EFFECTS OF INTRODUCING THE IMPROVED ENERGY MANAGEMENT SYSTEM IN THE URGENT CARE CENTER OF THE CLINICAL CENTER OF VOJVODINA

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Abstract: The Urgent Care Center of the Clinical Center of Vojvodina in Novi Sad, as a specific medical facility with very demanding conditions of work and functioning, has an extensive and constant energy demands. The building is new, set into operation in 2010. The state-of-the-art concept and the equipment installed create conditions for using advanced solutions in the framework of supervisory and control systems, increasing energy efficiency and reducing operating costs in the Urgent Center. The aim of this paper is the assessment of additional possibilities for increasing energy efficiency in the building using a number of control techniques available today. According to a source of energy, the most utilized is the electric power, which is consumed for air conditioning, compressed air, and lighting. Thermal energy is used for space heating in winter and the preparation of hot water. The first step in increasing energy efficiency was the continuous monitoring and recording of consumption. The next step was the analysis of the energy consumption and the discovery of critical areas of consumption. The final step was related to the plans and algorithms for the energy reduction. To this goal, the energy consumption in the period March 2014 - February 2016 was measured and recorded. According to that measuring and data analysis, an expert system based on the methods of computational intelligence that combines all the developed actions and algorithms for increasing energy efficiency in one unit was implemented.

Key words*: energy efficiency; public buildings; automatic supervisory and control*

1. Introduction

The Urgent Care Center of the Clinical Center of Vojvodina in Novi Sad (UC), as a particular medical facility with the very demanding conditions of work and functioning, has an extensive and constant energy demands. The building is new, completed and set into operation in 2010. UC consists of 5 floors (ground floor + 3 floors + attic) with a total area of 8350 m2 and more than 300 rooms with different purpose.

The building is equipped with a modern building management system (BMS), controlled from highly secured technical rooms, and maintained by qualified personnel. The BMS consists of more than 6000 physical I/O points and more than 2500 virtual points. The systems controlled by the BMS include heating, cooling, VRV system, AHUs, hallway lighting, the status of all equipment in distribution cabinets, power meters, UPSs, etc. All data is collected and stored onto a supervisory PC, where TAC Vista SCADA software is installed. The only equipment that is not incorporated in the BMS, yet needs to be monitored, are calorimeters for heating and sanitary hot water.

The modern concept and the state-of-the-art equipment installed allow maximum comfort and working conditions for all employees. Likewise, the modern concept and the realization of the entire system create conditions that increase energy efficiency and reduce operating costs by using the advanced solutions in the framework of the supervisory and control system in the UC.

According to the source of energy, the most utilized is the electric power, which is consumed for air conditioning, compressed air, and lighting. Thermal energy is used for space heating in winter and for the preparation of hot water.

The first step in increasing the energy efficiency was related to the continuous monitoring and recording of consumption. The next step was to analyze the energy consumption and find critical areas of consumption. The final step was related to preparing plans and algorithms for the energy reduction.

To this goal, the energy consumption in the period March 2014 - February 2015 was measured and recorded. The analysis was conducted and, parallel, corrective measures and actions to reduce energy consumption were introduced. The expert system based on the methods of computational intelligence that combines all the developed measures and algorithms for increasing energy efficiency in one unit was implemented. The implemented system was verified in the period March 2015 - February 2016.

2. The problem definition

UC is the first medical institution in Serbia which is fully computerized and uses a contemporary supervisory, control and data acquisition system (SCADA) [1, 2]. It is an energy efficient building. The annual energy consumption is 332 kWh/m2. Primary energy source for heating is district heating and for cooling chillers are used. There are solar panels for hot water heating (e.g. solar panels for sanitary hot water provide 36% of the total sanitary hot water demands).

The building is equipped with a modern BMS that integrates the following subsystems: 7 heating, ventilating and air conditioning (HVAC) systems (air-conditioning chamber); 2 chillers; 2 heat pumps; 8 electric power substations; Diesel Generator Set block; 5 uninterruptible power supply systems (UPS); ventilation for the operating rooms; monitoring of consumption and power quality; supervision of elevators; variable refrigerant volume (VRV) systems; external and internal lighting, and others.

