Energy efficiency improvement in hospital buildings, based on the example of a selected type of hospital facility in Poland

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Abstract. Energy demand in hospitals is of highly diverse nature: heat energy, cool energy and electricity. A guarantee of energy supply is required to ensure continuity of medical procedures. Taking care of the lowest possible costs of hospital operations, special attention should be paid to energy efficiency of the installations used in the hospital buildings. The paper presents an analysis of energy demand for heating, cooling, ventilation and lighting in an example hospital in Poland. The selected object was considered a reference as it was built according to a repetitive construction plan, according to which several dozen other hospitals were built in Poland. On the basis of data from 2013-2017, a summary of heat, cold and electricity demand for the hospital in its current technical condition was prepared. Concepts of technical and economic modernization of systems using energy in the analysed facility were proposed, assuming different ranges of changes for individual installations in the hospital. After the analysis of various modernization options, a project was proposed combining the use of heat pumps, photovoltaic installations and generation of heat and cooling in trigeneration, all of which allowed to reduce the costs of operation of the hospital energy systems by about 31%.

1. Introduction

Hospital buildings feature a high diversity of energy demand, e.g.: thermal energy for heating buildings and for domestic hot water, cooling for ventilation systems, electric energy required to operate medical equipment, lighting, ventilation and air conditioning systems. Due to the need to ensure the continuity of medical procedures performed, and to maintain the quality of the environment inside the building, a guarantee of energy supplies is required [1-2]. It is the specific activities carried out by hospitals that cause their high energy demands. This is mainly due to the size of hospital buildings, 24/7 system of operation, as well as the use of numerous energy-intensive devices and systems [3].

Directive 2010/31/EU of the European Parliament and of the Council, recommends that the EU Member States implement regulations requiring that after 31 December, 2018, new buildings occupied or owned by public authorities should be nearly zero-energy buildings [4]. In Poland, the majority of hospitals are financed from the budget of local governments and the National Health Fund, therefore, while seeking to implement the recommendations of the EU, and ensuring the lowest operating costs, they should pay special attention to the energy efficiency of installations used in hospitals.

In the course of hospitals operation, which is usually over 50 years, there are often needs for refurbishment of installations, and construction of hospital buildings, or modernisation of medical equipment [3]. The results of various research show that hospitals are most desirable objects for
planning modernization works, which is due to the stability of their thermal load and a positive heat/power ratio [5]. When planning modernisation works, a very important stage is to analyse the multivariate scope of modifications and technical solutions to be applied, adjusting them, for instance, to the financial resources of the administrator [6]. This paper presents an analysis of this type for one of the hospitals in south-western Poland. The selected object can be considered as a reference since it was built according to a repetitive construction plan, according to which several dozen other hospitals were built in Poland.

The hospital under study (shown in Figure 1) has 680 beds in 18 hospital wards, 14 specialist hospital outpatient clinics, diagnostic facilities, a rehabilitation facility, and basic health care units. The complex comprises 20 hospital buildings (including 7 for implementing medical procedures); in total 68 200 m² of temperature-controlled area. The current technical condition can be considered satisfactory, but does not meet the requirements for low-energy buildings, or NZEB (nearly zero-energy buildings). At present, the Hospital Manager does not intend to modernise the structure of the building or its thermal insulation, which is why the actual modernisation measures have been excluded from the scope of this article. The heating of buildings and domestic hot water is supplied by the company's own local boiler house, which is coal-fired, and by the district heating substation of the municipal heating network.

Figure 1. Location of the analysed hospital [7].

Section 2 presents the authors' proposed variants of modernisation of heat and electricity generating installations for the needs of the hospital under analysis. In order to be able to compare the energy efficiency of the proposed modernisation variants, there are also presented values of the energy demand of the hospital under analysis, determined in compliance with the Regulation of the Minister of Infrastructure and Development of 27 February 2015 on the methodology of determining the energy performance of a building or part of a building and energy performance certificates of buildings (pursuant to Directive 2010/31/EU of the European Parliament and the Council of 19 May 2010 on the energy performance of buildings) [8,3]. In order to provide a more accurate assessment of the actual energy demand, data on the consumption of energy carriers in the facility under analysis for the years 2013-2017 will also be taken into account. Section 3 presents a summary of the energy efficiency analysis of the individual modernisation variants, as well as the investment return periods estimated for the individual variants.

