

Heat Demand in Non-Residential Buildings: Renovation and Subsidy Effects

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Abstract – Considering Europe’s green agenda and established climate goals, discussions often center around energy efficiency and the responsible use of energy. Building renovation is recognized as a crucial step towards achieving these objectives. While most renovation discussions focus on residential buildings, the non-residential sector is frequently overlooked. In Riga, non-residential properties account for 25 % of the heat demand in buildings connected to the district heating system. This brings forth the concern that the contribution of non-residential buildings to reduce heat demand and the necessity for renovation is not adequately evaluated. This research utilizes available statistical data and system dynamics modelling to address this issue. The results show that the total annual heat demand may decrease by 27 %, while the alternative heating may be increasing by 5 % in 2050 relative to 2023. Using the currently available financial funds, renovating up to 89 % of municipal buildings and 91 % of educational institutions in state facilities is possible.

Keywords – Energy efficiency; district heating; non-residential buildings; renovation; system dynamic modelling.

1. INTRODUCTION

The district heating sector is undergoing significant transformation to reach the European Union’s climate neutrality goal. Considering scale of heat demand citizens must bear their share of responsibility for GHG emissions. To address this issue, building renovation funds have been available in Latvia for more than 10 years, and that would promote the rational use of heat in buildings. When studying the most current research related to building renovation, it is concluded that most studies have focused on the analysis of the renovation process and the implementation of RES [1], human behaviour and its importance in renovation [2], [3], life cycle assessment [4]–[6], advanced, innovative technologies and materials [7]. An interesting study that stands out from the rest has been carried out about buildings that were built in a certain period and that are not subject to renovation requirements, but at the time of the construction of the buildings, energy efficiency construction laws and requirements were not yet in force [8]. The researcher offers possible solutions based on simulations, which

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would help to introduce the necessary RES technologies to reduce GHG emissions in buildings without renovation. Renovation of cultural and historical buildings faces several problems: structural and material challenges [9], [10], economic and regulatory factors [11], [12], negative implementation options [13], [14], and socio-economic side factors [15]. However, some researchers offer various solutions calculations and solutions for the renovation of historical buildings: the new window-wall interface solution [16], different renovation scenarios comparing carbon footprint, energy performance and cost-effectiveness [17], multidisciplinary approach to renovation [18] passive and active renovation strategies [19].

In the studies of educational institution renovation [20]–[23] the authors examined the possibilities of new technologies for the renovation process and their energy efficiency indicators. It should be mentioned that many authors examine school renovations directly in connection with ensuring air quality. Another study on compliance of care facilities with modern requirements, allows to conclude that the number of people in Spanish care centres should be reduced to meet comfortable space in m² per person, and that 80 % of care buildings are energy efficient [24]. A new methodological approach for issuing social building renovation certificates is offered in the study [25], where more emphasis is placed on the need to pay more attention to air quality assessment. Also, the study [26] offers the development of a methodology but is based on the development of an economic assessment and schedule for buildings to be renovated, thus ensuring both the renovation of the most critical buildings and financial investments. When renovating buildings, the main emphasis is placed on improving the residential buildings, but it is also important to consider what are the possibilities for the increase of the renovation rate of non-residential buildings in the future [27], [28]. Several authors have pointed out in their research findings that qualitative research requires different data and often such data is not available [19]. Jang conducted a study of future energy consumption in one building, finding that changes in energy consumption are related to human behaviour [29]. If these changes are not accurately predicted, problems arise with the accuracy of the predictions. In addition, there is a need to expand research at the municipal level, as existing research is often based on a small number of buildings or university campuses [29]. Therefore, the aim of this study is to address renovation dynamics of non-residential buildings considering the existing available subsidy funding, the impact of the heat tariff, and the existing regulatory acts on the renovation rate. The study addresses the importance of non-residential building renovation process and its potential impact on future heat consumption. The research conducted is part of a larger study related to de-carbonization of district heating by integrating synthetic methane and hydrogen into the district heating production process.

