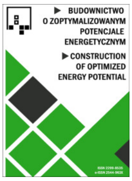
DOI: 10.17512/bozpe.2019.2.03

Budownictwo o zoptymalizowanym potencjale energetycznym
Construction of optimized energy potential

ISSN 2299-8535 e-ISSN 2544-963X



The thermal quality of housing elements and energy consumption of low-energy buildings - selected aspects

Krzysztof Pawłowski[1] (*orcid id: 0000-0002-6738-5764*)
Małgorzata Krajewska[1] (*orcid id: 0000-0002-8541-2295*)
[1] University of Science and Technology in Bydgoszcz

Abstract: In the article, there are introduced the selected design and executive aspects of low-energy buildings in relation to binding legal regulations. The integral part of this article are calculations and analyses concerning the thermal quality of low energy buildings and factors which form their energy consumption. Proper shaping of material sets for external envelopes and their junction in thermal and humidity aspects essentially influences building needs for energy and pollution emission of the natural environment.

Keywords: sustainable building, thermal quality of building elements, energy consumption of buildings

Please, quote this article as follows:

Pawłowski K., Krajewska M., The thermal quality of housing elements and energy consumption of low-energy buildings - selected aspects, BoZPE, Vol. 8, 2, 2019, 27-35, DOI: 10.17512/bozpe.2019.2.03

Introduction

Sustainable construction is both environmentally and human friendly and recognizes the principles of sustainable development resulting from saving natural resources and preventing environmental pollution. The most important issues for design, execution, and exploitation include: saving of natural resources by using renewable energy sources, lower the energy consumption of technological processes, lower the quantity of technological waste (by change or modernizing of construction materials and production technology), limiting energy consumption of existing or newly designed buildings, monitoring of building objects during exploitation, modern building installations, CAD in sustainable construction.

Across numerous countries, there are complex systems of building evaluation (e.g. Breeam, Leed & DGNB) in energy and ecology aspects. Certification procedures take into consideration national regulations and characteristics for the external climate. All systems which evaluate existing buildings concern, among other factors, the influence on the natural environment, health and comfort. Other considerations are the building envelope (structure and material layout of envelopes), the amount of energy used by buildings and the internal air parameters (interior usage comfort). Such a comprehensive evaluation requires the checking of physical parameters (heat and humidity) of the building envelope, its thermal stability and the effectiveness of room overheating prevention in summer seasons.

According to Article 5 of the Building Law Regulation (Dz.U. 2013, pos. pos. 1409, with later changes): „The building object as a whole and its particular parts with associated building equipment should be designed, considering its predicted usage period, in a way set by regulations, including technical and construction, and according to principles of technical knowledge, providing the fulfillment of basic requirements concerning: bearing load and stability of construction, fire safety, hygiene, health and environment, building safety use and availability, noise protection and thermal isolation, sustainable usage of natural resources."

In order to maintain a reasonable level of thermal energy required to use a building according to its designation, two methods are provided to help fulfill requirements in projected buildings:

- The first method consists of the design of partitions in a building whose values of heat transfer coefficient U [$W/(m^2 \cdot K)$] for external partitions, windows, doors, and installation technology fulfill the requirements of thermal insulation: $U_c \leq U_{c(max)}$.
- The second method is to design the building according to its need for non-renewable primary energy per room area unit with a controlled air temperature in the building, room or building part which constitutes an individual venue PE [$kWh/(m^2 \cdot year)$]: $PE \leq PE_{(max)}$.

The maximum value of the coefficients $U_{c(max)}$ for single partitions of a building and non-renewal primary energy need coefficient $PE_{(max)}$ were set in the regulation (Dz.U. of 2017 pos. 2285). Additionally there is a need to fulfill requirements for humidity protection concerning the risk of surface and interlayer condensation occurrence. Detailed calculation procedures and analyses of legal regulations in design, execution and exploitation of low energy buildings were included in (Grudzińska et al., 2017; Kaliszuk-Wietecka, 2017; Pawłowski, 2017).

In the article, calculations are presented and analyzed regarding the thermal quality of building envelope elements and factors which influence the energy consumption of a building.

