A STUDY OF THE RENOVATION OF SELECTED HOUSES TO MEET THE REQUIREMENTS OF THE ENERGY PERFORMANCE CLASS "D" ACCORDING TO EPBD IV

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Abstract
Under the forthcoming EPBD IV, existing residential buildings should meet the criteria of the energy performance class D by 2033. This case study deals with the energy performance of two selected houses in the Czech Republic. These houses were built in 1960 and 2000 and they currently do not meet the future requirements. Measures regarding the building envelope and the heat source were proposed. With the help of the building energy performance certificates and the calculation using the hourly method, the 2033 requirements were achieved.

Keywords
Energy building performance, renovation, non-renewable primary energy, insulation, EPBD IV

1 INTRODUCTION

The Energy Performance of Buildings Directive (EPBD), which aims to reduce the energy consumption of the EU countries, came into effect in 2006. A fourth version of this directive is currently being drafted. The final draft of the directive is not yet available but the European Commission has published a press release on the subject [1]. The report states, among other things, that existing buildings should achieve at least the E energy performance class by 2030 and the D energy performance class by 2033. Non-residential and public buildings would have to achieve the same classes by 2027 and 2030 respectively. At the same time, the directive considers the entire life cycle of a building and does not focus only on total or primary energy. It also seeks to reduce fossil fuels. In order to meet the EPBD IV targets, a large portion of buildings will need to be renovated [2].

More than 220 million construction units have been built in the European Union in the last century. In total, this represents 85% of the housing stock in the European Union. A significant proportion of the buildings, around 85% to 95%, that are currently built will still exist in 2050. 75% of these buildings have not been renovated and use fossil fuels and inefficient systems for heating and cooling. In order to achieve the 'Fit for 55' goal of reducing greenhouse gas emissions by 55%, building emissions must fall by 60%. Building energy consumption must fall by 14% and for heating and cooling by 18%. By 2030, 35 million building units should be renovated according to current targets.

The mainstay of renovation is consistent attention to energy efficiency. At the same time, it is necessary to produce only energy that will actually be consumed. Low energy consumption will make buildings affordable, especially for the lower and middle class. The life cycle of buildings will be considered and the use of organic building materials will become more frequent. The use of renewable sources, mainly from local sources, will lead to decarbonisation. Heating and cooling are responsible for 80% of energy consumption in residential buildings. The plan includes an increased use of waste heat. Asbestos and radon will be removed from the buildings during the renovation process and the buildings will be made accessible, with respect to their architecture and design.

The focus will be on the preparation of energy performance certificates for the buildings. They have an important role at the building level since they give information on the energy performance of the building, the amount of renewable energy or the energy costs. Also, they are a useful tool in selecting buildings that are the most energy intensive in the district, region or state and need the quickest intervention. Currently, the percentage of buildings that have an EPC varies between the member states. In some countries, less than 10% of buildings have an EPC. Their indicative value is then debatable, as few certificates are produced on the basis of a physical visit to the building. The European Union's plan for the future is to create a single repository where all building energy performance certificates will be stored [3].

DOI 10.13164/juniorstav.2024.24018

The European Union has committed itself to reducing greenhouse gas emissions by 55% of the 1990 levels. The second target is to achieve climate neutrality by 2050 [4]. Buildings produce more than one third of greenhouse gas emissions. This is set to change by 2050, thanks to the regulation that all buildings are required to be zero-emission. Currently, only 25% of existing buildings have been renovated. The remaining three quarters will have to be renovated in the coming years. Existing buildings will be guided towards this target through two milestones. The first will be in 2033; by this year, existing residential buildings will have to be upgraded to energy performance category D. By 2040, existing buildings must be renovated to meet a nationally determined level to meet the 2050 target. As f newly constructed buildings, the zero-emission obligation will apply from 2028, when new buildings owned by public bodies will have to comply, and from 2030 all new buildings. At the same time, new public and non-residential buildings will be required to install solar power generators from 2027. One year later, generators will also have to be installed on residential buildings undergoing renovation. Every new residential building will then have to have a solar power plant installed from 2030. Financial support from subsidy programs, tax reductions and administrative support will be incentives to carry out renovations [5].