The power consumption is measured all the time on several different points using power meters and calorimeters. The central system automatically regulates power consumption in rooms that are not occupied.

Nevertheless, in this well-designed and implemented system, there exists a space for energy efficiency improvement, which is an imperative issue today [3-6]. To achieve this goal, the implementation of optimization algorithms based on artificial intelligence, often used in solving many engineering problems [7-9], has been envisaged. Continuous measurement and data acquisition create a database, necessary for the implementation and the analysis of the impact of implemented solutions. The collected data was used for designing supervisory and control algorithms for the following tasks:

- Optimization of the settled temperatures by zones in the building [10-14];
- Optimization of the output temperature of the cooling fluid in the chillers [15-17];
- Optimization of the concentration of CO2 in the air conditioning system [17-19];
- Prediction and selection of a more efficient type of heating dependent on the weather forecasts for the coming days;
- Reduction of peak electricity consumption [7, 20].

The basic solutions for some of the previous problems are provided in [10]. The aforementioned solutions provide high-quality control, though they also leave space for their improvement through the artificial intelligence (AI) based expert system (ES). During the design of the expert system, particular attention was attributed to the influence of the Sun on the building energy consumption, which is a critical and an important issue in the optimization of the HVAC system functioning [17, 21]. According to that, the accurate modeling of building and modeling of the Sun impact [22-25], are the most important steps in the optimization procedure [26-28]. The modeling of natural phenomena, physical systems, and their behavior is the first and the fundamental step in defining control algorithms, which are currently more and more based on AI [8] and information communication technologies (ICT) [28-30].

3. The expert system design

For the full realization of all optimization algorithms, the following elements were added to the existing supervisory and control system: presence sensors, magnetic contacts on the windows, dead band for heating/cooling, CO2 control, timers, time schedules, curtains, heat curve and heat recovery [9].

Regarding the entire system level, ES implements the optimization method. Based on the outside temperature, the implementation method sets the desired value of the heaters/boilers fluid output temperature, which is a constant (maximal) in today's heating systems. The primary source of energy for heating is the municipal heating plant. However, since the facility also has two heat pumps as an alternative, choosing a heat source in a transition period is in accordance with the heating requirements of the building related to the average outdoor temperature in order to generate savings. An important method of saving energy is the heat recovery. The air returning from the room is not let out; rather, it is used for heating/cooling the outside air entering the room.

Communication between the central SCADA developed ES software and the simulation model drawn up in the Energy Plus tool [30] is achieved using ASCII files.

The integration of ES with the BMS system requires a comprehensive and continuous monitoring of the behavior and performance of the system.

During the analysis and selection of energy efficient methods, it is necessary for the user to enter several parameters. First, one needs to choose the type of the room. The software supports the following types of rooms: single, double and multiple bedded hospital rooms, reception, waiting rooms, halls, restaurants, rooms for staff, offices, toilets, rooms for diagnosis and therapy, operating rooms, rooms for giving birth, intensive care units, laboratory, pharmacy, autopsy rooms, technical rooms, and so on.

Then, one has to select the types of windows, interior and exterior walls, doors, floors, and ceilings. Finally, it is necessary to choose the ratio of the number of days when the space heating and cooling is required. Based on the geographic location and climatic conditions, the preset values for the desired day and night temperatures for heating and cooling are already entered in the ES, together with the humidity set point.

The data collected via the existing UC's BMS (outside temperature, the return temperature of the cooling fluid, the temperature of the cooling fluid at the chiller's output and the status of each chiller's compressor) were necessary to obtain a reliable and representative chiller's model based on the artificial neural network (ANN). A genetic algorithm (GA) was used to determine the optimal outlet temperature of the cooling fluid depending on the feedback and external temperature. This directly determines the optimum number of active compressors in the chiller.

