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VYTVOŘENI METODIKY ZAVÁDĚNÍ SYSTÉMU MANAGEMENTU HOSPODAŘENÍ S ENERGIÍ VE VÝROBNÍM PODNIKU

DEVELOPMENT AND IMPLEMENTATION OF ENERGY SAVINGS AND ENERGY MANAGEMENT METHODOLOGY IN AN INDUSTRIAL ENTERPRISE

DOKTORSKÁ PRÁCE
DOCTORAL THESIS

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ABSTRACT

In recent times energy consumption and energy savings challenges have come on line both at the national and corporate levels and been under debate among researchers and experts. Mankind has entered on the transitional path from getting energy from mineral resources, which are limited, to the renewable resources. However investigation and implementation of modern renewable technologies are embarrassed by question of investments and time expense. Because of that energy efficiency lays in the center of the European energy safety strategy, which is one of the most cost effective ways to enhance security of energy supply. Enterprises are one of the biggest energy suppliers. Thus this research is focused on the problems of energy saving and improving of energy efficiency at the enterprise. This work represents the development and implementation of energy saving and energy management methodology in vehicle production process of an enterprise. Method of energy consumption visualization in virtual reality environment is also created and considered.

KEYWORDS

energy savings, energy efficiency, energy management, methodology of energy savings, reducing energy consumption, production process, energy visualization and monitoring, virtual reality

ABSTRAKT

V současné době se problematika energetických úspor dostává do popředí zájmu jak na úrovni jednotlivých podniků, tak i na úrovni celého státu. Často bývá příčinou sporů ve vědeckých kruzích i mezi odborníky z praxe. Lidstvo tradičně začalo využívat energii z minerálních přírodních zdrojů, které však ve srovnání s obnovitelnými zdroji energie mají omezení. Výzkum a implementace moderních technologií jsou ztíženy otázkou investic a časově omezeny. Proto se evropská strategie energetické bezpečnosti zaměřuje na energetickou účinnost, která je jedním z nejefektivnějších způsobů zlepšení bezpečnosti spotřeby energie. Velké společnosti a podniky jsou jedním z hlavních spotřebitelů energie. Proto je tato vědecká práce zaměřena na problematiku úspor energie a zlepšování energetické účinnosti podniku. Těžiště práce spočívá ve vytvoření a zavedení metodiky pro úsporu energie a managementu hospodaření s energií ve výrobním procesu automobilového podniku. Dále je pro účely této práce vytvořen a popsán způsob vizualizace spotřeby energie v prostředí virtuální reality.

KLÍČOVÁ SLOVA

energetické úspory, energetická účinnost, hospodaření s energií, metodika snížení energetické spotřeby, výrobní proces, vizualizace a monitorování energie, virtuální realita

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DECLARATION

I declare that I have written my doctoral thesis on the theme of “Development and implementation of energy savings and energy management methodology in an industrial enterprise” independently, under the guidance of the doctoral thesis supervisor and using the technical literature and other sources of information which are all quoted in the thesis and detailed in the list of literature at the end of the thesis.

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TABLE OF CONTENTS

Figures and Tables

The list of abbreviations

GDP – Gross Domestic Product

CENEF – Center for Energy Efficiency

CEMEP – European Committee of Manufacturers of electrical equipment and power electronics

IEA – International Energy Agency

EnMS – Energy Management System

EnPIs – Energy performance Indicators

EMS – Environment Management System

LCA – Life cycle assessment

CEN – European Committee for Standardization

HVAC – Heating Ventilation and Air Condition

kW – kilowatt

kVar – kilovolt-amperes reactive

kVA – kilovolt-amperes

HP – horsepower

VR – Virtual reality

1 INTRODUCTION

The problem of energy resources and their constant reduction is discussed at all political levels and all over the world. The developed and developing countries, energy-exporting and energy-importing countries pay attention to the energy problems to a greater extent. Due to the fact that non-renewable resources are finite it is necessary to develop a new way of energy production. A large amount of money is invested to new innovation projects and production of clear energy. Wind energy, solar energy, energy of biomass as the types of energy production represent new directions of future human development and absorption. In European Union these kinds of getting energy are utilized, but not everywhere. Educated personal and investments are required. Because of that in European Union and some developing countries as Russia and China the available technologies are actively and purposefully improving besides of development of new ways of energy production [1].

There are two different ways of solving energy problem (extensive and intensive); and intensive way is more suitable. The **extensive way** is a way of increasing milling operation by prospection of new deposit of minerals. Right now extensive scenario is more preferable, but in future collapse of some minerals can happen. Some countries almost have come to the line of own limit of mineral resources. That’s why intensive way has to become at the first place within problem of future energy.

The **intensive way** consists of an energy efficiency increase of using technologies. Under modern market conditions due to energy efficiency technologies one tone of equivalent oil costs less in 3-4 times then one tone of mining fuel [2].

Three principal potentials of energy efficiency savings are marked out. The first potential lies in buildings savings. The plan focuses on instruments to maintain the renovation process in public and private buildings and to improve the energy performance of the used components. The second large potential includes transport. Different transport modes — rails, road, sea and air must be used and combined effectively. More environment-friendly and energy-saving forms of transport must be promoted. And the third one lies in an industrial sector, and this work is dedicated to the third potential of energy efficiency savings.

This circumstance was a reason to develop and to increase energy efficiency of energy consumers in many countries. During last quarter of XX century, for example, energy capacity of Germany decreased in 2.5 times [3].

Thus this dissertation work is directed to search the potential of energy efficiency improvement in an enterprise. The work consists of two main parts. In the first part the possible way of saving energy by using energy management system and energy saving technology solutions are considered. Possible payback period of implementation is founded. In the second part energy flow visualization method for machine tools for clarifying aspects of using energy is developed.

2 STATE OF ART

2.1 Energy efficiency in the World pollution

According to one of many studies in this area [4] the EU is able to reduce cost-effectively their energy consumption by 20% compared to current levels, which corresponds to EUR 60 billion per year in terms of money or aggregate energy consumption of Germany and Finland in 2000 [5]. The study also notes that the energy efficiency is undoubtedly the fastest, most efficient and cost-effective way to reduce greenhouse gas emissions and improve air quality. Energy efficiency is also an important factor in the management of natural resources, sustainable development and can play a significant role in reducing the dependence of the European economy from these resources. Although large-scale initiatives to increase energy efficiency require significant investments, their implementation is capable to make a significant contribution to achieve the objectives of the Lisbon strategy, contribute to the creation of millions of new jobs and boost the competitiveness of the European economy [4]. On this basis, the EU announced the adoption of the Action Plan on Energy Efficiency. This plan was designed to provide savings up to 20% of the energy consumed in the countries of the European Union (about 39 million tones oil equivalent) and 27% of the energy consumed by manufacturing industries. This will reduce the annual direct costs of energy consumption in the EU by 100 billion Euros and reduce annual CO_2 emissions by 780 million tons by 2020 [6].

Many of the industries over the last 20 years have made significant energy efficiency improvements. The main targets of market enterprises are increasing productivity and product quality, reducing costs and expanding into new markets. EU legislation on energy efficiency was adopted relatively recently, although by this time some EU countries already have national regulations in this area. In most cases, the activity was carried out by enterprises on a voluntary basis and was aimed at costs reduction, but the EU and individual Member States also contributed to this process. According to the forecasts, the greenhouse gas emissions associated with the production of energy by the year 2050 can be returned to the level of 2006, while the growth in oil consumption may be limited based on the technology available at the moment, mainly due to higher energy efficiency. Energy efficiency improvement is priority for more sustainable future from an energy point of view and in many cases is the cheapest, fastest and environmentally acceptable approach to reduce emissions and limit the growing energy needs.

Energy is the same resource for the production, as well as other kinds of valuable raw materials. Its use is associated with the cost and environmental impact. Effective management of the use of energy is an important factor in increasing the profitability and competitiveness of the business, as well as to mitigate the adverse effects on the environment [7].

The energy efficiency improvement takes an important place in EU policy documents. The analysis of the economic and environmental aspects of the implementation of best available technologies within the enterprise should take into account the importance of energy efficiency in the context of emission limit values and other equivalent parameters. As noted in the documents of the European Commission, it is expected that the integration of new technologies into the production process as a whole will have a positive or more or less neutral impact on the profitability of enterprises. The advantage of energy efficiency is that measures aimed at reducing the impact on the environment, as a rule, and provide financial returns from energy efficiency. For specific technologies and methods reported data on benefits and costs are given in following chapters. These data can be used in making decisions about the implementation of various technologies. The economic and technical feasibility of appropriate modernization should be analyzed in the case of the introduction of technology in existing enterprises. Under current conditions there is an alternative to increase the energy efficiency of energy production and it is one of the priorities of energy policy. The peculiarity of the new stage of the world energy is based on the principles of sustainable development, environmental protection and ecological safety. The major global challenges of energy in the future are:

- effective use of non-renewable and renewable energy resources;
- increase of the role of clean energy and stimulation of the search for new sources of energy;
- the development of research on new energy-efficient technologies [8].

2.2 Kyoto Protocol

The Kyoto Protocol is an international instrument adopted in Kyoto (Japan) in December 1997, in addition to the United Nations Framework Convention on Climate Change. The Protocol entered into force in 2005. The Kyoto Protocol is the first global agreement on the protection of the environment, based on market mechanisms of regulation - the mechanism of international trade quotas on emissions of greenhouse gases.

After the signing the Kyoto Protocol began the process of changing the world's energy policy and the creation of forms of production and consumption of energy. Future trends in energy policy XXI in the direction of protecting the environment from pollution are: development of new clean energy technologies, both traditional and emerging forms of energy; the development of effective control over the efficient use of natural-resource potential and the quality of the environment: air, water and land. In this context, any analysis of the future of Europe's energy supply, especially the various alternatives must take into account two new factors. In Europe Union one of the most important policy measures improving energy efficiency has become a system of greenhouse gas emissions trading.

Nowadays it is generally accepted fact which endangers the harmonious development of the world. It should be noted that the Kyoto Protocol is only a first step in the fight against climate change. An effective policy towards sustainable development, solving the problem of climate change, at the same time would strengthen energy security. Today the European energy market cannot be developed without taking into account the problem of climate change and sustainable development objectives. The European Union will not be able to fulfill the commitments under the Kyoto Protocol, unless steps are taken to reduce energy demand. Firm policies to combat climate change should not hurt economic development. This policy should serve to promote new technologies and accelerate structural change and lead to greater efficiency of energy production and increase European competitiveness. Through the policy of promoting environmentally friendly technologies The European Union should support the efforts of other countries to address the challenges of climate made the territory of these countries. This is especially true in countries where there is rapid economic growth. The problem of climate change has had an impact on the willingness of countries - members of the EU to conduct comprehensive energy conservation measures at Community level and take on binding commitments. The Action Plan to increase energy efficiency in the European Community, which was adopted by the Commission in April 2000, represents the targets for the implementation of two-thirds of cost-effective energy savings potential by 2010. In several European countries one of the components of energy security is the protection of the environment and the achievement of climate stabilization, which was largely due to the advent of the greenhouse effect and global warming as a result of the use of primary energy - coal, oil and gas. Much attention is paid to the greenhouse effect. The quantitative emission limitation or reduction of emissions for the period from 1 January 2008 to 31 December 2012 was proposed. The purpose of limitation is to reduce by this period the cumulative average emissions of six types of gases (CO_2, CH_4, HFCs, PFCs, N_2O, SF_6) on 5.2% compared with 1990. Major commitments were made by industrialized countries to reduce emissions:

1) EC - 8%;
2) Japan and Canada - 6%;
3) The countries of Eastern Europe and the Baltic States - an average of 8%;
4) Russia and Ukraine should keep the average annual emissions in 2008-2012 at the level of 1990 [9].

At present the annual global greenhouse gas emissions is estimated at 25.7 billion tons (more than 25% are in the U.S., about 25% - to the EU, 14% - China, 7% - Russian). In order to prevent catastrophic climate change the Kyoto Protocol requires decreasing their emissions of greenhouse gases and reducing them by 5.5 %. Many experts are assessing the costs and benefits of reducing greenhouse gas emissions, developing appropriate environmental and economic programs, conduct discussions on the mechanisms of transfer of emissions allowances, carbon taxes, etc. [9].

2.3 Government policies according to energy consumption and energy efficiency in industry of Russia, USA and EU

International Energy Agency set up a goal to reduce energy intensity of Gross Domestic Product (GDP) by 40% till 2028 year. The same aim is set up for Russian energy government but with different date, by 2020 year. Obviously, such an ambitious goal cannot be achieved automatically by the simple combination of the favorable factors. According to estimates Center for Energy Efficiency (CENEF) given in the Russian State Program Federation «Energy conservation and energy efficiency for the period up 2020» through measures program should be ensured reduction of energy GDP by 13.5% to 2020 solution to this problem is impossible without the development and implementation quality and comprehensive energy efficiency policies [10].

In 2008 was published a list of 25 recommendation activities for increasing energy efficiency in various sphere by IEA. These recommendations do not affect all possible measures, but provide useful basis for their ordering and for cross-country comparisons in this area. One of the sectors, where administration measure of energy efficiency policy is strongly restricted is industrial sector. This administration influence regards only energy management and energy audit. U.S. law and European energy saving in industry paid to it much more attention. Analysis of the number of policies applied in the EU industry MURE project showed that in Germany there are 30 applied policies; in France – 14; in the UK - 13; in the Netherlands – 9 [11].

State regulation of industrial energy efficiency can be focused on two main groups of industries:

- Large energy-intensive industries (energy, ferrous metals, nonferrous metallurgy, chemicals and petrochemicals, pulp and paper industry, cement industry). The main software tool for energy-intensive activities is a target to reach agreement specified indicators to improve energy efficiency. An important direction to achieve these indicators is the modernization of the main technologies in energy-intensive economic activities;
- Medium and small enterprises. The main tool for non-energy activities is the creation of the mass implementation of typical technical projects through the implementation of program activities, by which provided motivation industrial consumers energy to these projects. An important way to increase the efficiency for these industries lies in the modernization industrial equipment.

The main policy instrument for energy-intensive activities, the so-called goal settings arrangements, is the formation of long-term (5-12 years) target energy efficiency agreements between government and industry associations and (or) large holdings and companies. These agreements are fixed targets energy efficiency agreement plans to improve energy efficiency at the company level and (or) plants; formed reporting and monitoring process to achieve the target installations; schemes are tax and other incentive plans and program implementation support for energy efficiency in industry [12]. Goal settings agreement - is a partnership between business and government to improve energy efficiency, reduction of harmful emissions into the environment or greenhouse gases. Under this arrangement, the government prepares and concludes with industry associations or large holdings agreement on targets to reduce energy intensity of main industrial products. Enterprises and holdings that have accepted such agreements may be granted by tax breaks and subsidies for the purchase of energy-efficient equipment or lower taxes on emissions. In addition, they thereby demonstrate its social responsibility, and their credit rating is improved by reducing their «carbon influence».

For the implementation of agreements on energy efficiency improvement requires the following 10 steps:

1. Set the goal of **reducing energy intensity** of industrial production by 2020;
2. For some industries the Department of Energy Ministry of Economic Development and (or) the Ministry of Industry and Trade **prepared the «Guidelines for the Measurement of energy efficiency in the industry»** as is already done in many countries. Targets can be formulated in terms of absolute volume of savings, reduce unit costs, or make changes in an index of energy efficiency;
3. Determine industrial groups and holdings, as well as possible, unions and associations that may become parties to the **agreements to increase energy efficiency**. Define threshold of energy consumption, since which the company may become a party;
4. Produce decomposition goal of reducing energy intensity in industry system goals of **reducing energy intensity** of basic industries (as a weighted average of the main product) and (or) for certain industrial products for industrial agreements;
5. Form a system of comparing energy efficiency parameters ("Benchmarking") to individual businesses, in which they can compare their unit costs with the average for the industry and with the "ideal" specific consumption for technologies that work in similar conditions. Furthermore, this system should provide advice on the implementation of activities and assess changes in the level **rating of the enterprise energy after implementation of the proposed activities**;
6. Industry groups, companies, associations, or associations within these agreements are signed **conduct energy audits and develop a plan to improve energy efficiency** to the target level. Should be prepared the «Guidelines for the preparation of improvement plans energy efficiency». Companies undertake under this plan to implement projects with payback within five years and introduce standards energy management;
7. Negotiations government representatives and industry associations in agreement **establish targets and plans**. Targets and plans are reviewed at least one time every five years;
8. Consistent annual reporting forms to **implement the plan achieve target parameters and improve energy efficiency**. A system of monitoring and

verification of the data is determined by the authorized government agency for work on monitoring and verification;

9. Identifies financial incentives for participants target agreements, successfully implementing plans and **reaching the target parameters increase energy companies** and associations, as well as fines for not fulfilling the obligations;
10. Evaluating the effectiveness of **targeted energy efficiency agreements** authorized by the government conducted analytical center at least 1 time in 3 years.

The task of evaluating is to formulate recommendations for improving the program and evaluate its direct and indirect effects. In the Netherlands, the history of application of this mechanism starts with the 1992 Agreement entered into with companies that consume more than 17 thousand toes. Target setting was to reduce specific energy consumption by 30% in 2005-2020. The program involved 900 companies. In the period of 1998-2007 Dutch industry decreased energy consumption by an average of 2.4% per year versus 1.7% average for the EU [10].

International government by policies and government orders are trying to reduce energy consumption. This kind of work in Europe and U.S. is going for the last 20-35 years, but Russia has started to form a list of orders and normative base of documents about 5 years ago. The meaningful event was the acceptance of Federal Law N261 «About energy consumption, increasing of energy efficiency and changing different enations of Russian Federation». From this point on rulemaking at the federal level in the field of energy efficiency developed on a «Big bang». Since 2009, at the federal level there have been several tens of regulations that govern the relations in the field of energy conservation and energy efficiency. Also, was amended a number of already existing regulations. Today we can count more than 70 legal acts, which regulate relations in the field of energy conservation and energy efficiency and style mechanisms to implement the requirements of the Federal Law number 261 and the State Program of the Russian Federation «Energy conservation and energy efficiency for the period up to 2020» developed countries spent on the establishment of a regulatory framework for energy efficiency two to three decades. Russia tried to «compress time» and do the same job for 2 years. On this path, unavoidable costs both in terms of completeness of the regulatory framework, as well as its quality [13].

In the follow below table is presented a structural comparison between Russian policies of increasing energy efficiency in industrial sector to International Energy Agency recommendation.

Table 1: «Comparison of International Energy Agency recommendation and Russian energy efficiency policies» [14]

IEA recommendations	Russian energy efficiency policies
Governments should support the work of the IEA indicators energy efficiency, which is the basis of an important policy analysis, ensuring that accurate data on energy consumption in industrial sector are regularly reported in the IEA	Government order establishes a series of indicators for energy-intensive industries Industry and system monitoring software, which will track indicators of energy efficiency in industry.
Governments should consider the adoption of mandatory minimum standards for electric generating capacity, based on international best practice	Federal law sets mandatory energy audits for organizations with the state or municipality, organizations engaged in regulated activities and organizations engaged in the production.
Governments should examine barriers to effective optimization energy use in electric systems, as well as to develop and implement policy packages aimed at overcoming these obstacles	Government decree establishes that the Ministry of Regional Development provide to the operator of the state information system information, including data on the implementation of the requirements of a technical documentation accompanying the goods in the product labeling on their labels and information about energy efficiency classes of goods.
Governments should consider the effective assistance development of energy management through the development and support tools, training, certification and training experts in this field	Government Decree approves regulations on requirements for collection, processing, collating, analysis and use of energy certificates based on the results of mandatory and voluntary energy audits.

Governments should consider developing and implementing a package of policies and measures to promote energy efficiency in small and medium-sized enterprises	Order of the Ministry of Energy sets the format of energy certificates. Standards for energy efficiency of electric motors available. But the package of measures to promote energy efficiency in small and medium-sized enterprises and certification of energy managers are missing.

Besides goal settings arrangements and recommendation in the world there is significant experience realization policy increasing energy efficiency in industrial sector. Implementation and successful exploitation require follow measures:

- development of statistical observations of the levels of energy efficiency in industry and state park consuming equipment;
- introduction of a system of formation of targets increase energy efficiency, system comparison with best practices ("Benchmarking"), as well as monitoring the implementation of the target system agreements on energy efficiency and effectiveness programs on standard projects;
- introduction of new standards and technical regulations for industrial equipment;
- industry energy audits, including specialized for individual types of industrial systems equipment, energy saving and the development of plans;
- establish standards for energy management and the organization of training and providing them with information systems;
- support the development of energy service business for maintenance and energy efficiency standard basic types of industrial equipment;
- introduction of subsidies and tax breaks;
- introduction of support for energy efficiency in industry by utility companies;
- regulation of tariffs for energy.

An important source of data for the information system in the field of measures to improve energy efficiency can become a state energy registry, which included information about the organization and its principal activities; production volumes of major products, services, consumption of energy resources on the efficiency of energy resources; reports on energy surveys, reports on the implementation of the recommendations of energy audits. Based on the information state energy registry should form the generalized information about the efficient use of energy resources and energy conservation, ways of increasing the efficiency of energy resources collectively by economic activity, producing the most energy intensive products and services, the public sector, housing and communal services, other sectors of the economy.

