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CHARACTERISTICS OF THE RENEWABLE ENERGY SOURCES TECHNOLOGY TRANSFER CENTER'S BUILDING IN THE CONTEXT OF REQUIREMENTS FOR THE PASSIVE STANDARD

Abstract
The aim of this paper is to present the requirements for the passive standard based on the example of the RES TTC building. The requirements were divided into main energy demand and detailed recommendations for each indicator. The calculations and analyses have shown that to achieve the required energy demand, better solutions than the recommended ones need to be applied, such as air handling units with better heat recovery efficiency. The same applies to the U heat penetration coefficient of heat for the outer partitions. The use of ventilation units with a recommended efficiency of 75% does not guarantee achieving a passive standard.

Key words
passive construction, energy efficient construction, sustainable development

The origin of energy-efficient construction

The fossil fuel resources are limited and non-renewable. The fact that after using up conventional fuels we cannot count on their renewal is a serious problem, but at the same time it is challenging the engineers of various specialties around the world. It is becoming increasingly common to strive for the highest possible effectiveness, efficiency and energy savings in all sectors of the economy [1]. Based on the available analyses it can be stated that the resources of raw materials such as crude oil and natural gas will be exhausted within the hundred years. In turn, coal will no longer be available in the next century [2].

For economic reasons, it is necessary to seek new sources of energy, use renewable energies, and to use the current state of knowledge and technology to reduce energy consumption to a minimum. In the context of the construction industry, the answer to this problem is energy-efficient and passive construction. If investors are not convinced by the ecological aspects, the need to reduce carbon emissions and the issue of global warming, the economic aspects of the rapidly rising energy prices will certainly influence their decisions. Energy-efficient and passive construction will not be a luxury in the future and will become a must and a universally accepted standard.

Savings should start where consumption is highest, and according to the research presented in the EU Energy in figures report [3], households consume as much as 26.2% of final energy. It is more than the industry sector (25.6%), which seems to be the most energy intensive. The building of the Technology Transfer Center is a response to the existing challenges and is itself a natural scale experimental facility. The TTC is a passive design structure that has been equipped with a range of advanced measuring devices, and the collected data will form the basis for the development of research and practical recommendations in the field of passive construction, directly contributing to its development.

The assumptions of passive construction

The concept of passive housing, in the form and definition used today, emerged in 1988. Dr. Wolfgang Feist and Professor Bo Adamson are its creators. In 1996, the Passivhaus Institute was established in the German city of Darmstadt, the aim of which is the improvement and dissemination of the ideas of buildings that do not require conventional heating systems.

The two main and most important requirements for the passive standard are:

- The annual energy demand for heating and ventilation, determined in accordance with the "Passive House Design Package" (PHPP - Passivhaus-Projektierungs-Paket), cannot exceed 15 kWh/(m^2·year).
- The total primary energy demand for all building maintenance needs (heating, domestic hot water and electricity) may not exceed 120 kWh/(m^2·year) [4].

It should be clarified at the outset that primary energy should be understood as the total amount of energy contained in a fuel that needs to be burnt to cover the building's heating needs, domestic hot water production, the operation of all electrical appliances, and lighting [5].

In addition, it is also worth checking the indicator of the demand for energy consumption for cooling of not more than 15 kWh/(m^2·year), and the maximum power demand for heating ≤ 10 W/m^2 [6].

These conditions are considered as auxiliary because they are based on assumptions adopted for a passive building that must also be highly efficient in terms of electricity consumption.

The criterion of the maximum demand for heating power of ≤10 W/m^2 stems from calculations. "Assuming in accordance with DIN 1946 the exchange of around 30 m^3/h of air per person, with 30 m^2 of usable area per person, the result is at least 1 m^3 / (m^{2}h) of supply air per every square meter" [4].

In addition, the temperature limitation of the heater t<50^{0}C was imposed due to the scorching of dust at higher temperatures. The temperature increase of the air after heating is assumed to be around 30 K. Given that the specific heat of air is c = 1005 J/(kg·K) and the air density is 1.229 kg/m^3, the maximum heat load of the heater is calculated as follows:

$$P = 1\ m^3/(m^2h) \cdot 1.229\ kg/m^3 \cdot 1005\ J/kg{\cdot}K \cdot 30\ K = 10.29\ J/s{\cdot}m^2 = 10\ W/m^2\ [7]$$

Minimal indicators (Table 1) have also been identified, aimed at facilitating the design of a passive building by setting certain limits for heat transfer or air tightness coefficients, which should be verified using the so-called Blower Door Test (tightness test) [8]. Achieving the limit values does not, however, guarantee the fulfillment of the main requirements for energy demand.

