Shaping of Selected Elements for A Low Energy Building

Krzysztof Pawlowski ¹, Magdalena Nakielska ¹

¹ Faculty of Civil and Environmental Engineering, University of Technology and Life Sciences in Bydgoszcz, Poland

krzypaw@utp.edu.pl

Abstract. Reaching the standard of low energy building requires fulfilling criteria of energy saving and thermal protection as well as humidity criterion on design and exploitation stages. The basic factors shaping energy saving construction include among other: building architecture, construction and material solutions of external partitions and building joints using modern thermal insulation materials (building casing), type and efficiency of ventilation, central heating and hot water preparation systems and integral management of a building in energy production. In this work, there is an analysis of shaping of selected elements for low energy consumption. Physical parameters of selected external partitions and joints were defined using professional computer programs taking into account external and internal air parameters. Additionally, there was presented the influence of installation systems efficiency and energy source used on demand factor for non-renewable primary energy EP. Based on performed calculations and analyses, there were formulated design, executive and exploitation guidelines in shaping of building elements for low energy consumption buildings.

1. Introduction

A low energy building, according to regulations resulting from the Construction Law [1] and regulation [2], should be characterized with appropriate parameters, thus fulfilling requirements in thermal protection and energy saving, humidity protection, safety of usage (construction bearing capacity, acoustic isolation, fire protection, and appropriate parameters of interior microclimate). Achievement of minimum value for annual indicator for non-renewable primary energy EP [kWh/(m²·year)] depends on many consistent factors:

- **Building architecture**: situation of the building according to geographic directions, compact body of the building (minimum shape coefficient A/V), size and situation of transparent partitions, providing the protection against warming up of rooms in summer with sun-shields, arrangement of rooms in a building depending on calculated temperatures of internal air, roof geometry, type of vegetation on a building plot.

- **Construction and material solutions of external partitions and their joints (elements of building’s external case)**: using high quality materials with innovative insulation properties (PIR and PUR boards, aerogels, vacuum and transparent insulations), a school of construction joint design in thermal-humidity aspect with application of numeric programs, choice of materials for non-transparent partitions with minimum value of a heat transfer value $U$ [W/(m²·K)], choice of transparent partitions with maximum value of heat transfer value $U\leq0.90$ W/(m²·K) and in limiting room overheating in summer period.
- **Type and efficiency of ventilation system**: hybrid of mechanical ventilation with heat recovery system, mechanical ventilation with ground heat exchanger, support of existing ventilation systems of natural ventilation – application of solar chimneys, high system efficiency over 70%.

- **Type and efficiency of central heating, hot water installations, usage of renewable energy sources**: high efficiency of systems above 70%, supporting of central heating and hot water systems, renewable energy sources (solar, wind and geothermal energy).

- **Integral management of the building in energy generation**.

  In the work there is an analysis of selected factors influence on achievement the standard of “a low energy building”.

2. **The shaping of material sets for internal partitions and their joints in low energy buildings**

   Appropriate choice of material sets (construction, insulation and finishing layers) enables to achieve low values of heat transfer coefficient \(U\) [W/(m²·K)] of a full partition and linear heat transfer coefficient \(\Psi\) [W/(m·K)] for construction joints (2D) and minimizes the risk of surface and inter-layer condensation. Before selection of an appropriate insulating material at the design stage of new erected and modernization of existing buildings, attention must be paid to their following properties: heat conduction coefficient \(\lambda\) [W/(m·K)], volume density, acoustic insulation, steam permeability, diffusive resistance coefficient \(\mu\) [-], sensitivity to biological and chemical factors and fire protection.

   During our own calculation at the first stage the permeation coefficient value was defined \(U_c\) [W/(m²·K)] for two-layer walls for various insulation materials - Table 1.

