Preliminary assessment of preconditions to deliver carbon neutrality in apartment buildings by 2050

Lauri Lihtmaa^{1*} and Targo Kalamees^{2,1}

¹Nearly Zero Energy Buildings Research Group, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia

² Smart City Center of Excellence (Finest Twins), Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia

Abstract. Member states of European Union have large stock of residential buildings that require urgent renovation in order to reach carbon neutrality by 2050. In our paper we provide a preliminary evaluation of preconditions of such goal within the context of shrinking regions. Our data originates from renovation subsidy database of large renovation programme managed by state fund and from Nation Statistical Bureau. First we estimate the potential of apartment buildings occupation within the next 30 years. We exclude buildings that are going to be abandoned due to the demographical and migration reasons. Next we calculate the potential of construction sector to deliver required amount of renovations. We observe that the in our case current renovation rate must at least be increased by factor of three in order to comply with the carbon neutrality goal. This, however, is very challenging because supply of renovations' construction is limited and overstimulated demand could increase construction prices significantly while rendering the effect of state incentives inefficient. Therefore an urgent technological change in renovation delivery is required to reach carbon neutrality goals.

1 Introduction

Carbon neutrality is one of the big challenges within the energy sector. To mitigate climate change it is necessary to transform energy consumption from fossil fuels to renewables and also conserve energy. As buildings require about 40% total energy produced in Europe (50% in Estonia), it is obvious that there is a great potential for reducing energy demand. Energy performance of building directive (EPBD) [1] requires all new buildings to be nearly Zero Energy Buildings (nZEB) from 2020. However, in most of European countries, the majority of buildings stock was built after World War II mainly during the period with low requirements on energy performance. Therefore existing buildings include a large potential for energy performance improvement [2–6], especially in cold climate.

As reductions in CO₂ emissions are generally proportional to the energy saving potentials [7] EPBD requires EU member states to renovate almost all buildings by 2050 in order to achieve carbon neutral economy. This significant challenge is addressed in long term energy efficiency strategies that are prepared by member states and presented to European Commission. In order to set renovation milestones for next decades we need to know which buildings and where to involve in renovation strategy.

In their literature review on energy performance of buildings during the operational stage Gherardi and Ghisi [8] showed that buildings' stock-level analysis has extensive potential to improve building performance

analysis. Nägeli et al. [9] developed bottom-up building stock model of Switzerland and Sandberg et al. [10] modelled building stock in 11 European countries while showing that models can effectively reproduce the past development, current stock size and composition and the long-term dynamics in the system in an acceptable way.

It is clear that some buildings that are currently in use, will be left out of service by 2050. On one hand this happens naturally by the buildings stock renewing process which speed is estimated about 1% per year and modern carbon neutral buildings will be built instead. However, there are important reasons why buildings could be abandoned before the end of their life cycle.

There are two major trends that affect the demand for buildings in the future. Firstly, we point out the urbanisation which leads to major restructuring of the location of population. Larger and economically diverse centres are growing (supported by erecting of new nZEB buildings) as the periphery shrinks. The growth of the stronger regions is fuelled at expense of weaker regions [11]. This trend amplifies the regional divide between core-periphery lines [12]. Secondly, European population is getting older and shrinks [13].

As the population declines there is less demand for buildings, especially in peripheral regions. It is evident that there is no rationale to include such buildings in renovation plan.

Current calculations of the amount of buildings that require renovation are done rather simply. For example the previous renovation reports in Estonia are based on total amount of surface area recorded in building registry

* Corresponding author: research@ecobon.ee

[14,15]. Furthermore, building stock modelling has mostly applied in the context and expectation of population growth [10,16]. Those approaches ignore the effect of abandoned buildings in the future. More importantly, the calculations of carbon conservations targets are also based on this data which in turn could result in overestimated potential of energy and carbon reduction targets. However, abandoned buildings are not consuming energy and thus are not emitting carbon dioxide. This in turn renders the carbon goal more obtainable.