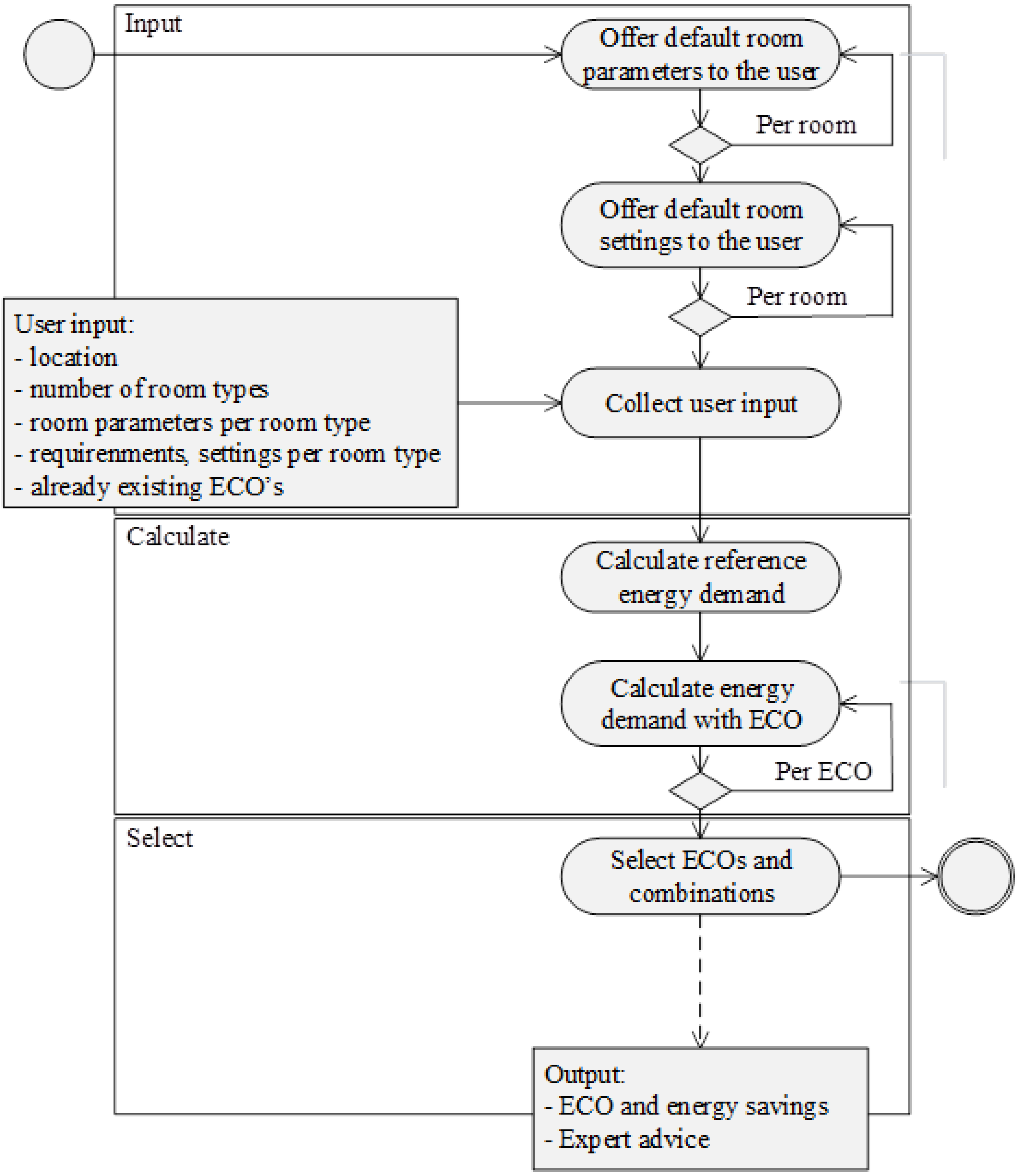

Figure 1. The algorithm for the optimization of the building with pre-defined temperature zones

In addition, GA controls the injection of fresh air into the system. The amount of fresh air injected depends on the concentration of CO2 in the rooms and requests for their ventilation. The goal of the optimization algorithm is that the CO2 concentration is maintained within tolerable limits with the minimum fresh air injection in the system.

