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Changes in Energy Consumption, Greenhouse Gasses Emission and Microclimate in Classrooms after Thermal Modernization

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Abstract **–**The total thermal modernization of buildings provides to improvements in the technical condition of structure and installations. The economic effect could be observed in the energy consumption reduction for heating, air-conditioning, warm water preparation, lighting etc. Moreover it results in greenhouse gasses emission reduction. In many cases modernization changes also influence microclimate in the building. The paper shows the estimated ecological effect (13%) of modernization and results of measurements of indoor air quality conducted in classroom located in the building of Białystok University of Technology. During research indoor temperature, relative humidity and carbon dioxide level were recorded. The experiments were conducted in 2014, when the building was before thermal modernization and repeated in 2015, after some improvements of external barriers and HVAC system.

Keywords**:** greenhouse gasses emission, carbon dioxide, temperature, humidity, thermal comfort, schools

1. Introduction

The building sector has a significant influence on carbon dioxide emission and natural resource utilization as showed Nejat et al. (2015). It is responsible for about one-third of energy-related greenhouse gasses (GHG) emissions (Robert and Kummert, 2012). CO_2 emissions will continue the increase which was observed last years and would reach even above 70 billion tons in 2050 (Wada et al., 2012). The problem of greenhouse gasses reduction was discussed in many papers for instance by Rosas-Flores et al. (2012), Ordóñez and Modi (2012), Klein-Banai et al. (2013) or Hong et. Al. (2012).

The European Union established the Energy Performance of Buildings Directive (EPBD) in 2002 and improved it in 2010. The European Union (EU) is committed to reducing its greenhouse gas emissions by 20 % by 2020. The recent EPBD (2012) requires European countries to minimize energy consumption and improve their building regulations.

In Poland energy certification schemes should be prepared according to Rozporządzenie Ministra Infrastruktury i Rozwoju (2014). The methodology for calculations of the energy performance of buildings takes into account a lot of factors. One of the most important ones are parameters of the thermal building characteristics. Based on materials used for external walls, roofs, floors etc values of heat transfer coefficients for barriers are calculated. They must be lower than given in Rozporządzenie Ministra Transportu, Budownictwa i Gospodarki Morskiej (2013). For instance external walls should achieve values below 0.25 W/m^2K whereas roofs 0.2 W/m^2K. Moreover parameters of windows, heat gains of people or sun, efficiency of heating system are taken into account. Besides energy for cooling, hot water supply and the built-in lighting installation are considered. The primary energy is dependent on source of energy (conventional or renewable) used in the building. Maximum primary energy factor EP for single family houses in Poland was set as 120 W/m^2year, when for residential buildings 105 W/m^2year, and for public objects 65 W/m^2year. The values will be reduced in 2017 to respectively: 95, 85 and 60 W/m^2year. Starting from 2014 the obligation to estimate carbon dioxide emission was introduced.

All these changes provide to better energy standard of new buildings. Also an importance of renewable energy sources usage in all kinds of objects to heating, air-conditioning, hot water preparation and electricity generation was noticed because without using them it is mostly extremely difficult to confirm new regulation requirements.

The modernization of building often influences the thermal comfort and indoor air quality. The recommended parameters in schools were described in standards PN-EN ISO 7730:2006 and PN-EN 15251:2007 or papers (Gładyszewska-Fiedoruk et al., 2013 a,b). The maximal carbon dioxide level which should not be exceeded is estimated for 1000 ppm (WHO, 2000). The indoor temperature in classrooms is expected to be in range 20-26^{o}C, while relative humidity 40– 60% (Recnagel et al, 1999, PN-EN 13773:2008, PN-78/B-03421).

