

The analysis of energy-saving technologies used in buildings with low energy consumption

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Abstract: Designing, constructing and using of buildings with low energy consumption are a complex process requiring knowledge of architectural design, construction physics and building systems with the use of renewable energy sources (RES). The article presents the legal bases and characteristics of low-energy buildings. Implementation of the binding technical requirements in the field of hygrothermal characteristics consists of monitoring numerous parameters of an entire building, and in particular of its partitions and their joints and building systems. Therefore, the paper presents calculations regarding determining the material systems of building partitions and building joints with the use of professional software. The main part of the article is to establish the impact of energy-saving technologies on the energy consumption of the newly designed buildings, but also of the buildings that are undergoing modernisation processes.

Keywords: energy-saving technologies, low-energy building, external partitions, thermomodernization of the building

1. Introduction

According to the Regulation of the Council of Ministers of 22 June 2015 on the adoption of the National Plan to increase the number of low energy buildings [1] a low-energy building is one which meets the requirements for energy saving and insulation included in the technical and functional guidelines referred to in Article 7 paragraph 1 point 1 of the Act – Construction Law [2], i.e. in particular Section X and Annex 2 to the Regulation [3] in force from 31 December 2020 (in the case of buildings occupied and owned by public authorities – from 1 January 2019).

On the basis of analyses of legal regulations [3], criteria for the assessment of external partitions and buildings in terms of hygrothermal requirements have been formulated:

- the criterion of thermal protection and energy savings:
 - designing of building partitions so that the values of heat transfer coefficients U_c [W/(m²·K)] of external partitions, windows, doors and installation technique comply with the requirements of the regulation [3],
 - designing of thermal insulation (perimeter) for a partition in contact with ground with thermal resistance greater than R_{min} [(m²·K)/W],
 - requirement for protection against rooms overheating during summer g [-],
 - designing of a building with the primary energy demand EP [kWh/(m²·year)] with

the value meeting the requirements of the regulation [3], including the use of highly efficient installations and renewable energy sources (RES) in the building,

- the criterion of humidity:
 - risk of development of surface condensation – calculation of the temperature factor f_{Rsi} [-],
 - risk of development of interstitial condensation.

The fundamental change of the regulation [3] in the field of thermal protection of buildings is the change of maximum values of heat transfer coefficients $U_{c(max)}$. Partial requirements for thermal insulation of external walls, roofs, floors, windows and doors have been tightened. Moreover, the type of partition (multi-layer or single-layer) and the purpose of the building (residential, public utility, storage, farming, etc.) are no longer relevant.

According to the changes introduced in the regulation of the Minister of Infrastructure and Construction of 14 November 2017 amending the regulation concerning building technical requirements and building localisation [3], the thermal requirements pertain to simultaneous fulfilment of two requirements for the heat transfer coefficient U [$W/(m^2 \cdot K)$] for individual building partitions and the non-renewable primary energy demand indicator EP [$kWh/(m^2 \cdot year)$] for the entire building.

The minimum requirements referred to paragraph 1 of the regulation [3] shall be deemed to be fulfilled for a building undergoing renovation where the building partitions and renovated technical equipment at least comply with the thermal insulation requirements set out in annex 2 to the regulation [3].

The paper presents an analysis of selected energy-saving solutions in buildings with low energy consumption in terms of hygrothermal requirements according to the regulation [3].