Furthermore, a new optimization algorithm based on the use of solar radiation for increasing energy savings [22-25] was developed and implemented. Solar radiation provides a solar gain. Based on the clearly defined model of the clear and cloudy day, the optimization algorithm calculates the optimal positioning of the blinds on the windows, so a room uses the maximum natural light. In this way, it is possible to optimize the use of artificial lighting and select the number and type of light bulbs in order to achive the desired brightness of the desktop. Artificial light management is based on fuzzy logic, which also considers the heat gain of the solar radiation and recommends the blinds to be completely closed in the high outside temperatures to avoid the increased power consumption for the operation of the cooling system.

Figure 1 presents the algorithm for the zoned space optimal temperature control. “ECO” in the illustration refers to the current or pre-defined operating regime for the HVAC system.

4. Results

On completing the set consumption monitoring and the insight into all available information related to the behavior and usage in the facility, high consumption in some periods could not be explained.

However, following the daily changes in the usage of electricity and hot water, a few following examples of irrational behavior were detected:

1. Power consumption at night was lower, but not significantly lower than during the day;
2. Efficiency of heat recovery was very low or even negative in certain periods;
3. Set points of air conditioning chambers have deviated from the optimal value.

Accordingly, the following improvements were made:

1. A schedule for the ventilation system which implies turning off the fans at night (for 8 h, some of them even more) was created, which led to a reduction in electrical power consumption;
2. New heat exchanger replaced the defective one;
3. An optimization algorithm for zones with preset temperature was improved. This ensured the optimal demands for the air conditioning chamber, which resulted in a significant reduction in the consumption of electricity (during summer) and hot water (during winter).

The realized system was set into exploitation at the beginning of 2015. The further text demonstrates and describes the results. Table 1 depicts the monthly energy consumption during one year before and after introducing ES. Overall saving is 162,516MWh/year, or 5.9%. Figure 2 presents the total energy consumption per month. The graph demonstrates that the total energy demand is lower after introducing ES in the UC.

Table 1. Total energy consumption

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	**Total**
2014/15 [MWh]	233.3	197.3	165.8	170.2	210.4	221.4	167.7	181.4	248.3	320.4	340.2	317.1	2,773.7
2015/16 [MWh]	221.4	186.6	150.0	166.2	191.2	200.7	159.7	169.0	239.6	312.3	328.4	285.3	2,611.2
Avg/day 2014/15 [MWh]	7.5	6.6	5.3	5.7	6.8	7.1	5.6	5.9	8.3	10.3	11.0	10.2	
Avg/day 2015/16 [MWh]	7.1	6.2	4.8	5.5	6.2	6.5	5.3	5.5	8.0	10.1	10.6	9.2	
Saving/day[MWh]	0.4	0.4	0.5	0.2	0.6	0.6	0.3	0.4	0.3	0.2	0.4	1.0	
Saving [MWh]													162.5
Saving [%]													5.9

