Application of Control Automation and Energy Management Programs in the Energy Audit of the Company

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Abstract

The Energy Efficiency Act and the resulting notice of the Minister of Energy of 23 November 2016. "on a detailed list of energy efficiency improvement projects predicts "installation of measuring and control equipment, teletransmission equipment and automation in the implementation of energy management systems" as one of the methods of improving energy efficiency. Using specific examples of energy audits carried out by the author, this article demonstrates how such a solution can improve energy efficiency in the buildings of companies from various industries and what conditions must be met by such a system in order to operate efficiently.

Keywords: *energy efficiency, energy auditing, energy management programs*

Introduction

The Energy Efficiency Act of 20.05.2016 [5] imposes an obligation for large companies to carry out an energy audit once every 4 years. Since this obligation was first required from 30.09.2017, companies should perform the audit again next year. Experience from previous audits shows that auditors most often recommended to companies basic upgrades, such as: thermomodernization of buildings (e.g. office buildings, factory halls), replacement of lighting with LED, replacement of district heating or heat sources, use of RES (e.g. photovoltaics). In the current audit period, there are two possible cases:

1. If a company has implemented the recommendations, new, energy-efficient and economically justified methods of saving energy should be identified.

2. If the recommendations have not been implemented, it is worth taking a second look at them and take into account further factors that will lead to the proposed actions leading to the most optimal use of energy in the new audit.

Energy savings in buildings

Let's start by considering how one can reduce energy consumption in buildings. Many companies have buildings: offices, production, service, warehouses, stores. There are also, hotels, holiday homes, etc. The essential condition is that the building is large, with a large area and volume and, consequently, a sufficiently high energy consumption for heating, cooling, lighting. Applying these recommendations to a small building such as a gatehouse, a small shop or a detached house would not produce the expected results.

Application of weather-based regulation

Weather-based regulation of a heat source e.g. gas boiler, heat pump or heat node is well known, although seldom used. An obvious advantage is the ability to set the temperature of the heating circuit to the current outside temperature. The first benefit of this approach is to reduce overheating of rooms due to the use of too much heating power. For example, if the controller detects an increase in the outside temperature, it will begin to reduce the heating power. This saves energy while maintaining full thermal comfort. Otherwise, overheating the room as a result of not accounting for the increase in the outside temperature will cause, in addition to increasing energy consumption, discomfort to the user of the overheated room. Another important advantage of this method is that users can pay less attention to the heating, and it is very important. Adjusting the heating curve to your current needs allows the heating device to run longer at lower inlet and return temperatures of the space heating installation. In the case of heat pumps, working with a lower supply temperature increases the COP of the heat pump and thus reduces the consumption of electricity or gas (in the case of gas-powered heat pumps) to provide the same amount of heat. Table 1 shows the differences:

As you can see from the examples cited in the table, skilful control of the heat pump can produce savings of several percent energy. A similar example for more commonly used (than heat pumps) condensing gas boilers is given in Table 2.

Improving efficiency by a few percent may seem insignificant compared to Table 1 data, but for large energy values produced during the heating season, an improvement by a few percent can mean big savings in both energy and its cost. However, it is worth noting here that most weather controllers produced and sold with heating devices operate on the principle of fixed heating curve settings usually introduced by the service installing another heating device e.g. boiler. Installation companies usually set high heating parameters, because then they have no problems with the complaint that the device does not heat up.

