Krajowa Agencja Poszanowania Energii S.A.

Self-evaluation manual on energy consumption

for small and medium-sized enterprises

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THE NATIONAL ENERGY CONSERVATION AGENCY

Where are the potential energy savings?

Energy consumption monitoring

Minimising the energy consumption

European Union

Ministry of Climate and Environment

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Table of Contents

Introduction

For whom is this manual intended?

This manual is intended for small and medium-sized enterprises (SMEs) of all branches of economy - from food industry plants (dairy, meat plants, bakeries, craft breweries, etc.), textile manufacturing, services (cleaners, workshops, hairdressers, etc.) to companies that only have office spaces.

In this manual one can find an answer for the question why they should improve energy efficiency in their enterprise and how to do it. All selected methods are divided into technological and non-technological ones. Issues and corresponding actions presented in this manual are a guide on where to look for savings. It is also meant to encourage us to look closely at our enterprise, to implement improvements and as a result - receive measurable financial benefits. Some of these actions can be done on one's own; they are either low-cost or even cost-free. However, some of them require conducting **energy audit**, which shows and validates possible savings; it also delivers recommendations on profitable actions and indicates their payback period.

If one applies for funding from programmes dedicated to support energy efficiency improvements, conducting an **energy audit** is a necessity. Additionally, this manual is a help for the entrepreneur in determining how his enterprise fits in the context of **Industry 4.0**.

The main idea behind improving energy efficiency in an enterprise, or behind any other modernisation project, is based on a reliable pattern consisting of 5 primary actions, as presented on Fig. 1. Information necessary for completing each of these steps can be found in this manual.

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Fig. 1. Schematic diagram of modernization process.

This manual describes issues related to usage of heat and electrical energy. Here the user will find an array of technical suggestions and propositions for management, all of which have a measurable effect attributed. In some instances, those effects are presented in percentages and determine possible reduction of power consumption. However, when undertaking some of these modernisations is considered, the effect will not simply be a sum of the named percentage values. Each such instance is described in detail in this manual.

In which areas the energy may be saved?

Table 1 presents areas in which heat and electrical energy is used. In each of these areas there is a potential for energy consumption or cost reduction.

All enterprise activities can be divided into 3 groups:

1. providing the plant with utility (electrical energy, heat, natural gas, water),
2. direct production of material goods or services,
3. exploitation of ancillary and office equipment.

Table 1 Possibilities of reducing heat and electrical energy consumption for individual enterprise activities.

Area	Machines and appliances	Possible activities supporting efficiency
PRODUCTION	all drives, AC and DC motors (transporters, conveyor belts, presses, etc.)	replacing old ones (ten-year-old and older) for new, with better energy efficiency or for energy-saving ones; avoiding operating with small load, using reduced supply voltage for small load in machine tools with AC motors (reducing neutral gear start)
	All pumps – circulating, process, feeding, fuel, etc.	considering change of control method (most often for variable-speed control), proper selection for the system, improving sealing and/or bearings or exchange for new ones, optimising the number of pumps and means of their connection, improving supply conditions on the suction side
	blowing, exhaust and pneumatic conveying fans	considering change of control method (most often for variable-speed control), optimal selection, preventing compressor stall, optimising the number of operating fans
	compressed air systems	considering change of control method for one that includes frequency converter, eliminating leakages, reducing operating pressure, selecting adequate number of compressors, implementing master control system, utilising generated waste heat
	heaters	replacement, reasonable reduction of power, changing time of use
	electric furnaces	changing time of use, operating during periods with lower energy prices, improving thermal insulation
	machine tools	replacing motors for more efficient ones
	steam, hot water	improving or mending pipeline insulation, improving room insulation, recovering heat from condensate, recovering heat from production processes, regular servicing of steam traps, monitoring and optimising excess-air ratio in boilers
POWER SUPPLY	energy supplier	changing the energy supplier for one with better offer, considering installation of photovoltaic system
	ordered capacity	reasonable reduction of ordered capacity, if power consumption is relatively stable, even if incidentally exceeded

Area	Machines and appliances	Possible activities supporting efficiency
	power transformers	reducing energy loss by replacement of transformers, adjusting transformers to the load
	reactive power	reasonable improvement of power factor through compensation of the reactive power
	energy meters	possibility of monitoring energy consumption of respective areas or separate machines, owing to installation of sub-meters in the dedicated areas
	heating/cooling	improving facility insulation, using system heat/cold, application of cogeneration/trigeneration
ANCILLARY EQUIPMENT, OFFICE, OR HOUSEHOLD APPLIANCES	ventilation of rooms	optimising temperature on bigger areas in particular, utilising natural ventilation, heat recovery through recuperators
	room air conditioning	optimising temperature while continuously observing thermal comfort, eliminating simultaneous heating and cooling, application of “free cooling” method, division of the area for several smaller ones with separate control, application of curtains preventing windows from heating up from the sun
	heating	eliminating simultaneous heating and cooling, changing the source of heat, especially if it’s constantly used, improvement of thermal insulation
	lighting in hallways, offices, warehouses, parking lots, passageways	opting for energy-saving sources of light while keeping same light intensity and colour, switching off unnecessary sources, implementing motion sensors, exploiting natural light in an optimal way, using bright paints, cleaning walls and ceilings, cleaning light fittings
	cold stores and freezers	improving thermal insulation, keeping partitions airtight, using more efficient refrigeration units, keeping heat exchangers clean, avoiding opening refrigeration equipment unnecessarily
	vertical and horizontal transportation	optimal utilisation, elimination of futile transportation, replacing drives for more efficient ones, improving conditions for storing goods with different temperature than ambient temperature
	office equipment - fax machines, microwave ovens, kettles, washing machines, computers, chargers, copy machines, etc.	reasonable elimination of downtime on standby mode, optimal utilisation, selecting appliances with optimal energy efficiency class with regards for demand (following EU energy label)
	condition of walls, windows, ceilings, and foundations	replacement or repair of the leaking ones, improvement of thermal insulation and elimination of thermal bridges
	other	energy consumption monitoring, changing habits of the staff, regular servicing, changing organisation of work, switching off inoperative appliances and machines, moving certain processes for night-time

Evaluate yourself!

In the table below a number of questions helpful for self-evaluation are presented. They can be an introduction to company audit. However, to answer these questions one must conduct an overview of knowledge and means of energy management in their company. Some of the questions are scored (written in bold), where a positive answer gets 1 point. These points, after summing up, will show what is the state of enterprise compared to a reference enterprise, for which all answers are scored as positive (reference amount is 20 points).

№	Question	
1	How much electrical energy does your enterprise consume annually and what was its cost for the last two years?	
2	How much heat does your enterprise consume annually and what was its cost for the last two years?	

№	Question	Yes	No	Don't know
3	**Is the energy consumption monitored in your enterprise?**			
4	**Does your enterprise analyse electrical energy tariffs with regards to change of the supplier?**			
	Does your enterprise analyse electrical energy tariffs considering the criteria: adjustment to current needs, demand and/or maximum power?			
5	Are there situations of exceeding consumption of ordered capacity in your enterprise?			
6	If there are situations of exceeding consumption of ordered capacity in your enterprise, were the reasons of those investigated?			
7	**Were the restrictions of reactive power consumption analysed in your enterprise lately?**			
8	**Do you know what does Industry 4.0 mean?**			
9	Do you think that your enterprise has reached status of an enterprise in the context of Industry 4.0?			
10	**Has there ever been energy audit conducted in your enterprise, have standards PN-EN ISO 9001 or PN-EN ISO 50001 been implemented?**			
11	If your enterprise has implemented standard PN-EN ISO 9001, do you see any benefits emerging from that?			

№	Question	Yes	No	Don't know
12	If your enterprise has implemented standard PN-EN ISO 50001, do you see any benefits emerging from it?			
13	Have your enterprise implemented other standards or does it have any other certificates, apart from the abovementioned?			
14	**When purchasing or utilising office equipment and household appliances, do you pay attention to their energy labels?**			
15	Did you know that there is a possibility of implementing additional sub-meters in the especially vulnerable areas in an enterprise?			
16	Are there any areas (appliances, installations) in your enterprise that are prone to failures?			
17	**If there are the especially vulnerable areas in your enterprise which would require additional submeters, do they already have any?**			
18	Is your enterprise operating in a longer shift system than single-shift one?			
19	Are there any long-lasting and energy-intensive processes in your enterprise (e.g., heating presses, a furnaces or other equipment, chamber cooling, etc.) that can be moved from day shift to night shift? and if yes, did you consider such an option?			
20	**Is the documentation of your enterprise complete (invoices for energy, construction documentation, plans of the building, diagrams of all installations, characteristics of primary equipment)?**			
21	**Is the whole documentation also fully digital in your enterprise?**			
22	**Are there motion sensors for lighting control in your enterprise?**			
23	**Is there energy-saving lighting in your enterprise?**			
24	**Is the lighting system regularly inspected for cleanliness and completeness?**			
25	**Was the choice of the method of tap water heating preceded by economic analysis?**			
26	Is the tap hot water heated with utilisation of the recovery heat from production processes in your enterprise?			
27	In your enterprise, is the tap hot water heated through electric instantaneous heaters or electric heaters with storage tank?			
28	In your enterprise, is the tap hot water heated through electric heaters with storage tank?			
29	Are there boilers for solid-fuel, liquid fuel, or gas in your enterprise?			
30	**If there are boilers for solid-fuel, liquid fuel, or gas in your enterprise, was analysis of burning process conducted and was the energy efficiency of the boilers measured?**			

№	Question	Yes	No	Don't know
31	If there was analysis of burning process conducted and efficiency of the boilers was measured, when was it done last?			
32	**Does your enterprise monitor state of thermal insulation of pipes with steam or hot water?**			
33	If compressed air is used in your enterprise, does the compressor have free access to cool air?			
34	If compressed air is used in your enterprise, is the heat produced by the compressor utilised?			
35	If compressed air is used in your enterprise, is the compressed air system regularly inspected and are leakages eliminated on a regular basis?			
36	Are there pumps or fans in your enterprise that are making noise?			
37	If there are pumps or fans that are making noise in your enterprise, was the cause of this inspected?			
38	If large amount of water is consumed in your enterprise, is the system of water recovery applied, e.g., recovery of so-called greywater or water from production processes?			
39	Is there air conditioning in your enterprise?			
40	If there is air conditioning in your enterprise, is it essential?			
41	If there is air conditioning in your enterprise, was its installation preceded by economic analysis?			
42	If there is air conditioning in your enterprise, is it providing thermal comfort?			
43	**Are there blinds or veneers/layers preventing heating up the window glass from the sun in your enterprise?**			
44	Is "free cooling" method applied in your enterprise?			
45	Is heat recuperation applied in your enterprise?			
46	Are there any renewable energy elements applied in your enterprise, such as solar cells, solar thermal collectors, wind turbines, heat pumps?			
47	**If you are using any renewable energy elements in your enterprise, were they tested for their energy efficiency and economic aspects of their usage?**			
48	If you are using any renewable energy elements in your enterprise, were they optimally selected with regards to possibilities of exploitation?			

