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Forecasting Heat Demand of Residential Buildings Connected to District Heating: The Case of Riga

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***Abstract* – A large proportion of greenhouse gas emissions come from heating and hot water supply and developed district heating systems will play an important role in meeting climate targets. The research presents a methodology for the study of the influence of combined factors on future thermal energy demand. System dynamics modeling has been applied to residential buildings in terms of renovation, new building construction, subsidy fund and assessment of reducing future thermal energy and greenhouse gas emissions. Changes in the consumption of thermal energy of district and decentralized thermal supply, under the influence of energy efficiency and financial factors were studied. Renovation of old buildings has a great impact on achieving the goals set on the way to climate neutrality by reducing heat energy consumption. As shown by the simulations carried out with the existing funding and legislation, by 2050 the expected reduction for users of district heat supply in Riga is 3 % and for users of alternative heating 2 %, from the existing 2023 consumption.**

***Keywords* – District heating; energy efficiency; heat demand; house renovation; system dynamics modelling.**

1. INTRODUCTION

The provision of heating and hot water in buildings accounts for a large part of greenhouse gas (GHG) emissions [1]. The construction of new buildings, as the introduction of new generation heating systems combined with the insulation of existing buildings should reduce heat consumption. However, in parallel with energy-saving measures, there is also an increase in energy demand due to the load electrification. To ensure the supply of electricity, energy producers need detailed and reliable network forecasts. Powell work [2] provides a detailed analysis of the heating, cooling and electrical load forecasting of a large district heating system (DH) for a college campus. A similar study was carried out by Tan studying the combined forecasting of electricity, heat, cooling, and gas loads in the Suzhou Industrial Park [3]. Fang performs weekly and seasonal demand forecasting of a Finnish district heating (DH) company's thermal energy using a regression and time series model [9]. A slightly different model is offered by Cholewa, creating a thermal energy prediction model for one building [4], and the model is intended for short-term forecasts. Research on demand

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forecasting is also conducted for the Latvia DH [5], [6]. A research gap has been identified in comparing previous studies: many future thermal energy consumption forecasts are either for short-term forecasting, which is mostly a week, or, if a longer period is considered, within one year, the studied system is of a small size, one object or the size of a student town.

Work of Bagaini [7] is based on comparison and classification. The introduction of the OSS concept in the market of house renovation can promote the renovation of buildings and reduce political and documentary obstacles, which mostly delay the progress of building renovation. The work from Frantál [8] paid attention to the differences between regions (geographical, socioeconomic, financial), which are the main factors in the use of subsidies and the amount of money that is used. The study shows that there is a correlation between the number of subsidies per capita and the number of subsidies between regions. There are significant differences between areas considered poor and at risk of energy poverty [8]. Bolton concluded that people do not trust contractors, and the financial aspect is also very important. Relating the interviews to the existing policy, the author emphasizes that "energy efficiency policy should promote the wider benefits of modernization, such as improving comfort and health, rather than stories of economy and efficiency" [9]. Similarly, Conradie studies behavioural theory norms and the influence of attitude on the intention to carry out energy efficiency renovation [10]. Belaïd has studied the behaviour of citizens and the obstacles that influence investment in energy efficiency in France [11]. Maia analysed the gradual renovation of buildings and the impact of renovation on costs [12]. Flores-Abascal has analysed the energy efficiency indicators using multi-criteria methodology, including energy poverty and indoor quality [13]. Lui has analysed various political approaches in China related to the renovation of low-rise buildings, and the purpose of the study is to analyse and stimulate the dynamics of renovation at the regional and national levels [14]. Considering the location of the study, system dynamics model was created for the National Climate and Energy Policy design, and heat consumption of buildings is modelled on a national scale [15]. One of the latest studies was conducted in 2023 for Riga, to predict heat consumption, but in this model, only one side of the city with a minority of populated areas and a scattered number of buildings connected to the DH company is considered [16]. Compared to similar studies, for example at the national level, the parameters used are compared in general, considering the peculiarities of the specific region, the speed of renovation, the number of inhabitants. Also, the building consumption indicators are average for all country.

Therefore, in this study, a system dynamics model is used to estimate the future heat demand for the DH company, which is the largest DH company by network size in the Baltics, and one of the largest in eastern European and Nordic countries. Since long-term thermal energy forecasting requires the evaluation of various impact factors, such as building renovation, human behaviour, improvements in renovation parameters, the impact of heat network losses, the impact of policies and subsidies. An analysis of the scientific literature related to these factors was performed. The proposed model differs from other models of this type by the level of detail, since modelling of heat energy consumption considers dynamics of specific heat consumption (kWh/m^2), the development of building area (m^2), accounts the building stock by the year of commissioning. The authors aim to propose a more accurate model, considering the energy efficiency indicators of each type of building sector, based on the period when the buildings were put into operation. Another advantage of the model is that it allows to calculate dynamics of the rate of connection to DH systems of the existing buildings and future building stock. Furthermore, sensitivity analysis allows to determine the impact of different strategies on the rate of renovation and connection to the DH system. Although this study uses data and technical assumptions that characterize the Riga district heating system, the model can be adapted for the analysis of other countries, regions, or cities.

2. METHODS

The system dynamics model to study heat consumption in the Riga DH system was created in Stella Architect environment [17]. The modelling time horizon is from 2023 to 2050 with a time step (dt) of ¼ year, since the smallest time constant in the model is one year. Data, from the Riga DH company, the statistics databases, publications, or reports were used, and assumptions were made when no data were available. Heat consumption of the residential buildings supplied from DH and the ones using alternative heating (AH) systems were considered. The main feedback effect (Fig. 1) is a relation between the gap between the goal and the actual heat consumption which must be reached by renovation of the building space and the subsidies for renovation. As heat consumption decreases due to renovation, motivation to provide subsidies for the renovation also declines, leading to reduced rate of renovation, ceteris paribus. A decreased rate of renovation results in larger heat consumption than otherwise would be if everything else remained the same. Thus, two balancing loops, one for the living space connected to DH and the other for the living space with AH, are formed as seen in Fig. 1.

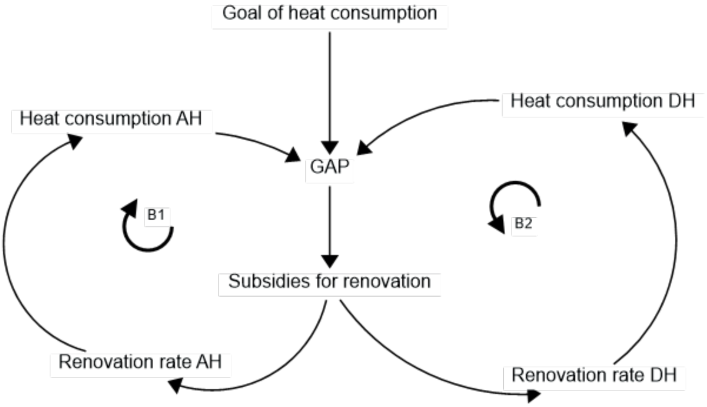

Fig. 1. Causal loop diagram (CLD) of the model. DH - district heating; AH – alternative heating; Renovation rate AH – renovation rate of the living space with alternative heating; Renovation rate DH - renovation rate of the living space with district heating.

