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ANALYSIS OF A PASSIVE DESIGN SPORTS HALL: CONSTRUCTION AND USE

ANALIZA BUDOWY I EKSPLOATACJI PASYWNEJ HALI SPORTOWEJ

A b s t r a c t

This article presents an analysis of how the construction and insulation materials used for the walls of a sports hall built according to passive design affect the overall construction costs. The authors also attempt to answer whether the objective of achieving the lowest possible energy consumption in a building is actually economically sound. Cost analyses will be carried out to this end, the optimum insulation thickness will be determined, and the time necessary to balance the investment expenditure will be calculated for an energy-efficient construction project.

Keywords: cost analysis, energy-efficient construction, passive buildings

S t r e s z c z e n i e

W artykule, posługując się przykładem hali sportowej, wybudowanej w technologii budownictwa pasywnego, przeprowadzono analizę dotyczącą wpływu materiałów konstrukcyjnych i izolacyjnych ścian na ogólne koszty budowy. Autorzy podejmą także próbę odpowiedzi na pytanie, czy dążenie do uzyskania jak najmniejszego zużycia energii w budynku jest uzasadnione ekonomicznie. Zostaną w tym celu przeprowadzone analizy kosztowe, wyliczenia optymalnej grubości izolacji oraz obliczenie czasu zwrotu inwestycji energooszczędnej.

Słowa kluczowe: analizy kosztowe, budownictwo energooszczędne, budynki pasywne

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1. Introduction

The construction sector is a particularly important part of implementing any sustainable development concept. A significant majority of sustainable development concepts refers to the problem of economic growth harmonization and the management of economic and natural resources [1]. The concept of energy-efficient buildings is receiving a great amount of attention. Faced with the rapid growth of energy carriers price, we are looking for solutions that would reduce the demand for energy, and thus costs [4]. There is no doubt that construction of such facilities is beneficial for the natural environment, but is it a 100% economically feasible proposition? In Poland, similar to the majority of the European Union countries, we are witnessing the gradual introduction of legal regulations limiting energy consumption in newly constructed, as well as in renovated or modernized, buildings. The European Union has issued numerous directives in recent years aimed at improving energy efficiency of buildings. The gradual process of introducing more and more stringent requirements related to energy consumption levels in construction has led to a considerable reduction in this area [4]. Energy standards for passive buildings vary according to the country and the type of structure being built, yet they have one thing in common – a low coefficient of energy consumption. The term passive building has received a lot of publicity throughout the world, and now it is regarded by investors and designers as prestigious [3].

The energy efficiency classification for buildings has never been clearly defined. Different definitions are valid in different countries, depending on the point of reference [4].

This article uses the classification developed by the Society for Sustainable Development. The point of reference in this classification is the operational energy indicator. The more stringent requirements for insulation properties of construction barriers may serve the purpose of defining the boundary values which are considered exemplary. Yet, in the opinion of numerous experts, in the context of power generation based on new energy sources, they may prove too strict [6].

2. Passive sports hall

The sports hall which is the subject of the analysis has been built at 3rd LO (Comprehensive High School) in Kraków. It was approved for use on 1 September 2014.

The parameters of the hall:

- The area covered by the planned facilities: 1,866.0 m^2
- Total net area: 1,874.4 m^2
- Gross volume of the above-ground storeys: 16,362.6 m^3
- Height (stated in order to determine the technical requirements): 10.42 m.

Since the hall has been built with passive construction technology, its energy demand is less than 15kWh/m2 per year (Fig. 1). In order to achieve such low levels of energy consumption, a number of solutions had to be implemented during the construction process, e.g. excellent thermal insulation (the walls – 30 cm of polystyrene foam, the roof – 40 cm of polystyrene foam + 10 cm of polyurethane foam, floor – 40 cm of polystyrene foam), triple pane windows, solar panels and an air exchange unit with a recuperator.