2. The characteristics of the buildings with low energy consumption

On the basis of analyses and calculations, basic groups of factors regarding the classification of low-energy buildings were determined:

- *architecture of a building*: location of a building with respect to the directions of the world, compact structure of a building (minimum A/V shape coefficient), size and location of transparent partitions, rooms arrangement, roof geometry,
- *structural and material solutions of building partitions and their joints*: use of high quality materials; use of modern insulation materials, e.g. polyurethane foam dusts, aerogels, vacuum boards, transparent insulations; the way of designing of building joints in terms of hygrothermal characteristics with the use of numerical tools,
- *thermal insulation of building partitions*: thickness of thermal insulation sometimes exceeding 25÷30 cm, obtaining the value of heat transfer coefficient $U \leq 0,10 W/(m^2 \cdot K)$ for non-transparent partitions and $U \leq 0,90 W/(m^2 \cdot K)$ for transparent partitions, taking into account the requirements for room overheating in summer,
- *type and efficiency of the ventilation system*: hybrid or mechanical ventilation with heat recovery, mechanical ventilation with heat recovery and ground heat exchanger, high efficiency of the system (above 70%),
- *type and efficiency of the central heating and hot water system*,

- *use of renewable energy sources (RES): solar energy, wind energy, geothermal energy,*
- *building management system, which also allows to control energy production.*

For over a decade, legal regulations related to the design, construction and use of buildings with low energy consumption have been enforcing such technological and organisational solutions, as a result of which newly erected buildings consume less and less energy during their use for heating, ventilation and hot water. Changes of the maximum value of the heat transfer coefficient U_{\max} (formerly k_{\max}) impact the amount of energy consumption during the use of buildings. Unfortunately, legal regulations in this field do not regulate the requirements for limiting heat losses through building joints – thermal bridges, because no limit values have been set, e.g. for maximum values of linear heat transfer coefficient Ψ_{\max} [W/(m·K)]. It should be emphasized, however, that a building is a structure of building partitions and their joints of individual physical character and is subject to external and internal environmental influences. In many cases, the structural and material analysis of building partitions and joints and the execution technology is generally not a problem at the time of designing. However, the knowledge of physical parameters related to heat and humidity exchange allows to avoid many design and manufacturing defects.

The application of a suitable thermal insulation material allows to achieve low values of heat transfer coefficient U [W/(m²·K)] of a full partition and linear heat transfer coefficient Ψ [W/(m·K)] and to minimize the risk of surface and interstitial condensation. Before choosing the right material for thermal insulation, when designing new buildings or renovating existing buildings, the following properties should be taken into account: heat conductivity coefficient λ [W/(m·K)], bulk density, acoustic insulation, water vapour permeability, diffusion resistance coefficient μ [-], sensitivity to biological and chemical factors and fire protection. On the basis of calculations and analyses carried out in this field, an exemplary selection of thermal insulation materials was compiled (Fig. 1).

Example of selection of thermal insulation materials

External wall insulation (from the outside): polystyrene (EPS), grey (graphite) polystyrene (EPS), phenolic foam boards, mineral wool, other innovative materials: airogel mats, parogel, vacuum insulation panels (VIP)

Thermal insulation of **pitched flat roofs and roofs above unused attics**: cellulose wool, mineral wool

Wooden roof insulation: wood panels, sheep wool panels, mineral wool panels, polyurethane foam (PUR/PIR), cork panels

Insulation of **partitions coming into contact with the ground (perimeter insulation), plinths and floors**: extruded polystyrene (XPS), foam glass

Indoor insulation: cellular concrete blocks (Multipor), climate panels, thermal insulation plasters (renovation)

Insulation with the use of “**new generation**” **thermal insulation materials**: airogel, parogel, reflective insulation, vacuum insulation VIP, transparent insulation, silicate foams

Fig. 1. Example of selection of thermal insulation materials – author’s own elaboration