The thermal quality of a building envelope

The legally binding laws involved in the process of design, construction, and exploitation of low-energy buildings force the development of technological and organizational solutions in order that newly erected buildings consume less and less energy for heating, ventilation, and preparation of hot water during the usage period. Fluctuations in the maximum value of the heat penetration coefficient $U_{max.}$ (former k_{max}) influence the energy consumption value during building exploitation. Unfortunately, legal regulations concerning the subject do not regulate requirements for limiting the heat loss through building partitions - heat bridges - because no limiting values are set e.g. in maximum values of the linear heat transfer coefficient Ψ_{max} [W/(m·K)]. It must be stressed that a building is a structure of building partitions and their joints of individual physical characteristics and is influenced by the external and internal environment. In numerous cases, the analysis of building partitions and joints in any aspect of, construction, material, and execution technology usually does not raise any objections at the design stage. However, knowledge of the physical parameters associated with heat and humidity exchange avoids numerous design and execution defects.

In many cases, the solution of heat transfer is reduced to the definition of heat flow through a flat building partition in a one-dimensional field (1D), without taking into account the heat flow in the two-dimensional field (2D) and three-dimensional (3D). But the real field of heat exchange is usually an external partition as a building part thus connected by a system of joints with binding partitions (ceiling, internal or external wall, ground floor).

The thermal quality of a building envelope is influenced by the following calculation parameters:

- heat transfer coefficient of a single partition in a one-dimension field (1D) - $U/U_{(1D)}$ [W/(m^2·K)],
- linear heat transfer coefficient of a heat bridge in the two-dimensional field (2D) - Ψ [W/(m·K)], branch heat transfer coefficient for a single part of partition, e.g. in the case of a window and external wall connection ($\Psi_{\acute{s}c.}$ - for external wall, $\Psi_{O.}$ - for window),
- heat transfer coefficient of a partition including linear heat bridges (2D) - $U_{(2D)}$ [W/(m^2·K)],
- minimum temperature on internal surface of partition in place of a heat bridge (2D) - $t_{min.}$ [°C],
- temperature factor $f_{Rsi(2D)}$ [–], defined based on $t_{min.}$.

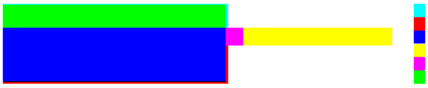
Below are calculations of the physical parameters of a joint: connection of external wall with a window in section through a door frame and lintel (in two variants: I - without a nib, II - with a nib, with insulation extended on the door frame), using TRISCO-KOBRU 86 software, with the following assumptions (Figs. 1 and 2):

- Joint modeling according to rules set by PN-EN ISO 10211:2008.
- Heat intercepting resistance (R_{si}, R_{se}) according to PN-EN ISO 6946:2008 with the calculation of heat fluxes according to PN-EN ISO 13788:2003 in the calculation of temperature distribution and temperature factor $f_{Rsi(2D)}$.
- Internal air temperature t_i = 20°C (dining room), external air temperature t_e = = –20°C (zone III).

- Values of heat conduction coefficient of building materials λ [W/(m·K)] assumed on tables in work (Pawłowski, 2017).
- Two-layer external wall: aerated concrete blocks of thickness 24 cm - λ = = 0.1 W/(m·K), styrofoam EPS (case A) - λ = 0.040 W/(m·K), graphite styrofoam (case B) - λ = 0.031 W/(m·K), polyurethane boards (case C) - λ = = 0.022 W/(m·K).
- Window woodwork with heat transfer coefficient $U_{O.}$ = 0.81 [W/(m^2·K)].

variant I - without a nib variant II - with a nib

a) calculation model



b) heat flux lines - adiabates

c) temperature distribution - isotherms

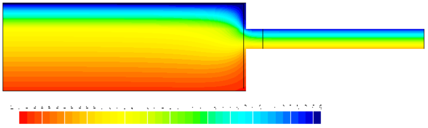
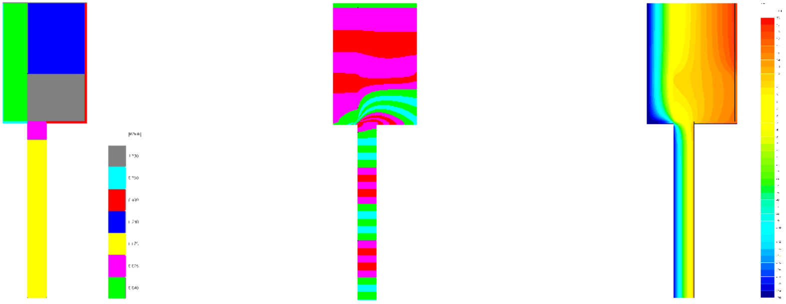
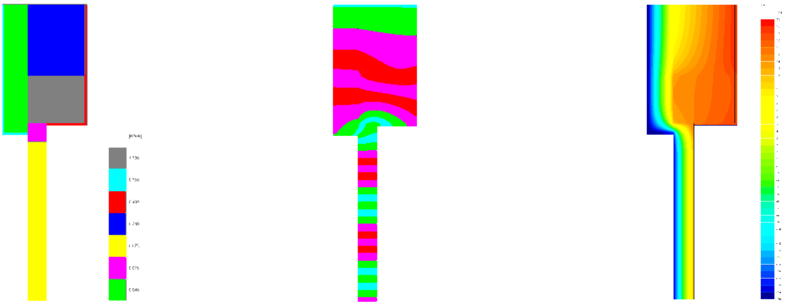