2. METHODS AND METHODOLOGY

Data collection from various available sources is used for the solution and determination of impact factors (subsidies for renovation, heat tariff, willingness to invest in renovation, etc). System dynamics modelling was carried out to determine the possible development of heat demand until 2050, as well as to determine the main factors influencing the dynamics of renovation. The model contains sub-modules related to the allocation of subsidies for renovation, and analysis of dynamics of renovation and construction of new non-residential buildings. The buildings of the non-residential buildings were divided into three blocks with the areas in 2022 – municipal (libraries, court buildings, social institutions, etc.), 1 812 658 m², educational institutions (kindergartens, schools, universities, adult education establishments), 1 920 779 m² and others (shops, logistics centers, offices, etc.),

11 446 872 m² (Fig. 1) [30]. Each block was divided into areas by year of commissioning and type of heating (DH or AH).

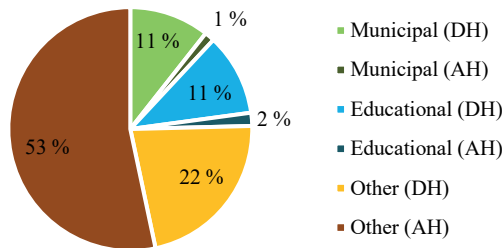


Fig. 1. Distribution of non-residential buildings by area and type of heating (DH-district heating; AH-alternative).

Analysing the available data for 6 years [30], [31], it was concluded that 80 % of newly constructed municipal buildings, 86 % of educational buildings and 29 % of other non-residential buildings are connected to DH. Such differences in the type of heating among those buildings can be explained by the fact that state institutions are mostly concentrated in the areas where DH is available. Large logistics and shopping centres are built outside densely populated areas, and where DH is not available. The construction rate of new educational buildings in the model is driven by difference between the existing and the desired specific area of educational space (per educational participant). The specific area requirements for different categories of educational institutions were analysed, considering the minimum required area per child in preschool educational institutions, per student in general and higher education institutions. These values were taken from regulatory documents that set minimum requirements [32], [33]. However, these requirements determine only the minimum required level, not the actual need. A demographic forecast was included in the model, considering the expected change in the number of people at each stage of education in the future. Three main target groups were analysed: children aged 1.5 to 6 years attending preschool educational institutions; students aged 7 to 18 years; and students aged 18 to 65 years [34], [35]. The construction of municipal and other (shops, offices, workshops etc.) buildings is related to social demand and the need to create an energy-efficient environment. Based on the available statistical data [30], it is impossible to determine a possible future construction. Based on historical data for the last 10 years, the average number of built-up m² was determined, which is approximately 0.15 % of municipal and 0.8 % of other of total area annually.

The main task of the sub-module for calculation of renovation rates of non-residential buildings is to account for the factors that directly or indirectly influence the decision in favour of renovation. The renovation differs for DH and AH users. Currently there are no specific rules for renovation for the non-residential areas, but for the residential areas [36] it is stipulated that solutions must be sought especially for buildings built before 2003. Therefore, for the non-residential stock it is assumed that buildings built before 1991 are being renovated, due to the greatest heat loss. The decision to renovate depends on time to make decisions and willingness to invest funds. In this context, investments in renovation were particularly relevant for municipal and educational institutions, which have adopted the commitment to renovating all their buildings as an example of good practice. Based on the available information about renovation, 39 % municipal, 46 % educational institutions and 7 % other buildings had been renovated by 2022. The desire to invest in renovation depends

on tariffs, which ultimately influenced the decision-making process (Fig. 4). The fossil gas tariff is compiled from various available literature sources [37]–[41]. REPowerEU and EU ETS II will strengthen CO₂ prices, which may increase gas costs in 2030 and beyond. It is mentioned that if CCS (carbon capture) and medium-carbon hydrogen (H₂) technologies are introduced, natural gas can maintain its bridge role until 2050 [42]. There are no published district heating end-user tariff (EUR/MWh) forecasts available for the period until 2050, however, several studies provide structural data and components that allow modelling. Therefore, future forecasts for the Riga DH tariff have been based on historical data. A piece-function model was used, which divides the forecast into two main stages: growth stage (2025–2035) – linear price increase from 85 EUR/MWh (2025) to 120 EUR/MWh (2035). Assumption: during this time, RES projects are actively implemented (e.g., biomass cogeneration, heat pumps), which require capital investments and infrastructure adaptation. Stabilization/decline phase (2035–2050) – linear decrease from 120 EUR/MWh (2035) to 100 EUR/MWh (2050). Assumption: after the deployment of RES infrastructure and market maturity, technology costs decrease, prices stabilize or slightly decrease (Fig. 2). As can be seen in Fig. 2, the heat tariff for DH is approximately three times higher than the prices of natural gas (used for AH). The impact factor is calculated based on historical data (renovation volume and tariff) using a linear function with a maximum threshold, which calculates the impact factor directly from the tariff value.