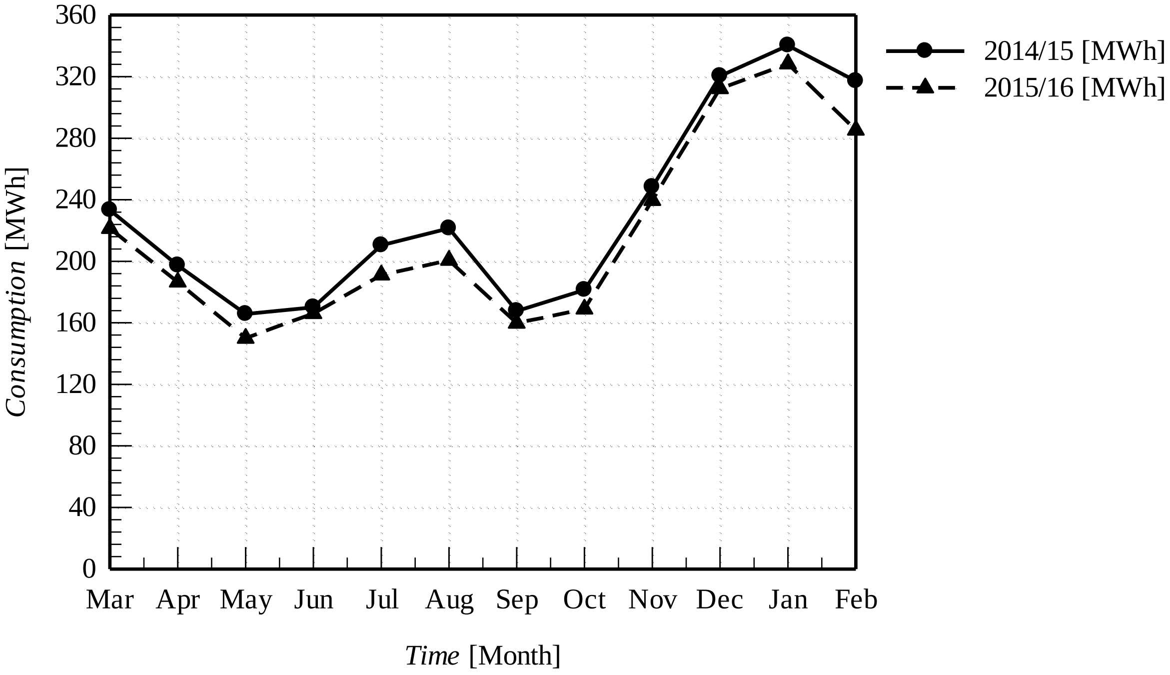

Figure 2. Total energy consumption per month

When the hot water is under consideration, Table 2 and Figure 3 depict the results. It can be observed that there is a connection between the date consumption and outside temperature, which is inversely proportional to temperature changes. Consumption of the hot water is directly dependent on weather conditions. During the winter months, hot water is used in the heating system. Likewise, this can be related to the fact that the consumption of hot water for heating during the summer months is zero. On the other hand, the sanitary hot water is used throughout the year. Its consumption is also directly connected to the ambient temperature, but not as much as heating water. Both sanitary and heating water are in inverse proportion to outside temperature.

Table 2. Energy consumption for water heating

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	**Total**
2014/15 [MWh]	90.6	51.3	4.1	3.6	2.7	1.3	6.1	28.6	97.9	162.3	185.6	162.8	796.9
2015/16 [MWh]	80.1	42.6	4.0	3.6	2.7	1.3	6.0	21.4	96.2	155.7	172.4	149.3	735.3
Saving [MWh]	10.5	8.7	0.1	0.0	0.0	0.0	0.1	7.2	1.7	6.6	13.2	13.5	
Avg.tmp. 2015/16 [ºC]	10.2	12.7	16.4	20.7	22.3	21.8	17.7	13.6	9.2	3.8	3.1	3.4	
Avg.hum. 2015/16 [%]	74.1	80.0	78.9	73.3	78.9	77.6	85.0	82.8	84.8	86.3	82.1	78.8	
Saving [MWh]													61.6
Saving [%]													7.7