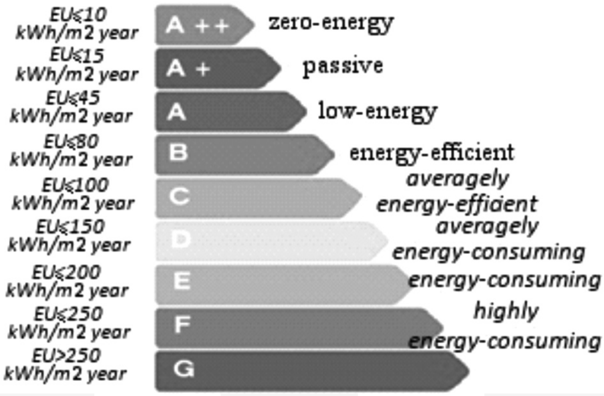

Fig. 1. Energy efficiency classification of buildings. Source: the authors, based on [4]

There are no thermal bridges in the building; it is effectively air-tight and generally meets the design specifications, which has been confirmed by photos taken during an inspection with the use of a thermal imaging camera (Fig. 2a, b).

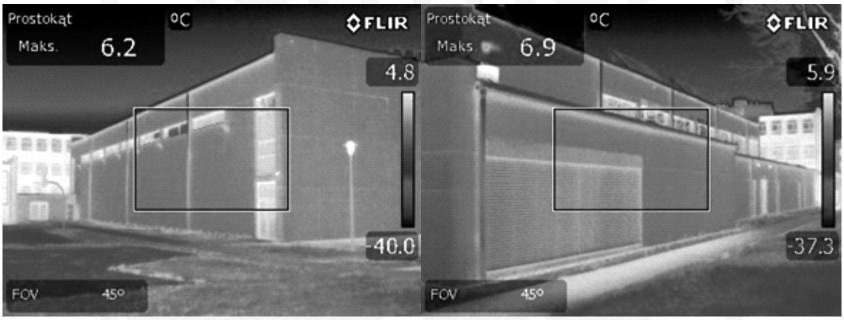

Fig. 1. A thermal image of the sports hall, a) northern façade, b) southern façade

3. Cost analysis

3.1. The construction cost of the sports hall

The total cost of the sports hall construction amounted to approximately 6.5 million PLN. The analysis presented below takes into account only the architectural cost estimate, which included the following: external walls, internal walls (ground floor and first floor), internal plasters, wall facing, paint, suspended ceilings, foundations, thermal insulation, floors, a roof over the arena (roofing material), PVC profiles, wood profiles, metalwork, thermal insulation for the external walls, bathrooms and changing room furnishings, office furnishings, and sports equipment. The cost estimate for the above elements, done by the authors for the purpose of this paper, with the use of Zuzia 11 software, amounts to 2,414,805.59 PLN.

The main question that is usually asked in projects of this type is whether the construction costs could be reduced. The analysis must therefore focus on the assessment of how the general cost estimate value is affected by the type of material used to build the external walls of the hall, as well as the type of windows that have been installed in the building.

3.2. Analysis of cost estimate variants

Table 1 presents the materials which were used for the external walls of the hall, and table 2 displays the analysed alternative materials. Table 3 in turn shows the total estimated costs for each variant.

Table 1

The sports hall external wall technical parameters for variant 1

Material	d [cm]	λ [W/mK]
Thin-layer polymer architectural coating	0.01	0.1200
SILKA N25 calcium-silicate blocks	25.00	0.4600
Fasada Platinium polystyrene foam panels	30.00	0.0032
Regular plaster	1.00	0.8200
Wood wool acoustic panels	3.50	0.0700

Source: Own work.

Table 2

The sports hall external wall technical parameters for alternative variants

Material	d [cm]	λ [W/mK]
POROTHERM T&G type 25 wall hollow bricks	25.00	0.3130
YTONG cellular concrete class PP4/0.6S+GT	24.00	0.1600
Rockwool mineral wool panels	30.00	0.4600
Fasada Platinium polystyrene foam panels	15.00	0.0032

Source: Own work.

The analysis also includes two types of windows: the triple panel window U = 0.7 W/m^{2}K and the double panel window U = 0.7 W/m^{2}K, which is reflected in the results of calculations for different variants in individual cost estimates.