The efficiency of the heating device is reduced, because by implementing such a poorly selected heating curve, the controller quickly forces the heating device to obtain high temperatures outside the range of optimal efficiency. It is rare for a user who engages in self-selected parameters of the heating curve. This is not easy, as it also depends on a few factors such as the thermal capacity of the building, internal and so-

Tab. 1. Efficiency of heat pumps according to the Regulation[3]
Tab. 1. Sprawność pomp ciepła zgodnie z rozporządzeniem [3]

Type of heat pump	COP		Efficiency improvement
	55/45°C	35/28°C	%
glycol/water heat pump type, compressor, electrically powered	3,5	4,0	14,3
air/water, compressor, electrically powered	2,6	3,0	15,4
glycol/water, absorption , gas-powered	1,4	1,6	14,3
air/water, absorption, gas-powered	1,3	1,4	7,7

Tab. 2. Average efficiency of condensing gas boilers according to the Regulation [3]
Tab. 2. Średnia sprawność gazowych kotłów kondensacyjnych zgodnie z rozporządzeniem [3]

Condensing gas boiler power	Efficiency		Efficiency improvement
kW	70/55°C	55/45°C	%
less then50	0,9	0,9	3,3
from 50 upto120	0,9	1,0	3,3
from 120 upto 1200	0,95	0,98	3,2

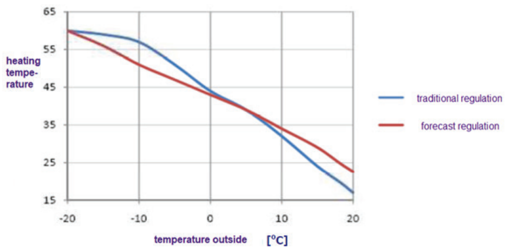

Fig. 1. Comparison of traditional and forecast adjustment [6]
Rys. 1. Porównanie korekty tradycyjnej i prognozy [6]

lar profits. Therefore, this often needs to be corrected several times before optimal operating parameters are set. However, since most users do not do this, one of the energy audit recommendations that can be implemented without investment costs is to adjust the weather controller settings.

Implementing of forecast regulation

Forecast regulation is a method of regulating heating more efficiently than the previously described weather regulation. Additional savings are achieved by predicting weather changes based on its 5-day forecast. This allows one to better adjust the heating level to weather changes. At the same time, so-called climate regulators are installed in the building, whose task is to record changes in temperature and humidity in heated rooms. This makes it possible to estimate some of the building's parameters, such as thermal capacity and take it into account in further calculations of the amount of energy and heating power required by the building. An example of such a solution is E-Gain.

Savings are achieved both during the period when the outside temperature rises and when it decreases. During the period of increase in external temperature, the heat demand of the building decreases. The weather controller will only react once the change has been recorded by the weather controller. By having this information, the forecast controller can limit the heating in advance so that, using the thermal capacity of the building, the temperature of the heated rooms is kept constant. As a result, the weather controller will first lead to a slight overheating of the room, and then significantly and quickly reduce the heating when a change is detected. The forecast controller will smoothly and slowly reduce the temperature of the heating circuit, having a longer time to change parameters (the forecast is ahead of the measurement data from the temperature sensor). In the case of condensing gas boilers and heat pumps, this control will allow them to work in conditions close to optimal conditions and thus increase their efficiency.

When the outside temperature drops, the mechanism is similar. The weather controller will react when the outdoor temperature sensor is changed. If it cools down rapidly to prevent the building from cooling down quickly, the controller will raise the inlet temperature of the space heating installation. This in turn, will ensure that the efficiency parameters of condensing gas boilers and heat pumps are again outside the optimal range. The forecast regulation will result in the possibility of early accumulation of energy, using the thermal capacity of the building (and energy in the space heating buffer, if any) and thus, will again last longer the possibility of operation of condensing gas boilers and heat pumps under conditions of optimal efficiency.

Examples of practical implementations of the aforementioned mechanism presented at [8] show that the actual measured reductions in energy consumption through the use of forecast regulation ranged from 10% to around 17% of previous energy consumption. The practice of the author of energy audits of buildings and enterprises shows that the use of heating control automation based on forecast regulation is an action that bring short payback times.

