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RATIONAL INCREASING OF ENERGY EFFICIENCY OF SACRAL BUILDINGS

Aleksandra REPELEWICZ
Czestochowa University of Technology

Abstract:
The paper presents the possibilities of increasing energy efficiency of sacral buildings. Churches in the Zawiercie pastoral district of the Archdiocese of Czestochowa have been used as examples of typical sacral buildings of low energy efficiency. Such structures need to be thermally insulated during their use. Certain possibilities of raisingthe energy efficiency of churches have been presented. The paper describes different systems: increasingof wall and roof insulation, installation of new windows, and modern heating systems. Installation of a new heating system has been considered the most effective and the easiest to be implemented one.

Key words: *sacralbuildings, church buildings, thermal insulation, heating systems*

INTRODUCTION

Most new church buildings in Poland were built in the 1980s. After many years of difficulties, building permits for religious facilities became easier to obtain, enabling intensive making up for huge deficiencies. Churches were built in virtually all cities and villages. Unfortunately, quantitative effects were not accompanied by high quality.

Most churches were erected hastily, in absence of appropriate building materials and equipment, resulting in many design errors today's administrators have been left to cope with. They include low thermal insulation of dividing structures. Coupled with inefficient heating systems, heating during a service creates problems and unnecessary additional costs to a parish. Heating costs often exceed the financial capabilities of a parish.

Based on the experience gained during the research conducted in sacral buildings of the Archdiocese of Czestochowa, the author wishes to present the possibilities to raise the energy efficiency of churches at the lowest costs possible, when a parish has no capacity to carry out comprehensive thermal modernization of buildings.

A CHARACTERISTIC OF CHURCHES IN THE ZAWIERCIE PASTORAL DISTRICT OF THE ARCHDIOCESE OF CZESTOCHOWA

The performed analysis covered buildings erected after 1945 in the Zawiercie pastoral district of the Archdiocese of Czestochowa. This district currently comprises 43 parishes. Since the end of World War II, 37 new sacral buildings were built in that area, including 25 parish churches and 12 filial ones.

Post-war churches of the Zawiercie pastoral district are structures of varied size, architectural style and functionality. They include large churches, located in cities (Zawiercie, Poręba, Myszków), medium-sized (in smaller towns), as well as small filial churches and chapels (in small villages). The table below indicates the types of walls and roof structures in the churches under consideration.

A typical divine service generally lasts no more than one hour, while the faithful are wearing outdoor clothing. Thus, a sufficient internal temperature could range from 8°C to 16°C. Technically, a church is a public building, bound by the current requirements for thermal insulation of walls, stipulating the heat transfer coefficient W/(m^{2}K) for a temperature of 8° < ti ≤ 16°C as $U_{(max)}$ ≤ 0.45 [3].

Table 1 shows that the values of $U_{c\,(max)}$ range from 2.090 to 0.540 (W/m^2·K). None of the churches concerned have walls meeting the current requirements. Concurrently, 21 churches of the Zawiercie pastoral district (57%) have no external plaster yet.

Table 2 shows that 18 out of 37 churches have wooden roof trusses, representing 49% of all post-war churches in this district. Moreover, two buildings have a partly wooden structure resting on reinforced concrete girders. As many as 12 buildings with a wooden roof structure are filial churches, being inherently smaller. In nine church buildings, roofs are made of steel; in six, of reinforced concrete. Two churches have a mixed-structure roof – reinforced concrete and steel. All of these are relatively large objects, usually located in cities.

THERMAL MODERNISATION OF EXTERNAL CHURCH WALLS

All the contemporary sacral objects of the Zawiercie pastoral district failed to meet the current requirements for thermal insulation of walls. Even buildings erected over the last 20 years often have single-layer walls made of materials with low thermal insulation, causing high heating costs. Some buildings have not been finished yet – more than a half of them lack external plaster. An analysis of architectural designs preserved in parish archives has shown that some buildings were designed with thin-coat plaster on a Styrofoam layer.