   **Table 1.** Calculation results of heat transfer coefficient \(U_c\) [W/(m²·K)] of three-layer thermally homogenous external walls according to PN-EN ISO 6946 [5].

| Material layers                  | \(d\) [m] | \(\lambda\) [W/(m·K)] | \(x\) [m] | \(U_c\) [W/(m²·K)] |
|----------------------------------|-----------|------------------------|-----------|---------------------|
| I                               |           |                        |           |                     |
| Gypsum plaster                   | 0.01      | 0.40                   | 0.10      | 0.24 0.16           |
| Aerated concrete blocks          | 0.24      | 0.17                   | 0.12      | 0.22 0.14           |
| Insulation                       | x         | *                      | 0.15      | 0.19 0.12           |
| Thin-layered parget              | 0.005     | 0.76                   |           |                     |
| II                              |           |                        |           |                     |
| Gypsum plaster                   | 0.01      | 0.40                   | 0.10      | 0.32 0.19           |
| Blocks of lime and sand          | 0.24      | 0.55                   | 0.12      | 0.27 0.16           |
| Insulation                       | x         | *                      | 0.15      | 0.23 0.14           |
| Thin-layered parget              | 0.005     | 0.76                   |           |                     |

* Insulation variants: A – styrofoam boards \(\lambda = 0.040\) W/(m·K), B – PIR boards \(\lambda = 0.022\) W/(m·K), for calculations of \(U_c\) it was assumed \(\Delta U = 0.01\)

**Values of heat transfer coefficient** \(U_c\) of external walls fulfilling the condition: \(U_c \leq U_{c(max)} = 0.20\) W/(m²·K) are marked in green

In order to define the temperature distribution and additional heat loss resulting from various material structure (joint of several partitions of a building) detailed calculations were performed using the TRISCO software for selected physical parameters:

- heat flux \(\Phi\) [W],
- heat transfer coefficient for a full partition \(U\) \((U_{1D})\) [W/(m²·K)],
- linear coefficient of heat transfer (defining additional heat losses resulting from occurrence of linear heat bridges) \(\Psi\) [W/(m·K)],
- minimum temperature on internal surface of a partition at a heat bridge \(t_{min}\) [°C],
- temperature factor defined based on minimum temperature on internal surface of a partition at a heat bridge, \(f_{Rsi(2D)}\) [-].

Detailed calculation procedures of physical parameters for internal partitions and their joints were introduced in [3, 4].

In the calculations using the TRISCO software the following assumptions were made:

- modelling of joints was performed according to guidelines set in PN-EN ISO 10211 [6] and in [3, 4],
- heat intercepting resistance \((R_{si}, R_{se})\) were assumed according to PN-EN ISO 6946 [5] in heat fluxes calculation and PN-EN ISO 13788 [7] in temperature distribution and temperature factor \(f_{Rsi(2D)}\) calculations,
- internal air temperature \(t_i = 20\, ^\circ C\) (living room), external air temperature \(t_e = -20\, ^\circ C\) (zone III),
- values of heat conduction coefficient of building materials \(\lambda [W/(m\cdot K)]\) were assumed from tables [4],
- selected calculation cases are set in Tables 2 and 3.

In Figure 1, there are shown results of computer simulation of an exemplary joint (the joint of an external wall with a window in section through the window casing) using the TRISCO software.

The values of linear heat transfer coefficient \(\Psi [W/(m\cdot K)]\) are used for calculation of heat loss by permeation \(H [W/K]\) and further to define an annual demand factor for usable energy EU [kWh/(m\(^2\)·rok)]. Using rough values, for instance data from PN-EN ISO 14683 [8], is not justifiable because it does not consider material change in the heat bridges in discussion. The values of temperature factor \(f_{Rsi} [-]\) serve for risk evaluation for occurrence of condensation on joint internal surface.

### Table 2. Calculation results of physical parameters for selected joints of two-layer walls (construction layer of aerated concrete blocks).