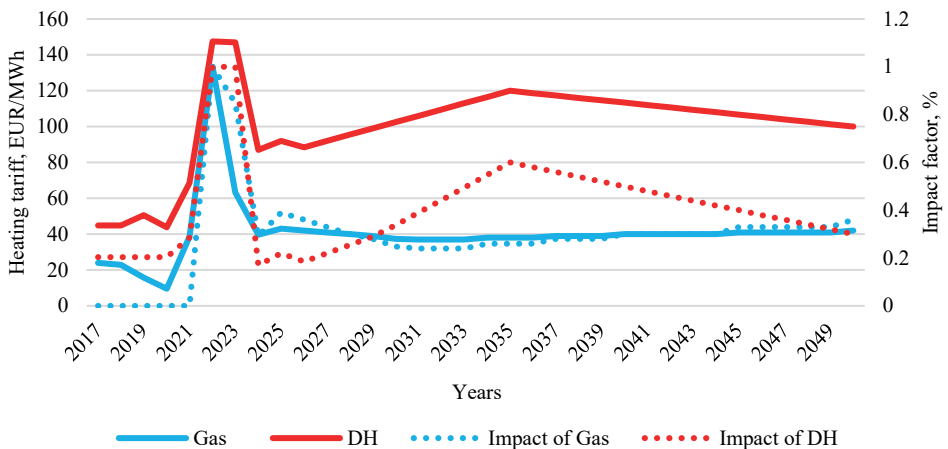


Fig. 2. Tariff and tariff effect on renovation. The heating tariff and gas prices are plotted on the left axis with solid line, the impact factors are plotted on the right axis with dotted lines.

The final decision on renovation depends on the availability of subsidies, for all but areas belonging to the other building (shops, offices, workshops etc.), category, as subsidies are not available for this category.

Building renovation is significantly affected by available subsidies, therefore, a subsidies sub-module was developed to assess the impact of subsidies on the renovation process and the amount of subsidies needed. Currently, several support mechanisms, or subsidies, are available in Latvia for building renovation [43]–[45] and connecting buildings to DH. Within Riga, these subsidies are essential, as Riga used 24 % of the total subsidies available in Latvia for renovation [43]. These subsidies are split between DH and AH users, with 78 % of municipal buildings and 81 % of educational buildings using DH. The situation with AH users is different; when deciding on renovation, they can evaluate the possibility of connecting to

the DH supply during the renovation process, which could contribute to the creation of more efficient energy systems. Although subsidies are granted for the connection to DH during the renovation, it takes time and the availability of subsidies to fulfil the necessary conditions. This contributes to increasing the number of buildings connected to DH during renovation, which ultimately reduces the total number of unrenovated buildings. Although funds are currently available for connecting buildings to DH without renovation, this is not considered in the model, as based on the DH data under study, because there is no data on the connection of such buildings.

Subsidies were granted only if the total target of renovated buildings was not met. To evaluate the progress, it was necessary to determine the difference between the set goal and the actual situation regarding the renovated buildings. It was assumed that subsidies would be awarded in a fixed amount every five years, which would ensure stability in financing the renovation. Currently, subsidies are allocated without dividing them between municipal and educational institutions, thus creating a common subsidy fund for these categories. To determine the amount of subsidized areas, the average costs of renovation per square meter were analysed, considering inflation.

Dynamics of heat demand is an important factor that allows us to determine whether the climate goals set by the European Union will be achieved in the future. To determine whether these goals will be met, an analysis of heat demand was made by analysing three sectors. The first sector was buildings built between 1992 and 2022, and these buildings do not require renovation, and their heat consumption will remain the same. The second sector are new buildings which will be built between 2023 and 2050, and their heat consumption most likely will decrease over time due to better energy efficiency standards of the newly built space. The third sector are buildings built before 1991, and the heat consumption of these buildings will be affected both by the renovation rate and by the consumption of the newly renovated buildings, as well as by the consumption of the unrenovated buildings. The future specific heat consumption coefficient (Fig. 3) is determined using available historical data from previous periods, incorporating the reduction rate observed over the past years.