1. Taking an inventory

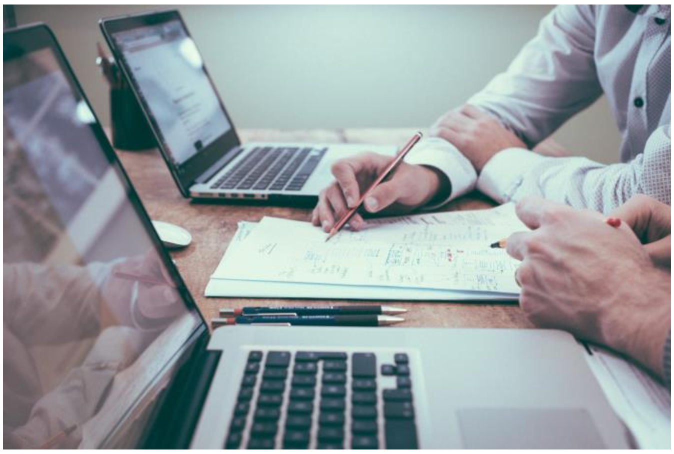
When it comes to actions leading to reducing operating costs of an enterprise, taking inventory of documentation and settlements with utility provider is the first stage. Complete technical documentation (diagrams of installations, equipment specifications, keeping accurate records of all modifications, etc.) is necessary to conduct proper analyses. If an enterprise wants an audit to be conducted, it must at first take care of completing the up-to-date documentation.

To take actions improving energy efficiency, it is vital that technical inventory, as well as inventory of available documentation in an enterprise are performed, as modernisation of a given area without full knowledge of it is very difficult or even nearly impossible. Very often happens that documentation of some installations, equipment or machines is incomplete, out-of-date, or missing (no diagrams of installations, incomplete data of equipment). Only after addressing these deficiencies one can start to implement actions improving energy efficiency. The greatest difficulties that auditor faces at the beginning of an audit are: missing diagrams of compressed air installations, no knowledge of servicing of some of the equipment (especially when it comes to steam), as well as limited access to some parts of the plant or to heat substation. When it comes to invoices and documentation concerning settlements with utility provider, there are usually no deficiencies and this area is fully supervised. However, the invoices are often paid and archived without any analysis. Additional difficulty is missing data for energy consumption in previous months and years. It is worthwhile to take care of availability of such data before one participates in any kind of technical activity.

Taking accurate inventory of installations, equipment and documentation may significantly help with planning out a modernisation or creating strategy for systematic reduction of energy consumption in following months or years.

2. Monitoring the energy consumption

To effectively reduce operating costs of an enterprise, it is essential that energy and utility consumption are monitored. Introducing improvements should start with this.



In majority of enterprises, especially the small ones, only singular electrical energy and utility (gas, water) meters are installed. Their only purpose is for settling with the providers. Because of small number of employees, utility consumption in small enterprises is usually not monitored and as a result potential energy savings aren't noticed. Monitoring consumption of respective utilities allows to reduce energy consumption by minimising losses that might appear mainly because of:

- leakages in installations resulting from damage to the installation (pipe corrosion, fatigue cracks),
- increasing leakage in electrical installation due to, for instance, wires overheating and degradation of insulation,
- increasing hydraulic resistance because of accumulation of, among others, limescale in water or steam systems.

There are three ways of detecting irregularities in functioning of given installations, each of them provides us with different data and is equally important:

- generating profile of the annual electricity or other utility consumption and comparing the consumption between respective months;
- comparing consumption between the same periods in respective years;
- benchmarking the energy or utility consumption (consumption for a single product unit) with consumption in other plants in the same branch.

The first two are easy and cost-free. They only require time, as they are based on critical analysis of invoices. The third method requires access to similar data from other plants in the same branch or to certain representative average for respective industries. Such data can be acquired in professional chambers gathering producers of similar goods or from results of European Union programmes directed at the increase of energy efficiency. Economy and industry association agreement, like the one established in Switzerland in the '80s, called Energy Efficiency Network (EEN), would be helpful in gathering data and supporting improvement of energy efficiency. Such concept has developed since then and today we know it as Learning Energy Efficiency Network (LEEN); it helps with optimising energy consumption in enterprises by implementing measures improving energy efficiency. Formation of LEEN depends mostly on the entrepreneurs. LEENs are successfully operating in Germany, France, Austria, and Mexico.

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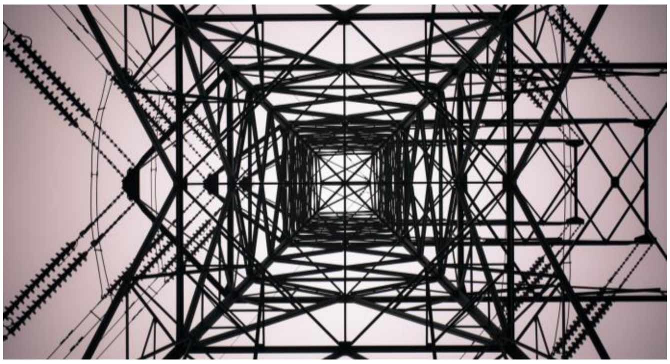
3. Minimising the energy consumption in utility distribution

Rotating machines are the most numerous group of equipment that also uses the biggest amount of energy. There are many ways to reduce the amount of energy that electric motors, pumps, compressors and fans are consuming, even up to about 35%.



Amount of electrical energy that the equipment is consuming depends on its purpose - heating, drive, lighting, and cooling. However, in small and medium enterprises majority of energy is consumed by rotating machines - electric motors that are propelling pumps, fans, compressors, conveyor belts, jacks.

According to approximated data, electricity consumption structure presents itself as shown on Fig. 2. Taking all energy sources in Poland into consideration, about 65% of primary energy is used for electrical appliances, and ca. 35% as heat. The electrical equipment was divided into several primary groups, among which the biggest amount of energy is consumed by pumps, then fans, compressors, and cold generators.

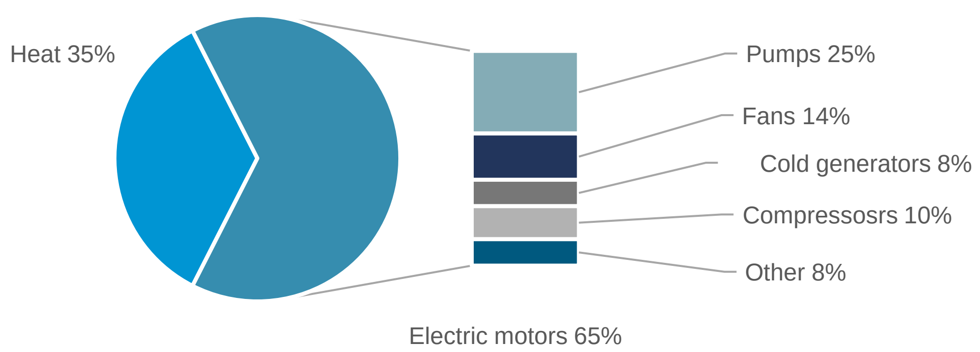


Fig. 2 Electrical energy consumption structure according to delivery.

3.1. Electric motors and frequency converters

Using energy-saving motors instead of standard ones may improve drive efficiency by several percent. Such modernisation is profitable for drives with continuous running duty, i.e. to a maximum of two starts per hour. Rated efficiencies of energy-saving motors are reaching a value of 95.5%, whereas frequency converters reach even up to 96%. Three-phase motors are more efficient than single phase motors with the same engine power. When undertaking an audit, firstly, one must specify the biggest and most energy-intensive drives, and then examine them.

In all branches of industry about 90% of electric motors are single- and three-phase AC motors. In Poland, basic standard concerning electric motors is PN-EN 60034-30-1 Rotating electrical machines. This standard with very few exceptions applies to almost all motors; it defines **energy efficiency classes** of AC motors supplied directly from the grid and applies to motors with rated power from 0.12 kW to 1 MW, rated voltage from 50 V to 1 kV. Energy efficiency classes are as follows: IE1 (Standard Efficiency), IE2 (High Efficiency), IE3 (Premium Efficiency), IE4 (Super Premium Efficiency). Typical values of induction motor efficiency are shown on Fig. 3 - for nominal load motor efficiency is at maximum, however, when load is reduced to below 40%, efficiency lowers by about 10 percentage points.

Nominal efficiencies of motors depend on their power. The more power the motor has, the more efficient it is. This correlation is shown on Fig. 4; comparison of standard motor efficiencies and corresponding energy-saving motors are shown in table for example 1. Electric motor efficiency is represented by this formula:

$$\eta_s = \frac{P_M}{P_{EL}} = \frac{M \cdot \omega}{P_{EL}}$$

P_M – power on pump shaft (nominal power presented on motor rating plate),
P_{EL} – electric power delivered to the motor.

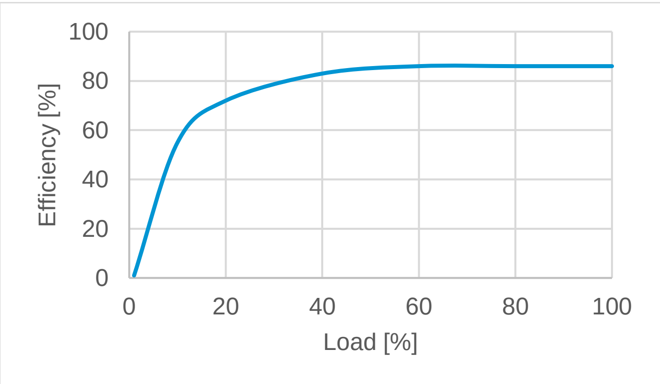


Fig. 3 Typical efficiency progress of induction motor

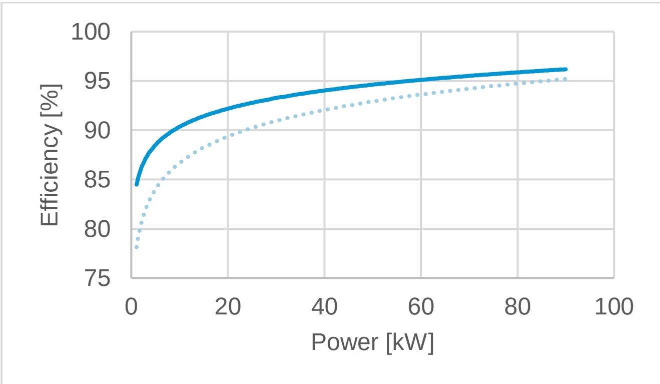


Fig. 4 Classes of induction motors

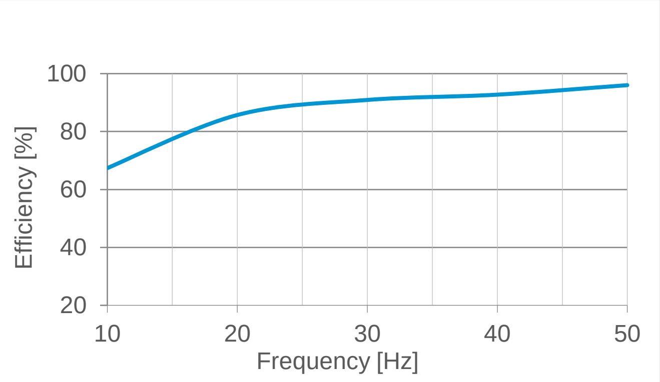


Fig. 5 Typical efficiency progress of frequency converter.

