) shows the aggregated DHW heating demand annually. It can be seen that grids with higher DHW heating demand match spatially with high space heating density grids in Figure 12.

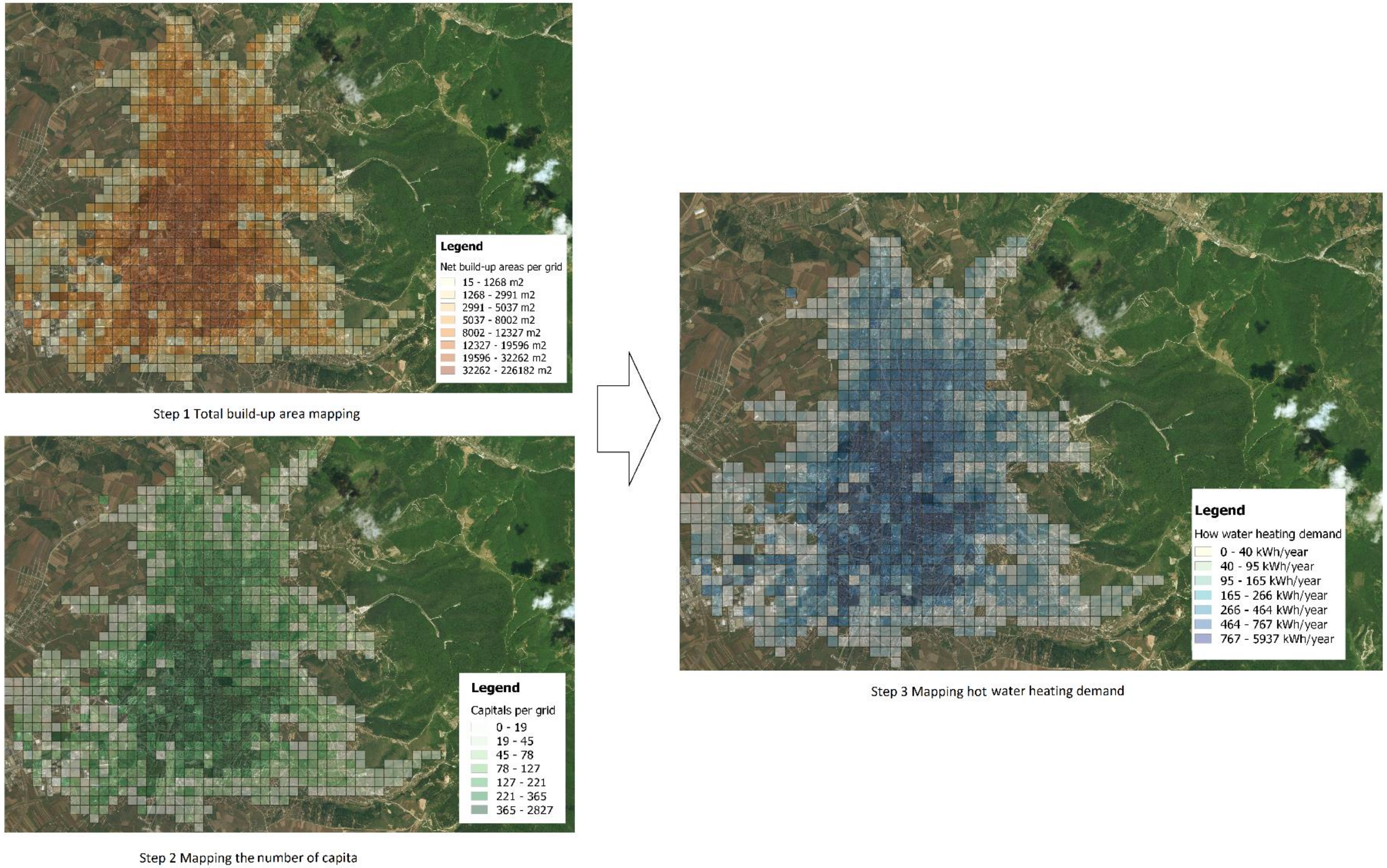

Figure 13. Top-down mapping approach for estimation of DHW heating demand spatially

The grids of DHW and space heating demand were aggregated for the quantification of the total heat demand of the city, which is used for further analysis of DH expansion potential. The results of total heat demand of the city with a spatial resolution grid of 250 m x 250 m are presented in Figure 14. Heat demand for space heating and DHW accounted for 1.95 and 0.217 TWh/year respectively. In this way, the total aggregated city heat demand was estimated to be 2.167 TWh/year. These results are obtained while considering that all building categories are heated to their net areas (fully heated), which may not be reflecting a real case. In contrast, when considering buildings that are heated partially in the model (the share of heated rooms in houses that are being heated partially in Pristina) it was estimated that the total city space heating demand is 1.61 TWh/year and the hot water demand has remained the same (0.217 TWh/year) as in the previous scenario.