There are approximately 2.35 million buildings in the Czech Republic. According to a 2011 survey, the average age of buildings is 49.8 years, and they are mostly built of brick. More than 70% of the buildings have had their windows replaced, 50% of the buildings have a new façade and a third of the buildings have had their roofs renovated. However, there are still more than 800 000 houses in the Czech Republic that are in a completely original state [6].

2 METHODOLOGY

Two detached houses have been chosen for this paper. Both are located in the Zlín Region in the Czech Republic. They are situated in the city centre and have mild shading.

The first house was built in 1960 as a semi-detached house. The orientation of the house is to the north and south. The shared façade faces the east. The house has one underground floor, two above-ground floors and a saddle roof. The floor plans and a sectional view are shown in Fig. 1. The external walls are made from bricks with a thickness of 450 mm without thermal insulation. The ground floor is made from concrete. The ceiling above the second floor is joist floor filled with slag with a thickness of 160 mm. The original wooden windows were changed in the past years and double-glazed windows were installed. All basic parameters of the building under consideration are described in Tab. 1. The house is heated by a gas condensing boiler. Hot water is prepared in the same way. The hot water storage tank has a volume of 300 l. The house has natural ventilation, only bathrooms have a mechanical exhaust installed. There are no renewable sources of heat. For the calculation, the house is considered as two zones – the living rooms and the attic. The temperature in the first zone is 20 °C, the second zone is unheated.

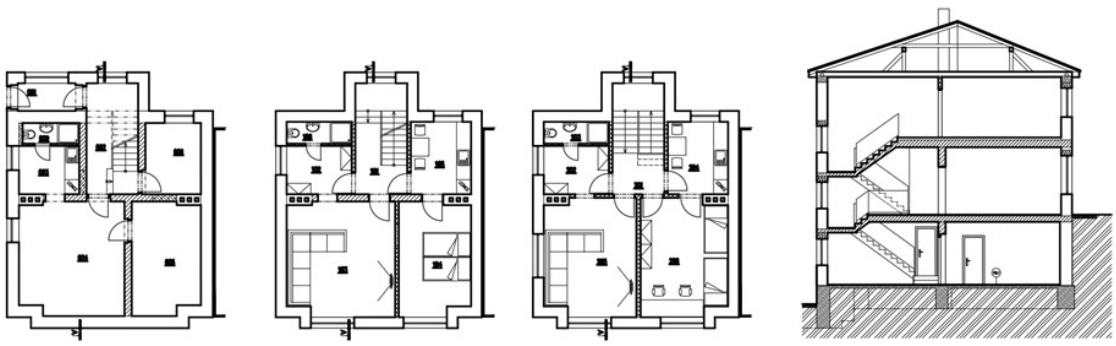

Fig. 1 Floor plans and sectional view of the House 1960.

The second house was built in 2000 as a single house. The orientation of the house is to the north and south. The house has one underground floor, one ground floor and an attic. The roof is saddle. The floor plans and a sectional view are shown in Fig. 2. The external walls in the basement are made from bricks with a thickness of 450 mm. The above-ground floors are made from aerated concrete with a thickness of 375 mm. The ground floor is made from concrete. The ceiling above the attic is made from steel beams with ceiling clay blocks. The house has plastic double-glazed windows. All basic parameters of the building under consideration are described in Tab. 1. The house is heated by a gas condensing boiler. Hot water is prepared in the same way. The hot water storage tank has a volume of 160 l. The house has natural ventilation. There are no renewable sources of heat. For the calculation, the object is divided into three zones. The first zone includes the living rooms, the temperature is

20 °C. The basement is in the second zone, the attic in the third. Both of the latter zones are unheated. The areas and volumes of both buildings and of each individual zone are listed in Tab. 2.