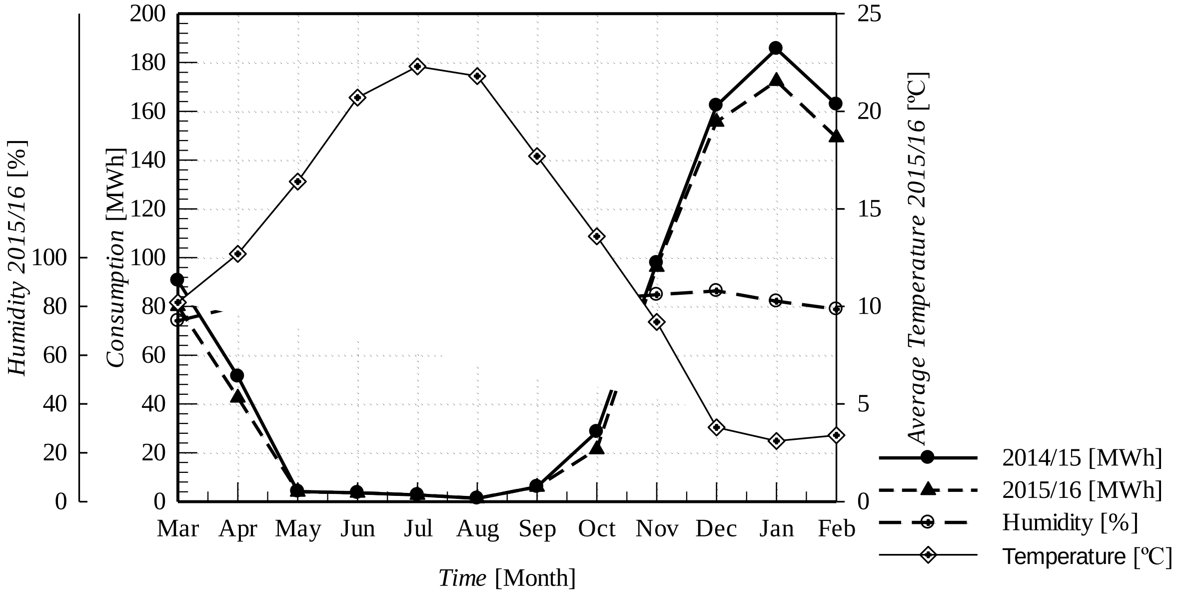

Figure 3. Energy consumption for water heating per month

Table 3 and Figure 4 present the participation of hot water in overall energy consumption. In winter months, hot water production is near or over 50% of spending; on the other hand, in summer time it is neglectable. It can also be observed that, during the period May-September, only sanitary water is spent and in the overall consumption, its portion is very small.

Table 3. Energy consumption for water heating

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
2014/15 [%]	38.8	26.0	2.5	2.1	1.3	0.6	3.6	15.8	39.4	50.7	54.6	51.3
2015/16 [%]	36.2	22.8	2.7	2.2	1.4	0.6	3.8	12.7	40.2	49.9	52.5	52.3
For heating [%]	89.5	82.5	0.0	0.0	0.0	0.0	0.0	70.6	90.4	92.8	93.5	90.8
Sanitary [%]	10.5	17.5	100.0	100.0	100.0	100.0	100.0	29.4	9.6	7.2	6.5	9.2

Table 4 and Figure 5 present a comparison between electric power consumption and the values of the outside temperature. Low outside temperature in the heating season does not significantly affect energy consumption. However, in the summer, due to the increased labor of the cooling system, power consumption is increased and can be said to be directly proportional to temperature.