Fig. 1. Calculation model and results of the computer simulation of a joint: connection of external wall with a window in section through a door frame (*own study*)

a) calculation model b) heat flux lines - adiabates c) temperature distribution - isotherms



variant I - without a nib



variant II - with a nib

Fig. 2. Calculation model and results of the computer simulation of a junction: connection of external wall with a window in section through a lintel (*own study*)

In Tables 1 and 2 there are results from the calculation of the physical parameters for the analyzed building joints using different thermo-insulation materials 12 and 15 cm thick. In the case of a joint between two different partitions: the external wall and window, it is necessary to define the additional heat loss individually: the branch linear heat penetration coefficient $\Psi_{\text{śc.}}$ in relation to the external wall and the branch linear heat penetration coefficient $\Psi_{\text{O.}}$ in relation to the window. Detailed calculation procedures are showed in (Pawłowski, 2016).

Table 1. Calculation of the physical parameters of a joint: connection of external wall with a window in a section through a door frame (*own study*)

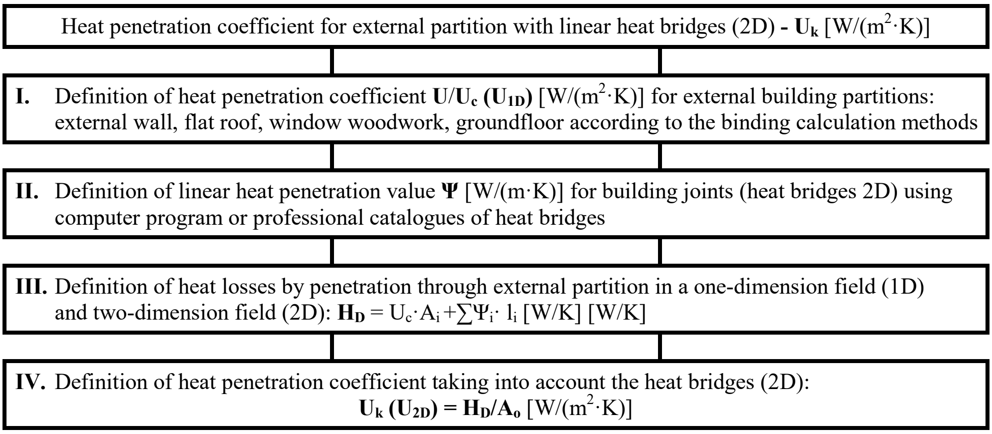
Variant	$U_{\text{śc.}}/U_{\text{O.}}$ $[\mathrm{W/(m^2\cdot K)}]$	Ψ $[\mathrm{W/(m\cdot K)}]$	$\Psi_{\text{śc.}}$ $[\mathrm{W/(m\cdot K)}]$	$\Psi_{\text{O.}}$ $[\mathrm{W/(m\cdot K)}]$	$t_{\text{min.}}$ [°C]	$f_{\text{Rsi(2D)}}$ [–]
OS IA$_{12}$	0.23/0.81	0.054	0.076	–0.022	12.14	0.804
OS IA$_{15}$	0.20/0.81	0.059	0.081	–0.022	12.30	0.808
OS IB$_{12}$	0.19/0.81	0.055	0.077	–0.022	12.45	0.811
OS IB$_{15}$	0.16/0.81	0.059	0.082	–0.023	12.59	0.815
OS IC$_{12}$	0.15/0.81	0.057	0.080	–0.023	12.80	0.820
OS IC$_{15}$	0.12/0.81	0.061	0.084	–0.023	12.91	0.823
OS IIA$_{12}$	0.23/0.81	0.043	0.043	0.000	14.16	0.854
OS IIA$_{15}$	0.20/0.81	0.047	0.046	0.001	14.41	0.860
OS IIB$_{12}$	0.19/0.81	0.043	0.042	0.001	14.63	0.866
OS IIB$_{15}$	0.16/0.81	0.046	0.044	0.002	14.85	0.871
OS IIC$_{12}$	0.15/0.81	0.043	0.041	0.002	15.17	0.879
OS IIC$_{15}$	0.12/0.81	0.046	0.043	0.003	15.35	0.884