In order to enhance the efficiency of energy resources, generalized information about the efficient use of energy resources should refer to publicly available information, except for information, access to which is limited by federal law (restricted access information). Ministry of Economic Development through its subordinate Federal State Statistics Service, and specially selected consulting firm should establish a system for comparing the energy efficiency requirements («benchmarking») for companies producing similar products. Under this system, companies will be able to compare their unit costs with the average for the industry and with the «ideal» specific consumption for the world's best technologies, working in similar conditions. In addition, the system should provide advice on the implementation of activities and assess changes in the level rating of the enterprise efficiency after implementation of the proposed activities. The system should operate in two modes:

- compulsory and impersonal, which contain data on the specific energy consumption for the production of industrial products for enterprises; but the company is not listed. It is also uses foreign data, including data specific benchmarking information systems and indicators of global best practices in the level of energy efficiency;
- voluntary with mentioning the company name. In this case, the system rating companies voluntarily created on the basis of industry associations with the support of industrial research and information center. The work is organized in the form of annual special workshops, as well as a page on the Internet and heading in specialized publications.

Creating this system will establish a reliable information base for the preparation of goal-setting agreements on improving energy efficiency and provide reliable rapid assessment of energy saving potential in enterprises, as well as provide a basis for the development of their plans to improve energy efficiency. Special information campaign will help Russian companies to identify and implement energy-saving potential. There is a need to make information about energy-saving projects more accessible and useful for industrial enterprises.

Since 2012 in the U.S. has launched a certification program «Superior Energy Performance» which will provide industry technology roadmaps for continuous improvement of energy efficiency while maintaining competitiveness. The program provides a clear and universally accepted system of checks to improve energy performance and management practices. The central element of the program is the introduction of a global standard ISO 50001 energy management with additional requirements to achieve and improve the energy performance of registration. According to experts, the program requirement of ISO 50001 standard SEP can improve the energy efficiency of industrial enterprises from 10% to 30% [15].

In the EU an important measure of energy efficiency industry became Directive 2005/32/EC on eco-design, which sets standards for 40 types of industrial equipment (including motors, pumps, refrigeration equipment, lighting systems, furnaces, hydrant equipment, etc.), as well as Directive 2004/8/ES22 for Energy Efficiency Trends and Policies in the Industrial Sector in the EU-27. Standards are introduced in stages, with a gradual tightening of requirements [7].

For the stable and interconnected work of defined enterprise all necessary acts, normative documents, directive have to be combined under control of energy management. The guidelines and checklists for plan of energy conservation and energy efficiency of the industrial enterprise should be developed. This will standardize the development of plans, conducting their feasibility study, which in turn will allow them to compare and summarize their performance. The plan shall contain: a description of the enterprise, the energy balance of the enterprise, assessing the energy efficiency potential for the realization of the list included in the action plan, the forecast energy prices, investment, scheduled plan, the expected effect of energy and cost savings.

2.4 Energy consumption and energy efficiency

Energy efficiency and energy savings as arrangements for providing energy security take one of the leading places in the strategy of European Union. According to the plans of the European Commission by 2020 through the implementation of programs in this area member States will be able to save up to 20 % of the energy [16]. Since 2008 every member of the European Union has to develop a national energy efficiency plan in compliance with all requirements of the European Commission. Thus, the energy policy of the European Union has a response to threats to energy security integration association. Since the energy independence and stable supply of energy and power are the foundation of economic growth and prosperity of EU citizens, the development of energy policy issues has begun to be transferred to the management of the national authorities of the Union. At the present stage of development of the EU's energy policy is one of the leading areas of its internal and external policies. It is a strategy, which aims to achieve energy independence in the region and ensure energy security for all EU members. However, it should be noted that the debt crisis in the Member States will be an obstacle to the active implementation of the energy policy. It is clear that at present the main EU funding will be channeled to support the single currency - the euro, so the launch of large-scale projects in the field of energy security is unlikely. EU countries will maintain focus on traditional energy markets and the use of fossil fuels.

Energy efficiency is a term that widely uses qualitative data indicating the means to achieve various goals, including those of national and international policies and goals of the business, the most important of which are:

- reducing carbon emissions;
- improving security of energy supply;
- cost reduction (increase business competitiveness).

At first sight, the concept of "energy efficiency" seems to be simple to understand. However usually, it is used without strict definition, whereby the term "efficiency" can mean different things at different times in different locations and circumstances. As a result of this uncertainty the use of the term has been described as "evasive and non-permanent," leading to the "inconsistency and confusion." In situations where you want to express the energy savings quantified, there is no universally accepted definition of "a serious obstacle, especially in cases of comparative analysis of large enterprises or industries" [17].

Energy efficiency (and its opposite - inefficiency) in the context of manufacturing enterprises can be considered in two ways, which can be defined as follows:

I. The ratio of energy input to the output of a process (the number of products, services, work, or other forms of energy)

II. Rational (or effective) energy - optimum use of energy in amounts as desired and at the time when it is needed. Inefficiency (wasteful and inefficient use) is the result of sub-optimal ratio between the cost of energy and the need for it, which could be due to the reasons such as inadequate design solutions, operation or maintenance, operation of the equipment in the absence of the relevant requirements, implementation process at a temperature higher than necessary, the lack of adequate measures for the storage of energy, etc.

Methods to improve energy efficiency are described in a variety of sources available in many languages. In this paper the basic concepts and approaches relevant in the context of reducing energy consumption, pollution prevention and control at the level of the entire manufacturing enterprise are discussed. Traffic data and other sources show that increasing energy efficiency at the level of individual components and the use of certain techniques can provide some energy savings, a substantial increase in energy efficiency requires a comprehensive optimization of enterprise systems in general and in its composition.

The priority given to energy efficiency of individual components can lead to too narrow view of the problem of energy efficiency. In some cases, the direction of financial and other resources for private events lead to the diversion of resources from the implementation of integrated solutions that could provide much greater energy efficiency.

Energy efficiency saves energy and money on utility bills, helps to protect the environment by reducing the demand for energy sources that in turn reduce emission of greenhouse gases. Efficient use of energy is the most important and economical, but at the same time the most underused and misunderstood way of increasing profitability of an enterprise. Energy efficiency basically means doing more with less energy – irrespective of whether the notion is defined by engineers, financiers, owners, or politicians [17].

There are a lot of studies on the theme of energy savings and energy efficiency improvement. Based on the literature analysis two main approaches to decrease energy consumption were determined:

1. Energy management such as energy audit, energy efficiency, energy training program
2. Energy technology, which is directly improve manufacturing system of energy efficiency

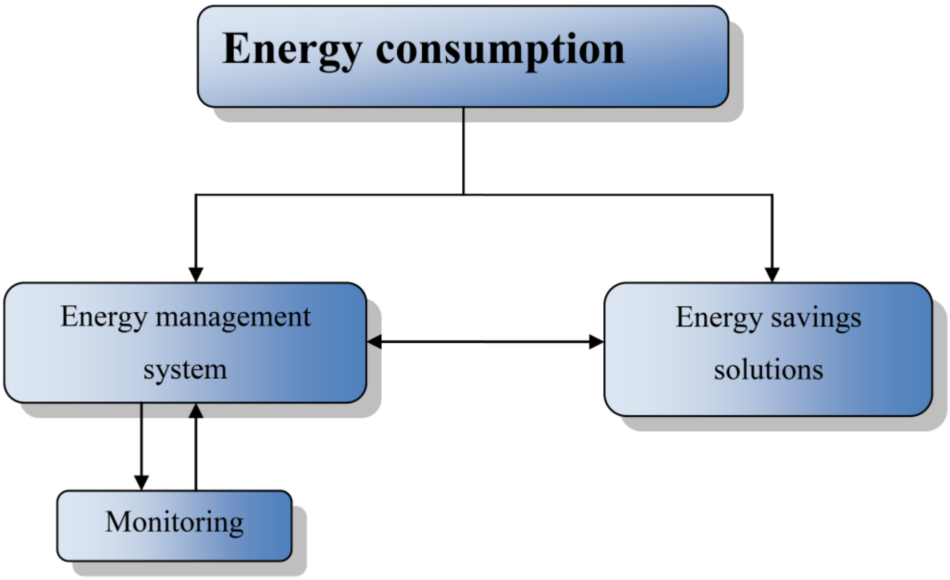

Figure 1: Possible ways of energy savings in the enterprise

Based on the conducted analysis of the different studies on the theme of energy efficiency, analysis of standards, directives and laws, I found out the absence of methodology based on the requirement of standards and laws of European Union, which demand to systematically accomplish performance targets regarding energy consumption reduction in the production process and to search potentially significant elements of the system. Such methodology is presented in part below and based on the principle of quality management PDCA (Plan, Do, Check, Act) figure 2.

Plan

In the planning phase, the first step in the PDCA cycle, a have to be analyzed problems and the potential causes. Solutions and plans to test and improve on the problem have to be proposed. Standards and goals for completion are determined. Management must also determine who will implement the plan, what exactly will be done, when it will begin and where the components of the plan will be implemented.

Do

Implementing and completing the production process involves carrying out and following through on the plan. The business tests the proposed changes and recording specific actions taken during the second phase in the PDCA model.

Check

The third step of the PDCA cycle involves analyzing the data. For some businesses, this can include comparative sales analysis as to how the results measure up with the predictions made in step one. An evaluation of consumer satisfaction may be appropriate in some cases to see if the product has improved over a previous survey.

Act

Businesses using the PDCA cycle will use the results of the previous step to redesign as necessary. If the process works and goals are met, including the modifications into current production or management is part of the action step. If goals and standards are not met, the PDCA model calls for the business to take action by incorporating what was learned and beginning the planning step again, thus repeating the four-step model.

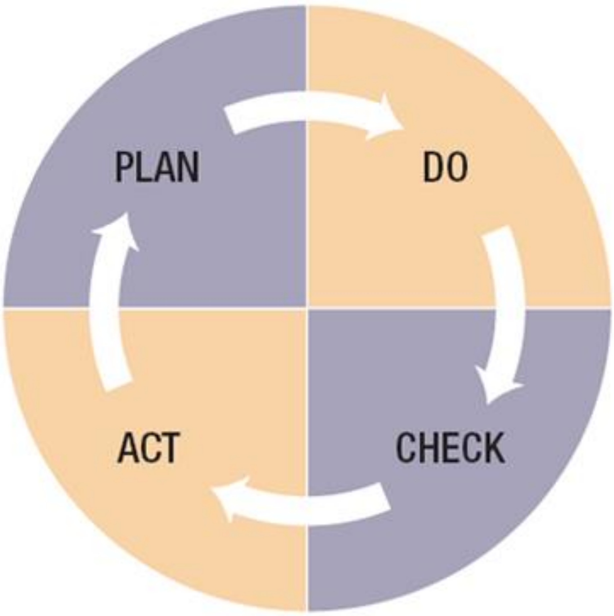

Figure 2: Continuous improvement with PDCA cycle [18]

2.4.1 Energy management system

Appropriate management system provides the framework and foundation for the assessment of the current level of energy efficiency, identifies opportunities for improvement and ensures continuous improvement. All effective standards, programs and leadership in the field of energy management (as well as environmental management) contain the concept of continuous improvement, assuming that energy management is a process, not a project, which will sooner or later come to the end. The best performance is achieved by the means of energy management systems with following components:

Energy policy - energy policy, action plans, as well as regular analysis and evaluation of the system are part of the commitment of senior management within the overall environmental strategy. The organization creates a framework for action with respect to its intentions and principles of energy efficiency;

Organization - a company, association, firm, enterprise, authority or institution, or part or combination thereof, whether incorporated or not, public or private, which has the authority to manage their energy use and energy use;

Motivation - both formal and informal channels of communication, which are regularly used by managers and staff responsible for energy and energy efficiency at all levels;

Information System - a comprehensive system encompassing tasking, monitoring energy consumption, gaps identification, energy savings quantification;

Marketing - promotion the value of energy efficiency and the effectiveness of energy management within and outside the organization;

Investment - positive preference in favor of "green" investment schemes with a detailed analysis of all possibilities for new construction and modernization of existing facilities [18].

Certain energy savings can be achieved by individual components optimization, but the greatest potential for energy savings is associated with the use of the system approach. This approach launches at the enterprise level with consideration of its component of manufacturing units or system optimization. The system approach is important in connection with the use of energy resources. Traditionally, efforts are focused on the optimization of the energy managers of energy-consuming processes and equipment. The organization should maintain a system and ensure the appropriate level of knowledge, understanding and compliance of procedures. Therefore, effective energy management includes the following components as can be seen from Figure 3.

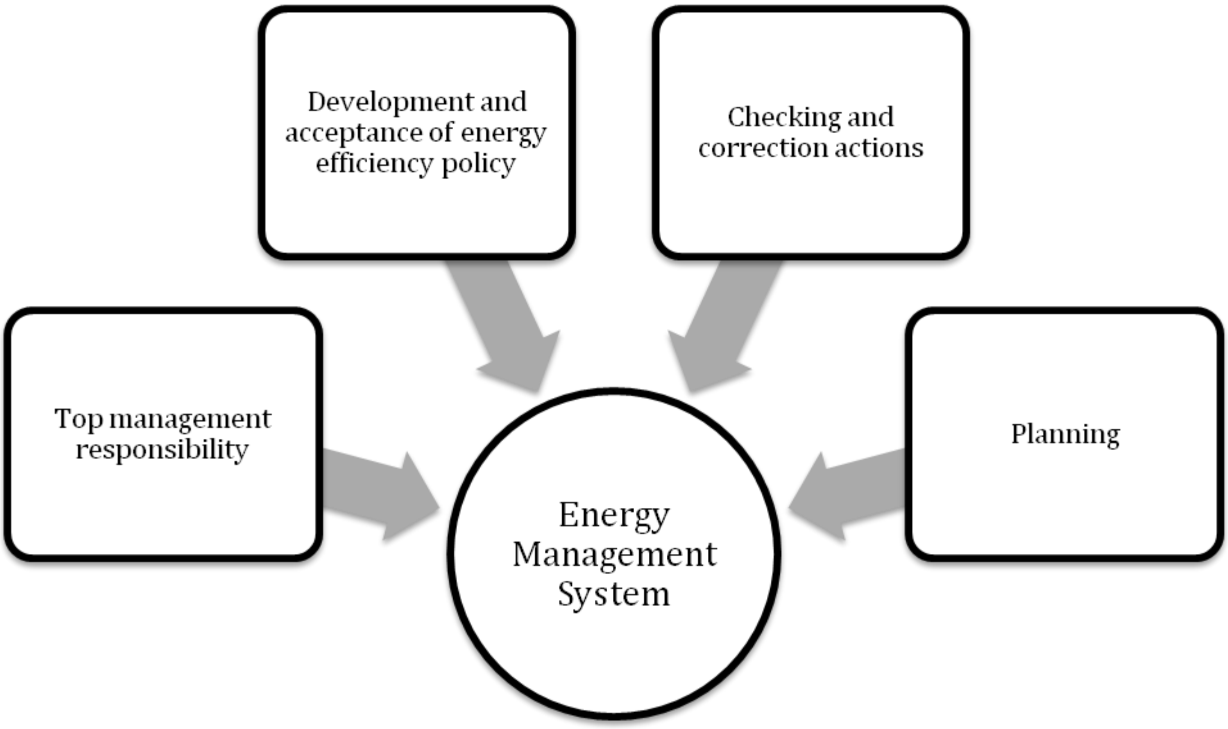

Figure 3: Implementation of EnMS procedures [18]

Top management responsibilities

Top management commitment is a necessary prerequisite for a successful energy management. Top management incorporates energy efficiency among the highest priorities of the company. There should be one representative from senior management, which will be responsible for energy efficiency and perform following tasks:

- promote a culture of energy efficiency and maintain the necessary drivers for the functioning of the system,
- develop a strategy for energy efficiency in the overall context for integrated pollution prevention and control,

- define the objectives of the company to achieve its objectives in the field of energy efficiency in the overall context of the policy goals of energy savings,
- identify short-term and medium-term actions to implement long-term vision,
- provide a platform for an integrated approach to decision-making, designed to provide comprehensive pollution prevention in combination with energy conservation, especially in the planning of new installations or substantial modernization,
- guide the company in making decisions about investments and purchases in accordance with integrated pollution prevention and energy efficiency.

Integrated pollution prevention and control are achieved through the integrated approach of decision-making process, including the purchase of necessary resources and capital equipment, planning, production activities, maintenance and environmental management. In addition, the formulation of energy efficiency policy is a part of top management responsibilities.

Development and acceptance of energy efficiency policy

Top management is responsible for the production of energy efficiency policy installation. The policy should:

- appropriate to the nature of the installation (including such local conditions as climate), as well as the scale of operations and associated power consumption of the installation;
- include a commitment to strive for energy efficiency;
- include a commitment to comply with all applicable legal requirements and other regulatory requirements relating to energy efficiency, as well as other liabilities (including energy deals) assumed by the organization;
- provide a framework for setting and reviewing goals and objectives in the field of energy efficiency;
- be documented and communicated to all employees;
- be accessible to the public and all interested parties.

Checking and remedial measures

- implementation and maintenance of the documented procedures for the regular monitoring and measurement of the key characteristics of the production process and other activities that may have a significant impact on energy efficiency;

- implementation and maintenance of the documented procedure for periodic evaluation of compliance with legislation, regulations and voluntary agreements in the field of energy efficiency;
- implementation and maintenance of the procedures for responsibility allocation and definition of the powers to identify and eliminate inconsistencies permit conditions, other legal claims and liabilities, as well as the goals and objectives of the organization; and procedures to take specific actions, in order to mitigate any effects of non-compliance, and to initiate and implement corrective and preventive actions in accordance with the scale of the problems;
- implementation and maintenance of the procedures for determining the content, provision and storage of readable, identifiable and traceable records in the field of energy efficiency, including staff training records and the results of audits and evaluations;
- organization of regular reporting on progress of tasks implementation in the field of energy efficiency.

Planning

- procedures to identify aspects of the installation of energy efficiency and maintain the current condition of relevant information;
- procedures for evaluating proposals for the introduction of new processes and equipment, creating new units, upgrading, reconstruction and technical re-equipment aimed to identify aspects of energy efficiency, as well as the impact on the planning and procurement in the direction of optimizing the energy efficiency;
- procedures for identifying legal requirements applicable to the organization in the field of energy efficiency;
- establishing and reviewing documented goals and objectives in the field of energy efficiency, taking into account legal and other requirements of the organization, as well as the position of the stakeholders;
- development and regularly update of energy management program that includes some responsibilities for the goals achievement at all levels and in all functional areas; in addition, the means and time frames for achieving the goals and objectives have to be defined.

2.4.2 Energy savings solutions

Many scientists all over the world try to solve the problems of energy savings and energy efficiency improvement in production and other components of production process. The scientists from Germany, USA, China and Japan take a leading place in scientific development of this issue. Some examples are presented below.

Dietmair (2009) investigated energy consumption of mechanical machine during milling operation and methods of its reduction; he proposed a basic model for energy consumption decrease [19]. In the study he represented the method to model the behavior of energy consumption of mechanical machine. It is important to note that this method allows forecasting energy consumption under diverse configuration and different scenarios that is necessary for process planning.

Mori (2012) analyzed the enterprise performance and the key moments, which make possible to control high energy consumption; in particular he proposed to change working time for employee that allow to save on switching the air-conditioners during earlier time rather than in rush hours. Saturday and Sunday were established as working days. The temperature regime of an enterprise was changed. Under temperature lower than 26C the air-conditioners were not used [20].

The scientists from General Motors Corporation Liu, Huang and Zhao from Beijing Technical University pointed out the importance of the energy efficiency problem in mechanical enterprise, which was not investigated to the full extent until the present. They analyzed the processes of manufacturing line of the vehicle assembly line and presented a model to evaluate energy consumption of whole enterprise, which consists of 4 steps: valuation and estimation of energy consumption of particular processes; estimation the influence of production process on the environment; usage of software Energy Plus for energy consumption estimation of the building; and summing up aggregation of all received information as the final stage [21].

The study Neugebauer *et. al by* Technical University of Chemnitz (2011) investigated the methodology of design of mechanical equipment with high level of energy efficiency. The problems of energy efficiency improvement of one mechanical machine with methodology applied for the whole production process [22].

Baker and McKenzie (2005) analyzed energy consumption of industrial dryers. The results showed that about 29% of consumed energy by industrial dryer is spent for nothing. Energy consumption guide described practical methods for benchmarking the energy usage of the given dryer against typical industry data, and suggested a number of techniques for energy savings implementation [23].

Schmidt *et al.* (2011) proposed a new approach to model mechanical machine regarding its optimization. The main energy consumers of mechanical machine were identified and structured. In addition, they presented identification and classification of energy losses and their potential [24].