The pressure test protocol is one of the requirements for the certification of passive buildings. Additional recommendations concern the characteristics of materials and construction products or ventilation systems. However, the final result and observance of the energy criteria is the most important. The decision and responsibility for how this is achieved has been left to the designer, who has complete freedom to choose the solutions.

Table 1. Passive construction standards [9]

Indicator	Value
Coefficient of heat penetration through the outer partitions U	≤ 0.15 W/(m^2·K)
Linear heat penetration coefficient for thermal bridges Ψ	≤ 0.01 W/(m·K)
Window heat penetration coefficient (including window frames and casings) U_W	≤ 0.8 W/(m^2·K)
Solar energy penetrability factor for windows g	≥ 0.5…0.6
Air tightness n_{50}	≤ 0.6 h^{-1}
Recuperator efficiency η	≥ 75 %
Electricity consumption by the recuperator	≤ 0.45 Wh/m^3

PHPP - Passive House Design Package

The analysis of the RES TTC building was done using the PHPP program. It is a tool for complex building evaluation in terms of meeting the standards of passivity. The main computational module of the system is based on the ISO 13790: "Energy Utilization of Buildings - Calculating Energy Consumption for Heating and Cooling" standard. Many additional calculation sheets have also been included [6].

It is accurate to state that: "It is not enough just to compile individual components, materials and products suitable for use in passive buildings, but it is not sufficient for turning a structure into a passive building. The whole is something more than the sum of its parts. The interactions between the components, materials and products make it necessary to perform an integrated design, so that only then can the standard of a passive building be achieved. " [10]

The PHPP package includes many interconnected spreadsheets that require entering the necessary, detailed data. Based on them, the final, most important values are calculated, including the annual demand for heat energy for heating and the total demand for primary energy. Based on those calculations, it is stated whether the building has reached the passive standard.

PHPP spreadsheets include a list of surfaces, a calculation of U coefficients of partitions, a calculation of heat loss by elements in contact with the ground, a list of window surfaces, the U_w coefficient for windows and the total orientation-dependent radiation, the ventilation installation, a calculation of the energy demand indicator for heating, a calculation of the frequency of occurrence of excessive temperatures, a calculation of electricity demand, a calculation of the primary energy demand indicator and the CO_2 emission indicator, and a calculation of internal heat sources.

Analysis of the RES TTC building

The RES TTC building was to achieve the passive standard. A detailed analysis has been carried out in view of the requirements and recommendations. The first and basic indicators to be calculated are the coefficients of heat penetration through the outer partitions. It is important to choose such structural solutions that would allow for avoiding the formation of thermal bridges. Table 2 shows the comparison of coefficients for the RES TTC with the coefficients provided in the technical conditions.

Table 2. Heat transfer coefficients

Type of partition	**Heat transfer coefficient [W/m²K]**			
	RES TTC	Technical conditions for buildings		
		from January 1, 2014	from Sunday, January 1, 2017	from Friday, January 1, 2021
External walls	0.11	0.25	0.23	0.20
Roof	0.08	0.20	0.18	0.15
Floor on the ground	0.06	0.30	0.30	0.30
Windows	0.80	1.3	1.1	0.90

The new regulations of the Ordinance of the Minister of Infrastructure on the technical conditions to be met by buildings and their location have been in force since January 1, 2014. The change in regulations is due to the obligations that the European Union has imposed on the member states - the Recast EPBD. The direct consequence of introducing new regulations is, among others, gradual improvement of the energy efficiency of buildings by systematically lowering the maximum permissible heat penetration coefficients. The RES TTC building meets the most stringent requirements that will apply from January 1, 2021.