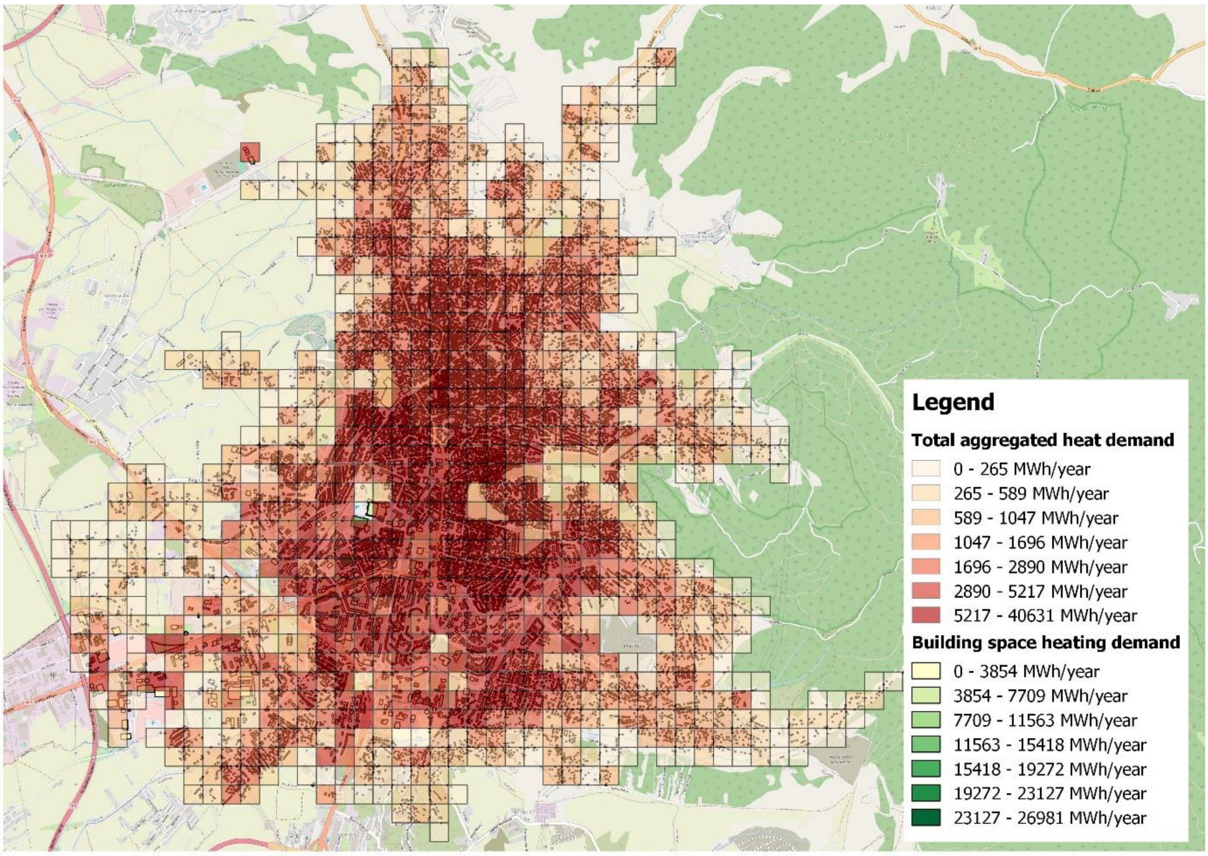

Figure 14. Total heat demand aggregated in a map with a 250 m x 250 m grid including heat demand for space heating and hot water preparation.

Figure 15 shows spatially the red grids with 250 m x 250 m, where it is economically feasible to expand the DH system. The analysis was performed considering actual heat prices, levelized cost of heat, as well as the cost of DH expansion network. In Pristina, the specific cost of district heat that consumers pay to heat distribution company is 58.8 euro/MWh_{th}, the levelized cost of heat was calculated as 40.3 euro/MWh_{th} using the prices of heat supply technologies [60] and the specific cost of DH expansion in inner cities was considered as 289 euro/m. These input data was integrated into a GIS model using the equation (15). In this way, grids with value greater than zero are considered as economically feasible areas for DH network supply. Total aggregated heat demand that is feasible to be connected to DH is 1.80 TWh_{th}/year in the scenario where buildings are fully heated. While considering the partially heated rooms in houses, the total aggregated heat demand in DH was reduced to 1.316 TWh_{th}/year.