| Item | Analysed joint of external joints | Insulation material thickness | Physical parameters of construction joints |
|------|----------------------------------|------------------------------|--------------------------------------------|
|      |                                  |                             | \(\Psi [W/(m\cdot K)]\) \(\Delta t_{\text{min}} [^\circ C] / f_{Rsi(2D)} [-]\) |
|      |                                  |                             | \(A^0\) \(B^0\) \(A^1\) \(B^1\) |
| 1.   | Joint of external walls in corner | 0.10                        | 0.075 / 0.060 / 0.88 / 0.91 |
|      |                                  | 0.12                        | 0.071 / 0.056 / 0.87 / 0.91 |
|      |                                  | 0.15                        | 0.067 / 0.052 / 0.88 / 0.91 |
| 2.   | Joint of external wall with ceiling in section through tie beam | 0.10                        | 0.131 / 0.075 / 0.92 / 0.95 |
|      |                                  | 0.12                        | 0.111 / 0.063 / 0.93 / 0.96 |
|      |                                  | 0.15                        | 0.090 / 0.051 / 0.94 / 0.96 |
| 3.   | Joint of external wall with window in section through casing (with nib) | 0.10                        | 0.052 / 0.054 / 0.84 / 0.86 |
|      |                                  | 0.12                        | 0.055 / 0.057 / 0.85 / 0.87 |
|      |                                  | 0.15                        | 0.059 / 0.060 / 0.85 / 0.87 |

*) Variants of insulation: A – styrofoam boards \(\lambda = 0.040\) W/(m·K), B – PIR boards \(\lambda = 0.022\) W/(m·K)

**Figure 1.** Exemplary representation of computer simulation results for external two-layer wall joint with a window in section through the window casing.
Table 3. Calculation results of physical parameters for selected joints of two-layer walls (construction layer made of lime-sand blocks).

| Item | Analysed joint of external joints | Insulation material thickness | Physical parameters of construction joints | $\Psi$ [W/(m·K)] | $t_{\text{min. [C]}}$ / $f_{\text{Rsi}(2D)}$ [-] |
|------|----------------------------------|-----------------------------|---------------------------------------------|------------------|-----------------------------------|
| 1.   | Joint of external walls in corner | 0.10                        | A*)                                        | 0.129            | 0.090                             | 13.55 / 0.84  |
|      |                                  | 0.12                        |                                             | 0.117            | 0.079                             | 14.27 / 0.86  |
|      |                                  | 0.15                        |                                             | 0.105            | 0.068                             | 15.07 / 0.88  |
| 2.   | Joint of external wall with ceiling in section through tie beam | 0.10                        | A*)                                        | 0.125            | 0.073                             | 16.79 / 0.92  |
|      |                                  | 0.12                        |                                             | 0.105            | 0.060                             | 17.24 / 0.93  |
|      |                                  | 0.15                        |                                             | 0.086            | 0.048                             | 17.72 / 0.94  |
| 3.   | Joint of external wall with window in section through casing (with nib) | 0.10                        | A*)                                        | 0.061            | 0.063                             | 14.16 / 0.85  |
|      |                                  | 0.12                        |                                             | 0.064            | 0.065                             | 14.43 / 0.86  |
|      |                                  | 0.15                        |                                             | 0.070            | 0.069                             | 14.70 / 0.87  |

*) Variants of insulation: A – styrofoam boards $\lambda$ = 0.040 W/(m·K), B – PIR boards $\lambda$ = 0.022 W/(m·K)

The values of physical parameters for external partitions and building joints (2D) – Table 1, 2, and 3, depend on assumed set of material layers (heat conduction coefficient $\lambda$ [W/(m·K)], diffusive resistance coefficient $\mu$ [-]) and on joint shape of two differentiated partitions, for example external wall joint with a window.

3. Factors shaping the energy characteristics of a building
The energy characteristics of a building i.e. definition of building energy parameters constitutes one of its documents during the design, construction and exploitation process. The methodology of energy calculation i.e. definition of factors:

- **EU** (usable energy) – annual demand for usable energy, allowing for heating and ventilation, preparation of hot water and cooling, and heat gains: internal, depending on room and building type, solar radiation through glass areas – defined by the month balance method in relation to individual parameters of internal and external air [kWh/(m²·year)],

- **EK** (final energy) – annual demand for final energy for heating system, hot municipal water system, cooling, built-in lighting installation (it does not concern housing buildings), accounting for average system efficiency – defined on components of demand for usable energy [kWh/(m²·year)],

- **EP** (primary energy) – annual demand for non-renewable primary energy for heating system, preparation of hot municipal water, cooling, built-in lighting installation (it does not concern housing buildings) with addition of auxiliary energy usage for systems, taking into account factors of non-renewable primary energy amounts for generating and supplying the energy carrier or energy for technical systems $w_1$ – defined based on components of demand for final energy [kWh/(m²·year)],

- **ECO2** – unitary emission value of CO2, resulting from fuel burn process in the heating system, hot municipal water preparation, cooling, built-in lighting and auxiliary equipment in technical systems [tCO2/(m²·year)],

- **UOZE** – share of renewable energy sources in annual demand for final energy [%], for the building or its part described in the regulation [9].