2. Methods
In order to be able to select the most advantageous solutions for generating and using energy for the needs of hospital facilities, it is necessary to understand the operating conditions of individual
installations, their technical parameters, and to determine the demands for particular types of energy (heat and electricity) [9]. In the course of the research, on the basis of data from 2013-2017, a summary of demand for heat, cooling, and electricity for the hospital in its current technical condition was prepared. Energy audit of the hospital building was also carried out in order to identify the devices using energy, and the various forms of energy consumed.

It was found that the profile of heat energy used for central heating was typical of hospital buildings of that size. That meant that the annual demand for heat (heating, domestic hot water, cooling, ventilation, steam), in the analysed period, was from the 41240 to 47460 GJ/year. The demand for thermal energy for the monthly periods was on average from 1700 to 7200 GJ/month during the heating season, and from 1600 to 1800 GJ/month in the summer season. In order to be able to compare the heat demand in the object under study with other hospitals, the average energy consumption rate for hospital buildings was determined, which in the period from 2013 to 2017 declined from 194.8 kWh/m²·year to 148.5 kWh/m²·year. Electricity consumption in the hospital under analysis remained at a similar level of approx. 6250 MWh/year. The monthly electricity demand varies between 480 and 570 MWh/month. An increase in monthly demand for electricity can be observed in the summer months (use of air conditioning units) by 10-15%.

In order to determine the scope of modernization for the selected hospital building, an analysis was carried out of technical solutions proposed for use in hospitals by different scientists [10-12]. When selecting the solutions proposed in individual modernisation variants, we also considered the possibility of using cogeneration, or even trigeneration systems (simultaneous generation of heat, cooling and electricity) [13]. The energy analyses carried out by various researchers also indicate that in the case of hospital facilities using heat pumps in the heating system, the primary energy consumption is 71% lower compared to the reference system based on typical gas boilers and waterborne heating [14]. When developing the concept of hospital modernisation, we also took into account the results of research confirming that the use of LED lighting in the hospital is very energy efficient, as it is the case in residential buildings [15].

None of the proposed variants of modernization involved changes to the buildings’ ventilation system. That decision was taken, because the use of the most energy efficient system of mechanical ventilation supply and exhaust heat recovery would involve too much interference in the building structure (difficult to implement due to the need for continuity of medical procedures conducted by the hospital). In order to determine heat losses from hospital buildings to the environment through external partitions, thermos-vision tests of hospital medical buildings were carried out so as to assess the state of thermal protection of the object. In most of the hospital buildings, it would be necessary to improve the insulation performance of the external partitions. However, activities related to insulation of structural elements of buildings were not in the scope of this study.

On the basis of the conducted literature research and having reviewed the technical conditions of the hospital, four concepts of modernisation of the heat source and obtaining and using electric energy for the needs of the hospital were developed, including a diverse range of investment. The scope of the changes proposed in the individual variants are summarized in Table 1.

### Table 1. The scope of the proposed changes in the individual variants of modernization

| Solutions used in a given modernisation variant | Variant 1 | Variant 2 | Variant 3 | Variant 4 |
|-----------------------------------------------|-----------|-----------|-----------|-----------|
| The lighting system using LEDs                | x         | x         | x         | x         |
| Two gas engines with electrical power of 2 x 400 kW<sub>e</sub> | x         |           |           |           |
| Absorption unit for the production of chilled water 6/12°C using heat from a cogeneration source | x         | x         |           |           |
| Micro gas turbine with an electrical capacity of 1 x 600 kW<sub>e</sub> | x         |           |           |           |
| Photovoltaic panels with a total power of approx. 180 kWp - the building area was approx. 1080 m² | x         | x         |           |           |
| Gas engine with electrical power of 1 x 400 kW<sub>e</sub> | x         |           |           |           |
Solutions used in a given modernisation variant

| Variant | 1          | 2          | 3          | 4          |
|---------|------------|------------|------------|------------|
| 1       | Heat pump with heating power of 1 x 135 kW, using well water pumped from deep wells for the hospital's own needs as the lower source of heat | x          |            |            |
| 2       | Heat pumps with heating power of 2 x 350 kW, using 100 vertical wells with a depth of 200 m each as the lower heat source |            | x          |            |
| 3       | Load-bearing steel structure allowing the installation of panels in the form of a canopy for the main car park at the hospital |            |            | x          |
| 4       | Photovoltaic panels with a total power of approx. 200 kWp - the building area was approx. 1450 m² |            |            |            |

3. Results and discussion

The proposed variants of modernization of the heat and electricity supply systems were compared by estimating their energy efficiency and cost in the climatic conditions of the hospital location (south-west Poland). The efficiency of individual heat and electric energy sources was determined (following the methodology laid down in the Regulation of the Minister of Infrastructure and Development on the methodology for calculating the energy performance of a building or part of a building and energy performance certificates of 27 February 2015) [8], as well as the share of covering the energy demand for all variants proposed for the hospital under study. A more comprehensive presentation of the methodology of the analyses and calculations carried out is not possible due to the limitations of the volume of this publication. The results are shown in Table 2.