Gytowsky *et al*. (2006) examined the utilization of energy during manufacturing processes and proposed a strategy for restructuring of manufacturing process for the purpose of consumed energy minimization. The first strategy is re-engineering of the system of mechanical machine maintenance. For example, the redesign of machine tools and injection molding machine from hydraulic to all electric significantly reduced the specific energy used by this machine. The other strategy is to increase the rate, at which the physical mechanism can perform the desired operation. The strategy is illustrated by the significant improvements in cutting tools over the last century which have resumed in reduction in machining times by about two orders of magnitude [25].

The system of automatic monitoring of mechanical machines was proposed by Vijayaraghavan and Dornfeld (2010). This system is applied for estimation of relationship between energy consumption and working capacity of mechanical machine [26].

Krishnan *et al*. (2009) presented results of energy efficiency analysis at the level of mechanical machine in the industrial sector. The evidence of energy consumption was taken from several industrial processes, then described and analyzed including plastic injection molding and steel metal working. Modeled computer simulation showed that energy efficiency of the process injection molding increased by 49% under enterprise's equipment optimization [27].

Suzuki et al. proposed energy savings methods for air conditioning in semiconductors manufacturing system. In additional, the energy for the air conditioning was classified into fresh air intake, recirculation air conditioning and cooling system of manufacturing systems. The fresh air intake in summer was focused on and the moisture in the fresh air was condensed on a heat exchange-fin, which decreased the thermal exchange and increased the intake-air resistance. This approach achieved 24% improvements of coefficient of heat exchange, 5% of energy savings of the refrigerator [28].

Based on the conducted analysis of the different studies on the theme of energy efficiency, analysis of standards, directives and laws, I found out the absence of methodology based on the requirement of standards and laws of European Union, which demand to systematically accomplish performance targets regarding energy consumption reduction in the production process and to search potentially significant elements of the system. Such methodology is presented in part below and based on the principle of quality management PDCA (Plan, Do, Check, Act).

This step is necessary for continuous improvement of implemented saving solutions. Energy monitoring is a proven solution that uses technology to gather and report on a company's energy data, combined with the expertise to advise and guide companies on how to take action, seize cost-saving opportunities, and continually improve performance. The energy visualization method as the step of energy monitoring system was developed and presented below.

In addition, for the purpose of successful realization of energy efficiency improvement, it is necessary to coordinate the activities of different departments of the enterprise, the presence of policy and monitoring of the significant indicators of energy efficiency improvement. The important aspect is the development of the system of technical record of energy resources at the level of aggregates and computerization of data analysis. At the moment all these measures are voluntary and, unfortunately, the manager of enterprises does not often implement such systems. The reasons are such factors as lack of qualification of employees, the absence of motivation, the high cost of system development and implementation, the absence of methodology of integration of the energy consumption reduction system at the enterprise. The problem of energy efficiency improvement can be solved as follows:

- For the stable and interconnected work of defined enterprise all necessary acts, normative documents, directives have to be combine under control of energy management.
- Enterprise workers have to be trained and educated in the direction on friendly environment using resource and dealing with energy consumption.
- Should be developed guidelines and checklists for the plan of energy conservation and energy efficiency of the industrial enterprise. The plan should contain a description of the enterprise; the energy balance of the enterprise, assessing the energy efficiency potential for the realization of the list included in the action plan, the forecast energy prices, investment, scheduled plan, the expected effect of energy and cost savings.
- In order to start follow energy consumption and implementation of energy management system at each enterprise, measurement equipment has to be set up, which can help to avoid energy waste.

- All necessary activities have to be done as soon as possible, as it is established in Directive 2012/27EU.

2.4.3 Monitoring

Nowadays, simulation and visualization are widely applied in various areas such as education, computer entertainment, economics, business administration, and of course in the production engineering sector.

The conception of data visualization is associated with mental possibilities of humans. Due to different professional knowledge and social skills, the human perception of information lies in various spheres of comprehension. However, the human visual and mental system is able to work with a huge amount of data, as it identifies information using predefined rules. One main goal of data visualization is to present information in an intuitively understandable way, regardless of different knowledge or skills of the addressee.

According to Zhu et al. (2005) the structure of human memory contains iconic, working and long-term memories [29]. The memorization of information in all three memories can be enhanced by visualization in a different way.

Visualization of data is important because the human eye can process many visual sing simultaneously. The human visual system is able to quickly process visual signals, and advanced information technology has transformed whether the computer is a powerful tool for managing digital information. Visualization is a bridge between the human visual system and computer, helping to identify the images, build hypotheses and extract insights from vast amounts of data, which contribute a research and prediction.

It is established that a person learns much better graphics data interpretation. However, a human visual system identifies the images in accordance with certain rules to be effective visualization system. It is necessary to learn the rules and follow them. In accordance with the results the structure of human memory has an iconic, working and long-term memory. Each of them may be enhanced in various ways of visualization [30].

Iconic memory is sensory-copy information, human readable without conscious control. It has a high capacity and high speed fade in time: less than 1 second. Part of the visual information is transmitted to the working memory. In the iconic memory is unintentional formation processing of incoming information, run a set of parallel processes for the isolation of various visual signals without participation conscious cognitive processes. Dependent and independent channels for processing visual information are allocated. For instance, visual cues such as color and proximity of objects are non-interdependent channels of perception, so there can be used separately to encode different attributes. Another example - the color and brightness - can be mixed with each other as their visual channels intersect.

Working memory integrates the data extracted from the iconic memory with the information downloaded from the non-volatile memory in the process of solving a human problem. In the working memory abstract visual images, resulting from unintentional processing are displayed in the information space images of long-term memory. Information from the working memory is deleted after solving the current problems. Rendering pro-addition of working memory comes in two ways: the expansion of memory and visual enhancement of cognitive processes. The benefit-giving high capacity of working memory for input signals, visualization by itself, can play the role of external memory, while saving space in the working memory. Strengthening and support cognitive processes occur due to the fact that the visualization makes decisions perceived. Visualization decrease cognitive load in decision making.

Long-term memory stores information due to human experience, in the form of a network of related concepts. The method by which the network is built, determine why some concepts easier to remember than others.

The science which deals with graphs, analysis, data representation and data visualization calls infographics. The three parts of all infographics are the visual, the content, and the knowledge. The visual consists of colors and graphics. There are two different types of graphics – theme and reference. Theme graphics are included in all infographics and represent the underlying visual representation of the data. Reference graphics are generally icons that can be used to point to certain data, although they are not always found in infographics. Statistics and facts usually serve as the content for infographics, and can be obtained from any number of sources, including census data and news reports. One of the most important aspects of infographics is that they contain some sort of insight into the data that they are presenting – this is the knowledge.

Infographics is effective because of its visual element. Humans receive input from all five of their senses (sight, touch, hearing, smell, taste), but they receive significantly more information from vision than any of the other four. Fifty percent of the human brain is dedicated to visual functions, and images are processed faster than text. The brain processes pictures all at once, but processes text in a linear fashion, meaning it takes much longer to obtain information from text [29].

The study of perception is necessary for the development of imaging systems. However, the transformation process of research results into finished the design principles of all still remains an open question.

The type of visualization is subdivided in follow:

- scientific visualization;
- visualization software;
- visualization of information.

Visualization types are listed for different data types. However, similar techniques are used: using the same elements and follow the general rules of combining visual signals. The boundaries between these types of imaging are blurred. Due to the nature of the abstract data as input information visualization and visualization software these two types understood as one - visualization information [31].

Scientific visualization helps scientists and engineers to more efficiently learn the physical phenomena that are hidden in large volumes of information. Information may be obtained by simulation or recording of the various sensors, medical scanners, telescope, satellite systems. A distinctive feature of scientific visualization is the physical nature of the rendered objects that have natural counterparts. Development of mathematical models describing physical objects plays a crucial role in the mapping information. Colors or other visual aids are usually added to the physical object in order to describe certain of its attributes.

Visualization of information and software as opposed to scientific visualization often has not predefined geometric or physical structures on which information is displayed. Visualization software is usually either in a visual representation of the code, or in the animation of algorithms that helps engineers to manage the development, debugging, optimization of complex software.

Cooperation between infographics and virtual reality environment makes process visualization more understandable and clearer. Immersive visualization is a great tool for data representation. Different manners of data representation from infographics science can be used as huge tools in three-dimensional, fully interactive space, which is actually possible by using Virtual Reality environment. Immersive visualization systems are high tech systems that consist of advanced displays, image generating computers, video switching/distribution, and perhaps most importantly, suitable application software that allows users to be immersed into a displayed image. In an immersive environment, images are often displayed in stereoscopic 3D. Tracking systems can also be utilized, enabling a user to move all around in a 3D "virtual" or simulated environment, and even interact with data in real time. The result is an experience that looks and feels like it is real.

To follow main idea of visualization “to decrease differences in knowledge skills” would be possible to propose that energy flow visualization is a great tool for many tasks in the enterprise. By using virtual reality in connection with energy management methodologies, energy audit, machine tools or entire block schema of production becomes possible to provide general information between production team independently on field of occupation. The understandable picture of energy consumption will give clear conception of process.

The best effect of visualization will be achieved by implementing human in immersive environment. It is possible by using virtual reality systems, which are rapidly integrated in real life. Utilization of virtual reality becomes more common in industry, especially in production and designing new machine tools. Application virtual reality visualization offers a deep immersive into researching problems and tasks.

Over the last few years virtual reality has become part of the mainstream product design and development process of many companies in the manufacturing industry. By the means of virtual reality or virtual environment it is possible to generate immersive models in full scale. Growing complexity of parameter new systems designing and engineering have to deal with virtual reality. New machine tools and industrial elements can be easily designed by means of visualization. Especially concerning research on energy efficiency, visualization is an important step for understanding [33].

In current work the data visualization of energy consumption, its implementation in Virtual Reality by using particle system and magnitude of energy data visualization to the energy management system are considered.

3 THE AIMS OF DISSERTATION

First of all this research is focused on the problem of energy saving and improving of energy efficiency at the enterprise. The main aim of research is to find the energy weak places in the production process of the automotive enterprises. Based on their analysis the possible ways of saving energy will be proposed.

In order to solve the problem of energy efficiency improvement, the following aims were defined in the dissertation:

- **Development and implementation of energy savings and energy management methodology in an industrial enterprise.**

Development of methodology is based on European law, directives and international standards, such as Directive 2012/27/EU, EN ISO 50001:2011, EN ISO 14001:2008. Analysis of these directives is presented in chapter 4.

- **Identification of possibilities of energy consumption reduction in the production process.**

This part is dedicated to analysis of corporate energy consumption. I conduct a review of modern commercial measuring power equipment and propose actions designed to decrease energy consumption through the example of automotive production process.

- **Development of methods of energy flow visualization in Virtual reality environment.**

This method should be directed to solve a problem with data shortage and lack of information. Especially for processes that cannot be seen in reality, intuitive visualizations are the basis to create understanding for the process itself. Energy management is a complex problem where deep understanding of the underlying processes, like energy flows, is a necessary basis.

This study is conducted on the basis of two universities. Technical University of Brno (Czech Republic) and the Technical University of Chemnitz (Germany), as well as the facilities of the Czech Republic, Germany and the Russian Federation.

4 DEVELOPMENT AND IMPLEMENTATION OF ENERGY SAVING AND ENERGY MANAGEMENT METHODOLOGY IN AN INDUSTRIAL ENTERPRISE

In order to fulfill necessary activity according energy usage and reach defined aims, the following methodology is developed and presented below.

To realize idea of energy saving in production process, it is necessary to begin with development of energy management methodology. This methodology will be a basement for creation and development of energy savings activities in production process. Like other management systems energy management system is essential to consider as a system for production control, distribution and energy consumption, transportation etc. Energy management in production is considered as a feature for increasing of energy efficiency. There are three main approaches of energy management system to decrease energy consumption:

1. Reducing consumption by self-restriction. Restriction sometimes is regulated by legislation or economic pressure;
2. Well-educated, motivated and solid team, which is directed to a main goal of saving energy;
3. Increasing of energy efficiency by reasonable load energy management of machine tools and enterprises equipment.

4.1 Analysis of the directives and legislations

Energy situation in Europe is governed by national law, directives and standards. In 2007 the challenging target in energy and climate changes was laid down. This aim is directed to reduce the European Union’s primary energy consumption by 20% till 2020, decrease hydrocarbon gas emission by 20% and increase the ration of renewable energy resources by 20%.

Different directives are responsible for various issues of energy and energy consumption and for their hidden potential. But the most important aspect about energy consumption is to increase energy efficiency. The issue of energy efficiency is the center of the Directive 2012/27EU. The Directive aims to increase business opportunities and provide jobs in the field of energy efficiency. This directive was issued to help European Union to achieve specified goals, which were not accomplished before. In 2011 European Commission presented a proposal of Directive

2012/27EU, which is based on previous matter and experience regarding energy problem. However, it has to be correctly and fully implemented in the different States of European Union.

Directive 2012/27EU establishes the measures of energy efficiency at all stages of production process, where it is applied. There is a distinct definition of European Union objectives in the field of energy efficiency that is defined as «the Union's 2020 energy consumption has to be no more than 1474 Mtoe of primary energy or no more than 1078 Mtoe of final energy» [16].

Absolute or partial execution of the Directive plays a significant role in achievement of EU 20 strategy objectives, which will be the base of a new European strategy of climate and energy policy by 2030. This policy is described in **Opinion of the Committee of the Regions — Green Paper on Framing 2030 Climate and Energy Policy.**

By means of Directive 2012/27 EU countries have to ensure the defined amount of energy savings at the level of ultimate customer during period from 2004 till 2020, which is identified by the way of implementation: creation of system of mandatory energy efficiency improvement or complementary policy activities.

Taking into consideration the great potential of energy savings in all types of companies, the energy audit has to be conducted as one of the measures to reveal the capacity of energy efficiency objectives. The EU members need to develop programs of audit procedure, which is mandatory for large manufacturing companies; and at the same time they can stimulate the voluntary performance of energy audit among small and medium enterprises.

The significant directive on energy efficiency 2012/27/EU was introduced in 2012. This directive contains 30 articles and 15 attachments. The following definitions and issues are the most important elements of the directive:

1. *Exemplary role of public bodies*

From the first of January 2014 public institutions should annually renovate 3% of the floor area of heated or cooled buildings, in order to meet minimum energy performance requirements. It applies to buildings with a total floor area over 500 m^2. Since 9.7.2015, the threshold is lowered to 250 m^2.

2. *Purchase of high efficiency products*

Central government institutions should purchase products, services and buildings with high energy efficiency only. The threshold laid down in Article 7 of Directive 2004/18/EC.

3. *Systems of the energy efficiency obligation*

- Each Member State should establish the system of compulsory energy efficiency improvements. Annually all energy distributors or all retail energy sales (from 1 January 2014 to 31 December 2020) have to reach new savings in the amount of 1.5% of annual energy sales to final customers.
- Member States have to publish an annual energy savings report
- Member States as alternative system of compulsory energy efficiency improvements may take additional policy measures such as energy taxes or CO_2 equipment.

4. *Energy audits and energy management systems*

- Member States should ensure that all final customers have access to energy audits
- Audits may be carried out by internal experts of enterprise or external energy auditors
- Determined rules promote the high-quality energy audits that are carried out independently by qualified and accredited experts. Member states may set up support schemes for SMEs to cover the cost of an energy audit and the implementation of highly cost effective recommendations from the audits.

5. *Measurement of consumed energy*

Member States have to ensure that final customers are provided with individual meters of electricity, gas, district heat supply and the cold and hot water at competitive prices. The members of EU have to provide electricity, gas, district heating and district cooling to final customers, which display the information about the amount and time of energy supply and consumption.

6. *Info billing*

Member States have to informed final customers about energy consumption, where there is absence of smart meters.

7. *The cost of access to information on metering and billing*

Government should receive information on consumption and billing charge.

8. Program to enhance information and position of consumers

Member States have to apply appropriate measures for small customers, including households

9. Promoting efficiency in the supply of heating and cooling

Member States have to conduct a comprehensive assessment of the potential for combined heat and power and efficient district heating and cooling by 31. 12. 2015

10. Conversion, transmission, transportation and distribution of energy

Consumers should pay attention to energy efficiency during these operations

11. Energy Services

- Member States shall encourage the market for energy services and the access of SMEs to this market by spreading information about it,
- support the development of energy quality labels, among others trade associations,
- publish the list of available qualified or certified providers of energy services,
- support the public sector in the acceptance of offers of energy services primarily to renovate buildings.

12. Reporting on progress in energy savings by 30 April each year starting in 2013.

Regulation of energy efficiency directive about metering and consumers' information takes over and improves some regulation from previous directive 2006/32/ES (information about energy efficiency in most of directive will be amended). It is also important to note that article 9 does not require installation of intelligent measurement system (this requirement is described in directive 2009/72/ES and 2009/73/ES), however it specifies that if Member State integrate intelligent measure system then obligation will be related to article 9. For instance, intelligent measure system is able to calculate electricity that final consumer gets from the grid. At the same time «final consumer» can be not only a person, but also an organization, which is buying energy from supplier.

The Directive 2009/125/EC was accepted regarding environmental designing or Eco design. This directive establishes obligate environmental requirements for products associated with higher energy consumption. The directive on Eco design is based on the fact that 80% of negative influence of energy consumption can be avoided at the design stage of product of one kind or another. The EU can make markets more ecologically friendly in the countries of European Union by the means of the Directive implementation. By virtue of the Directive on Eco design it is possible to save up to 12% of electricity that is used at the moment, and moreover, it enables to provide additional improvements of the product. Eco design allows to decrease consumption of energy resources that represents one of the most important issues of the EU policy.

Complementary to the Directives of the European Union the international standards ISO play a great role in activities regarding the energy consumption reduction and decrease of ecological impact on the environment.

4.1.1 EN ISO 50001:2011 Energy Management System

Implementation of the energy management system certified by the means of EN ISO 50001:2011 encourages the reduction of energy consumption through a structured approach of energy use monitoring. This system identifies the areas for improvement and then implement action plans to improve the energy performance.

General requirements

These standards require establishment, implementation and improvement of energy management system (EnMS). All necessary procedures have to be documented according to EN ISO 50001:2011. Organization has to build the structure of EnMS including scope and boundaries of activities. Plan can be determined in different ways, but there are several typical examples of system establishment plan: the use of project management system, simple flow diagram or action from a meeting.

Management responsibilities

The responsible manager has to be appointed by top management. This should be a person, who has the appropriate skills and competence to carry out the required tasks. System should be able to demonstrate that these commitments are in place. In addition, there are requirement for top management designed to approve the formation of an energy management team and requirement for the management representative, in order to identify a person, who will work with them and support energy management activities.

Energy policy

Along with all common management system standards, EN ISO 50001:2011 requires to have an energy policy in the enterprise. The top management needs to define the policy that should be appropriate to the nature and scale of the enterprise's energy use and consumption. Moreover, the energy policy has to meet the other requirements. For instance, it has to support the purchase of energy efficient products and services, and be designed for energy performance improvement. The energy policy is the cornerstone of the system and should clearly lay out the commitments, aims and expectations of the enterprise regarding the energy management system.

Energy planning

The first step is the energy review, which includes an inventory of past and present energy use, a list of the variables affecting energy consumption, a definition of what constitutes a «significant energy use», and an analysis of these factors. It is followed by the selection of energy performance indicators. The final outcome is the definition of an energy baseline. An energy baseline needs to be established using the information from the initial energy review. These should cover a time period suitable for the enterprise.

The amount of energy baseline depends upon the size and complexity of the enterprise and how far it is necessary to split up energy use and consumption for the energy performance monitoring. These baselines will be used to determine the improvements in energy performance of organization.

Energy performance indicators (EnPIs) must be set in accordance with monitoring and measuring energy performance. Organization also needs to develop methodology for the EnPIs determination and updating. They will be reviewed and compared against energy baseline, in order to demonstrate improvement.

Along with other management systems, the final part of planning system is to set objectives and targets. Within EN ISO 50001:2011 requirements, the action plans have to be established, implemented and maintained, in order to show how the targets will be achieved. The action plans should include allocation of responsibilities, timescales and statements regarding energy performance improvement and the method of results verification.

Implementation and orientation

In pursuance of so called «do» part of the standard, EN ISO 50001:2011 requires to apply the action plans and other outputs form the planning process, in order to implement and operate the enterprise’s system. There are specific requirements for the enterprise’s employees in areas such as: importance of conformity with the energy policy and EnMS requirements, their roles and responsibilities, the benefits of improved energy performance, and the impact of their activities. The standard EN ISO 50001:2011distinguishes from the other management system standards, specifically it does not require to make energy policy publicly available.

Checking

The «checking» part of the standard engages the enterprise to monitor measures and analyze the key characteristics of operations that determine energy performance. The results must be recorded; and the energy measurement plan has to be defined and implemented. The level of measurement will vary depending on the enterprise and can be ranged from reading utility meters up to complete software application systems that consolidate data inputs and deliver automatic analysis. The measurement level should be appropriate to the size and complexity of the enterprise. The uses data should be accurate and repeatable, so the enterprise will need to calibrate or otherwise verify the monitoring and measurement equipment. The final part of the standard covers the control of records. This is similar to the requirements within other management system standards: the records should be legible, identifiable and traceable to the relevant activity.