In setting the annual demand for final energy supplied to the building or its part for heating system $EK$ [kWh/(m²·year)], there are taking into account efficiencies resulting from: heat control and usage in heated space ($\eta_{H,e}$), transfer of heat from heat source to heated space ($\eta_{H,d}$), heat accumulation in capacitance element of heating systems ($\eta_{H,s}$), heat generation from energy carrier or energy delivered to a heat source ($\eta_{H,g}$). The heating installation in a building must fulfil requirements of technical and building regulations and should also take into account technical knowledge in energy saving solutions. The designed system should be highly efficient. The energy sources should be designed as highly effective and take necessary care to lower the energy loss during transfer, and if there is an accumulative tank, the loss by accumulation should be minimal, and elements responsible for regulation and heat
usage also should be selected optimally. Maximum possible efficiency can be reached according [10] by: using condensing boilers, heat pump with high efficiency coefficient (COP), correct wire leading for heating carrier (compact installation) and their proper insulation, proper insulation of buffer tanks and loading and unloading them appropriate to their work specificity, low temperature plane heating systems, heating or mixed, selection of control technology ensuring the highest effectiveness of regulation in a given installation structure and with given way of use, usage of highly efficient auxiliary pumps characterized with low power consumption, resulting in low consumption of auxiliary power.

The annual demand for non-renewable primary energy \( EP \) [kWh/(m²·year)] defines the total effectiveness of the building. It concerns energy contained in sources, including fuels and carriers necessary for covering demand for final energy, including additional expenditures for supplying this energy to a building. The value of expenditure coefficient of non-renewable for generation and supplying of energy carrier or energy for technical systems \( w_i \) is assumed based on data, which made available by the supplier of this carrier of energy or energy. Reaching low values indicates low demand and thus high energy effectiveness of the building.

There are gathered parameters of energy characteristic of two buildings (Table 4), under analysis defined on base of procedures presented in the regulation [9].

| Table 4. Comparative analysis of energy characteristic parameters of analysed buildings |
|-----------------------------------------------|---------------|---------------|
| Analysed parameters of a building             | Building I    | Building II   |
| Type and designation                          | Single-family housing, Bydgoszcz | Single-family housing, Bydgoszcz |
| External partitions                           | \( U_c < U_{\text{max}/2014-2017} \) | \( U_c < U_{\text{max}/2014-2017} \) |
| Ventilation system                            | gravitational, blowing through ventilators | gravitational, blowing through ventilators |
| Area of rooms with controlled air temperature (heated or cooled area) \( A_t \) [m²] | 96.60 | 171.43 |
| Factor of annual demand for usable energy \( EU \) [kWh/(m²·year)] | 62.09 | 43.11 |
| Average seasonal efficiency of heating system | 0.606¹ | 0.693¹ |
| Average seasonal efficiency of system of municipal hot water preparation | 0.646² | 0.564⁴ |
| Indicator of annual demand for final energy \( EK \) [kWh/(m²·year)] | 98.32 | 58.60 |
| Indicator of non-renewable energy expenditure for generating and supplying energy carrier of energy for technical systems \( w_i \)² | hard coal (\( w_i=1.1 \)) biomass (\( w_i=0.2 \)) | hard coal (\( w_i=1.1 \)) biomass (\( w_i=0.2 \)) |
| Indicator of annual demand for non-renewable demand for non-renewable primary energy \( EP \) [kWh/(m²·year)] | 89.33 | 65.49 |
| \( CO_2 \) unitary emission value [t\( CO_2/(m²·year) \)] | 0.03 | 0.02 |
| Share of renewable energy source in annual demand for final energy [%] | 21.26 | 11.00 |