Example: An office building in Warsaw consisting of 8 storeys above ground and 1 underground is powered by urban

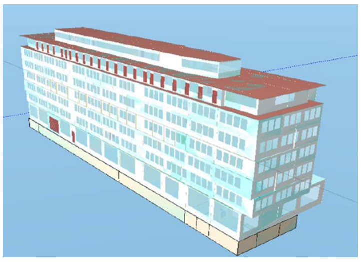

Fig. 2. Office building in Warsaw
Rys. 2. Budynek biurowy w Warszawie

Tab. 3. Examples of calculations of options for upgrading space heating installations including forecast regulation and precise indoor temperature control
Tab. 3. Przykłady obliczeń opcji modernizacji instalacji ogrzewania pomieszczeń, w tym regulacji prognozowanej i precyzyjnej regulacji temperatury wewnętrznej

Pos.	Type of improvement	Efficiency factors							
		Existing state	New variant						
			W1	W2	W3	W4	W5	W6	W7
1	heat generation	$\eta_{H,g}$ = 0,99	0,99	0,99	0,99	0,99	0,99	0,99	0,99
2	heat transmission	$\eta_{H,d}$ = 0,90	0,90	0,90	0,90	0,95	0,91	0,95	0,91
3	regulation and use of heat	$\eta_{H,e}$ = 0,88	0,88	0,93	0,89	0,93	0,89	0,93	0,89
4	heat accumulation	$\eta_{H,s}$ = 1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
5	total efficiency of the system	$\eta_{H,tot}$ = 0,78	0,78	0,83	0,79	0,87	0,80	0,87	0,80
6	taking into account heating breaks during the week	w_t = 1,00	1,00	0,93	0,93	0,93	0,93	0,93	0,93
7	taking into account the heating breaks during the day	w_d = 1,00	1,00	0,95	0,95	0,95	0,95	0,95	0,95

Evaluation of the proposed project

Pos.	Description	jedn.	Existing state	New variant						
				W1	W2	W3	W4	W5	W6	W7
1	Total efficiency of the heating system η_{tot}	-	0,78	0,78	0,83	0,79	0,87	0,80	0,87	0,80
2	taking into account heating breaks during the week w_t	-	1,00	1,00	0,93	0,93	0,93	0,93	0,93	0,93
3	taking into account the heating breaks during the day w_d	-	1,00	1,00	0,95	0,95	0,95	0,95	0,95	0,95
4	Cost savings	Plz/rok		2 151,95	23 030,97	16 172,55	29 258,72	17 951,46	29 258,72	17 951,46
5	Cost of the project N_H	PLz		12 201,00	945 324,78	220 701,49	3 359 887,34	453 390,29	3 342 601,37	451 724,46
6	SPBT	years		5,7	41,0	13,6	114,8	25,3	114,2	25,2

network heat. Building area is 6,915.0 m2, volume – 30,942.0 m3. Heat demand is approx. 0.9 MW and the energy demand for heating in heating season is 3,244.6 GJ.

Analysis of options for modernization of the heating system shows that in this operation the shortest return time gives the preservation of the existing heat node, while using forecast automation of the control of the work of thespace heating installation. The following table shows the variant W1, demonstrating a simple return on investment of 5.1 years:

The aforementioned Regulation (Rozporządzenie Ministra Infrastruktury i Rozwoju z dnia 27 lutego 2015 w sprawie metodologii wyznaczania charakterystyki energetycznej budynku lub części budynku oraz świadectw charakterystyki energetycznej) shows the effect of the way in which indoor temperatures are regulated on the efficiency of heating regulation:

The efficiency values shown Table 4 refer to the most popular water heating system.

Energy management program referring the space heating

Maximum efficiency of using internal heat sources

By using the right algorithms and obtaining data from multiple sources, the energy management program can combine the advantages of forecast regulation and precise regulation of room temperature to achieve maximum savings. An important feature of the enterprise's energy management program is access to extensive data from different areas of the company's operations at the same time, allowing for further savings.

