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Renovation alternatives to improve energy performance of historic rural houses in the Baltic Sea region

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ABSTRACT

This paper analyses renovation alternatives to improve energy performance of historic rural houses in three countries (Estonia, Finland, Sweden) in the Baltic Sea region (cold climate). The study was conducted by a combination of field measurements and simulations. Indoor climate, typical houses and structures as well as the current condition and need for renovation were determined by field measurements. Based on field measurements, indoor climate and energy simulation models were validated and used to calculate energy use for different renovation measures. Energy renovation packages were calculated for different scenarios (minimal influence on the appearance of the house, improvement of thermal comfort, improvement of building service systems) for different energy saving levels. The analysis showed that the improvement of building service systems and the energy source holds the largest energy saving potential. The building envelope of old rural houses needs improvement also due to high thermal transmittance and air leakage. The insulation of the external wall has the largest single energy saving potential of the building's envelope. The results show how energy savings depend on energy saving targets, typology of the building, thermal transmittance of original structures, and building service systems.

1. Introduction

With the recast of Energy Performance of Buildings Directive (EPBD) [1] Europe has adopted an ambitious vision for the energy performance of its buildings. Lechtenböhme and Schüring [2] clearly showed that the improvement of the building shell of residential buildings offers a huge potential for energy savings which amounts to an annual 90 Mtoe by 2030 for the EU27. Over two thirds of this enormous potential is located in existing buildings. Therefore, in addition to new buildings, also existing buildings undergoing extensive renovations, will have to meet 'very high energy performance' standards by 2021.

Energy-renovation of buildings is a multi-criteria approach, where the cost of refurbishment, annual fuel economy after refurbishment, tentative pay-back time, harmfulness to health of the materials used, aesthetics, maintenance properties, functionality, comfort, sound insulation and longevity, etc., should be taken into account [3]. The cost-effectiveness, energy performance and environmental impact are typically used in the optimization of renovation solutions [4], [5]. Zavadskas and Antucheviciene [6] combined the economic benefits of the regeneration of buildings with the environmental potential as well as social interest. Optimisation can be done before or after setting the levels for energy performance requirements. Cost-effectiveness [7] can be considered when setting the levels for energy performance requirements [8] or designing of new buildings [9].

In addition to many quantitative values, optimisation may include also qualitative measures. Preserving environmental and historic values of buildings is one of the important considerations in all energy-renovation projects. Environmentally or historically valuable buildings may not follow the strict requirements on energy performance. As the overall number of historically valuable buildings is generally small, lower requirements for energy performance for valuable buildings do not destroy the ambitious vision for a reduction in the overall energy use of buildings. Therefore, energy performance requirements may be set according to realistic energy performance measures that do not destroy the historic value of buildings. Due to this, it is necessary to calculate energy performance for different renovation measures.

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Fig. 1. Example houses from Estonia (left), Finland (middle) and Sweden (right).

Many studies [10,11] have analysed the improvement of energy performance of historic buildings in towns. Much less information exists about energy-renovation of traditional rural houses. In their recent research, Bjarløv and Vladykova [12] have demonstrated practical ways of reducing thermal bridges significantly, increasing air tightness, upgrading insulation and adding mechanical ventilation to approximately half of the housing stock without significantly changing the architectural expression or having to relocate the occupants during the renovation for standard family detached and semi-detached wooden houses in arctic Greenland. Todorović [13] stated that it is impossible to reach sustainability without harmonious interdisciplinary interaction, without a balance between the physical and the spiritual, science and art, technology development and cultural and other human value improvements without an ethic of sustainability. Therefore, it is important to consider historic and milieu values in the improvement of the energy performance of traditional rural houses.

Even if there are no official requirements for the energy performance of historic buildings, owners and inhabitants of buildings wish solutions to be proposed for improvements of energy performance due to high maintenance costs. Therefore, a multi-criteria approach is a useful tool also in this area. The optimisation of renovation depends on a variety of aspects, such as the initial levels and the final purpose of the energy performance changes, indoor climate, historic and social values, the necessity for renovation from structural, building physical, indoor environmental building service related features. For decision making both are important: improvement as a percentage from initial conditions as well the final level. Whether or not the need for renovation is high, energy related measures are more effective. Therefore, energy performance should be analysed from the state of "as built" up to different renovation measures.

Current paper analyses renovation alternatives to improve energy performance of historic rural houses in three states (Estonia, Finland, Sweden) in the Baltic Sea region (cold climate).

2. Methods

The study was done by a combination of field measurements and simulations. Indoor climate, typical houses and structures, as well the current condition and necessity for renovation were determined by field measurements. Based on field measurements, indoor climate and energy simulation models were validated and used for the calculation of the use of energy for different renovation measures.

2.1. Studied houses

There were 24 historic rural houses in Estonia (EST), 20 houses in Finland (FIN), and 23 houses in Sweden (SWE) under investigation. In each of the three regions, the houses described in Chapters 2.1.1–2.1.3 were considered of the same type. From the studied houses, three example houses were selected, one house from each country (see Fig. 1, Table 1) representing a typical rural house and renovation needs in the Baltic Sea region. The function and technical information of the studied houses are summarised in the next three paragraphs below and in Table 1. The technical condition and need for renovation are analysed (Section 2.2.1).

2.1.1. Estonia

In Estonia the predominant historic farmhouse is a barn-dwelling. The poly-functional barn-dwelling served both, as a living and husbandry building. It consists of three main parts end to end: a kiln-room, a threshing room and bedrooms (Fig. 2). The kiln-room served as a living and working room all year round, although in autumn grain was dried there. Over time improvements have been made to enhance houses and better adapt them to people's needs [16]. At the turn of the 18th to19th century, the need to build chimneys in dwellings in order to get rid of smoke was considered to be most urgent. The barn-dwelling was far from comfortable and cosy for people. Even though the barn-dwelling adequately corresponded to the general needs of life of the peasants then, it included many shortcomings from a modern person's point of view.

Nowadays the kiln-room is mostly used as a kitchen, but also as a living room or storage. Depending on the use of the current house, the threshing room is used as a garage or storage. The threshing room is usually unheated because the external walls are typically made of natural stone with a thickness of 0.5–0.7 m. The external walls of the kiln-room and bedrooms are made of wooden logs with a thickness of 0.12–0.20 m. The houses were mainly heated with wood heated ovens. Typically, there was only passive stack ventilation and window airing. Domestic hot water was originally heated by kitchen ranges and nowadays mostly by electricity.

2.1.2. Finland

In Finland, the most common historic house type is a log house which is used only for living purposes. Eighty percent of the studied Finnish houses were that type log houses. Even though they were built during the long period of 1700–1940, the basic wall structure of different buildings is similar. The cladding is made of wooden board. Traditional roof structure is shingle and it can still be found under the tile or tin roof. Tin is the most common roof material in the studied buildings. The most frequent floor structure is a plank floor with an outdoor-ventilated crawl space. The floor structures have been originally constructed with different thermal insulation layers of sand, moss or sawdust and birch bark. They have undergone changes during renovations. After renovation, original insulation has been replaced in many of the studied houses with wood fiber board or other insulation materials. In Finland, traditional windows have two glass panes in wooden frames. Windows have already been renovated in several studied houses and, for example, new triple glazed windows had been installed in one house. Doors are traditional wooden doors without any thermal insulation in all the studied houses.

Traditionally, historic houses were heated with wood heated ovens in Finland. Because of this, all the studied houses are