2.1. *Area Development Sub-Model*

The construction of new residential area increases a heat demand therefore one of the sub-models analyses dynamics of the construction.

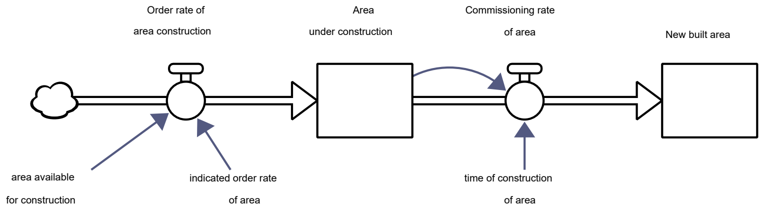

Fig. 2. Main stock and flow diagram for new living area development.

The demand for the construction of new area depends on the land space available for construction and the demand for new living area. The demand for new area depends on the population's income level, loan interest rates, land availability, demographic situation and construction costs [18]. The income level was calculated using Eq. (1):

$$a = 1.2285x^2 + 10.299x + 214.52, \tag{1}$$

where a – inhabitants' income per household member, EUR; x – the difference between the base year (2004) and the actual year. The construction costs were calculated using Eq. (2):

$$b = 58.687x + 708.35, \tag{2}$$

where b – costs of the newly built area, EUR/m^2; x – the difference between the base year (2002) and the actual year.

The bank loan yearly interest rate is assumed to be 2.1 % and remains constant throughout the modelling. Population growth, internal and external migration (Fig. 3), and changes in household size and structure (such as the demand for smaller or larger dwellings) affect the demand for new housing.

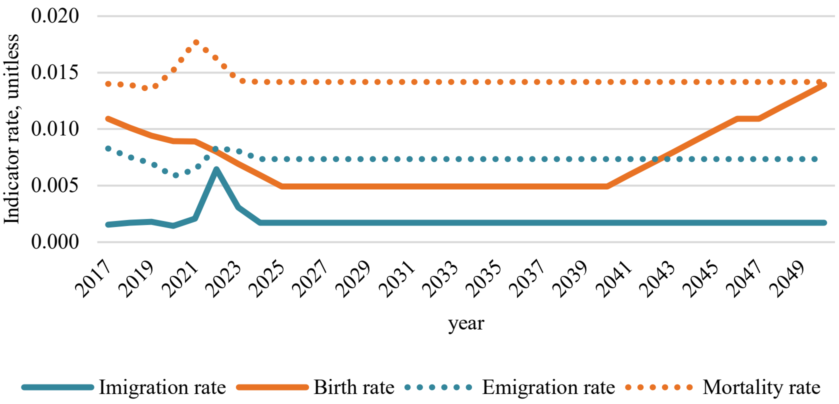

Fig. 3. Indicator rates for population in Riga.

Based on the available statistics from 1990 to 2023 and their research, as well as various future forecasts, about changes in the population, factors of future changes have been put forward because of the analysis. There is an increase in mortality during Covid-19 (Fig. 3), and the difference between arrivals and departures is related to the war in Ukraine. Therefore, these years are not considered in the forecasting statistics. The model includes a parameter – "desire for improvements in housing", which is defined as the desired area per person, and in 2021 in Riga it was 28 m^2 per person [19]. Based on statistical data on built-up areas and the number of inhabitants, the average increase in living area is 0.4 m^2 per person per year. Subsequently, the demand for constructing a new area is formed by the difference between the existing available area and the desired area per person. Construction time includes potential delays and design phases. Newly built areas are divided by type of heat supply, i.e. DH and AH. Based on the data available to the company over 10 years [20], on average 71 % of new buildings decide to connect to DH. For the main values described in this section see Table 1.

TABLE 1. VALUES USED IN THE LIVING SPACE DEVELOPMENT SUB-MODEL FOR BASE SCENARIO

Name	**Value**	**Units**	**Reference**	**Description**
Existing available free land areas	Changes over time	m^2	Assumption	It is assumed that the remaining built-up area is 30 % of the existing built-up area.
Existing living area		m^2	[21]	The built area of residential buildings until 2022.
Bank lending interest rate	2.1	%	[22]	Average, calculated based on available statistical data, assumed to be constant.
Euribor	Changes over time	%	[23]	Average calculated based on available statistical data, if the rate will decrease annually by 0.1% until it reaches 1 %. Once the 1 % mark is reached, the rate remains unchanged.
Demolition of area	0.002	% per year	[20]	The assumption is based on the data available to the company regarding the area, which is disconnected from DH because of demolishment.
Population	Changes over time	people	[24]–[32]	Calculation is based on the indicators: births, mortality, immigration, emigration.
Birth	Changes over time	people	[33]	Trendline graphic method.
Mortality	Changes over time	people	[34]	Trendline graphic method, not including data for time during Covid-19.
Immigration	Changes over time	people	[35]	Trendline graphic method Not counting the year of the start of the war, when Ukrainians arrived in large numbers.
Emigration	Changes over time	people	[35]	Trendline graphic method.
Household size	Changes over time	people	[36], [37]	It is assumed that on average there are 2 people in the household, but from 2041, the number increases by 0.1 every year, based on the forecasts of the increase in the birth rate.
Cost of the new construction area	Changes over time	EUR/m^2	[38]	Trendline graphic method.
Construction time	3	Years	Assumption	

2.2. Residential Area Renovation Sub-model

Potential areas for renovation are all areas of buildings built before 1991 and not renovated (Fig. 4). The interest in renovation depends on the probability of investing in renovation, which depends on the tariff and information campaign about benefits of renovation. The higher DH tariff leads to higher interest in renovation (Fig. 5).

The relationship between heat tariff and renovation activity is notable, with minimal interest in renovation when tariffs are below 50 EUR/MWh. Therefore, the effect of heat tariff is determined that depends only on the tariff level. If the tariff is below 45 EUR/MWh, then the impact factor is set as “0”, because at such a low tariff society is not motivated to carry out renovation activities. However, a surge in renovation applications occurred when tariffs exceeded 100 EUR/MWh due to rising fuel costs (Fig. 6).