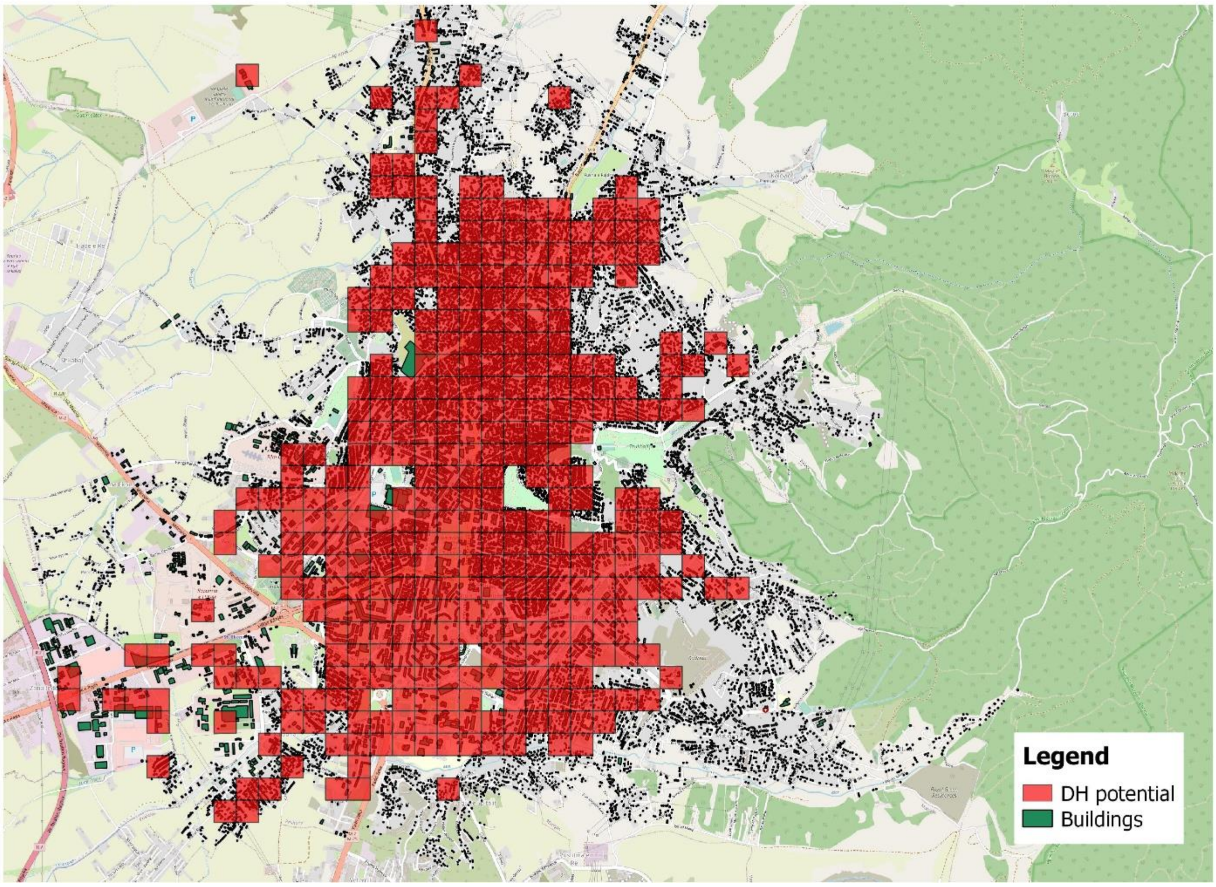

Figure 15. District heating potential

Figure 16 shows the results of hourly modelling of DHW and space heating demand in economically viable expanded DH network, when buildings are heated-up partially to their net areas. The results show that the existing DH system can be expanded four times, when excluding DHW from the analysis. Moreover, it was estimated that the space heating demand of buildings in expanded DH system accounts for 1.143 TWh/year, for which the maximum utilized capacity to power such demand would be 600 MW.

In contrast, when considering DHW demand, besides space heating demand of buildings, it was found that DH could be expanded five times in comparison to existing DH share. The modelling of hot water heating demand in potential DH is shown in figure 17. Again higher demand for hot water is observed during the winter in comparison to other seasons. The estimated maximum DHW capacity would be 70 MW during Sundays of the winter season. It means that DHW demand capacity would account for 10% of total potential installed DH capacity.