The energy-saving measures used in low energy buildings can be divided into three main groups. The first group includes technologies related to the reduction of heat losses by partitions, and in particular: insulation of external partitions (floors on the ground, ceilings, roof, walls), selection of window and door frames taking into account thermal requirements according to the regulation [3]. The second group concerns the reduction of losses and improvement of

installation system efficiency: replacement or modernisation of radiators, replacement or modernisation of heating system (insertion of floor or air heating, etc.), installation of thermostats, installation of modern weather compensators or room controllers, insulation of hot water and central heating ducts, replacement or modernisation of hot water production system, replacement or modernisation of ventilation system (application of mechanical ventilation with heat recovery – recuperator). The last or third group consists of design, execution or modernisation works focusing on a heat source, which may include: design and installation or replacement of a heat source (replacement of a boiler with a new one with better efficiency or replacement of a local source with a district heating system), replacement of an energy carrier (replacement of a boiler with another one that produces energy by burning another type of fuel; the exception is replacement of a fuel in the same boiler, which is adapted to burn several types of raw materials), use of technology that uses renewable energy sources for heating purposes (e.g.: heat pumps, biofuels, solar thermal collectors), use of cogeneration (simultaneous production of electricity and heat – this applies to shared houses), use of automatic source control. The groups of energy-saving measures described above are especially related to the buildings undergoing thermal modernisation.

Detailed analyses, calculations and examples of structural, material and technical solutions for buildings with low energy consumption are presented in the following papers [4 – 8].

3. The influence of energy-saving technologies on the energy consumption of a building

The basic technical measure in the field of thermal quality of building envelope elements is the selection of thermal insulation material to insulate external partitions in newly designed and modernised buildings. The heat transfer coefficient U_c [$W/(m^2 \cdot K)$] is the basic parameter used to test the thermal criterion ($U_c \leq U_{c(max)}$). Along with the changing values of $U_{c(max)}$ (from 31.12.2020 for external walls, at $t_i \geq 16^\circ C$; $U_{c(max)} = 0,20 W/(m^2 \cdot K)$), some of their structural and material solutions do not meet the basic criterion ($U_c \leq U_{c(max)}$). Therefore, it is justified to make detailed calculations in this respect.

To calculate the heat transfer coefficient of the double-layer external wall U_c [$W/(m^2 \cdot K)$], with the use of various materials, the following assumptions were made:

- heat transfer resistance for the wall; heat transfer resistance values were adopted according to PN-EN ISO 6946:2008 [9] for the horizontal direction of the heat flux: heat transfer resistance on the external surface of the partition: $R_{se} = 0,04 [(m^2 \cdot K)/W]$, heat transfer resistance on the internal surface of the building envelope: $R_{si} = 0,13 [(m^2 \cdot K)/W]$,
- values of heat conductivity coefficient λ [$W/(m \cdot K)$] have been assumed on the basis of tables in the paper [10].

The results of calculations are presented in Table 1 depending on the value of the heat conductivity coefficient λ [$W/(m \cdot K)$] and the thickness of the thermal insulation material.

Table 1. Results of the calculations of the U_c heat transfer coefficient according to PN-EN ISO 6946:2008 [9] in reference to the double-layer external wall – author’s own elaboration.

No.	Material layers	d [m]	λ [W/(m·K)]	x [m]	Variants of thermal insulation					
					I	II	III	IV	V	VI
					heat conductivity coefficient of thermal insulation materials λ [W/(m·K)]					
					0.040	0.038	0.035	0.031	0.021	0.015
1.	Plasterboard	0.01	0.40	0.10	0.26	0.25	0.24	0.22	0.16	0.12
	B. made of cellular concrete	0.24	0.21	0.12	0.23	0.22	0.21	0.19	0.14	0.11
	Thermal insulation	x	y	0.15	0.20	0.19	0.18	0.16	0.12	0.09
	Thin layer plaster	0.005	0.76	0.20	0.16	0.15	0.14	0.13	0.09	0.07
2.	Plasterboard	0.01	0.40	0.10	0.32	0.31	0.29	0.26	0.19	0.14
	Limestone sandstone bloc	0.24	0.56	0.12	0.28	0.26	0.25	0.22	0.16	0.12
	Thermal insulation	x	y	0.15	0.23	0.22	0.20	0.18	0.13	0.09
	Thin layer plaster	0.005	0.76	0.20	0.18	0.17	0.16	0.14	0.10	0.07
3.	Plasterboard	0.01	0.40	0.10	0.33	0.32	0.30	0.27	0.19	0.14
	Full brick	0.25	0.77	0.12	0.28	0.27	0.25	0.23	0.16	0.12
	Thermal insulation	x	y	0.15	0.23	0.22	0.21	0.19	0.13	0.10
	Thin layer plaster	0.005	0.76	0.20	0.18	0.17	0.16	0.14	0.10	0.07