Management review

Management review is an essential part of an effective system. It allows top management to step back and take an overall look at system, not only review if it meets the requirements of the standard and legal and other requirements, but also whether it is suitable for the enterprise and it delivers what enterprise wants from EnMS. Although it is not specified the format of management review. The majority of enterprises use meetings as the form of review that allows discussions and any necessary actions to be agreed. The frequency of management reviews varies from company to company, normally ranging from monthly to annually.

EN ISO 50001:2011 specifies requirements applicable to energy use and consumption, including measurement, documentation and reporting, design and procurement practices for equipment, systems, processes and staff that contribute to energy performance.

4.1.2 EN ISO 14001:2004 Environment Management System

Structure of Environment Management System (EMS) standard is based on the PDCA cycles as other standards of this family that makes it easy to integrate. The enterprise, which has decided to develop EMS should take into account the follow points:

- establish the current position with regard to the environment;
- make the achievement plan(s);
- implement and operate the plan(s);
- measure performance according to the plan(s);
- take actions based on the results (desired or required).

The last point may involve plans changing. This should be an on-going process that results in continual improvement.

General requirements

The enterprise needs to define and document the scope of the EMS and ensures that it is implemented and supported throughout the enterprise. Continual improvement of the EMS is required. The enterprise has the freedom and flexibility to define its boundaries and may choose to implement an EMS with respect to the entire enterprise, or to specific operating units of the enterprise. In setting the scope, the credibility of the EMS will depend upon the choice of organizational boundaries. For example, excluding the part of the enterprise from the scope of the EMS may attract criticism. The scope of the EMS must also be documented.

Environmental Policy

The Environmental Policy is the documented statement of commitment from top management. This policy sets the overall EMS intentions of the enterprise and contains a commitment to prevent the pollution and to continuous improvement. Each Environmental Policy is unique; it is communicated to all employees and it is available to the public. This Policy is the starting point for setting the enterprise's EMS objectives and targets.

Planning

Planning is the second stage, where the requirements are determined, objectives and targets are set, and the program to achieve the targets and objectives are developed. The enterprise needs to review its operations, activities, products and services, in order to identify the interactions with the environment. The enterprise identifies the environmental aspects that occur during normal business operations, abnormal conditions, incidents and future activities. Environmental objectives and targets need to be developed, documented and communicated throughout the enterprise.

The enterprise needs one or even more programs to achieve its objectives and targets. These programs assign responsibility throughout the enterprise for achieving objectives and targets, and specify the means and time frame of such achievement.

Implementation and Operation

The third component of an EMS consists of implementation and operation. Roles, responsibilities and authorities of personnel, whose activities have directly or indirectly impact on the environment, need to be defined, documented and communicated throughout the enterprise. The company must provide adequate resources for the implementation and maintenance of the EMS. One or more individuals need to be appointed by top management as the «Management Representative». The Management Representatives are given the responsibility and authority to ensure that the EMS complies with EN ISO 14001:2004 and report the performance of the EMS to top management.

Training requirements of personnel whose work may create a significant impact upon the environment and ensure that these personnel have received appropriate training has to be identified. Awareness is required for all personnel throughout the enterprise of the Environmental Policy, the EMS program and procedures, and the actual or potential impact of their activities on the environment. The competence of personnel performing activities, which might have significant environmental impacts, needs to be determined by the enterprise through education, appropriate training and experience, as required. Processes and activities that may have a significant impact on the environment need to be identified and be relevant to the enterprise's policy, objectives and targets. The enterprise must ensure that these operations are conducted as intended by planning and carried out under controlled conditions. Controlled conditions may include documented procedures that contain operating criteria. The enterprise must also identify the significant environmental aspects of the goods and services that it uses and provide the relevant procedures and requirements to its suppliers and contractors.

Checking and corrective action

Monitoring is continuous assessment of performance over time. Monitoring is normally based on measurement capability (e.g. meters, gauges, etc.). The essence is to monitor and measure the key «environmental characteristics» – or significant impacts. The process of monitoring will vary between organizations and can also be defined in legislation. It is a critical area of the standard. Monitoring procedures must also include the documenting of information, in order to monitor performance and conformance with objectives and targets.

Characteristics of operations and activities that can have a significant impact on the environment need to be monitored and measured regularly. Records of monitoring and measurement information are required to track performance, to prove that operating controls were effective and to demonstrate conformance with objectives and targets. Monitoring and measurements results need to be compared to the legal and other requirements to determine compliance. Any equipment used for monitoring and measurement must be capable of the accuracy required and calibrated on a regular basis. Records relating to the EMS must be identified, collected, stored and maintained, in order to provide objective evidence of conformance to the EN ISO 14001:2004 standard, legal and other requirements. These records include training records, EMS audit results, management review records and the results of monitoring and measurement.

Audits of the EMS are required on a periodic basis to provide assurance to the organization of EMS implementation, to determine if the EMS is operating as planned, to provide information for management review and to determine the capability of the EMS in achieving the organizations environmental objectives and targets.

Management Review

The purpose of a management review is to evaluate the effectiveness of the EMS and its ability to achieve the desired results. It is the top level critical review of the EMS; and it is conducted at sufficient intervals (at least annually). The management review is a critical assessment of the performance of the EMS by top management. It is not compulsory for the review to be conducted at one meeting, as is commonly believed and indeed the format does not have to be conducted as a conventional meeting (e.g. comprehensive information can be prepared, for management to then critically review the performance of the EMS remotely).

The purpose of this standard is to help organizations to protect the environment and to respond to changing environmental conditions. According to ISO 14001, any organization can achieve these goals if it establishes an environmental management system (EMS) and if it continually tries to improve the suitability, adequacy, and effectiveness of this system.

4.1.3 EN ISO 14044:2006 and EN ISO 14040:2006

Two standards according Life Cycle Assessment (LCA) are reviewed in the following section. The LCA methodology is described in the internationally accepted EN ISO 14040 series, accredited by the European Committee for Standardization (CEN). These standards reflect the state of the art methodology of the LCA which is generally accepted amongst the LCA practitioners. As a result, any LCA study, especially those commissioned for legislative purposes has to be performed according to these standards.

EN ISO 14044:2006 Environmental management - Life cycle assessment - Requirements and guidelines is designed for the preparation, conduction, and critical review of life cycle inventory analysis. It also provides guidance on the impact assessment phase of LCA and on the interpretation of LCA results, as well as the nature and quality of the collected data.

EN ISO 14040:2006 Environment management – Life Cycle Assessment – Principles and framework provides a clear overview of the practice, applications and limitations of LCA to a broad range of potential users and stakeholders, including those with a limited knowledge of life cycle assessment.

Life Cycle Assessment is a method of comparison of environmental impacts of products, technologies or services with a view to their whole life cycle, so called “from cradle to grave”. The emissions to all components of the environment during product production, use and disposal are considered. Processes of raw material mining, material and energy production, additional processes or sub processes are also involved.

Within the meaning of EN ISO 14040:2006 and EN ISO 14044:2006 LCA method can be defined as compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.

According to standard EN ISO 14040:2006 LCA method consists of main phases, which are described in chapter 5 of this standard «Methodological framework». It does not describe the LCA technique in detail, nor does it specify methodologies for the individual phases of the LCA:

Goal and scope definition

The Goal and scope definition is the phase, in which the initial choices that determine the working plan of the entire LCA are made. The goal of the study is formulated in terms of the exact question, target audience and intended application. The scope of the study is defined in terms of temporal, geographical and technological coverage, and the level of sophistication of the study in relation to its goal. Finally, the products that are the object of the analysis are described in terms of function, functional unit and reference flows.

Inventory analysis

The part of inventory analysis is description of material and energy flows within the product system and especially its interaction with environment, consumed raw materials and emissions to the environment. All important processes and subsidiary energy and material flows are described in it.

Impact assessment

Details from inventory analysis serve for impact assessment. The indicator results of all impact categories are counted here; the importance of every impact category is assessed by normalization and eventually also by weighting. The result of impact assessment is represented by table summary of all impacts.

Interpretation

Interpretation of life cycle involves critical review, determination of data sensitivity and result presentation. The final objective of this phase according to the current standards is to draw conclusions and to make recommendations reflecting the identification of significant issues and the evaluation element. A clarification added in the new standards is the requirement to identify limitations of conclusions and recommendations. Methodological and study limitations were also added to the list of items that need to be checked for consistency when assessing preliminary conclusions from the study.

Life cycle assessment (LCA) is an analytical method used to comprehensively quantify and interpret the energy and material flows to and from the environment over the entire life cycle of a product, process, or service. LCA is rapidly emerging as a key method, if not the key method, for evaluating the environmental effects of products, processes and even whole buildings.

The main goals of EU climate and energy policy should ensure energy supply that is environmentally, socially and economically sustainable as well as safe and secure. It is based on the energy efficiency improvement, usage of indigenous renewable energy sources and the development and introduction of innovative energy technologies that in turn will help to reduce greenhouse gas emissions and improve public health and the state of the environment, and, in addition, create new jobs.

4.2 Background of energy savings and energy management methodology

Development on the energy savings and energy management methodology requires basic planning. This planning enables an organization to profile its situation in regards to energy consumption reduction. EN ISO 50001:2011 requires energy planning to be a documented process and to lead to actions that continually improve energy performance. Energy planning involves a review of activities that can affect energy performance. It starts with pulling together measurement data and other energy information that can have an influence on energy performance in the organization.

Energy management methodology is used for energy savings methodology. The method is based on the system approach of integration process as well as specific technical measures. It assumes full responsibility for the use of the organization's management of energy. Management system may be organized in different ways, but in most cases it is based on the principle of «Planning - Implementation - Check - Act», which is widely used in other areas of corporate management. For realization of energy savings methodology it is necessary to reorganize cycle PDCA in a different way, at the same time keep the main idea of PDCA cycle of integration with International Standards of certification.

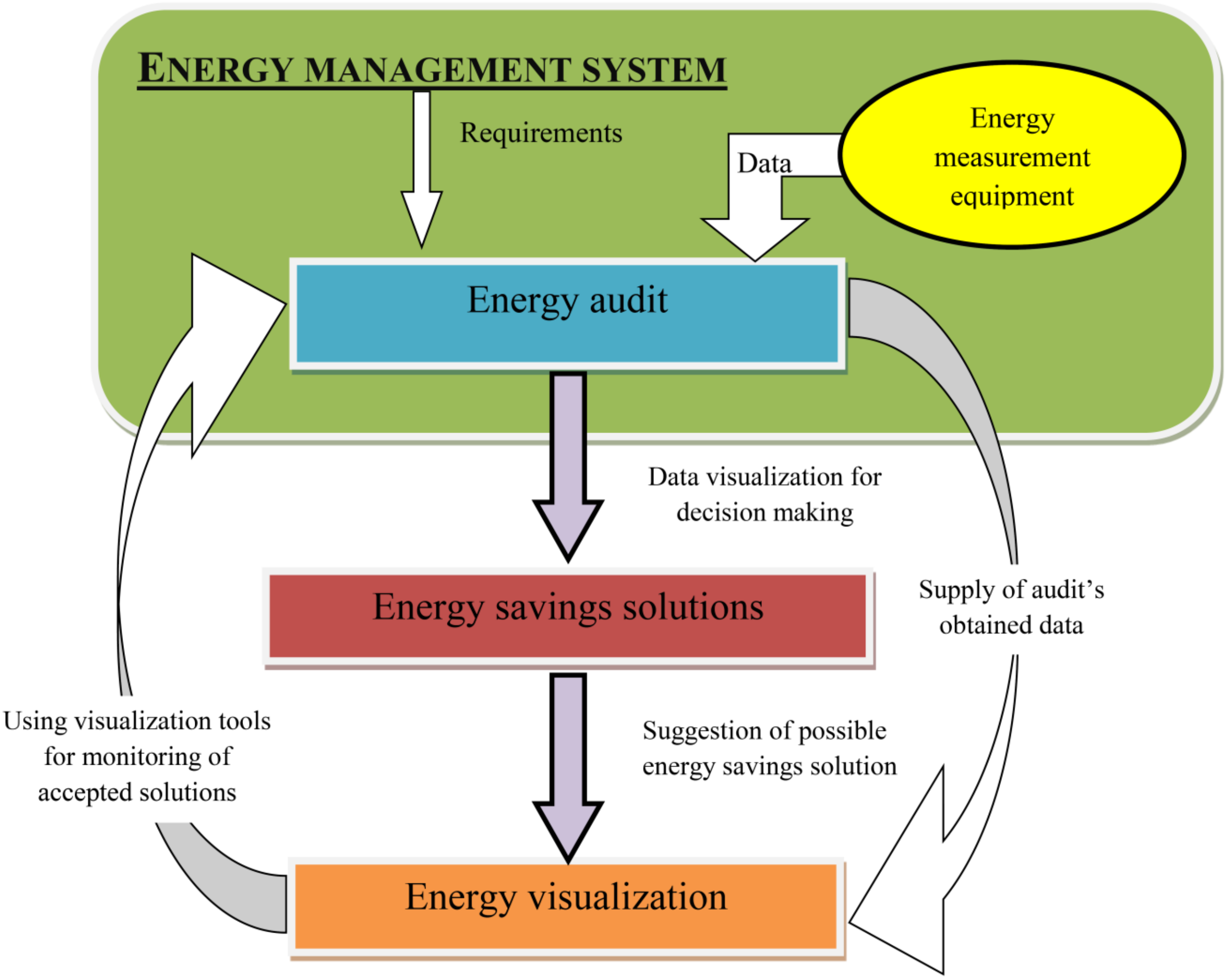

Figure 4: Background of energy savings and energy management methodology

As seen from the figure 4 the first step of suggested methodology is energy audit. For its realization it is necessary to use compliance energy measurement equipment. Energy measurement quipment is intended to obtain reliable information about the amount of consumed electricity and released to deal with financial payments for electricity and power. Determination and forecasting of technical and economic indicators of energy consumption ensure energy efficiency and organization of electricity. Block scheme of whole process development of energy saving and energy management methodology is presented in figure 4.

4.2.1 Energy audit

Energy management system and energy audit play extremely important role dealing with energy saving and improvement of energy efficiency. Because of their information content and data collection of all enterprise energy audit realization and subsequent implementation of energy management system are first steps of development this methodology.

Energy audit is a beginning of implementation of energy management system at the enterprise. In general, the audit methodology does not depend on the type of product, or on the technology, nor the form of organization of the test production. Certain standard algorithm is laid at its foundation, which can provide an effective work of the auditor, which must take into account all forms of energy consumed, develop proposals to reduce them, and optimize the structure of energy consumption.

1ststage of energy audit called *Process introduction*.

This stage is dedicated to introduction of production process, data collection and data analysis of useful information. Defining the scope of the current consumption of all energy and its cost is a good starting point. This information is essential for understanding the problems of energy use and the correct prioritization to achieve the best results of energy audit. During this stage information is collected for the last 12th months and even bigger period. At the end of the first induction phase energy auditors should have an idea about the enterprise and major processes, information about season changing for energy prices and energy costs for different period of time. This information gives clear picture of the day-to-situation of energy use in the enterprise and the ability to identify priority areas for further work.

2nd stage of energy audit is *Energy flow review*.

The expenses of energy during production processes have to be investigated. This is usually achieved through discussions with the leadership of production workshops, craftsmen and technologists, the survey process lines businesses and citation schemes technological processes. For each element of such scheme the flows of energy, raw materials, products, industrial effluents and waste should be identified. Based on currently available information and visual observation, the enterprise should calculate the value of energy flows and losses, as well as to compile a list of the main consumers of energy resources (such as for the core processes and for auxiliary). Substantial help in understanding the technological processes and energy flows can be provided by a process flow diagram. Sometimes these schemes are available at the facility. In this case they should only complement the missing information. But in most cases they have to develop their own. Process flow diagram is a diagram showing the major stages through which consistently tested materials from the initial state to the finished product. In the scheme must be shown where to file, use of energy, recycling of materials, and waste in the process.

3th stage of energy audit is *Proposal of energy saving solutions.*

The purpose of this stage is a critical analysis of the collected information on the early stages, in order to suggest the ways to reduce energy costs. There are three basic ways to reduce energy consumption:

- excluding misusing;
- eliminate waste;
- increase the energy efficiency.

Typical areas of inappropriate use of compressed air may be cooling of or cleanup. Sources of energy loss can be excessive overheating of the furnace equipment left switched on after hours, leakage in the distribution, excessive pressure steam or compressed air in the system. Low energy conversion efficiency can be caused by poor efficiency of the boiler, air compressor, refrigeration equipment or inefficient exploitation. After identification of the sources of loss and sections of irrational use of energy development of proposals and projects to improve the situation can be suggested. Methods for increasing energy efficiency and reducing energy consumption are presented in chapters below.

4th stage of energy audit is *Integration to energy management system.*

This is a final stage of audit of the enterprise. Integration to energy management system allows you to get a detailed picture of energy consumption, an accurate assessment of energy savings projects planned for implementation in the enterprise. This control system is based on standard measurements and conducting audits, providing a work of the enterprise, which consumed only when absolutely necessary for the production of energy.

4.2.2 Personnel training and information

The maintenance and staff training play an important role. The level of employees declined in all European enterprises over the past decades. Staff responsibilities include solving various types of problems and maintenance of various types of equipment. The personnel training may be appropriate for normal conditions and allow maintaining an acceptable level of skill in certain areas; however, over time it may lead to a reduction in the special training for specific systems, for example, the ability of the staff to perform custom work, such as energy audits or investigations on the basis of incidents. Staff training is an important factor in the implementation of energy efficiency programs, as well as the integration of the latter into the organizational culture. The personnel training include:

- programs of advanced training and vocational education;
- opportunities for training related to specific skills and areas of activity, including professional, managerial and technical;
- development in the field of energy management: issues of energy efficiency should be clear to all management personnel, not just specially designated managers.

The feeling of «stagnation» at the leadership level influences the degree of enthusiasm that, in turn, effect the implementation and development of innovative approaches in the field of energy efficiency, information interchange. The exchange of information is an important tool for building motivation, which can be used by modern enterprises to achieve a variety of goals. Staff should be informed about the issues of energy efficiency, as well as stimulate and encourage them to contribute to the improvement through energy efficiency, avoid excessive energy consumption and efficient operation. The proper approach to this field allows to organize an effective two-way exchange of information on energy efficiency, in particular, allows staff to report their observations and suggestions, thus contribute to the achievement of common goals. Funds should be used to inform employees and receive feedback on the performance of the company. Well-organized information system facilitates the flow of information about the aims and objectives and the achieved results. There are various channels of information exchange and dissemination of information - newsletters, newspapers, newsletters, posters, stands, group briefings, meetings, or meetings on specific issues. In particular, it is possible to use existing corporate information channels for the dissemination of information about energy efficiency. Distributable information should include specific data on energy consumption, as well as the dynamics of these data over time. This information may be supplemented by the periodic publication of successful experiences in the field of energy efficiency. An effective way of information presentation is graphic materials, including various types of charts, graphs and diagrams. In particular, such form can be used to show an increase in efficiency over time, a comparative effectiveness of different units or plants. Organization of information exchange is important not only "vertically" - between the leaders, who are interested in achieving certain goals, and employees directly working on their achievement, but also "horizontally" - between different groups of specialists within the enterprise. Different tools can be used for dialogue with other enterprises to exchange the ideas and best practices.

The organization of interaction between several enterprises of the same industry or units of one company for the exchange of experience (working groups, networking) can be used as one of this practice. Such mechanisms are most effective, when participated enterprises are at the same level of energy management implementation. Networking is particularly useful in overcoming the typical problems, such as the development of energy efficiency and organization of the system of monitoring of energy consumption. Networking can also include an element of competition in the area of energy efficiency, as well as providing a platform for negotiations with potential suppliers of energy efficient equipment and services.

An extensive demonstration of positive results also pays off in a long-run perspective, for example, the establishment of awards for high performance, best-practice approaches and innovation. Savings energy managers may require additional resources - both additional staff and additional skills and abilities of the staff. Training can be conducted in-house expertise of the organization or by external experts, in the form of organized training courses or self-study. At the national and local level in the EU there is a large amount of information that can be used for training (for example, different Internet resources). There are also information resources targeted to a specific industry, trade and professional associations, and other organizations. Methods of distance learning in the field of energy management and energy efficiency, as well as adequate resources are in the formative stage. On the Internet there are a number of websites offering educational materials in areas such as energy efficiency, energy management, best practice approaches, energy audit, benchmarking and checklists. Typically, the web-sites offer instruction within these topics, and some resources are designed for non-industrial users.

Nowadays the idea about the interdependence of energy efficiency and reliability of the enterprise is justified. Under present conditions, when the economy is globalized, market boundaries are erased, and the industry is so dependent on energy resources and energy market conditions, the competition moves to the field of energy efficiency products and services. Moreover, long-term benefit is obtained by those who create and manage an effective energy management system. It is recognized that the energy management is a key element of the quality policy. Energy management should be viewed as a set of management methods to improve energy efficiency, in contrast to the engineering, technical, technological and others. Separating the management (organizational, administrative) processes impacts energy efficiency. It is obvious that only a combination of different measures - both managerial and technical - will give the best result. Engineering solutions and technical innovations will also lead to more efficient use of energy resources in the enterprise; however, the implementation of the energy management system will make energy efficiency and the overall functioning of the enterprise sustainable.