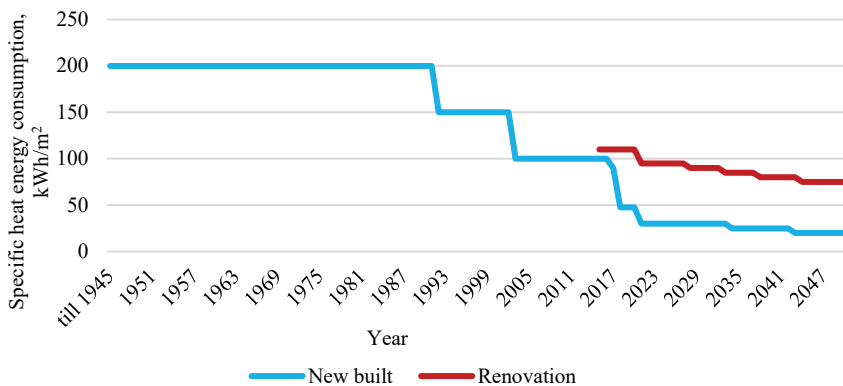


Fig. 3. Specific heat consumption for newly built and renovated non-residential buildings.

The heat energy demand for heating for each of the building groups is calculated based on specific heat consumption (Fig. 3). Considering that this is not the only influencing factor, heating days, outdoor temperature and indoor temperature are also considered. Future heating day forecasts are based on regulatory enactments [46], as well as company data on the average length of the heating season since 1992, and on the duration of the heating season for non-

residential buildings. The calculation of the outdoor temperature is based on regulatory enactments [46], as well as future predicted temperature changes [47]. Indoor temperatures are determined by various legal acts [32], [33], [48] based on the specifics of building use and range from +16 °C to +21 °C depending on the room and physical exertion of people. The average indoor temperature was used in the modelling based on the minimum requirements set out in regulatory acts and the information specified in the concluded heat supply contract. The demand for heat energy also includes hot water demand. Hot water demand is calculated based on company data for the period from June to September, determining the average consumption per month and dividing it by the connected building m². Considering that such data is not publicly available for AH users, it is assumed that hot water consumption per 1 m² is the same also for AH users. The main modelling variables used in the baseline scenario and their values are summarized in Table 1.

TABLE 1. VALUES USED IN THE MODEL FOR THE BASE SCENARIO

Name	Value	Units	Reference	Description
Tariff DH	45–148	EUR/MWh	[31]	Changes over time, calculated, based on historical data
Tariff AH	39–133	EUR/MWh		Changes over time, calculated, based on historical data and forecasted data
Effect on subsidy availability for joint decision renovate	0–1	unitless	assumption	If there are subsidies then 1, else 0.
Time to decide to join DH	6;10	years	assumption	6 years for municipal and educational and 10 for others
Probability to join DH	0.5	%	[31]	Based on historical data
Average time for renovation	2	years	assumption	Based on average renovation time
Indicated budget	31.07	MEUR	[43], [44], [45]	Total available budget for renovation in Latvia
Interval of allocating subsidies	5	years	[45]	Time to use up the available subsidy amount
Cover of subsidies	85	%	[45]	Share of subsidies in the total costs of renovation
Average costs of renovation	393	EUR/m ²	[49]	
Annual increase fraction of average costs of renovation	17	%	[50]	
Specific consumption of hot water	16.419	kWh/m ² per year	[31]	Assumption based on the average requirement set out in legislation and the information specified in the concluded contract for the supply of heat energy.
Indoor temperature	20	°C		
Normative outdoor temperature	1.1	°C	[46]	
Actual outdoor temperature	3.15–3.42	°C	[47]	Changes over time. Based on the existing historical data and the future projections, assuming an annual temperature increase of +0.01 °C
Normative heating days	192	days	[46]	
Number of actual heating days	174	days	[31]	Assumption, based on changes in the average length of the heating season since 1992, and residents' demand for comfort
Average suggested area for kindergarten/schools/university	7–10 10–15 10–20	m ² /per people	[51]–[53]	Assumption in model desired area 10m ² per people
Birth, children, adults, retired	Changes over time	people	[34], [35]	Calculated based on historical data

2.1. Validation and Limitations of the Model

Validation was performed based on the data for the period from 2017 to 2023 since during this period subsidies were allocated separately to public and educational institutions. The subsidy module was changed to provide for two separate subsidy flows. Validation was performed by comparing the simulated and the actual renovation rates as well as the simulated and actual heat consumption in all three building sectors (Fig. 4). The difference in simulated and real data for the municipal buildings connected to DH is -5 %, for the education buildings +5 %, and for the other +1 % (Fig. 5). The difference in simulated and real data for the municipal buildings with AH is +8 %, for education institutions 0 %, and for the other +1 % for a six-year period.

