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Theoretical and real effect of the school's thermal modernization—A case study

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ABSTRACT

The economic considerations force the building body optimization during its design, as well as during the modernization of existing facilities. The thermal modernization effects are calculated according to the national rules and standards. The theoretical savings from the reduction of heat losses by transmission and ventilation in a secondary school located in Poland were calculated (59–71%) and compared with the real savings (33%), calculated on the base of data from the measurements conducted in several heating seasons before and after modernization. The achieved ecological effect (33%) was also lower that theoretical one (69%). The results of this work are worth taking into account in further schools modernizations and a city planning. The simple model for energy use estimation was proposed. The bigger sample of schools will be analyzed to propose changes in the calculation procedure after the end of the whole study.

1. Introduction

The energy consumption in the building sector has a major contribution in the total energy balance and it is mostly used in the heating and cooling systems, for hot water production, lighting and electrical appliances. The kind of installation which uses the biggest part of energy depends on the climate. Liao and Dexter [1] showed that in the UK heating accounts for over 60% of delivered energy, while Zhang et al. [2] counted it for 58%. In Poland it is approximately 70% as demonstrated by Stolarski et al. [3]. Countries located in the mild climate use less energy for heating and much more for cooling. For instance in the study conducted by Rosas-Flores et al. [4] it was shown that in Mexico about 46% of total energy is connected with electrical and air conditioning devices, but only 7% with heating system. Information about energy consumption in Argentina was given by Filippin [5] whereas Corgnati et al. [6] Desideri and Proietti [7] Dall'O and Sarto [8] described the situation in Italy, Dascalaki and Sermpetzoglou [9] in Greece and Phdungsilp [10] in Bangkok. The individual percentage in the overall balance for each system depends not only on the building location but on many other factors which should be taken into consideration, so it changes all the time. One of the most important reasons that causes the increase or decrease of the system contribution into overall energy consumption are people's habits and preferences, for instance the air conditioning system has become more popular nowadays than 10 or 20 years ago. The growth over 20 years reached 14.6% in UE, while in the same time energy consumption for warm water systems has increased only by 0.5% as demonstrated by Balaras et al. [11]. The increase of fuel prices often makes people more liable to find new technologies and solutions that could save energy. There are some published studies focused on the factors influencing the energy consumption, but most of them are dedicated to the residential buildings for instance [2]. The thermal modernization process results in the energy costs reduction, but the environmental factor is also worth mentioning, because countries all over the world try to reduce CO_2 emission. It should be noted that the comprehensive thermal modernization of buildings, including heating, ventilation and air condition (HVAC) systems, hot water preparation, lighting and improving the thermal insulation of the building structure are the most effective ways to do it. According to Ziębik et al. [12] taking the renovation of the buildings and the HVAC systems efficiency as a whole, increases the attractiveness of projects in comparison with the situation when these two improvements are being done separately and independently. There are various methods of CO_2 reduction estimation described in the literature. The correlation between energy consumption and CO_2 emission was discussed in [13,14,15]. In the study conducted by Filippin [5] it was shown that schools use from 20 to 60 kg of CO_2 per square meter for heating and electricity. According to Ward et al. [16] there is a need to set CO_2 emissions reduction targets for

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Nomenclature

CF	CO_2 emission factor [kg/kW h]
CO_2	CO_2 emission [kg/a]
ΔQ	annual savings [€]
e	energy consumption [kW h, GJ]
$H_{ve,adj}$	overall heat transfer coefficient by ventilation [W/K]
$\eta_{H,a}$	heating system efficiency for accumulation [–]
$\eta_{H,d}$	heating system efficiency for distribution [–]
$\eta_{H,e}$	heating system efficiency for regulation [–]
$\eta_{H,g}$	system efficiency for heat generation [–]
$\eta_{H,gn}$	dimensionless gain utilization factor [–]
$\eta_{H,sys}$	overall system efficiency for heating [–]
λ	thermal conductivity [W/m K]
MLR	multiple linear regression
N	initial investment [€]
n	air change rate [h^{-1}]
$Q_{H,gn}$	total heat gains for heating mode [kW h/month]
$Q_{H,ht}$	total heat transfer for heating mode [kW h/month]
$Q_{H,nd}$	energy need for heating [kW h/a]
Q_{ve}	The overall energy consumption for ventilation [kW h/month]
R	thermal resistance [m^2 K/W]
SPBT	simple payback time [a]
U	heat transfer coefficient [W/m^2 K]
θ_e	temperature of the external environment [°C]
θ_{int}	set-point temperature of the building zone [°C]

the higher education sector to drive reductions in CO_2 emissions in line with the national targets. In the study of Rosas-Flores et al. [4] the method of the CO_2 estimation for buildings using electricity was showed and modify for a general formula as follows:

$$CO_2 = \sum CF \times e \quad [\text{kg/years}] \tag{1}$$

where CF is the CO_2 emission factor for the heat energy supply in kg/kW h, e is energy consumption in kW h.