We would also like to point out that EPBD does not explicitly state that energy policy must address regional and social aspects. However, there are evidence that ignoring such aspects in policy application can have negative externalities which further exacerbates the social polarisation. For example recent studies show that renovation grants tend to distribute unequally between and within regions [17,18].

Therefore we can argue that long term renovation strategies must also address migration and demographical trends in order to address carbon neutrality in cohesion with regional development.

The requirement of EPBD to renovate most of the building stock is such an ambitious goal that we can even question to what extent it is achievable. On one hand, boosting renovation activities require incentives and information dissemination. However, if the demand for engineers and builders grow, the prices also tend to rise, which in turn renders the incentives and grants inefficient. This could seriously hinder the achievement of carbon neutrality goal. Thus, the growth capacity of the building sector is of paramount importance and must be analysed while designing a renovation strategy.

The objective of this study is to assess how the buildings' renovation goal can be achieved in the context of urbanisation and population decline taking account the growth limits of construction sector. We employ the example of residential sector in Estonia and focus on the apartment buildings.

2 Methodology

In order to predict building stock for the preliminary assessment of the goal of climate neutrality of buildings by 2050, we use the migration and demographic projections for forecasting the occupancy of existing buildings within the next 30 years, Fig 1. We analyse what kind of preconditions are needed to deliver the renovations by building sector. Specifically we look into the dynamics of renovation demand and construction prices.

To give an estimation of apartment buildings renovation potential, we start by describing the current residential stock that is built before the year of 2000 ($n=22597$). This is due to the reason that newer buildings are considered sufficiently energy efficient and we can use data from census of 2000 to compare with the data from building registry.

We use regional population forecast from National Statistical Bureau to estimate population change in counties ($n=15$) in order to calculate future occupation of apartment buildings. There are five scenarios for population forecast [19] in Estonia for 2050. We use the base scenario which is considered the most probable. For comparison reasons we also make rough estimations with more positive and more pessimistic scenario. As official population forecast is only addressing years till 2045, we used linear extrapolation to fit the forecast for EU carbon neutrality target of 2050.

To further specify the effects of regional population migration we use the results from commuting studies also prepared by National Statistical Bureau. We assume that if a region is shrinking, population is moving from smaller and economically weaker places to larger centres. This assumption is compliant with urbanisation and migration trends [20,21].

Next, we analyse the amount and regional distribution of new builds by utilising building permits from national buildings registry. Doing so we are able to assess the demand for new apartments and evaluate the capacity of construction sector in different regions.

Next, we look to what extent construction prices for renovations have changed during the period of 2010 and 2019. This period is selected because at that time Estonia has introduced an comprehensive subsidy programme to accelerate renovation activities [22]. Therefore, there is an exhaustive database readily available to analyse technical, economic and spatial dynamics of energy renovations. We only include buildings that have implemented deep energy renovations ($n=609$).

Next, we compare renovation cost dynamics against apartment buildings' construction price index in order to understand if the role of stimulated renovation demand has caused renovation costs to increase more than natural growth. Informal interviews with representatives of construction companies ($n=3$) are used to interpret the results.

We use MS Excel for statistical analysis and ArcGis software for spatial analysis.

We would like to point out that this study is a preliminary assessment and therefore we are yet unable to forecast which types of apartment building are going to be abandoned. At the time our contribution is sufficient for broader energy renovation strategy. However, for the regional application more specific analysis is required.

We acknowledge that renovation volume has been hindered also by renovation barriers such as mistrust, lack of social and financial capital, lack of motivation, information asymmetry. which have been addressed in numerous papers previously [23–27]. Instead we focus on the renovations delivery.

Fig 1. Influencing factors and data source to determine potential of renovations by 2050.

3 Results and discussion

3.1. Apartment buildings according to existing database

Apartment buildings account for 51% ($34\,282 \times 10^3 \text{ m}^2$) of the total net area of dwellings in Estonia. According to the 2000 census, 70% of people (i.e. 931,000 persons) lived in apartments. The most active construction period was 1961 – 1990, when about 79% apartment buildings were construed [28]. Dominating construction types for apartment buildings are brick and concrete (Fig 2). In total, there are about 22.6 thousand apartment buildings in building registry that are built before 2000. As a rule, dwellings in peripheral areas are older. Today the designed service life of older apartment buildings is close to the end which could lead to hazardous situations and therefore urgent intervention is needed.

