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Effects of pollution reduction and energy consumption reduction in small churches in Drohiczyn community

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ABSTRACT

The main aim of the thermomodernization of historic churches was to reduce energy consumption for heating and improve air quality by reducing the amount of pollutants emitted into the atmosphere.

Calculation methodology was adopted in accordance with the Decree of the Minister of Infrastructure on the detailed scope and form of an energy audit [4,5] and based on the fuel indexes (WO) and CO_2 emission (EC) for reporting under the Community Emissions Trading [13].

We have achieved a significant reduction of the annual heat demand and the reduction of emissions: SO_2, NO_x, CO_2 and dust as a result of the modernization, with the exception of the Church in Chlopkow (No. 1).

The results of the energy and environmental analysis show the validity of the religious buildings thermomodernization and upgrading their heat sources. These effects are necessarily connected with the economic effects.

Practical application of this paper was to show the possibility of carrying out thermomodernization upgrades for reducing demand for heating, for thermal power and protecting the environment.

1. Introduction

Sacral buildings are very energy-consuming, and therefore expensive to maintain. The reasons for the high demand for energy is a lot of – age and often historic character of buildings, limiting the possibility of substantially building insulation standard methods, poor condition of the buildings due to lack of funds for the renovation or massive structure is characterized by a low energy passivity, and thus large heat loss [1]. Thermomodernization of the historic religious buildings requires not only to get acquainted with the technical condition of the building, but also a wide architectural knowledge and most of all take into account the requirements of conservation. Such objects require appropriate documents proving that the restorer has committed planned range of the facility modernization. In these buildings is necessary to use the appropriate building materials to enable most accurate reproduction of architectural details and no admission to the deterioration of microclimate inside the temple and most of all humidity conditions.

Proposing the type of the building heating it is necessary to take into account some technical problems, the heating elements should be integrate properly and not disrupt the design and nature of the temple.

Fees for thermal energy represent a significant percentage of the total cost of maintenance and operation of religious buildings. The recipe for the reduction of energy costs is to take decisive thermomodernization action. Most of church buildings are heated improperly, so that fluctuations in temperature and humidity, which translates to, in terms of culture – especially the destruction of elements of interior design, and economic – to the low efficiency of heating systems in use.

This article shows how to perform thermomodernization of churches to improve the energy efficiency of buildings and improve air quality by reducing the amount of pollutants emitted into the atmosphere. The changes were proposed to the heating system and the heat source. In the four churches: Chlopkow, Czerwonka Grochowska and Wyszki replacing the existing heat sources for biomass fired boilers were recommended. The biomass fuel is considered to be a replacement for conventional fuels, especially coal. It is a renewable fuel and in CO_2 settlements is treated as not furnishing fuel greenhouse gas emissions [2]. In the church in Kozuchowko the oil boiler maintenance-free was advised, and in a tiny church in Serpelice because of the good condition of the coal boiler no changes in the heat source was planned.

The paper presents the environmental and energy effects that can be achieved by conducting thermomodernization of sacral

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buildings and upgrading the heating system and the heat source thus showing the validity of carrying out these activities.

2. Ecological effects of the thermomodernization undertakings

In order to determine the environmental effects of buildings undertakings it is necessary to estimate the level of emissions before and after the upgrade.

Volumes of the annual emissions can be calculated using the emission factors of pollutants [3]. The results of the calculations are the basis for calculating fees and penalties for the use of the environment. Environmental effects that can be obtained in the result of the thermal modernization of buildings are determined in the article, as the difference between the emission of pollutants into the air by the fuel burning before and after the renovation.

They are defined with the formula:

$$\Delta E = E_0 - E_1, \quad [\text{Mg/year}] \tag{1}$$

where E_0 is the annual emissions of pollutants resulting from the burning fuel before thermomodernization, [Mg/year] and E_1 is the annual emissions of pollutants resulting from the burning fuel after thermomodernization, [Mg/year].

The size of the annual emissions of pollutants (SO_2, NO_x, CO_2) released into the air from the combustion of fuel before and after thermal efficiency was determined by the following formula:

$$E_0, E_1 = B \cdot w, \quad [\text{kg/year}] \tag{2}$$

where B is the annual amount of burned fuel, [Mg/year] and w is the emission factor of sulfur dioxide, nitrogen dioxide, carbon monoxide, carbon dioxide, according to [3], [kg/Mg of fuel], [kg/m^3], [kg/10^6 m^3].