All the calculations in this study were made in the Czech software DEKSOFT and were successfully compared with the hourly calculation according to ASHRAE 2017 [7,8]. This software uses the ČSN EN ISO 52016-1norm about the Energy performance of buildings – Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads – Part 1: Calculation procedures [9]. This method of calculation uses a uniform set of data for the whole of the Czech Republic.

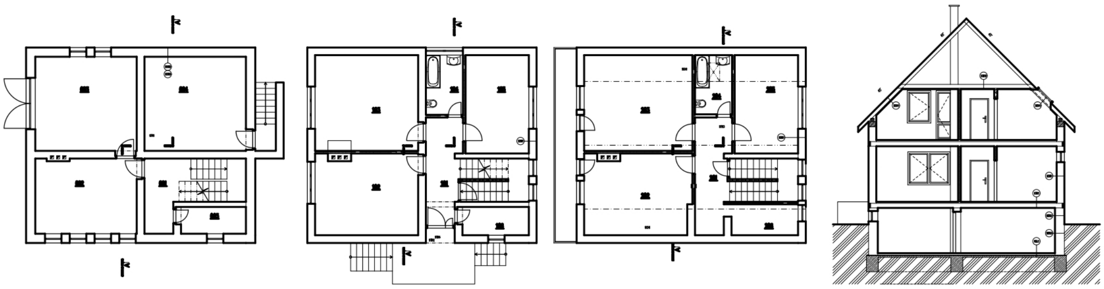

Fig. 2 Floor plans and sectional view of the House 2000.

Tab. 1 Basic parameters of the building under consideration.

Construction	House 1960 Area [m^2]	House 1960 U value [W·m^{-2}·K^{-1}]	House 2000 Area [m^2]	House 2000 U value [W·m^{-2}·K^{-1}]
External wall, 500 mm	*52.89*	*1.27*		
External wall, 450 mm	*181.42*	*1.37*		
External wall, 375 mm			*206.80*	*0.58*
Basement wall			*36.53*	*1.37*
Windows	*27.22*	*1.60*	*24.88*	*2.40*
Doors	*1.82*	*2.40*	*3.50*	*4.00*
Ceiling above last floor	*80.93*	*0.96*	*71.09*	*0.25*
Roof	*87.56*	*6.21*	*48.42*	*0.28*
Slab on the ground	*85.49*	*4.33*	*105.69*	*3.41*
Basement ceiling			*104.68*	*0.58*

Tab. 2 Areas and volumes of the houses.

Description	House 1960		House 2000		
	Zone 1	Zone 2	Zone 1	Zone 2	Zone 3
$A_{f,int}$ [m^2]	*196.75*	*76.88*	*180.55*	*87.94*	*61.01*
$A_{f,ext}$ [m^2]	*247.35*	*80.93*	*210.37*	*105.69*	*71.09*
V_{int} [m^3]	*435.04*	*98.09*	*384.12*	*154.77*	*105.93*
V_{ext} [m^3]	*732.11*	*103.25*	*607.74*	*245.2*	*113.59*

$A_{f,int}$ Net floor area of the zone
$A_{f,ext}$ Floor area taken from the external dimensions
V_{int} Air volume in the zone
V_{ext} Volume of the zone from external dimensions

The calculation method is based on the hourly calculation. This calculation considers that the temperature of the air in one zone is even and the heat from each element is conducted equally. The thermal balance of each zone is calculated every hour. This ensures that the hourly and daily minima and maxima are detected. The room occupancy, the thermostat function and the shading barriers also affect the calculation. All design details are simulated separately. Opaque structures such as walls or roofs are modelled as four layers with five nodes. Windows and doors have two nodes. The hourly method covers three areas of usage – calculation of power

DOI 10.13164/juniorstav.2024.24018

consumption, calculation of indoor temperature and calculation of proposed power necessary for cooling and heating.