Another very important element that has been analyzed is the windows. When calculating the energy demand indicator for heating energy, the effects of windows are considered in two aspects. First, windows are the largest component of the total heat loss through penetration. This means that one should strive to ensure that the window heat penetration coefficient is as small as possible. It depends, however, on several factors:

$$U_w = \frac{A_g U_g + A_f U_f + l_g \Psi_g}{A_g + A_f}$$

where:
A_g - glazing area [m²],
A_f - frame surface area [m²],
U_g - glazing heat penetration coefficient [W/m²K],
U_f - frame heat penetration coefficient [W/m²K],

L_g - total glazing circumference [m],
Ψ_g - linear heat transfer coefficient of the thermal bridge on the contact of the glass and the window frame [W/mK].

At the same time, it is important to remember that thanks to the proper selection of windows, there is a gain in heat from the sun, which is especially important in the winter. Therefore, the transmittance of solar radiation energy g should, as recommended, be between 0.5 and 0.6. However, the problem may be the summer period, where excessive heat gains from the sun can cause the building to overheat. The installation of blind shutters that are included in the design phase is to prevent this unfavorable phenomenon. Table 3 shows the exemplary parameters of the different types of windows that were considered when optimizing the solutions. Table 4 shows the detailed calculation of the U_w coefficient for the variants analyzed.

Table 3. Window parameters for each variant

Coefficients		Coefficient g	Thermal bridge Ψ_g [W/mK]
U_g [W/m²K]	U_f [W/m²K]		
Variant 1			
0.50	1.00	0.53	0.045
Variant 2			
0.50	0.81	0.53	0.025
Variant 3			
0.60	1.00	0.51	0.045

Table 4. List of U_w coefficients for individual windows

Descrip-tion	Orientation	Dimensions of the window opening		U_w coefficient [W/m²K]		
		Width [m]	Height [m]	Variant 1 TTC RES	Vari-ant 2	Variant 3
O2	South	1.10	3.10	0.82	0.68	0.88
O4	South	2.45	2.50	0.73	0.64	0.80
O3	South	2.30	2.50	0.75	0.66	0.82
O2	South	1.10	3.10	0.82	0.68	0.88
O1	South	3.85	2.50	0.71	0.63	0.78
O7	East	6.00	1.35	0.80	0.69	0.87
O2	East	1.10	3.10	0.86	0.72	0.92
O2	North	1.10	3.10	0.89	0.75	0.95
O6	North	2.10	0.75	1.05	0.86	1.09
O5	West	3.10	0.75	1.02	0.84	1.07
Dz2	South	1.10	3.05	0.86	0.72	0.92
Dz2	South	1.10	3.05	0.89	0.75	0.95
Dz1	North	2.00	3.10	0.77	0.67	0.84
Dz2	North	1.10	3.10	0.89	0.75	0.95
		Average value for all windows:		0.80	0.68	0.86

At the same time, the same method of installation of windows was assumed in the insulation layer (Fig. 1). This is particularly important due to the need to minimize the thermal bridges on the casing-jamb connection. Installation of windows with external blinds is particularly complicated. In this case, the external roller shutter is attached with a polyurethane foam spacer.

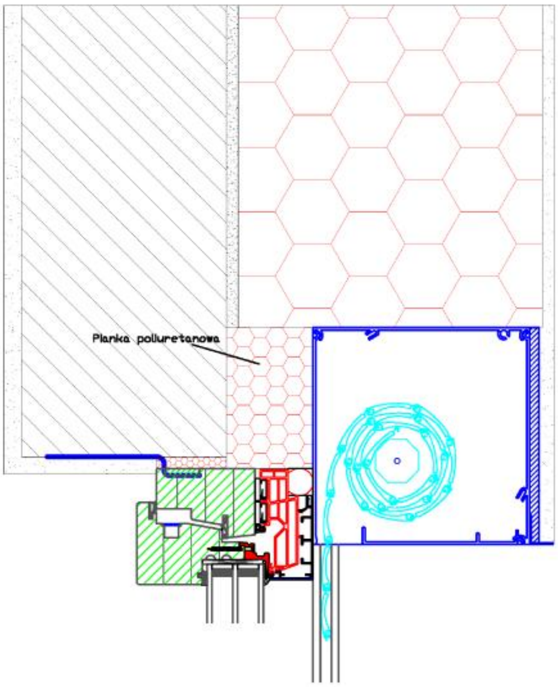

Fig. 1. An exemplary detailed view of the assembly of a window with external blinds
Source: technical materials of the Wiegand Fensterbau company [11]

The advantages of installing a window in the thermal insulation layer are best illustrated by the simulations of the distribution of isotherms (Fig. 2). Opting out of installation in the insulation layer would automatically increase the thermal bridge from the roller shutter in that case, since there would be no space left for polyurethane foam.