Normally programs calculating the space heat of buildings assume average value of internal heat sources. Adaptive controllers with a proportional-integrating calculators operate in the similar way. Therefore, such solutions work well in large buildings whose internal profits do not appear to be subject to significant fluctuations. Such buildings can be exemplified by houses in multiple occupancy, schools during their working periods, nursing homes, offices etc. Even in buildings such as schools or offices the level of internal profits is subject to daily fluctuations. However, the working hours of a school or office are set and can be easily taken into account to create a suitable hourly and weekly schedule.

This method will not work in the case of e.g. production buildings where internal profits from production facilities can make a significant contribution to covering the losses of ventilation heat and through building partitions. At the same time, due to the variable load on the production plant, and since each part of the production cycle requires the involvement of a different energy, the value can vary considerably.

The author performed energy audits in companies where the share of internal profits was at 50%, or even close to 100% of the thermal losses of the building. Each reduction in the level of production significantly affected the demand for power for heating the building. In this case, setting the heating power parameters based only on the outside temperature will not work. This will cause the heating equipment to work frequently for short periods of time, but with too much power, losing the efficiency opportunities shown in Tables 1 and 2.

Some heating devices have adaptive controllers, which eliminates the problem, because the controllers "learn" the parameters of the building e.g. thermal capacity, on the basis of conversion, what temperature increases were achieved in previous periods, at a given outside temperature. This allows

Tab. 4. Improvement of efficiency due to precise adjustment of the installation of space heating [3]
Tab. 4. Poprawa wydajności dzięki precyzyjnej regulacji instalacji ogrzewania pomieszczeń [3]

Water heating with member or plate heaters in case of adjustment	Regulatory efficiency	Efficiency improvement %
Central without automatic local adjustment	0,77	0
Automatic local	0,82	6,49
Central and local with thermostatic valve with proportional action with proportional range P - 2K	0,88	14,29
Central and local with proportional and integrating valve with proportional action with proportional range P - 1K central and local with pi proportional-integrating valve with adaptive and optimization functions	0,89	15,58
Central and local with PI proportional-integrating valve with adaptive and optimization functions	0,93	20,78

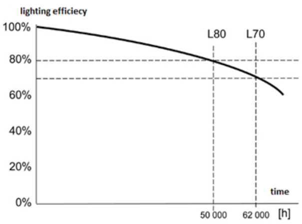

Fig. 3. Decrease in LED performance during operation [9]
Rys.3. Spadek wydajności diod LED podczas pracy [9]

the user to be relieved of the need to adjust the heating curve and works well in buildings with stable parameters mentioned earlier. In production buildings, calculating the average of previous periods does not always work, because current production may increase or fall significantly, as had happened during the pandemic.

In production buildings, only a well-configured energy management system, which has power readings of the currently operating equipment in the building, and not only the outside temperature, will allow for the correct selection of heating power and thus the inlet temperature to the space heating system. So as not to lose thermal comfort, ensure the longest possible operation of heating equipment in optimal thermal efficiency parameters.

The power management program, by knowing how many devices work on production and at what power, can know the level of internal profits immediately after turning them on. This information allows it to react before the heat from the production machines starts to be felt, as in the case of forecast regulation, the regulator is prepared for conditions that are yet to occur. This will allow one to increase the heating capacity with a decrease in the power currently used in production and a decrease when this power increases. The adaptive heating controller does not have this information and will only react to the change in room temperature when it is noticeable. Thanks to this, the energy management program will be better able to use the possibilities of improving the efficiency of heating devices than with the above-described control systems depending on the inlet temperature to the space heating system presented in Tables 1 and 2.

Lighting control

In most of the cases under consideration, the modernisation of lighting amounts to the replacement of luminaires or light sources with LEDs. On the other hand, Regulation [2] (in paragraph 3(1) requires "indication of the technically acceptable and economically justified types and variants of the energy efficiency improvement project, taking into account the use of different technologies". One of the alternative solutions for the use of LED luminaires is the selection of LED light sources, but with the possibility of controlling the light intensity e.g. by regulating the current flowing through the light source and applying automatic lighting regulation in the energy management program.