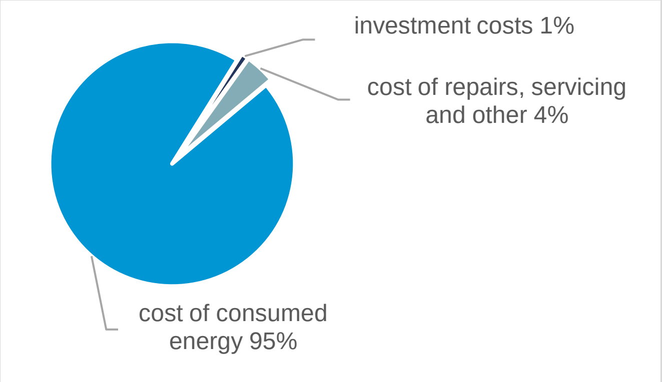


Fig. 6 Motor expenses in a typical motor LCC.

If one uses almost only AC motors, the only possibility (without taking into consideration almost non-existent fluid coupling) of smooth change in their rotational speed is application of frequency converters. However, regardless of a producer, their efficiency in initial frequency function reduces in a way that with substantial decrease of rotational speed it may even fall to 65% (Fig. 5).

As shown in Fig. 6, majority of expenses in the life cycle are spent on energy costs, so economic accounting of costs of repair, as well as efficiencies of older motors show that for motors with power up to about 25 kW **the repair is not profitable at all**, as such cost is like price of a new motor. Moreover, considering that an energy-saving motor is ca. 20% more expensive than a standard one and that costs of motor operation during its life cycle are mainly energy costs (ca. 95%), when applying continuous running duty, in long-term, the cheapest solution is to purchase an energy-saving motor instead of a standard one.

Example 1

For five motors with rated power PN equal 0.75 kW, 7.5 kW, 18.5 kW, 30kW and 90 kW that run t=6000 hours a year, assuming electrical energy price of c_{EL} = 0.45 PLN/kWh, determine how profitable it is to change standard motor for motor with increased energy efficiency.

To determine profitability of such change, one must determine motors efficiency η, energy price and market prices of new energy-saving motors c_{EE}. Presented in table below.

P_N [kW]	η [%]	
	standard η_{ST}	energy-efficient η_{EE}
0.75	73	83.2
7.5	87.8	90.7
18.5	90.9	92.6
30	92.5	93.5
45	94	94.4
90	94.3	95.1

In each case, by knowing efficiencies one may determine, respectively, electrical power P_{EL}, difference between electrical energy consumed by a standard motor E_{ST} and energy-saving motor E_{EE} per year ΔE, as well as SPBT, by applying formulas:

$$P_{EL} = \frac{P_N}{\eta}$$

$$\Delta E = \left(\frac{P_N}{\eta_{ST}} - \frac{P_N}{\eta_{EE}}\right) \cdot t$$

$$SPBT = \frac{c_{EE}}{\Delta E \cdot c_{EL}}$$

P_N [kW]	c_{EE} [PLN]	ΔE [kWh/year]	$\Delta E \cdot c_{EL}$ [PLN/year]	SPBT [years]
0.75	270	755.7	340.0	0.79
7.5	760	1638.7	737.4	1.03
18.5	2334	2241.8	1008.8	2.31
30	5500	2081.2	936.5	5.57
45	7500	1217.1	547.7	13.69
90	13000	4817.2	2167.7	6.00

As presented in the table, after the purchase and replacement of a standard motor for an energy-saving one, approximate payback period for motors with power up to 10 kW is very short - about 1 year, and for motors up to about 20 kW it does not exceed 3 years. Therefore, such action is financially profitable.

3.2. Pumps

If one would implement all actions increasing energy efficiency of pumps, one could achieve a decrease in energy consumption even by 40%. Suboptimal control causes the greatest losses. That is why when conducting an audit one must, in particular, examine the pumps that operate in variable flow system. Energy audit may reveal losses that may be reduced or eliminated.

On Fig. 2 one can see that among all rotating equipment, pumps are constituting about half of all electrical equipment. That is why energy efficiency improvement may bring a significant effect. The fact that pumps in installations are most often scattered in various places and their number is relatively bigger than of any other equipment, are a detriment to all these modernising actions. Thus, possible modernisations are troublesome. Basing on data from Europump Ltd. it can be inferred that if all methods increasing energy efficiency of pumps would shortly be implemented, it would be possible to save even up to **40%** of total electrical energy used for their propulsion. Therefore, one can see that savings potential is truly substantial, but there are certain obstacles of technical (interruption of production, issues with launching a new production line) and sociological (change of habits, work procedures) nature that are preventing its utilisation. Structure of losses that are possible to avoid or of potential savings is presenting as follows:

- losses arising from suboptimal control method and suboptimal control of pump parameters – 20%,
- losses resulting from suboptimal installation design – 10%,
- losses resulting from poor pump-installation configuration – 4%,
- losses resulting from too low efficiency of installed pumps – 3%,
- energy losses resulting from insufficient installation operation – 3%.

As we can see from this list, suboptimal control method of pumps has the biggest influence on losses. During an audit of pumps, it is worthwhile to examine equipment listed below:

a) old pumps,

b) pumps driven with motors with bigger power (above 10 kW),

c) pumps that have a long operating time (e.g., water supply, air conditioning),

d) pumps in which flow or pressure are constantly and substantially changing.

The most successful methods of saving energy are shown in Table 2. When undertaking an audit, it is worthwhile to check whether the pumps are meeting all the criteria.

Table 2. The most successful methods of reducing amount of electrical energy consumed by pumps

Applying to the pump	Improving pump efficiency
	Choosing suitable pump
	Changing rotor and reducing diameter of the rotor
Applying to the operation	Applying optimal control method
	Controlling the number of operating pumps
	Optimal pump-installation configuration
Applying to the design	Design has been executed according to appropriate specifications
	Proper design of installation and related equipment

Pump efficiency is represented by formula:

$$\eta = \frac{\rho g Q H}{P_M}$$

ρ – density of transferred fluid (water density in temperature of 20°C is ρ = 998 kg/m^3),

g – standard acceleration due to gravity [m/s^2],

Q – fluid flow rate [m^3/s],

H – pump head [m],

P_M – mechanical power on pump shaft [W].

Three most popular methods of pump control with low specific speed[1] – centrifugal pumps, are compared on Fig. 7.

Pump efficiency characteristic has its maximum, so pump and installation should be matched in such a way that it could operate in optimal conditions, which means, with maximum efficiency. The biggest change, however, is achieved by changing pump control method. Three most popular methods of control for pumps with low specific speed (centrifugal and helicoidal pumps) are compared on Fig. 7. The graph implies that if there is a necessity of controlling (reducing) pump flow rate, the by-pass control will cause even an increase in consumption of power, throttle control will reduce the consumption in an almost linear way, while rotational speed control will cause a much bigger drop in power consumption. The difference in power consumption ΔP is a measure of profits one can gain from switching from most popular throttle control to variable-speed with frequency converter.

[1] Specific speed – a value that is determining i.a. shape of pump rotor, $n_q = n \cdot Q^{0,5}/H^{0,75}$; where n – nominal rotational speed [rpm], Q – flow rate in an optimal point BEP [m^3/s], H – pump head in optimal point BEP [m]; BEP – Best Efficiency Point.

Changes in the method of control should be applied after analysing at least one year of operation. However, with high certainty, it can be claimed that if control of flow rate is deeper than 8-10% of the optimal point, a change for variable-speed control will be very beneficial, and payback period will become very attractive - from 0.5 to 1.5 years. If there is high variability of flow rate intensity, power consumption can be reduced (in one object) even by a half by changing control method from throttle to variable-speed.

It is important to monitor not only current parameters of pump performance, but also basic indicators during pumping system operation. For example, a specific energy e_P [kWh/m^3], which is one of the energy efficiency indictors and represents the amount of energy ΣE required to transfer one unit of fluid ΣQ.

$$e_P = \frac{\sum E}{\sum Q}$$

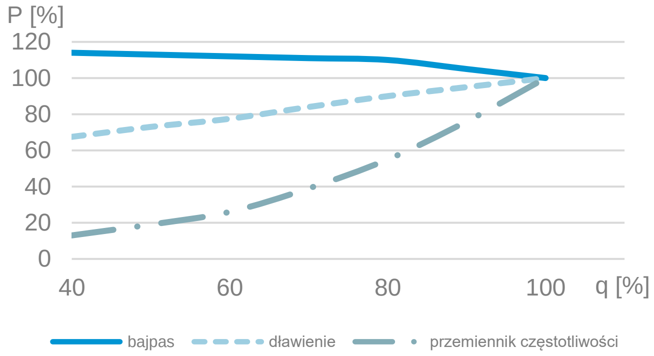
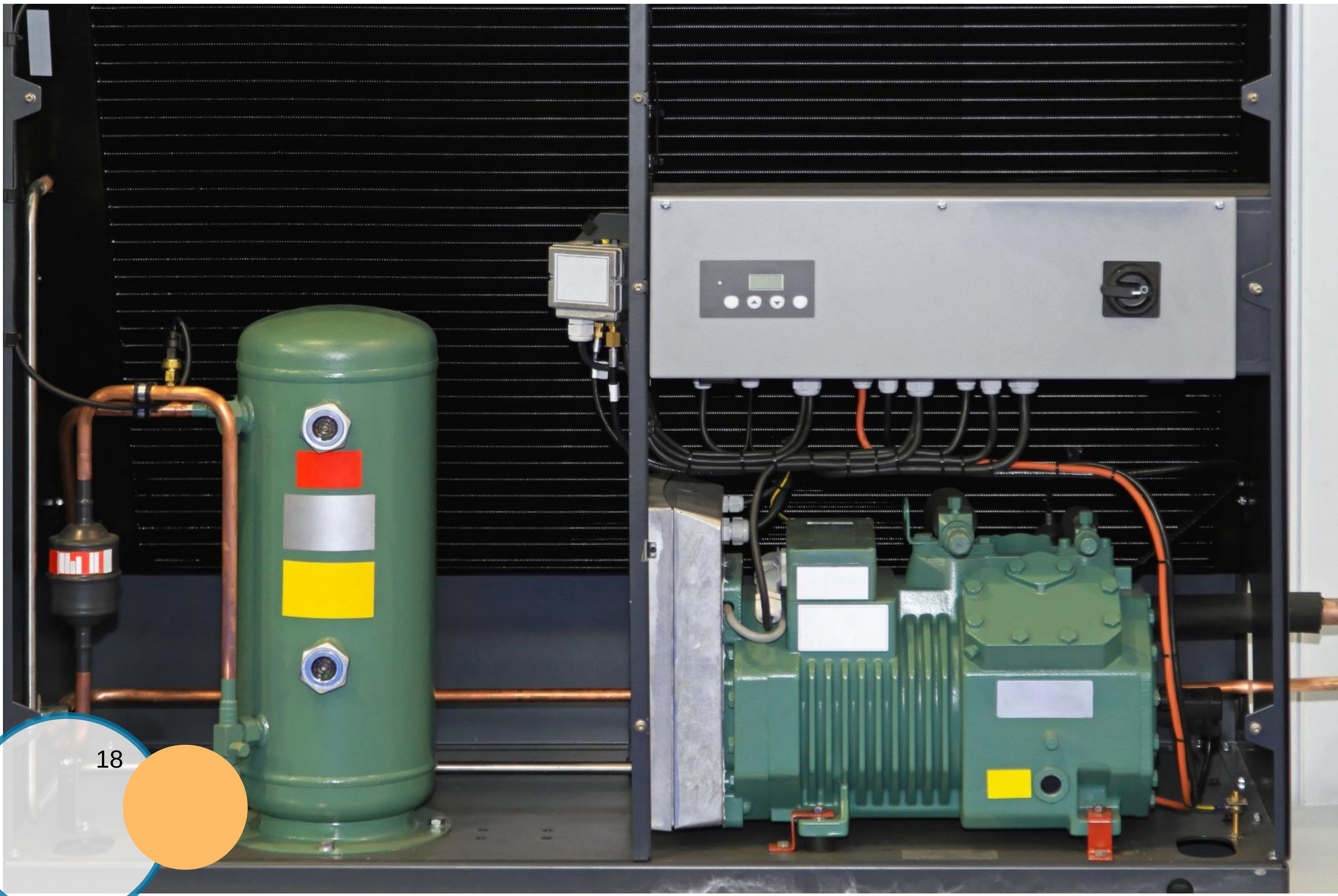
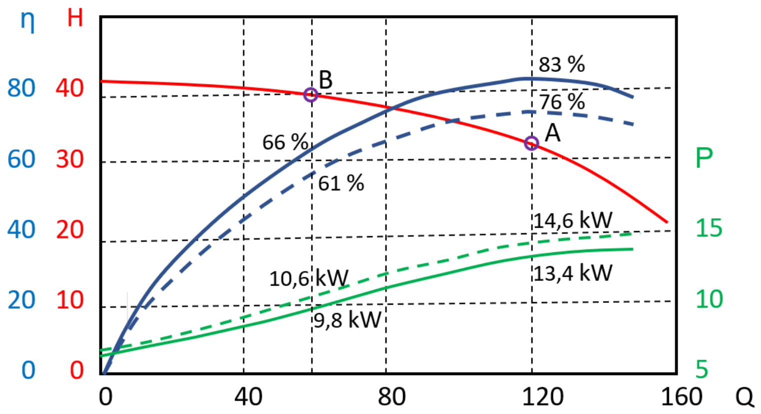