In Europe the leader of regulations relating to buildings was Denmark. In the 1970's the first regulation were issued in France, Germany, Italy and Greece [11]. In Poland the restrictions concerning the thermal insulation of the building structure have been changed several times. The values for buildings with the inside temperature over 16 °C are shown in Table 1.

There is a plan to reduce actual heat transfer coefficients, for instance the external walls will probably have the maximum U = 0.20 [W/m^2 K] from 2020, while the roofs U = 0.15 [W/m^2 K] If the new regulation is adopted the windows will have U lower than 0.90 [W/m^2 K]. A popular technique for improving the energy performance of buildings is to apply thermal modernization of the building envelope, especially in old buildings built in the 1940–1980's of the 20th century, where heating energy consumption is much higher than in the newer ones. In Poland in 1999 the government issued the Act on supporting the energy efficiency modernization, which was changed in 2008 and now is also related to renovated buildings. This national plan is aimed at the owners of residential houses and non-domestic buildings used by local authorities, like schools, universities, offices, hospitals, etc. and helps investors to get a modernization grant from BGK bank. Otherwise the investor can get the financial support from ESCO (Energy Saving Company), NFOŚiGW (National Fund for Environmental Protection and Water Management), Ekofunduszu (Ecofund) etc. Those organizations promote projects connected with the environmental protection, so they are mainly offered to people who intend to apply Renewable Energy Systems. The principle of aid from the EU funds is the prohibition of the double funding. In all cases the investor should have an energy audit for the building in question. The simple pay-back time considers the initial investment costs and the resulting annual cash flow. This parameter is often used in energy audits in Poland [17,18] and is calculated by dividing the initial investment by the annual savings.

$$SPBT = \frac{N}{\Delta Q} \quad [\text{years}] \tag{2}$$

where: N is the initial investment [€], ΔQ are the annual savings [€].

One of the most important groups of buildings are schools. This kind of objects consume from 4% (in Spain) to 13% (in the USA) of total energy used in the commercial sector [19,20]. The energy consumption in some selected schools was analyzed by Lo [21] Tae-Woo et al. [22] or Issa et al. [23]. In order to predict energy costs it is necessary to use a functional method of energy consumption calculation and this problem, connected with schools was shown in [2,5,7,16,24].

However, instead of the real buildings' thermal indexes or potential theoretical energy savings, showed in the published literature, this study investigates the differences between the theoretical and real effect of the school thermal modernization. The present study was inspired by the problems indicated by schools managers when predicted savings were more than the achieved ones. The aim of this paper was to check the difference between calculated energy consumption and values achieved from measurements, because they are much higher than expected. The study is focused on a typical secondary school located in Białystok (Poland) which was modernized in 2008. The paper shows the improvements in the building and the simple pay-back time (SPBT) calculations [17].

2. The materials and methods

2.1. Description of the object and the modernization range

The measurements were conducted in a building situated in Bialystok, Poland. The main climatic and geographic parameters are:

- 53°07′ North latitude and 23°10′ East longitude,
- Altitude of 120–160 m above sea-level,
- The average global radiation on a horizontal plane—3528 MJ year/m^2,
- Insulation time 1780 h/year,
- The minimum monthly average temperature −4.9 °C in January,
- The maximum monthly average temperature +17.3 °C in July,
- The average annual temperature 6.9 °C.
- The information about temperature represents about 30-year period.

The building (Fig. 1) was constructed in the 1970's and the complete thermal modernization was done in summer 2008. There are about 940 pupils and teachers in the building.

The school consists of the main building, gym and communicators. There are classrooms, toilets, offices and laboratories in the main buildings and a sport hall with facilities in the gym. The most important information about schools is presented in Table 2.

The external walls had been made of full ceramic bricks and an aerated concrete, because it was a popular technique in the 1970's. During the thermal modernization they were insulated with thermoplastic EPS 70 (size 0.14 m, thermal conductivity λ = 0.04 W/m K). The thermoplastic was marked according to PN-EN 13163:2009 standard. The cross section of the external walls was presented in Fig. 2.