Table 3

Distribution of construction costs in PLN for individual variants

Insulation	Polystyrene foam 30 cm		Polystyrene foam 15 cm		Mineral wool 30 cm	
windows	double pane	triple pane	double pane	triple pane	double pane	triple pane
SILKA	2 367 137.30	2 414 805.59	2 323 727.54	2 371 395.83	2 364 939.71	2 412 608.00
PORO-THERM	2 361 838.58	2 409 506.87	2 318 428.82	2 366 097.11	2 359 640.99	2 407 309.28
YTONG	2 388 501.43	2 436 169.72	2 345 091.67	2 392 759.96	2 386 303.84	2 433 972.13

Source: Own work.

The reference variant, which has been implemented in reality, is the one with external walls made of the following materials: Silka + 30 cm polystyrene foam and triple pane windows. If we reduce the insulation thickness by half and use windows of a lower coefficient U[W/m2K], the calculations presented in table 3 indicate that the greatest savings could be achieved in the following variants:
- Porotherm + 15 cm polystyrene foam + double pane windows (3.99% cost reduction as compared to the reference variant, i.e. 96,376.77 PLN),
- Silka + 15 cm polystyrene foam + double pane windows (3.77% cost reduction – 91,078.05 PLN).

4. Operational energy

The operational energy (OE) demand is defined by the amount of energy required annually for heating (or cooling), ventilation and tap water heating [4]. The OE calculations for the analysed sports hall (Tab. 4) have been done with the use of the BuildDesk Energy Certificate software.

Each alternative design variant involves an increase in the hall's energy consumption. The cheapest variants, as compared to passive technology, result in energy consumption increases of:
- 73.90% – Porotherm + 15 cm polystyrene foam + double pane windows,
- 39.96% – Silka + 15 cm polystyrene foam + double pane windows.

Table 4

Operational energy demand in kWh/m^2 per year for individual variants

Insulation	Polystyrene foam 30 cm		Polystyrene foam 15 cm		Mineral wool 30 cm	
windows	double pane	triple pane	double pane	triple pane	double pane	triple pane
SILKA	17.04	14.94	20.91	18.66	17.56	15.44
PORO-THERM	22.11	19.83	25.98	23.59	22.64	20.34
YTONG	19.77	17.56	22.73	20.43	20.20	17.98

Source: Own work.

5. The time necessary to balance the investment expenditure

The simple time necessary to balance the investment expenditure may be calculated from the following formula:

$$SPBT = \frac{N}{\Delta O} \tag{1}$$

where
N – the investment expenditure
ΔO – the savings

The time needed to balance SILKA + 30 CM POLYSTYRENE FOAM + TRIPLE PANE WINDOWS as compared to the cheaper solutions:

– POROTHERM + 15 CM POLYSTYRENE FOAM + DOUBLE PANE WINDOWS – 27 years,
– SILKA + 15 CM POLYSTYRENE FOAM + DOUBLE PANE WINDOWS – 47 years.

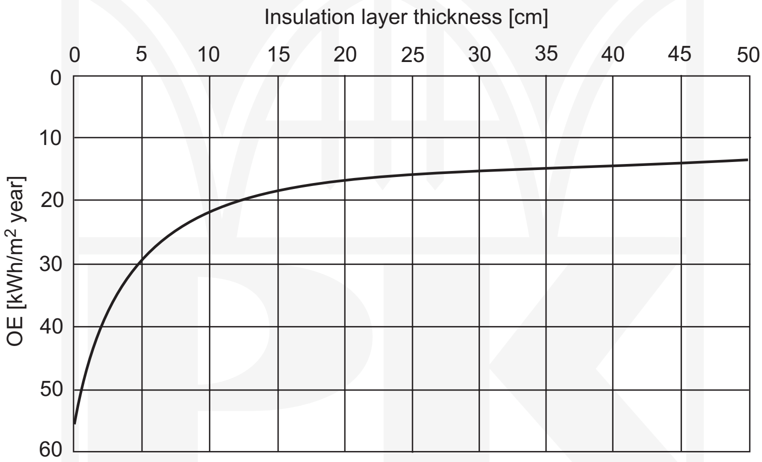

Fig. 3. Dependence of the insulation layer thickness on the operation energy demand for the passive sports hall Source: the authors.

It could be observed (Fig. 3) that, at a certain point, further increasing the insulation thickness no longer significantly reduces the operational energy consumption. The costs related to the additional insulation grow, yet the energy consumption drops only slightly, which results in the lengthening of the time necessary to balance the investment expenditure.