Variants of thermal insulation: **I** – plasterboard $\lambda = 0.040$ W/(m·K), **II** – mineral wool boards $\lambda = 0.038$ W/(m·K), **III** – extruded boards $\lambda = 0.035$ W/(m·K), **IV** – graphite polystyrene boards $\lambda = 0.031$ W/(m·K), **V** – resol boards $\lambda = 0.021$ W/(m·K), **VI** – airgel boards $\lambda = 0.015$ W/(m·K); to calculations of U_c it was assumed $\Delta U=0$

The values of heat transfer coefficient U_c of external walls fulfilling the requirement: $U_c \leq U_c(\max) = 0.20$ W/(m²·K) were marked in green in the table.

Significant influence on the value of heat transfer coefficient of a building partition U_c [W/(m²·K)] has the value of heat conductivity coefficient λ [W/(m·K)] of an insulating material, but also of a construction layer. With regard to one type of insulation, it may vary significantly depending on the product, which is due to the rapid development of the market of thermal insulation materials and increasingly advanced production technologies. In the case of airgel insulation (produced in mats of 1cm thickness), calculations for the thickness of 10, 12, 15 and 20 cm were presented only for the purposes of comparison with other thermal insulation materials.

It is worth noting that the issues of thermal physics of buildings often amount to the thermal analysis of the external partitions of buildings subjected to the effects of external and internal temperatures changing in time. In many cases, the solution of heat flow amounts to the determination of heat transfer through a flat building envelope in a one-dimensional field (1D), without considering heat flow in a two-dimensional field (2D) and a three-dimensional field (3D). However, the real (actual) field of heat exchange is usually the building envelope as part of the building, i.e. connected by a system of joints to the existing envelope (ceiling, external or internal wall or floor on the ground). There may be places within the partition that interfere with its continuous character – material inserts, window and door frames, variable thickness of thermal insulation. In all these cases the following temperature field appears: flat (2D) or spatial (3D), which significantly changes the procedure of thermal-humidity calculations of a partition.

Below is presented the calculations of physical parameters of the joint: connection of the external wall with the window in cross-section through the frame with the use of jamb

(insulation extended to the frame), with the use of the software TRISCO-KOBRU 86 [11], adopting the following assumptions:

- joint modelling was performed in accordance with the regulations presented in PN-EN ISO 10211:2008 [12],
- heat transfer resistance (R_{si} , R_{se}) was adopted in accordance with PN-EN ISO 6946:2008 [9] for the calculation of heat fluxes and PN-EN ISO 13788:2003 [13] for the calculation of temperature distribution and temperature factor $f_{Rsi(2D)}$,
- indoor air temperature $t_i = 20$ °C (dayroom), outdoor air temperature $t_e = -20$ °C (zone III),
- values of heat conductivity coefficient of construction materials λ [W/(m·K)] have been adopted on the basis of tables included in the paper [10],
- two-layer external wall: cellular concrete block ($\rho=600$ kg/m³) 24 cm thick – $\lambda=0,21$ W/(m·K), case A: EPS polystyrene ($\rho=30$ kg/m³) – $\lambda=0,036$ W/(m·K), case B: graphite polystyrene ($\rho=30$ kg/m³) – $\lambda=0,031$ W/(m·K), case C: phenolic (resol) panels ($\rho=16$ kg/m³) – $\lambda=0,022$ W/(m·K),
- window frames with heat transfer coefficient $U_w=0,81$ [W/(m²·K)].