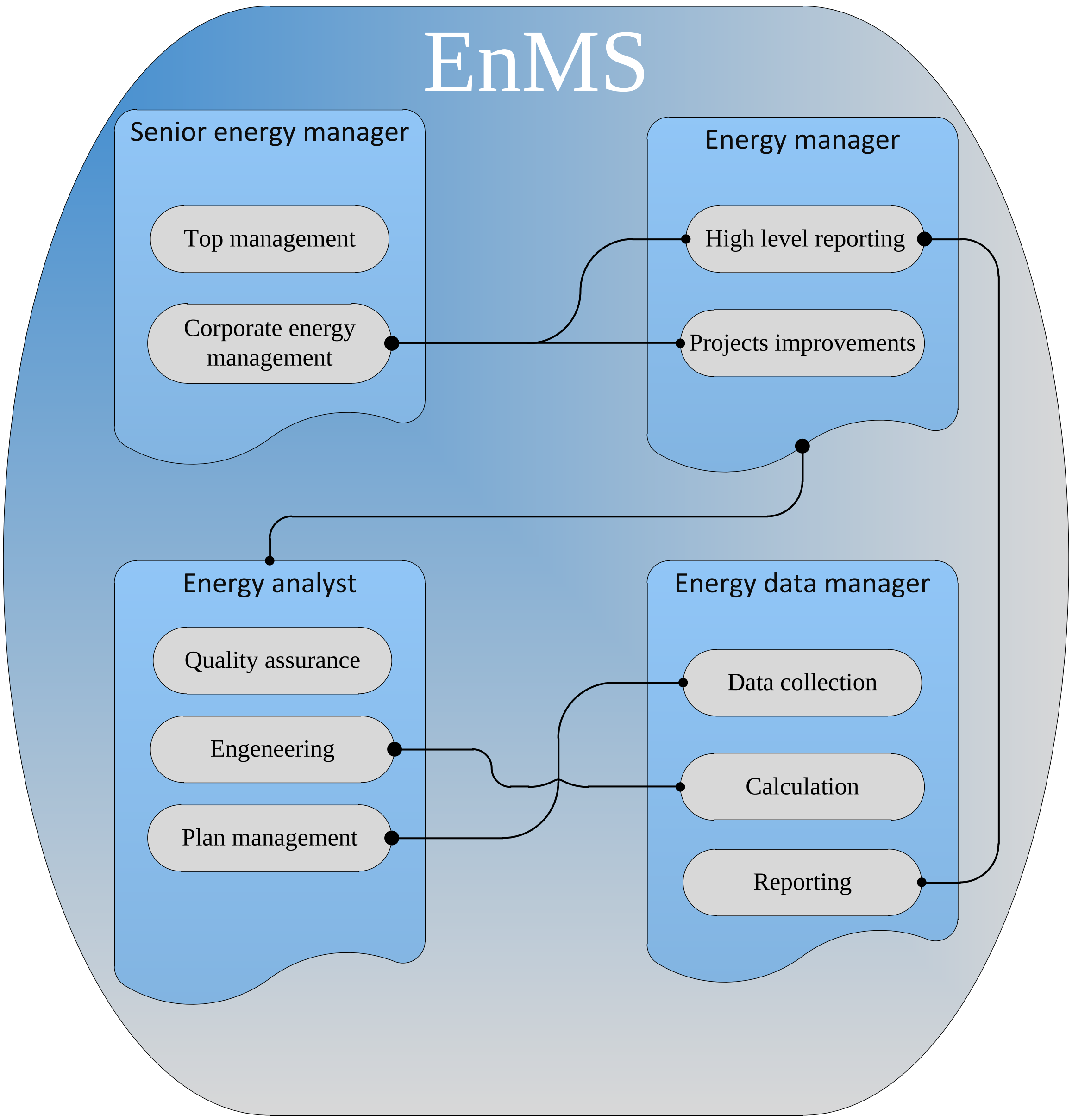

Figure 5: Energy Management relationship within enterprise

Senior energy manager

The senior energy manager is responsible for setting the corporate energy management strategy together with higher level executives and making energy management goals to be set and monitored.

Energy manager

The Energy Manager is a deputy of Senior Energy Manager, who ensures that the corporate energy management strategy is clear and realistic, and that corporate energy management goals are being met. Along with top management Energy Manager works closely with manufacturing sectors personnel, who provide the data on local progress towards energy goals.

Energy analyst

The Energy Analyst represents the «power user» and lives and breathes hands-on analysis of energy management data. Being an expert in databases and statistics, the energy analyst is the «go to» person for the energy manager for energy management business intelligence and analytics.

Energy data manager

The Energy Data Manager provides IT support for the energy management team's specific needs, including setting up sensors and system integration for collection real-time energy consumption data, implementing data calculation rules, and setting up standard reports that the Energy Analyst and Energy Manager will work with day-to-day. The Energy Data Manager might be part of the IT organization, or hold a specialized role within the energy management team.

4.2.3 Energy efficiency as a part of energy management methodology

Increasing of energy efficiency is based on engineering, but fundamental role is laid in organization of activities, which has a goal as an optimal usage of energy resources. Thus energy management has to be considered as complex arrangements, which include marketing, consultation, technics and organizational measures.

One of the most important activities is peak load management. Load management is the process of balancing the supply of electricity on the network with the electrical load by adjusting or controlling the load rather than the power station output. This can be achieved by direct intervention of the utility in real time, by the use of frequency sensitive relays triggering the circuit breakers by time clocks, or by using special tariffs to influence consumer behavior. Load management allows utilities to reduce demand for electricity during peak usage times, which can reduce costs by eliminating the need for peaking power plants. One of the objectives of energy management methodology implementation is establishing an energy efficiency production planning and control system by avoiding load peaks of electricity.

The figures 6a and 6b represent the example of using load management in production process.

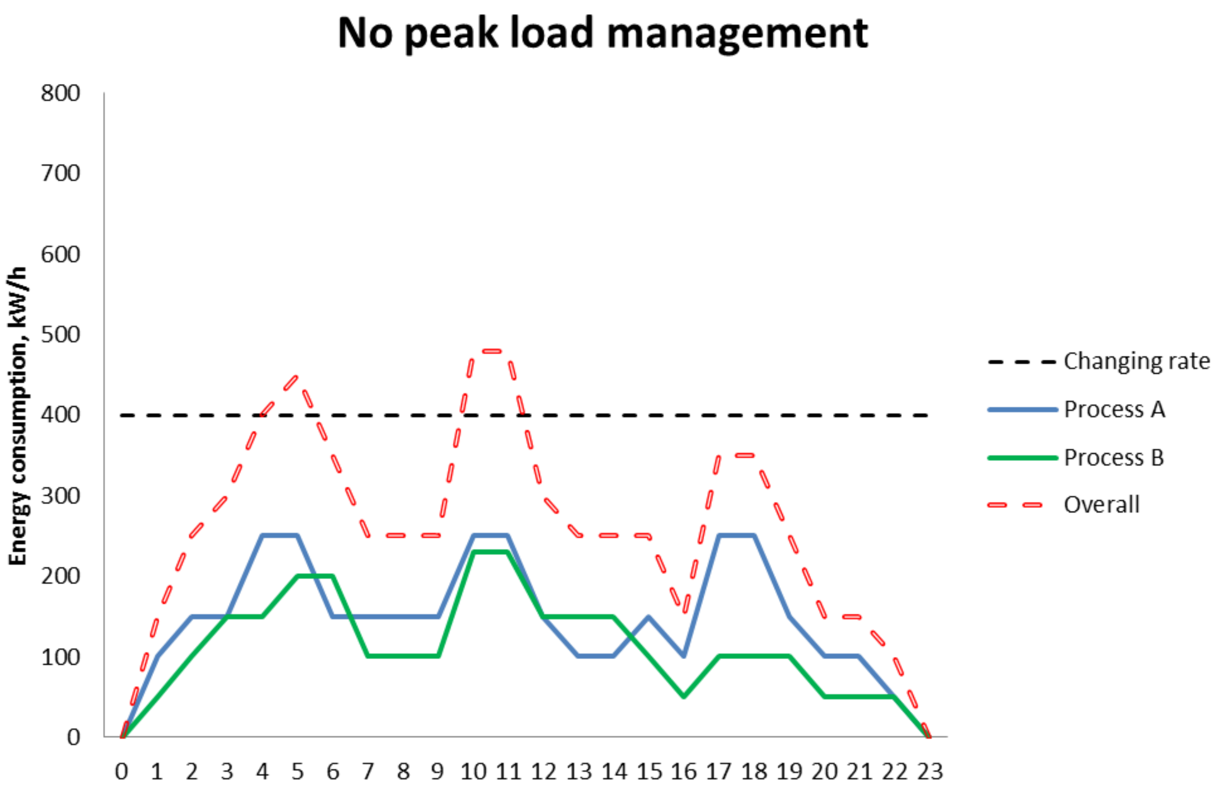

Figure 6a: Load peak management example

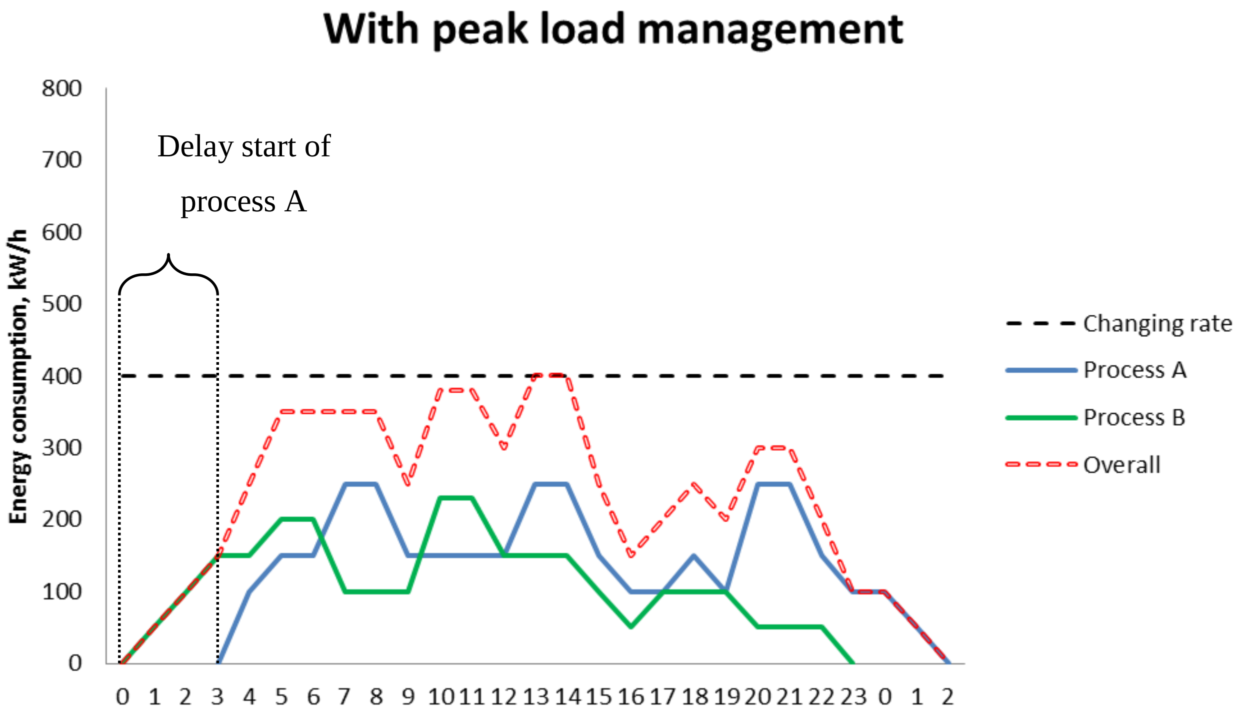

Figure 6b: Load peak management example

Peak-load management is the process of reducing the effects of large energy load blocks during a period of time by advancing or delaying their effects until the power supply system can readily accept additional load. Advance or delay start of different process can lead to greater potential to save energy and consequently money. When peak-load management is applied to reduce energy costs, it is often referred to as «peak shaving». Peak shaving describes when a facility uses a local energy storage system to compensate for the facility's large energy consumption during peak hours of the day. Most facilities do not operate 24 hours per day. In fact, most facilities do not even operate most of the day. In this scenario, the energy demand, typically measured in kW, remains relatively low most of the day and rises only during operational hours. By charging an energy storage system during the off hours of the day and discharging it during the operational hours, the peak demand charge from the utility can be reduced.

In most cases, utility companies provide a lower billing rate for energy used outside of peak operating hours, which further increases the economic benefit of implementing peak load management. For example, consider that ČEZ group pricing on January 1, 2013 varied from approximately 66,6 Kč /MWh to approximately 18883,86 Kč /MWh* between lower billing rate and higher billing rate, it is useful to realize operation during outside of peak operation hours.

For calculation example a random firm from group Akumulace 8 (C25d) (see annex I) was chosen with circuit breaker 3*30A. Annual energy consumption of this firm in high billing rate is 4,358 MWh and annual consumption in lower billing rate is 4,237MWh.

Annual price will be: **Pricing of ČEZ group see annex I*

A=permanently payment = 12 (relevant column 1-14 + column 20)*

B= payment for using energy in high billing rate= annual energy consumption (column 15+17+18+19+21)*

C=payment for using energy in lower billing rate=annual energy consumption (column16+17+18+19+22)*

Sum annual = A+B+C

A = 12 × (365,00 + 45,00) = 4 920,00 Kč

B = 4,358 × (1 883,86 + 132,19 + 583,00 + 7,56 + 1 942,00) = 19 822,84 Kč

C = 4,237 × (60,66 + 132,19 + 583,00 + 7,56 + 1 236,00) = 8 556,24 Kč

Annual price = A + B + C = <u>33 299,08 Kč</u>

If energy consumption in high billing rate (HBR) will be shift to lower billing rate (LBR) even by 30% then resalt will be:

HBR = 3,0506 MWh

LBR = 5,5444 MWh

A = 12 × (365,00 + 45,00) = 4 920,00 Kč

B = 3,0506 × (1 883,86 + 132,19 + 583,00 + 7,56 + 1 942,00) = 13875,99 Kč

C = 5,5444 × (60,66 + 132,19 + 583,00 + 7,56 + 1 236,00) = 11196,42 Kč

Annual price = A + B + C = <u>25072,40 Kč</u>

As is seen from example the shifting about 30% from high billing rate to low billing rate can lead to saving bills in 33299,08 Kč – 25072,40 Kč = **8226,67** annually.

Sometimes it is not possible to shift process to another time due to production requirements. These processes are called critical processes. Their nonfulfillment may appear time delay in overall production process. The task about shifting processes should be discussed by operators, energy engineers and energy manager. There is an algorithm, which is described behavior of process operator during each production process.

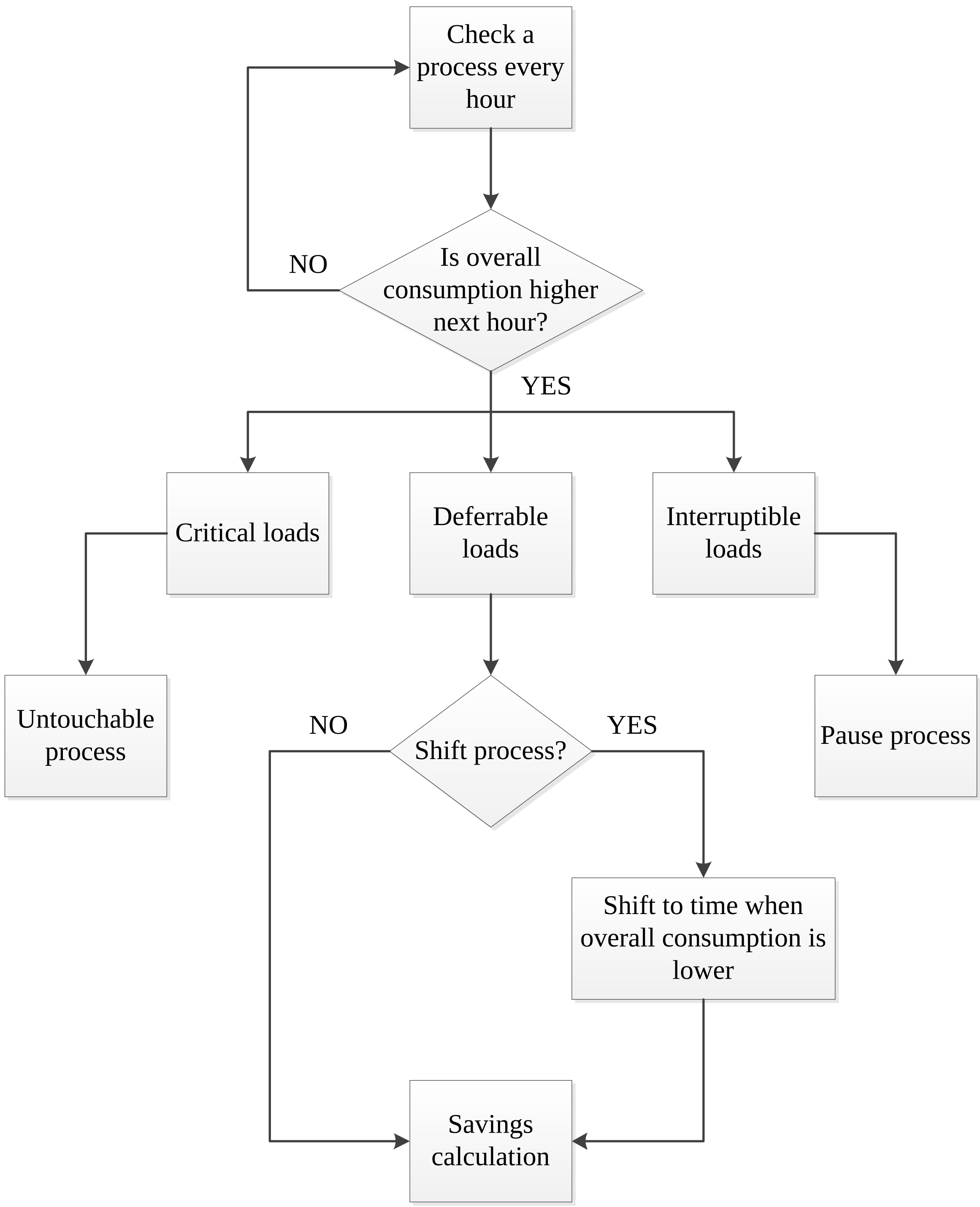

Figure 7: Diagram of shifting process

5 IDENTIFICATION OF POSSIBILITIES OF ENERGY CONSUMPTION REDUCTION IN THE PRODUCTION PROCESS

5.1 Energy consumer's identification in production process

There are two types of energy accounting: commercial and technical. Commercial accounting is used for financial calculation and includes determination of places for energy measurement by energy measurement equipment, their type and period of checking. Technical accounting is used for control of energy consumption in different departments or working shops in the enterprise. Energy accounting is the process of measuring the energy consumed by special instruments - electricity meters. Counters are integrating devices, i.e. their readings depend on the time, during which the measurement is made.

Measurement equipment is a device capable for measuring and accounting as electricity meters (active and reactive power), measuring current and voltage transformers and remote sensors. Measuring complex measurement equipment is a collection of interconnected devices on the established pattern. Set of measurement systems that are installed on a single object (such as an enterprise) is called a system of electricity metering. The most common type of electrical appliances counters are active and reactive energy. Distinguish counters direct connection to the network and counters for connection to the measuring current and voltage transformers. There are two types of settlement metering using single and three phase meters: induction and electronic. An induction meter has a movable plate on which currents flow induced magnetic field conductive coils. The electronic counter AC voltage and current affect the electronic elements to create the output pulses whose number is proportional to the measured active energy.

The totalizer is an electromechanical or electronic device that comprises a memory and a display. In recent years, there is a widely usage of the electronic induction meters, providing greater accuracy, the ability to store and transfer data, less likely to interfere with the operation of the device in order distortion of his testimony. Electronic counter can be multitariff, if it has a countable set of mechanisms, each of which runs at set intervals corresponding to different rates. The use of such counters gives the consumer a choice tariff differentiated by time of the day.

Active energy meters are made of the following classes of accuracy. Requirements for accuracy class is determined depending on the purpose and the installation accounting system; number of requirements defined in the legal and regulatory documents. The electricity market has high requirements for precision metering. Creation of the park instrumentation induction electricity meters has low metrological reliability - beyond the accuracy class for recalibration interval. Among the measures to improve the accuracy in measurement of the proposed shift to electronic meters past the relevant certification tests.

As the meter, the meter can take power curves as a function of time. Load curve is important information for energy service company and electricity supply company. It provides a measure of the electrical load, identifies periods of maximum consumption and developes measures to address the schedule. Ideally, the enterprise should aim for a rectangular load schedule. In practice, the question is to reduce the maximum values of the graph.