2. Description Of Object And Thermal Modernization Range

The building of Environmental Engineering and Civil Engineering Faculty of the Białystok University of Technology was built in 1988. It consists two parts: one of them has three floors and basement, while the second one only one floor and basement (Fig1). In this research one of classrooms with area 140 m^2 , design for 120 students in the lower part was chosen (Fig.2). It has one external wall with windows, three internal walls (to other classrooms and hall), a roof and a floor above magazines. Before modernization the external walls were made of brick with insulation and a heat transfer coefficient U was 0.4 W/m^{2}K. Windows had U values 2.0 W/m^{2}K, while the roof 0.3 W/m^{2}K. In autumn 2014 the building was modernized. External walls and roofs were insulated to minimize energy for heating and new U values decreased respectively to 1.5 W/m^{2}K, 0.21 W/m^{2}K and 0.20. W/m^{2}K.to (Sadowska et al., 2014). The modernization of HVAC system included heating pipes and radiators exchange, insulation of pipes, installation of new thermostatic valves and central regulation in a heat source (Gładyszewska-Fiedoruk and Krawczyk, 2014). Modernization of heat source was implemented and the higher part of building is still heated from heat center located in the basement, whereas in the lower part two heat sources are used: heat center and heat pumps (Piotrowska-Woroniak, 2014). Energy and ecological effects of heat pumps installation was shown by Duarte et al. (2015). Moreover in 2015 modernization of ventilation is planned. There is natural ventilation in most classes and in some of them mechanical ventilation will be installed in future.

Fig. 1. The building

Fig. 2. The classroom

2. Measurements Methodology

The energy consumption for heating before and after thermal modernization in this classroom was estimated using standard PN-EN 13790. Heat transfer through walls, windows, roof and floor was estimated from formula 1:

$$Q_{tr} = H_{tr,adj}(\theta_{\text{int}} - \theta_e)t \qquad [\text{ kWh/month}] \qquad (1)$$

while heat for ventilation from formula 2:

$$Q_{ve,} = H_{ve,adj}(\theta_{\text{int}} - \theta_e)t \qquad [\text{kWh/month}] \qquad (2)$$

Then

$$Q_{H,ht} = Q_{tr} + Q_{ve} \qquad [\text{kWh/month}] \qquad (3)$$

and

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn} \cdot Q_{H,gn} \qquad [\text{kWh/month}] \qquad (4)$$

where: $Q_{H,ht}$ is the total heat transfer for heating mode in kWh/month, $\eta_{H,gn}$ is the dimensionless gain utilization factor, $Q_{H,gn}$ gives the total heat gains for the heating mode in kWh/month, $H_{ve,adj}$ is the overall heat transfer coefficient by ventilation in W/K, θ_{int} is the set-point temperature of the building zone in ^{o}C, θ_e is the temperature of the external environment in ^{o}C, t is the time period in Ms.

The final energy consumption $Q_{k,H}$ was calculated by dividing total energy consumption by total efficiency of the heating system including heat generation, distribution and regulation:

$$\eta_{H,tot} = \eta_{H,g} \cdot \eta_{H,d} \cdot \eta_{H,a} \cdot \eta_{H,td} \qquad [-] \qquad (5)$$

where: $\eta_{H,g}$ is the heating system efficiency for heat generation, $\eta_{H,d}$ is the heating system efficiency for heat distribution, $\eta_{H,a}$ is the heating system efficiency for heat accumulation, $\eta_{H,e}$ is the heating system efficiency for regulation.

The carbon dioxide emission from heat generation E_{co2} was estimated using formula from Polish Regulation (Rozporządzenie Ministra Infrastruktury i Rozwoju, 2014):

$$E_{CO2} = 36 \cdot 10^{-7} \cdot Q_{k,H} \cdot W_{k,H} \qquad \text{[tCO2/year]} \qquad (6)$$

where : $W_{k,H}$ is a CO2 emission factor depending on type of energy source. The values of W factors are shown in table 1.

Table. 1. CO2 emission factor depending on type of energy source (Rozporządzenie Ministra Infrastruktury i Rozwoju, 2014).

Heat source	$W_{k,H}$ [tCO2/year]
Natural gas	56.1
Light oil	74.1
Coal	98.3
Biomass	0
Geothermal energy	0

The amount of CO2 emission connected with usage of electrical energy needed to work of an equipment in heat center $E_{co2en,el}$ (for instance pumps) was also estimated using formula:

$$E_{CO2en,el} = 36 \cdot 10^{-7} \cdot E_{en,el} \cdot W_{en,el} \qquad \text{[tCO2/year]} \qquad (7)$$

where: $E_{en,el}$ is electrical energy usage for equipment work [kWh/year].

In Białystok electrical energy is produced in cogeneration system from coal and biomass (Krawczyk and Topolańska, 2015). The share of both fuels changes all time, and it is worthy to note that biomass and coal parts were similar in 2014.