Both buildings were insulated to meet the 2033 requirements. The façade of the House 1960 was insulated with 140 mm expanded polystyrene. The ceiling above the top floor was insulated with 300 mm expanded polystyrene. The building had moisture problems in its original state so the waterproofing of the substructure was completed during the renovation. As a result, the basement floor was simply insulated with 100 mm of expanded polystyrene. The basement walls which are in contact with the ground were insulated with 80 mm of extruded polystyrene. The windows of this house were replaced in the past years.

The sloping roof of the House 2000 was insulated with 100 mm expanded polystyrene in the past. The ceiling above the top floor was insulated with 50 mm expanded polystyrene. To meet the 2033 requirements, the external walls of the first floor and the habitable attic were insulated with 140 mm expanded polystyrene. The basement walls were insulated with 100 mm expanded polystyrene. In order to improve the average heat transfer coefficient, it was proposed to replace the windows and balcony doors with new plastic ones with triple glazing. The entrance door of the building is has double glazing. All basic parameters of the buildings under consideration after renovation are described in Tab. 3.

Tab. 3 Basic parameters of the buildings under consideration after renovation.

Construction	**House 1960**		**House 2000**	
	Area [m^2]	**U value [W·m^{-2}·K^{-1}]**	**Area [m^2]**	**U value [W·m^{-2}·K^{-1}]**
External wall, 500 mm	*53.13*	*0.25*		
External wall, 450 mm	*203.01*	*0.25*		
External wall, 375 mm			*215.14*	*0.23*
Basement wall			*34.14*	*1.37*
Windows	*27.22*	*1.60*	*24.88*	*0.86*
Doors	*1.82*	*1.40*	*3.50*	*1.20*
Ceiling above last floor	*85.43*	*0.13*	*71.09*	*0.25*
Roof	*90.84*	*6.21*	*48.42*	*0.28*
Slab on the ground	*90.10*	*0.37*	*105.69*	*3.41*
Basement ceiling			*110.57*	*0.38*

3 RESULTS

Four main factors were evaluated in this paper. The U value of the building envelope was assessed first. The second element evaluated is non-renewable primary energy. The third assessed value is energy consumption for heating and the last value is the total energy supplied to the building. Given the increasing popularity of heat pump installation [10], a heat pump option was simulated for both buildings.

U value of the building envelope

The average U value of the building envelope was calculated to be 1.12 W·m^{-2}·K^{-1} for the House 1960 in its original state. Insulation has reduced this value to almost a quarter, namely 0.32 W·m^{-2}·K^{-1}. For the House 2000, the original value of 0.63 W·m^{-2}·K^{-1} was reduced by less than a half to 0.35 W·m^{-2}·K^{-1} due to the renovation. The values are shown in Fig. 3.

Non-renewable primary energy

The House 1960 had a non-renewable energy demand of 319 kWh·m^{-2} per year in its original state. The modifications made to the building have reduced this need by more than 60% to 132 kWh·m^{-2} per year. For the second house, built in 2000, the non-renewable primary energy savings were almost a half of that. From the original 205 kWh·m^{-2} per year, it dropped to 113 kWh·m^{-2} per year. The values are shown in Fig. 3.