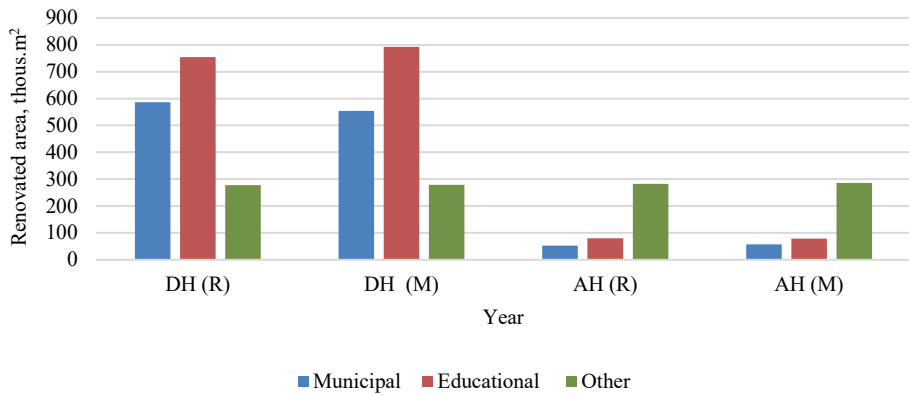


Fig. 4. Validation of the model – comparison of the modelled (simulated) and the actual figures of renovated area. The letter M stands for modelled (simulated) data, and the letter R stands for real statistical data.

Comparison of heat demand was done for the buildings connected to DH. The difference of the simulated and the actual heat consumption is quite small, i.e., within limits of 2–5 % (Fig. 5). The biggest difference can be observed during Covid 19, when many non-residential buildings were closed.

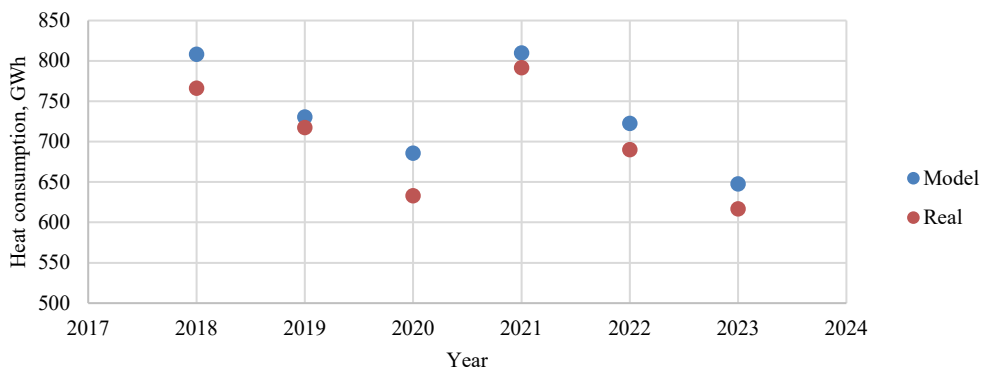


Fig. 5. Validation of the model – comparison of the simulated and the actual heat consumption of buildings connected to DH.

3. RESULTS

The results show that heat consumption in DH is decreasing by 22 %, while in the buildings with alternative heating it is increasing by 5 % in 2050 relative to 2023 (Fig. 6). This trend can be explained by the fact that about 80 % of municipal and education buildings that have been renovated are connected to DH, while the rest are users of AH. Such large differences between heat demand in DH and AH sectors are related to the total distribution of non-residential stock where buildings with AH dominate (Fig. 1). Because subsidies are available to state-owned facilities, which are the largest users of heat in DH, there is a large decrease in heat demand in DH. In turn, the majority of AH are other users, for whom subsidies are not available, and the minority of state-owned facilities that are renovated cannot compensate for the increase in heat consumption from new facilities that enter this sector.