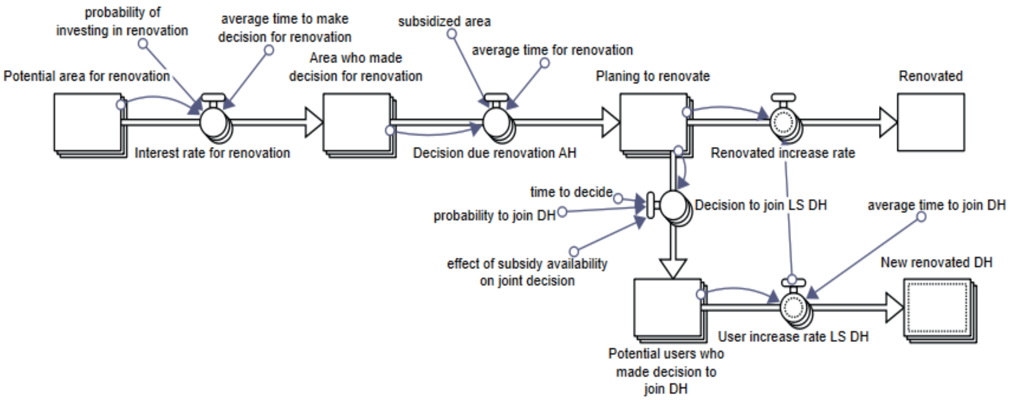

Fig. 4. Main stock and flow diagram for renovation in alternative heated (AH) areas.

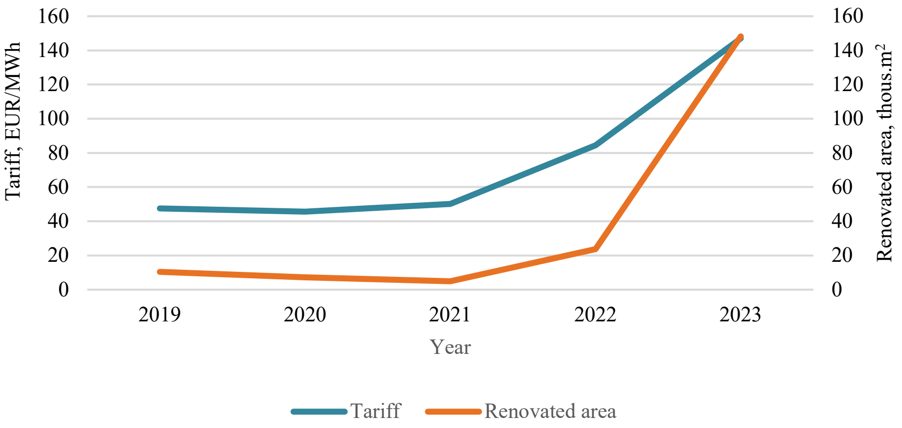

Fig. 5. Relation between renovated areas and tariff. Left y axis – heat tariff of Riga's DH supply; the right y axis – the total number of renovated building area.

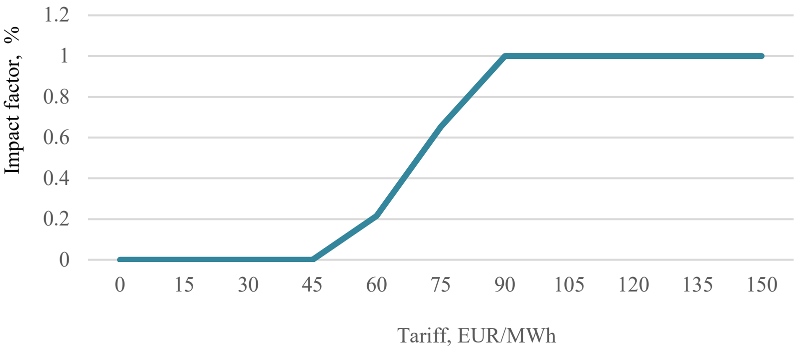

Fig. 6. Effect of heat tariff on decision to renovate. Larger impact factor leads to larger probability of investing in renovation.

The effectiveness of information campaigns was calculated based on the information in the National Energy and Climate Plan model [15]. It takes about two years on average for property owners to decide on renovations. This estimate is based on the experiences shared by representatives of renovated buildings, showing that it takes from 2 to 5 years from the initial renovation idea to contract finalization and subsidy receipt. The decision for renovation rate is affected by the average time for renovation and subsidies. Subsidies for Riga [39] are calculated for all buildings, regardless of their heating type. Analysis of data shows that until 2023, 67 % of the buildings renovated, were connected to DH and 15 % had AH. However, from the buildings renovated after 2023, 88 % were connected to DH and 12 % used AH, and that has been considered in the subsidy model (Fig. 7).

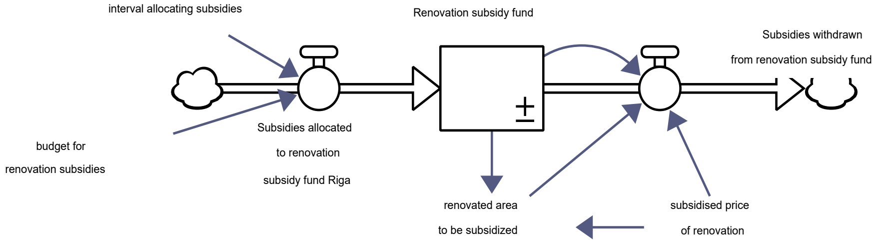

Fig. 7. Main stock and flow diagram for subsidy fund.

Similar stock-and-flow sub-model (Fig. 4) is made also for DH. System is presented since the areas with AH often plan renovation and connection to DH. The decision to join DH depends on the subsidies available for changing heating type [40], and it takes time to make this decision. Currently, 30 % of the buildings with AH deciding to renovate are also willing to connect to DH [20]. This proportion could rise to around 50 % in the future based on National Climate Target Plans and upcoming regulations [41].

2.3. Renovation Subsidy Sub-Model

The subsidy module was developed to evaluate the impact of current and potential future subsidies on building renovations and to determine future subsidy amounts (Fig. 7).

The goal of renovating buildings built up to 1991 is a key factor determining allocation of subsidies. The overall goal is to renovate 70 % of all buildings by 2050, considering that some buildings, e.g., those with cultural and historical significance, cannot be renovated. The difference between this goal and the actual renovated stock creates an effect on the allocation of subsidies. As the gap between the goal and the actual value is closed, less subsidies are granted, and no subsidies are granted when the goal of 70 % is reached. Data shows that Riga used circa 20 % of the total subsidies available in previous years, with an increase to 26 % in 2023. The subsidies are anticipated to be allocated every five years until the desired impact is reached. It was found out that during the renovation, subsidies cover circa 49 % of the total renovation costs [39]. that the renovation costs increase annually by circa 17 % [42] and the average costs are 393 EUR/m^2 [43]. This proportion and cost increase rate remains constant during the simulation.