Fig. 7 Correlation between pump-motor unit power consumption and the method of pump control.



Example 2

Calculate the profits from replacing an old pump (the worse one – dashed line) for a new one (the better one – continuous line) for two points of pump performance. Efficiencies of base pump and its replacement in point A are respectively 76% and 83%, in point B – 61% and 66%. Annual operation time is 6000 hours, the price of electrical energy is 0.45 PLN/kWh. Motor efficiency η_s = 93%.



Power on pump shaft PM, electric power PEL (marked green on the diagram), efficiency ηp (blue) and hydraulic parameters Q and H (red) are related:

$$\eta_P = \frac{\rho g Q H}{P_M}$$

$$P_{EL} = \frac{P_M}{\eta_s}$$

Basing on characteristics, the basic parameters of pump operation were determined.

Operation point A (Q = 120 m^3/h; H = 34 m) (optimal operation point)

	η [%]	P_M [kW]	P_{EL} [kW]	Energy consumption per year [MWh/year]	Cost [PLN/year]
Base pump	76	14.6	15.7	94.20	42 390
Better pump	83	13.4	14.4	86.45	38 902
			Difference (profit)	7.74	3 488

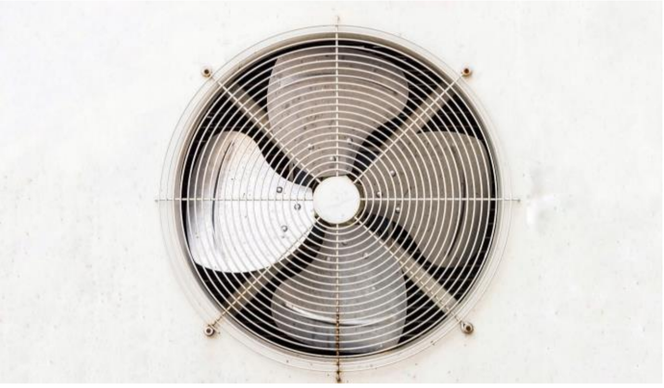
Operation point B (Q = 60m^3/h; H = 39.5m)

	η [%]	P_M [kW]	P_s [kW]	Energy consumption per year [MWh/year]	Cost [PLN/year]
Base pump	61	10.5	11.3	67.74	30 483
Better pump	66	9.8	10.5	63.22	28 449
			Difference (profit)	4.52	2 034

Replacing an old, worn out pump with little power for a new one – with much better efficiency, may reflect on annual savings in an amount exceeding purchase of the new pump and save about **8 MWh** of electrical energy per year.

3.3. Fans and blowers

Oversized fans generate losses. Determining their efficiency and Specific Fan Power indicator is fundamental for energy audit. Additionally, when conducting an audit, it is possible to determine a number of actions related to fan work and service, performing which may reduce energy consumption even by 40%.



Some actions improving energy efficiency suitable for fans are the same as those for rotodynamic pumps. Fans are widely used mainly in building ventilation, utility distribution, exhaust extraction, providing airflow and air cooling for combustion. There are several main types of fans and blowers that are meant for various purposes. Most often they are not fixed together but, similarly to pumps, installed in several places. As any other rotating equipment that cooperates with suitable installation, fan must be appropriately matched with such installation and its purpose, i.e., a fan must operate in optimal point – which means with maximum efficiency. Efficiency of a fan may be determined by a simple formula:

$$\eta = \frac{\Delta p \cdot Q}{P_M}$$

where:

Δp – total pressure difference (static and dynamic) of a fan [Pa],

Q – airflow rate [m^3/s],

P_M – mechanical power on pump shaft or motor electric power [W].

The second very important indicator is Specific Fan Power (SFP).

SFP is determined by a formula:

$$SFP = \frac{P_{EL}}{Q} = \frac{\Delta p}{\eta}$$

This indicator divides fans into three groups:

- SFP < 1.5 kW/(m^3/s), which means the system is energy efficient,
- SFP = 1.5 - 4 kW/(m^3/s), when its energy efficiency is medium,
- SFP > 4 kW/(m^3/s), when its energy efficiency is low.

Table 3 presents major losses in fan installations, avoiding which may bring measurable profit. It is worth to remember that those numbers are related to only one named modernisation and cannot be simply summed up. Thus, when determining total potential of multiple improvements, individual improvements have smaller shares and they do not sum up to a number higher than 100%.

Table 3 Savings potential resulting from reduction of respective faults and defects.

№	Loss	Potential
1	Losses caused by suboptimal control method	30%
2	Lack of adjustment to the process if it has changed in time (oversizing)	50%
3	Selecting an unsuitable type of fan and with unsuitable characteristics	30%
4	Improper ductwork design - avoiding unnecessary losses	30%
5	Leaving the fan switched on unnecessarily	50%
6	Losses caused by oversized motor	10%
7	Losses caused by inlet air turbulences	15%
8	Losses caused by unnecessary resistance on inlet	15%
9	Losses resulting from unnecessarily narrowed flow rate	15%
10	Losses caused by worn out bearings	7%
11	Incorrect connection of motor phases	15%
12	Losses caused by one phase loss	15%
13	Loss resulting from poor belt tension on gear wheels	3%

Moreover, fan start should be soft. Although it doesn't affect the engine's efficiency, it influences fan's and ancillary equipment's durability, which, in turn, influences availability of the equipment and installation. It should be ensured that one of methods mentioned below is applied and adopted in installation:

- starting with using a frequency converter,

- starting with using motor soft starter that reduces inrush current (which means high current in a short period of time),

- starting with using Y/Δ starter,

- starting with using fan control inlet guide vane.

3.4. Compressed air systems

Compressed air is often an indispensable utility, however an expensive one, as compressors are energy-intensive and have overall low efficiency. Nonetheless, there are technical methods that reduce compressor energy consumption even by 30%. Energy audit may be very helpful in showing all possible savings.

What is peculiar about compressed air installations, is that most often they are in one place (compressor room), from where the air is distributed.

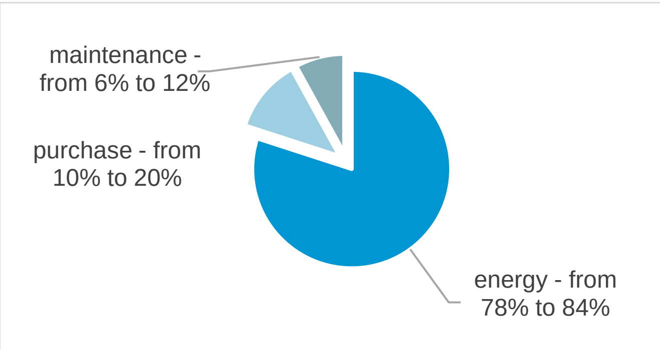


Fig. 8 Individual costs in LCC for compressed air installations.

It is worth to invest in activities leading to energy consumption reduction in compressed air installations, as payback period of such investments is very appealing and often amount to 0.5-1 year. This is mainly due to energy costs that one must pay during compressor lifecycle, which are presented on Fig. 8. Table 4 shows actions improving energy efficiency and their potential for reducing energy consumption. It is worth to remember that those numbers are only related to a single modernisation and cannot simply be summed up, so when determining total potential of multiple improvements at once, individual improvements have smaller shares and they do not sum up to a number higher than 100%.

Table 4 Potential applications of means of efficiency improvement in compressed air systems

Actions and points of energy consumption	Prevalence	Savings potential
Air leakage reduction	**80%**	**40%**
Proper design of entire installations	50%	10%
Reduction of pressure losses that result from friction	50%	5%
Frequent replacement of filter cartridges	40%	5%
Modernising compressors	30%	5%
High quality electric motors	25%	3%
Variable-speed drives	25%	25%
Adapting advanced control systems	20%	20%
Waste heat recovery	20%	40% *)
Reasonable pressure reduction	15%	10%
Correction of cooling, drainage, filtration systems	10%	5%
Applying proper terminal equipment	5%	10%

*) – heat recovery system does not influence energy consumption of compressed air system; it may, however, reduce expenses for heat production.

Pressure drops in installation itself and in various equipment (expansion tank, filter, dryer, joints, valves) in it are strongly dependant on airflow rate, that is, on compressor performance. This dependency is approximately quadratic. It may happen that for a specific compressor, flow rate, as well as pressure drop, will be too great for parts of installation with too small diameter.

Example 3

To determine minimal allowed diameter of simple installation with length L = 100 m, determine installation operation cost for two diameters of standard compressor room and estimate payback period. Each compressor capacity and power are: V = 100 Nm³/h and 12 kW, as well as V = 400 Nm³/h and 44 kW, energy price c_E = 0.45 PLN/kWh. Annual operation time is 8760 hours.

