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Orginal Article

The influence of internal installation solutions in single-family housing on the *“EP”* factor in light of the new requirements of WT 2021

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Abstract: The first part of the article presents the upcoming changes in the regulations regarding energy consumption by single-family housing. Current and forthcoming requirements in 2021 for building insulation and maximum *EP* primary energy demand factor were indicated. The second part of the paper presents the results of research aimed at determining what type of heat source for heating purposes and the type of ventilation will be able to meet the latest requirements. The analysis was based on the determination and comparison of the *EP* factor in the considered single-family building for selected heating variants assuming two different types of ventilation: gravitational and mechanical supply-exhaust with a heat recovery system. Based on the results obtained, an attempt was made to determine the tendency of changes in the design of single-family buildings in terms of choosing the type of heating and ventilation.

Keywords: energy consumption, building energy efficiency, energy performance

1. Introduction

Due to more and more intensive development of the building industry, more and more attention is focused on its energy efficiency, i.e., above all, on reducing its energy consumption. The instrument in this assessment is the energy characteristics, including the annual rate of demand for non-renewable primary energy (*EP*), taking into account losses arising at the stage of energy production and transmission [1].

From 2021 on, designers will have to face new requirements for buildings known as WT 2021. They will have a significant impact on many architectural, construction and installation solutions, especially those related to the choice of heating system. Currently, most of the energy used for heating and domestic hot water (DHW) is supplied from non-renewable sources, which have a significant negative impact on the environment and increase the operating costs of the systems [2]. In order to reduce the building’s primary energy demand, in addition to reducing the heat transfer coefficient U [W/(m^{2}K)] of the building envelope, renewable energy sources such as heat pumps, photovoltaic cells or standard systems are increasingly being used, but with higher efficiency than traditional ones, such as condensing gas boilers [3].

The article attempts to assess the extent to which changes will have to be made to the architecture of single-family housing. It focuses on examining what installation solutions, including the energy source and type of ventilation, will be able to meet the new WT 2021 requirements for maximum primary energy demand (*EP*). The energy performance-based indicator of the annual design primary energy demand of the building for heating, ventilation and domestic hot water preparation was used for the analysis.

2. Overview of regulations

The continuous economic development of many countries results in a constantly increasing demand for energy, of which over 40% is consumed by the construction sector [2], [4]. The main sources of fuel are non-renewable resources, including hard coal, oil and natural gas. Fossil fuels are the main source of carbon dioxide emissions and pose a real threat to the natural environment, therefore a number of measures have been taken throughout the European Union to reduce the demand and consumption of primary energy, mainly by promoting renewable energy sources [2], [5].

The first document on improving energy efficiency and energy labelling in the field of construction was Directive 2002/91/EC of the European Parliament and Council of 16 December 2002 on energy performance [6]. It resulted in the introduction in all EU member states of the obligation to carry out energy certificates for newly built, modernized or sold facilities. This was primarily aimed at improving the comfort of use and operation of facilities. Currently, from 1 January 2013, Directive 2010/31/EU of the European Parliament and Council (EU) of 19 May 2010 on the energy performance of buildings (*EP*BD) is in force [7]. The implementation of the regulations of the *EP*BD directive in Poland was carried out through the Act on Energy Characteristics [8] as well as through the amendment of the Regulation of the Minister of Infrastructure on technical conditions to be met by buildings and their location of 5 July 2013 [9]. Its amendment assumed the introduction of restrictions gradually, in three stages. The first stage was implemented from January 2014, the second from January 2017 and the last one will be effective from the end of December 2020. The changes of selected limit values of the heat transfer coefficient and the maximum *EP* coefficient for heating, ventilation and domestic hot water preparation for single-family buildings are presented in Table 1.