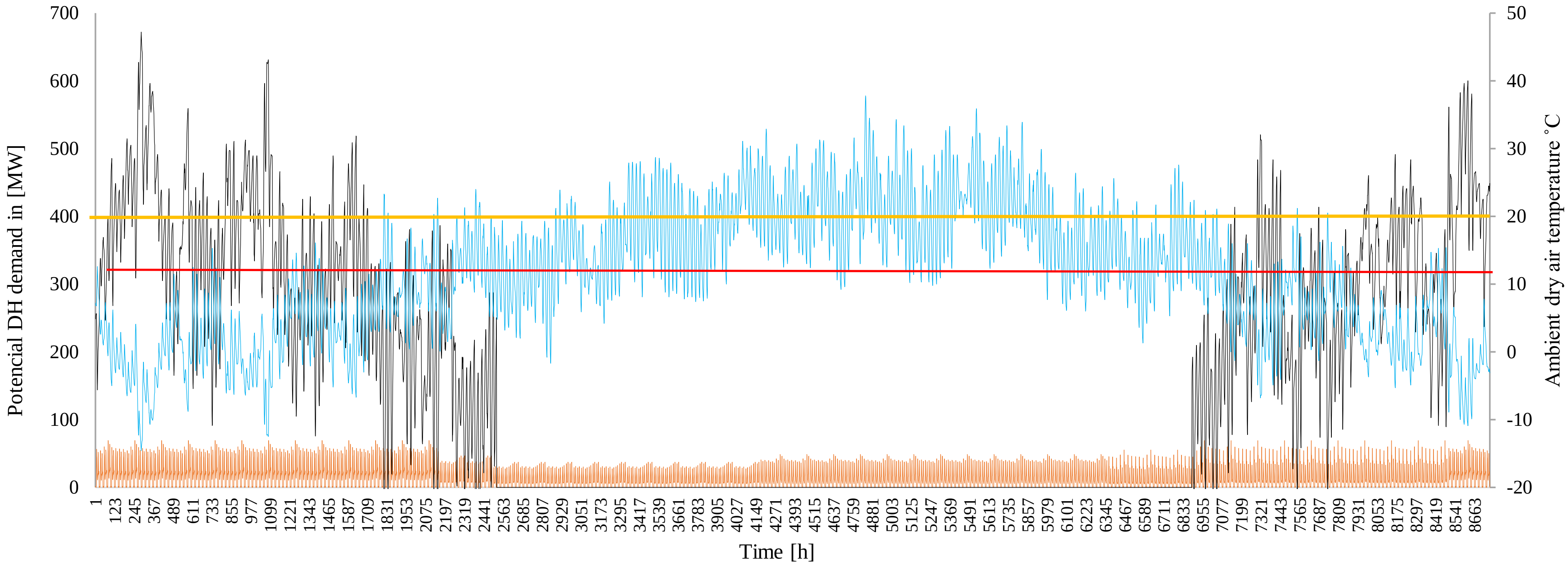

Figure 16. Q_{SH} potential space heating demand profile of Pristina DH for one- hour resolution (in black) when houses are partially heated, local Pristina ambient dry air temperature (in blue), T_{in} internal desired dry air temperature (in yellow) and the HDD threshold with 12˚C (in red), Q_{HW} hot water heating demand (in orange).

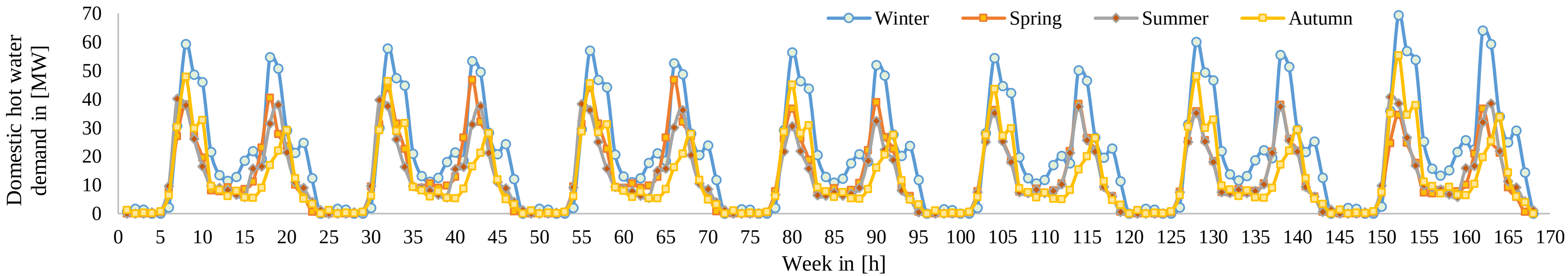

Figure 17. Hourly residential hot water heating demand Q_{HW} in [MW]