Firstly, pressure drops for individual installation elements were determined; for set pressure on delivery p_{REC} flow rate and pressure were determined on compressor p_{COMP}, as well as on outlet from the compressor room p_{OUT}. Red values mean that they exceed allowed limit. It was assumed that generation pressure reduction by 0.29 bars will reduce the amount of power the compressor consumes by 2%. Payback periods were calculated with regards to expenses that need to be spent on enlarging the diameter.

flow rate	100 Nm³/h	100 Nm³/h	400 Nm³/h	400 Nm³/h	400 Nm³/h
speed	7 m/s	3 m/s	29 m/s	11 m/s	**7 m/s**
	d = 25 mm	d = 40 mm	d = 25 mm	d = 40 mm	**d = 50 mm**
Δp compressor room	0.33 bar	0.29 bar	0.87 bar	0.35 bar	**0.31 bar**
Δp installation	0.28 bar	0.03 bar	3.65 bar	0.35 bar	**0.11 bar**
Δp total	**0.61 bar**	**0.32 bar**	4.52 bar	**0.7 bar**	**0.42 bar**
p_{COMP}	7.11 bar	6.82 bar	**11.02 bar**	7.2 bar	**6.92 bar**
p_{OUT}	6.78 bar	6.53 bar	10.15 bar	6.85 bar	**6.61 bar**
p_{REC}	**6.5 bar**	**6.5 bar**	**6.5 bar**	**6.5 bar**	**6.5 bar**
annual cost	47 304 PLN/year	46 358 PLN/year	-	173 448 PLN/year	**169 979 PLN/year**
cost of installation with Al	-	7 810 PLN	-	-	**10 240 PLN**
SPBT =	-	8.3 years	-	-	**3 years**
cost of PP-R installation	-	3 215 PLN	-	-	**5 010 PLN**
SPBT =	**-**	**3.4 years**	**-**	**-**	**1.5 years**

As one can see from the table, with flow rate 100 Nm³/h both diameters are acceptable, as speed inside the installation does not exceed few meters per second, however, with flow rate four times greater, only two the biggest diameters are meeting speed criteria, while on diameter 25 mm there would be a throttling effect preventing proper and effective compressor performance.

4. Air conditioning

In case of purchasing new air conditioners and air conditioning installations, the only possible action contributing to improvement of energy efficiency is to choose equipment with the highest energy efficiency class (following energy label), as well as the highest coefficient of performance. In case of old air-conditioning installations, there is a number of actions that can be taken to reduce energy consumption. Implementation of all simple measures can reduce power demand of an installation even by about 20%.

Air conditioning is a specific area and it slightly differs from other systems, as it develops fast enough for energy intensity indicators to improve rapidly. Even though air conditioners are indicators of comfort, using them is often a necessity (e.g., food industry, server rooms). The decision on purchasing should be made by following energy label (see chapter 7), which should show the highest class. There are also other factors which increase energy intensity of such installations.

Before air conditioning/conditioner audit is undertaken, it is worthwhile to make an equipment assessment (Table 5).

Table 5 Air conditioning system pre-audit questions.

№	Question	Yes	No
1	Is air conditioning necessary in the building/room?		
2	Which energy class is the air conditioner characterised by?		
3	Does the air conditioner operate in an on/off mode?		
4	Has the air conditioner an inverter?		
5	Is the air conditioner properly matched with the area?		
6	Is the air conditioner periodically inspected and cleaned?		
7	Are there any leakages from the installation?		
8	Has too high temperature of heated air or too low temperature of cooled air been noticed?		
9	Did the purpose of utilised rooms change after installation of air conditioning?		
10	Is the equipment subjected to fast and frequent change of setpoints during its operation?		
11	Are the air intake vents and exhaustion terminals placed adequately far away from each other?		
12	Have permanent change of air conditioner parameters been noticed after some time?		
13	Is air conditioner operation (power consumption and temperature) monitored?		
14	Is it possible to simultaneously use an air conditioner and other equipment with opposite operating mode in a room?		

№	Question	Yes	No
15	Are there situations in which a window is opened when the air conditioning is running?		
16	Is it possible to reasonably rearrange the workstations to make smaller areas being air conditioned?		
17	Does the utilities provider offer also supply of cooling?		
18	Is microbiological pollution eliminated in water installations (in case of humidifiers, chilled water systems, water condenser cooling, free-cooling method, etc.)?		
19	Has the thermal insulation and vapour barrier in air conditioning ducting and installations no breaks?		
20	Is warranty period of the installation known?		
21	Has the installation been assembled by a professional?		

Air conditioner operation cost is proportionate to consumption of power and operation time, assuming that the price of electrical energy is fixed. Consumption of power is not fixed and depends on the outside temperature, as well as inside temperature setpoint. The market offers many solutions, most profitable of which is the one with the highest energy efficiency ratio, that is, relationship between cooling power and electric power. Such values for different-sized air conditioners were presented in Table 6. The efficiency of air conditioners in class B is about 10% lower than the efficiency of conditioners with the same cooling power from class A. The efficiency of class A++ is about 10 % lower than of class A, while the efficiency of class A+++ is about 20% higher than of class A++.

Table 6. Typical values of input and output power of air conditioners, P_{EL} – electric power, P_{COOL} – cooling power, P_{HEAT} – heat output.

Capacity	Values						
P_{EL} [kW]	0.095	0.545	0.6	0.87	1.205	1.3	1.5
P_{COOL} [kW]	0.39	2.5	2.6	2.6	4.2	3.5	4
P_{COOL} /P_{EL}	**4.1**	**4.6**	**4.3**	**3.0**	**3.5**	**2.7**	**2.7**
P_{EL} [kW]	0.1	0.7	0.8	0.9	1.6	1.2	1.6
P_{HEAT} [kW]	0.6	3.2	3.0	3.0	5.4	3.8	4.8
P_{HEAT}/P_{EL}	**5.6**	**4.6**	**3.8**	**3.3**	**3.5**	**3.2**	**2.9**

Another very important aspect is proper selection of the air conditioner. A simple conversion factor can be applied. 1 m^2 area requires 100 W of cooling power for air conditioning to be effective. Efficiency of inverter air conditioners (with smooth control of cooling power) is higher by up to 30% in comparison with standard air conditioners, thanks to avoiding loss caused by transient states.

Currently five years of warranty is a standard. One must remember that having a professional to install the equipment is a guarantee that warranty will be valid. During air conditioner exploitation, it is worth to observe whether its operation parameters (power consumption from the grid, cooling, and heating power) are not decreasing. In case of situations like power consumption increase, increased noise, compressor heating-up or reduced cooling power, it is worth to check whether exploitation is carried out properly – whether there has not been any refrigerating fluid leakage; whether filters, condensers and evaporators are clean; whether there is no compressor or fan failure. Pollution of heat exchangers can decrease their operation effectiveness by 5%. One may clean the filters on his own, however, if fluid leakage has been observed, quick servicing intervention is necessary, as leakage not only reduces energy efficiency, but is also very harmful for the environment.

Example 4

Calculate monthly cost of air conditioner operation with cooling power of P_{COOL} = 2.5 kW and energy efficiency ratio of *EER* = 4.6. Air conditioner load factor is *LF* = 25%, electrical energy price is c_{EL} = 0.45 PLN/kWh. Check whether the air conditioner will operate efficiently in a room of 45 m^2.

Energy efficiency ratio (EER) is an information on how much cooling energy is transferred by one electrical energy unit. Electric power is calculated from formula:

$P_{EL} = P_{COOL}/\mathrm{EER} = 2.5/4.6 = 0.54$ kW

Load factor *LF* gives an information on how much time (in percent) the device was used during one cycle. Therefore, monthly energy cost is:

$K_{EL} = P_{EL} \cdot C_{EL} \cdot LF \cdot 8760/12$
$K_{EL} = 0.54 \cdot 0.45 \cdot 0.25 \cdot 8760/12$
$K_{EL} = 44.34$ PLN

Every 1 m^2 requires 100 W of cooling power, so air conditioner with cooling power P_{COOL} = 2.5 kW will operate efficiently on area of

A = 2500/100 = 25 m^2.

This means that examined air conditioner will not be able to effectively cool the whole office area. Either another air conditioner will need to be installed or workstations will need to be compressed in smaller area or air-conditioned areas will need to be separated with partitions.

5. Heating

Small enterprises which use only wall heaters, first of all should implement thermostats, as they allow to control temperature in the room. It may reduce heating costs even by 15-20%. Additionally, eliminating simultaneous heating and cooling of rooms through opened windows or unclosed gates will reduce the costs by additional ca. 5%. If heat is utilised on a large scale, there are several methods guaranteeing the highest performance efficiency of the equipment.

For small consumers of system heat, possibilities of its reduction are limited to economic heat management, avoiding overheating rooms, avoiding simultaneous use of heating and air conditioning, installing thermostats on heaters to enable smooth heat control and to look after the condition of the district heating substation, pipelines, and their insulation. Moreover, heating costs mainly depend on the condition of thermal insulation of building roof, walls and windows and its foundation. With poor insulation, heating efficiency lowers, and heat losses increase. It is estimated that in most unfavourable conditions (poorly insulated walls, single-glazed windows, lack of heater control, leaky pipes, losses in thermal insulation), heating costs may increase even by 30-35%.

For enterprises with bigger heat consumption areas of production, delivery and utilisation of heat are an extensive subject, nonetheless, it is worth to present few most important aspects related to energy efficiency.

As it was mentioned in the introduction, an indispensable first step is taking inventory of means of heat production and delivery. If all heat in an enterprise comes from district heat, activity in this area is reduced to monitoring heat consumption in individual months and years (chapter 2), minimising heat loss resulting from heat transfer through walls, windows, doors, window- and door frame-woodwork of the building (chapter 8), as well as losses resulting from ventilation/air conditioning, and irrational use of heat (chapter 4).

At first, reference heat source efficiency needs to be determined – in case it hasn't been provided by heat source supplier or the measurements aren't sufficient to determine heat supply efficiency. It can be estimated based on data presented in Table 7.

Table 7 Comparison of efficiency of selected heat sources as per Regulation by Minister of Infrastructure and Development of 27.02.2015.

