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Analysis of energy economic renovation for historic wooden apartment buildings in cold climates

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HIGHLIGHTS

- Energy saving potential in historic wooden apartment buildings is up to 63%.
- In historic wooden apartment buildings an economically viable energy saving level is 50%.
- The largest energy saving potential lies in heat source and building service systems.
- Of the building structures, insulation of the external wall has the highest potential.
- New heating and ventilation systems must be installed to fulfill regulations limits.

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ABSTRACT

Buildings represent the largest sector of primary energy consumption and play a major role in saving energy and reducing greenhouse gas emissions. Our analysis of energy consumption and potential energy savings is based on field measurements, computer simulations and economic calculations. The average primary energy consumption (PE) of wooden apartment buildings was 331 kW h/(m^2 a) 83% higher than the limit 180 kW h/(m^2 a) set in national regulations for apartment buildings subject to major renovation. The studied buildings represent a high potential for energy savings. The renovation packages were compiled using different insulation measures, HVAC solutions and energy sources to achieve a 20–65% reduction of primary energy. For historic buildings, the renovation solutions that concentrate on the building envelope can be problematic due to the need to preserve cultural and architectural values. Our calculation results indicate that the cost optimal PE level is around 250 kW h/(m^2 a) and the point at which renovation packages recover expenses is around a PE level of 170 kW h/(m^2 a). In terms of the architectural appearance the point at which renovation packages recover expenses is around a PE level of 210 kW h/(m^2 a). We propose to set a different PE limit for historic wooden apartment buildings with an architectural appearance worth preserving.

1. Introduction

Buildings represent the largest sector of primary energy consumption and play a major role in saving energy and reducing greenhouse gas emissions. Improvements of apartment buildings have raised their inhabitants' awareness of energy consumption in the building and have increased willingness to invest in energy saving solutions. Results [1–3] have indicated that the main savings potential lies in the improvement of the building's shell of existing building stock. Research by Altan and Mohelnikova [4] underline the importance of such thermally insulated building envelopes together with new windows for the reduction of overall energy consumption. It was shown by Morelli et al. [5] that theoretical energy use can be reduced by 68% as compared to the energy use prior to the retrofit by the installation of insulation, new windows and a ventilation system with heat recovery.

For historic buildings, the renovation solutions that concentrate on the building envelope are problematic due to the need for preserving cultural and architectural values. For historic, heritage, and traditional buildings, the improvement of energy performance should be a special case [6]. The energy savings in historic buildings are a new research challenge [7]. In addition to the analysis of the building's energy saving potential and its influence on the architectural appearance, economic viability [13–15] is an essential issue because the cost of the measures varies according to the type of the measure, the type of the building, individual conditions and the circumstances of the renovation.

Many studies discuss energy renovation of apartment buildings in scale from building components [8–11] through single buildings [12–14,16,17] up to full building stock [18–24]. Studies of

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energy-renovation have concentrated on historic apartment buildings [5,6,25,26] rather than on the energy-saving potential of historic wooden apartment buildings. This study discusses the technical potential and economic impact of potential energy renovation solutions for historic wooden apartment buildings in the Northern European cold climate in Estonia.

2. Methodology

We combined here field measurements, computer simulations and financial calculations of energy renovation measures.

2.1. Studied buildings

The study concentrates on the historic wooden apartment buildings that were built before the Second World War. They are a mark of industrial development and general urbanization in the history of Estonia.

Altogether 29 buildings and 41 apartments were investigated. Apartments in a typical historic three-story wooden apartment building consist of up to three rooms, with a separate kitchen, entry and sanitary rooms. The basement floor typically houses storerooms or rooms for small businesses. Fig. 1 shows the appearance and the floor plan of one of the reference buildings.

The chosen buildings occupy a volume of about 490–980 m^3, the heated area of the buildings was between 242 and 823 m^2 and the average age was 98 years. Fig. 2 shows the cumulative distribution of the closed net area and the living space area of wooden apartment buildings in Estonia.

The external walls are typically made of 120–160 mm thick logs, without additional insulation, covered with wooden cladding or render. The attic floor is filled with a mix of the sand and sawdust as insulation materials. The buildings have two-pane windows with wooden frames. In 65% of the buildings, the apartments were heated by a wood heating stove (original) and in 35% by radiators (new). The heat source for the radiator system was mainly electricity or a gas boiler and in one of the buildings district heating. Most of the buildings were equipped with an electrical boiler to heat the domestic hot water. The studied dwellings had natural passive stack ventilation.