¹ heat generation efficiency – 0.82 (liquid fuel stove with closed combustion chamber of power to 50kW, fireplace), heat transfer efficiency – 0.96 (central heating from local heat source, situated in a heated and insulated building), heat accumulation efficiency – 1.0 (without buffer tank), heat efficiency and heat usage – 0.77 (water heating with plate heater, floor heating)
² heat generation efficiency – 0.85 (liquid fuel stove with closed combustion chamber of power to 50kW), heat transfer efficiency – 0.95 (hot municipal water tank in standard 2015)
³ heat generation efficiency – 0.82 (solid fuel boiler, fireplace), heat transfer efficiency – 0.96 (central heating from local heat source, situated in a heated and insulated building), heat accumulation efficiency – 1.0 (without buffer tank), regulation efficiency and heat usage – 0.88 (water heating with plate heaters, floor heating)
⁴ heat generation efficiency – 0.83 (two-function solid fuel stove), heat transfer efficiency – 0.80 (water heating in a single-family house), heat accumulation efficiency – 0.85 (150l tank)
⁵ heating system – hard coal + biomass, system of hot water preparation – hard coal
4. Conclusions
Design and construction of low energy buildings is a complex process and demands knowledge of numerous issues from building materials, general building, building physics, building installations, renewable energy source, and architecture.

Correct design of the building’s case (external partitions and construction joints) consists in fulfilling heat and humidity requirements described in the regulation [2]. Obtaining the heat transfer value $U_c \text{[W/(m}^2\cdot\text{K}]}$ below the limit value, consists in correct situation of insulation material and defining its appropriate thickness. However, attention must be paid to appropriate shape of material sets of building joints (connection of two or three partitions in node), design also in literature as heat bridges (thermal bridges). The selection of materials, especially insulation should account for innovative solutions allowing optimization (lowering) of their thickness.

Credible definition of demand value for non-renewable primary energy EP needs comprehensive knowledge of many technical issues and calculation procedures in this area. Aiming at fulfilling requirements for “a low energy building standard” for EP indicator (for example: a single family building, below 70 kwh/(m^2·year)) requires: design of partitions and building joints ensuring minimum heat loss by permeation ($U_c \leq U_{c,max}$), limiting heat losses through linear and spatial heat bridges, selection of appropriate installation elements for central heating and central municipal water, cooling (with particular stress on efficiency) and application of non-renewable energy source.

Based on performed calculation, computer simulation and analysis it must be stressed that low energy building is a building in which design and technical solution were used allowing its use, with low energy consumption while providing comfortable hygienic and sanitary conditions.

References
[1] Regulation of 7 July 1994 – Building Law (Dz. U. of 2013 position 1409, with amendments).
[2] Regulation of the Minister of Transportation, Building and Marine Economy changing the regulation about technical conditions for building and their situations (Dz. U. of 2013 position 926).
/Announcement of the Minister of Infrastructure and Development of 17 June 2015 about unified text for technical conditions which buildings and their situation should fulfill. Dz. U. of 2015 position 1422/.

[3] A. Dylla, “Thermal physics of buildings in practice. Thermal and humidity calculations,” Wydawnictwo Naukowe PWN S.A. Warszawa, 2015.
[4] K. Pawłowski, “Design of external partitions in view of binding technical conditions concerning buildings. Thermal and humidity calculations of external partitions and their joints,” Grupa Wydawnicza Medium Warszawa, 2016.
[5] PN-EN ISO 6946 :2008 Building components and building elements. Heat resistance and heat permeation coefficient. Calculation method.
[6] PN-EN ISO 10211 :2008 Heat bridges in buildings. Heat fluxes and surface temperatures. Detailed calculations.
[7] PN-EN ISO 13788:2003 Heat and humidity properties of building composites and building elements. Internal surface temperature allowing to avoid the critical humidity of an internal surface condensation. Calculation methods.
[8] PN-EN ISO 14683:2008 Heat bridges in buildings. Linear coefficient of heat transfer. Simplified methods and rough values.
[9] Regulation by the Minister of Infrastructure and Development about methodology of calculation of energy characteristic of a building and apartment or part of building constituting a single unit and way of preparation and standard certificates of energy characteristics (Dz. U. of 2015, position 376).
[10] Handbook on improvement of building energy characteristics, Ministerstwo Infrastruktury i Budownictwa, Warszawa, 2016.