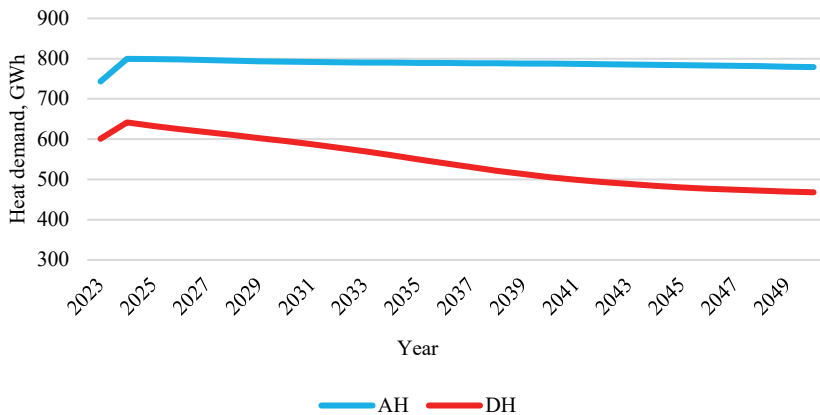


Fig. 6. Heat demand in DH and AH.

The renovation rate is analysed in two main groups: state buildings (municipal and educational) whose rate of renovation depends on the availability of subsidies, and other objects whose rate of renovation depends only on the owners' willingness to invest in energy efficiency solutions since no subsidies are available. Using the currently available subsidy funds, it is possible to renovate up to 89 % of municipal buildings and 91 % of educational buildings. In the sector of other buildings, the extent of renovation could reach only 62 %.

A sensitivity analysis was conducted to evaluate the impact of the amount of subsidies, the subsidy utilization rate in Riga, and the willingness of stakeholders to invest in energy efficiency initiatives on the rate of renovation. The simulation was performed by comparing the parameters "Indicated budget" (characterizing amount of subsidies) and "Probability of investment in renovation" (characterizing willingness to invest). Each of these parameters was analysed by varying the value by 50 % relative to baseline (Fig. 7), and both parameters were changed simultaneously by the same values. Changes in the available subsidies by half, increase the renovated area in 2050 by 13 % relative to the base scenario (Fig. 7). If the amount of available subsidies is increased twice, the renovated area can be 21 % larger compared to the base model. In this case, educational institutions would be completely renovated by 2039, while municipal institutions by 2040.

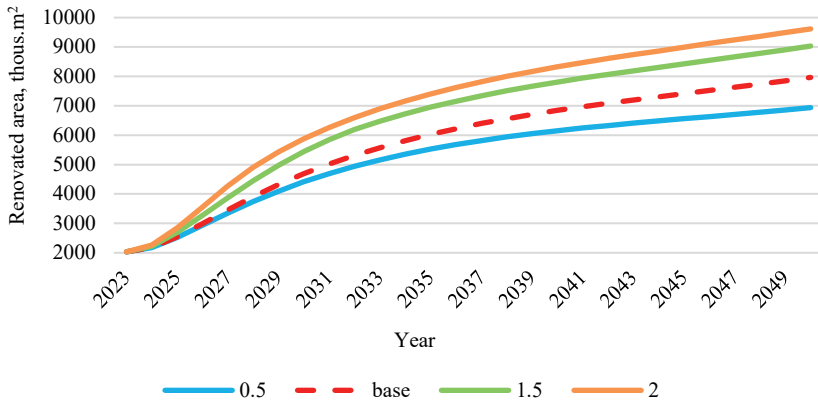


Fig. 7. Dynamics of the renovation depending on the indicated budget for renovation subsidies and probability of investing in renovation.

Changes in the rate of renovation due to the available subsidies influence heat demand (Fig. 8). The effect of renovation on heat demand is 2 % in 2050 when compared to the results of the base model for the same year. Furthermore, if renovation subsidies are doubled, heat demand decreases by 3 % compared to the base model.