Figure 2 shows the connector calculation model and results of computer simulation: heat flux lines (adiabats) and temperature distribution (isotherms).

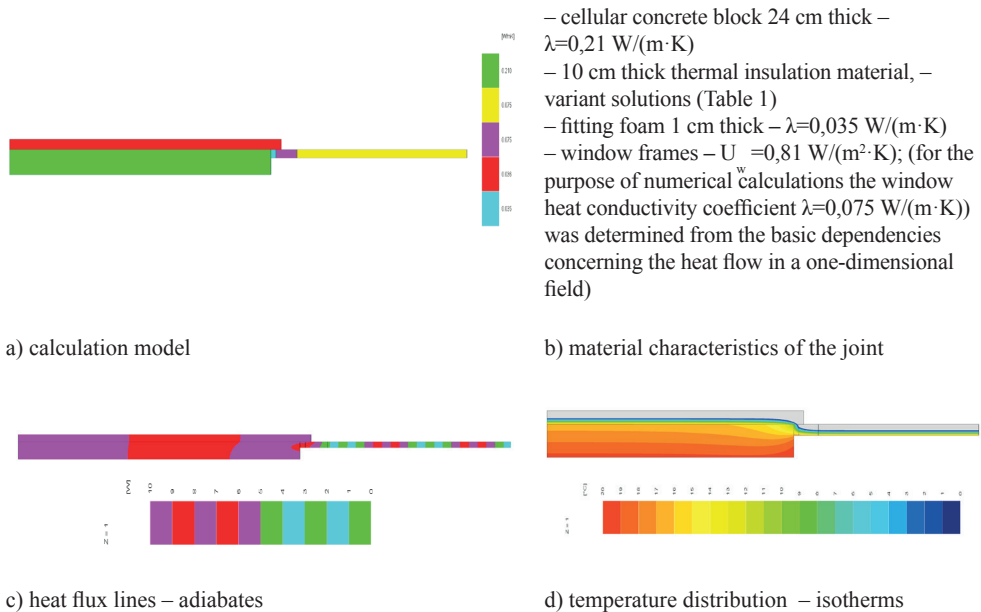


Fig. 2. Calculation model and results of computer simulation of the analysed connector – author's own elaboration

Table 2 presents the results of calculations of physical parameters of the analysed joint with the use of various thermal insulation materials (10 cm thick).

On the basis of the calculations (Table 2) it can be concluded that the analysed joints generate additional heat losses determined, among others, in the form of linear heat transfer coefficient Ψ_i [W/(m·K)] and temperature reduction on the internal surface of the wall t_{min} [°C].

In case of this type of joints it is justified to determine the branch coefficients of heat transfer, separately for the external wall $\Psi_{i,sc}$ [W/(m·K)] and for the window $\Psi_{i,O}$ [W/(m·K)], because it allows to determine additional heat losses, separately for the external wall and the window. The procedure of calculating the branch heat transfer coefficients Ψ is based on:

- separation of internal branches of the thermal bridge, assignment of initial and boundary conditions,
- calculation (numerically) with the use of a software of heat fluxes flowing through the separated branches (parts) of the bridge,
- calculation of appropriate branch coefficients according to the relevant dependencies with the use of data corresponding to the separated branches.

The paper presents calculations of linear and branch heat transfer coefficient Ψ_i [W/(m·K)] by internal dimensions. It is also possible to determine the coefficients by external dimensions Ψ_e and internal total dimensions Ψ_{oi} . Performing detailed calculations, with the use of certified software in a stationary approach [11], allows to obtain reliable results of hygrothermal parameters. Calculation procedures for determining physical parameters of building joints, according to PN-EN ISO 10211:2008 [12], are presented in detail in the paper [10].

Table 2. The results of calculations of physical parameters of a joint: connection of an external wall with a window in the cross-section through the frame with the use of various thermal insulation materials – author’s own elaboration.