4. CONCLUSION

A method for obtaining the bottom-up aggregated space heating and DHW demand maps and curves for actual and potential DH demand has been developed. The method has been applied to the urban building stock of Pristina. When compared to other bottom-up approaches that are applied for the estimation of DH potential, this research has further considered the analysis of DHW demand. Besides, this research also takes into account the impact of fully and partially heated buildings, which reinforces the replicability of this approach in both developed and developing countries. It was estimated that total potential heat demand for space heating and DHW that is economically viable to be supplied by DH system is 1.80 TWh/year when considering that buildings are heated to their net heated area. However, this is not the actual case for Kosovo, as houses are not being heated to their net heated areas [35]. When considering this in the model, the total estimated heat demand that is feasible for being supplied by DH is reduced to 1.32 TWh/year. Actual heat supply by DH for buildings in Pristina is 250 GWh/year and is used only for space heating purposes, so the potential for expansion of DH in this city is significant. This means that only 19% of potential DH demand is being supplied by existing DH in Pristina. This research also developed a method for modelling the hourly distribution of DHW demand in DH considering hourly, daily, weekly and seasonal variation in hot water demand profile. Temporal distribution of space heating and DHW demand is important for planning and modelling analysis of sustainable DH systems. In terms of needed capacities to meet the demand in the expanded DH, research has shown that for space heating the maximal capacity would be around 600 MW. Additional 70 MW thermal capacity would be needed for covering DHW demand in DH during the winter season.

A similar approach can be used in other urban areas if the specific data regarding the building floor, building heights and energy performance certificate per building category is known. However, for all other urban areas in Kosovo, such data is not available. There exists only spatial data regarding the 2D urban area views recorded from space satellites, which can be applied for the production of building floor areas, but the evaluation of building heights and their categories can only be done through the visual investigation of buildings or by using surveys. Such a process of data collection and processing requires considerable amount of time and resources, hence this method for data collection could prove to be a non-feasible approach. Temporal heat demand profile (both space heating and DHW) can be of high importance when studying renewable heat integration in the DH system (for instance: solar thermal collectors, waste heat resources, the power to heat technologies among others). Local authorities, utilities and policymakers can harness the results regarding the expansion priorities of DH, plan the utilization of their maximum heat production potential, develop new capacities, increase the reliability of heating supply solutions as well as meet the targets and obligations regarding the energy efficiency implementation measures.

REFERENCES

[1] International Energy Agency [IEA], Word energy balanced. Accessed on 10.06.2020. https://www.iea.org/.

[2] L. Pérez-Lombard, J. Ortiz, and C. Pout, "A review on buildings energy consumption information," Energy Build., vol. 40, no. 3, pp. 394–398, Jan. 2008, doi: 10.1016/j.enbuild.2007.03.007.

[3] X. Guo and A. P. Goumba, "Air source heat pump for domestic hot water supply: Performance comparison between individual and building scale installations," Energy, vol. 164, pp. 794–802, Dec. 2018, doi: 10.1016/j.energy.2018.09.065.