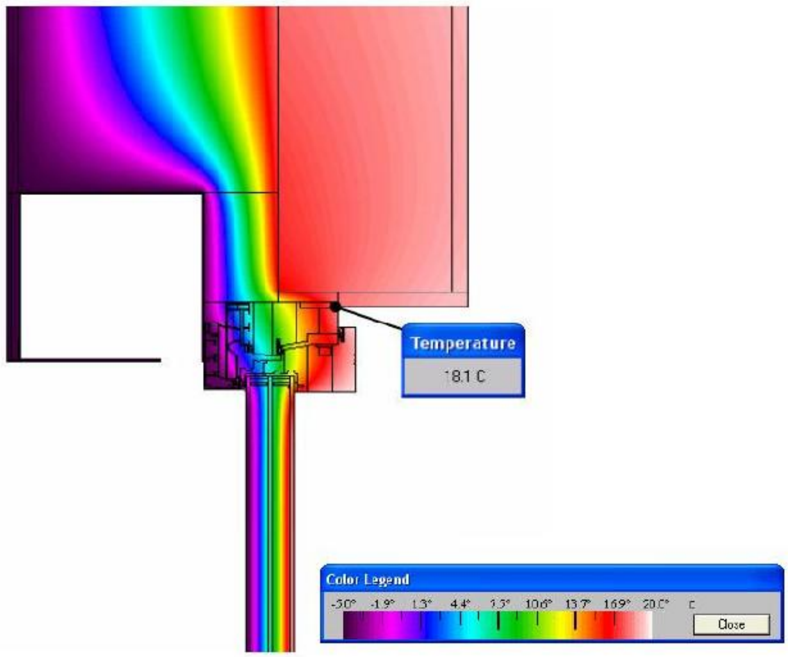

Fig. 2. The course of isotherms for external roller shutter windows
Source: Wiegand Fensterbau technical materials [11]

The large number of variables that affect the heat transfer coefficient for the whole window makes it possible to select the appropriate variant only after numerical verification. In the case of the RES TTC, a decision was made to implement option 1 for which not all windows have a U_w coefficient of ≤ 0.8 [W/m^{2}K]. An additional constraint with each investment is, unfortunately, also the economic aspect and the limited resources during implementation that do not always allow for the best solution.

The ventilation system [12] is the key element of each passive building. That was also the case with the RES TTC. By analyzing the calculations (Table 5), it appears that the largest component in the overall sum of the heat losses is the loss through ventilation (Fig. 3). In the beginning, calculations were made on the assumption that the efficiency of the recuperator was 75%. This value is a limit value and it is recommended for it not to be lower. In addition, it should be borne in mind that, like all the devices in a passive building, the recuperator must also be characterized by low electricity consumption. The electricity consumption should in this case amount to no more than 0.45 Wh/m^3.

Table 5. Balance of heat losses and gains

Heat loss through Q_T penetration	[kWh/a]	[kWh/(m^{2}a)]
external walls	3508	
roof	3750	
floor on the ground	2771	
windows	5170	
front door	155	
thermal bridges	460	
Q_T sum	15814	31.7
Heat loss through ventilation Q_L	7857	15.8
Sum of heat losses: $Q_V=Q_T+Q_L$	23671	47.5
Heat gains from the sun Q_S	6167	12.4
Internal household heat sources Q_I	8562	17.2
Useful heat gains Q_G	14178	28.8
Demand for heat for heating Q_H	9493	18.7