Fig 2. Distribution of apartment buildings by the net area and by the construction types in Estonia [29].

3.2. Occupation of apartment buildings in 2050

The apartment building forecast depends on construction of new buildings and decline of existing buildings. Both parameters are influenced by demand which in turn depend strongly on population change.

Within last decade the average rate of new apartment buildings is 150 per year. New apartment buildings have mostly concentrated in capital region of Harju County and in southern centre of Tartu County. Those are the regions, which grow and also have gained most renovation subsidies form state's renovation programme during the last decade [30].

The main scenario of population forecast for 2050 estimates 3.5 percent decrease of residents. However, inner state migration shows that only two counties grow at the expense of others (Table 2). This means that a significant amount of apartment buildings are going to be abandoned within next decades. Our calculations show that 5322 apartment buildings which makes 17.1 percent of current total surface area, will be left out of service by 2050 (Table 2).

National Statistical Bureau's population forecast also includes more positive and pessimistic scenario which results about 4000 and 6000 of abandoned apartment buildings respectively. We can observe that those scenarios have little effect on the occupation change of apartment buildings compared to main scenario. This is because the impact of overall population decline is marginal compared to inner state migration which bases on the urbanisation and regional change principles.

In conclusion, the amount of apartment buildings that require extensive renovation is about 14.5 thousand which includes 64% of current apartment buildings stock (Table 1).

Table 1. Renovation potential forecast by 2050

	No of buildigs
Apartment buildings (built before 2000)	22 600
Renovated using subsidy programme (2010-2019)	1 100
Renovated without of any subsidy (2000-2019)	2 000
Building abandonment by 2050	5 000
Total renovation need by 2050	14 500

Table 2. Forecast of population and occupation change in apartment buildings by 2050.

Region	Population change (%)	Current stock of apartment buildings (built before 2000)		Abandonment of apartment buildings (by 2050)	
		No of buildings	Net area (thousand m ²)	No of buildings	Net area (thousand m ²)
Harju county	22.4	8 055	12 956	-56	-47
Hiiu county	-22.2	159	114	-82	-59
Ida-Viru county	-43.4	2 140	4 230	-1 068	-1 672
Jõgeva county	-39.2	688	559	-374	-269
Järva county	-40.6	764	715	-453	-365
Lääne county	-32.9	521	489	-185	-165
Lääne-Viru county	-33.9	1 486	1 361	-599	-499
Põlva county	-33.6	458	428	-221	-167
Pärnu county	-18.5	2 111	1 605	-540	-376
Rapla county	-22.9	651	564	-284	-237
Saare county	-20.3	540	454	-193	-134
Tartu county	5.8	2 476	2 803	-126	-83
Valga county	-39.7	596	582	-262	-208
Viljandi county	-32.8	1 265	881	-575	-356
Võru county	-29.9	687	638	-304	-224
Grand Total		22 597	28 378	-5 322	-4 861

3.3. Capacity of construction sector

Typical energy renovation includes additional thermal insulation (typically onsite construction) of walls (15 – 20cm) and roof (30 – 40cm), replacing windows, installing new heating system and mechanical ventilation system with heat recovery [31–33]. In Estonia there are about 200 deep energy renovations per year. Continuous motivation of apartment associations to renovate their buildings combined with renovation grant [22] has resulted increased demand for construction works year by year.

National Statistics show that the construction price index has increased 15 percent during the years of 2011–2019. At the same time our analysis of renovation subsidy programme shows that renovation costs have increased 59 percent. While the average renovation cost in 2015 was 247 €/m², it has increased to 297 €/m² in 2017[34].