Table 1
Construction of walls of churches in Zawiercie pastoral district

No.	Kind of external walls	Coef. $U_{c(max)}$	Number of churches
1	ceramic bricks 51 cm, no external plaster	1.151	16
2	hollow cinder blocks 51 cm + external plaster	0.753	2
3	ceramic bricks 64 cm, no external plaster	0.931	2
4	limestone 60 cm + external plaster	2.090	2
5	ceramic hollow 51 cm + external plaster	0.938	1
6	hollow cinder blocks 51cm (part of walls) and silica brick 51 cm; no external plaster	0.753 and 1.396	1
7	ceramic bricks 51 cm + external plaster	1.104	1
8	ceramic hollow 38 cm + clinker brick 12 cm, no external plaster	1.035	1
9	ceramic bricks 38 cm + external plaster	1.357	1
10	ceramic briks 51 cm, limestone about 20 cm, no external plaster	1.056	1
11	hollow cinder blocks 38 cm + external plaster	0.951	1
12	ceramic bricks 25 cm, styrofoam 8 cm, clinker brick 6 cm	0.423	1
13	hollow maxi bricks 60 cm + external plaster	0.826	1
14	hollow cinder blocks 42 cm + external plaster	0.880	1
15	hollow cinder blocks 20 cm + gas concrete 24 cm + external plaster	0.738	1
16	hollow maxi bricks 40 cm + external plaster	1.126	1
17	limestones 40 cm+ styrofoam 5 cm + Max hollows 19 cm	0.540	1
18	hollow maxi bricks 49 cm+ external plaster	0.968	1
19	hollow maxi bricks 29 cm + sawdust concrete 10 cm + limestone 25 cm	0.726	1

Table 2
Construction of churches roofs in the Zawiercie pastoral district

No.	Kind of roof construction	Number of churches
1	Wooden structure	18
2	Steel structure	9
3	Reinforced concrete structure	6
4	Reinforced concrete and steel structure	2
5	Reinforced concrete and wooden structure	2

Due to financial reasons, the walls have not been finished yet, as it does not affect the use of the interior.

Paradoxically, it is advantageous today. Wall insulation layer thicknesses designed in the past would not meet today's standard requirements. Delayed finishing of walls provides an opportunity to apply an adequately thick insulation layer.

Based on an analysis of commercial offers from different manufacturers and contractors, the average cost of thermal insulation of walls can be determined. The cost of materials needed to insulate 1 m^2 of a wall (using the wet method), with the following layers: mortar adhesive, 15 cm of Styrofoam, reinforcing mesh, mortar on the reinforced layer, primer and plaster, is approx. 55 to 65 zł. Labor costs, including assembly and dismantling of scaffolding, are 35 to 45 zł. The total cost is 90 to 110 zł.

Insulation of 1 m^2 of a wall with mineral wool is slightly more expensive. The cost of materials is approx. 80 to 100 zł; labor costs amount to 45-55 zł. The total cost is 125-155 zł.

All churches under study were built in the economic system, with strong participation of parishioners' voluntary work. Therefore, it can be assumed that labor costs could be lowered using the help of the faithful for some auxiliary work.

It should also be taken into account that final finish of external walls using category III traditional cement and lime plaster, for walls higher than 3.5 m (a height usually exceeded by church walls), costs approx. 25-30 zlotys per 1 m^2. Therefore, for buildings with no external plaster, the final cost of wall finishing, combined with thermal insulation, is the difference between the prices presented above and the price of traditional plaster.

INCREASING THE THERMAL INSULATION OF ROOF STRUCTURES

For public buildings, such as churches, the current requirements for thermal insulation of roofs and flat roofs are considered to be met if the heat transfer coefficient W/(m^2 K) for a temperature of 8° < ti ≤ 16°C is U (max) ≤ 0.5 W/(m^2 K) [3]. Insulation of a wooden roof structure, predominant in the majority of churches, is relatively simple and inexpensive. This investment is possible without dismantling the roof structure and covering, from the inside. Wood paneling nailed to the roof structure is a typical standard in contemporary church interiors. Dismantling of the paneling is relatively simple, and the paneling strips can also be reused.

After unveiling the wooden structure, it should be determined whether the existing insulating layer is eligible to be left or for removal. If it is suitable for further use, double -layer insulation should be applied (to minimize the impact of linear bridges in the form of rafters), using the same material which fills the space between the rafters. The second layer, of thickness depending on the heat transfer coefficient, is applied between the grid suspended to the rafters.

If removal of the existing insulation layer is necessary, a freely selected insulation material – polyurethane foam, cellulose insulation, glass wool mats or polystyrene – can be applied. The solution must be preceded by a comprehensive analysis and optimal adjustment of the insulation type to the requirements of a particular object.