Table 1. Heat transfer coefficients of building partitions [9]

	Before 2014	From 2014	From 2017	From 2021
Value of the heat transfer coefficient of building partitions U [W/m^{2}K]				
External walls	0.30	0.25	0.23	0.20
Flat ceilings, roofs	0.30	0.20	0.18	0.15
Floor on the ground	1/1.5	0.30	0.30	0.30
Partial maximum values of *EP*H+*W* ratio for heating, ventilation and hot water preparation [kWh/(m^2 – year)].				
Single-family building	-	120	95	70

The first significant change in the amendment of the technical conditions was the tightening of the requirements for the heat transfer coefficient for building partitions U [W/m^{2}K]. Before 2014, all external partitions, including walls and roofs, had to have a maximum U-value of 0.30 W/m^{2}K, while the floor on the ground was marked with a minimum resistance R of 1.5 m^{2}K/W. Gradually, these indices were reduced to be 0.20 W/m^{2}K for external walls, 0.15 W/m^{2}K for ceilings/roofs and 0.30 W/m^{2}K for floors on the ground at the end of December 2020. As a result of the introduced changes, it will be necessary to use better quality materials, with better thermal insulation properties and increased thickness of the insulation layer.

Another significant change was the introduction from 2014 of a new indicator – annual calculated primary energy demand for a building for heating, ventilation and domestic hot water preparation – EP [kWh/m^2-year] and its limit value depending on the type of building. Based on the parameters of the external environment, building architecture and the adopted building and installation solutions, the amount of energy required to cover the demand for heating and ventilation ($Q_{P,H}$), domestic hot water preparation ($Q_{P,W}$), air conditioning, cooling ($Q_{P,C}$) and lighting of the building ($Q_{P,L}$) is determined according to the formula below. (1) [8]

$$Q_P = Q_{P,H} + Q_{P,W} + Q_{P,C} + Q_{P,L} \text{ [kWh]} \tag{1}$$

In the case of single-family housing, the first two components are taken into account, namely: energy for heating and ventilation as well as for domestic hot water preparation $QP_{,H+W}$. According to WT 2021, all newly designed single-family buildings should have the maximum value of EP_{H+W} demand reduced to 70 [kWh/(m^2·year)]. In comparison with the restrictions introduced in 2014, this value is lower by over 40%. In order to meet the new criteria, it will probably be necessary to move away from traditional heat sources and increase the share of renewable energy sources, as well as to use more and more efficient ventilation devices [10].

Single-family construction is characterized by the least restrictive requirements for energy performance and, consequently, great freedom in choosing the heat source. According to the statistics of the Central Statistical Office (GUS), in 2018 the most popular heat sources in the residential construction industry were solid fuels (45.4%) and network heat (40.4%), followed by natural gas (13.9%), electricity (5.3%), liquid fuels (0.5%) and renewable energy sources (0.13%) [11]. However, less than 10% of them were equipped with ventilation devices with heat recovery.

In connection with the approaching change in the energy efficiency requirements for buildings, it is necessary to analyze the factors that make it possible to meet them. The article focuses on analyzing how the new requirements of the maximum value of the EP coefficient will affect the possibility of using specific solutions of internal installations, including heat sources for heating, ventilation and DHW as well as the type of ventilation.

3. Research method – thermal model of the building

In order to carry out the analysis, a simplified design of a single-family building was adopted as a calculation model, which is presented in Fig. 1. The building was designed on a 10x10 m rectangular projection, with two overground storeys with a flat roof covered with tar paper, made in traditional brick technology from Porotherm 25 *P+W* hollow blocks. The cubic capacity of the building is 600 m^3 and the usable area is 140 m^2. The location of the building in relation to the sides of the world was adopted according to the principle of entrance from the north and larger glazing from the south.

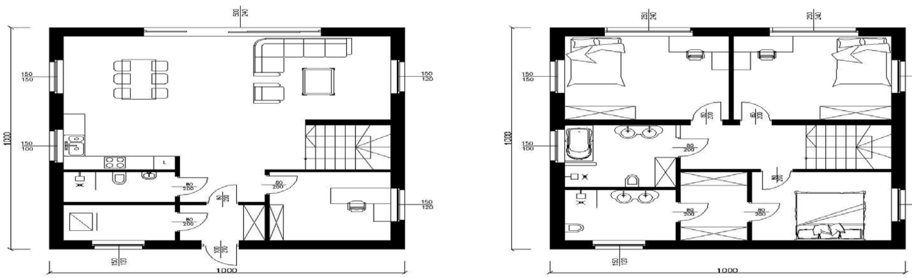

Fig. 1. Simplified plan of the building source: own study

For the purposes of calculations, the maximum values of heat transfer coefficients of individual building partitions have been assumed in accordance with the guidelines of technical conditions, which will be in force from 2021, while thermal bridges have been omitted due to their low impact on the final *EP* value. The windows were assumed to be 3-chamber windows with high tightness class. The building is located in the city surrounded by other buildings of similar height. Detailed data are presented in Table 2.