Physical parameters of a joint						
variant	U (U_{1D}) [W/(m ² ·K)]	Φ [W]	L^{2D} [W/(m·K)]	Ψ_i [W/(m·K)]	t_{min} [°C]	$f_{Rsi(2D)}$ [-]
A	0.24 ¹⁾	34.37	0.86	0.04	13.92	0.848
	0.25 ²⁾			0.03 ^{*)}		
	0.81 ³⁾			0.01 ^{**)}		
B	0.22 ¹⁾	33.35	0.83	0.04	14.30	0.858
	0.22 ²⁾			0.03 ^{*)}		
	0.81 ³⁾			0.01 ^{**)}		
C	0.17 ¹⁾	31.27	0.78	0.04	15.07	0.877
	0.17 ²⁾			0.03 ^{*)}		
	0.81 ³⁾			0.01 ^{**)}		

The variants with a jamb: A – extruded polystyren – $\lambda=0.036$ W/(m·K), B – graphite polystyren – $\lambda=0.031$ W/(m·K), C – phenolic (resol) boards – $\lambda=0.022$ W/(m·K);

$U (U_{1D})$ – heat transfer coefficient of individual parts of the analysed joint (¹⁾ concerns external wall, ²⁾ concerns a jamb with a window, ³⁾ concerns a window)

Φ – heat flux flowing through the analysed joint,

L^{2D} – linear thermal coupling coefficient of the analysed joint; $L^{2D}=\Phi/(\Delta t \cdot l)$

Ψ_i – linear coefficient of heat transfer of the analyzed joint, determined after internal dimensions,

^{*)} value of linear (branch) heat transfer coefficient concerning the external wall $\Psi_{i,sc}$.

^{**)} value of linear (branch) coefficient of heat transfer concerning the window $\Psi_{i,O}$.

t_{min} – minimum temperature at the internal surface of the partition in the place of the thermal bridge,

$f_{Rsi(2D)}$ – temperature factor, determined on the basis of t_{min} .

The use of a jamb (extension of thermal insulation to the window frame) allows to minimise additional heat losses (Ψ_i [W/(m·K)]) and the risk of surface condensation (t_{min} [°C], $f_{Rsi(2D)}$) in relation to the solution without extension of the thermal insulation. Detailed analyses in this respect were presented in the following papers [6, 7, 10].

When determining the energy consumption of a building, it is also necessary to take into account the efficiency of installation systems resulting from regulation and use of heat in the heated space ($\eta_{H,e}$), transfer of heat from the heat source to the heated space ($\eta_{H,d}$), heat accumulation in the volume elements of the heating system ($\eta_{H,s}$), production of heat from an energy carrier or energy input to a heat source ($\eta_{H,g}$). The heating system in a building shall comply with the requirements of the technical building regulations and shall take into account technical knowledge of energy efficient solutions. The system should be designed as a high-performance system. High efficiency heat sources should be planned, all possible efforts should be made to reduce heat transfer losses and if there is an accumulation tank, accumulation losses should be minimal and the elements responsible for the control and use of heat should be optimally selected. The best possible performance can be achieved according to [14] by, among other things: the use of condensing boilers, heat pumps with a high coefficient of efficiency (COP), appropriate routing of heating medium distribution lines (compact system) and their proper thermal insulation, appropriate insulation of buffer tanks and load and discharge control systems, low-temperature surface, radiator or mixed heating systems, use of high-performance auxiliary pumps with low power consumption (resulting in low consumption of auxiliary energy).

