Energy and Buildings 77 (2014) 313–322

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Cost effectiveness of energy performance improvements in Estonian brick apartment buildings

Kalle Kuusk*, Targo Kalamees, Mikk Maivel

Tallinn University of Technology, Chair of Building Physics and Energy Efficiency, Estonia

ARTICLE INFO

Article history:
Received 21 October 2013
Received in revised form 29 January 2014
Accepted 9 March 2014
Available online 24 March 2014

Keywords:
Energy saving measures
Low energy renovation
Real energy use
Cost effectiveness
Apartment buildings

ABSTRACT

The paper discusses energy renovation measures for brick apartment buildings in Estonia (cold climate). The study analyses the energy usage of brick apartment buildings and simulations for four reference building types selected to represent the brick apartment building stock. Our results show that renovation of old apartment buildings enables the same energy performance requirements as in new apartment buildings to be achieved. Therefore, focus should be on deep renovation of apartment buildings. It is particularly relevant in the context of the EU climate and energy targets for 2020 target. Deep renovation projects will result in low level energy usage in a building but at the same time substantial financial support packages are required to motivate apartment owners to take an extra step.

1. Introduction

In terms of energy performance, the environmental impact of new residential buildings is negligible compared to the impact of the existing residential building stock in the European Union [1]. Therefore, it is important to focus on renovating the existing residential building stock, in addition to the demonstration projects of the new Nearly Zero Energy (n*ZEB*) buildings. To reduce the energy consumption of buildings, the European Commission has put forward an Energy Performance of Buildings Directive [2], which, among other items states that under major renovations the energy performance of the building or the renovated part thereof is upgraded in order to meet minimum energy performance requirements in so far as this is technically, functionally and economically feasible.

Apartment buildings in Northern Europe consume energy for heating 150 kWh/(m^2 a) and for electricity 40 kWh/(m^2 a) [3]. It is possible to reduce space heat demand up to 10 times, for example according to the Passive House standard, one of the main energy performance criteria is the maximum space heating demand of 15 kWh/(m^2 a) [4]. It is well known that current energy consumption of apartment buildings can be significantly reduced, but in terms of the apartment owners, the renovation measures must be cost effective in order to enable the implementation.

Estonia was selected as a research base because Estonian apartment building stock contains many buildings of the same type, which allows conclusions to be drawn on the basis of the results from the reference buildings in the apartment building stock. According to the National Reform Programme “Estonia 2020” of Estonia’s competitiveness strategy [5], the most important measures of the energy saving strategy are to set up more stringent energy efficiency requirements, investing into apartment buildings and detached houses.

In Estonia most of the apartment buildings were built during the period 1960–1990. Preliminary studies have shown that the total heat consumption for typical apartment buildings prior to retrofit was between 170 kWh/(m^2 a) [6] and 280 kWh/(m^2 a) [7]. These values are close to the results of other Eastern European countries [8,9].

There is an urgent need for solutions to improve energy performance of dwellings because of rising energy prices and energy saving policies that focus on energy use in dwellings. Earlier studies suggest that the European Union (EU) 2020 energy savings target will be missed by a wide margin but at the same time the EU has sufficient cost-effective energy end-use savings potential to realise its overall 20% energy savings target [10]. The aims of this study are:

- to provide economically viable deep renovation measures for apartment buildings in cold climate;
- to find out the extent of renovation that makes financial support packages for apartment owners most useful.

* Corresponding author. Tel.: +372 53 400 184.
E-mail address: kalle.kuusk@ttu.ee (K. Kuusk).

http://dx.doi.org/10.1016/j.enbuild.2014.03.026
0378-7788/

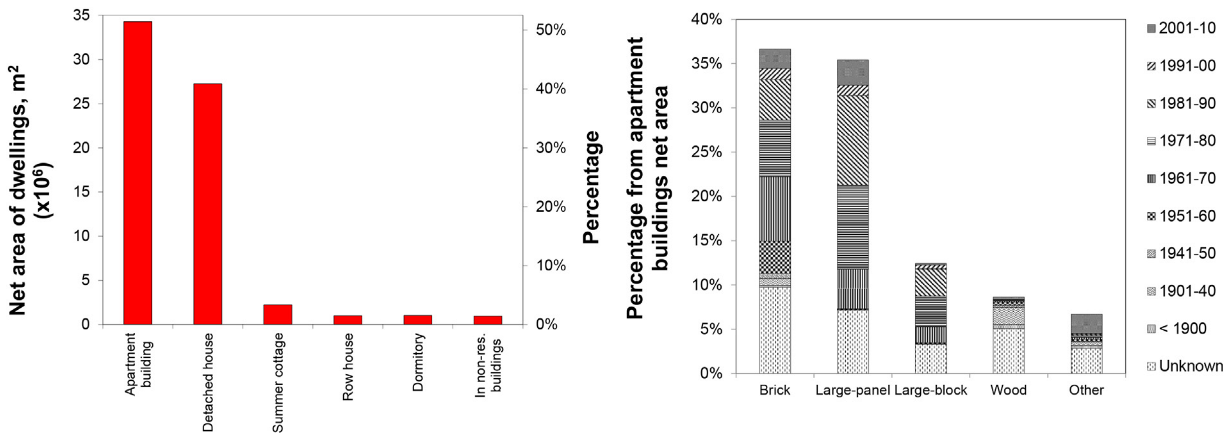

Fig. 1. The net area of dwellings (left) and distribution of construction types by the net area of apartment buildings in Estonia (right).

