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Assessment of single-family house thermal renovation based on comprehensive on-site diagnostics

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ABSTRACT

This paper presents test methods and results of assessment data necessary for determination of building energy consumption, based on measurements in an occupied typical single-family house in Poland. Comprehensive on-site measurements included the building envelope, heating system, domestic hot water system, ventilation system with heat recovery and indoor environment quality. A new wireless measurement system was used. The results obtained from the thermal diagnostics were used to analyze the energy consumption of the house in four different successive building modernization stages. The steps undertaken included improvement of wall and window insulation, installation of mechanical ventilation with heat recovery, improvement of house airtightness and replacement of the boiler and the hot water storage vessel with more efficient ones. Such steps are typical activities undertaken without a prior energy analysis by owners of single-family houses. Before thermal renovation the indicator of non-renewable primary energy was 243 kWh/(m^2 y) and after renovation this decreased to 147 kWh/(m^2 y). Proper selection of thermo-modernization measures would allow to reach the lower value of this indicator. However, it still would be higher than the required for newly built single-family houses in Poland. The execution of thermal diagnostics both before and after thermal renovation of the house enable the correct performance of that process and the achievement of greater energy savings.

1. Introduction

Energy saving in buildings and the reduction of CO_2 emissions are priorities in the policies of many countries worldwide. The Energy Performance of Building Directive [1] required EU Member States to implement measures targeted at significant reductions of energy consumption in buildings. For example, since January 1, 2017 newly constructed single-family houses in Poland have been required to achieve a primary energy consumption index for heating, ventilation and domestic hot water lower than 95 kWh/(m^2 y) [2]. But, almost all (approx. 5 million) existing single-family houses in Poland fail to satisfy these requirements. The ambitious commitment of EU Member States to significantly reduce the energy consumption of the building stock by 2050 cannot be achieved without the thermo-modernization of existing single-family houses.

Thermal retrofitting of single-family houses in Poland is more and more often performed. This usually includes replacement of windows, improvement the insulation of envelope, installation of a more efficient boiler, improvement of house airtightness and replacement of natural (stack) ventilation by mechanical ventilation with heat recovery [3]. Homeowners in Poland do not usually have knowledge about which thermo-modernization measures should be performed and do not realize how important the quality of these activities is. Therefore, the results of such measures are often unsatisfactory.

To achieve the best possible environmental and energy benefits at the lowest cost, thermal renovation measures should be optimized. Different methods of such optimization are presented in several papers. The multi-criteria assessment methodology for evaluation of different thermal renovation solutions for residential buildings based on effectiveness indices is presented in paper [4]. The results show what energy savings can be achieved by the replacement of windows, the improvement of roof and facade insulation, and the improvement of the heating system. Paper [5] presents how energy consumption and CO_2 emissions are affected by different thermal renovation measures in EU single-family houses. Several types of houses and systems were analyzed in three climatic areas. The results show that a high level of insulation of the house envelope and application of systems producing heat and electricity from renewable energy sources are key measures to reduce energy consumption and CO_2 emissions. In paper

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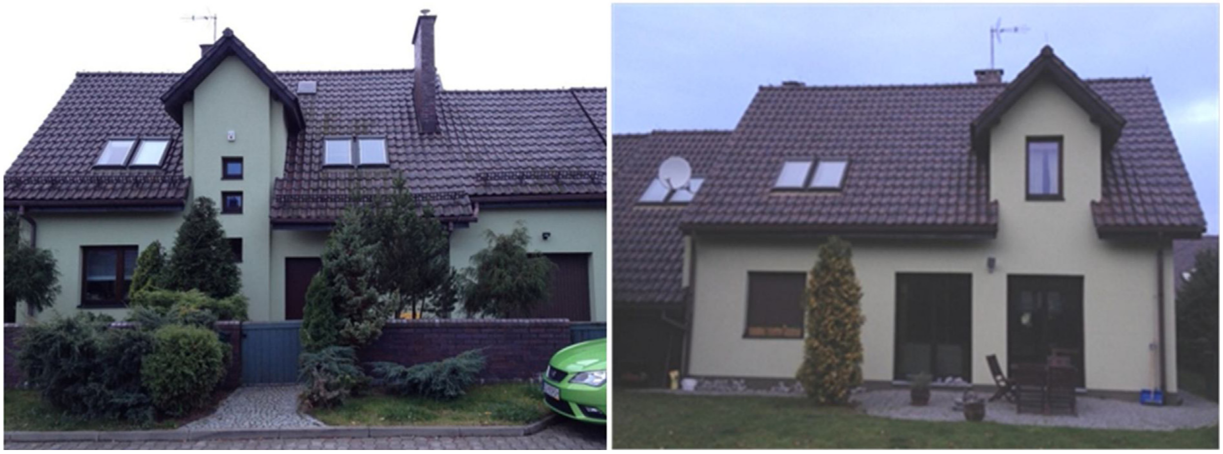

Fig. 1. View of the house: northern elevation (left), southern elevation (right).