The value of the annual indicator of non-renewable primary energy demand (EP) determines the total efficiency of a building. It refers to the energy contained in sources, including fuels and carriers, necessary to meet the final energy demand, taking into account the additional expenditures for delivering this energy to the building perimeter. The value of the indicator of input of non-renewable primary energy to the production and supply of an energy carrier or energy for technical systems w_i is taken from data disclosed by the supplier of that energy carrier or energy. Low values indicate low demand and therefore high energy efficiency of the building. On websites, some heat suppliers include values of the input ratio of non-renewable primary energy, for example:

- the ratio of input of non-renewable primary energy in 2016 for the heating network in the Warsaw District Heating System of Veolia Energia Warszawa S.A. supplied by the Combined Heat and Power Plants (CHP plants) Żerań and Siekierki, Heat Plants Kawęczyn and Wola and Waste Disposal Plant “Gwarków” OUZ-2, regardless of the quantity and type of heat sources and technologies used to generate and deliver heat to the final customer is $W_{pc} = 0,69$ [15],
- Gdańsk District Heating Company (GPEC sp. z o.o.) reports that the indicator of non-renewable primary energy input in 2015 for the district heating network is $W_{pc} = 0,658$ [16],
- non-renewable primary energy input indicator for the Bielsko-Biała district heating network for 2016: $W_{pc} = 0,71$ [17].

In case of lack of such data, the values of W_i coefficient specified in the Regulation [18] shall be used.

Improvement of the energy standard (reducing the embodied energy ratio) of an existing building can be achieved both with and without financial investment. The first way requires investments in the future that will be paid for over time. The estimated payback time can be presented using the SPBT coefficient. The second group includes measures related to the sustainable use of thermostatic valves, well thought-out ventilation of rooms, proper arrangement of radiators and saving of domestic hot water.

A single-family building with a basement and a usable attic erected in 1990 was chosen for the analysis. During the assessment of its technical and thermal condition it was found that

the values of heat transfer coefficients of external partitions do not meet the basic criterion according to the regulation [3]: ($U_c \leq U_{c(\max)}$). During the use of the building, a renovation was carried out, during which a leaky roof and window frames were replaced. On the basis of calculations carried out according to the regulation [18], it can be concluded that the analysed building is highly energy-intensive (utility energy demand index – $EU=152,06$ kWh/(m²·year), final energy demand index – $EK=410,90$ kWh/(m²·year), while non-renewable primary energy demand index – $EP=455,41$ kWh/(m²·year)). In order to adapt the analysed building to the binding legal regulations according to the regulation [3], it is necessary to perform thermal modernisation of individual elements: insulation of the ceiling above the unheated basement, insulation of external walls, replacement of the central heating system, replacement of the water heating system, installation of thermostats, insulation of heating cables.

The main division of variants is based on the differentiation of heat sources needed to heat the building and the preparation of hot water. – Table 3.

Table 3. Considered thermal modernisation variants of the analysed building considered – author's own elaboration based on [19].

	Variant I	Variant II	Variant III
The source of heat to central heating	boiler – biomass	boiler – coal, heat pump	condensing boiler
The source of heat to heating of water	boiler – biomass	boiler – coal, heat pump	condensing boiler / collectors
Insulation of external walls	polystyrene	polystyrene	polystyrene
Thermal insulation of the ceiling above the basement	polystyrene	polystyrene	polystyrene
Insulation of heating cables	PUR lagging	PUR lagging	PUR lagging
Installation of thermostats	+	+	+

On the basis of assumptions presented in Table 3 (variants I, II, III), calculations of energy performance indicators of the analysed building were carried out according to the procedures presented in the regulation [18] with the use of professional software. All external partitions after thermal modernisation met the basic thermal criterion: $U_c \leq U_{c(\max)}$, and from 31.12.2020 $U_{c(\max)}$ values were adopted as final values valid. However, additional heat losses resulting from the occurrence of linear thermal bridges were taken into account when using the value Ψ_c according to PN-EN ISO 14683 [20], in accordance with the used software to determine the energy performance of the building. The results of calculations of basic EU, EK, EP indicators for the analysed building are presented in Table 4.

Table 4. Results of calculations of energy performance parameters of a single-family building before and after thermal modernisation in different variants – author's own elaboration based on [19].