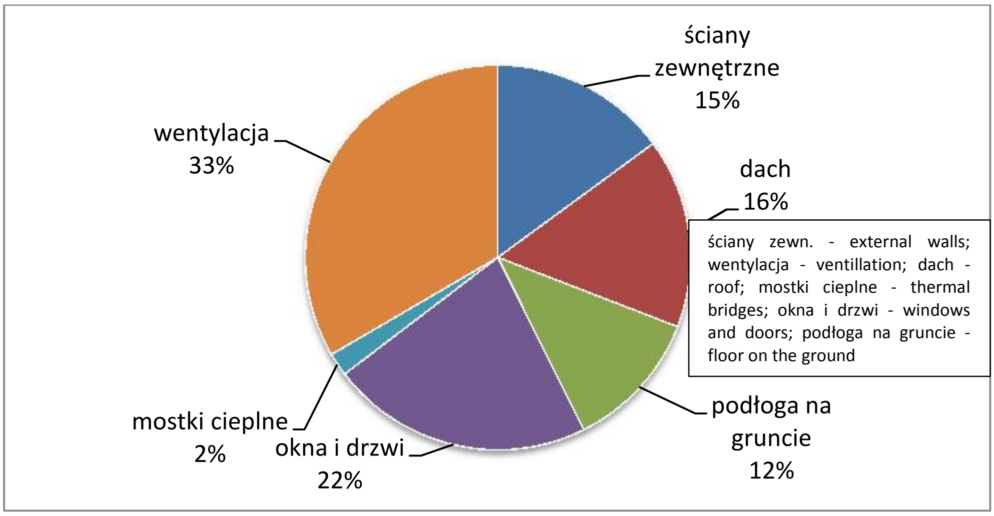

Fig. 3. Heat loss

It turns out that with these assumptions, the demand for utility energy for heating and ventilation is 18.7 kWh/(m^{2}a). This means that the limit value of 15 kWh/(m^{2}a) has been exceeded. For comparison, calculations for a recuperator with an efficiency of 85% were made. A significant improvement was observed - heat loss through ventilation would have decreased by as much as 30% (Table 6). Under this assumption, the heat demand indicator for heating would be 14.9 kWh/(m^{2}a), which is below the limit of 15 kWh/(m^{2}a).

Table 6. The importance of recuperator efficiency

Recuperator efficiency	
75%	85%
Heat losses through ventilation	
7857 kWh/a	5561 kWh/a

The Technology Transfer Center was also equipped with a pipe ground heat exchanger (PGHE). According to the design and the designer's records, the ground heat exchanger was designed as a system of pipes in the ground through which fresh ventilation air flows. In the ground that surrounds the pipeline (at a depth of from 1.6m to 2.0m), whatever the season, temperatures range from 3^{o}C to 5^{o}C. In winter, the external air introduced into the exchanger is pre-heated. In summer, the ground heat exchanger supports the role of the air conditioner, reducing the temperature of the air entering the object by several degrees.

In the case of TTC, due to the high level of ground water, the GHE was designed in a sealed version, utilizing electrically and poly-diffusion welded polyethylene pipes. The air supplied to the building must meet certain requirements. Because of this, the inner surface of ϕ200 mm HDPE pipes has been coated with an antibacterial layer of nanosilver. According to the recommendations, the efficiency of the ground heat exchanger was assumed to be 33% in the PHPP calculations.

The building - laboratory

The Technology Transfer Center building will be the subject of detailed research and analysis on energy efficiency, effectiveness of applied materials and solutions. Already at the concept stage, the team of designers has envisaged a BMS that will allow form managing the building and monitoring the energy consumption and internal environment parameters. This will make it possible to determine the effectiveness of the applied construction and installation solutions. In addition to measurements inside the building, external environmental parameters will be measured to record climate variables in time. All measuring sensors, according to the design assumptions, will interact with the BMS, which will allow monitoring, registration and processing of the collected data. The main sensors of the measuring system will be:
- a thermohygrometer - for measuring humidity and air temperature,
- a CO_2 meter - for measuring the concentration of carbon dioxide,
- a pyranometer - for measuring solar radiation,
- wind speed and direction gauge
- data modules - with measurement memory and the ability to transfer data over the Internet.

For research purposes, it is planned to archive all parameters from a minimum period of twelve months. On this basis, it will be possible to specify energy consumption precisely, which will allow for verification of the calculation values.

Conclusion

The biggest barrier that obstructs the dissemination of the idea passive housing in Poland is the higher investment costs. They are acceptable and easy to accept if the investor is a long-time user of the building at the same time. The experience gained during the design and construction of the TTC shows that individual assessment of each building to be made in the passive standard is necessary. Adoption of commonly-known detailed guidelines, concerning the U coefficients, may not be sufficient. The individual elements of a building that affect its energy characteristics should be analyzed, evaluated and economically optimized.

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