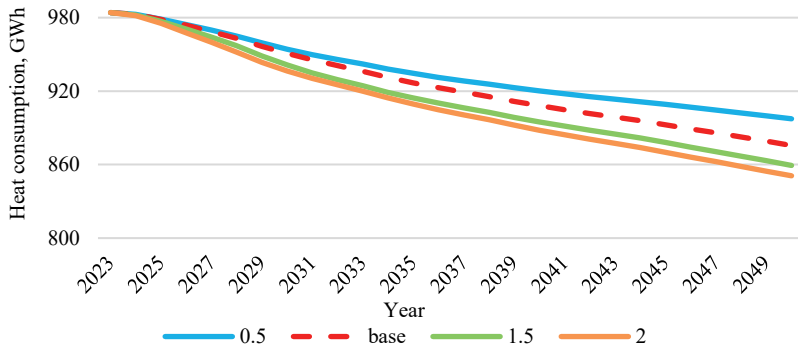


Fig. 8. Dynamics of the heat consumption in buildings built till 1991 depending on the indicated budget for renovation subsidies and probability of investing in renovation.

Considering that the tariff directly affects the extent of renovation, a sensitivity analysis was conducted to determine the impact of the tariff on the renovation. (Fig. 9). The impact of tariffs on renovation was determined separately for AH and DH users due to different tariffs and potentially different impact of the change in the tariff by 10 % relative to the existing value. Considering that Covid 19 restrictions and the outbreak of war in Ukraine directly affected the pace of renovation and practically stopped any renovation, a renovation rate increased after 2024, and one of the reasons were increased fuel prices. The renovation rate begins to decrease after 2026 as the tariff has stabilized. The tariff has an impact on renovation, but the extent of the impact depends on the size of the tariff (Fig. 2).

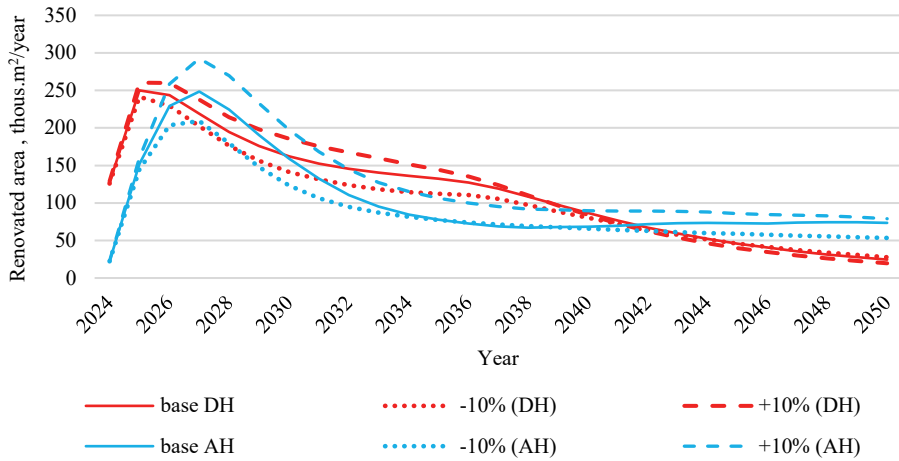


Fig. 9. The impact of the tariff on the renovated areas.

4. CONCLUSIONS

The results show that, considering the existing legislative situation and the planned tariff changes, it is possible to reduce the heat demand by 22 % in the year 2050, where the decrease could be 22 % in buildings with DH while a 5 % increase could be expected in buildings with AH. The largest consumers of heat, which make up 75 % of the total area of the non-residential buildings, are other users, and the consumption of those buildings determines most of the heat demand. Newly constructed buildings in other sectors are considerably more than in the sectors of municipal and educational sectors. New municipal and educational buildings are connected to DH in 90 % of cases, while in other sector buildings 62 % of cases choose alternative heating, thus significantly increasing the heat demand in this sector. Although various renovation funds are available, they are currently only available for state-owned buildings. Therefore, in the future, it is necessary to consider the possibility of promoting the involvement of other building users in the renovation processes. With the help of subsidies, the renovation extent of non-residential state buildings can reach 89 % among municipal buildings and 91 % among educational buildings. The extent of renovation among other sector buildings can reach only 62 %. Changes in the available subsidies by half, increase the renovated area in 2050 by 13 % relative to the base scenario. If the amount of available subsidies is increased twice, the renovated area can be 21 % larger compared to the base model. In this case, educational buildings would be completely renovated by 2039, while municipal buildings by 2040. Changes in the rate of renovation due to the available subsidies influence heat demand. The effect of renovation on heat demand is 2 % in 2050 when compared to the results of the base model for the same year. Furthermore, if subsidies for renovation are doubled, heat demand decreases by 3 % compared to the base model.

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