Analysis of the opportunities for improving energy efficiency in public buildings

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Abstract. Reducing energy consumption and maintaining an appropriate indoor air quality in buildings is a global trend. This is achieved in several ways – improving the building envelope thermal characteristics; fuel base replacement; introduction of smart energy consumption tracking systems. The aim of this paper is an analysis of the impact of energy efficiency measures introduced in buildings that provide health services. Measures have been taken to improve the energy performance of the envelope, as well as to modernize the system for the production and distribution of thermal energy. One complete year after energy savings measures implemented the total energy savings of 37.9% have been achieved. Further economic assessment has been made regarding the profitability of the applied measures.

1. Introduction

Issues related to increasing energy efficiency in buildings have been particularly relevant over the past three decades. The need arises both from the rise in energy carriers' prices and the provision of an adequate indoor climate. Globally, around 30% of energy consumption in buildings is attributable to municipal and public buildings [1]. The paper points out that the high share of energy consumption is due to the poor thermal performance of the enclosures, the inefficient operation of HVAC systems (Heating, Ventilation, & Air Conditioning) and the lack of or poor management of energy consumption.

Some papers [2–5] examine the effect from some of the most commonly applied energy-efficient measures in municipal and public buildings. For this purpose, energy audits were carried out using different mathematical approaches to model energy consumption. In some of the cases near-infrared-reflective architectural coatings was suggested to reduce heat losses. In [6], the effect of energy saving from replacing the lighting system has been examined in compliance with the regulatory requirements.

The choice of energy-efficient measures is most often in line with the calculated energy savings, respectively the financial parameters of the measure. In some cases, when the cost of the energy used is low and the investment is significant, the measure is unprofitable [7]. In this case, different co-financing mechanisms (whether national or international) are available to promote energy efficiency improvement in buildings.

In a number of cases, the regulatory framework and a grant scheme are the driving force behind the energy targets set in a given country [8].

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2. Problem identification

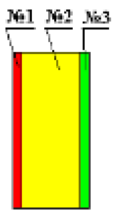
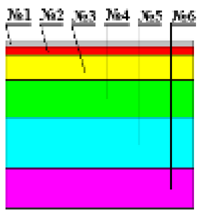
The subject of the present survey are four different buildings designed to provide health cares (public buildings), which are situated on a single site. Summary of the four buildings under analysis is presented below.

2.1. Fthysiatric ward (Building 1)

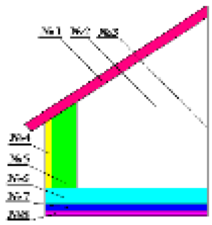
The first building is the Fthysiatric ward. The building is public state-owned and was built in 1889. The surveyed part of the hospital is a brick building with a monolithic structure. The facades are lime-cement plaster in a relatively good condition. The exterior walls are masonry of solid bricks with different thickness without thermal insulation. The building is equipped with contemporary aluminum frames with double glazed windows. The roofs are tiled without thermal insulation, with the same height throughout the attic spaces. The floors of the building are made of concrete slab without thermal insulation with laminate and terracotta coating. All parts of the building are heated. The working regime of the hospital is 24 hours and 7 days a week. Figure 1 shows the design and orientation of the building. Thermal characteristics of the building are presented in table 1.

Figure 1. Scheme of the building.

Table 1. Thermal characteristics of the building envelop 1.

