

SELECTED ASPECTS OF DESIGNING AND REALIZATION OF LOW ENERGY SINGLE-FAMILY HOUSES ACCORDING TO THE NF15 AND NF40 STANDARDS

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Abstract

The article presents chosen aspects of designing and realization of low energy single-family houses fulfilling the requirements of the NF40 and NF15 standards as determined in the priority program of the National Fund for Environmental Protection and Water Management entitled „An improvement of energy effectiveness. Subsidies to low energy houses”. An analysis concerns the minimal technical requirements pertaining to the outside shape and internal structure of NF40 and NF15 buildings, in comparison with the building law recommendation on technical conditions to meet by buildings and their location. An attention was paid to chosen problems of fulfilling the requirements of the NF40 and NF15 standards and the need of applying modern structural and material solutions and to especially accurate realization.

Introduction

Because of the necessity of lowering energy consumption in the building sector, the EU ratified amendments to the Directive EPDB 2010/31/UE on 19 March 2010 concerning the energetic characteristic of buildings. An important postulate encompassed in this directive is an obligation of the Member States; governments to introduce financial and market incentives promoting construction of low energy buildings (Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010).

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One of the form of realization of this recommendation is the Poland-wide program of subsidies for a low energy building which was worked out by the National Fund for Environmental Protection and Water Management (NFOŚiGW) and introduced for the period of 2013–2018. This program, which is being realized with the public financial resources, is aimed at the investors who build or buy single-family houses or flats in multi-family dwellings, which meet the requirements of the two standards: the NF40 low energy one or the NF15 passive (ŻURAWSKI 2013).

The symbols of the NF40 and NF15 standards represent the annual demand for a usable energy for the heating and ventilation $EU_{c.o.}$ of respectively 40 and 15 kWh/(m² · year), calculated in accordance with the principles determined in the standard (PN EN ISO 13790: 2009) using the monthly or hourly method including the weather data published by the Ministry of Transport, Construction and Maritime Economy as well as the relevant standards encompassed in the list of the Polish Committee of Standardization.

For the requirements of the program, the Polish National Energy Conservation Agency (KAPE) has elaborated an expert appraisal pertaining to the principles of designing and realization of low energy houses in Poland. This elaboration became the basis for the Recommendations approved by the Board of NFOŚiGW, determining the mandatory requirements for reaching expected energetic standards of residential houses and the way of design verification and checking the reliability of the construction (*Domy Energooszczędne. Podręcznik dobrych praktyk* 2012).

Each building which is being realized in the framework of the program must obligatorily fulfill the technical requirements of the Recommendations. It was also foreseen that the practical application of the technical requirements will be a subject to periodical analysis and, if need be, the Recommendations will be amended.

1.5 year after the initiation of the program, in August 2014, the technical requirements concerning the building designing in the NF40 and NF15 energy standards were modified. The diversification of criteria based on the climatic zones in Poland was abandoned.

The modified minimal technical requirements for residential houses, being realized according to the NF40 or NF15 energy standards, are available at the internet page of NFOŚiGW (*Attachment No 3 to the priority program of NFOŚiGW* 2014).

The article analyses the current technical requirements concerning the structure of single-family houses, fulfilling the NF40 and NF15 energy standards and, on the basis of a review of professional literature as well as the results of our own papers, the most significant problems of the designing in accordance with these requirements were pinpointed.

The chosen minimal technical requirements for single-family houses being realized in the NF40 and NF15 standards

The minimal technical requirements for single-family houses in the NF40 low energy or NF15 passive standards were divided into five groups pertaining to:

- liminary requirement for usable energy for the purpose of heating and ventilation $EU_{c.o.}$,
- building structure,
- parameters of mechanical blow-in and blow-out ventilation systems with heat salvage,
- parameters of the heating systems and heating installation,
- parameters of the systems and installation for preparation of warm usable water.

In Table 1, the minimal technical requirements in the scope of construction timing to enhance thermal insulation capacity of the building envelope and to minimize the heat losses in single-family houses fulfilling the NF40 and NF15 energy standards were presented.

In the second column of Table 1, the technical requirements concerning the structure of traditionally designed single-family houses, i.e. according to the recommendations of the Technical Conditions which have been in force in Poland since 1 Jan. 2014 (Decree of the Minister of Transport, Construction and Maritime Economy from 5.July. 2013).

In Table 1, the requirements in the scope of the liminary linear values of thermal losses coefficients of other thermal bridges do not apply to concave corners of external walls and other geometrical bridges in the building envelope in the cases, when in the places of occurrence of these bridges the same material and constructional solutions were used as in the case of the components of the building envelope.