[4] Z. Wang, P. Guo, H. Zhang, W. Yang, and S. Mei, "Comprehensive review on the development of SAHP for domestic hot water," Renew. Sustain. Energy Rev., vol. 72, pp. 871–881, May 2017, doi: 10.1016/j.rser.2017.01.127.
[5] F. Correa and C. Cuevas, "Air-water heat pump modelling for residential heating and domestic hot water in Chile," Appl. Therm. Eng., vol. 143, pp. 594–606, Oct. 2018, doi: 10.1016/j.applthermaleng.2018.07.130.
[6] T. Niemelä, M. Manner, A. Laitinen, T.-M. Sivula, J. Jokisalo, and R. Kosonen, "Computational and experimental performance analysis of a novel method for heating of domestic hot water with a ground source heat pump system," Energy Build., vol. 161, pp. 22–40, Feb. 2018, doi: 10.1016/j.enbuild.2017.12.017.
[7] Urban Persson, Sven Werner. Quantifying the Heating and Cooling Demand in Europe. Stratego, enhanced heating &ccoling plans. 2015. https://heatroadmap.eu/wp-content/uploads/2018/09/STRATEGO-WP2-Background-Report-4-Heat-Cold-Demands.pdf.
[8] Kosovo Agency of Statistics, Accessed on (10.02.2020), http://ask.rks-gov.net/en/kosovo-agency-of-statisticstp://.
[9] Eptisa, "National Building Energy Efficiency Study for Kosovo. Accessed on 15.04.2020. http://www.worldbank.org/content/dam/Worldbank/Feature%20Story/ECA/kosovo/Kosovo%20Eptisa%20Final%20Report_2013.04.13.pdf," Final Report, Feb. 2013.
[10] Marina G, Cyril R-L, Uwe G, Vincent A. Efficient district heating and cooling systems in the EU. Publications Office of the European Union; 2016.
[11] H. Lund, P. A. Østergaard, D. Connolly, and B. V. Mathiesen, "Smart energy and smart energy systems," Energy, vol. 137, pp. 556–565, Oct. 2017, doi: 10.1016/j.energy.2017.05.123.
[12] B. V. Mathiesen et al., "Smart Energy Systems for coherent 100% renewable energy and transport solutions," Appl. Energy, vol. 145, pp. 139–154, May 2015, doi: 10.1016/j.apenergy.2015.01.075.
[13] H. Lund et al., "4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems," Energy, vol. 68, pp. 1–11, Apr. 2014, doi: 10.1016/j.energy.2014.02.089.
[14] X. Yang, H. Li, and S. Svendsen, "Energy, economy and exergy evaluations of the solutions for supplying domestic hot water from low-temperature district heating in Denmark," Energy Convers. Manag., vol. 122, pp. 142–152, Aug. 2016, doi: 10.1016/j.enconman.2016.05.057.
[15] X. Yang, H. Li, and S. Svendsen, "Evaluations of different domestic hot water preparing methods with ultra-low-temperature district heating," Energy, vol. 109, pp. 248–259, Aug. 2016, doi: 10.1016/j.energy.2016.04.109.
[16] D. Connolly et al., "Heat Roadmap Europe: Combining district heating with heat savings to decarbonise the EU energy system," Energy Policy, vol. 65, pp. 475–489, Feb. 2014, doi: 10.1016/j.enpol.2013.10.035.
[17] J. Polo et al., "Solar resources and power potential mapping in Vietnam using satellite-derived and GIS-based information," Energy Convers. Manag., vol. 98, pp. 348–358, Jul. 2015, doi: 10.1016/j.enconman.2015.04.016.
[18] S. H. Siyal, D. Mentis, and M. Howells, "Mapping key economic indicators of onshore wind energy in Sweden by using a geospatial methodology," Energy Convers. Manag., vol. 128, pp. 211–226, Nov. 2016, doi: 10.1016/j.enconman.2016.09.055.
[19] C. Su, H. Madani, and B. Palm, "Building heating solutions in China: A spatial techno-economic and environmental analysis," Energy Convers. Manag., vol. 179, pp. 201–218, Jan. 2019, doi: 10.1016/j.enconman.2018.10.062.