In order to be able to dynamically control the lighting level, light level sensors must be installed at the workstations and combined with an energy management programme which can dynamically adjust the level of the artificial light flux according to the amount of natural light in order to maintain the required level of illumination but limit its overrun. The energy management program also eliminates energy losses due to aging of the light source. Typically, new luminaires have a higher light flue within the range of light than is required to ensure the right level of illumination, as the efficiency of light emission decreases over many years of operation and the lighting must meet the standards throughout its working life. This is illustrated by the chart below. Limiting the power of the luminaires so that the light flue is at the required level, and no more will save energy during most of the time from the expected service life.

If the decrease in efficiency of up to 80% is taken as the lifetime (graph is 50,000h), it means that to ensure that the standard is met throughout its life, a light source must be chosen so that 80% of its effectiveness is sufficient for this purpose. The consequence of this, in turn, is the fact that most of the working time the source gives a higher beam of light than is required. It can therefore be reduced to the level of the norm, thereby reducing its power, and thus saving energy. An additional condition is the use of light sources, the intensity of which can be adjusted. Such solutions occur among LED light sources, but this must be taken into account when buying.

Savings can be estimated from standard PN-EN 15193:2010P: "Energy performance of buildings – Energy requirements for lighting. The standard contains an array in

Tab. 6. Maximum values of electricity consumption indicators for lighting (according to PN-EN 15193:2010P)[10]
Tab. 6. Spadek wydajności diod LED podczas pracy [9]

Comparative values and criteria for the design of lighting in buildings								
Type of building	lighting level	Pem [kWh/m2·rok]	Ppc [kWh/m2·rok]	PN [W/m2]	No cte illuminance		With cte illuminance	
					LENI	LENI	LENI	LENI
					Limit value		Limit value	
					Manual	Auto	Manual	Auto
					[kWh/m2×rok]		[kWh/m2×rok]	
office	*	1	5	15	42,1	35,3	38,3	32,2
	**	1	5	20	54,6	45,5	49,6	41,4
	***	1	5	25	67,1	55,8	60,8	50,6
school	*	1	5	15	34,9	27,0	31,9	24,8
	**	1	5	20	44,9	34,4	40,9	31,4
	***	1	5	25	54,9	41,8	49,9	38,1
hospital	*	1	5	15	70,6	55,9	63,9	50,7
	**	1	5	25	115,6	91,1	104,4	82,3
	***	1	5	35	160,6	126,3	144,9	114,0

Tab. 7. Return time of lighting upgrades in two variants
Tab. 7. Czas zwrotu ulepszeń oświetlenia w dwóch wariantach

Pos.	Description	Units	Existing sate	Variant 1	Variant 2
1.	Unit power of primary lighting fixtures in building P_N	W/m^2	5,63	2,32	2,32
2.	Time of use of primary lighting during the day t_D	h	4 468	4 468	4 468
3.	Time of use of primary lighting during the night t_N	h	1 372	1 372	1 372
4.	Factor that takes into account the reduction in illuminance to the level required F_c	----	1,00	1,00	0,93
5.	Factor taking into account the absence of users in the workplace F_o	----	1,00	1,00	0,80
6.	Współczynnik uwzględniający wykorzystanie światła dziennego F_D	-----	1,0	1,0	0,80
7.	Leni numerical light energy indicator LENI	kWh/m^2*year	32,9	13,6	8,6
8.	Annual demand for final energy supplied to the building for the built-in lighting system $Q_{kL} = A_f \cdot$ LENI	kWh/year	139 178,9	57 465,6	36 213,0
9.	Annual final energy savings after ΔQ_{kL} lighting system upgrade	kWh/year		81 713,3	102 965,9
10.	Cunit Unit Electricity Charges C_{unit}	Plz/kWh	0,25154		
11.	Annual variable costs of electricity consumption for built-in lighting K	Plz/year	35 009,06	14 454,90	9 109,01
12.	Annual savings in electricity consumption costs for lighting Δ_{QK}	Plz/year		20 554,16	25 900,04
13.	Cost of upgrading the lighting system N_U	Plz		20 842,36	132 775,96
14.	Simple pay back time SPBT	years		1,0	5,1

which indicators are placed for the lighting of particular types of buildings"[10].