For the main values described in this section see Table 2.

TABLE 2. VALUES USED IN THE SUBSIDY SUB-MODEL FOR THE BASE SCENARIO

Name	**Value**	**Units**	**Reference**	**Description**
Renovation target	70	%	Assumption	Currently, renovation is voluntary. It is not possible to renovate all buildings, due to lack of money, cultural heritage, unwillingness, and other reasons.
Subsidies used in Riga as proportion of the total subsidies in the country	Changes over time 26–50	%	[39]	An assumption based on the possibility that more buildings will be renovated in future in Riga and that the other cities of the country will already have completed renovations.
Indicated budget for renovation subsidies in Latvia	57	Mill. EUR	[39]	
Interval of allocating subsidies	5	years	[39]	

2.4. Energy Sub-Model

The energy module aims to calculate the heat consumed and produced by consumers over the year. Building areas were categorized by their year of construction to accurately estimate heat consumption, as specific consumption rates are known for each building category by construction year. The consumption of hot water is determined for existing, newly built, and areas that change the heating type from AH to DH. Specific hot water consumption (kWh/m^2) for existing and new areas is determined from company data of average summer consumption. Heat losses in DH networks are based on the existing data, with future reductions expected according to the company's strategic goals, which aim to limit losses to 10 % by 2050. Heat consumption is calculated for the existing, renovated and newly constructed building areas. Changes of the specific (per m^2) heat consumption over time of newly built (built after 2022) and renovated areas (Fig. 8 and Fig. 9).

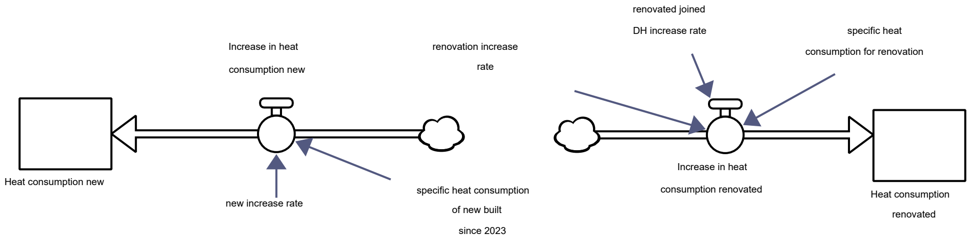

Fig. 8. Main stock and flow diagram for heat consumption in new and renovated areas.

Both the historical and the expected future specific heat consumption [44]–[47] was considered (Fig. 9). Based on the data available to the company, the theoretical and actual consumption of buildings over the last 5 years was compared, and the values of the specific heat consumption were corrected.

The heat consumption was corrected by considering the actual average outdoor temperature and the number of actual heating days during a certain year according to ISO standard [48] and calculated based [16].

For the main values described in this section see Table 3.

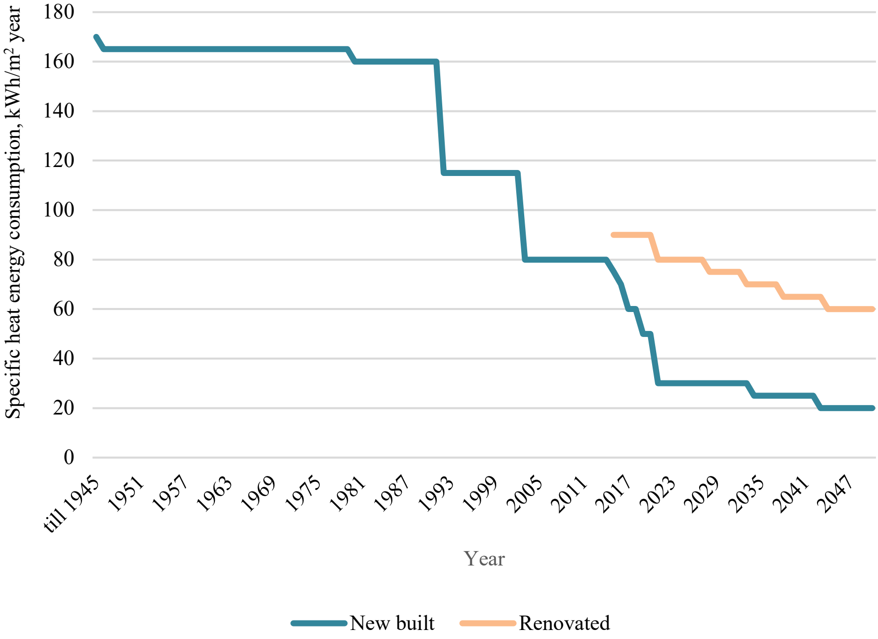

Fig. 9. Specific heat energy consumption for renovated and newly built areas.

TABLE 3. VALUES USED IN THE ENERGY SUB-MODEL FOR THE BASE SCENARIO

Name	**Value**	**Units**	**Reference**	**Description**
Hot water consumption	40	kWh/m^2 year	[20]	Average summer energy consumption in DH.
Heat losses in DH systems	Changes over time	%	[20]	Declines from 13 % to 10 %.
Heat losses in AH systems	20	%	Assumption	
Normative heating days	192	days	[49]	
Number of actual heating days	200	days	Assumption	Based on changes in the average length of the heating season since 1992, and residents' demand for comfort.
Indoor temperature	20	°C	Assumption	The average assumed usable comfort temperature.
Normative outdoor temperature	1.1	°C	[49]	
Actual outdoor temperature	Changes over time	°C	[50]	Based on existing historical data and future projections, assuming an annual temperature increase of +0.01 °C, starting at +3.15 °C in 2023.

2.5. Validation and Limitations of the Model

Validation was performed based on the period from 2017 to 2023. Validation was performed for demographic (immigration, emigration, births and mortality) and population economic indicators, renovated areas and DH energy consumption. As can be observed, the simulated data of the model agrees with the actual data (Fig. 10).