DOI 10.13164/juniorstav.2024.24018

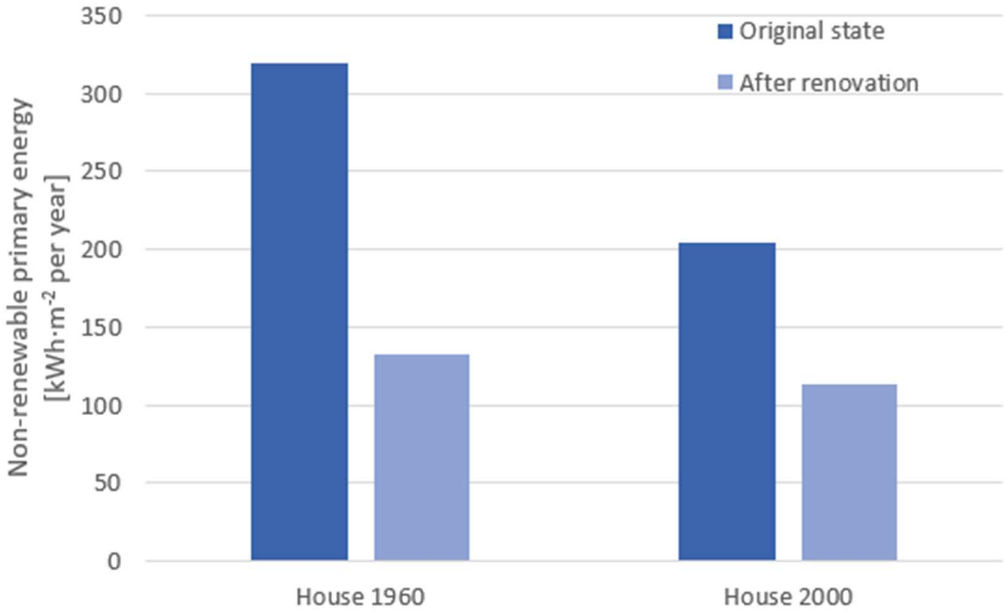

Fig. 3 Non-renewable primary energy.

Energy consumption for heating

The House 1960 had an energy consumption for heating of 194 kWh·m^{-2} per year in its current state. By insulating the exterior walls, the floor on the ground and the ceiling above the last living floor, this value dropped by two thirds to 62.8 kWh·m^{-2} per year. The second building, the House 2000, achieved a reduction from the original 113 kWh·m^{-2} per year to 48.6 kWh·m^{-2} per year. The values are shown in Fig. 4.

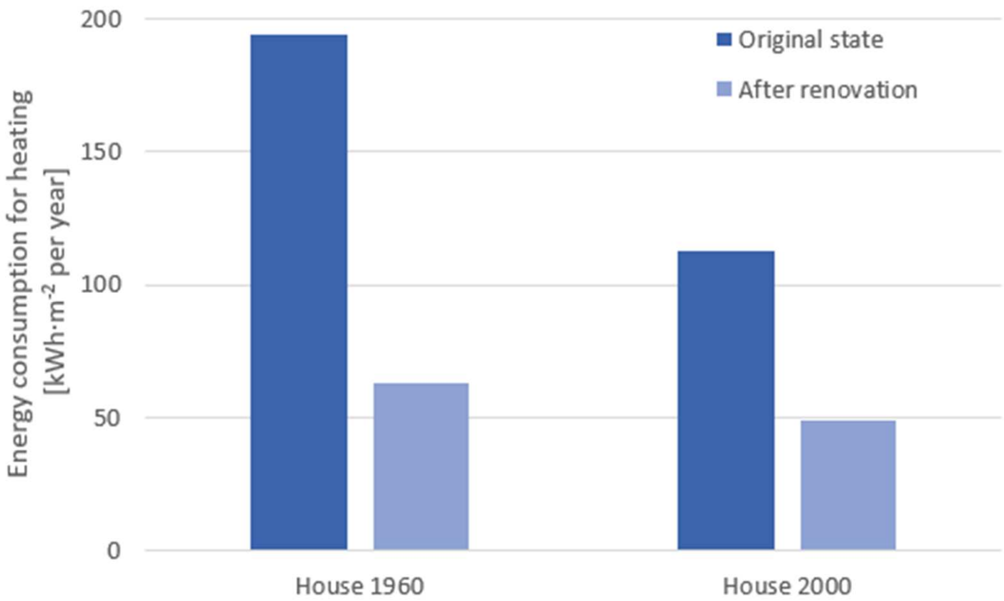

Fig. 4 Energy consumption for heating.