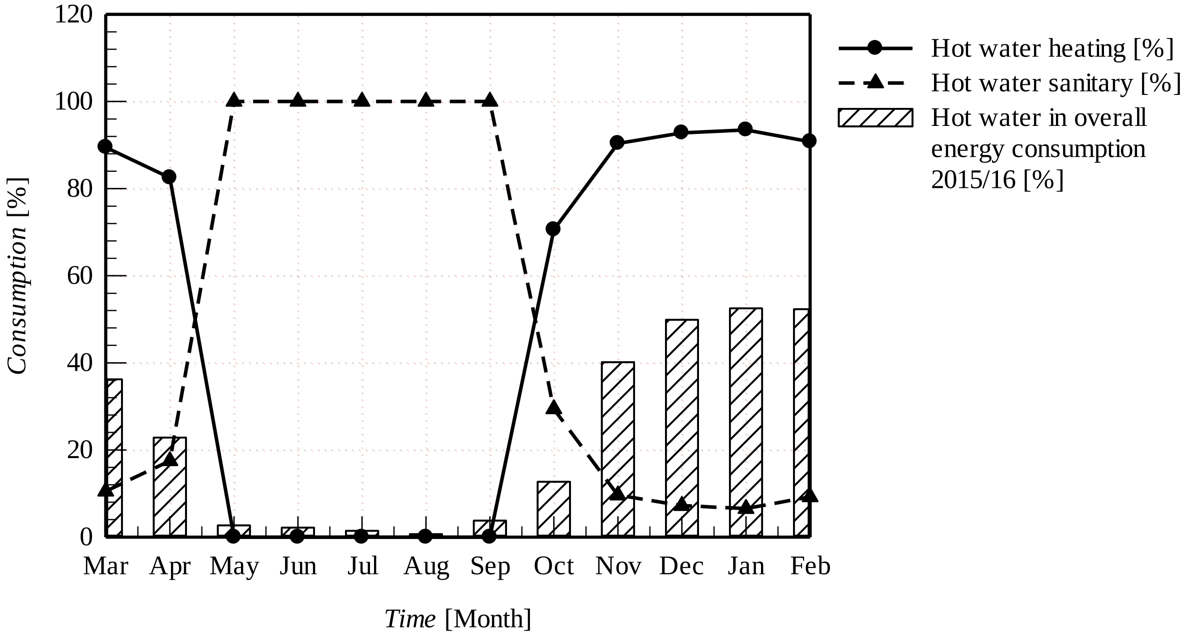

Figure 4. Hot water in overall energy consumption per month

Table 4. Electrical energy consumption

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	**Total**
2014/15 [MWh]	142.7	146.0	161.7	166.6	207.7	220.1	161.6	152.8	150.4	158.1	154.6	154.3	1.976.1
2015/16 [MWh]	141.3	144.0	146.0	162.6	188.5	199.4	153.7	147.6	143.4	156.6	156.0	136.0	1.875.2
Avg/day 2014/15 [MWh]	4.6	4.9	5.2	5.6	6.7	7.1	5.4	4.9	5.0	5.1	5.0	5.5	
Avg/day 2015/16 [MWh]	4.6	4.8	4.7	5.4	6.1	6.4	5.1	4.8	4.8	5.1	5.0	4.7	
Saving/day[MWh]	0.0	0.1	0.5	0.1	0.6	0.7	0.3	0.2	0.2	0.0	0.0	0.8	
Saving [MWh]													100.9
Saving [%]													5.1

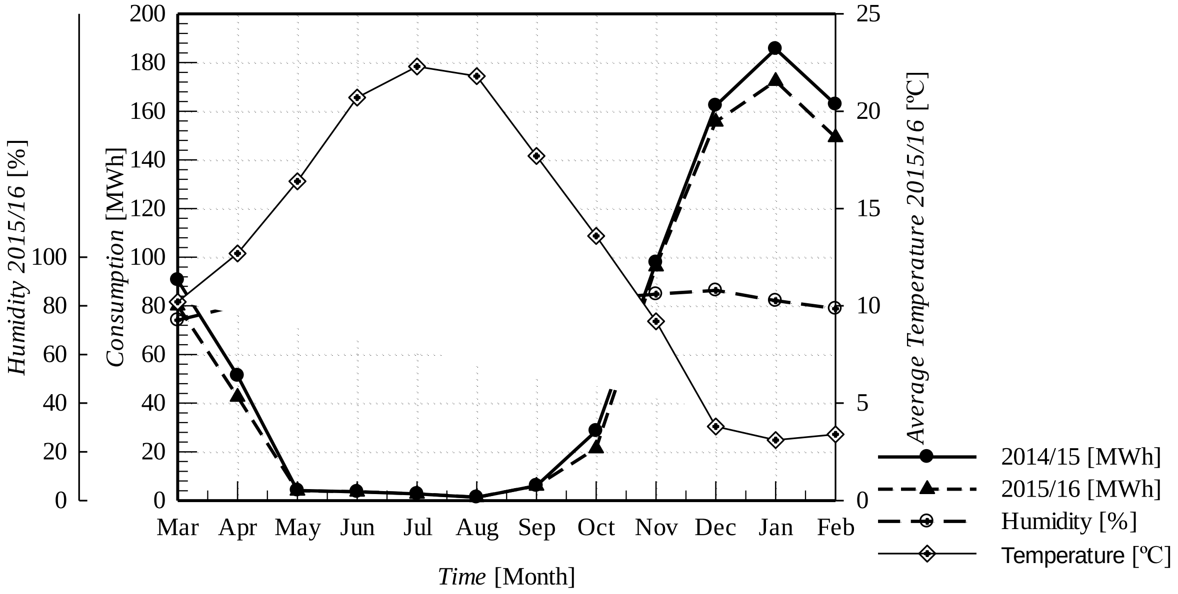

Figure 5. Electrical energy consumption per month

Finally, Table 5 and Figure 6 present the direct effects of the introduced ES. The overall energy consumption is reduced by 5.9%, which is realized through the reduction of electric power consumption by 5.1% and hot water reduction for 7.7%. All savings were obtained using only software modifications of the existing SCADA system without significant investment costs. Software changes were not free, but they were far below the generated savings. Only costs were related to additional sensors and transmitters; however, it was neglectable according to the price of the whole system. The change of the defective heat exchanger had its price, but the failure on it was detected using an expert system.