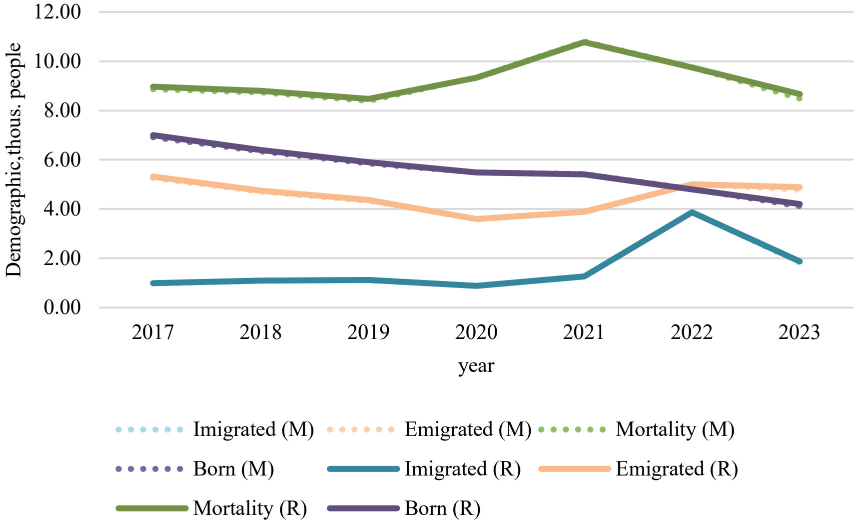

Fig. 10. Validation results of demographical indicators. The letter M stands for simulated data, and the letter R stands for real statistical data.

As can be seen from results of validation for renovated areas (AH and DH) (Fig. 11), the results of the model and the actual data agree quite accurately until 2020. The disagreement in 2020 and 2021 can be explained by Covid-19, when there was no possibility of completing the started projects due to restrictions, and post-COVID-19 differences when delayed projects were to be completed.

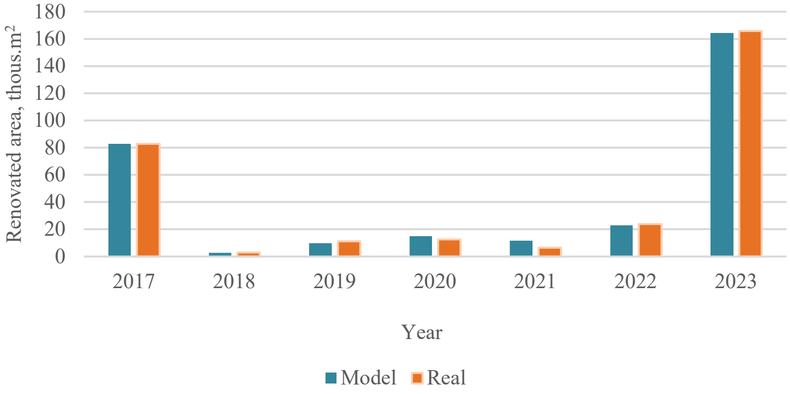

Fig. 11. Validation results of renovated area.

Validation of the heat demand (Fig. 11) was performed based on the outdoor temperature and the duration of the heating season in days. As can be seen, the biggest difference in the results was observed in 2020. The total error is 1 %. This could be explained by the improvement of citizens' energy efficiency literacy, efficient and rational use of energy, e.g., by regulating the indoor temperature.

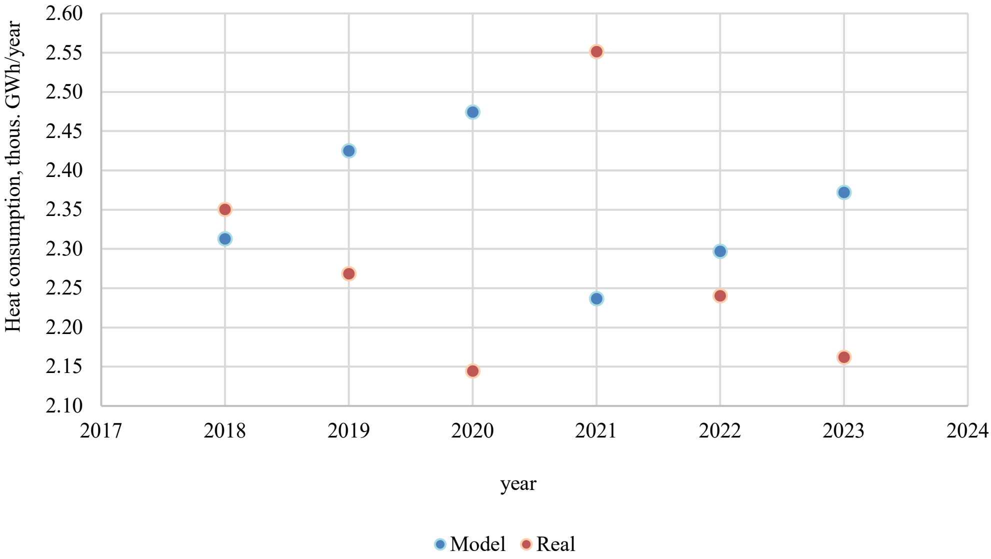

Fig. 12. Validation results of heat consumption.

Buildings constructed after 1991 were not considered for connection to DH, based on the company's data showing that buildings operational until 2022 had not previously been connected, likely due to their relatively new internal heating systems and low maintenance costs.

3. RESULTS AND DISCUSSION

Gradual renovation of residential houses will ensure the sustainability of the buildings, as well as reduce heat consumption, while connection to the DH will ensure a safe and continuous supply of heat energy and can also reduce GHG emissions from the process of heat energy production and consumption of residential buildings. The results (Fig. 12) show that in 2050 the total heat energy consumption in DH will decrease by 5 % or 119 GWh per year, and by 2 % or 20 GWh per year in AH compared to 2023. This slight decrease is due to the slow pace of renovations and construction of new buildings, which limits the decline in consumption.

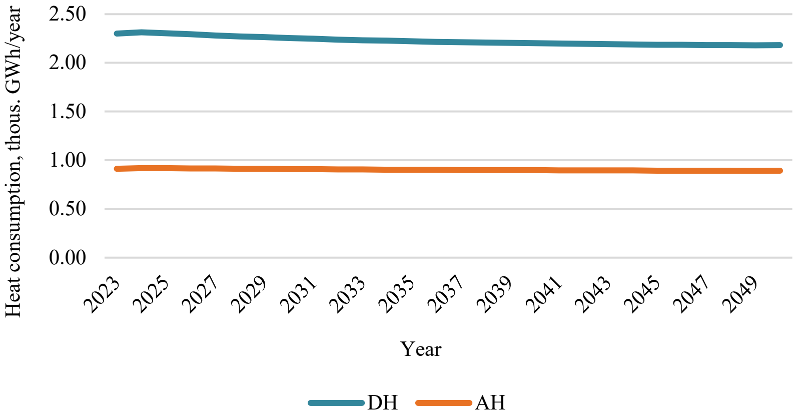

Fig. 13. Heat consumption in DH and AH systems.

The goal of renovating all buildings built before and in 1991 was to reduce GHG emissions. The difference between the goal and the actual renovated space (Fig. 13) shows that with the existing decisions and the speed of renovation, it is not possible to achieve the goal set – to renovate all buildings built before and in 1991.