Table 2. Heat transfer coefficients of analyzed building partitions [8]

Type of partition	Heat transfer coefficient U [W/m^2K]
External wall	0.20
Floor on the ground	0.30
Roof	0.15
External window	0.9
Front door	1.3

The aim of this article is to present the possibility of the analyzed building to meet the maximum primary energy consumption coefficient depending on the heat source used for heating, ventilation and hot water. Therefore, the most popular variants of heat sources such as: hard coal, natural gas, electricity, heating oil, biomass boilers, heat from a CHP plant* and a heat pump were adopted for the analysis. Each variant has been calculated in two versions, the first one assumes gravitational ventilation of the object, while the second one assumes mechanical supply and exhaust ventilation with heat recovery of 80%. In addition, each variant was calculated on the assumption that 50% of energy will be drawn from photovoltaic panels. Detailed characteristics of the proposed variants are presented in Table 3.

Table 3. General characteristic of considered variants

Variant	Type of fuel	Characteristics	Type of ventilation
I.A	Natural gas 100%	$w_{i\ gas}$=1.1 $\eta_{tot,gas}$ = 0.84	Gravitational
I.B			Mechanical
I.C	Natural gas 50%	$w_{i\ gas}$=1.1 $\eta_{tot\ gas}$ = 0.84	Gravitational
I.D	Solar energy 50%	$w_{i,solar}$=0 $\eta_{tot,\ solar}$= 0.89	Mechanical
II.A	Heating oil 100%	$w_{i\ oil}$=1.1 $\eta_{tot,oil}$ = 0.84	Gravitational
II.B			Mechanical
II.C	Fuel oil 50%	$w_{i\ oil}$=1.1 $\eta_{tot\ oil}$ = 0.84	Gravitational
II.D	Solar energy 50%	$w_{i,solar}$=0 $\eta_{tot,\ solar}$= 0.89	Mechanical
III.A	Hard coal 100%	$w_{i\ coal}$=1.1 $\eta_{tot,coal}$= 0.84	Gravitational
III.B			Mechanical
III.C	Hard coal 50%	$w_{i\ coal}$=1.1 $\eta_{tot\ coal}$ = 0.84	Gravitational
III.D	Solar energy 50%	$w_{i,solar}$=0 $\eta_{tot,\ solar}$= 0.89	Mechanical
IV.A	Biomass (wood, pellet) 100%	$w_{i\ biomass}$=0.2 $\eta_{tot,biomass}$= 0.62	Gravitational
IV.B			Mechanical
IV.C	Biomass (wood, pellet) 50%	$w_{i\ biomass}$ =0.2 $\eta_{tot\ biomass}$ =0.62	Gravitational
IV.D	Solar energy 50%	$w_{i,solar}$=0 $\eta_{tot,\ solar}$= 0.89	Mechanical
V.A	Electricity 100%	$w_{i\ electric}$=3 $\eta_{tot,electric}$ = 0.87	Gravitational
V.B			Mechanical
V.C	Electricity 50%	$w_{i\ electric}$=3 $\eta_{tot\ electric}$=0.87	Gravitational
V.D	Solar energy 50%	$w_{i,solar}$=0 $\eta_{tot,\ solar}$= 0.89	Mechanical
VI.A	Heat pump 100%	$w_{i\ pump}$=0 $\eta_{tot,\ pump}$ = 0.87	Gravitational
VI.B			Mechanical
VI.C	Heat pump 50%	$w_{i\ pump}$ =0 $\eta_{tot\ pump}$ =0.87	Gravitational
VI.D	Solar energy 50%	$w_{i,solar}$=0 $\eta_{tot,\ solar}$= 0.89	Mechanical
VII.A	District heat 100%	$w_{i\ unit}$=0.8 $\eta_{tot,\ unit}$ = 0.87	Gravitational
VII.B			Mechanical
VII.C	District heat 50%	$w_{i\ unit}$ =0.8 $\eta_{tot\ unit}$ =0.87	Gravitational
VII.D	Solar energy 50%	$w_{i,solar}$=0 $\eta_{tot,\ solar}$= 0.89	Mechanical

w_i – coefficient of input of non-renewable primary energy for the generation and delivery of the final energy carrier to the building,
η_{tot} – average total seasonal efficiency of the system

The research assumed the following unchanging climatic, location and operating data for the variants:

- climate classification: II,
- location: Poznań,
- outside air temperature: -18˚C,
- building shading: a building in the city surrounded by buildings of similar height,
- indoor temperature: 20˚C,
- ventilation air stream: 200 m^3/h – calculated with a simplified method based on [9],
- coefficient of solar radiation permeability through glazing g=0.75,
- unit daily water consumption: VCW =1.4 dm^3/m^2 day,
- type of receiver: underfloor water heating with central and local regulation with a two-joint or proportional regulator *P*.