The enterprise should find the way to turn off power-intensive units in the maximum passing hours, but include them in the daytime and nighttime, so that the production program of daily energy will be constant. Reduction claimed maximum is possible, if such regulation will be implemented throughout the entire period, which is stated on the load schedule (month, quarter, year). Conditionally accepted:

- The process is the same for each cycle (shift), but the change in the start and end of the cycle can translate a maximum load at a later time;
- The process is continuous and can not be shifted in time, but different products on electric capacity and the process itself are adjustable in intensity - should be placed on non-energy peak hours release products;
- Technology allows the interruption: the savings paid for electricity override the inconvenience;
- Working shop is free of technological restrictions, in order to reduce pressure.

In terms of value for electricity, there are two approaches for the exploitation of the energy supply system.

The first approach also called "classic" has been used for decades in many enterprises. It provides for regular inspection, in order to verify electrical and mechanical equipment. Such control can prevent damage of devices and instruments during their operation. The main problem of preventive maintenance is its irrationality - professionals have to inspect all equipment and to identify something that needs repair. This leads to increased labor and time costs. Furthermore, despite regular maintenance work execution, there is no guarantee that the equipment will not give up in between. The only advantage of the classical approach is minimizing the cost of improvement of electrical networks, and the main disadvantage is inefficiency.

Therefore, today more and more companies in the device electrical networks choose the second approach, which is based on innovation. It involves some investment in subsystem monitoring and remote control. Along with the usual components in enclosures there are mounted sensors that enable to monitor various parameters: current, voltage, temperature, power, etc. In the whole deployed enterprise-wide monitoring system the signals from all sectors are collected and processed. It allows the enterprise to predict the point at which may cause an overcurrent or short-circuit, and just eliminate the possibility of accidents, and reduce the cost of maintenance and repair of the electrical network. Detection of energy efficiency potential by using measuring in enterprise is described in the following section.

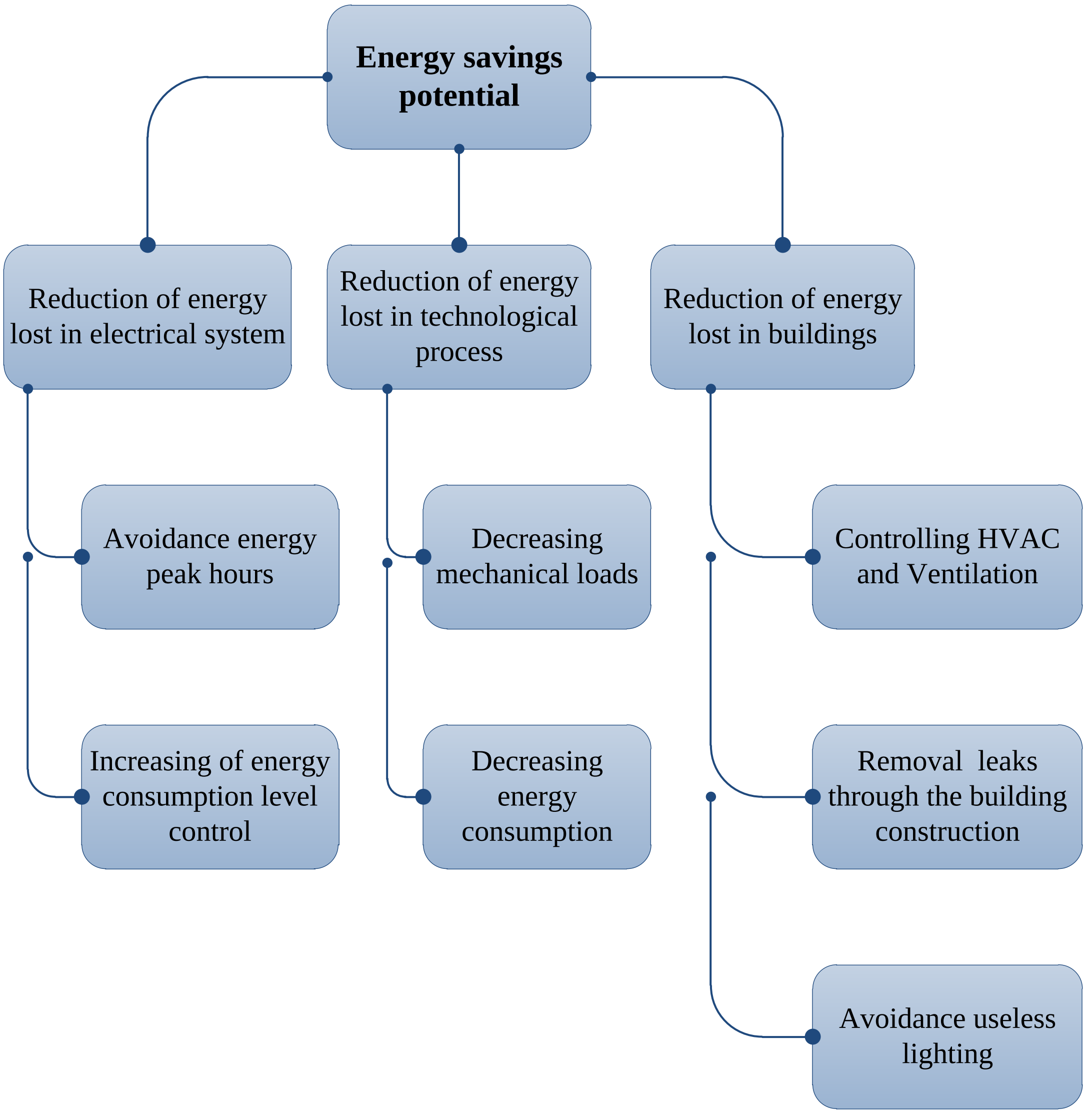

Figure 8: Detection of energy saving potential

5.1.1 Energy loss in electrical system

Measurement and tracking of energy consumption are the first steps towards reducing energy costs. The study is focused on the energy and the use of assessment tools for quantifying energy consumption on the input power supply and the largest systems will help identify opportunities to reduce costs. As a rule the causes of energy loss in electrical system are occurred in the following cases:

- Ignorance of the amount of consumed energy by each system.
- Energy consumption during peak hours, which can be avoided.
- Changes of electricity cost during a day are not considered.
- Loads are often left powered after the end of the working day or needlessly during the day at hours with maximum cost of electricity.
- Lack of adjustment in motor operation may lead to a higher output power than necessary.
- Lack of automatic control for the regular lighting and other equipment at night.
- Lack of seasonal adjusted light levels.

To solve such problem in an enterprise it is necessary to perform a thermal imaging survey of electrical cabinets and mechanical loads, in order to detect hot spots, indicate inefficient use of electricity and register the power for a certain period of time and determine the following: how much energy is consumed at different times of day and what is the loss of energy; check the total energy consumption in kWh, power factor, peak load, unbalance and harmonics. In order to make suitable measurement, the next equipment will be required:

- ✓ **Three phase energy logger** is a tool for electricians and technicians to explore the parameters of power quality logging and energy. Power quality meter measures the most electrical power parameters, harmonics, and voltage variations.

- ✓ **Industrial thermal camera** (also called infrared camera or thermal imaging camera) is a device that forms an image using infrared radiation, similar to a common camera that forms an image using visible light.

5.1.2 Energy lost in technological process

The scale and type of production processes at the facility have a great influence on what kind of energy loss will be found. The first simple means energy savings can be achieved in those industrial processes and other building systems that use electro-mechanical equipment, steam or compressed air. Measuring tools help to verify these systems and to quantify energy consumption by providing the data needed to calculate the efficiency of the motor, as well as efficient use of steam, air compressors and other industrial processes. Often causes of energy loss in technological process happened in:

- Uncontrolled loads are often remaining operate at the hours with the maximum cost of energy.
- Obsolete machine tools consume much more energy than new high model
- Excessive friction due to misalignment, bearing faults, unbalance and looseness leads to motor overload and excessive energy consumption.

To solve this kind of problems in the enterprise it is necessary to check the voltage and current levels from machine tools, check vibration levels for compliance with standards and define the necessary maintenance work, such as re-balancing and register the power for a certain period of time and determine the following: How much energy is consumed at different times of day and what the loss of energy; check the total energy consumption in kWh, power factor, peak load, unbalance and harmonics. To make suitable measurement next equipment will be required:

- ✓ **Visual IR Thermometer** features a digital camera with an infrared overlay map that allows you to instantly determine the exact location of the problem. With Visual Thermometer user gets a visible image of the object directly measurements.

- ✓ **Vibration Meter** is used in inspection, manufacturing and production, and the laboratory. The vibration meter is used to measure vibrations and oscillations in many machines and installations, as well as in the development of products such as tools or components. Measurements of the vibration meter provide the following parameters: vibration acceleration, vibration velocity and vibration displacement. In this way the vibration is recorded with great precision.

- ✓ **Three phase energy logger** is the tool for electricians and technicians to explore the parameters of power quality logging and energy. Power quality meter measures the most electrical power parameters, harmonics, and voltage variations.

- ✓ **Ultrasonic Leak Detector** is electronic stethoscope for use in industry, maintenance and manufacturing wherever precision leak detection or diagnostics are required. Ultrasound is composed of high-frequency sound waves above the range of human hearing. Detector uses this technology to sense frequency, which is electronically translated down into the audible range.

5.1.3 Energy lost in buildings

Buildings consume energy during normal operation, but the question is: which part of the energy consumed and how much is lost? Measured tools help to assess the energy efficiency of buildings, from HVAC and lighting to the building envelope. Before proceeding to the evaluation of the effectiveness of the building envelope many organizations are beginning to exploit the leak detection in HVAC systems or estimating the cost of lighting. Often causes of energy loss buildings happened in:

- Large obsolete equipment that consumes more energy than new high-performance model.
- Excessively powerful fans.
- Systems do not shut down in the off-season, as well as at night and on weekends.
- Inaccurate sensors cause unnecessary dip chiller or boiler
- Incorrect installation gates lead to the fact that the conditioned air out before reaching the destination.
- Leaks through the building.

Problems concerning building energy consumption can be solved by registration electricity consumption (kW, kWh and power factor) on the main switchboards and major loads during operating cycles, measuring the air flow and pressure to identify leaks and optimize ventilation and performing thermal imaging survey and duct dampers to detect leaks. Follow energy measurements can be used:

- ✓ **Air meter optimizes** the parameters of heating ventilation and air conditioning system in accordance with the requirements for the active control of indoor air quality and ensure normal conditions for life and work, as well as for quick troubleshooting on demand user premises. Air meter allows to measure: temperature air, flow rate, humidity, content CO and CO_2

- ✓ **Light Meter** measures the visible light from fluorescent, metal halide, high-pressure sodium or incandescent sources. It is a portable, easy-to-use digital light meter designed for simple one-hand operation reading in Lumen. Use the light meter to measure the illumination level in the interior and to switch off, reduce or increase the output level of lighting fixtures. Reduce the energy burden of the building by significantly increasing the efficiency of its lighting system.

- ✓ **Airflow measuring device** makes it easy to measure, because it combines the measurement of pressure, flow rate and air flow in one rugged and durable device. Air flow measuring device can be used for the following purposes: maintaining an optimal balance of air flow, ensuring the most comfortable conditions in the premises; measuring the pressure drop across filters and coils; the harmonization of ventilation devices installed in separate rooms; monitoring the pressure ratio inside and outside the building to control the tightness of its shell; crawl ducts to obtain accurate readings of air flow.

Possible measurement equipment is proposed above. In fact there are a lot of other different measurement systems and company production that can help to find potential places in production process. But it is important to know that each production process has to be analyzed deeper and described in detail individually.

5.2 Possibilities of energy consumption reduction

There is a variety of ways to save energy and energy consumption at the enterprise. Different ways to save energy by implementation new modern technologies are considered, which are more often found in the work of enterprises and organizations, and can significantly reduce the amount of used energy, while maintaining and sometimes increasing the useful effect of its application. Especially now, in the time of universal pollution and exhaustion of natural resources it is very important to think about environment.

As was mentioned before an assembly line process of automotive production was chosen as a production process in the present study. Automotive production process is one of the most complex processes in industry. Because of rapidly change of the consumer’s requirements and strong competition between automotive companies around the World, the companies are trying to make the best own product. In order to follow the modern concept of future automotive vehicle, new car should be friendly environment, have modern style and be medium-priced, i.e. affordable for the most of consumers. Saving problem of useless energy consumption will help automotive companies to keep the marketplace in the future. In addition, improvements made in automotive manufacture can also be applicable in industries, where similar processes or equipment are used, such as manufacture of farm equipment, industrial machinery, fabricated metals, heavy trucks, rail cars, ships and aircraft.

Production process of vehicle manufacture can be divided into five main steps: engine and parts manufacture, vehicle body production, painting, chassis production and assembly. Moreover, the supports, quality checking and car distribution logistics processes can be added to the main production process. The figure 9 represents the production line.

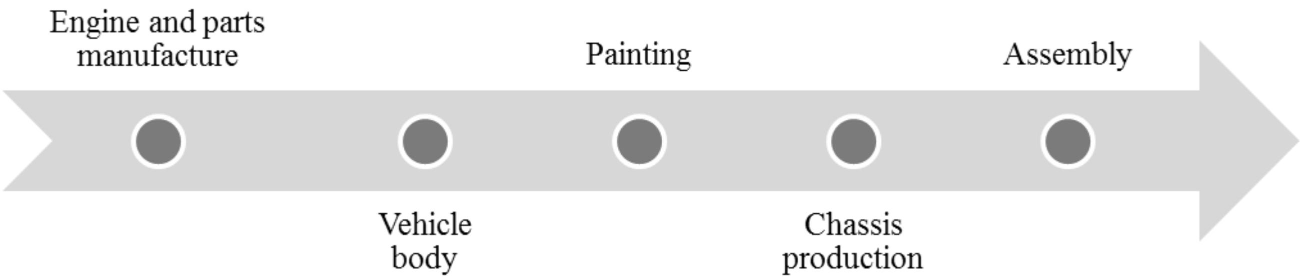

Figure 9: Main production process of vehicle production

Engine and parts manufacture

Manufacture of engine is a core of the vehicle production process. Many parts of engine in vehicle enterprises produce themselves, while other parts are purchased. Aluminum or irons are used to cast engines. Usually, for medium and large enterprises casting cylinder head of the engine is accomplished by the use of a stationary outer mold called chill mold, where inside and outside are also sometimes required cores, which are administered in a metal mold to create a single housing ready for casting.

Vehicle body production

Vehicle body is formed out of sheet steel or other materials. In the construction of a vehicle a body is a base where other details and parts are placed (engine, body panel, and chassis). In addition, the body affects the creation of such properties of the car as aerodynamics, design, passive safety, comfort and ergonomics of the interior space of the car. Currently, steel was and still are preferable in body production in some countries, because with the same mass detail made from steel is cheaper comparing to other materials. Meanwhile, there are some research and experimental works regarding using aluminum in the automotive industry. There is strong evidence supporting the usage of aluminum in vehicle body production. First of all, the production and consumption of aluminum occupies the first place among sub ferrous metals and metallurgical industries by volume, and production of steel has second place. The modern car, the details of which are made of aluminum, can be 24% lighter than its counterpart made of steel. Because of reduction in mass of automobile fuel efficiency of the car increases and the amount of emissions of harmful substances and compounds decreases, that in turn plays a crucial role in solving the problem of "greenhouse effect".

Painting

After the vehicle body is finished, the production is carried out to the next stage. This step is painting of the vehicle body. It is necessary to protect vehicle bodies from corrosion. Coloring process has two components: the color of the body and coloring plastics. They go through a succession of painting cycles, which help to maintain the visual quality of the paint and give the required hardness. The degreasing, washing and drying in air cooling unit surface preparation have to be made before painting. Preparation of the body surface at the stage degreases and phosphate is performed by immersion in a bath of catachresis and spray composition using phosphate and catholic electrophoresis. The last layer on the body is paint and varnish layer. Paint coating is applied in one or two layers. When a two-layer paint and varnish coloring layer is a durable glossy finish that gives the body color except additional effects.

Chassis

Chassis of the vehicle can be named as the main structure, to which other elements as engine, axle assemblies, transmission, steering mechanism, wheels, brakes are mounted. Vehicle chassis integrates mechanisms that transmit torque from the engine to the drive wheels.

Assembly

Modern manufacturing process of vehicle basically comes from idea of moving assembly line introduced by Ford. With a course of time the process has been improved by various manufacturing companies, but generally assembly process has two main assemblies: body and chassis. On the body assembly line the whole body is completed by welding together main elements as doors, windows, and hood. On the chassis assembly line the frame has the springs, wheels, steering gear, power train, brakes and exhausting system. The lines are meeting together at the point where the body is bolted to the chassis.

Motor vehicle assembly plants use energy for many different needs. The main energy types used in the production process are electricity, steam, gas and compressed air. Figure 10 provides an estimate of the typical electricity end-use distribution in vehicle assembly plants, based on studies of vehicle assembly plants. Around 50% of all electricity is used in motors to drive the different pieces of equipment in the plant, underlining the importance of motor system optimization in energy efficiency improvement strategies. About two-thirds of the budget for assembly plants is spent on electricity, while fuels mainly used for space heating, steam application and in the curing ovens of the paint lines. Electricity is used throughout the facility for many different proposes, for example, compressed air, metal forming, lighting, ventilation, air condition, painting, materials handling and welding. Estimates of the distribution of energy use in vehicle assembly plants are rare and may vary among plants based on the processes used in that facility. Also, not many plants have separate metering of energy use at different locations and processes in the plants.

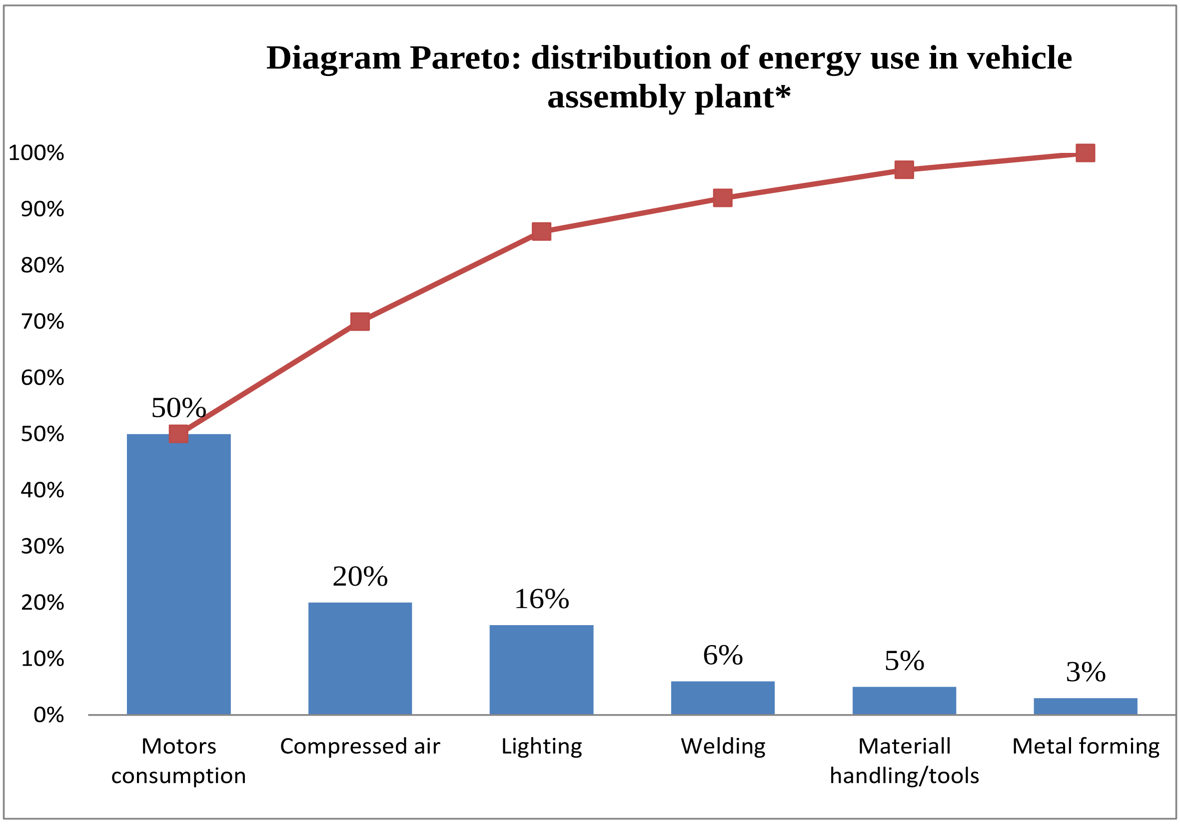

Figure 10: Diagram Pareto: distribution of energy use in vehicle assembly plant

**data has taken from German Association of the Automotive Industry* [37]

5.2.1 Motor energy consumption

Motors consume the most amount of electric energy in vehicle assembly plant. Energy is used by variety of systems, such as compressed air, refrigeration and cooling, HVAC, in processes e.g. stamping, machining, welding. In order to improving energy situation with motors in production lines, the "system approach" has to be used. Optimization of energy motors efficiency based on system approach (i.e. drives, motors, fans, driven equipment, control, and compressor) should be carried out not just for the energy efficiency of motors as individual component, but entire system. In electrical motor systems an electrical power transforms to mechanical. Electric drivers are the primary species for most industrial equipment using mechanical energy. Electric motors consumption account for a significant portion of the total energy consumption in the European Union. The motors consume about 68% of electricity in the industry. Energy consumption of motors system depends on various factors:

- coefficient of efficiency;
- selection of optimum motor and other components of the system;
- quality of energy;
- control of motor: start/stop and speed control;
- mechanical transmission system;
- maintenance practices;
- efficiency of the device consuming mechanical power.