Table 2. Calculation results of the physical parameters of a joint: connection of a wall with a window in section through a lintel (*own study*)

Variant	$U_{\text{śc.}}/U_{\text{O.}}$ $[\mathrm{W/(m^2\cdot K)}]$	Ψ $[\mathrm{W/(m\cdot K)}]$	$\Psi_{\text{śc.}}$ $[\mathrm{W/(m\cdot K)}]$	$\Psi_{\text{O.}}$ $[\mathrm{W/(m\cdot K)}]$	$t_{\text{min.}}$ [°C]	$f_{\text{Rsi(2D)}}$ [–]
N IA$_{12}$	0.23/0,81	0.207	0225	–0.018	11.91	0.798
N IA$_{15}$	0.20/0,81	0.213	0.232	–0.019	12.09	0802
N IB$_{12}$	0.19/0,81	0.208	0.227	–0.019	12.23	0.806
N IB$_{15}$	0.16/0,81	0.213	0233	–0.020	12.38	0.809
N IC$_{12}$	0.15/0,81	0.210	0.230	–0.020	12.57	0.814
N IC$_{15}$	0.12/0,81	0.214	0.234	–0.020	12.68	0.817
N IIA$_{12}$	0.23/0,81	0.066	0.068	–0.002	15.86	0.897
N IIA$_{15}$	0.20/0,81	0.070	0.071	–0.001	16.13	0.903
N IIB$_{12}$	0.19/0,81	0.062	0.063	–0.001	16.35	0.909
N IIB$_{15}$	0.16/0,81	0.065	0.065	0.00	16.58	0.915
N IIC$_{12}$	0.15/0,81	0.059	0.060	–0.001	16.88	0.922
N IIC$_{15}$	0.12/0,81	0.061	0.060	0.001	17.05	0.926

The values of the physical parameters for the analyzed joints (Tables 1 and 2) depend on type and thickness of the thermo-insulating material and the location of particular elements. Usage of a nib (extension of thermal insulation on window frame) minimizes additional heat losses (Ψ_i [W/(m·K)]) and the risk of surface condensation ($t_{min.}$ [°C], $f_{Rsi.(2D)}$) in relation to a solution without the extension of thermal insulation.

Next, the heat transfer coefficient was calculated for the external wall of the building taking into account linear heat bridges U_k [W/(m^2·K)] according to our own algorithm (Fig. 3).



Heat penetration coefficient for external partition with linear heat bridges (2D) - $\mathbf{U_k}$ [W/(m^2·K)]

I. Definition of heat penetration coefficient $\mathbf{U/U_c}$ ($\mathbf{U_{1D}}$) [W/(m^2·K)] for external building partitions: external wall, flat roof, window woodwork, groundfloor according to the binding calculation methods

II. Definition of linear heat penetration value $\mathbf{\Psi}$ [W/(m·K)] for building joints (heat bridges 2D) using computer program or professional catalogues of heat bridges

III. Definition of heat losses by penetration through external partition in a one-dimension field (1D) and two-dimension field (2D): $\mathbf{H_D} = U_c \cdot A_i + \sum \Psi_i \cdot l_i$ [W/K] [W/K]

IV. Definition of heat penetration coefficient taking into account the heat bridges (2D): $\mathbf{U_k}$ ($\mathbf{U_{2D}}$) = $\mathbf{H_D/A_o}$ [W/(m^2·K)]

Fig. 3. Calculation algorithm for heat penetration coefficient for external partition taking into account linear heat bridges 2D - U_k [W/(m^2·K)] (*own study*)

For the calculation, there were two external walls selected (with different window areas) (Fig. 4), assumed values for branch heat coefficient values $\Psi_{śc.}$ (Tables 1, 2).