For the NF15 and NF40 standards the values of $\Psi \leq 0,15 \text{ W}/(\text{m} \cdot \text{K})$ are allowed for the thermal bridges, but only in the case of constructing a building on the ground (strip foundations, spot footings, floors on the ground etc.) and in the case of floors separating dwelling rooms from underground garages.

An analysis of the specified, selected minimal technical requirements shows that the buildings constructed according to the NF40 and NF15 energy standards are characterized by considerably lower (respectively ca. 2 and over 5 times smaller) values of the annual demand for the heating and ventilation $EU_{c.o.}$, in comparison to the values attained in a building designed according to the currently binding building law in Poland.

The attainment of such a low value of annual energy demand in low energy buildings requires to design the shape and structure of a building in the way to

Table 1
Chosen minimal technical requirements for single-family houses in the NF40 and NF15 standards and according to the Technical Conditions 2014 (WT 2014)

Energy standard of a building	WT 2014	NF 40	NF 15
Annual demand for a usable energy for the heating and ventilation $EU_{c.o.}$ [kWh/(m ² · year)]			
–	ca. 80.0	≤ 40.0	≤ 15.0
Limitary values of the thermal transmittance coefficient of the building envelope U_{max} [W/m ² · K]			
External walls	0.25	≤ 0.15	≤ 0.10
Roofs, flat roofs and ceilings under unheated attics or above passages	0.20	≤ 0.12	≤ 0.10
Ceilings over unheated cellars and enclosed under-floor spaces	0.25	≤ 0.20	≤ 0.12
Floors on the ground	0.30	≤ 0.20	≤ 0.12
Windows, balcony doors and transparent non-opening partitions	1.30	≤ 1.00	≤ 0.80
Roof windows	1.50	≤ 1.00	≤ 0.80
External and garage doors	1.70	≤ 1.30	≤ 0.80
Limitary values of linear coefficient of heat losses in thermal bridges Ψ [W/m · K]			
Balcony slabs	not determined	≤ 0.30	≤ 0.01
Other thermal bridges	not determined	≤ 0.10	≤ 0.01
Air-tightness of a building (mechanical ventilation) n_{50} [1/h]			
–	≤ 1.50	≤ 1.00	≤ 0.6

Source: Worked out by the authors: Attachment No 3 to the Priority Program of NFOŚiGW (2014) and Decree of the Minister of Transport, Construction and Maritime Economy (2013).

obtain an improvement of thermal insulation capacity of non-transparent partitions, windows and doors (a considerable limitation of value of thermal transfer coefficient) and to lower heat loss through thermal bridges and uptightness of external shells.

Thickness of insulation layers of the building envelope components in the single-family houses fulfilling the NF15 or NF40 standards

The improvement of the thermal insulation capacity of the components of the building envelope is obtained as a result of usage of load-bearing layer materials characterized by an appropriately high thermal resistance R and the adequate thickness of insulation layers made of the most energy effective materials.

Table 2
Specification of calculated thickness of external walls insulation layers required to fulfill the demands of the WT 2014, NF40 and NF15 energy standards

External walls				
Insulation layer		energy standard/limitary U -value		
Kind of thermal insulation material	thermal conductivity coefficient λ , W/mK	WT 2014 $U = 0.25$ W/m ² K	NF40 $U = 0.15$ W/m ² K	NF15 $U = 0.10$ W/m ² K
Load – bearing layer made of chequer brick (25 cm thick) $R = 0.55$ m ² K/W				
Required insulation thickness [cm]				
Mineral rockwool	0.037	12	22	34
Graphite styrofoam	0.032	11	19	30
Polyurethane boards	0.023	8	14	21
Load – bearing layer made of cellular concrete blocks YTONG ENERGO (24 cm thick) $R = 2.52$ m ² K/W				
Required insulation thickness [cm]				
Mineral rockwool	0.037	5	15	27
Graphite styrofoam	0.032	4	13	23
Polyurethane boards	0.023	3	9	17
Load – bearing layer made of clay blocks POROTHERM (38 cm thick) $R = 3.24$ m ² K/W				
Required insulation thickness [cm]				
Mineral rockwool	0.037	3	12	24
Graphite styrofoam	0.032	3	11	21
Polyurethane boards	0.023	2	6.5	15

Source: Elaboration of the authors.