Type of envelope	Thermal resistance (R), m^2K/W	
External wall		
№ 1. Inner plaster $\delta_1 = 0.03$ m; $\lambda_1 = 0.70$ W/(mK)	**0.043**	
№ 2. Brick wall $\delta_1 = 0.38$m; $\lambda_1 = 0.79$ W/(mK)	**0.437**	
№ 3. External plaster $\delta_1 = 0.04$ m; $\lambda_1 = 0.87$ W/(mK)	**0.046**	
Overall heat transfer coefficient U=1.436 W/(m^2K)		
Floor		
№ 1. Terracotta $\delta_1 = 0.015$ m; $\lambda_1 = 1.28$ (W/mK)	**0.012**	
№ 2. Dressing cement plaster $\delta_1 = 0.02$ m; $\lambda_1 = 0.93$ W/(mK)	**0.021**	
№ 3. Reinforced concrete slab $\delta_1 = 0.10$ m; $\lambda_1 = 1.63$ (W/mK)	**0.061**	
№ 4. Timber structure $\delta_1 = 0.20$ m; $\lambda_1 = 0.61$ (W/mK)	**0.33**	
№ 5. Air cavity $\delta_1 = 0.3$ m; $\lambda_1 = 0.19$ (W/mK)	**1.58**	
№ 6. Pudding $\delta_1 = 0.20$ m; $\lambda_1 = 1.50$ (W/mK)	**1.58**	

Type of envelope	Thermal resistance (R), m^2K/W
External wall	
Overall heat transfer coefficient U=0.264 W/(m^2K)	
Roof	
№ 1. Roof tiles δ_1 = 0.03 m; λ_1 = 0.99 (W/mK)	**0.03**
№ 2. Air cavity δ_1 = 1.55 m; λ_1 = 1.99 (W/mK)	**0.778**
№ 3. Lacing	**-**
№ 4. Water-repellent plaster δ_1 = 0.04 m; λ_1 = 0.87 (W/mK)	**0.046**
№ 5. Solid bricks δ_1 = 0.26 m; λ_1 = 0.79 (W/mK)	**0.329**
№ 6. Timber structure δ_1 = 0.18 m; λ_1 = 0.61 (W/mK)	**0.295**
№ 7. Inner plaster δ_1 = 0.03 m; λ_1 = 0.70 (W/mK)	**0.043**
№ 8. Suspended ceilings δ_1 = 0.0125 m; λ_1 = 0.052 (W/mK)	**0.240**
Overall heat transfer coefficient U=0.695 W/(m^2K)	



Heat supply is provided by local heating installations (boiler and substation) located in the underground part of the building. The boiler room consists of one boiler with power of 116 kW that is installed 2004 – 2005.

The heat supply of the building is not regular. In the winter, the building is heated up to the end of the heating season, with the boiler running in mode - switching on and off at the temperature of the heat carrier at the boiler inlet (return water). During holidays and bank holidays the building is also heated. The circulation of the heat supplier is forced through a single circulation pump. Collectors (collector and distributor) and pipelines in the boiler room and substation premises are insulated, their fittings are maintained and work well. The heating installation is two-pipe with forced circulation, with parameters of the heat carrier 90/70° C. The radiators are cast iron, installed in all heated rooms.

2.2. Administration of hospital (Building 2)

The building is public state-owned, built in 1889 and used as Administration. The surveyed part of the hospital is a brick building with a monolithic massive structure. The facades are lime-cement plaster, in a relatively good condition. The outer walls are masonry of solid bricks of different thickness without thermal insulation. The building is equipped with contemporary aluminium frames with double glazed windows. The roofs are tiled without thermal insulation, with the same height throughout the attic spaces. The floors of the building are made of concrete slab without thermal insulation with wooden flooring (laminate) and terracotta. All parts of the building are heated. An outline of the building is presented in Figure 2.

The thermal performance characteristics of the building are presented in table 2.

2.3. Pneumology 1 (Building 3)

The structure of the building is similar to that of Building 2. A general view is presented in Figure 3.

The thermal performance characteristics of the building are presented in table 3.

Figure 2. View of the hospital administration.

Figure 3. View of pneumology 1 hospital building.

Table 2. Thermal characteristics of the building envelop 2.

Type of envelope	**Heat transfer coefficient (U), W/(**m²K)
External wall 1	**1.436**
External wall 2	**1.823**
Floor 1	**0.24**
Floor 2	**0.291**
Floor 3	**0.318**
Floor 4	**0.401**
Roof	**0.692**

Table 3. Thermal characteristics of the building envelop 3.