The measurements of indoor parameters were conducted during written exams in January 2014 and 2015. The measurements included indoor and outdoor air temperature, relative humidity , carbon dioxide level and pressure. They were conducted using a multifunctional measuring instrument for air quality tests Testo 435-4, with the following parameters: temperature in the range between 0 and +50 °C: ± 0.3 °C; relative humidity in the range between +2 and + 98 % RH: ± 2 % RH; atmospheric pressure in the range between + 600 and + 1150 hPa: ± 5 hPa.

3. Results And Discussion

Changes in energy consumption for the classroom were shown in fig 3 whereas CO2 emission in fig.4. After modernization theoretical energy consumption $Q_{,H,nd}$ decreased by 9,2%. Final energy consumption after modernization was estimated for 3 variants of heat sources: system combined from heat center and heat pump (variant a1), only new heat center (variant a2), and only heat pump (variant a3). For these cases final energy reduction amounted respectively 70%, 31% and 81% (fig.3). Because in Poland external temperatures in heating season are significantly low and bivalent sources are recommended variant first was selected.

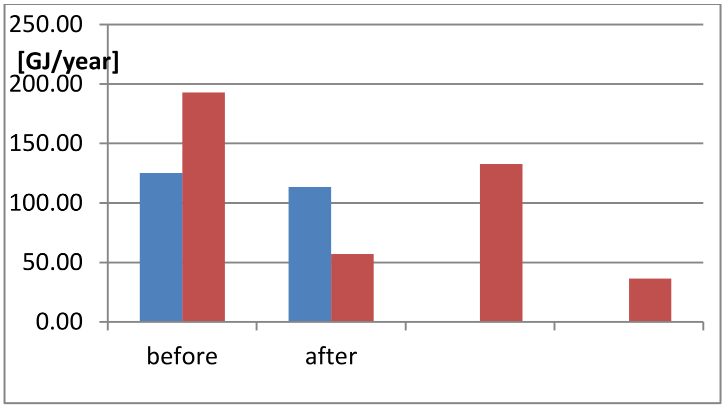

Fig. 3. Total energy consumption for heating

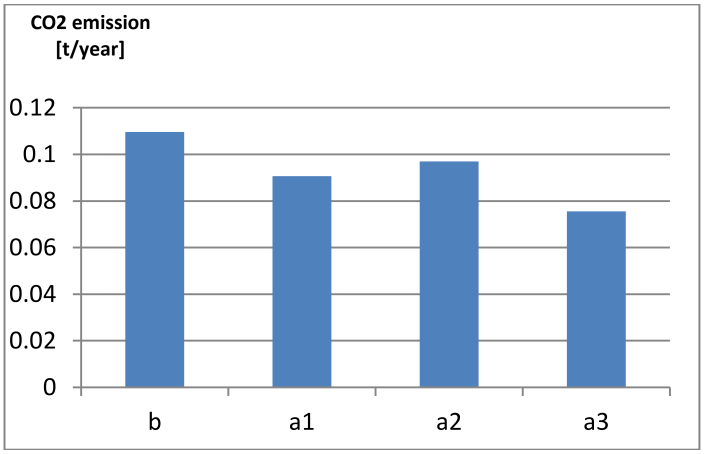

Fig. 4. CO_2 emission from heat generation

Carbon dioxide emission was calculated from fuels burning process to produce energy for heating and for electrical energy generation for pumps etc working in the heating system. The emission reduction was estimated for 13%,11% and 31%.

Parameters of outdoor air during measurements are presented in table 2.

Table. 2. Outdoor air parameters during measurements.

Parameter	Unit	15-01-2014 before modernization	15-01-2015 after modernization
Temperature	^oC	1,17	2,10
Relative humidity	%	70,20	83,90
CO2 concentration	ppm	564	481
Pressure	hPa	994,2	1013,85
Wind speed	m/s	8,14	11,60

Figures 5-7 show changes in carbon dioxide concentration, temperature and relative humidity during in classroom for both cases – before and after thermal modernization.