Table 2. Energy efficiency of the proposed variants of modernization

| Variant | The efficiency of [%] | The coverage of heat and electricity demand [%] |
|---------|------------------------|-----------------------------------------------|
|         | heat  | electricity | heat  | electricity |
| 1       | 45.9  | 37.2        | 41.2  | 82.6        |
| 2       | 48.1  | 33.4 (PV-16.7) | 43.8  | 66.5        |
| 3       | 62.8  | 38.1 (PV-16.7) | 40.3  | 79.3        |
| 4       | 91.7  | 16.7        | 44.6  | 62.7        |

All variants of modernization planned using LED light sources and VPhase voltage control systems in hospital buildings. That was expected to bring an estimated reduction in the demand for electricity for lighting by 58.7%. Knowing the power of the installed lighting points and the annual operating time of the individual lighting circuits, it has been calculated that the current annual consumption of 768.5 MWh can be reduced to 317.4 MWh. A great help in case of upgrading the lighting system was the ability to do the work in stages (eg. for individual wards or buildings), with no significant interference with the medical procedures performed.

The investment payback periods for individual variants of modernisation of energy source installations for the hospital were as follows:
- Variant 1 - 3.5 years,
- Variant 2 - 4.8 years,
- Variant 3 - 4.1 years,
- Variant 4 - 19 years.

An analysis of the results led to the conclusion that for the hospital, the best solution was modernization of systems of acquisition and management of electric and thermal energy according to Variant 3. Although the solutions proposed under this option did not guarantee the highest coverage of heat and electricity demand, they were nevertheless relatively cost-effective and highly efficient in terms of energy generation. Due to that, Variant 3 had one of the shortest investment payback periods,
which was very important given the financial situation of the hospital under study. The projections concerning the amount of electricity generated (from gas engine and PV panels - 1870 MWh/year) and heat (from gas engine and heat pump - 13300 GJ/year), by the installations used in Variant 3, allowed to estimate that the energy generation system, modernised according to this variant, would reduce the costs related to the acquisition of energy for hospital needs by approx. 31% (assuming for the calculation the current energy consumption of heat and electricity as well as the projected consumptions achievable by improving the energy efficiency of the installations upgraded according to variant 3 chosen). At the same time, it was established that the amount of electrical energy generated annually (in the sunlight conditions in Opole) by a photovoltaic installation designed for Variant 3 (with a total capacity of 180 kWp) should almost 100% satisfy the energy demand for lighting (LED with VPhase voltage control systems) of the medical buildings in the hospital.

The analysis of energy efficiency and cost-effectiveness allowed also to establish that the use of heat pumps, using ground heat as the lower source (by means of vertical boreholes) was a very expensive solution at the investment stage. That exceeded the financial capacity of the hospital and was not feasible without financial support, eg. from the government or European Union funds. Therefore, the modernization of the hospital according to Variant 4 had to be rejected, even though it offered the highest degree of coverage of the heat demand, the highest efficiency of heat acquisition, and being at the same time the least disruptive to the vicinity of the hospital. However, the heat pump proposed in Variant 3, which used well water as the lower source of heat, pumped from deep wells for the hospital's own needs, guaranteed heat for the heating of the hospital's domestic hot water throughout the year.

The situation was similar in the case of installation of photovoltaic panels on a steel structure which was a form of roofing over the parking lot at the main hospital. This solution involved high investment costs, which made the whole implementation of Variant 4 unprofitable because of the payback period of up 19 years. That period was only slightly shorter than the expected life cycle of the equipment proposed for installation. As in the case of heat pumps, installation of photovoltaic panels was profitable only with co-investments from external funds. Acquisition of electricity, with the highest demand in the summer months (April-September) - from 7:00 a.m. to 5:00 p.m. - would allow for direct use of electricity by the hospital's air-conditioning systems and medical equipment. In such a situation there would be no need for the use of energy storage systems, and the acquisition of the electricity would not cause environmental pollution. However, in the winter months (November-February), the amount of electricity produced would be very low, which would allow only marginally to meet the hospital's demand for electricity. In winter, when the photovoltaic system is not able to produce the required amount of electricity, the co-generation engine powered by natural gas can provide both electricity and heat for hospital heating. It should be noted however that the Energy Law in force in Poland imposes an obligation on investors implementing photovoltaic installations with a capacity of over 200 kWp to obtain a concession for electricity generation and to conduct business activity in this area [16].