As the majority of churches erected in the 1980s have vapor-tight covering (usually, roofing paper on full boarding), a ventilation gap between the insulation and boarding is necessary to drain the water vapor. Air vents under the eaves and in the ridge should be made subsequently (unless they have been made during the construction of the building).

It is difficult to estimate the cost of thermal insulation of 1 m^2 of a roof, as the scope of work in each case depends on the thickness and condition of the existing insulation, the suitability for reuse or necessity of disassembly. In both cases, the labor cost is further dependent on the building height and roof shape. Assuming that the existing insulation would require full replacement, it can be supposed that the insulation: foil – 20 cm of mineral wool – foil, with labor cost included, would cost, on average, 90 zł per 1 m^2. Price fluctuations could be significant, as prices of mineral wool and foils are very diverse. Disassembly and reassembly of paneling must be included.

Insulation technology of less widespread steel and reinforced concrete roof structures depends on the roof type and pitch. Flat roofs are usually insulated externally, e.g. using Styrofoam boards with bonded roofing paper.

CHURCH WINDOWS

The amended "Regulation on the technical conditions to be met by buildings and their location, along with other legislation to the Construction Law Act" tightens the thermal requirements for windows. [3, 4, 5] For public buildings, the current requirements for thermal insulation of windows are considered to be met if the heat transfer coefficient for the temperature of 8° < ti ≤ 16°C is $U_{(max)}$ ≤ 1.8 (W/m^2 K).

Churches of the Zawiercie pastoral district predominantly have steel windows (51% of all buildings). In two of these churches (6%), the windows were single-glazed.

During the author's previous research in the 1990s, steel windows were found to exist in 80% of buildings in the archdiocese. Therefore, a slow process of replacement of old windows can be observed. Among the objects located in the Zawiercie pastoral district, such replacement was recently carried out at the filial church in Mzyki.

Replacement of windows, which, beside their low thermal insulation, often have leaks, is among the most effective ways to improve the comfort and economy of use of churches. Prices of aluminum windows, which seem best suited to the specific nature of religious buildings, range from 400 to up to 1200 zł per 1 m^2.

Stained-glass windows pose a problem. In this case, it is difficult to speak about replacement, as they were a significant expense for the parish in the past and they decorate the interior. Additional external windows can be a good solution. It has been used, among others, at the historic church in Bolechowice in the Archdiocese of Cracow. Unfortunately, outside windows are single-glazed. It seems reasonable to use double-glazed ones, which increases the of the investment but significantly reduces future costs of heating [6].

MODERN HEATING SYSTEMS OF CHURCHES

Great diversity was observed regarding the ways of heating of the church interiors under study, whereas the existing heating systems usually have low efficiency. Building administrators are generally not satisfied with the heating costs [8]. A solution to this situation could be a change of the heating system.

The basic idea is that users of sacral buildings should be heated during religious services, and the feeling of cold due to high humidity at the church should be imperceptible. Moreover, the system should heat up quickly. For economic reasons, the optimal effect should be achieved using the lowest possible amount of energy. There are several modern systems to meet these goals.

The first one is under-bench heating. Radiators are installed under seats or kneelers. Low-temperature heat plates are applied, connected in series or in parallel rows. A heat plate heats a seated person through radiation and convection from the feet to the waist. The user has an immediate feeling of warmth, while the interior is not fully heated. Heat plates are mounted to the bench: in front of the person or under the seat. Heaters can also be mounted under or over kneelers. Localized floor-standing heaters are used supportively.

Depending on the number of occupied benches, to save energy, benches can be heated individually or in sectors, the system being controlled e.g. from the sacristy. The main drawback of under-bench heating is that it only heats seated persons.

Price of an under-bench heater with a length of 7 m is approximately 400 zł. When using double-length heaters, the cost increases by approx. 50%. Thus, the longer the bench, the lower the cost of the under-bench heater.

Another possibility is to use electric radiator heating. It is radiant heating through electric halogen and quartz radiators, so-called heat lamps. They are placed at a minimum height of 2 m above the occupied zone. With a suitably shaped housing, a stream of infrared radiation is directed straight to people who feel the heat as a result of absorption and thermal conversion.