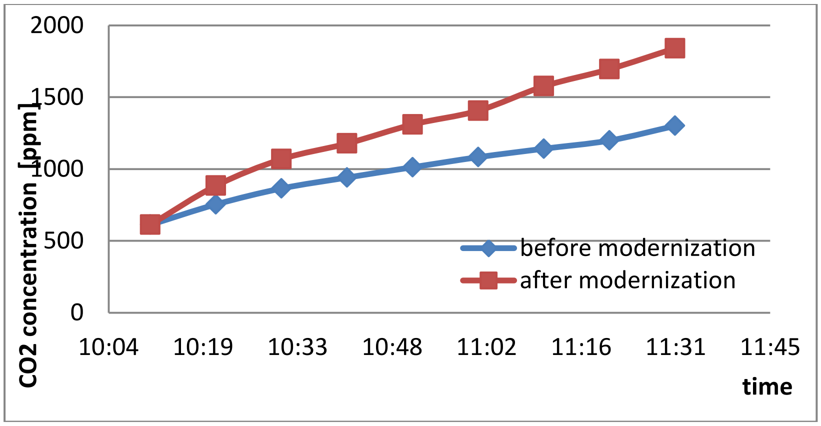

Fig. 5. CO2 concentration in classroom

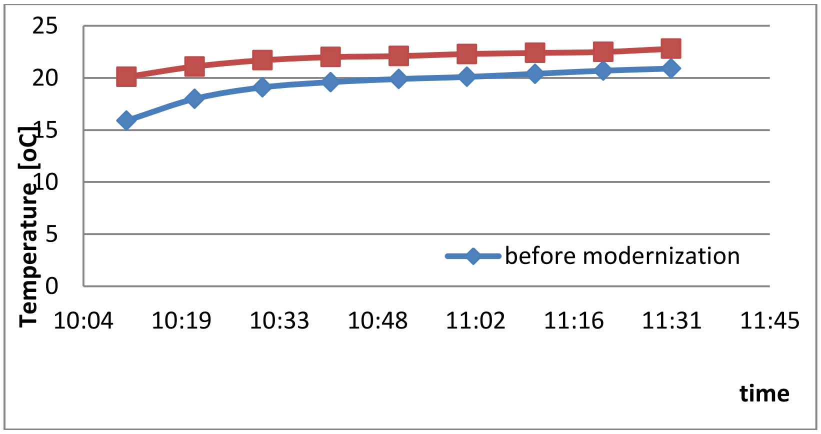

Fig. 6. Temperature in classroom

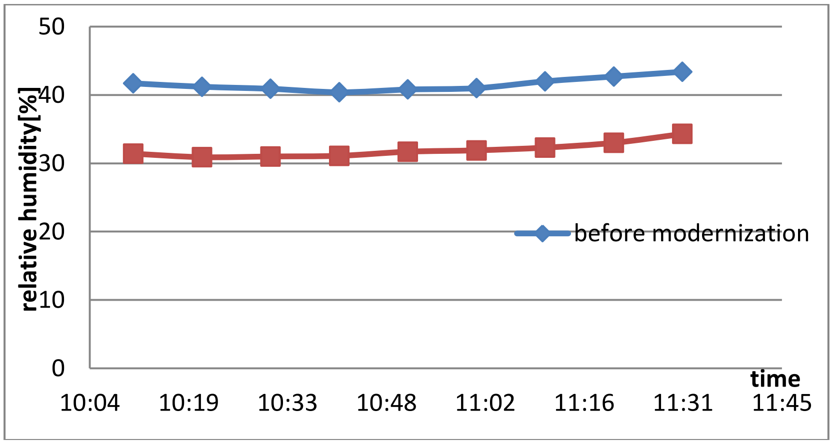

Fig. 7. Relative humidity

The results of measurements show that indoor temperature increased after thermal modernization (Fig.6) 1-2°C, but in both cases was in recommended range, while humidity decreased from average 41% to 31% so under recommended minimum level 40%. The raise of carbon dioxide concentration was significantly faster in classroom after modernization (to 1842 ppm comparing to 1301 ppm before modernization). It could be connected with more airtight windows and lower air change rate after windows replacement.

4. Conclusion

Thermal modernization of building structure and HVAC system leads to economical savings connected with energy reduction for heating and reduction in greenhouse gasses emission. The efficiency of modernization depends on many factors like: heat transfer coefficients of external walls, roofs and windows before and after improvements, the range of changes in heating and ventilation system etc. In the described classroom theoretical energy consumption for heating was reduced about 9% and ecological effect was estimated for 13%. Reduction in final energy consumption after modernization was estimated for 31-81% depending on percentage usage of heat sources (heat center and heat pump). Carbon dioxide emission could be reduced even 31% while share of fuels used in burning process to produce heat and electrical energy would be changed. Moreover indoor air quality was tested and the increase of temperature and carbon dioxide level were recorded whereas decrease of relative humidity was observed.

Acknowledgements

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