Table 3. Renovation cost dynamics in 2010–2019

Year	Count of subsidised renovations	Renovation cost change in year (%)	Construction price index change in year (%)
2010	1	-	-
2011	21	16.4	3.3
2012	89	11.2	4.2
2013	65	11.2	4.4
2014	22	16.6	0.3
2015	16	2.5	-0.8
2016	79	10.1	-0.6
2017	139	13.9	1.0
2018	106	6.2	2.7
2019	71	11.0	1.8

This shows that state stimulations are increasing the demand for renovations faster than construction sector is able to grow. Yearly change of construction index and renovation costs are illustrated in table 3.

Our results do not consider that carbon neutrality goal also includes the renovation of other types of buildings such as commercial, education and administrative buildings. This means that the demand for construction delivery is even higher, thus rendering the challenge of climate change combat more difficult to achieve.

Construction companies have testified that using current laborious technics they are unable to double the renovation delivery. Our calculations show that in average the renovation delivery must be increased by threefold. Therefore, we can argue that using current technology, construction sector is unable to deliver renovations in significantly increased rate in the future.

3.4. Preconditions for carbon neutrality

Combining the previously given results with informal interviews with the stakeholders of construction sector, we can conclude next preconditions for carbon neutrality goal for apartment buildings

Firstly, it is clear that current pace and the capacity of growth of construction sector is insufficient to deliver carbon goals. Virtually all renovations are bulky handcraft which is slow and expensive due to the labour costs. Therefore technological change from manual built to prefabricated renovation is required.

* Corresponding author: research@ecobon.ee

Secondly, in order to increase the productivity of designers, standardised solutions especially for large building estates should be used. This in turn raises the productivity of offsite renovation and production companies.

Third precondition is sufficient and consistent financial support for carbon neutrality renovation. State support is required to start pilot projects of prefabricated panels and to encourage early adopters to choose new solutions. Although first pilots of prefabrication are tested, we suggest to continue with this practice in order to develop engineering and construction skills as well to introduce the solution for customers. Support can be reduced when prefabrication has mainstreamed and the costs have reached desired equilibrium.

Prefabrication requires constant demand in order for the sector to be sustainable. Therefore, state support should be readily available in order to stimulate the demand within recessions of economic cycles. Prefabrication technology can also be applied for export as there are similar buildings especially in other post-soviet member states. However, for the smaller, custom and heritage apartment buildings prefabrication possibilities are limited and thus we need further research on how productivity can be increased in such cases.

Fourth precondition addresses the context of regional disparities. Communities in growing centres are more capable to renovate than in smaller places and especially in shrinking regions and periphery [17]. Therefore, limited state support for renovations should be distributed between regions differently. Larger centres where market-based development prevails, state support should be used for project management and consultations to ensure the quality of renovations. Novel solutions that promote productivity can also be eligible for support. Although there is no rationale for carbon neutral renovations in shrinking regions, those buildings also require some renovations. State support should be used in cases which present unsafe building usage and show dangers for occupants' health.

The major target group for renovation support are regional and local centres which are key importance in settlement structure. If those places have market barriers for energy renovations, it is reasonable for the state to stimulate renovation demand and support also direct construction costs.

Current study concentrates on apartment buildings. The second large dwelling type, detached house, should not be overlooked. Those buildings are also significant, both in their ubiquity and energy consumption. Csoknyai showed that detached houses are responsible for 50-80% of the total primary energy demand of the housing stock, depending on the country [35].

4 Conclusions

Achieving carbon neutrality in buildings is an important and difficult challenge within next three decades. On the one hand, shrinking regions cause the reduction of residential buildings that are occupied in next decades, thus reducing the overall renovation demand. However,

our study shows that current renovation rate is still insufficient and needs to be increased by several times to deliver the required amount of renovations by 2050.

Clearly, government incentives such as grants and tax rebates are effective measures to boost renovation activities within communities. Such stimulations in turn could cause the significant construction price growth due to the rising demand and thus render the incentives inefficient while also hindering the renovations in vulnerable regions. Our case study shows that renovation demand has increased construction costs at least by factor of two.

We also note, that non-residential buildings must be also upgraded to meet carbon goals. Furthermore, overall construction demand increases also due to the urbanisation and regional migration which causes the increased demand for new builds. Therefore, as our case shows, carbon goals could only be achieved by technological change that results of significant increase in engineering and construction productivity.

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