[20] S. N. Petrovic and K. B. Karlsson, “Danish heat atlas as a support tool for energy system models,” Energy Convers. Manag., vol. 87, pp. 1063–1076, Nov. 2014, doi: 10.1016/j.enconman.2014.04.084.
[21] M. Münster et al., “The role of district heating in the future Danish energy system,” 6th Dubrov. Conf. Sustain. Dev. Energy Water Environ. Syst. SDEWES 2011, vol. 48, no. 1, pp. 47–55, Dec. 2012, doi: 10.1016/j.energy.2012.06.011.
[22] H. Lund, B. Möller, B. V. Mathiesen, and A. Dyrelund, “The role of district heating in future renewable energy systems,” Energy, vol. 35, no. 3, pp. 1381–1390, Mar. 2010, doi: 10.1016/j.energy.2009.11.023.
[23] K. N. Finney, V. N. Sharifi, J. Swithenbank, A. Nolan, S. White, and S. Ogden, “Developments to an existing city-wide district energy network – Part I: Identification of potential expansions using heat mapping,” Energy Convers. Manag., vol. 62, pp. 165–175, Oct. 2012, doi: 10.1016/j.enconman.2012.03.006.
[24] T. Novosel, T. Pukšec, G. Krajačić, and N. Duić, “Role of District Heating in Systems with a High Share of Renewables: Case Study for the City of Osijek,” Int. Sci. Conf. “Environmental Clim. Technol. CONECT 2015, vol. 95, pp. 337–343, Sep. 2016, doi: 10.1016/j.egypro.2016.09.019.
[25] D. Meha, A. Pfeifer, N. Duić, and H. Lund, “Increasing the integration of variable renewable energy in coal-based energy system using power to heat technologies: The case of Kosovo,” Energy, vol. 212, p. 118762, Dec. 2020, doi: 10.1016/j.energy.2020.118762.
[26] Y. Xu, Y. Huang, N. Jiang, M. Song, X. Xie, and X. Xu, “Experimental and theoretical study on an air-source heat pump water heater for northern China in cold winter: Effects of environment temperature and switch of operating modes,” Energy Build., vol. 191, pp. 164–173, May 2019, doi: 10.1016/j.enbuild.2019.03.028.
[27] E. Fuentes, L. Arce, and J. Salom, “A review of domestic hot water consumption profiles for application in systems and buildings energy performance analysis,” Renew. Sustain. Energy Rev., vol. 81, pp. 1530–1547, Jan. 2018, doi: 10.1016/j.rser.2017.05.229.
[28] K. Ahmed, P. Pylsy, and J. Kurnitski, “Hourly consumption profiles of domestic hot water for different occupant groups in dwellings,” Sol. Energy, vol. 137, pp. 516–530, Nov. 2016, doi: 10.1016/j.solener.2016.08.033.
[29] D. George, N. S. Pearre, and L. G. Swan, “High resolution measured domestic hot water consumption of Canadian homes,” Energy Build., vol. 109, pp. 304–315, Dec. 2015, doi: 10.1016/j.enbuild.2015.09.067.
[30] J. de Santiago, O. Rodriguez-Villalón, and B. Sicre, “The generation of domestic hot water load profiles in Swiss residential buildings through statistical predictions,” Energy Build., vol. 141, pp. 341–348, Apr. 2017, doi: 10.1016/j.enbuild.2017.02.045.
[31] X. Oregi, N. Hermoso, I. Prieto, J. L. Izkara, L. Mabe, and P. Sismanidis, “Automatised and georeferenced energy assessment of an Antwerp district based on cadastral data,” Energy Build., vol. 173, pp. 176–194, Aug. 2018, doi: 10.1016/j.enbuild.2018.05.018.
[32] T. Törnros, B. Resch, M. Rupp, and H. Gündra, “Geospatial Analysis of the Building Heat Demand and Distribution Losses in a District Heating Network,” ISPRS Int. J. Geo-Inf., vol. 5, no. 12, 2016, doi: 10.3390/ijgi5120219.
[33] T. Novosel, T. Pukšec, N. Duić, and J. Domac, “Heat demand mapping and district heating assessment in data-pour areas,” Renew. Sustain. Energy Rev., vol. 131, p. 109987, Oct. 2020, doi: 10.1016/j.rser.2020.109987.
[34] A. Wyrwa and Y.-K. Chen, “Mapping Urban Heat Demand with the Use of GIS-Based Tools,” Energies, vol. 10, May 2017, doi: 10.3390/en10050720.
[35] D. Meha, T. Novosel, and N. Duić, “Bottom-up and top-down heat demand mapping methods for small municipalities, case Gllogoc,” Energy, vol. 199, p. 117429, May 2020, doi: 10.1016/j.energy.2020.117429.