[6] an existing house was taken as a case study in a multi-objective optimization model of thermal renovation measures. The feasibility of the proposed model was demonstrated. The results confirmed the practicability of this approach. A deep energy retrofit has been analyzed for three Toronto urban archetypes [7]. In all three cases, the building envelope parameters and the boiler parameters have the greatest impact on energy consumption. A tool for the optimization of buildings' thermal renovation considering several economic and environmental criteria is presented in paper [8]. Different insulation materials and windows, as well as the installation of solar panels were considered. Environmental aspects were examined using the Life Cycle Assessment (LCA) method. The housing stock in North East England has been simulated using the dynamic model [9]. Different thermal renovation measures were applied to test the possibility of the reduction of CO_2 emissions. Using a multi-objective optimization, it was possible to find the most cost-effective retrofit measures.

The optimization of the renovation measures presented in the above papers is mostly performed using different simulation tools. It is difficult to experimentally confirm the results of the simulations of individual measures performed to improve the energy efficiency of buildings.

The aim of the tests presented in this paper was to assess the effects of individual thermo-renovation measures in a single-family house. The evaluation was made using a method based on experimentally determined data which characterizes the energy efficiency of heating, ventilation and domestic hot water systems. The tests presented in this paper were performed within the framework of Task 4 "*Development of thermal diagnostics of buildings*" of the large strategic project "*Integrated System for Reducing Energy Consumption in the Maintenance of Buildings*" financed by the Polish National Center for Research and Development. The aim of Task 4 was to develop and disseminate new tools for thermal diagnosis of various types of buildings, including development of a methodology for building thermal insulation diagnostics, and a methodology for on-site diagnostics of heat and cold sources, heating and domestic hot water (DHW) installations, ventilation and air-conditioning systems and indoor environment in buildings. The results of Task 4 are presented in six volumes of the "Guidebook of thermal diagnostics of buildings" [10–15] and in many papers, i.a. [16–25].

The aim of the current paper was to evaluate the energy savings at four successive stages of a house thermal renovation. In order to analyze final energy consumption for heating, ventilation and DHW, a model of the house was built and calibrated using the results of measurements. Based on this model, it was possible to predict energy consumption at various stages of already conducted and potential thermo-modernization measures in the house. The tests in a single-family house, located in Gliwice, Poland, were performed after the first stage of thermal renovation. The steps undertaken included improvement of wall and window insulation, installation of a mechanical ventilation with heat recovery, improvement in the house airtightness and replacement of the boiler and the hot water storage vessel with more efficient ones. An estimation of the energy effects of ventilation system retrofitting in the tested house is presented in detail in paper [3].

2. Experimental house description

A comprehensive thermal diagnosis was performed in the refurbished two-story single-family house without basement shown in Fig. 1. The house was built in 1999 according to the technical requirements at that time. The heated area is 152 m^2, while the volume of the house is 395 m^3. The house is used by a family of three.

The external walls are made of cellular concrete blocks. The roof structure is wooden with thermal insulation of mineral wool between the rafters. The roof is covered by ceramic tiles. The floor is insulated from the ground with Styrofoam. Heating and hot water installations are supplied from an individual monofunctional (heating system only) gas boiler of a maximum power of 24 kW with a separate domestic hot water storage vessel of a capacity of 120 dm^3. The boiler is fitted with a control unit for weather–compensated operation. An installation of copper pipes has been laid both under the floor and in grooves in the walls. The hot water installation does not have a circulation loop. The heating system is dimensioned for the nominal parameters of 70/55 °C. The boiler pump conveys the heating medium to heating and domestic hot water installations through a three-way valve. Room temperature is controlled by thermostatic valves on radiators. Heating of domestic hot water takes priority over central heating.

The main renovation measures were performed in 2011. That year the insulation of external walls was improved, some of the windows on the first floor were replaced. Thermal features of the building envelope before and after retrofitting are shown in Table 1.

Moreover, in 2011 a mechanical ventilation system with heat recovery in rooms on the upper floor was installed. On-site thermal diagnostics of the ventilation system in the tested house and improvement of the house's airtightness were performed in 2012. During airtightness measurement using a smoke test significant leaks in the building envelope were identified. The largest leaks were found in the roller shutter boxes built into the lintel above the windows on the first floor. Some other leaks were found in the