Type of envelope	**Heat transfer coefficient (U), W/(**m²K)
External wall 1	**1.436**
Floor 1	**0.241**
Roof	**0.694**

2.4. Pneumology 2 (Building 4)
The structure of the building is similar to that of Building 2. A general view is presented in Figure 4.

The thermal characteristics of building 4 are presented in table. 4.

The heat supply of all buildings is the same - the supply of heat is supplied trough a convection system from a boiler located in the basement of the building.

Figure 4. Scheme of the building.

Table 4. Thermal characteristics of the building envelop 4.

Type of envelope	**Heat transfer coefficient (U), W/(**m^{2}K)
External wall 1	**1.436**
Floor 1	**0.249**
Floor 2	**0.305**
Roof	**0.682**

3. Analysis of the current energy consumption of the buildings

During the survey period, two different energy carriers were used –- electricity and diesel fuel. Electrical energy is used to ensure the operation of the lightning system in the hospital rooms, the operation of medical equipment, and the auxiliary equipment to the heating system - pumps and fans. Diesel fuel is used solely to maintain the microclimate in the buildings and to produce hot water for household purposes.

Figure 4 presents the energy consumption in the buildings for the period 2009–2011. The difference in consumption is no more than 15% and depends mainly on the use of the available equipment as well as the external weather conditions.

Table 5 and Figure 5 show the energy consumption by years for the period, as well as the number of heating day degrees. From Figure 5 it is evident that the share of electricity consumption during the surveyed period is between 31% and 35% and the consumption of the thermal energy – 65–69%.

The relative annual energy consumption, as shown in Figure 6, is calculated based on this data. It is clear that the relative annual energy costs do not significantly change over the last two years and are less than the costs in 2009. This is due to the fact that in 2009, there has been a replacement of the window frames of the building, as a result of which the specific energy consumption has decreased.

Table 5. Annual energy consumption of the buildings.

Year	**Electricity, kWh**	**Thermal energy, kWh**	**Total energy, kWh**	**Day degrees (DD)**
2009	246 270	543 210	789 480	2 714
2010	234 239	437 638	671 877	2 815
2011	222 256	477 538	699 794	2 989

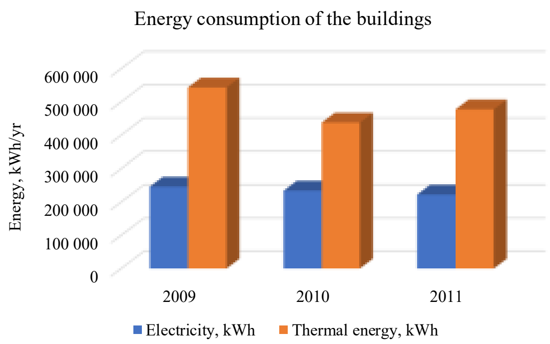


Figure 5. Yearly annual energy consumption of the buildings.

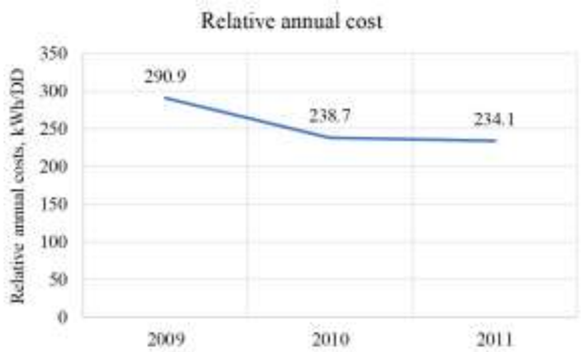


Figure 6. Relative annual costs, kWh/DD.

4. Modeling of energy consumption of the buildings

A survey of the energy consumption in the buildings was carried out. The results of the survey are presented in Figures 7–10. The normalization of the energy consumption was needed, in compliance with the normative requirements for maintaining the necessary temperature comfort. For all four buildings, the normalized energy consumption is increased, indicating that at the time of the survey the buildings were under-heated.