For example, for a good level of lighting in the office (in Table 3), using automation, one can reduce the LENI factor, i.e. the annual amount of kWh of energy per lighting 1 m² from 67.1 to 50.6 . This represents (67.1-50.6) 67.1 = 24.59%, or about a quarter of the additional electricity savings for lighting. There is no doubt that in the future, as electricity prices rise, systems using automation will become more common. Currently, due to the high cost of controlled LED and

Fig. 4. Principle of operation of the light-emitable tube [11]
Rys. 4. Zasada działania rurki emitującej światło [11]

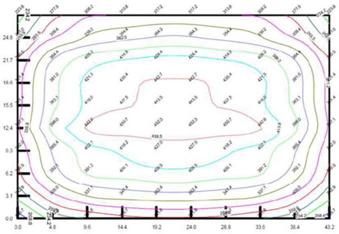

Fig. 5. Results of the simulation of the light intensity from light pipes in a sports hall[7]
Rys. 5. Wyniki symulacji natężenia światła światłowodów w hali sportowej [7]

the implementing elements of the energy management program, the payback times of such an investment are most often longer than standard solutions.

An example is show in Table 7:

Variant W1 is standard LED luminaires without control, W2- with the automatic control described above. Further increasing energy savings would combine automatic lighting adjustment technology with skylights or light pipes. Light pipes are a better option because, thanks to the lens at the top of the roof, concentrated solar radiation enters the tube. The high reflectivity allows one to transfer this light up to several meters, limiting losses to a minimum. At the same time, small dimensions in relation to the skylight reduce heat loss, as always the coefficient of heat transfer through the window or skylight is greater than through the ceiling insituated in accordance with the requirements of the Regulation.

An example of the use of light pipes in the hall is shown in the figure below. These are the results of simulation of the level of lighting of the hall in autumn-winter conditions. During the summer, the projected results will be about 2 times higher.

The introduction of solar energy into the lighting of the hall using light pipes is an example of the use of renewable energy, which is the sun. As you can see from the example, the use of solar energy to save electricity does not always have to be based on photovoltaics. However, maximum savings can only be achieved when we apply automatic lighting adjustment in the energy management program, as no attempt at manual adjustment can be just as effective with varying levels of sunlight.

Recapitulation

The use of an energy management program will allow for the best management of energy for heating. The solution proposed by the author to control the heating not only on the basis of the forecast method and reading of the regulators in the premises, but the pledging of information from production equipment to calculate internal profits in advance, will bring additional energy savings compared to the best systems currently in use. Real automatic control of heating, lighting is a guarantee of return on investment in the energy management program. This control also offers significant energy savings. Further in-depth analysis of energy consumption on the basis of data from the energy-managed programme can lead to further significant savings.

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Zastosowanie automatyki sterowania i programów do zarządzania energią w audycie energetycznym przedsiębiorstwa

Ustawa o efektywności energetycznej i wynikające z niej obwieszczenie Ministra Energii z dnia 23 listopada 2016 r. "w sprawie szczegółowego wykazu przedsięwzięć służących poprawie efektywności energetycznej" przewidują jako jedną z metod poprawy efektywności energetycznej „instalację urządzeń pomiarowo-kontrolnych, teletransmisyjnych oraz automatyki w ramach wdrażania systemów zarządzania energią" Artykuł przedstawia na konkretnych przykładach audytów energetycznych wykonanych przez autora, jak takie rozwiązanie może wpłynąć na poprawę efektywności energetycznej przedsiębiorstw różnych branż i jakie warunki musi spełnić taki system, by działać efektywnie.

Słowa kluczowe: *efektywność energetyczna , audyty energetyczne, programy do zarzadzania energią*