For the purpose of the analysis, it was assumed that the demand for domestic hot water of 5735.06 kWh/year is provided by the same source as the heating. Depending on the energy source, the corresponding type of heat source was selected as shown in Table 4.

Table 4. Summary of the heat source depending on the type of energy

Energy source	Type of heat source
Natural gas	Low-temperature gas condensing boilers (55/45°C) with nominal output up to 50 kW
Heating oil	Indoor oil furnaces
Hard coal	Coal boilers manufactured after 2000.
Biomass (wood, pellet)	Biomass boilers (wood: billets, briquettes, pellets, chips)
Electricity	Electrothermal heaters
Heat pump	Glycol/water heat pumps (55/45°C), compression-type, electro-powered
District heat	Compact district heating unit with casing with nominal output up to 100 kW

4. Research results

For the examined object the analysis of the primary energy demand (*EP* index) was carried out, depending on individual variants I-VII. The value of the *EP* index below 70 kWh/(m^2-year) was assumed as the criterion. It was determined by means of a simplified method of calculating the heat demand of the building, using the Regulation of the Minister of Infrastructure and Development on the methodology of determining the energy performance of a building or part of a building and energy performance certificates [8].

The following graphs show the calculated primary energy demand calculated in 2 stages.

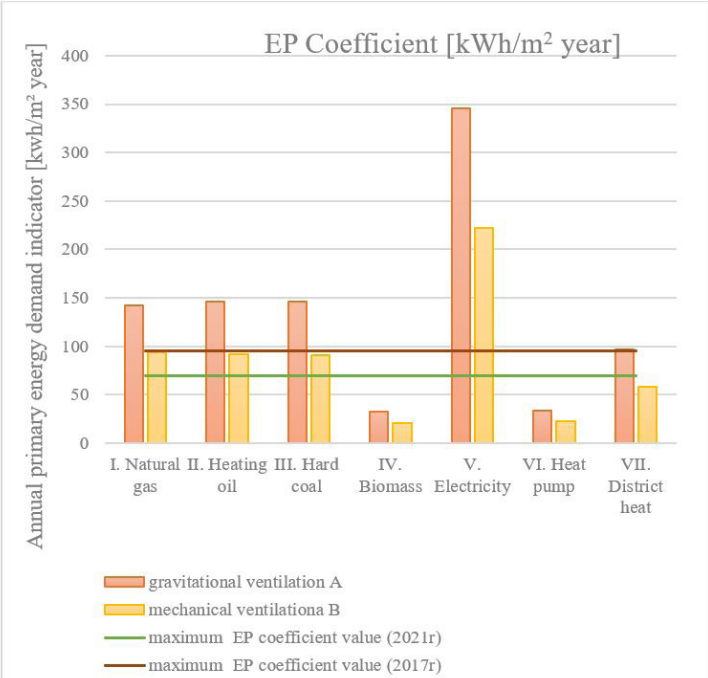

Fig. 2. Primary Energy coefficient (*EP*) for different types of source of heat

The first part of the study focused on the comparison of *EP* index for variants I-VII. A, I-VII. B , i.e. in which the heat demand is provided in 100% by one source. The data are presented in Fig. 2. Each fuel type was calculated with the assumption of natural ventilation – A and mechanical ventilation with heat recovery – B. The green line in the graph indicates the limit value of the *EP* index (70 kWh/m^2 year) required from 2021, while the red line indicates the current limit value (95 kWh/m^2 year). Analyzing the above graph it can be seen that in the case of fossil and liquid fuels (variants I-III), with the regulations in force, only the variant with mechanical ventilation ensures that the maximum *EP* indicator is met at the borderline, while from 2021 no variant from I-III, regardless of the type of ventilation, will meet the requirements. Mains heat meets current and past requirements only if mechanical ventilation is used. Renewable energy sources, including biomass boilers and heat pumps – variants IV and VI – are characterized by more than three times lower *EP* index than required, while the highest electricity – variant V.A V.A- 346 kWh/m^2 year V.B – 222 kWh/m^2 year