The survey shows that the energy consumption of the building is significantly higher than the standard for this type of buildings, therefore measures are recommended to increase the energy efficiency.

As a result of the audit, three energy saving measures have been introduced as reasonable for the buildings:

- Introduction of thermal insulation on the external walls of the buildings;
- Laying thermal insulation on roofs / attic spaces;
- Modernization of the heating system.

Given the architectural features of the building, it was found that laying thermal insulation is impossible on the external walls of the building, which is why its application is chosen to be on the inside of the external walls.

The modernization of the heating system consists of replacing the local boilers with natural gas. The suggested boilers are equipped with the corresponding control systems, characterized by a high efficiency.

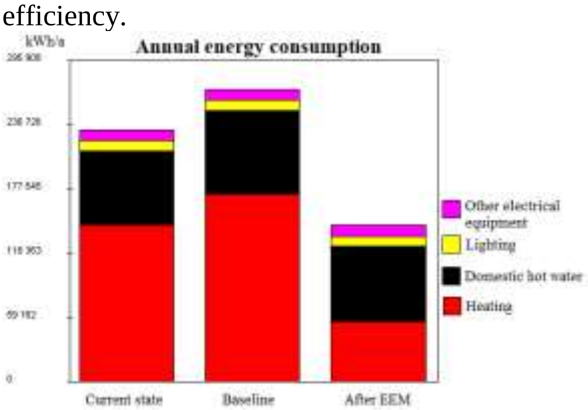


Figure 7. Outputs from the energy modeling of building 1.

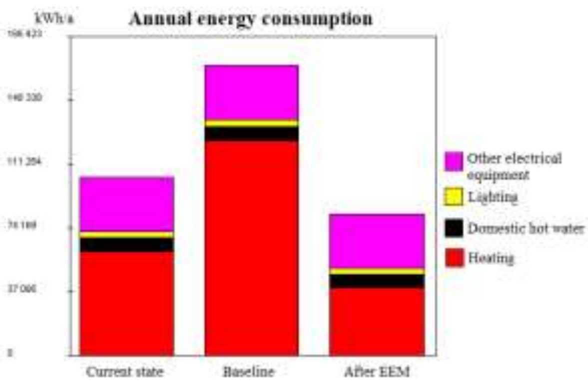


Figure 8. Outputs from the energy modeling of building 2.

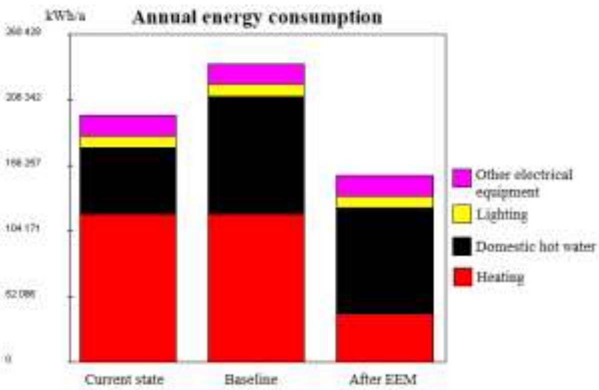


Figure 9. Outputs from the energy modeling of building 1.

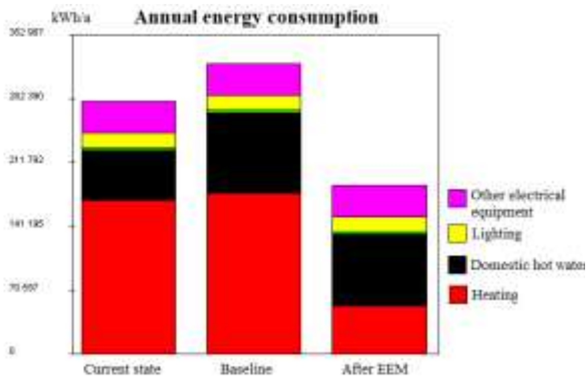


Figure 10. Outputs from the energy modeling of building 4.