For our simulations, four buildings were selected as reference buildings based on the size and representativeness of a typical historic wooden apartment building from the era before the Second World War. All the buildings have simple floor plan with a central staircase made of stone in buildings “B” and “C” and made of wood in buildings “A” and “D”. Building “D” has no basement and the 1st floor is on the ground, buildings “A” to “C” are with a basement floor. Key characteristics describing the size and shape of the reference buildings are presented in Table 1.

2.2. Field measurements

Field measurements included indoor climate studies [28], building surveys and measurements of the properties of the building’s envelope [29]. Data for the electricity, gas, district heating and water consumption for each building were collected from the suppliers on a monthly basis over a three to four year period. The consumption of the firewood for heating was obtained from the apartment owners. In the absence of more accurate data, the energy used for heating in the buildings was estimated based on the information about the wood consumption in the apartments. The energy consumption of the buildings was analyzed, based on collected data, to give an overview of the real energy use in historic wooden apartment buildings in cold climates.

2.3. Simulations

The multi-zone indoor climate and energy simulation program IDA Indoor Climate and Energy 4.5.1 (IDA ICE) [30,31] was used for the simulations. The simulations were used to calculate the energy consumption of the buildings, to predict the energy savings and to propose the retrofit measures. Validated in different studies [32–35], IDA ICE is a tool for building simulations of energy consumption, indoor air quality and thermal comfort.

Simulation models were calibrated based on field measurements, user behavior, measured indoor climate and air tightness results. The energy renovation measures were simulated with the standard use of the building (indoor temperature ($\geqslant$21 °C); ventilation airflow (0.42 l/(s m^2) (normal level of expectation: indoor climate category class II [36] per heated area); the usage rate of the building, lightning (8 W/m^2) and equipment (2.4 W/m^2); and the heat from the inhabitants (2 W/m^2) to reduce the influence of the user behavior. For outdoor climate, the Estonian test reference year (HDD 4160 °C/d at t_i + 17 °C) [39] was used. In our calculations, delivered energy efficiencies of energy production and heat distribution systems were taken into account (see Table 2).

In our calculation of primary energy usage (presented as the energy performance value EPV, kW h/(m^2 a), the delivered energy is multiplied by the weighting factors for energy carriers:

- wood and wood-based fuels (excl. peat and peat briquettes) : 0.75;
- district heating: 0.9;
- fossil fuels (gas, oil, coal): 1.0;
- electricity: 2.0.

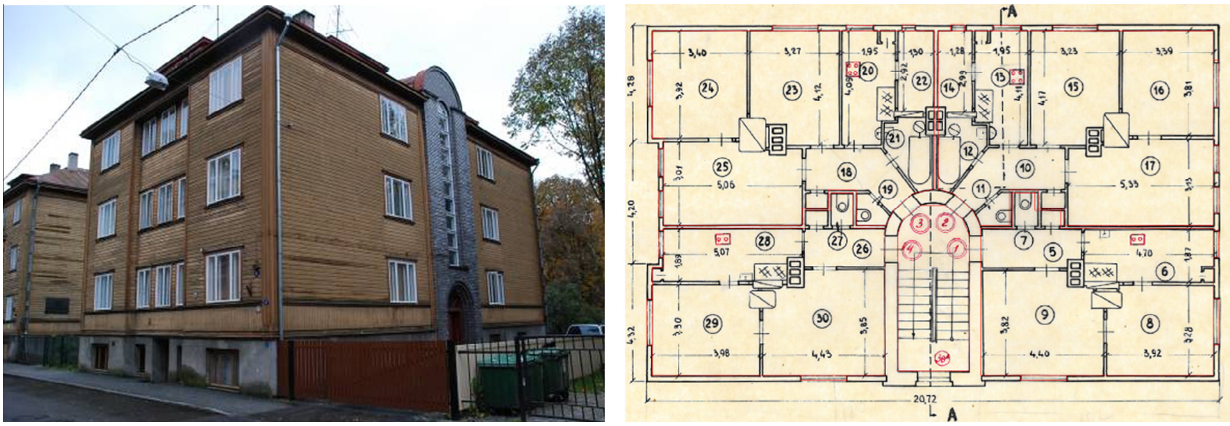

Fig. 1. Street view and the floor plan of a typical wooden apartment building (reference B).