CO_2 emissions from the combustion of biomass (firewood and wood waste, biogenic municipal waste and biogas) is not included in the total emissions from fuel combustion, according to the principles of the Community system of emissions trading, and the IPCC. This approach is equivalent to the use of zero-emission factor for biomass [3].

Dust emission when burning solid fuels (E_{dust} [kg]) was determined according to the following relationship:

$$E_{dust} = B \cdot w \cdot \frac{(100 - \eta)}{(100 - k)}, \quad [\text{kg}] \tag{3}$$

where B is the annual amount of burned fuel, [Mg/year]; w is the dust drift rate, according to [3], [kg/Mg of fuel]; η is the efficiency of the dust collector, [%]; k is the content of combustible dust, according to the certificate fuel [%].

Calculation of the emissions before and after thermomodernization were performed with calorific value of each fuels:

- wood 15.6 MJ/kg,
- coal 22.52 MJ/kg,
- oil 40.19 MJ/kg (heavy fuel oil – 0.2% sulfur content, light-oil sulfur content 0.2%),
- propane–butane gas 96.85 MJ/m^3 (sulfur content 40 mg/m^3) [3].

3. Energetic effects of the thermomodernization undertakings

Effects of energy that can be obtained in the result of the thermal modernization of buildings are determined in the article as the difference in demand for thermal power for heating and thermal energy demand for heating before and after thermal modernization, carried out in accordance with the Decree of the Minister of Infrastructure on the detailed scope and form of energy audit [4,5]. They are defined with the formula:

3.1. Reduction of the computational demand for thermal power

The value of reducing the demand for thermal power to cover the transmission heat loss in the individual churches were calculated based on the relationship:

$$\Delta q = q_0 - q_1, \quad [\text{MW/year}] \tag{4}$$

where q_0 is the demand for thermal power for heating before thermomodernization improvements, [MW/year] and q_1 is the demand for thermal power for heating after thermomodernization improvements, [MW/year].

The demand for thermal power to cover the transmission heat loss, before and after the improvements thermomodernization were calculated by the formula [5]:

$$q_0, q_1 = 10^{-6} \cdot A \cdot \frac{(t_{wo} - t_{zo})}{R}, \quad [\text{MW/year}] \tag{5}$$

where t_{wo} is the computational internal air temperature, [°C]; t_{zo} is the computational outside air temperature according to climate zone in Polish, [°C]; A is the total area of the insulated barrier before and after thermomodernization, [m^2]; R is the total thermal resistance of barrier evaluated before and after thermomodernization, [m^2 K/W].

3.2. Reduction of the computational heat demand

The value of annual reduction in heat demand to cover the losses of heat transfer in the churches were calculated based on the relationship:

$$\Delta Q = Q_{0u} - Q_{1u}, \quad [\text{GJ/year}] \tag{6}$$

where Q_{0u} is the thermal energy demand for heating before thermomodernization improvements, [GJ/year] and Q_{1u} is the thermal energy demand for heating after thermomodernization improvements, [GJ/year].

The value of heat demand to cover the heat transfer losses before Q_{0u} and after thermomodernization Q_{1u} by individual barriers were determined from the relationship [5]:

$$Q_{0u}, Q_{1u} = 8.64 \cdot 10^{-5} \cdot Sd \cdot \frac{A}{R} \, [\text{GJ/year}] \tag{7}$$

where R is the total thermal resistance of building partition evaluated before and after thermomodernization based on site inspection, [m^2 K/W], where minimum value of the total thermal resistance after the thermomodernization have to be at least:

- for exterior walls – R = 4.0 m^2 K/W,
- for roofs and ceilings in an unheated attic – R = 4.5 m^2 K/W,
- the floors above unheated basements and floors on the ground – R = 2.0 m^2 K/W;

A is the total area of the insulated barrier before and after thermomodernization, [m^2]; Sd is the number of degree-days, calculated according to the formula (8), [day K/year],

$$Sd = \sum_{m=1}^{Lg} [t_{wo} - t_e(m)] Ld(m), \quad [\text{day/K year}] \tag{8}$$

where t_{wo} is the computational internal air temperature, [°C]; $t_e(m)$ is the long-term average temperature of the month, [°C]; $Ld(m)$ is the number of heating days in the month, which was adopted in accordance with the characteristics and climate data for the location of the building; L_g is the number of heating months during the heating season.