5. Energy consumption after implementation of measures

The measures were put into operation in 2014, with three full years of since the implementation.

Energy savings from the implementation of the measures are calculated as the difference between the baseline energy consumption (or normalized) and consumption after the introduction of the measures. However, it should be noted that the baseline must be adjusted to the outdoor conditions with which it is compared. Thus the energy consumption of the buildings before the implementation of the measures in operation is according to table 6.

Table 6. Energy consumption of the buildings before energy efficiency measures implementation

Month	External temperature	Heating days	Day degrees	Baseline, kWh
January	2.4	31	546	87 162
February	2.1	28	501	80 069
March	5.4	31	453	72 305
April	16.6	16	54	8 691
October	13.8	0	0	0
November	5.3	30	441	70 452
December	1.5	31	574	91 619
Total		**167**	**2 568**	**410 297**

Table 7. Energy consumption of the buildings before energy efficiency measures implementation

Month	Baseline, kWh	Real consumption, kWh	Savings, kWh	CO2 emission reduction, t
January	87 162	52 434	34 728	12.7
February	80 069	46 404	33 665	12.0
March	72 305	47 902	24 403	9.6
April	8 691	7 453	1 237	0.8
October	0	0	0	0.0
November	70 452	42 747	27 705	10.2
December	91 619	57 961	33 658	12.8
Total	410 297	254 901	155 396	58.1

Table 7 presents information on energy consumption (natural gas) after the introduction of the measures, as well as the corresponding savings. It can be seen that the energy saving is 37.9% of the normalized baseline, with savings of 155,396 kWh / year or cash equivalent of EUR 13 433. The carbon savings achieved amount to 58.06 t / yr. The investments costs for the implementation of the measures are EUR 114 137, which sets a payback period of 8.49 years.

6. Financial analysis

A financial analysis summary of the cost-effectiveness of the proposed energy-efficient measures is shown below. Table 8 provides information for the achieved savings, both in natural units and in currency. It can be seen that the savings from the introduction of measure 1 - about 43%, followed by the heating rehabilitation measure - 36% are the most significant ones. About 21% are the savings from increasing the roof's energy efficiency of the buildings.

Table 8. Net incomes from implementation of the measures.

Energy efficiency measure	Energy savings achieved, kWh	Total savings, EUR
Thermal insulation of walls	66 323	5 733
Thermal insulation of roof	33 814	2 923
Rehabilitation of heating system	55 259	4 777

Table 9 provides information on the financial parameters of the implemented measures: Internal rate of returns (IRR), Net present value (NPV), simple payback period (PB) are shown. It is clear that the highest value of IRR and NPV is achieved from the measure for thermal insulation of the external walls. The total simple payback period of the measures is 8.5 years and the IRR value is 11.3%. The real interest rate is 5%, which includes 0.5% inflation rate and 5% nominal interest rate.

Table 9. Main financial indicators

Energy efficiency measure	Investment, EUR	PB, yrs	IRR, %	NPV,EUR
Thermal insulation of walls	39 947	7.0	13	31 499
Thermal insulation of roof	28 534	9.8	8	7 893
Rehabilitation of heating system	45 654	9.6	6	3 930

7. Conclusion

The paper presents a feasibility study for the implementation of energy-efficient measures related to the improvement of energy efficiency in public buildings. The proposed measures are rehabilitation of the external walls, rehabilitation of roof spaces and modernization of the heating system. Energy modelling of the building was carried out, and based on the determined savings, the energy efficiency measures were prioritized. After one year of operation of the building, the actual energy consumption was also recorded. The comparison between baseline and actual consumption shows an energy saving of 37.9%. The internal rate of return for the selected measures is between 6-13%, with the net present value being a positive figure. This qualifies the measures as profitable.

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