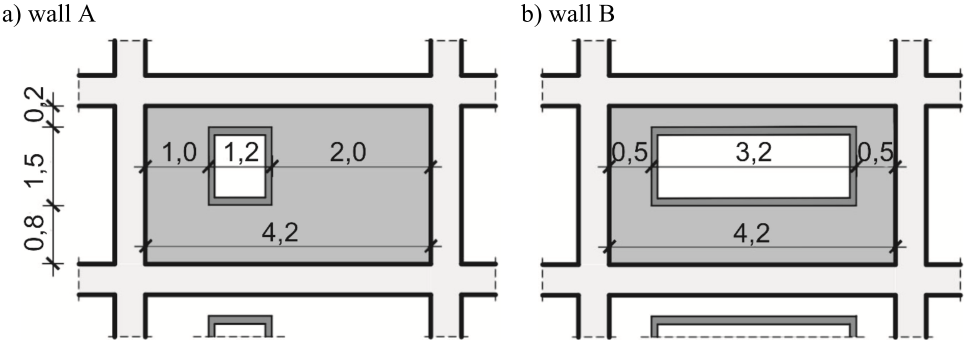


Fig. 4. Analyzed external walls of a building (*own study*)

Table 3. Calculation results of the external wall heat transfer coefficient, including linear thermal bridges (*own study*)

Variant	U_C (U_{1D}) [W/(m^2·K)]	Wall A		Wall B	
		H_D [W/K]	U_k (U_{2D}) [W/(m^2·K)]	H_D [W/K]	U_k (U_{2D}) [W/(m^2·K)]
IA_{15}	0.20	2.36	0.27	2.47	0.43
IIA_{15}	0.20	2.02	0.23	1.70	0.30
IB_{12}	0.19	2.25	0.26	2.36	0.41
IIB_{12}	0.19	1.91	0.22	1.59	0.28
IB_{15}	0.16	2.02	0.23	2.25	0.39
IIB_{15}	0.16	1.65	0.19	1.44	0.25
IC_{12}	0.15	1.93	0.22	2.20	0.38
IIC_{12}	0.15	1.55	0.18	1.34	0.23
IC_{15}	0.12	1.68	0.19	2.04	0.23
IIC_{15}	0.12	1.30	0.15	1.19	0.21

The heat transfer coefficient, taking into account linear heat bridges U_k [W/(m^2·K)], involves heat losses in a one-dimensional field (1D) - $U_{ci}\cdot A_i$ and two-dimensions (2D) - $\sum\Psi_i\cdot l_i$. The definition of this parameter allows us to define the influence of building joints (heat bridges) on total heat losses.

The thermal quality of the building envelope elements constitutes the basic element in fulfilling requirements in sustainable construction. However, when we define the energy consumption of a building as an indicator of building demand for final energy EK [kWh/(m^2·year)], there is a need to take into account the efficiency of the installation systems of the building resulting from: regulation and usage of heat in the heated space ($\eta_{H,e}$), heat transfer from the source to the heated space ($\eta_{H,d}$), heat accumulation in the capacity elements of the heating system ($\eta_{H,s}$), heat production from the heat medium or energy supplied to heat source ($\eta_{H,g}$). Heating installation in a building must fulfill technical and constructional requirements and it should include technical knowledge of energy-saving solutions. The designed system should be highly efficient. Heat sources should be highly efficient and all efforts should be made in order to lower losses during the heat medium transfer and if there is an accumulation tank, accumulation losses should be minimized. Also, elements responsible for regulation and heat usage should be optimized. Maximal possible efficiencies can be reached through: using condensation boilers, heat pumps with a high-efficiency rate, correct leading of heat medium ducts (contained installation) and proper insulation, proper insulation of buffering tanks and load/unload control suitable for their work specificity, low-temperature heat planar systems, with radiators or mixed using highly-efficient auxiliary pumps characterized by low-power consumption (resulting in low consumption of auxiliary energy).

The annual demand for non-renewal primary energy (PE) defines the energy efficiency of a building contained in the sources, including fuel and media necessary to cover the demand for the final energy with additional cost for the delivery of this energy to the building's borders. The value of non-renewable primary energy cost coefficient for creating and delivering energy media or energy for technical systems w_i is assumed based on data made available by this energy media or energy provider. Low values obtained indicate insignificant demand and thus high energy efficiency of a building. It must be stressed that using renewable energy sources guarantees the assumption of coefficient w_i ($w_i < 1$) for calculation and consequently low value of coefficient PE [kWh/(m^2·year)] and low pollution emission to the atmosphere.