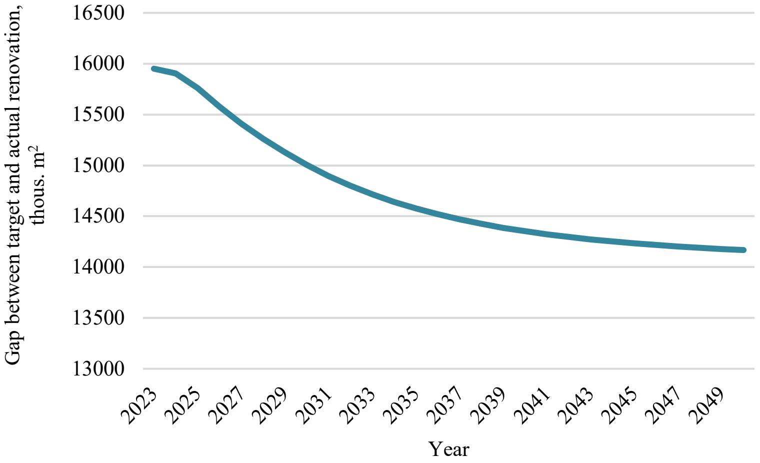

Fig. 14. Gap between target and actual renovated area.

It is generally assumed that the lack of funding holds back the rate of renovation. For this reason, a sensitivity analysis was performed for the parameter – “indicated budget for renovation subsidies”. By doubling the number of subsidies, it is possible to reduce the difference between the goal and the actual renovated area by 20 % or 3254 thousand m^2, but still not achieving the goal (Fig. 14). By increasing the number of existing subsidies tenfold, it is possible to achieve a considerable amount of renovation.

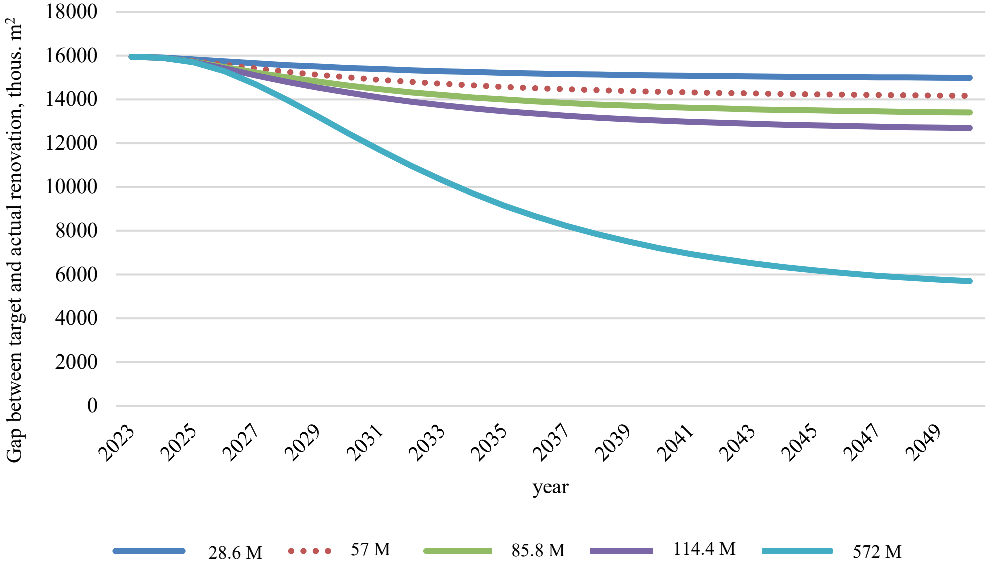

Fig. 15. Dynamics of the gap between the target and the actual renovated area depending on the indicated budget for renovation subsidies.

4. CONCLUSIONS

Modeling of potential future heat consumption indicates that the rate of renovation has a great influence on reducing consumption. If the existing development trends remain the same, a 5 % decrease in heat consumption is expected in DH systems and 2 % in systems with AH. In total, only 11 % of the total living space may be renovated by 2050. Only 1 % of the total area using AH may decide to connect to DH during the renovation process. The number of subsidies is the determining factor for the intensity of renovation. The study will continue by supplementing building stock with the non-residential buildings and considering fuel diversification.

REFERENCES

[1] REN21 Secretariat. Renewables 2023 global status report. 2023. [Online]. [Accessed 16.10.2023]. Available: https://www.ren21.net/gsr-2023/modules/energy_demand/

[2] Powell K. M. Sriprasad A., Cole W. J., Edgar T. F. Heating, cooling, and electrical load forecasting for a large-scale district energy system. *Energy* 2014:74:877–885. https://doi.org/10.1016/j.energy.2014.07.064

[3] Tan Z. *et al.* Combined electricity-heat-cooling-gas load forecasting model for integrated energy system based on multi-task learning and least square support vector machine. *Journal of Cleaner Production* 2020:248:119252. https://doi.org/10.1016/j.jclepro.2019.119252

[4] Cholewa T. *et al.* On the short term forecasting of heat power for heating of building. *Journal of Cleaner Production* 2021:307:127232. https://doi.org/10.1016/j.jclepro.2021.127232

[5] Petrichenko R., Baltputnis K., Sauhats A., Sobolevsky D. District heating demand short-term forecasting. In 2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe). IEEE, 2017. https://doi.org/10.1109/EEEIC.2017.7977633

[6] Rusovs D., Jakovleva L., Zentins V., Baltputnis K. Heat Load Numerical Prediction for District Heating System Operational Control. *Latvian Journal of Physics and Technical Sciences* 2021:58(3):121–136. https://doi.org/10.2478/lpts-2021-0021

[7] Bagaini A., Croci E., Molteni T. Boosting energy home renovation through innovative business models: ONE-STOP-SHOP solutions assessment. *Journal of Cleaner Production* 2022:331:129990. https://doi.org/10.1016/j.jclepro.2021.129990

[8] Frantál B., Dvořák P. Reducing energy poverty in deprived regions or supporting new developments in metropolitan suburbs? Regional differences in the use of subsidies for home energy efficiency renovations. *Energy Policy* 2022:171:113250. https://doi.org/10.1016/j.enpol.2022.113250

[9] Bolton E., Bookbinder R., Middlemiss L., Hall S., Davis M., Owen A. The relational dimensions of renovation: Implications for retrofit policy. *Energy Res Soc Sci* 2023:96:102916. https://doi.org/10.1016/j.erss.2022.102916

[10] Conradie P., Martens E., Van Hove S., Van Acker B., Ponnet K. Applying an Extended Model of Theory of Planned Behaviour to Predict Intent to Perform an Energy Efficiency Renovation in Flanders. *Energy Build* 2023:298:113532. https://doi.org/10.1016/j.enbuild.2023.113532