№		Type of source	Average efficiency
1		**Coal boiler**	
	a	Produced before 1980	0.60
	b	Produced in 1980-2000	0.65
	c	Produced after 2000	0.82
2		**Biomass boilers**	
	a	Operated manually, fuelled by straw with power < 100 kW	0.63
	b	Operated manually, fuelled by straw with power > 100 kW	0.70
		With automatic operation, fuelled by straw with power up to 100 kW	0.70
	c	With automatic operation, fuelled by straw with power 100-600 kW	0.75
	d	Operated manually, fuelled by wood with power < 100 kW	0.70
	e	With automatic operation, fuelled by wood with power 100-600 kW	0.85
		Closed combustion fireplaces	0.70
3		**Electric heaters**	0.99
	a	Tankless water heaters	0.94
		Electrothermal heaters	1.00
	b	Convector radiators, radiant heaters, infrared floor heating	0.99
		Local oil or gas furnaces	0.84
4		**Masonry heaters**	0.80
5		**Gas boilers**	
	a	Fuelled by gas or liquid, with open combustion chamber, on/off	0.86
	b	Low temperature, with closed combustion chamber, power up to 50 kW	0.87
	c	With closed combustion chamber, power up to 50-120 kW	0.91
	d	With closed combustion chamber, power up to 120-1200 kW	0.94
	e	Condensing boiler with power up to 50 kW, high temperature (70/55°C)	0.91
	f	Condensing boiler with power 50-120 kW, high temperature (70/55°C)	0.92
	g	Condensing boiler with power 120-1200 kW, high temperature (70/55°C)	0.95
	h	Condensing boiler with power up to 50 kW, low temperature (55/45°C)	0.94
	i	Condensing boiler with power 50-120 kW, low temperature (55/45°C)	0.95
	j	Condensing boiler with power 120-1200 kW, low temperature (55/45°C)	0.98
6		**District heating substations**	
	a	Compact substation with housing, with power < 100 kW	0.98
	b	Compact substation with housing, with power > 100 kW	0.99
	c	Compact substation without housing, with power < 100 kW	0.91
	d	Compact substation without housing, with power 100-300 kW	0.93
	e	Compact substation without housing, with power > 100 kW	0.95

№	Type of source	Average efficiency
7	**Heat pumps**	*)
a	Water-to-water, compression-type, electric (55/45°C)	3.50
b	Water-to-water, compression-type, electric (35/28°C)	4.00
c	Brine-to-water, compression-type, electric (55/45°C)	3.50
d	Brine-to-water, compression-type, electric (55/45°C)	4.00
e	Direct expansion, compression-type, electric	4.00
f	Air-to-water, compression-type, electric (55/45°C)	2.60
g	Air-to-water, compression-type, electric (35/28°C)	3.00
h	Air-to-water, compression-type, gas-powered (55/45°C)	1.30
i	Air-to-water, compression-type, gas-powered (35/28°C)	1.40
j	Air-to-water, absorption, gas-powered (55/45°C)	1.30
k	Air-to-water, absorption, gas-powered (35/28°C)	1.40
l	Brine-to-water, compression-type, gas-powered (55/45°C)	1.40
	Brine-to-water, compression-type, gas-powered (35/28°C)	1.60
	Brine-to-water, absorption, gas-powered (55/45°C)	1.40
	Brine-to-water, absorption, gas-powered (35/28°C)	1.60
	Air-to-air, compression-type, gas-powered	1.30
	Air-to-air, absorption, gas-powered	1.30

*) These values are not efficiencies in a classic sense, but only coefficients of heat pump performance referring to ratio of moved thermal power and electric power supplying heat pump, thus, they are not contradicting basic nature laws and do not prove the existence of perpetuum mobile.

It is worth to remember that proper operation of installation, proper care of boiler water purity and its proper preparation (degassing and demineralization) is particularly important not only because of heat transfer efficiency, but also due to installation lifespan, as corrosion and limescale can significantly reduce ability to transfer heat as presented in Table 8.

Table 8 Comparison of selected thermal conductivities.

Material	Thermal conductivity [W/(m2K)]
copper	350
boiler steel	116
carbonate limescale	2.3
silicate limescale	0.3
rust Fe_2O_3	1.1

In case of gas boilers powered by gas, solid and liquid fuels, during an audit it is necessary to conduct burning process analysis. Primary indicator is coefficient named excess-air ratio λ, and exhaust gas temperature. It is measured in flue gas duct in close distance from boiler, based on the amount of oxygen in exhaust fumes [O_2]; this measurement should be performed by a professional. It is represented by this formula:

$$\lambda = \frac{21}{21 - [O_2]}$$

where [O_2] is content of oxygen in flue gas.

This value is a relationship between actual amount of air used for combustion and theoretical value resulting from chemical reaction for the same amount of air (stoichiometric); taking into consideration non-ideal fuel-air blend one should always guarantee certain greater amount of air for combustion than the stoichiometric amount.

This value is specific for each type of boiler and should not exceed values shown in Table 9. Optimal value for this coefficient means that burning process is correct and the boiler has optimal efficiency. For instance, for natural gas, after increasing the coefficient from 1.1 to 1.3, boiler efficiency decreases by ca. 2-3 percentage points, which results in higher labour costs.

Table 9 Value of coefficient λ for various fuels

Type of fuel and furnace	λ
Black and brown coal	1.2 – 1.4*)
Heating oil	1.10
Natural gas	1.05 –1.15

*) - depending on type of boiler furnace.

Analysis of heat loss that results from the condition of insulation of hot water or steam pipes is another very important element of increase of energy efficiency in thermal installations. Each insulation loss and each degraded thermal insulation are directly resulting in heat losses. Similarly, insulating valves is a very good practice. During an audit, inventory of steam and/or hot water installation should be conducted to uncover all missing or damaged elements of insulation. Next, based on formulated conversion factors, one should determine heat loss. Fig. 9 presents a diagram that allows to determine heat loss. It should be noted that except for pre-insulated pipes, shortages in piping insulation occur very often, which, on one hand, results in unjustified increase of temperature in areas in which the pipes are placed; on the other hand, it results in increase of boiler labour cost even by **15%**. Similarly, it is possible to calculate heat loss resulted by uninsulated valves and other hot fittings. The best method of determining temperature of a pipeline is thermal imaging.

Analysis of heat sources and methods of their distribution in an enterprise, as well as implementation of methods suggested in post-audit conclusions, may bring profit of **10-15%** in overall energy balance.

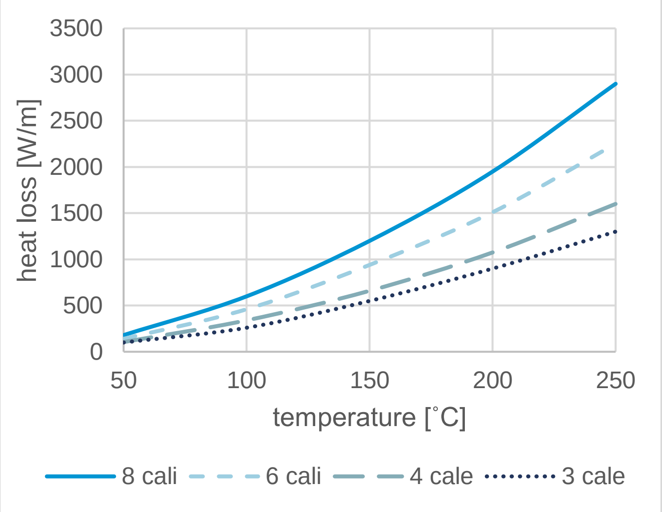


Fig. 9 Relationship between heat loss and temperature for uninsulated pipelines.

Example 5

Determine energy savings that may be gained by replenishing thermal insulation of pipelines. Boiler power is Q_B = 1.52 MW.

The first step is to have an inspection of all vapour and hot water pipelines in terms of any damage. For that purpose, site inspection with thermal imaging has been conducted and the results are noted in a table. A fragment of such listing can be found below. In each case power loss has been calculated using diagram like one presented on Fig. 9.

Place	Temperature [°C]	Diameter d [inch]	Length of section l [m]	Loss [kW]
1	140	0.75	2	0.43
2	170	0.75	2	0.59
3	175	0.75	5	1.40
4	175	0.75	1.5	0.42
5	160	3.2	25	15.23
6	170	3.2	25	16.90
7	80	3.2	25	4.73
8	100	3.2	2	0.55
9	140	0.75	2	0.43
10	165	1	50	15.05
…	…	…	…	…
			Total	**285**

As one can see in this table, total power loss during plant operation time due to lack of insulation, in this case is P_{LOSS} = 285 kW. If this loss is then related to total heating power, it will show a percentage of contribution of these losses in the balance.

Percentage of savings on heat is:

$s_H = P_{LOSS}/Q_B = 285/1520$

s_H = 18,7%

6. Lighting

Energy required for lighting most often constitutes 6-9% of overall energy consumption in an enterprise. If an enterprise has not modernised the lighting in recent years, such modernisation may often bring reduction of energy consumption even by 50-60% (in some cases even up to 90%), while typical payback period is 1-8 years.

There are several methods increasing energy efficiency of lighting. During an audit, firstly it is worth to take an inventory of existing lighting and analyse it in terms of methods specified in Table 10.

If answer for any of the questions is negative, there is a possibility that in case of lighting there are areas that may require improvement.

Table 10 Methods to increase the energy efficiency of lighting.

Question	Yes	No
Have voltage reducers been installed in lighting circuits? **)		
Is lighting in the workplace adjusted to workstation requirements?		
Are motion sensors installed and used in facilities and/or warehouses?		
In the facilities, is sunlight exploited in maximum?		
In the facilities, are light fittings energy-saving/LED?		
Does the existing lighting have proper colour, and does it reflect accurate colour of products?		
Does lighting produce correct light intensity?		
In the buildings, is there a division of light switches that enable to switch on the light in small sections, instead of switching on the light for the whole floors/large rooms?		
Is there a system of improving environmental awareness among the staff?		

**) For some types of light sources, in case of which it is technologically acceptable to reduce supply voltage and full lighting power is not necessary at a given moment, it is possible to achieve savings not by switching those sources off but by temporary reduction of their power.

Replacement of light sources for energy-saving ones must be conducted under certain conditions: it must guarantee amount of luminous power required by standards for a given place and truthfully reflect colours. It may happen that modernisation of lighting, which has small percentage share in overall energy consumption, will cause not only reduction in energy consumption, but also a significant reduction of operating costs of an enterprise due to production quality. Better workstation lighting and better light colour may significantly reduce the amount of produced defective goods and reduce the number of accidents at work. In buildings, lighting modernisation requires detailed inventory of actual state, with equally detailed assessment of the type of used lighting and its usage. Reliable audit may significantly contribute to reduction of electrical energy consumption in an enterprise.

7. Office equipment

During an audit one should also analyse office equipment and household appliances, as they significantly influence costs and energy consumption. The most important element is to check energy efficiency class of the appliances (energy label will be useful), as well as to regularly conduct an audit.

When analysing possibilities of energy consumption reduction in an enterprise, one cannot neglect office equipment. Percentagewise, contribution of such appliances to energy consumption in small enterprises is much greater than in the big ones. It may seem that energy efficiency potential of an office is insignificant and that it shouldn't be taken into consideration. However, it is important in case of service companies, for which main activities are office and intellectual work. There are few areas that should be taken care of.

Using appliances with energy label showing the highest energy efficiency class is very important. What is an energy label? It's producer's declaration, supported by energy consumption research for a given product. Primarily it includes data about energy class of an appliance and other parameters, e.g., generated noise level or amount of consumed water. This information allows the buyer to easily compare products. According to 2010/30/EU directive, significant group of household appliances must have energy labels. Since 1st March 2021 labels for some appliances will change and new energy efficiency rating will be presented. According to currently applied rating, the highest values of efficiency are represented by letter "A" with few additional signs "+". According to the new pattern, to come back to more consistent rating from A to G, expand the rating for the highest values, and create classes for even more effective equipment that will most likely enter the market in the future, names of these classes are changed, eliminating additional pluses in the highest values, and moving individual designations along further letters of the alphabet. Classes A and B remain empty for now, as currently there is no such efficient equipment in the market, while, for instance, a washing machine that until now was in class A+++, after 1st March 2021 will be in class C. Directive 2010/30/EU was replaced by Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017, which at EU level regulates frame obligations for labelling products consuming energy, whereas detailed regulations for individual appliances will be published in separate legal acts issued at a later date (at the time of editing this manual they have not been published yet).