Table 5. Annual energy consumption before and after the expert system introduction

	Before expert system [MWh]	After expert system [MWh]	Consumption reduction per year [MWh]	Consumption reduction per year [%]
Electric energy	1,976.570	1,875.689	100.881	5.1
Hot water	796.923	735.288	61.635	7.7
Overall energy	2,773.493	2,610.977	162.516	5.9

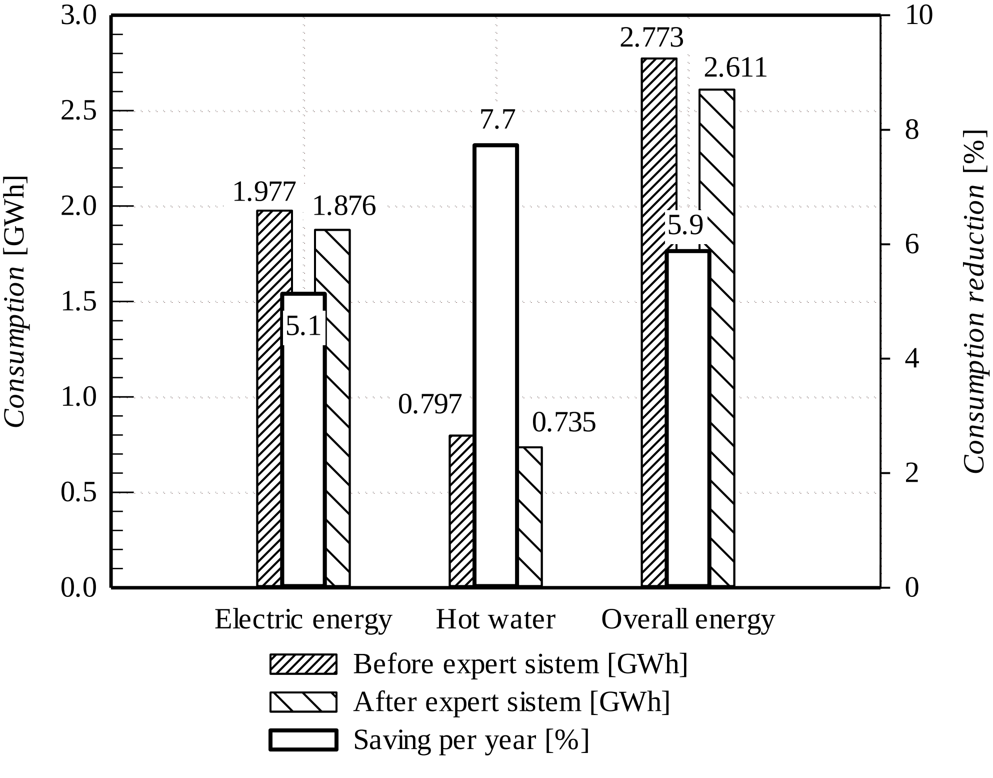

Figure 6. Annual energy consumption before and after the expert system introduction

5. Conclusion

This paper describes the effects of introducing the improved energy management system in the urgent care center of the clinical center of Vojvodina. This improvement in an expert system is based on artificial intelligence techniques. The central system automatically regulates power consumption in rooms that are not occupied. The algorithm for the zoned space optimal temperature control "ECO" was implemented into the expert system. All energy savings were obtained using only software modifications of the existing SCADA system.

The result of using such a system was an overall reduction in electricity consumption from 1,976,570kWH/year to 1,875,689kWh/year and a decrease in energy consumption for water heating from 796,923kWh/year to 735,288kWh/year.

The realized savings in electricity consumption of 5.1% and in the hot water consumption of 7.7% demonstrate the correctness of the proposed approach to solving the problems of energy efficiency and justifying the introduction of the control algorithms based on computational intelligence methods in the energy flow control systems in the urgent care center of Vojvodina.

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