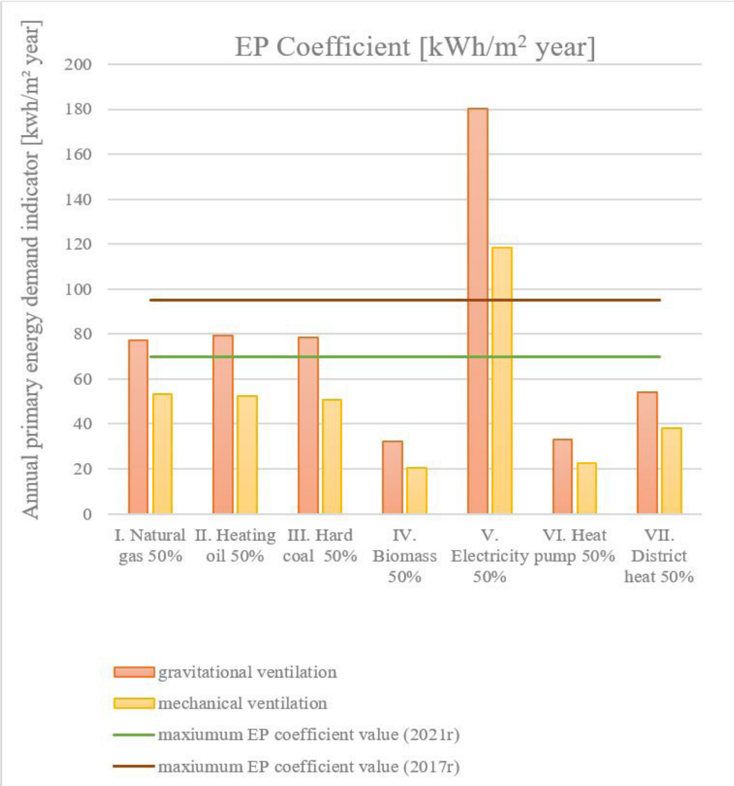

Fig. 3. Primary energy coefficient (*EP*) for different types of source of heat supported by photovoltaic panels

In the next stage of the research, an analysis was carried out concerning the influence of the assembly of photovoltaic panels on the *EP* indicator for the object under study. For each variant it was assumed that 50% of the demand is covered by solar energy. The results are shown in Fig. 3. The differences between variants A – B and C – D are significant. Only electricity, despite being supported by a 50% renewable energy source, still deviates significantly from the results of other sources and exceeds the maximum indicators. The use of mechanical ventilation (variant D) in all other cases is sufficient for the *EP* indicator to meet the new standards. For popular fossil (I.D, III.D) and liquid (II.D) fuels, *EP* is around 50 kWh/m^2 year, while for variants with gravity ventilation – I.C, IIC, and IIIC still exceeds them and is around 80 kWh/m^2 year. For renewable energy sources (IV and VI) the use of photovoltaic panels has a slight impact on the *EP* ratio.

In the last stage of the study, an attempt was made to determine what conditions would have to be met in order for the variants I.C.II.C.III.C, V.C and V.D to be applied from 2021. The use of both natural gas, coal and fuel oil with gravity ventilation will only be possible with an additional photovoltaic installation that will provide more than 60% of the energy demand. To be able to design a building based solely on electricity, the solar installation would have to provide more than 83% of the energy demand for gravity ventilation and 71% for mechanical ventilation. A graphical overview is presented in Figure 4