Energy labels apply to the equipment as shown in Table 11.

Table 11 List of equipment subjected to labelling.

Office equipment and electronics	Ovens and cooker hoods (household appliances)
	Dishwashers (household appliances)
	Washing machines (household appliances)
	Refrigerating equipment (household appliances)
	Tumble dryers
	Lamps
	Television
Equipment installed in buildings	Air conditioners
	Heaters (rooms and water)
	Local space heaters
	Solid-fuel boilers
	Ventilation systems (housing)
Other	Industrial refrigeration equipment - refrigerated cabinets
	Tyres

Additionally, it is worth to take care of the following aspects of operation that have influence on energy consumption in office rooms and other rooms in the facilities – in accordance with Table 12.

Table 12 Possible additional activities reducing energy consumption in rooms in office building and other.

The actual state	Activity
Many offices and common areas exploited by many people may be cooled and heated at the same time.	Check whether they are reasonably utilised; whether heating and air conditioning are not used at the same time; whether there is a necessity to create other conditions for a dedicated area; whether permanent partitions are used.
Many issues may be solved without using paper.	Check whether printing paper is reasonably managed.
Many appliances are set for constant standby.	Check whether all electric appliances are disconnected from the grid when they are not used for a longer period.
There are buildings that have skylight.	Check whether sunlight is utilised instead of artificial light wherever it is possible, and whether cleanness of windows, ceilings and walls is maintained.
Windows are the reason for unnecessary cooling of rooms during cold days.	Check whether window blinds are used, as they may significantly reduce air cooling from the windows.
Windows are the reason for excessive warming up of rooms during hot days.	Check whether it's possible to apply protective film on window glass to limit its heating up from the sun.
Lighting in office rooms is often switched on, even when it is not necessary.	Check whether the light is switched off, when it is not necessary, and whether energy-efficient lighting is used, for instance, LED lighting.

8. The facility

Structural audit may be conducted as a separate assignment, nonetheless, it is an important part of energy audit of an enterprise. In general, modernisation of facilities in view of energy consumption (thermo-modernisation) isn't an investment that pays off quickly. However, it may significantly influence other aspects of usage of the facility – heating, thermal comfort, ventilation. Besides high-cost activities that improve energy efficiency of the facility, there are also fast in implementation low-cost activities.

Another audited area, besides installations and utility, should be the facility itself. One should perform evaluation of heat permeability for building envelope - from foundations and floors, through outer walls, flat roof, doors, and outer gates, to roof windows and outer windows. Percentage distribution of losses by individual parts of the facility may vary depending on thickness of the outer walls, as well as the state and thickness of their insulation; age, construction and state of outer and roof windows, type of roof and thickness of its insulation. Nonetheless, in case of short, detached buildings a balance of all losses by building envelope shows that the biggest part of loss is due to flat roof (25-30%) and outer walls (12-18%). The smallest share belongs to doors and floors on the ground (few percentage points). These losses are considerable, and savings gained from reducing them by having a thermo-modernisation can be easily noticed in energy balance of an enterprise. However, because of the costs of such works, payback period is long and usually unappealing - a decade or more. In this case various programmes supporting thermo-modernisation offered by the government and state organisations may be helpful.

In Table 13 main criteria, according to which one may determine level of energy consumption of the facility, are presented. It should be remembered that demand for energy in a building is also related to ventilation system and heat sources in the building.

Table 13 Initial questions for pre-audit evaluation of facility state.

№	Question	Yes	No
1	Do you know in what condition is thermal insulation of walls, ceilings, foundations, flat roofs, floors, or roofs?		
2	Is the condition of the abovementioned building envelope good in your opinion?		
3	Does window and door frame woodwork require modernisation or repair?		
4	Is it necessary to modernise thermal installation or installation for domestic hot water?		
5	Are there linear and point thermal bridges?		
6	Were any actions aiming for elimination of thermal bridges undertaken?		
7	Is BMS (Building Management System) applied in your facility?		
8	Is the process of switching on and off the heating performed manually in the facility?		
9	Is weather regulation applied in your facility?		
10	Are thermostatic valves used in central heating system?		
11	Are there automatic doors in the facility?		
12	Are there vestibules implemented by main entrances to the facility?		

In case of assessment of building envelope, it is hard to determine its thermal permeability. In such case, one needs to rely on construction project, which may not reflect actual state, as the facility may have been altered or subjected to some repairs, and the insulation may have degraded. All deficiencies and “faults” during construction may result in appearance of thermal bridges - areas, where locally a lot of heat transfers outside. It is worth to have an assessment of the state of the building with thermal imaging, which may show areas of loss with great accuracy (most often around windows, balconies, doors, pipeline exits through walls, sharp elevation edges). Assessment of thermal conductivity based on site inspection, construction project and thermal imaging are a base for undertaking structural audit, which is an important part of energy audit of an enterprise.

9. Organisation of work

Proper organisation of work is a non-technical tool to improve economy in an enterprise. Implementation of quality system in an enterprise allows to permanently introduce good standards and favourably influences company's prestige. During an audit it is worth to examine organisation of production in terms of performed technological processes, because if these processes are energy-intensive, their proper management (e.g. moving them for night shift, with lower energy tariff) allows to reduce costs. It is also worth to analyse production process in order to eliminate downtime.

When analysing enterprise activity economy, one should also review organisation of work. Good organisation increases competitiveness and flexibility of the company It also influences operation costs. If electrical energy tariff in an enterprise, as per contract, includes various prices of energy during the day, one should consider moving energy-intensive processes to tariff with reduced costs. Such processes include, for instance, heating of chambers or presses, or cooling of cold stores/freezers. During production, it is worth to avoid machine **short-term downtime**, and to organise production in such a way that the equipment which must be hot during operation would not wait long for another part of intermediate product. Tyre industry is a good example for this, where during vulcanisation, moulding presses must remain hot and they lose heat if they need to wait for intermediate product.

Second element is the concept of implementation of change in work organisation processes. It is worth to consider implementation of management method based on **KAIZEN** concept, that is, constant improvement and pursuit after enhancement of production quality by introducing thinking process on each stage of the production.

Currently we are in the middle of another industrial revolution and more and more companies start to meet requirements called **Industry 4.0**. This production method is based on introduction of the newest management, communication, and production technologies, which considerably improve production rate by its automation and robotization; its quality, flexibility, and competitiveness by reducing unit costs and energy consumption per unit. Substantial progress is achieved by extensive implementation of digitisation into design and production processes. It is worth to analyse automation and integration of production process and possibilities of its improvement. Full integration of processes may triple production rate and reduce energy consumption per unit by more than 10%. Payback period depends on new technology price, but usually it shouldn't be longer than 7-10 years. To evaluate oneself for this, it is worth to check whether some of the criteria shown in Table 14 are met.

Table 14 Enterprise assessment criteria according to Industry 4.0 concept.

№	Question	Yes	No
1	Is the production process based on programmable machines?		
2	Is it possible to place an order online?		
3	Is it possible to automatically place an order for materials for a warehouse?		
4	Is it possible to automatically choose materials from the warehouse?		
5	Is an automatic production of intermediate products or components possible?		
6	Is an automatic handling of elements possible?		
7	Is it possible to automatically set up components for assembly?		
8	Is an automated distribution possible?		

10. Determining effects of modernisation

Primary result of modernisation is reduction of energy consumption. Not every action resulting in energy savings is appealing, as financial effect is the most important one, and which is a basis for a decision on conducting a modernisation.

In case of modernisations which are expected to bring quick results (in a few of years at most), a simple payback time (SPBT) measured in years or months is a good tool to estimate investment's profitability. On the other hand, in case of modernisations with longer payback period (more than several years) a more accurate measure is discounted payback time (DPBT).

Simple payback time may be determined using this formula:

$$\sum_{i=1}^{t} disC_i > C_{INV} \quad \rightarrow \; SPBT = t$$

If one can assume constant saving due to modernisation in years, this formula simplifies to:

$$SPBT \; = \frac{C_{INV}}{C_S}$$

To calculate DPBT, at first one needs to calculate cash flow, that is, discounted amount of cash (income) *disC* in each year, and check in which one the income is higher than the expenditure.

$$SPBT = \frac{C_{INV}}{C_S}$$

To calculate discounted payback time, one needs to first calculate cash flow, that is, discounted amount of cash (income) disC in each year, and check in which one sum of these flows is higher than expenditure.

$$disC_i = \frac{C_{Si}}{(1+r)^i}$$

$$\sum_{i=1}^{t} disC_i > C_{INV} \quad \rightarrow \; DPBT = t$$

where:

t – first year, at the end of which expenditure has been paid back, calculated in annual simulation cash flow, where year of investment counts as year zero;

C_{INV} – costs incurred due to modernisation at its beginning, expressed in currency unit [PLN];

C_{Si} – in calculation of SPBT C_{Si} represents annual net savings (cost savings) in year after year t; in calculation of DPBT C_{Si} is a cash flow in year *i;*

C_S – fixed annual net savings, resulting from modernisation [PLN/year];

$disC_i$ – discounted cash flow in year I;

r – discount rate determined by WIBOR (often assumed as r = 0.04 - 0.1);

i - number of subsequent years.

Optionally, for values SPBT or DPBT, one may determine indicator of investment net present value NPV, like the previous ones, which is a difference between discounted cash flow and initial costs spent for the investment. It determines financial effect of an investment in a given period of time. It can be calculated from the below formula:

$$NPV = \sum_{i=1}^{n} \frac{C_{Si}}{(1+r)^i} - C_{INV} \qquad (1)$$

Investment is profitable, if its NPV in a given period of time will meet value greater than or equal to 0.

General criterion for choosing appropriate solution is minimising overall operation cost in life cycle of the equipment, which can be determined by the following dependencies:

$LCC = C_{MIN}$

and

$LCC = C_{INV} + C_{INS} + C_{EX} = C_{INV} + C_{INS} + C_E + C_M + C_R + C_F$

where:

C_{INV} – investment costs,

C_{INS} – costs related to installation services,

C_{EX} – costs of exploitation during assumed lifecycle,

C_E – total energy costs (mainly electricity, but also, for instance, fuel for cogeneration aggregate with a combustion engine) used for compressor supply and other additional equipment during assumed period of installation exploitation,

C_M – maintenance costs in the assumed period,

C_R – costs of present repairs and servicing,

C_F – costs of removing failure impacts and costs resulting from failure itself.

These simple mechanisms of determining financial profitability of an investment are very useful. However, in some cases it might happen that despite a very appealing payback period and NPV willing to reach positive value soon, the investment couldn't be carried out due to high investment cost. Investment cost consists not only of equipment/machine price itself, but also of several other costs, including related works that very often are expensive.

Another important aspect of modernisation is its environmental effect. It means reduction of CO_2 emission, which results from reducing energy consumption thanks to the modernisation. Determining this effect is an essential element of energy audit. A special document published by the National Centre for Emissions Management (KOBiZE) is used to determine the amount of avoided CO_2 emission. In this document, coefficients of CO_2 emission reduction are described in detail for a given year, depending on fuel or energy source that given installation or equipment uses. The most popular ones:

- for electrical energy from grid this coefficient equals WE = 778 kg CO_2/MWh,
- for heat from natural gas this coefficient is WE = 55.43 kg CO_2/GJ.