[11] Belaïd F., Massié C. Driving forward a low-carbon built environment: The impact of energy context and environmental concerns on building renovation. *Energy Economics* 2023:124:106865. https://doi.org/10.1016/j.eneco.2023.106865

[12] Maia I. E. N., Harringer D., Kranzl L. Staged renovation and the time-perspective: Which other metric should be used to assess climate-optimality of renovation activities? *Smart Energy* 2023:11:100110. https://doi.org/10.1016/j.segy.2023.100110

[13] Flores-Abascal I. *et al.* A novel multicriteria methodology to assess the renovation of social buildings. *Journal of Building Engineering* 2023:77:107505. https://doi.org/10.1016/j.jobe.2023.107505

[14] Liu Z. *et al.* Incentive initiatives on energy-efficient renovation of existing buildings towards carbon–neutral blueprints in China: Advancements, challenges and prospects. *Energy and Buildings* 2023:296:113343. https://doi.org/10.1016/j.enbuild.2023.113343

[15] Blumberga A., Bažbauers G., Blumberga D., Jaunzems Dz. Valsts Pētījumu Programma. Projekts Enerģētikas un klimata modelēšana virzībā uz oglekļa neitralitāti. (National Research Program. Project Energy and Climate Modeling Towards Carbon Neutrality). 2020. [Online]. [Accessed 18.03.2024]. Available: https://videszinatne.rtu.lv/wp-content/uploads/2021/02/5_NEKP2030-un-klimata-merki.pdf (In Latvian)

[16] Ziemele J., Gendelis S., Dace E. Impact of global warming and building renovation on the heat demand and district heating capacity: Case of the city of Riga. *Energy* 2023:276:127567. https://doi.org/10.1016/j.energy.2023.127567

[17] ISEE Systems. 'Stella® Architect.' [Online]. [Accessed 09.01.2024]. Available: https://www.iseesystems.com/store/products/stella-architect.aspx

[18] Centrālā statistikas pārvalde. Mājsaimniecību rīcībā esošie ienākumi reģionos (eiro mēnesī) 2004–2023. [Central Statistical Bureau. Household disposable income in regions (euro per month) 2004–2023]. [Online]. [Accessed 23.12.2024]. Available: https://stat.gov.lv/lv/statistikas-temas/iedzivotaji/majsaimniecibu-ienakumi/tabulas/mis030-majsaimniecibu-riciba-esosie?themeCode=MI (In Latvian)

[19] Centrālā statistikas pārvalde. Apdzīvoti tradicionālie mājokļi pēc dzīvojamās platības uz vienu iemītnieku reģionos. [Central Statistical Bureau. Inhabited traditional dwellings by living space per inhabitant in regions]. [Online]. [Accessed 23.12.2024]. Available: https://data.stat.gov.lv/pxweb/lv/OSP_PUB/START__POP__MA__MAS/MAS030 (In Latvian)

[20] AS Rīgas Siltums. Uzņēmuma dati [Company data].

[21] Valsts zemes dienests. Būves raksturojošie dati [Structure characterizing data].

[22] Latvijas Banka. Izsniegto kredītu vidējās svērtās procentu likmes [Bank of Latvia. Weighted average interest rates on loans issued]. [Online]. [Accessed 23.12.2024]. Available: https://statdb.bank.lv/lb/Data.aspx?id=175&pk_vid=581ef93ce004c6cb1681913440a14944 (In Latvian)

[23] Triami Media. Historical Euribor rates. [Online]. [Accessed 23.12.2024]. Available: https://www.euribor-rates.eu/en/euribor-charts/#google_vignette (In Latvian)

[24] Centrālā Statistikas pārvalde. Iedzīvotāju skaits gada sākumā, tā izmaiņas un dabiskās kustības galvenie rādītāji reģionos, pilsētās un novados 1967–2022. [Central Statistical Bureau. Population at the beginning of the year, its changes and main indicators of natural population growth in regions, cities and counties 1967–2022]. [Online]. [Accessed 16.10.2023]. Available: https://data.stat.gov.lv/pxweb/lv/OSP_PUB/START__POP__IR__IRS/IRS030/ (In Latvian)

[25] Latvijas Zinātņu Akadēmijas Ekonomikas Institūts. Rīgas apkaimju klasifikācija pēc to prognozējamā iedzīvotāju skaita izmaiņām līdz 2030. gadam. 2020. [Institute of Economics of the Latvian Academy of Sciences. Classification of Riga Neighborhoods by their Forecasted Population Changes by 2030]. [Online]. [Accessed 09.01.2024]. Available: http://sus.lv/lv/petijumi (In Latvian)

[26] Apkaimes. Iedzīvotāju skaits [Neighborhoods. Population]. [Online]. [Accessed: 01.04.2024]. Available: https://apkaimes.lv/statistika/iedzivotaju-skaits-2/ (In Latvian)

[27] Gatulytė I., Verdiņa V., Vārpiņa Z., Lublóy Á. Level of health literacy in Latvia and Lithuania: a population-based study. *Archives of Public Health* 2022:80(1):166. https://archpublichealth.biomedcentral.com/articles/10.1186/s13690-022-00886-3

[28] Brzozowski J. S. Szkołut S., Sikorska J. LATVIA Migration and demographic patterns in Central-Eastern Europe. Hungary. Migration and demographic patterns in Central-Eastern Europe Report. Latvia. Migration and demographic patterns in Central-Eastern Europe Contents. 2023. [Online]. [Accessed 16.10.2023]. Available: http://dx.doi.org/10.5281/zenodo.7782043

[29] Krišjāne Z., Bērziņš M., Sechi G., Krūmiņš J. Residential Change and Socio-demographic Challenges for Large Housing Estates in Riga, Latvia. In: Hess, D., Tammaru, T. (eds) *Housing Estates in the Baltic Countries. The Urban Book Series*. Springer.2019:225–245. https://doi.org/10.1007/978-3-030-23392-1_11

[30] Thalberg S. Demographic Patterns in Europe. A review of Austria, Germany, The Netherlands, Estonia, Latvia, and Lithuania. 2003. [Online]. [Accessed 16.10.2023]. Available: https://www.researchgate.net/publication/5095904_Demographic_Patterns_in_Europe_A_review_of_Austria_Germany_The_Netherlands_Estonia_Latvia_and_Lithuania

[31] Dahs A. Historical Regional Demographic Divergence in Latvia: Lessons of the Common Past with Eastern Partnership Countries. *TalTech Journal of European Studies* 2014:4(2):119–133. https://doi.org/10.2478/bjes-2014-0019

[32] Varpina Z. Countries of old men? Demographic challenges in Estonia, Latvia and Lithuania. 2018. [Online]. [Accessed 16.10.2023]. Available: https://www.researchgate.net/publication/325284279_Countries_of_old_men_Demographic_challenges_in_Estonia_Latvia_and_Lithuania#fullTextFileContent