To obtain maximum energy saving potential it is necessary to start with the optimization of an entire system, which includes a subsystem with an electric motor, and only then proceed to optimize subsystem.

Electro motor

Electric motors are divided into two main classes: DC motors and AC motors. In industry both types of motors are applied, but in the past few decades in most cases the advantage is given to the AC motor. The advantages of AC motors include:

- reliability, simplicity of design,
- limited maintenance requirements;
- high efficiency (especially in high power motors);
- relatively low cost.

Because of these advantages AC motors are widely used. However, they are able to function effectively only with a certain rotational speed. If the load is unstable, there is a need to regulate the speed that can be realized by energy efficient manner using the variable speed drives. In industry the most common AC motors is multi-phase system, which has one winding, actively participating in the process of energy conversion. AC motors are divided into:

induction (asynchronous) motors, which are capable to create their own start-up torque (although slight) and do not require assistive devices to run. This technology is well suited for motors up to several megawatts;

synchronous motors, which are able to create a moment with the rated speed. Such motors are unable to create their own starting point and as a result, need additional funds to start and acceleration, for example, specific regulatory devices. Synchronous motors are often used where high power is required.

DC motors with permanent magnet excitation and, in particular, brushless synchronous motors are used where necessary speed is less than typical in AC motors. The ease of electric speed control was the traditional advantage of DC motors. Furthermore, this type of motors has a considerable magnitude starting torque, which is important for some applications. However, the rapid development of electronic tools and algorithms for controlling AC motors has led to the fact that technology DC practically lost supremacy even in traditional areas of application. In contrast, modern AC motors are superior to their counterparts working on direct current, in many respects.

Control device

In its simplest form, the control device is a switch or contactor to enable or disable the motor by closing or opening the circuit. The switch may be operated manually or remotely, by a control voltage. Switch with added functions for motor protection is a motor starter. More complicated way to connect the motor to the network is to use the soft start (also called "trigger switch from star to delta"). This device provides a smooth launch of the AC motor, limiting the "inrush" at startup and thus protecting the motor and fuses in chains. In the absence of the soft start AC motor extremely rapidly accelerates to full speed.

Control devices or regulating devices allow you to control motor speed and torque generated by them. Principle of operation of a typical AC motor controller is to convert the frequency of the current obtained from (50 Hz in Europe), in a given frequency that allows you to change the motor speed.

Using variable speed drives, which are a combination of an electric motor with a control device, can lead to significant energy savings associated with better control characteristics of the process. Other positive effects of application of such devices include reducing mechanical wear and noise reduction. Working with variable load variable speed drives can significantly reduce energy consumption. For applications such as pumps, compressors and fans power consumption reduction may be in the range 4-50 %. Using variable speed drives helps to reduce power consumption and improve overall performance.

Other possible beneficial effects of the use of variable speed drives include:

- expanding the range of possible modes of operation executive device;
- motor insulation from networks that may contribute to a more sustainable mode of the motor and improve efficiency;
- ability to accurately synchronization of multiple motors;
- increase the speed and reliability of response to the operating conditions.

Variable speed drives are not the best solution for any environment. In particular, their use is not justified under permanent load, because the losses in the control device are 3-4% of energy consumption.

Energy efficiency motors

Energy-efficient motors and high-efficiency motors are characterized by high energy efficiency. The initial acquisition costs of such motor can be higher by 20-30% compared with traditional equipment with a power of 20 kW motor, and 50-100% at a power of less than 15kW. The specific value depends on the value of the energy efficiency class (higher class motor comprises more steel and copper), as well as other factors. However, when the motor power is 1-15 kW power, savings can be achieved in the amount of 2-8% of total energy consumption that results in less heating of the motor, reduces wastage and helps extend the life of the winding insulation and bearing. Therefore, the transition to the use of energy-efficient motors leads to:

- increase in the reliability of the motor;
- minimization of downtime and maintenance costs;
- increase in resistance to thermal stress;
- improvement of ability to work under overload conditions;
- increase in resistance to various violations of operating conditions – overvoltage and under voltage, unbalanced phase waveform distortion;

- increase in the power factor;
- reduction of noise level.

According to the European agreement between the European Committee of Manufacturers of electrical equipment and power electronics (CEMEP) and the European Commission, most motors manufactured in the EU, clearly indicated their level of energy efficiency. The new EN 60034-30:2009 defines worldwide the following efficiency classes of low-voltage three-phase asynchronous motors in the power range from 0.75 kW to 375 kW.

IE1 = Standard Efficiency (comparable to EFF2)
IE2 = High Efficiency (comparable to EFF1)
IE3 = Premium Efficiency

Higher efficiency class leads to higher complexity of motor production and higher amount of used material (as for instance copper). The motor price will increase accordingly. In relation to the motor life time the purchase price is only a few percentage points and due the saved energy cost the pay-back period is short. Eco-design requirements for electric motors shall be applied in accordance to the following timetable:

1. from June 16th, 2011: motors shall not be less efficient than the IE2 level;
2. from January 1st, 2015: motors with a rated output of 7,5 - 375 kW shall not be less efficient than IE3 or meet IE2, if equipped with a variable speed drive;
3. from January 1st, 2017: all motors with a rated power of 0,75 - 375 kW shall not be less efficient than IE3 or meet IE2, if equipped with a variable speed drive [32].

Optimal motor load

Often nominal power of the motor is excessive in terms of the load. The motors are rarely operated at full load. According to studies carried out in enterprises of the EU, on average, motors are run at a load of 60% of par. Motors reach maximum efficiency at load of 60 to 100% of nominal. Induction motors achieve maximum efficiency at a load of about 75% of nominal value and efficiency remains practically unchanged while reducing the load to 50% of nominal. When the load is lower than 40% of the nominal motor operating conditions differ substantially from the optimum, and the efficiency decreases rapidly. At high power motors threshold below there is a sharp decrease in efficiency about 30% of rated load. Using motors with optimal nominal power brings follow benefits:

- promotion of energy efficiency, allowing the motors to operate at maximum efficiency;
- reduction of network losses associated with low power factor;
- contribution to some reduction in speed fans and pumps and as a result, power consumption of these devices.

When the load increases, the efficiency begins to increase, reaches a maximum value at a load of about 80% of the face and then begins to decrease sharply due to the intense growth of electrical losses.

Repairing of motors

In operation, there is a possibility of electric failure, particularly if the power of the motor is greater than 5 kW. Often, these motors are repaired several times over the lifetime. These tests show that the repair of defective motor may reduce the efficiency of 0.5-1%, and in some cases - for 4% or more (for older motors). Choosing between repair and replacement of the failed motor, you should consider several factors: the cost of electricity, motor power, the average load and operating time (h/year). As a general rule to purchase energy-efficient motor failed return is justified, if the motor is to a considerable time. For example, in an environment where time is of the motors 4000 h/year, the cost of electricity is 0.06 euro/kWh, and the required power is in the range of 20-130 kW, the payback period in the case of energy-efficient replacement for the motor is less than 3 years.

Rewind motors

The winding is a main item, which is fully dependent on the motor power. It may be damaged during the operation or be incorrect due to the fault of the manufacturer. In any case, if the coil is done correctly, it must be replaced. This process is called motor rewinding. Rewind of motors is widely practiced in the industry. It is cheaper and in many cases faster option than buying a new motor. However, rewind motor may reduce its efficiency by more than 1%. Additional costs connected with purchase of a new motor can quickly pay off due to the higher efficiency, so fast it may be sub-optimal solution, taking into account costs over its lifetime.

Electric motors are used in all manufacturing plans and production assembly automotive plans are not an exception. The applicability of specific methods and the economic effect of their use depend on the scope and the specific conditions of the enterprise. Range of activities, while meeting the criteria of feasibility and cost-effectiveness should be conducted on the basis of the analysis needs of the enterprise as a whole and the particular system. This analysis should be carried out by a qualified consultant in the field of electric or own engineering company personnel with appropriate qualifications. In particular, a careful analysis of this kind is important considering the options associated with the variable speed drive and energy efficient motors, because under certain conditions the introduction of these devices may not lead to energy savings and cause additional energy costs. In addition, it is important to assess the proposed plans for the introduction of new systems with electric and potential modernization of existing systems. The result of this analysis should be a list of activities applicable in a particular enterprise, the evaluation of volumes savings, and cost and payback period for each activity. For example, in the production of energy-efficient motors more materials (copper and steel) are used than in the production of traditional motors. These energy-efficient motors have higher efficiency, but also smaller slip, which is the higher speed and higher value of the inrush current. Here are some examples of situations in which the use of energy-efficient motor is not optimal:

- HVAC system during operation under full load conditions for a replacement of the traditional power-efficient motor leads to an increase in fan speed (due to less slip value) and, as a consequence, the load torque. In this case, the introduction of energy-efficient motor can lead to an increase in energy consumption compared to conventional drive. In the case of energy-efficient motor constructive scheme should include measures to avoid increasing the speed of terminal equipment;
- if the system is operated at least 1-2 thousand hours/year, the introduction of energy-efficient motor cannot make a significant contribution to energy saving;
- if the system is started and stopped frequently, electricity saved can be spent because of the higher starting current characteristic energy-efficient motors;
- if the system is typically operated at partial load, but for a long time, the volume of energy savings as a result of the introduction of energy-efficient motors can be negligible compared to the potential of the variable speed drive.

5.2.2 Reactive power compensation

Reactive Power (kVAr) is the difference between working power (active power measured in kW) and total power consumed (apparent power measured in kVA). Some electrical equipment used in industrial and commercial buildings requires an amount of «reactive power» in addition to «active power» in order to work effectively. Reactive power therefore generates the magnetic fields which are essential for inductive electrical equipment to operate - especially transformers and motors. While it is the active power that contributes to the energy consumed, or transmitted, reactive power does not contribute to the energy. Reactive power is an inherent part of the «total power». The figure 11 shows the relationship between the reactive power, active power and total power on a power factor angle.

Active power (P)

It is the useful power that is doing the actual work. It is measured in W, kW, MW and calculated as, P = S*cos φ

Reactive power (Q)

It is a consequence of an AC system. Reactive power is used to build up magnetic fields. It is measured in var, kvar, Mvar and calculated as, Q = S*sin φ

Total power (S)

It is the combination of active and reactive power. Apparent power is measured in VA, kVA, MVA

Power factor (cos φ)

It is a measurement of the efficiency in a system. Power factor describes the relationship between active (P) and apparent Power (S)

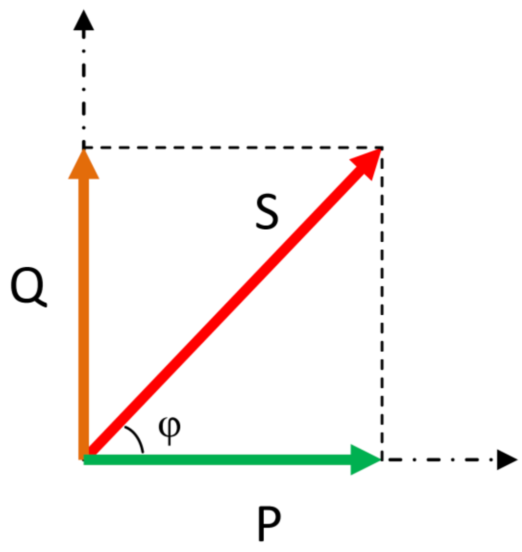

Figure 11: Definition of powers

From the above power triangle it is possible to see that consumes two kinds of power: active power and reactive power. Also, active power is never negative, whereas reactive power can be either positive or negative in value so it is always advantageous to reduce reactive power in order to improve system efficiency.

The main advantage of using AC electrical power distribution is that the supply voltage level can be changed using transformers, but transformers and induction motors of household appliances, air conditioners and industrial equipment all consume reactive power which takes up space on the transmission lines since larger conductors and transformers are required to handle the larger currents.

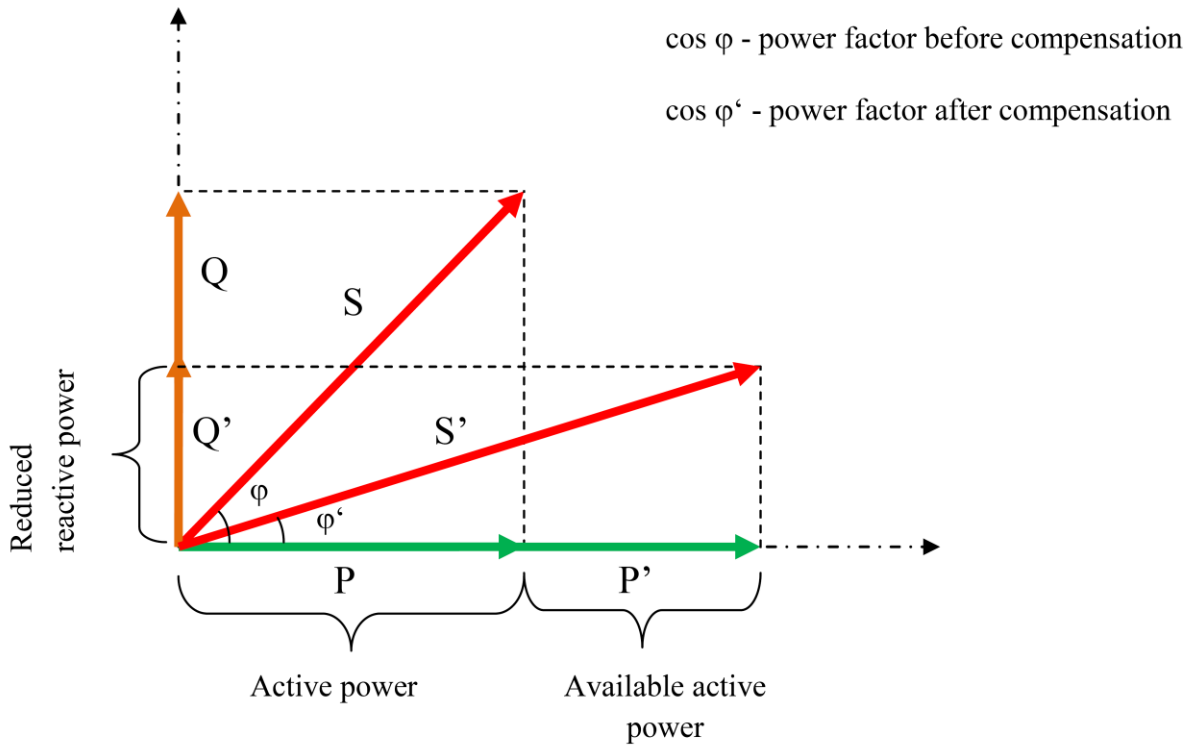

Figure 12: Reactive power compensation

Power factor compensation is one of the ways to reduce energy costs with a short payback. It is defined as the management of reactive power to improve the performance of alternating-current (AC) power systems.

Power factor correction device typically includes a capacitor that is connected in parallel as the additional load. The effect of these two opposing reactance in parallel is to bring the circuit's total reactive power close to zero. This correction, of course, will not change the amount of total power consumed by the load, but it will result in a substantial reduction of apparent power. This is the principle behind most of the power saver devices available in the open market. With power factor correction device inductive loads run more efficiently with corrected or at least improved power factors and thus mean less wear and tear of the appliance (i.e., the motor since current drawn by the motor is reduced), improving product life.

The total power is a combination of both reactive power and active power. Active power is a result of resistive components and reactive power is a result of capacitive and inductive components. Almost all circuitry on the market will contain a combination of these components.

Since reactive power takes away from active power, it must be considered in a system to ensure that the apparent power output from a system is sufficient to supply the load.

5.2.3 Compressed air

Compressed air is the air, which is stored and used at a pressure greater than atmospheric. Compressed air system takes a certain mass of air that occupies a certain volume, and compresses it to a smaller volume. Because of poor efficiency of compressed air it is probably the most expensive form of energy usage. About 10% of energy is used for compressed air system in 15 members of EU. Compressed air in automotive assembly production is mainly used in two ways: additional component of production process (cleaning workshops and surfaces, securing of dust) and in a role of energy products (driving the tools using compressed air, driving the pneumatic actuating devices). In the automotive plants compressed air is used mainly as a component of the process. Required pressure and air purity, as well as a timeline of its consumption are determined by the particular process.

By its nature, the use of compressed air is clean and safe technology due to the low risk of fire or explosion, as spontaneous and in contact with hot parts. Unlike power supply systems, compressed air systems do not require a return line or cable. Compressed air systems are used to bring the device in motion, characterized by a high energy density and, in the case of volumetric devices type provide constant torque at a constant pressure even at low rotational speeds. From the standpoint of many practical applications, this is an advantage over electric devices. Pneumatic systems are adaptable to the changing needs of the process, and pneumatic logic device can be used to manage them.

In many cases, compressed air supply systems are an integral part of the manufacturing company and should be analyzed in parallel with the common needs of the production of compressed air. In the enterprises of automotive production compressed air systems are a significant consumer of energy. In terms of growing importance of energy efficiency there is a need to develop technologies and tools for the optimization of existing compressed air systems, as well as the introduction of new, more efficient systems.

In turn, the efficiency of production, preparation and transportation of compressed air is determined by the quality of design, implementation, operation and maintenance of the relevant system. The system design should ensure the effective needs of the production of compressed air. Prior to implementation of measures in order to optimize the energy efficiency of the compressed air, it is necessary to analyze processes that consume compressed air and the needs of these processes. It is advisable to integrate activities to ensure the effectiveness of the compressed air in the overall energy management system supporting this activity by means such as a reliable audit system and a database of its characteristics.

Currently, the total device of compressed air system does not meet the existing conditions of the enterprise. Stepwise addition to the new system of compressors and compressed air consumers without a parallel review of the source device of the whole system often leads to the fact that systems are working in conditions that are far from the optimum.

One of the most important characteristics of the compressed air system is the pressure; the specific value is determined by a number of requirements, depending on the use of compressed air. Typically, this value represents a compromise between the arguments in favor of low-pressure (higher efficiency) and high pressure (the ability to use smaller and cheaper equipment). In most cases, consumers use the pressure of 6 bars; however, pressure requirement can reach 13 bars. Often, the system pressure is selected based on the maximum pressure required to consumers. It is important to bear in mind that too low pressure can lead to some malfunction of the devices, while too high pressure causes no such adverse effects, but results in lower efficiency of the system. In many cases, the system operates at a pressure of 8 bar and 10 bars.

An important feature of the system is the amount of storage tanks for compressed air. Since in most cases consumers of compressed air are a variety of devices, few of which operate continuously, the need for compressed air is subject to significant fluctuations. Sufficient volume of tanks enables smooth fluctuations performance requirements of the system and to satisfy short-term peaks in demand. Smoothing start creates the conditions for more uniform compressors operating at capacity, which reduce downtime and total electricity consumption. The system may have multiple tanks. It can be productive and places tanks near devices other than short-term intensive consumption of compressed air that caters to the needs of the peak and operate the system at a lower pressure.

The third issue that must be addressed when designing a system is the choice of pipeline diameter and location of the compressors. Any difficulties or obstructions for the movement of air as well as the need to overcome the long sections of pipes, lead to a drop in pressure. As a rule, most distribution systems pressure drop occurs at the endpoints, where there are elements of insufficient size, including hoses, pipes, joints, filters, regulators and lubricators. Reduce frictional losses may contribute, in particular, the use of welded pipes.

In a system properly designed, the pressure drop between the compressor and the end user is at least 10% of the outlet pressure of the compressor. This can be achieved by regular monitoring of the pressure drop selection dryers, filters, hoses, and compounds having a low pressure drop at the design conditions, reducing the path traversed by the air distribution system, as well as the necessary translation in the case of pipe diameters of increased consumption of compressed air.

Variable speed drive for compressors

The most obvious economic benefits of VSD occur with fans and pumps. The compressors are equipped with a variable speed drive, especially in conditions where the demand for compressed air varies substantially during the day and from one day to another. In order to control the operation of compressors, the enterprise can use such traditional approaches, such as on/off, modulation, capacity control, etc. However, if the use of such techniques leads to frequent blackouts and inclusions, as well as long periods of idling, the result could be a reduction in efficiency. In the case of using a variable speed electric compressor speed is adjustable depending on changes in demand for compressed air, providing a high level of energy efficiency. Compressors equipped with variable speed drives additional to energy savings can provide a number of other positive effects:

- high pressure stability, which is essential for some processes are sensitive to this parameter;
- power factor is considerably higher than conventional actuators, thereby reducing reactive power ;
- motor inrush current never exceeds its full load current. As a consequence, in electrical circuits can use the elements, calculated on a smaller rated current.
- soft start at low speeds provided by variable speed drive avoids current peaks and torque that tends to reduce mechanical wear of equipment and electrical load, contributing to extending the life of the compressor;
- reduced noise levels because the compressor operates only when it is necessary.