Table 3
Specification of calculated thickness of roof insulation layers required to fulfill the demands of the WT 2014, NF40 and NF15 energy standards

Roofs				
10% share of wood in the heterogeneous layer with insulation was assumed for the calculation		energy standard/limitary U -value		
Kind of thermal insulation material	thermal conductivity coefficient λ , W/mK	WT 2014 $U = 0.20$ W/m ² K	NF40 $U = 0.12$ W/m ² K	NF15 $U = 0.10$ W/m ² K
Required insulation thickness [cm]				
Mineral rockwool	0.037	23	38	49
Graphite styrofoam	0.032	20	33	42
Polyurethane boards	0.023	14	23	30

Source: Elaboration of the authors.

In Tables 2, 3 and 4, the results of calculation of the thickness of insulation layers of chosen components of the building envelope (external walls, roofs and floors on the ground) for attaining the required U -value in single-family houses meeting the NF40 and NF15 energy standards are presented.

The calculations were performed according to the PN-EN ISO 6946:2008P standard „Building components and elements of a building. Thermal resistance and the coefficient of thermal transfer. The calculation method”.

Table 4
Specification of calculated thickness of floor-on-the ground insulation layer required to fulfill the demands of the WT 2014, NF40 and NF15 energy standards

Floor on the ground				
The thermal resistance of other layers was left out		energy standard/limitary U -value		
Kind of thermal insulation material	thermal conductivity coefficient λ , W/mK	WT 2014	NF40	NF15
		$U = 0.30 \text{ W/m}^2\text{K}$	$U = 0.20 \text{ W/m}^2 \text{ K}$	$U = 0.12 \text{ W/m}^2 \text{ K}$
Required insulation thickness [cm]				
Mineral rockwool	0.037	12	18	30
Graphite styrofoam	0.032	10	16	26
Polyurethane boards	0.023	8	11	19

Source: Elaboration of the authors.

From the analysis of the above presented results of the calculations issues that:

- the mandatory thickness of insulation layers for attaining the required U -values for non-transparent divisions are many fold bigger in the building fulfilling the NF40 or NF15 standards, as compared to the building designed according to the requirements of the Technical Conditions (WT 2014). For example, the insulation thickness from mineral rockwool of an external wall with a load – bearing layer from POROTHERM clay blocks of 38 cm thickness in the NF40 and NF15 buildings must be respectively 4 and 8 times bigger than in the buildings fulfilling the WT 2014 requirements;

- the thickness of an insulation layer mandatory to attain the needed U -values of non-transparent divisions depends on the thermal resistance of a material of the load – bearing layer. For example, in a NF15 building the change of the load – bearing layer material from chequer bricks 25 cm thick to cellular concrete block 24 cm thick or clay blocks 44 cm thick allows the reduction of the thickness of an insulation layer from mineral wool respectively by 20% and 56%;

– the mandatory thickness of an insulation layer for attaining the U -value of external walls depends on the thermal resistance of an insulation material. In the case of the YTONG ENERGO blocks (24 cm thick), the usage of polyurethane boards insulation, instead of mineral rockwool allows to reduce the thickness of an insulation layer by 37% (in a NF15 building).

Thermal bridges in the buildings fulfilling the NF40 or NF15 standards

To reduce the occurrence of thermal bridges in the low energy buildings, the following general principles are to apply:

– the insulation layer should surround the entire heated part of a building in a continuous and uninterrupted way, thus for example, the roof insulation layer should be connected with the external wall insulation over its entire length,

– everywhere, where it is possible, gaps, thickenings, or punctures in the insulation layer should be avoided,

– in the design of a building, sharp edges should be avoided, because they are difficult to insulate (e.g. it is especially difficult to maintain insulation continuity in the neighborhood of skylight windows),

– structural solutions should be used to promote insulation continuity, e.g. self-supporting balconies and foundation on the foundation slab.

In the calculations of the thermal transmittance coefficients of non-transparent partitions, corrections should be included for air gaps in the insulation layer, for mechanical fasteners going through an insulation layer, and for precipitation on a roof with inverted layers (Attachment No 3 to the priority NFOŚiGW program 2014).

The heat losses issuing from the occurrence of punctual thermal bridges should be limited by the choice of mechanical fasteners with pivots characterized by a low thermal conductivity coefficient and appropriate stoppers for closing openings in thermal insulations.

In the case of low single-family houses, not subject to strong wind, the mechanical fasteners can be abandoned and replaced by the gluing of the insulation to the wall. Gluing should be done in such a way which prevents air circulation between the insulation layer and the load-bearing wall, and also prevents slit occurrence between insulation sheets which could generate thermal losses. All sources of leakage in the insulation layer should be filled in with trims of insulation material used or with spray insulation (e.g. PUR caulk).