2. Methods

2.1. Studied buildings

This study focuses on the energy performance of apartment buildings, as they form the largest share of dwellings in Estonia. According to statistics, there are 264 000 dwellings with a total net area of 66 700 000 m^2, see Fig. 1 left. Apartment buildings account for 51% (34 300 000 m^2) of the total net area of dwellings. Another large group of dwellings is detached houses with 41% (25 100 000 m^2) of the total net area of l dwellings.

Brick apartment buildings were selected for the study because that constructional material is dominant in Estonia, and 80% of brick apartment buildings are over 30 years old, see Fig. 1 right. Only during the main industrialisation period in the 1970–1980s, prefabricated concrete large panels were the dominant type of buildings.

For further investigation of indoor climate and energy performance, 30 brick apartment buildings were randomly selected from the database of the Estonian Union of Co-operative Housing Associations, based on age, number of floors, size and structures of buildings. The buildings were constructed between 1940 and 1990. All the buildings studied were in private ownership.

Typically, the studied dwellings had natural passive stack ventilation. In some apartments, kitchens were supplied with a hood. In all of the dwellings, windows could be opened for airing purposes. Buildings were heated with district heating and mainly one-pipe radiator heating systems. Typically, radiators were not equipped with special thermostats; therefore, individual control of the room temperature was impossible. Room temperature for the whole building was regulated in heat substations depending on outdoor temperatures.

Original drawings of the buildings were analysed to determine the thermal properties of the building envelope. The thermal transmittance of the external wall was measured in six buildings. The thermal transmittances of the building envelope of the apartment buildings were:

- External walls: $U_{wall} \approx 0.8–1.2$ W/(m^2 K) (thickness was typically 43–56 cm, some cases including ∼5 cm mineral wool $\lambda \approx 0.05$ W/(m K) for thermal insulation);
- Roof-ceilings: $U_{roof} \approx 0.7–1.1$ W/(m^2 K) (∼20 cm mixture of sand and sawdust or ∼5 cm mineral wool $\lambda \approx 0.05$ W/(m K) for thermal insulation);
- Windows: $U_{window} \approx 2.9$ W/(m^2 K) (a two-pane window tightened to the wall with a tow (not an airtight connection) and windows designed to be leaky to guarantee natural ventilation);
- The building envelope contains considerable thermal bridges [11].

In many cases buildings were insufficiently heated and ventilated. This resulted in bad indoor climate and high indoor humidity loads [12], but at the same time reduced occupants' energy bills.

Based on typology, age, size and number of floors of the building, four building types were selected as reference buildings from different construction periods (<1960, 1961–1970, 1971–1980, 1981–1990) (Fig. 2 and Table 1) for energy simulations and economic calculations. Most apartment owners' associations had already realised some minor energy saving measures; to perform energy simulations for the current state of buildings it was assumed that 2/3 of the windows had been replaced ($U_{window\ (glass/frame)}$, 1.8/2.0 W/(m^2 K)) and the building end walls had been insulated with a 50 mm thermal insulation [13].

Building types Ref "A", Ref "B" and Ref "C" had unheated basements. Building type Ref "D" had no basement. Storage rooms and technical rooms were located in the heated area of the first floor.

Reference buildings were selected to represent the whole distribution of age, size and number of floors, see Fig. 3. By changing the net areas of the reference buildings by ±25%, we can cover 50% of the whole building stock of brick apartment buildings.

2.2. Measurements

The actual use of energy was determined for the building as a whole and differences between the apartments were not distin-

Table 1
Characterisation of reference buildings "as built" based on measurements and calculations from drawings.

	Reference buildings			
Construction period	Ref. "A" <1961	Ref. "B" 1961–1970	Ref. "C" 1971–1980	Ref. "'D" 1981–1990
Number of floors	2	4	5	10
Net area, m^2	508	1383	3147	11 374
Heated area, m^2	388	1154	2623	10 781
Compactness: building envelope, m^2/volume, m^3, m^{-1}	0.60	0.44	0.47	0.32
Number of apartments	8	32	40	162
Thermal transmittance of walls U_{wall}, W/(m^2 K)	1.1	1.0	0.8	0.8
roof U_{roof}, W/(m^2 K)	1.1	1.1	0.9	0.7
windows $U_{window\ (glass/frame)}$, W/(m^2 K)	2.9/2.0	2.9/2.0	2.9/2.0	2.9/2.0