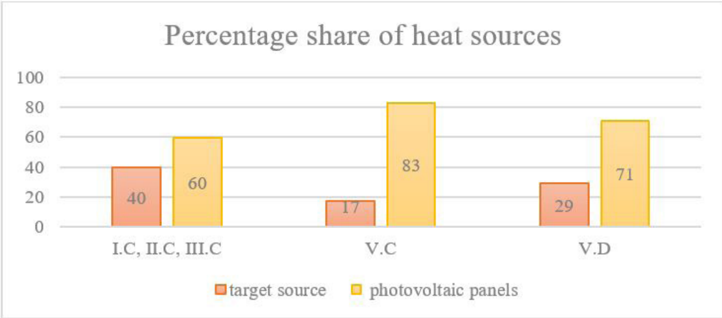

Fig. 4. Demand of primary energy (*EP*) for different types of source of heat

According to the analyses, the type of ventilation used in the facility has a large impact on the *EP* indicator. In a building with mechanical ventilation it is about 35% lower than in the case of gravity ventilation. As can be seen from Figure 2 in the light of the current WT 2017 regulations for variants I-III, the key to meeting the requirements turned out to be the choice of mechanical ventilation with heat recovery. For example, for variants III.A, i.e. using a coal-fired boiler together with gravity ventilation, the *EP* ratio was about 145 kWh/m^2 a year, while for variant III.B it was already within 90 kWh/m^2 year. The lower the value of *EP* ratio as in the case of variants with renewable energy sources (IV.A – 32 kWh/m^2 year, IV.B – 20 kWh/m^2 year) the less important the type of ventilation.

The presented differences are mainly due to the fact that in the case of gravitational ventilation, heat losses for air exchange in the facility constitute 40% of total losses. The use of mechanical ventilation with heat recovery significantly reduces them to 14%. The list of heat losses for the analyzed object is presented in Table 5 and Figure 5.

Tab. 5. Comparison of heat losses in a building depending on the type of ventilation

	Gravitational ventilation	Mechanical ventilation [recovery 80%]
Heat loss by penetration	13742.38 (60%)	13742.38 (86%)
Heat loss for ventilation	9188.62 (40%)	2192.34 (14%)
Total heat loss	22931 (100%)	15934.72 (100%)

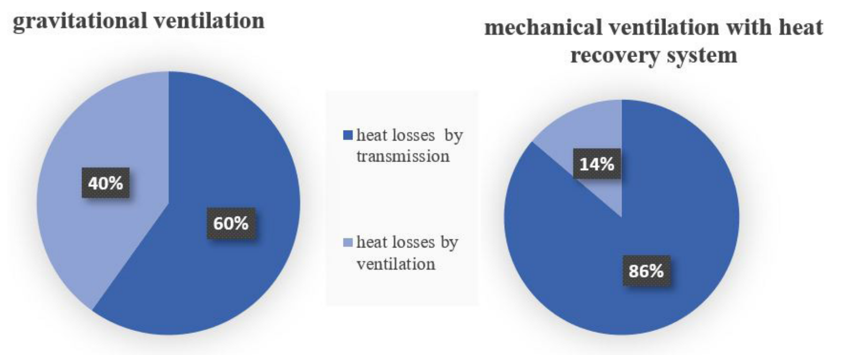

Fig. 5. The percentage share of heat loss in a building depending on the type of ventilation

5. Summary and conclusions

It is a current priority in all Member States of the European Union to introduce measures to reduce energy consumption mainly from fossil fuels and promote the use of renewable energy sources in the construction sector. More and more stringent regulations in this area will result in limiting the use of non-renewable energy sources. Currently, with respect to single-family construction, which is the subject of analysis, predominantly solid fuels are used for heating purposes, including coal and wood, and increasingly often gaseous fuel. Since 2021, after tightening the guidelines for maximum energy consumption coefficient *EP* and heat conduction ratios, it will be more and more difficult to choose an appropriate way of heating a facility that will meet them.

Consequently, the article analyzes how selected installation solutions, including the selection of the heat source and ventilation system of the object, affect the value of the building’s *EP* ratio assuming the construction of building partitions characterized by the maximum permissible *U*-values. This analysis shows that traditional boilers, even with high efficiency, will not be able to meet the restrictive standards. In order to obtain the *EP* ratio below the required value, a significant share of renewable energy in the total energy balance will be required.

A detailed analysis shows the directions of development of single-family housing in installation issues and leads to the following conclusions:

The use of traditional heating systems fired exclusively with hard coal, fuel oil or natural gas will be hardly possible from 2021.

Mechanical ventilation with heat recovery reduces the total heat loss for the building by about 30%, which significantly reduces the *EP* ratio.

New restrictions will result in a significant increase in design as the main heat source for biomass boilers, heat pumps or mixed production with photovoltaic panels.

A heating system based only on renewable energy sources will not force the use of mechanical ventilation in single-family facilities.

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