Total supplied energy for building

The total energy supplied to House 1960 in its original state was 308.7 kWh·m^{-2} per year. The proposed measures have reduced the energy demand to 122.9 kWh·m^{-2} per year. For House 2000, the reduction was almost halved

DOI 10.13164/juniorstav.2024.24018

from 192.8 kWh·m^{-2} per year to 100.5 kWh·m^{-2} per year. The details of the energy supplied is broken down into heating, preparation of hot domestic water and lighting. The exact values are given in Tab. 4 and a comparison of the energy supplied is given in Fig. 5. The values for preparation of DHW and lighting are slightly lower for the renovated buildings, even if the technical systems have not been interfered with. This is due to an increase in the energy reference area; hence a lower energy demand per m^2.

Tab. 4 Supplied energy for each system.

	House 1960 original state	**House 1960 after renovation**	**House 2000 original state**	**House 2000 after renovation**
Heating	*272.0*	*88.6*	*158.0*	*67.5*
Preparation of DHW	*31.9*	*29.7*	*26.7*	*25.3*
Lighting	*4.8*	*4.6*	*8.1*	*7.7*

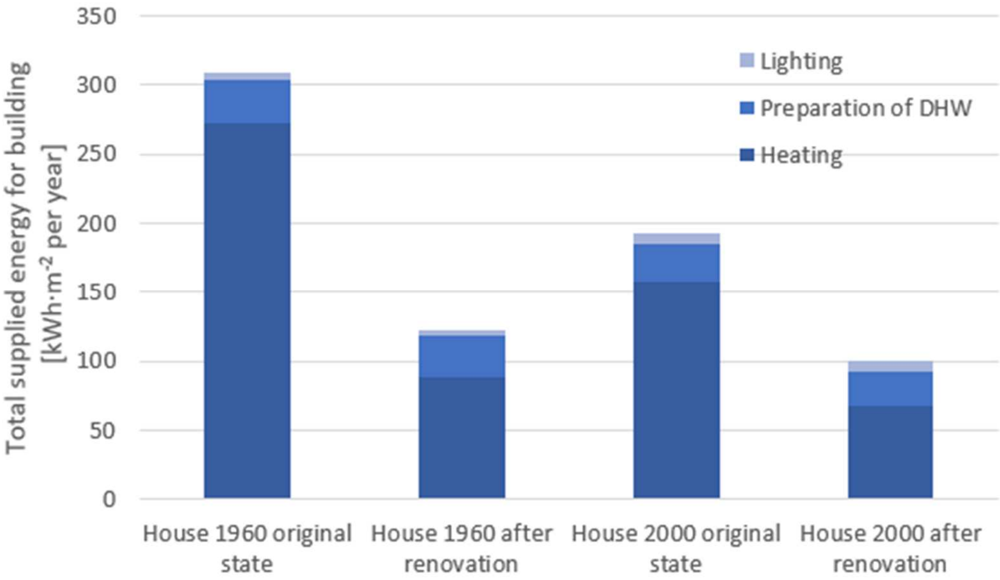

Fig. 5 Total supplied energy for building.

Installation of heat pump

An air-to-water heat pump was designed for both houses. The heat loss in both buildings after insulation is approximately 7.5 kW, the heat pump output is rated at 80% of the heat loss. Thus, in both cases, a 6 kW pump with a coefficient of performance of 3.5 was designed. A 3 kW heating rod was used as a bivalent source. The graph in Fig. 6 shows the decrease in energy from non-renewable sources. For the House 1960, there was a decrease of about one fifth, for the 2000 house a decrease of 12%.