[36] S. C. Taylor, S. K. Firth, C. Wang, D. Allinson, M. Quddus, and P. Smith, "Spatial mapping of building energy demand in Great Britain," GCB Bioenergy, vol. 6, no. 2, pp. 123–135, Mar. 2014, doi: 10.1111/gcbb.12165.
[37] K. Sperling and B. Möller, "End-use energy savings and district heating expansion in a local renewable energy system – A short-term perspective," Appl. Energy, vol. 92, pp. 831–842, Apr. 2012, doi: 10.1016/j.apenergy.2011.08.040.
[38] U. Persson and S. Werner, "Heat distribution and the future competitiveness of district heating," Appl. Energy, vol. 88, no. 3, pp. 568–576, Mar. 2011, doi: 10.1016/j.apenergy.2010.09.020.
[39] U. Persson, "District heating in future Europe: Modelling expansion potentials and mapping heat synergy regions," PhD thesis, Chalmers University of Technology, Gothenburg, Sweden, 2015.
[40] Fraser Stevenson, "Assessing the feasibility of a district heating scheme for Bowmore, Islay.," University of Strathclyde Engineering, 2016.
[41] K. N. Finney et al., "Modelling and mapping sustainable heating for cities," Incl. Spec. Issue -TEM Spec. Issue, vol. 53, no. 2, pp. 246–255, May 2013, doi: 10.1016/j.applthermaleng.2012.04.009.
[42] A. Skujevska, M. Rosa, and A. Kamenders, "Evaluation of Energy Consumption of Municipal Buildings by Heat Energy Demand Mapping," Int. Sci. Conf. "Environmental Clim. Technol. CONECT 2015, vol. 95, pp. 444–450, Sep. 2016, doi: 10.1016/j.egypro.2016.09.061.
[43] S. Nielsen and B. Möller, "GIS based analysis of future district heating potential in Denmark," Energy, vol. 57, pp. 458–468, Aug. 2013, doi: 10.1016/j.energy.2013.05.041.
[44] S. Nielsen, "A geographic method for high resolution spatial heat planning," Energy, vol. 67, pp. 351–362, Apr. 2014, doi: 10.1016/j.energy.2013.12.011.
[45] E. Fuentes, L. Arce, and J. Salom, "A review of domestic hot water consumption profiles for application in systems and buildings energy performance analysis," Renew. Sustain. Energy Rev., vol. 81, pp. 1530–1547, Jan. 2018, doi: 10.1016/j.rser.2017.05.229.
[46] Eurostat database: https://ec.europa.eu/eurostat/data/database/ accessed on 02/01.2020.
[47] Google Earth Pro: https://www.google.com/earth/versions/ accessed on 15.01.2020. .
[48] QGIS: https://qgis.org/ accessed on 25/12/2019.
[49] Typology and energy performance of residential buildings in the Republic of Kosovo, 2019, accessed on 14/01/2020.
[50] F. Krasniqi, Heating and Air Conditioning I, Second edition. Kosovo: University of Prishtina, 2018.
[51] Murakawa S, D N, Takata H, Tanaka A, An Analysis on the Loads of Hot Water Consumption in restaurants. In: CIB W062 31rd International Symposium on Water Supply and Drainage for Buildings CIB W062 Symposium 2005, 2005.
[52] Murakawa S, Y K, Takata H, Tanaka A, Calculation for the cold and hot water demands. in the guest rooms of city Hotel. In: CIB W062 Proceedings of the 33rd International Symposium on Water Supply and Drainage for Buildings, 2007.
[53] Takata H, Murakawa S, Nishina D, Yamane Y, Development of the calculating method for the loads of cold and hot water consumption in office buildings. In: CIB W062 Proceedings of the 29th International Symposium on Water Supply and Drainage for Buildings, 2003.
[54] Water Heating Data Collection and Analysis. Residential End Use Monitoring Program (REMP), Report from Commonwealth of Australia.
[55] D. George, N. S. Pearre, and L. G. Swan, "High resolution measured domestic hot water consumption of Canadian homes," Energy Build., vol. 109, pp. 304–315, Dec. 2015, doi: 10.1016/j.enbuild.2015.09.067.

[56] Krippelova Z, Peráčková J. Measurement of hot water consumption in apartment building. Bud o zoptymalizowanym potencjale Energ 2014:49–54.
[57] Masiello J, Parker D. Factors influencing water heating energy use and peak demand in a large scale residential monitoring study, In residential buildings: technologies, design. Perform Anal, Build Ind Trends 1992:157–70.
[58] District heating: https://iea-etsap.org/E.../E16_DistrHeat_EA_Final_Jan2013_GSOK.pdf. accessed on 25/01/2020.
[59] Levelized Cost Calculations. Available online: http://en.openei.org/apps/TCDB/levelized_cost_ calculations.html (accessed on 10/01/2020.
[60] Danish Energy Agency, "Technology data for energy plants. 2012. https://energiatalgud.ee/img_auth.php 4/42/Energinet.dk._Technology_Data_for_Energy_Plants._2012.pdf. Accessed on 14/01/2020," Aug. 2016. Accessed: Jan. 14, 2020. [Online]. Available: https://ens.dk/sites/ens.dk/files/Analyser/technology_data_catalogue_for_el_and_dh_-_aug_2016_upd_oct18.pdf.
[61] Meteonorm. https://meteonorm.com/ Accessed dataset in 03.01.2020.
[62] Annual Hydrometeorological report, http://www.ammk-rks.net/ accessed 15.01.2020.
[63] Kosovo Energy Regulatory Office. https://www.ero-ks.org/w/en/. Accessed on 10/01/2020.