Energy and hygrothermal performance challenges in the renovation of a over 100-year-old wooden apartment building into a nearly zero-energy building

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Abstract

The aim of this work was to analyze the renovation needs, hygrothermal performance before renovation and energy performance challenges of a wooden apartment building in the cold climate of Estonia, as the energy performance goals to ensure the carbon neutrality of the building stock are very ambitious. The need for renovation of old wooden apartment building are unavoidable. The need for investment is high, and in order to reduce the total cost, it is necessary to combine the renovation, which should be done in any case, with the improvement of energy performance. The reasons for making a renovation decision go beyond the boundaries of a single building, which is why it is necessary to use the principle of neighborhood renovation and include renewable energy solutions onsite or nearby.

Keywords: Renovation strategy, historic wooden apartment building, deep renovation, renovation need.

1. Introduction/Background

The revision of the Energy Performance of Buildings Directive (EPBD) will update the existing regulatory framework to reflect higher ambitions and more pressing needs for climate and social action to achieve a zero-emission and fully decarbonized building stock by 2050. Results have indicated that the main savings potential lies in the improvement of the existing building stock. The proposed measures should modernize the building stock, increase the speed of renovation and make it more durable and accessible. Although Member States may adapt energy performance requirements to buildings that are officially protected due to their architectural or historical value, people living in these buildings may still want to improve the energy performance of their homes in order to reduce energy costs and avoid energy poverty.

So far, research on improving the energy efficiency of historic buildings has been limited to the rather small reduction of heat loss. Arumägi et al. [1] developed a method for deep renovation of the entire building, taking into account all the different parts of the building and solving the joints of the facade elements, as a result of which the energy performance of the historic building is significantly improved without deteriorating the architectural appearance of the building. In this work, the energy performance ambition has been raised higher (nearly zero energy building, nZEB) to see if meeting the future carbon neutrality goals can preserve the historical urban visual environment (the replica of an original solution is considered to be acceptable) and no longer cause additional hygrothermal risks.

2. Methods

The building used for reference is a two-story wooden log building (12 apartments, 617 m²), located in the historical heritage conservation area of the city of Võru in Estonia and was built in the first half or middle of the 19th century (Figure 1).

The building technical condition, moisture damages, indoor hygrothermal loads before renovation and need for renovation were determined by onsite survey. Indoor hygrothermal loads were measured from two apartment.

The improvement of energy performance was modelled by dynamic whole building indoor and climate software IDA ICE considering Estonian climate and standard use condition.

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3. Results and discussion

Indoor climate measurement indicated highest indoor moisture supply $\Delta v = 6 - 8$ g/m$^3$. Based on the cross-sectional measurement from Estonian dwellings [2] we may indicate this as very high indoor hygrothermal load showing that current natural passive stack ventilation is not enough to remove excess moisture from dwellings. Balanced ventilation with efficient heat recovery and noise reduction is required to guarantee that it continues operating. Indoor temperature was on average 22 – 23 °C with quite high daily variation because of stove heating.

Moisture supply in crawl space during spring was on average $\Delta v = 0 - 1$ g/m$^3$, reaching to $\Delta v = 2.5$ g/m$^3$ at extreme cases. Indoor relative humidity (RH) in crawl space during spring was 50 – 70 %. Because of relatively high thermal transmittance of base floor high heat loss from apartment increased the temperature in crawl space. Heat from apartment and low moisture production (sand ground) from ground kept the RH below mould growth level. Visual inspection using the small camera did not show microbial damage on wooden base floor. Based on the feedback from occupants the base floor needs to be renovated to minimise cold floor feeling and decrease the heat loss of floor.

The condition of the building's exterior facade and roofing was in such a state that it needs to be replaced both to protect the underlying structures and to improve the exterior of the building. This is a typical situation when the service life of the unmaintained wooden boarding is more than 40 – 50 years. Therefore, a comprehensive complete renovation has to be done anyway to extend the service life of the building. Arumägi [3] have showed that though adding insulation to the external wall is most labor-intensive, it is most effective in lowering heat losses and increasing the air tightness of the historic wooden building. If additional insulation is needed anyway, it is reasonable to choose the thickness of the insulation in such a way that heat loss can be minimized.

The reference case is a building with its original structure, stove heating, and natural passive stack ventilation. Energy renovation measures were applied to the building’s envelope (external wall (EW), roof (Rf), windows (W), and floor (Fl)) and the building’s service systems (heating, ventilation, energy source). Improving the building envelope also has a positive effect in cases of air leakages, air leakage rate $q_{leak} = 4$ m$^3$/h·m$^2$ is considered in case of major renovation.

To reach nZEB level, local production of renewable energy is added to the architecturally and technically appropriate combinations. Electricity generation with solar panels was considered as a solution for local production of renewable energy.

![Figure 1. The principle of additional heating, how to maintain the Figure 1. The principle of additional heating, how to maintain the figure and proportions of the facade](image)

<table>
<thead>
<tr>
<th>Renovation strategy</th>
<th>Heat source</th>
<th>$U$, W/(m²·K)</th>
<th>PV, kW²</th>
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<tbody>
<tr>
<td>Major renovation</td>
<td>District heat</td>
<td>0.16</td>
<td>0.9</td>
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<td></td>
<td>GSHP</td>
<td>0.20</td>
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<td></td>
<td>AWHP¹</td>
<td>0.13</td>
<td>0.7</td>
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<td>nZEB, external wall 7 cm insulation</td>
<td>District heat²</td>
<td>0.27</td>
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<td>GSHP</td>
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<td></td>
<td>AWHP²</td>
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<tr>
<td>nZEB, optimal external wall insulation</td>
<td>District heat³</td>
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¹ requirement of the lower air leakage rate is needed to reach target
² minimum required installed nominal power

Acknowledgments

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