Summary and conclusions

Design and execution of a building fulfilling the requirements for sustainable construction is a complex process including issues of architecture, construction materials, general construction, building physics, and building installations.

The thermal quality of a building envelope is evaluated by the definition of coefficients U_c, which are used in further calculations in thermal and humidity analysis of partitions and the whole building (e.g. heat loss in penetration coefficient H_D [W/K], final and primary energy [kWh/(m^2·year)]). It must be stressed that in the formation of material layers in external partitions and their joints it is necessary to fulfill criteria regarding: thermal insulation, surface and interlayer condensation, acoustic insulation, fire protection, and construction bearing load and durability. Some material layers systems fulfill the requirements in thermal insulation ($U_c \leq U_{c(max)}$). However, after including additional heat losses resulting from the occurrence of heat bridges (e.g. resulting from the connection of the external wall with a window) the values of coefficient of U_k (U_{2D}) [W/(m^2·K)] are significantly higher than values resulting from heat flow in a one-dimension field (1D) - Table 3.

Lowering of limit values of heat penetration coefficient U_{max} without considering heat flows in fields (2D) and (3D) (heat bridges), causes larger heat loss through construction partitions and their joints. It is also reasonable to define the limit values of the heat penetration coefficient Ψ_{max} at 0.5-0.10 W/(m·K) depending on the specificity of a joint under analysis.

The fulfillment of requirements for a low energy building in the primary energy coefficient PE (e.g. for single-family building, below 70 kwh/(m^2·year)) requires: design or modernizing of building partitions and joints ensuring minimum heat loss through penetration ($U_c \leq U_{cmax}$), proper choice of elements in installation of central heating and hot water, cooling (with particular stress on efficiency) and application of renewable energy sources.

Bibliography

Grudzińska, M., Ostańska, A. & Zyczyńska, A. (2017) *Low Energy and Passive Buildings*. Warszawa, Grupa Wydawnicza Medium.

Kaliszuk-Wietecka, A. (2017) *Budownictwo zrównoważone. Wybrane zagadnienia z fizyki budowli*. Warszawa, Wydawnictwo Naukowe PWN.

Pawłowski K. (2016) *Projektowanie przegród zewnętrznych w świetle aktualnych warunków technicznych dotyczących budynków. Obliczenia cieplno-wilgotnościowe przegród zewnętrznych i ich złączy*. Warszawa, Grupa Medium.

Pawłowski K. (2017) *Zasady projektowania budynków energooszczędnych*. Warszawa, Grupa Wydawnicza Medium.

PN-EN ISO 10211:2008 *Mostki cieplne w budynkach. Strumienie ciepła i temperatury powierzchni. Obliczenia szczegółowe*.

PN-EN ISO 6946:2008 *Komponenty budowlane i elementy budynku. Opór cieplny i współczynnik przenikania ciepła. Metoda obliczania*.

PN-EN ISO 13788:2003 *Cieplno-wilgotnościowe właściwości komponentów budowlanych i elementów budynku. Temperatura powierzchni wewnętrznej umożliwiająca uniknięcie krytycznej wilgotności powierzchni wewnętrznej kondensacji. Metody obliczania*.

Program komputerowy TRISCO-KOBRU 86, PHYSIBEL c.V, Belgia. Licencja stanowiskowa na cele badawczo-dydaktyczne.

Rozporządzenie Ministra Infrastruktury i Budownictwa z dnia 14 listopada 2017 r. zmieniające rozporządzenie w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie (Dz.U. 2017, poz. 2285).

Ustawa z dnia 7 lipca 1994 r. - *Prawo budowlane* (Dz.U. 2013, poz. 1409 z późn. zm.).

Jakość cieplna elementów obudowy i energochłonność budynków niskoenergetycznych - wybrane aspekty

Streszczenie: Przedstawiono wybrane aspekty projektowe i wykonawcze budynku niskoenergetycznego w świetle obowiązujących przepisów prawnych. Integralną część pracy stanowią obliczenia i analizy dotyczące jakości cieplnej elementów obudowy budynków niskoenergetycznych oraz czynników kształtujących ich energochłonność. Poprawne ukształtowanie układów materiałowych przegród zewnętrznych i ich złączy w aspekcie cieplno-wilgotnościowym w istotny sposób wpływa na zapotrzebowanie budynku na energię i emisję zanieczyszczeń środowiska naturalnego.

Słowa kluczowe: budownictwo zrównoważone, jakość cieplna elementów budynku, energochłonność budynku