The minimal technical requirements for the NF40 or NF15 buildings necessitate that the assessment of the linear thermal transmittance coefficients resulting from heat transfer through thermal bridges should be done by conducting numerical calculations on the basis of the PN-EN ISO 10211:2008 standard. Thus it is unacceptable to apply simplified methods or to use the data taken from the thermal bridges catalogues.

The established in the technical conditions limitary values of linear thermal transmittance coefficients Ψ for the NF40 and NF15 buildings in the energy standard are very low (especially these for the NF15 standard buildings: $\Psi \leq 0.10$ W/mK). In the places, where there is a lack of continuous thermal insulation, the limitary values of linear thermal transmittance coefficients in thermal bridges Ψ are difficult to reach (GERYŁO et al. 2002). For example, in the common area of an external door with on-the-ground floor, as the thickness of the floor insulation increases, the value of the linear thermal transfer does not lower but it goes up (RYNKOWSKI 2014). It results from the fact that the thermal insulation of an on-the-ground floor with a thick layer of an insulator increases the temperature of basement soil, which augments the heat flow discharging in the contact place between the door and the floor. Hence the conclusion that the thickness of insulation layers of external partitions should be optimized, taking into account the required values of the linear thermal transmittance coefficients.

The fulfillment of the minimal energy NF40 or NF15 standards requirements pertaining to windows and external doors

In the minimal technical requirements for the buildings being constructed in the NF 40 and NF15 energy standards, the limitary values of the thermal transmittance coefficients for windows U_w were determined as not higher than 1.0 and 0.8 W/m² · K respectively. These are values, which are lower by 13.3% and 46.7% respectively than the limitary windows thermal transmittance coefficient determined in the Technical Conditions 2014 ($U_w = 1.5$ W/m² · K).

Yet it should be kept in mind that the values of the U_w -values depend on the thermal transmittance coefficients of the components of windows, i.e. of glassing (U_g), of frame (U_f) and of a distance frame (Ψ_g), and also on the windowpane share in the total surface of the window and the number of its divisions.

The designer should verify the producer's specifications for the calculation accurateness of the U_w -value, which should be done according to the PN-EN ISO 10077-1:2007 standard.

In the low energy buildings, a good solution is to use windows with a big glassing share (e.g. non-openable ones), which are characterized by the low U_w -values. While applying non-opening windows one should consider safety conditions, the necessity of airing a room in summer (in each room there should be at least one openable window) and the possibility of window cleaning from outside.

To attain low values of the linear coefficient of thermal losses through the rim of windows, the special construction of distance frames (so called warm distance frame) should be used as well as deeper setting of windowpanes in the window profile.

Windows in the buildings designed in the NF40 or NF15 energy standards should also fulfill the following additional requirements:

- so called warm assembly of windows should be used, i.e. in the layer of thermal insulation,

- the windows should be air-tight – the air infiltration coefficient for openable windows and balcony doors should amount not more than $n = 0.3 \text{ m}^3/(\text{m} \cdot \text{h} \cdot \text{daPa}^{2/3})$,

- because in NF40 and NF15 buildings, a gravity ventilation is not used but mechanical one with heat recovery, the windows cannot be equipped with diffusers,

- the connection of windows with the frame should be designed and realized in such a way as to attain their complete air-tightness.

An amount of solar gains has a very important significance for the energy efficiency of a building. Therefore glassed or transparent partitions of a low energy building should be characterized by a possibly high solar energy transmittance index, in the case of double- or triple-glazed panes $g \geq 0.60$ or $g \geq 0.50$ respectively (*Domy Energooszczędne. Podręcznik dobrych praktyk* 2012).

In view of the thermal comfort of the inhabitants, the protection of rooms against overheating is also important. Therefore in the windows and other glassed external partitions facing east, west and south, shading elements should be foreseen. The glassing shadowing solutions should not limit an access of solar radiation in winter. One of the simplest and at the same time most effective methods of glassing shadowing is planting a deciduous plant, which during the winter months stays leaf-less (it is possible to keep the needed natural lighting of the interior in winter).

The requirements concerning thermal insulation capacity of the entrance and garage doors in the NF40 and NF15 standard buildings are determined by the limitary values of thermal transmittance coefficients, $U_d = 1.3$ and $0.8 \text{ W/m}^2\text{K}$ respectively (Attachment No 3 to the priority NFOŚiGW 2014 program). These are values respectively 23.5% and 53% lower than the limitary U_d -values of entrance doors foreseen in the Technical Conditions 2014.