Parameters	Before thermal modernisation	After thermal modernisation		
		Variant I	Variant II	Variant III
EU [kWh/(m ² ·year)]	152.06	88.44	88.44	88.44
EK [kWh/(m ² ·year)]	410.90	181.34	130.22	136.52
EP [kWh/(m ² ·year)]	455.41	35.81	141.65	116.30

Therefore, the only option that can be used to adapt the analysed building to the 'low energy building' standard ($EP \leq EP_{\max} = 70$ kWh/(m²·year) and $U_c \leq U_{c(\max)}$) is Variant I (Tables 3 and 4). Meeting the requirements of the regulation [3] without the use of renewable energy

sources (RES) is very difficult and sometimes impossible. That is why, the higher the percentage of their use, the lower the demand for non-renewable primary energy EP [kWh/(m²·year)]. It is possible to reduce the indicators (EU, EK and EP) by improving the insulation quality of external walls (U_c much lower than $U_{c(max)}$ in force after 31.12.2020) by using innovative thermal insulation materials with a low value of heat conductivity coefficient λ [W/(m·K)].

4. Summary and conclusions

The selection of energy-saving technologies in low energy buildings is a complex process, which includes the issues of architectural design, building physics and building systems.

The thermal quality of the building envelope is assessed by determining the U_c , coefficients, which are used for further calculations of the hygrothermal analysis of partitions and the whole building (e.g. the coefficient of heat loss through penetration H_{tr} [W/K], the demand for usable EU energy, final energy EK and primary energy EP [kWh/(m²·year)]). It should also be emphasised that while shaping the arrangement of material layers of external partitions and their joints, the following criteria must be taken into account: thermoinsulating power, surface and interstitial condensation, acoustic resistance, fire protection, as well as load capacity and durability of the structure. Some arrangements of material layers meet the requirements for thermal insulation ($U_c \leq U_{c(max)}$), but it is not permitted to place the thermal insulation layer in any position of the partition after the analysis of humidity, acoustics or fire requirements.

It is also important to determine the reliable physical parameters (hygrothermal parameters) of building joints, which values depend on the location and thickness of thermal insulation material and the position of window frames in the external wall – Table 2. The use of approximate and indicative values, e.g. based on PN-EN ISO 14683:2008 [20], is not justified because they do not take into account changes in material systems and the type and thickness of thermal insulation.

Stricter requirements for thermoinsulating power and energy consumption of buildings require the introduction of energy saving measures, which have a significant impact on the energy efficiency of buildings. Detailed analyses of the influence of thermal quality of building partitions on their energy demand (EU, EK, EP) have been described in detail, among others, in the paper [21]. Thermal modernisation works undertaken in existing buildings should be carried out on the basis of a detailed analysis of their technical and thermal condition. On the other hand, the evaluation of the quality of works related to insulation of external partitions should be carried out on the basis of thermovision tests. The results and analyses in this respect are presented in the paper [22] for the housing estate in Upper Silesia. It is necessary to perform calculations and analyses concerning the undertaken energy-saving measures at the stage of their design, execution and use.

To comply with the requirements to achieve the standard for a low energy building with the EP ratio (e.g. for a single-family building, below 70 kWh/(m²·year)) it is necessary to: design or modernise building partitions and joints ensuring minimum heat loss through penetration ($U_c \leq U_{c(max)}$), selection of appropriate heating components of central heating, hot water and cooling system (with particular emphasis on the efficiency) and the use of renewable energy sources (RES).

5. Literature

- [1] Resolution of the Council of Ministers, adopted on 22 June 2015 for the adoption of the National Plan to increase the number of low energy buildings
- [2] Act of 7 July 1994 – Construction Law (Journal of Laws of 2013, item 1409, with later amendments).

- [3] Regulation of the Minister of Infrastructure and Construction of 14 November 2017 amending the regulation concerning building technical requirements and building localisation (Journal of Laws of 2017, item 2285).
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