This heating system entails no negative phenomena observed in other systems. Dry air is virtually transparent to the radiation, it does not heat up and therefore it does not intermediate in heat transfer. No useless mass of warm air is accumulated under the roof. The system is characterized by slight temperature rises and humidity decreases comparable to natural fluctuations. There are no hot currents over the heat lamps and the radiation does not dry the buildings and their equipment excessively.

The prices of halogen heaters are highly diverse, starting from 700 zł for small heating elements adapted to heat an area of approx. 10 m^2, to approx. 2000 zł for heaters with higher power.

Small local heat sources in the form of electric heating mats with an area of 1-3 m^2 can be used supportively at churches. They are laid on floors in places where this is particularly reasonable: at the altar, pulpit, sedilia, organ, etc. The mats can be either mounted permanently or removed for summer and spread out for winter.

A combination of two or more heating systems, known as hybrid heating, is often the best solution. During the weekdays (when 100% of the faithful occupy seats), under-bench heating and a few local heat sources (mats and screens) can be used, activated independently as necessary. Supportively, in cold weather and when a service involves more people than seats, radiant heat can also be used. Outside the period of use, the object remains unheated. Combination of under-bench heating and local heat sources with radiant heating is particularly preferred due to the complementarity of heated body zones of individuals [7, 9, 10, 11, 12].

A separate issue is the heat source for heating the sacred objects. Regardless of the system used at the church building it should be pursued to use the renewable energy. The transformation in energy production based on 'ecological modernization' of the production market included energy saving as well as broadly understood increase of the energy efficiency, all in accordance with the principles of sustainable development. The goal of the transformation was to replace completely all non-renewable sources by renewable sources which are safe for the environment. This could be, for example, solar or wind energy [1, 2].

SUMMARY

Contemporary sacral buildings often fail to meet the expectations of administrators and users in terms of comfort and economic aspects of internal heating. Insulation of walls, roofs and windows is very low in churches of the Zawiercie pastoral district of the Archdiocese of Czestochowa. This district can be considered representative of the Polish sacral architecture. The proportions of buildings erected in villages and in cities are similar to those across the country, as is the ratio of large to small objects and parish churches to filial ones. As a result, it seems possible to generalize the conclusions to all the churches built in Poland after World War II. Therefore, we can assume with high probability that a huge number of churches across the country needs thermal renovation.

The estimated insulation costs, as calculated previously, are relatively high, especially for large objects featuring hundreds of square meters of walls and roofs. These costs could be reduced through voluntary work of parishioners, traditionally willing to participate in construction of churches in Poland. Another possibility is acquisition of EU funds. An example is the church of Our Lady the Queen of Poland in Radomsko, also located in the Archdiocese of Czestochowa, where the finish of external walls was combined with thermal insulation for which an EU grant had been obtained.

Due to high costs, it is often not possible to carry out comprehensive thermal renovation. The only possible solution is to spread the investment over time. It seems that the effects that would be most perceptible to the faithful can be achieved using a modern heating system. In the author's opinion, hybrid heating will become increasingly popular, enabling differentiation of the mode of heating depending on the current needs. A different heating mode will be used on Sundays and religious holidays than on weekdays. A confessional or a place for the organist and choir would be switched on as necessary. A division of the interior into several independently heated zones will cause measurable economic effects while providing full comfort of use of the facility. The cost of application of modern interior heating is the lowest of all the described ways to increase the energy efficiency of church buildings. A fairly radical conclusion drawn by the author is that, due to the nature and short duration of use of church interiors, use of these modern heating systems is the most effective factor increasing the energy efficiency of sacral buildings. In absence of significant funds, this one can suffice.

Another element that can be relatively simply subjected to thermal renovation is the roof structure. Most churches feature wooden structures with insulation so simple that most works can be made by persons without high qualifications. Finishing in the form of common wood paneling is suitable for disassembly and reassembly.

For technological reasons, replacement of windows should be performed before the thermal insulation of walls. The effects of this exchange, especially for leaking windows, will also be more perceptible to users. Costs may vary depending on the area and nature of windows at a building; for most churches, however, they will probably be lower than the cost of insulation of walls.

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dr inż. Aleksandra Repelewicz
Czestochowa University of Technology
Faculty of Civil Engineering
ul. Akademicka 3, 42-200 Częstochowa, Poland
e-mail: arepelewicz@bud.pcz.czest.pl