The requirements concerning the air-tightness of single-family houses fulfilling the NF40 or NF15 standards

In the minimal technical requirements for the buildings designed in the NF40 and NF15 energy standards, the limitary values of the coefficient expressing the number of air exchange between the external and internal environment (as a result of uptightness of a building at the pressure differences of 50 Pa) were determined at the level of $n_{50} \leq 1.0$ and $n_{50} \leq 0.6$ 1/h respectively. These are values of 1.5 or 2.5 times lower respectively than the limitary coefficient values of $n_{50} = 1.5$ 1/h determined in the Technical Conditions 2014.

The high level of building envelope's air-tightness in low energy buildings is aimed to eliminate thermal losses resulting from uncontrolled inflow of cold (and humid) air to the interior through gaps in the partitions. It should also protect against moistness and inter-layers condensation of steam, which might infiltrate to the leaky partition from the building interior (ZAKLIKOCKI 2014).

The attainment of the limitary values of the n_{50} coefficient in the buildings designed in the NF40 or NF15 standards requires a correct design of structural details and their painstaking realization.

The most important design recommendations concerning assuring the required air-tightness of a building are as follows:

- tight components of a building envelope should surround continuously and uninterruptedly the entire heated part,
- connections each components of the building envelope (e.g. at the meeting place of external wall and sloped roof) should be durable and air-tight, simple to make and inexpensive (these conditions are fulfilled by for example glued link with mechanical pressure),
 - each partition should have only one layer responsible for air-tightness,
 - determining the placement of the layer responsible for air-tightness, it should be considered that the diffusion resistance of a partition should be biggest from the inside and diminish towards outside,
 - an air-tight components of a building envelope, which usually at the same time fulfill the role of a vapour barrier, should be placed on the internal side of a partition, before the thermal insulation layer,
 - it is very important to make all kind of perforations through building casing air-tight, such as hook-ups, holes, electric sockets.

The air-tightness of NF40 and NF15 buildings should be checked at the construction stage, after the realization of all air-tight layers and the installations, which go through them by the means of air-tightness test (ŻURAWSKI 2013). The test is done according to the PN-EN 13829:2002 standard „The thermal properties of buildings. A valuation of air-tightness of buildings. The

method of pressure measurement with the aid of a ventilator” by usage of a blower door.

Summary and conclusions

The fulfillment of the criteria as determined by the minimal technical requirements for the buildings meeting the NF40 or NF15 energy standards in the scope of designing their outside shape and structure may be impeded by the following problems:

- the needed thickness of insulation layers of external partitions are very big (e.g. a roof in a NF15 building should be insulated with mineral wool at least 49 cm thick), which may cause problems of complicated assembly (e.g. in the case of a skylight window or a kneewall) and also may result in a considerable lowering of the usable height of an attic;

- attaining the required limitary values of the linear thermal transmittance coefficients may prove to be difficult in the case of thermal bridges in places lacking insulation continuity;

- the window carpentry designs in NF40 or NF 15 buildings should be especially conscientiously chosen because of the necessity of fulfilling a number of criteria: the proper geometry, air-tightness, proper U -value, as well as solar energy transmittance index;

- the postulate of the minimal technical requirements for the NF40 or NF15 standards to maintain a high level of air-tightness of a building is to be fulfilled only through the use of a high degree of accuracy achieved by specialist building teams.

On the basis of an analysis of the possibility of meeting the technical requirements for the buildings being constructed in the low energy or passive standards, the following practical conclusions may be stated:

- because of the very big thickness of traditional insulation in the building being realized in the NF40 or NF15 standards, other insulation materials should be applied, e.g. polyurethane boards, polyurethane foam or multilayer mats consisting of a few courses of bubble foil and highly reflexive screens, aerogels and nanogels (an aerogel board 17 cm thick allows to attain the wall's thermal transmittance coefficient $U = 0.010 \text{ W/m}^2\text{K}$), or vacuum insulation (a board 7 cm thick allows to attain the wall's thermal transmittance coefficient $U = 0.010 \text{ W/m}^2\text{K}$);

- elimination of the majority of thermal bridges (necessary for reduction of heat losses) is possible only in the case of careful design of the structural details of a building (e.g. self-supporting balconies, situating on the foundation slab made in a permanent shuttering made of insulating material of appropriate density and of proper compressive strength and dampness resistance);

– a good solution for improvement of thermal insulation capacity of partitions is a design of two-layer partitions. In the internal layer (protected by the external layer against atmospheric influences), an insulation continuity and maximal air-tightness as well as the removal of thermal bridges are being attained (BAĆ et al. 2014). Glazed fragments of external partition (e.g. Trombe's wall) enable to increase the share of solar gains in the energy balance of a building.

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