However, each year these values need to be checked directly in KOBiZE publications.

For typical efficiency-oriented investments, payback periods, counted as SPBT or DPBT, may reach wide scope of values (Table 15). Individual values are strongly dependant on the type of operation of each equipment, as well as on baseline state of the equipment and installations.

Table 15 Approximate achievable payback periods for selected investments

Activity	SPBT [years]
Changing methods of pump and ventilation regulation	0.5-1.5
Changing methods of compressor regulation	0.8-2.5
Improvement of steam pipeline insulation	2-5
Changing lighting for energy-efficient one	1-10
Exchanging household and office appliances for new, more energy efficient ones	7-15
Microgeneration by photovoltaic cells	9-14
Thermo-modernisation of facilities	6-15
Heat pump installation	4.5-17

For some modernisations, expenditure returns in a very profitable amount of time - in less than a year. This concerns modernisations of pump or ventilation control, including potential replacement of motors. In case of changes in compressed air systems, in which more than one compressor is operating, very appealing payback periods can be achieved as well.

Other investments analysed for their profitability consider installations for heat transfer - steam and hot water. If pipelines are made in state-of-the-art technology employing pre-insulated pipes, then they do not require any modernisations, except for cases of physical damage of such pipes because of, for instance, various types of construction or assembly works. However, pipelines with external thermal insulation are often subjected to degradation, which results in heat loss increase. Modernisation of thermal insulation and reduction of loss is very beneficial, while standard payback period is within 2 to 5 years.

Considering only payback period, one can see that modernisation of light sources is a bit less profitable. It's payback period amounts from several years to over a decade. However, light sources replacement is often a necessity, as current lighting may not meet luminous intensity standards. That is why when deciding to replace light sources, one shouldn't consider only the payback period.

Another financially appealing modernisation is a replacement of office equipment and household appliances for new, more energy efficient ones. It can be assumed that purchasing an equipment, which energy class is one level higher than the energy class of the old equipment, will result in reduction of energy consumption by between 20% to 30%. However, considering higher prices of energy-saving products in comparison to the other ones, it can be estimated that total payback periods are between 7 and 15 years.

In current legal status, installation of own electrical energy sources is possible in each building. However, it is not always a reasonable solution.

Currently, programmes that financially support photovoltaic microgeneration investments are making them more appealing. After summing up all costs and benefits of installation, assuming that it is placed in the sunniest area of the building, payback period is between 9 and 14 years.

Thermo-modernisation of the facility is financially less appealing than all types of investments abovementioned. Of course, it's often necessary. However, for buildings older than a decade, payback of expenditure for thermo-modernising (improving thermal insulation of ceilings, walls, windows, and foundations) will be returned only after about 8 to 15 years. Naturally, payback period strongly depends on the condition of the building before modernisation and its extent, and even more on labour costs and market price of building materials, as the price of the latter can rapidly change in different years. Due to price fluctuations of building materials and usually long-lasting process of the modernisation itself, this type of investment is riskier than the other ones.

The last of the abovementioned suggestions is replacement of heat pumps. These types of modernisations usually consist of replacing existing heat sources by heat pumps and require extensive and expensive installation, construction, and ground works. For facilities which require heating power between 40 and 80 W/m^2, payback period of such investment is between 4.5 to 17 years. Such a big range is largely a result of differences in applied technologies and state of the facility insulation.

Example 6

Calculate *SPBT*, *NPV* and annual savings of toe (tons of oil equivalent), resulting from compressed air system modernisation. The modernisation consists of elimination of compressed air leakages from the installation and implementation of frequency converter on one of the compressors. Weighted average cost of capital is equal to $r = 0.043$ (4.3%).

Eliminating compressed air leakages is a low-cost energy-saving activity.

Annual repair costs and regular installation servicing costs are:

$$C_R = 3\,800 \text{ PLN.}$$

During an audit, the amount of leaked air and annual cost of leakages (avoidable) have been determined:

$$C_L = 7\,200 \text{ PLN/year.}$$

Simple payback time is:

$$\text{SPBT} = C_R \,/\, C_L = 3\,800/7\,200$$

$$\text{SPBT} = 0.53 \text{ years} = 7 \text{ months}$$

NPV has been determined basing on formula (1) by calculating savings (avoided losses), accumulated net cash flow, and finally discounted accumulated NPV in each year and after 10 years.

Years	0	1	2	3	4	5
Income [PLN]	-3 800*)	7 200	7 200	7 200	7 200	7 200
Accumulated net flow [PLN]		7 200	14 400	21 600	28 800	36 000
Discounted accumulated NPV [PLN]		3 103.16	9 721.73	16 067.43	22 151.51	27 984.76
***NPV* (after 10 years) =**	53 736 PLN					

*) – formally, this cost is not an income but investment expenditure, however, they can be simply allocated as negative income in year 0.

Basing on engineering calculations, it has been estimated that due to sealing of installation, annual energy savings will be equal to 4.33 MWh/year. Hence by applying conversion factor of 1 toe = 11.63 MWh, the energy savings have been estimated:

$$L_{toe} = 4.33/11.63$$

$$L_{toe} = 0.37 \text{ toe/year}$$

Example 6

Implementing a frequency converter is an action of medium cost and usually requires purchasing well-matched converter.

Estimated frequency converter cost, basing on market offers, is equal to:

$$C_{FC} = 10\ 250\ \text{PLN}.$$

During an audit, annual financial savings resulting from implementation of a frequency converter has been estimated. It is a result of compressor not operating on neutral gear:

$$S_{FC} = 48\ 000\ \text{PLN/year}.$$

Simple payback time is:

$$\text{SPBT} = C_{FC} / S_{FC} = 10\ 250/48\ 000$$

$$\text{SPBT} = 0.21\ \text{years} = 3\ \text{months}.$$

NPV coefficient has been determined basing on formula (1) by calculating incomes (avoided losses), accumulated net cash flow, and finally discounted accumulated NPV in each year and after 10 years.

.

Years	**0**	**1**	**2**	**3**	**4**	**5**
Income [PLN]	-**10 250***)	48 000	48 000	48 000	48 000	48 000
Accumulated net flow [PLN]		48 000	96 000	144 000	192 000	240 000
Discounted accumulated NPV [PLN]		35 771.09	79 894.86	122 199.53	162 760.10	201 648.47
***NPV* (after 10 years) =**	373 323 PLN					

*) – formally, this cost is not an income but investment expenditure, however, they can be simply allocated as negative income in year 0.

Basing on engineering calculations, it has been estimated that due to sealing of installation, annual energy savings will be equal to 4.33 MWh/year. Hence by applying conversion factor of 1 toe = 11.63 MWh, the energy savings have been estimated:

$$L_{toe} = 5.13/11.63$$

$$L_{toe} = 5.13\ \text{toe/year}$$

Example 7

Calculate SPBT, amount of saved toe and amount of reduction in CO_2 emission for modernisation consisting of replacement of degraded insulation (see Example 5). Insulation degrades due to its ageing, frequent modernisations, and water absorption during failures. Installation operates *t* = 6000 hours per year. Gas price is equal to c_G = 145 PLN/MWh.

Loss of power due to lack of insulation or its degradation is equal to:

P_{INS} = 285 kW

Loss of energy due to lack of insulation or its degradation is:

$E_{INS} = P_{INS} \cdot t = 285 \cdot 6\,000$
E_{INS} = 1 710 MWh/year
E_{INS} = 6 156 GJ/year.

The amount of heat produced by boilers before modernisation was:

E = 9 120 MWh/year.

Pipeline repair cost has been estimated, basing on actual market prices:

C_R = 95 000 PLN.

Thus, annual cost (benefit) of saved energy is equal to:

$C_E = c_G \cdot E_{INS} = 145 \cdot 1\,710$
C_E = 248 000 PLN/year,

Simple payback time is equal to:

$SPBT = C_R/C_E = 95\,000/248\,000$
***SPBT* = 0.38 = 5 MONTHS**

Energy savings [toe]:

$L_{toe} = 1\,710/11.63$

L_{toe} = 147 toe/year

To calculate avoided CO_2 emission, one needs to define a coefficient of CO_2 emission for gas, which is equal to 0.05582 $MgCO_2$/GJ. Therefore, the amount of avoided emission is:

m_{CO2} = $E_{INS} \cdot 0.05582 = 6\,156 \cdot 0.05582$

m_{CO2} = 343.63 MgCO2/year.

List of selected major regulations and standards

- COMMISSION REGULATION (EC) No 245/2009 of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to eco-design requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps, and repealing Directive 2000/55/EC of the European Parliament and of the Council
- COMMISSION REGULATION (EC) No 640/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to eco-design requirements for electric motors
- COMMISSION REGULATION (EU) No 547/2012 of 25 June 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to eco-design requirements for water pumps
- COMMISSION REGULATION (EU) No 327/2011 of 30 March 2011 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to eco-design requirements for fans driven by motors with an electric input power between 125 W and 500 kW
- COMMISSION REGULATION (EU) No 622/2012 of 11 July 2012 amending Regulation (EC) No 641/2009 with regard to eco-design requirements for glandless standalone circulators and glandless circulators integrated in products
- DIRECTIVE (EU) 2019/944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU
- REGULATION (EU) 2017/1369 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU
- Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the labelling of tyres with respect to fuel efficiency and other essential parameters and repealing Regulation (EC) No 1222/2009- COM/2018/296 final - 2018/0148 (COD).
- COMMISSION REGULATION (EU) No 548/2014 of 21 May 2014 on implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to small, medium and large power transformers
- REGULATION OF THE MINISTER FOR THE ECONOMY of 10 August 2012 on the detailed scope and method of executing an energy efficiency audit, a model for energy efficiency audit card and methods for calculating energy conservation
- 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
- ACT of 20 May 2016 on energy efficiency
- ACT of 21 November 2008 on supporting thermo-modernisation and renovations
- ACT of 29 August 2014 on building energy performance
- ACT of 14 September 2012 on labelling of energy consumption
- List of selected major standards:
- PN-EN 16247 – Energy audits of companies and proceeding
- PN-EN ISO 50001 – Energy management systems
- PN-B-02025:2001 – Calculating seasonal heating demand to heat residential and multi-apartment buildings
- PN-EN 12464 – Light and lighting – Lighting of workplaces
- PN-82/E-04040.03 – Photometric and radiometric measurements. Light intensity measurement
- PN-EN 60034-30-1 – Rotating electrical machines - Efficiency classes of motors
- PN-EN 50160:2002 – Voltage characteristics in public distribution systems
- PN-EN 61000-6-4:2008 – Electromagnetic compatibility - emission standards
- PN-EN 60076-1:2001/A1:2007 – Power transformers

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- Page 13, Picture 3 – Own work
- Page 13, Picture 4 – Own work
- Page 14, Picture 5 – Own work
- Page 14, Picture 6 – Own work
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- Page 18, Picture 7 – Own work
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- Page 21 – Designed by Freepik
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