[33] Centrālā statistikas pārvalde. Dzīvi dzimušo skaits pēc dzimuma reģionos, republikas pilsētās un novados [Central Statistical Bureau. Number of live births by sex in regions, cities of the republic and municipalities]. [Online]. [Accessed 23.12.2024]. Available: https://data.stat.gov.lv/pxweb/lv/OSP_PUB/START/IDS030 (In Latvian)

[34] Centrālā statistikas pārvalde. Mirušo skaits pēc dzimuma un pa vecuma grupām reģionos, republikas pilsētās un novados. Central Statistical Bureau [Number of deaths by gender and age groups in regions, cities and counties of the republic]. [Online]. [Accessed 23.12.2024]. Available: https://data.stat.gov.lv/pxweb/lv/OSP_PUB/START/IMV020 (In Latvian)

[35] Centrālā statistikas pārvalde. Iedzīvotāju starptautiskā ilgtermiņa migrācija reģionos, republikas pilsētās un novados [Central Statistical Bureau. International long-term migration of the population in regions, cities and counties of the republic]. [Online]. [Accessed 23.12.2024]. Available: https://data.stat.gov.lv/pxweb/lv/OSP_PUB/START__POP__IB__IBE/IBE080 (In Latvian).

[36] Centrālā statistikas pārvalde. Mājsaimniecības un ģimenes [Central Statistical Bureau. Households and Families]. [Online]. [Accessed 17.10.2023]. Available: https://www.csp.gov.lv/lv/majsaimniecibas-un-gimenes (In Latvian).

[37] Centrālā statistikas pārvalde. Privāto mājsaimniecību kopējais skaits un mājsaimniecības vidējais lielums [Central Statistical Office. Total number of private households and average household size]. [Online]. [Accessed 23.12.2024]. Available: https://data.stat.gov.lv/pxweb/lv/OSP_PUB/START/MVS010 (In Latvian)

[38] Arco real estate. Tirgus pārskats [Market review]. [Online]. [Accessed: Dec. 23, 2024]. Available: https://www.arcoreal.lv/lv/tirgus-parskati/latvija/ (In Latvian)

[39] Altum. Daudzdzīvokļu māju energoefektivitāte 2022.–2026. [Energy efficiency of apartment buildings 2022–2026]. [Online]. [Accessed 23.11.2024]. Available: https://www.altum.lv/pakalpojumi/iedzivotajiem/daudzdzivoklu-maju-energoefektivitate-2022-2026/ (In Latvian)

[40] Vides investīciju fonds. Atjaunīgo energoresursu iekārtu uzstādīšana [Environmental Investment Fund. Installation of renewable energy equipment]. [Online]. [Accessed 23.11.2024]. Available: https://lvif.gov.lv/valsts-atbalsts/iedzivotajiem/ (In Latvian)

[41] Rīgas Dome. Par teritoriālajām zonām siltumapgādes veida izvēlei un prasībām siltumapgādes sistēmas iekārtu izvēlei [Riga City Council. On territorial zones for choosing the type of heat supply and requirements for choosing heating system equipment]. Latvia, 2024. [Online]. [Accessed 22.11.2024]. Available: https://likumi.lv/ta/id/350039-par-teritorialajam-zonam-siltumapgades-veida-izvelei-un-prasibam-siltumapgades-sistemas-iekartu-izvelei (In Latvian)

[42] Altum. Pandēmija un būvniecības cenas pret māju renovāciju – kā panākt neizšķirtu rezultātu? [Pandemic and construction prices versus home renovation – how to achieve a draw?]. [Online]. [Accessed 24.11.2024]. Available: https://www.altum.lv/pandemija-un-buvniecibas-cenas-pret-maju-renovaciju-ka-panakt-neizskirtu-rezultatu/ (In Latvian)

[43] Altum. Laikus neiesniegti daudzdzīvokļu ēku renovācijas dokumenti – zaudēta Eiropas nauda [Untimely submission of renovation documents for apartment buildings – European money lost]. [Online]. [Accessed 24.11.2024]. Available: https://www.altum.lv/laikus-neiesniegti-eku-renovacijas-dokumenti-zaudeta-eiropas-nauda/ (In Latvian).

[44] Ministru kabinets. Ēku energoefektivitātes aprēķina metodes un ēku energosertifikācijas noteikumi [Cabinet of Ministers. Methods for calculating the energy efficiency of buildings and regulations for the energy certification of buildings]. Latvia, 2021. [Online]. [Accessed 03.12.2024]. Available: https://likumi.lv/ta/id/322436-eku-energoefektivitates-aprekina-metodes-un-eku-energosertifikacijas-noteikumi (In Latvian)

[45] Ministru kabinets, Noteikumi par ēku energosertifikāciju [Cabinet of Ministers, Regulations on Energy Certification of Buildings]. Latvia, 2013. [Online]. [Accessed 03.12.2024]. Available: https://likumi.lv/ta/id/258322-noteikumi-par-eku-energosertifikaciju (In Latvian)

[46] Ministru kabinets. Noteikumi par ēku energosertifikāciju [Cabinet of Ministers, Regulations on Energy Certification of Buildings]. Latvia, 2015. [Online]. [Accessed 03.12.2024]. Available: https://www.vestnesis.lv/op/2015/228.4 (In Latvian)

[47] Ministru kabinets. Noteikumi par ēku energosertifikāciju [Cabinet of Ministers, Regulations on Energy Certification of Buildings]. Latvia, 2010. [Online]. [Accessed 03.12.2024]. Available: https://likumi.lv/ta/id/211642-noteikumi-par-eku-energosertifikaciju (In Latvian)

[48] International Organization for Standardization. ISO 15927-6:2007, Hygrothermal performance of buildings – calculation and presentation of climatic data – Part 6: accumulated temperature differences (degree-days). [Online]. [Accessed 25.12.2024]. Available: https://www.iso.org/standard/35564.html

[49] Ministru kabinets. Noteikumi par Latvijas būvnormatīvu LBN 003-19 “Būvklimatoloģija.” [Cabinet of Ministers. Regulations on Latvian Building Code LBN 003-19 “Building Climatology]. Latvia, 2019. [Online]. [Accessed 25.12.2024]. Available: https://likumi.lv/ta/id/309453-noteikumi-par-latvijas-buvnormativu-lbn-003-19-buvklimatologija (In Latvian)

[50] LVĢMC. Klimata pārmaiņu analīzes rīks [Climate change analysis tool]. [Online]. [Accessed 09.01.2024]. Available: https://www4.meteo.lv/klimatariks/ (In Latvian)