6. Optimal insulation thickness

The differences in construction costs between the promoted cost-efficient variant and the expensive one may – in the case of a sports hall – amount to almost 100% (Fig. 4).

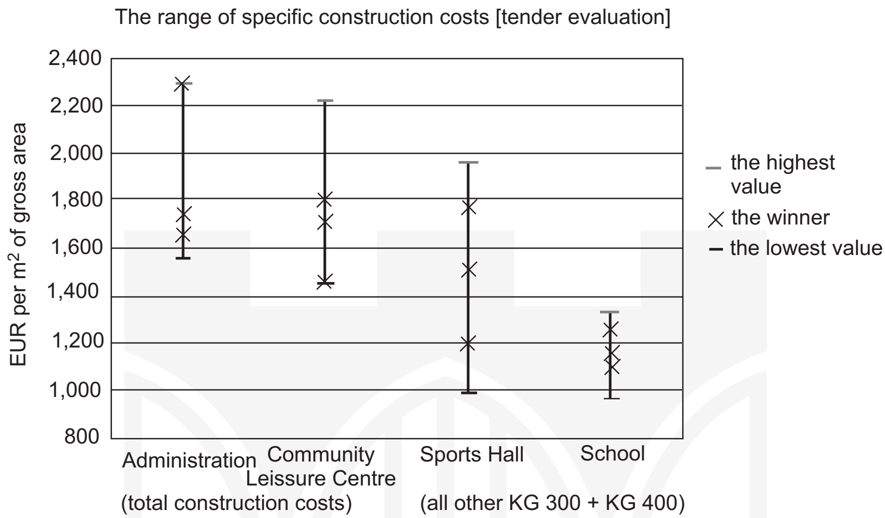

Fig. 4. "Cost efficiency" of architectural designs in comparison with additional costs of energy-efficient construction. Source [2]

Given such a huge difference in investment expenditure for the same construction project, we are impelled to ponder the question concerning the optimal insulation layer thickness [2]. The decision on the insulation layer thickness rests with the designer. The present cost of thermal insulation material and the cost of heating supply are known. The remaining factors are not quite known, although they are foreseeable, e.g. the discount rate value or the rates of energy cost increase above the inflation level in future years. The optimal insulation thickness formula (2) is shown below [5]:

$$d_{opt} = \lambda \sqrt{\frac{G_0 \sum_{i=1}^{n} \frac{(1+s)^i}{(1+r)^i}}{\lambda K}} \quad (2)$$

d_{opt} – optimal insulation thickness,
λ – heat conduction coefficient of the basic thermal insulation material,
G_0 – annual heating cost ratio as related to 1 m^2 of barrier [PLN/m²],
DD – number of heating degree-days
G – energy cost [PLN/GJ],
N – period of benefiting from the effects of warm weather [summer],
S – rate of heating cost increase over the inflation rate in time,

r – discount rate,
K – insulation material cost *loco* construction site [PLN/m^3],
R_0 – thermal resistance of the barrier's layers other than the thermal insulation (the ground) together with heat transfer resistance on the surface of barriers.

Given the following values of the relevant parameters: DD – 3050.1; G – 90 PLN/GJ; λ – 0.0032; K – 215 PLN/m^3; R_0 – 1.2265; inflation – 6% and the energy prices increase – 5%, the optimal values of insulation thickness for different periods of benefiting from the effects of warm weather are showed in Table 5.

Table 5

Optimal insulation thickness for the analyzed sports hall

Period of benefiting from the effects of summer	10	20	30	40	50
Optimal insulation thickness [cm]	18	20	21	22	23

Source: Own work.

7. Conclusions

The energy consumption of a building results – to a great extent – from the low thermal insulation of its walls (25–35%), so the design stage should include the process of optimization leading to a determination of the most economically feasible thermal insulation thickness [4].

Frequently, striving to meet the standards of a passive building is not accompanied by immediate financial gains, and a thick insulation layer is not indispensable for the optimal functioning of a building. In this article an analysis was made for the purpose of determining the best economic solutions in the context of construction costs and subsequent use of external wall insulation. An analysis was also performed in order to determine the best insulation thickness in relation to the expected period of use.

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