Regardless of the hospital management's decision as to which variant of modernization would be implemented, it would be necessary to continue using the district heating network and the national power grid. In the event of a failure of the district heating network or the national power grid, the co-generation system assumed in Variant 3 ensured the security of heat, cooling and electricity supply necessary for the implementation of medical procedures in the hospital.

4. Conclusions
The analyses made it possible to assess the possibility of using various configurations of heat and electricity sources in order to achieve the greatest possible reduction of costs incurred for the purchase of heat and electricity, while maintaining energy security. The conducted analyses may serve as a model for designing modernisation activities of other hospital facilities with comparable technical parameters and located in similar climatic conditions.
Following the analysis of various modernisation variants, the implementation of Variant 3 assuming the use of a heat pump, a photovoltaic installation, changing the lighting installation of buildings, as well as generation of heat and cooling in trigeneration (by means of a gas engine) was proposed. Thus implemented modernisation of the hospital's energy system would allow to reduce the costs of operation of the hospital's energy systems by approx. 31%, while at the same time reducing the hospital's negative impact on the environment, e.g. by reducing the carbon footprint, including emissions of carbon dioxide and other gases to the atmosphere. In the case of hospitals, which are usually located in heavily urbanised areas, the reduction of nuisance to the urban environment is particularly important.

The use of LED light sources and VPhase voltage control systems of power supply, would reduce the demand for electricity for lighting by 58.7%. The LED lighting system would also be a much less of an internal heat source, which increases the hospital building's demand for cooling during the summer.

References
[1] Khodakarami J and Nasrollahi N 2012 Thermal comfort in hospitals - A literature review Renewable and Sustainable Energy Reviews 16 4071-77
[2] Buonomano A, Calise F, Ferruzzi G and Palombo A 2014 Dynamic energy performance analysis: Case study for energy efficiency retrofits of hospital buildings Energy 78 555-72
[3] Kolokotsa D, Tsoutsos T and Papantoniou S 2012 Energy conservation techniques for hospital buildings Advances in Building Energy Research 6 159-172
[4] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. Official Journal of the European Union L 153/13
[5] Saidur R, Hasanuzzaman M, Yogeswaran S, Mohammed H A and Hossain M S 2010 An end-use energy analysis in a Malaysian public hospital Energy 35 4780-85
[6] Sadler B, DuBose J, Malone E and Zimring C 2008 The business case for building better hospitals through evidence-based design Health Environments Research & Design 1 22-39
[7] https://www.google.pl/maps (access 14.11.2018)
[8] Regulation of the Minister of Infrastructure and Development on the methodology for calculating the energy performance of a building or part of a building and energy performance certificates of 27 February 2015. Journal of Laws of the Republic of Poland 2015/376
[9] Arcuri P, Florio G and Fragiacomo P 2007 A mixed integer programming model for optimal design of trigeneration in a hospital complex Energy 32 1430-47
[10] Bizzarri G and Morini GL 2006 New technologies for an effective energy retrofit of hospitals. Applied Thermal Engineering 26 161-9.
[11] Schijndel AWM 2002 Optimal operation of a hospital power plant Energy and Buildings 34(10) 1055-65.
[12] Jeon J, Lee S, Hong D and Kim Y 2010 Performance evaluation and modelling of a hybrid cooling system combining a screw water chiller with a ground source heat pump in a building. Energy 35(5) 2006-12
[13] Zither D and Poredos A 2006 Economics of a trigeneration system in a hospital Applied Thermal Engineering 26(7) 680-87
[14] Vanhoudt D, Desmedt J, Van Bael J, Robeyn N and Hoes H 2011 An aquifer thermal storage system in a Belgian hospital: Long-term experimental evaluation of energy and cost savings Energy and Buildings 43 3657-65
[15] Suszanowicz D 2017 Internal heat gain from different light sources in the building lighting systems E3S Web of Conferences 19 01024
[16] The Act of 20 February 2015 on renewable energy sources. Journal of Laws of the Republic of Poland 2018/1269