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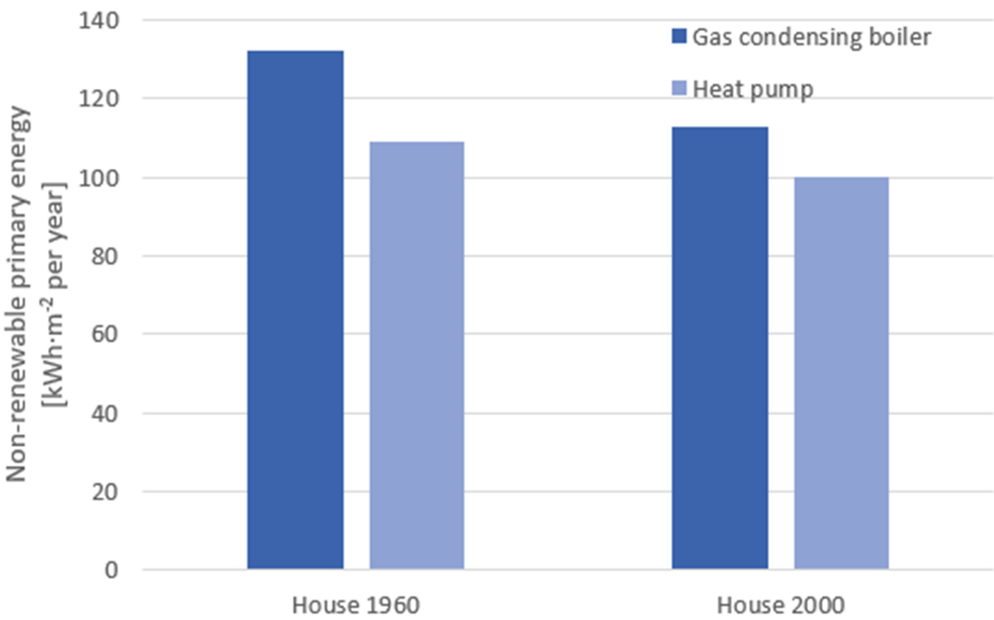

Fig. 6 Comparison between gas condensing boiler and heat pump.

4 DISCUSSION

The insulation of both buildings will reduce energy from non-renewable sources and thus meet the European Union requirements for residential buildings to meet the energy performance class D. There has also been a decrease and improvement in other monitored values. The individual energy saving measures were designed to meet the recommended heat transfer coefficient values. The exception to this is the ground floor in the House 1960 building. Here, for technical reasons, it was not possible to propose a greater thickness of insulation. Only the requirement for the required value was met.

The paper shows that only a comprehensive insulation of the building can help to meet the requirements. Considering the current trend of installing heat pumps, a simulation was carried out for both renovated buildings, where the building is heated and hot water is prepared by a heat pump. In both cases, the buildings qualified as category C after the installation of the heat pumps. However, it should be noted that it would be pointless to install a heat pump without implementing thorough measures on the building envelope side. It is always necessary to deal with structural modifications first and then the technical systems of the building. Ideally, these measures are carried out simultaneously to lead to maximum efficiency.

5 CONCLUSIONS

With regard to the future requirements of the European Union on the energy performance of buildings, a simulation of two buildings in the Czech Republic was carried out. The following parameters were evaluated: U value of the building envelope, energy consumption for heating and total supplied energy for the buildings. The calculations were performed using the hourly method with the help of building energy performance certificates. It was confirmed that the energy performance class requirements can only be met by insulating the building envelope. The criteria for Category D could have been met in terms of non-renewable primary energy in both the 1960 brick and 2000 gas-silicate block buildings. The simulation included the installation of a heat pump for both insulated buildings. By installing heat pumps, the buildings were upgraded to category C. Based on the results, a comprehensive insulation of the buildings will be needed to meet the 2033 requirements. In the Czech Republic, no energy saving measures have been implemented in 20% of the flats. In total, there are around 800,000 households.

DOI 10.13164/juniorstav.2024.24018

Acknowledgement

This article was written with the support of the project: Specific research of Brno University of Technology FAST-S-23-8176 Experimental research of heat and mass transfer in systems and systems of technical equipment of buildings.

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