Compressor equipped with a variable speed drive may be used for various purposes. In cases where there are significant fluctuations in the level of consumption of compressed air. In situations, where the compressor is continuously run at full or close to full load, the use of variable speed drive does not result in significant energy savings and is not warranted.

Compressors with a variable speed drive may be installed in an existing compressed air system. Moreover, the frequency controller may be equipped with an existing drive of the compressor that is designed for operation at a constant speed. However, the joint supply of motor and controller achieve a greater effect, as these devices are specially selected for maximum efficiency over a range of speeds.

Load management

Most enterprises in the compressed air system include several compressors. The overall energy efficiency of the system can be significantly improved through the introduction of a control system, capable of receiving information from the production of compressors and fully or partially manage their operation modes. The effectiveness of this control device substantially depends on the capabilities of the communication channel between it and the production equipment. Improvement of communication channels opens up additional possibilities for obtaining information from the production of compressors; control the operation of the individual compressors, as well as optimization of the overall system power consumption of compressed air. Load management strategy, implemented by means of a control device, must take into account the characteristics of individual compressors. The most common modes of management of individual compressors are:

- switching between load (stroke), idling and stop;
- smooth speed control.

In systems with a single compressor there is an optimal mode of operation of the system, at which the compressor runs continuously at a constant speed and optimum efficiency. However, in circumstances, when the compressed air consumption is not constant, it will be more effective to stop the compressor or its translation to idle during a long break in consumption.

Compressors without the ability to control the speed run at a constant speed can switch between load (work at full capacity), idle or stop (in the last two modes, the compressor is zero). In some cases it may be necessary to work on the compressor idle instead of stopping. This occurs in the case when the required capacity for the system requires more frequent switching between full load and zero than the allowable frequency of stopping / starting of the drive.

When the compressor is idling, the consumed power is typically 20-25 % of the power consumed at full load. Additional losses are associated with the purge compressor stop and the high starting current of the motor. In systems with a single compressor frequency switching between speakers is directly dependent on the load (demand for compressed air) and the reservoir volume for the temporary storage of compressed air, the allowable range of pressures in the system, as well as the nominal capacity of the compressor.

For the compressors with variable speed operating speed may vary smoothly in the range between minimum and maximum allowable speed. By the inevitable losses in the inverter and the frequency of losses in an asynchronous motor, connected with changes in frequency efficiency, its own variable speed drive is always lower than the efficiency of the drive at a constant speed.

In systems with one compressor, these negative effects can be compensated by means of optimal control mode speed and eliminating losses associated with idling, stopping and starting, which would be at work in the same system at a constant speed compressor. Due to the limited range of operating speeds, even when working with variable speed compressors may be some loss associated with idling, stopping and starting.

In systems with multiple compressors central control unit provides changing needs through a complex combination of different modes of compressors and switch between these modes. Strategies for control of such a system also include a variable speed compressor, variable speed, if available in the system to minimize the period of idling, and the switching frequency with a constant speed compressor. Adding a compressor with adjustable speed to a system with multiple compressors may be especially useful in circumstances, where the compressed air system characterized by the relatively small capacity of storage tanks for air tightly and rapidly changing consumption, a small number of compressors or insufficient capacity compressors diversity. On the other hand, a system with enough variety power compressors enables exact matching of production and consumption of compressed air with a minimum idling and switching frequency by selecting the optimal configuration of compressors.

The largest volumes of energy saving can be achieved in the case where the installation of a modern management system is planned at the design stage of the compressed air along with a selection of compressors or in the process of upgrading a system that includes the replacement of the main equipment (including compressors). In this case, the enterprise should pay attention to the choice of the central control device and individual compressors controllers with advanced, developed and mutually compatible communications functions.

Reduce leaks in pipes and equipment

Energy savings potential is associated with the reduction of leaks in compressed air systems. Leakages are directly proportional to the operating pressure of the system. Leaks occur in any compressed air system and occur constantly, and not just during system operation. In large, well-served by overhead power systems compressor associated with leaks should not exceed 10%. The corresponding value for small systems should not exceed 5%.

Resulting in a loss of energy, leaks can be simultaneously a source and other production losses. Leaks cause a decrease in the pressure of the compressed air system, which can reduce the performance of pneumatic devices and as a consequence the entire production process. In addition, leading to more frequent cycles start / stop, leak cry accelerated deterioration of almost all system equipment (including the compressor unit itself). Maximizing equipment can also lead to increased maintenance requirements of the latter, as well as to increase the total emergency stops. Finally, the result of leakage of air can be unjustified increase in compressor capacity.

Leaks are a significant source of energy loss in industrial compressed air systems. In the enterprise, where there is no adequate system maintenance compressed air leakages that can reach 20% of total production of compressed air. On the other hand, preventive work to identify and eliminate leaks even in the larger system of compressed air may reduce the amount of leakage to less than 10% of the total system performance. There are several methods for the detection of specific leaks:

- listening (in the case of large leaks);
- using a soap solution applied with a brush on the suspected leak;
- using an ultrasonic detector;
- with the aid of special gases, such as hydrogen or helium, and the respective detectors.

Although leakage may be in any location of the system, it is most often associated with the following elements:

- couplings, hoses and fittings;
- pressure regulators;
- acting traps and isolation valves;
- connections and seals threaded connections;
- pneumatic devices that consume compressed air.

Since the repair of leaks is widely applicable and provides the greatest volumes of energy saving, it represents the most important area of reducing energy consumption of compressed air systems.

5.2.4 Heat and steam

The steam is one of the common heat transfer systems in thermal heated liquid or gaseous medium. Other traditionally used coolants include water and thermal oil. Water may be used in those instances when the operating temperature does not exceed 100°C. However, high pressure water, is characterized by higher boiling points can be used at operating temperatures above 100°C, in some cases exceeding 180°C. Thermal oil has a higher boiling point (and is specifically designed for long life). However, they tend to have a lower specific heat and thermal conductivity than water. Water vapor has a number of advantages listed below, and may be used in a variety of systems, which imply direct contact of the coolant with different hardware elements.

Benefits include a pair of low toxicity, safe use of flammable and explosive materials, ease of movement, high efficiency, high heat of condensation, as well as low cost as compared to the coolant thermal oil. Since most of the energy is in the form of steam latent heat, significant amount of steam can be efficiently transmitted at a substantially constant temperature, which facilitates the settlement of energy to many technological processes. Typically, steam system consists of four main components: the steam generator (boiler), the distribution system (steam pipes or condensate), the consumer or end-user (installation or process using steam or heat) and condensate system. Efficient production and distribution of steam, as well as proper operation and maintenance of the steam system can make a significant contribution to the reduction of heat loss.

Steam production. Steam is produced in a boiler or heat recovery steam generators by transferring heat from the hot gases produced during the combustion of the fuel to the water. When the water receives sufficient heat became a phase transition from a liquid to a gaseous state. In certain boilers, to further increase the heat content of a superheated used in pair. Pressurized steam flows from the boiler or the steam generator to the distribution system;

Distribution of steam. Distribution system provides steam from the boiler or steam generator to the site of end use. Many distribution systems have several steam lines, which served various steam pressure. These subsystems are separated by different elements of pipeline valves shut-off valves, pressure relief valves, and in some cases, turbo expanders. Energy efficiency of the steam system requires a proper balance between the pressure of steam, condensate organization, adequate insulation and effective pressure control.

Using a high-pressure steam has the following advantages:

- the higher temperature of saturated steam;
- lower amount of steam that can be used steam pipes of smaller diameter ;
- if the consumers of high-pressure steam is supplied, its pressure can be reduced prior to use;
- higher pressure allows for more stable conditions in the boiler vaporization.

Low pressure steam has the following advantages:

- less energy loss in steam generation and distribution system;
- minimal residual heat in the condensate;
- lower losses associated with leaks in steam lines;
- less intensive scale formation.

Due to the fact that the steam systems are characterized by high operating pressure, safety is a very important aspect of the operation of such systems. Furthermore, steam systems can take place, hydraulic shocks and corrosion of various kinds. As a consequence, the reliability and life of the various components are essentially dependent on the system design, quality of installation and maintenance.

5.2.5 Heating Ventilation and Air Condition

The structure of a typical HVAC system includes heating or cooling equipment, pumps or fans, ducts, chillers and heat exchangers, providing heat to the settlement of the premises and the process or the removal of heat from them.

At the automobile enterprises a wide range of activities related to space heating and cooling are carried out. Specific activity and its application depend on the industry and the climate, where the enterprise is located. Ensure favorable conditions at the work space, creation conditions to ensure product quality and maintaining the optimal conditions for storage or processing of materials are main direction of using HVAC systems. Quite large energy consumption is related to heating or cooling working space in the enterprise. In many cases, the heating temperature maintained industrial buildings can be reduced without compromising by 1-2°C and, conversely, when cooling set point temperature can be increased by 1-2 ºC without sacrificing comfort.

There are two main approaches to reduce energy consumption of heating/cooling. First one is based on heating or cooling needs and includes follow points:

- reducing thermal protection of buildings;
- efficient glazing;
- limit air infiltration;
- automatic closing doors;
- maintain a low temperature after hours (by programming the control system); or decrease (increase) of a given temperature level;

Second approach is based on increasing of energy efficiency system by:

- waste heat recovery;
- the use of heat pumps;
- use of radiant and local heating combined with low temperature in areas where there are no jobs places.

Reducing the level of a predetermined temperature by 1°C when the heating or increasing the level 1°C in case the cooling can reduce energy consumption by 5-10% depending on the average temperature difference between the room and the outdoor air. In many cases, increasing the target temperature in air conditioning provides a greater effect since the temperature difference in this case is usually higher. However, this pattern is generalized, and a specific amount of savings depends on the climatic conditions of the region.

5.2.6 Lighting

Artificial light accounts for a significant share of global electricity consumption. Some buildings lighting costs are unnecessary, since the corresponding energy is expended in excess lighting. Therefore, at present lighting is one of the major components of energy consumption, especially for office buildings and other large objects requiring illumination. At the same time there are many ways to use energy for lighting, differing in terms of energy efficiency. There are several methods that can be used to minimize the energy consumption associated with lighting of any building:

1. Identification requirements for coverage of each room or area

Determining what level of illumination required for each activity is an essential part of activities to optimize lighting systems, as system power increases with the level of illumination. Artificial light is divided by the total, local and specialized, and the difference between these lights is primarily in the distribution of light emitted by the sources. Obviously, for smaller corridor there is enough light level than the operator's position.

General lighting system is designed for uniform illumination of the room or area in general. Indoor lighting may be common fixtures located in the upper zone or, for example, lamps arranged on tables or on the floor. Outdoors in the dark light level may be negligible.

Specialized lighting is designed to perform specific tasks, such as reading or quality control of materials and, as a rule, is the most concentrated kind of lighting.

2. Analysis of the quality and organization of lighting

Design of buildings and interiors (including the choice of the geometry of space and surface materials) have to taking into account the climatic characteristics of natural light and location of the building to optimize the use of natural lighting. Greater use of natural lighting not only reduces power consumption, but also has a positive effect on the health and performance of the staff. Planning for optimizing the use of natural light and choice of luminaires and lamps, corresponding to the level of the best available technologies in the field of energy efficiency are also two main components of analysis and quality organization of the enterprise.

3. Lighting control systems

One effective way to solve the problem is to install energy saving motion sensors and presence. The principle of operation is simple: sensors automatically turn on/off lights in a room depending on the intensity of the natural flow of light and / or the presence of people. Also it is very important to lead training of personal to the most effective use of lighting equipment.

5.3 Economic analysis

Using a new efficiency method can significant reduce energy consumption of vehicle production process. Investments to new technology every time have to be calculated and assessment to worth of its implementation. Payback period for different type of process improvements also has to be calculated. Payback period calculation for motor exchanging and variable speed drive installation is presented below, but similar calculation can be done with other types of improvements.

Main focus of effort for energy saving in automotive production process should be directed to two parts: energy savings related to production process, as painting, welding, material handling and second is building and working environment. It is necessary to observe possibility such a motor management plan for machine tools, production line and other using equipment, variable speed drive for compressors and funs, for example, for painting process as the most energy intensive process.

5.3.1 Motor management plan

Motors are using commonly in automotive production process: pumps, machine tools, compressed air, production line etc. All this aspects is necessary to consider in the motor plan management. It is better to prevent damage of motors by installation or repairing of new equipment then carries out work to removal accident consequences. This plan will help to realize the long-term energy conservation system on all motors enterprise. It will ensure that the failures and malfunctions are eliminated quickly and efficiently. Motor plan management consists from the following steps:

- carry out work related to inventory of motor in the production process;
- develop a general instruction on carrying out repairs;
- develop guidelines for preventive maintenance and repairs;
- create a safety stock of frequently used parts;
- create a specification to purchase new motors.

Acquisition costs exceed the cost of energy-efficient motor traditional motor by about 20%. Before purchase or repair motor it is important to evaluate and consider the possibilities to minimize costs with the following considerations:

- AC motors payback period can be 1 year or less;
- motor with increased energy efficiency may require a longer payback period through energy efficiency.

Payback period for energy efficiency measures, such as the acquisition of energy efficient motor rewinding instead of the failed traditional can be estimated as follows:

Annual saving comparing to new motor and rewind motor can be calculated from equation (1):

$$Savings = hp * L * 0{,}746 * hr * COST_E * \left(\frac{1}{\mu_{REW}} - \frac{1}{\mu_{EEM}}\right) \quad (1)$$

where,

$COST_E$ - average energy cost;

hp - motor horsepower;

L – load of motor;

0,746 – conversation from horsepower to kW;

$hp -$ annual operating hours;

$\mu_{REW} -$ rewound efficiency;

$\mu_{EEM} -$ efficiency of new motor

Payback period can be calculated from equation (2):

$$Payback = \frac{COST_{EEM} - COST_{REW}}{Savings} \quad (2)$$

where,

$COST_{EEM}$ - cost for purchasing new energy efficiency motor;

$COST_{REW}$ - cost for rewinding motor;

The equation (3) for calculation of payback period occurs by substitution equation (1) to (2):

$$Payback = \frac{COST_{EEM} - COST_{REW}}{hp * L * 0{,}746 * hr * COST_E * \left(\frac{1}{\mu_{REW}} - \frac{1}{\mu_{EEM}}\right)} \quad (3)$$

For various motors, payback period will be different depending on load during its using, price for electricity and other factors. Three different variants for motors with various HP are presented below.

Table 2: Approximately price for various motors*

HP	Rewind cost	Rewond efficiency	Efficiency of new motor	Premium Efficiency motor price
2	$485,0	76,7%	86,5%	$536,0
10	$625,0	83,0%	91,7%	$1.031,0
100	$2.650,0	90,3%	95,4%	$6.872,0

**data have taken from NEMA* [38]

The purchase of energy-efficient motor is justified, if the motor works considerable time. In the case of working time 4000 h/year with energy cost 0,156 $/kWh (sourse: Enerdata/McKinsley) and load 75% then payback for 2HP motor (1.47 kW) will be:

$$Payback\ 2HP = \frac{COST_{EEM} - COST_{REW}}{\boldsymbol{hp} * L * 0{,}746 * \boldsymbol{hr} * COST_E * \left(\frac{1}{\mu_{REW}} - \frac{1}{\mu_{EEM}}\right)} = \frac{536\$ - 485\$}{1{,}47\ kW * \frac{75}{100} * 4000\frac{H}{Year} * 0{,}156\frac{\$}{kWh} * \left(\frac{1}{0{,}77} - \frac{1}{0{,}87}\right)} \approx 0{,}5\ Year \approx 6 months$$

As seen from computation payback period for 2HP motor amounts is 8 months. The same computation conducted for motors with horsepower 10 and 100 HP.

$$Payback\ 10HP = \frac{COST_{EEM} - COST_{REW}}{\boldsymbol{hp} * L * 0{,}746 * \boldsymbol{hr} * COST_E * \left(\frac{1}{\mu_{REW}} - \frac{1}{\mu_{EEM}}\right)} = \frac{1031\$ - 625\$}{7{,}35\ kW * \frac{75}{100} * 0{,}746 * 4000\frac{H}{Year} * 0{,}156\frac{\$}{kWh} * \left(\frac{1}{0{,}83} - \frac{1}{0{,}91}\right)} \approx 1{,}126\ Year \approx 14\ months$$

$$Payback\ 100HP = \frac{COST_{EEM} - COST_{REW}}{\boldsymbol{hp} * L * 0{,}746 * \boldsymbol{hr} * COST_E * \left(\frac{1}{\mu_{REW}} - \frac{1}{\mu_{EEM}}\right)} = \frac{6872\$ - 2650\$}{73{,}55\ kW * \frac{75}{100} * 4000\frac{H}{Year} * 0{,}156\frac{\$}{kWh} * \left(\frac{1}{0{,}9} - \frac{1}{0{,}954}\right)} \approx 1{,}91\ Year \approx 23\ months$$

But not always it is useful to purchase and install new motors. Replacement of old motors with new energy efficient makes sense in cases where the motor will operate more than 2000 hours per year. Often, rewind old motor turns a lot cheaper than buying new. Typically, the motor should be changed when the value of its rewinding will be more than 60% of the cost of the new motor. For that reason, to make a calculation and conduct an audit of motors each automotive enterprise should develop and maintain the motor management plan.

5.3.2 Variable speed drive installation

As was mentioned before, installation and using variable speed drive can help to save about 20-40% of energy. Undoubtedly, variable speed drives are extremely useful devices, but not always their application may be economically justified because of the relatively high cost of their acquisition. In most cases payback period of variable speed drive is determinate as the costs related to the purchase of the variable speed drive to the amount of energy savings after installation.

In determining the economic efficiency of application of variable speed drives on the objects the following factors should be taken into account:

1. energy efficiency of implementation (usually 20%-40%);
2. reduce the cost of maintenance;
3. increase lifetime of the motor.

Payback for implementation of variable speed drive can be calculated from equation (4) [35]:

$$Payback_{VSD} = \frac{COST_{VSD}}{\delta * COST_{EN}} \quad (4)$$

where,

$COST_{VSD}$ - price for variable speed drive;

δ - coefficient of efficiency, which determinates by factors 1 and 3. Past experience application of speed drives shows that depending on the specific values determined by these factors, the value of the coefficient is in the range 1,2 to 1,6;

$COST_{EN} -$ energy savings.

$$COST_{EN} = hp * P_{VSD} * k * COST_{E} \quad (5)$$

$P_{VSD} -$ power of variable speed drive;

$k -$ coefficient of expected energy reducing;

Payback period is accounted for three variable of speed drive with different power (1,5 kW; 7,5 kW and 75 kW). The working conditions were taken the same as for calculation of payback period for installation of new energy efficiency motors, in particular: time of working 4000 h/year with energy cost 0,156 $/kWh. Taking into account current range of load changes, the expected energy savings equal to accept 20%. Prices for the variable speed drive are taken from West Shore Controls.

In the base of these data payback period for variable speed drives will be:

$$Payback\ 1{,}5\ kW_{VSD} = \frac{417\$}{1{,}2 * \frac{4000H}{Year} * 1{,}5\ kW * 0{,}2 * 0{,}156 \frac{\$}{kWH}} \approx 1{,}8\ Year \approx 22\ months$$

$$Payback\ 7{,}5\ kW_{VSD} = \frac{1280\$}{1{,}2 * \frac{4000H}{Year} * 7{,}5\ kW * 0{,}2 * 0{,}156 \frac{\$}{kWH}} \approx 1{,}14\ Year \approx 14\ months$$

$$Payback\ 75\ kW_{VSD} = \frac{11505\$}{1{,}2 * \frac{4000H}{Year} * 75\ kW * 0{,}2 * 0{,}156 \frac{\$}{kWH}} \approx 1{,}02\ Year \approx 13\ months$$

As seen from results payback period depends on many factors, but installation of variable speed drive is justified when:

- motor has a large power consumption (with a motor 1 kW the energy consumption will not be very much);
- motor runs almost continuously - 24 hours a day, 365 days a year (on the motor, even a large capacity, which runs 1 hour a day will not save a lot);
- electricity rates are high (when cheap electricity to save it’s not as profitable).

Frequency converters are allowed to exercise quite difficult management techniques to perform motor protection, improve operating modes depending on the overload and do other functions. The use of frequency converters with asynchronous motors is considered as promising and economically substantiated replacement rate as regulated constant current drive and unregulated AC drive.

6 DEVELOPMENT OF METHODS OF ENERGY FLOW VISUALIZATION IN VIRTUAL REALITY ENVIRONMENT

6.1 Monitoring: energy visualization method

Visualization of energy flows direct to energy efficiency development of machine tools, process production or entire enterprise. New machine tools and industrial elements can be easily designed by means of visualization. Especially concerning research on energy efficiency, visualization is an important step for understanding. Virtual reality has become an important part of product design and development process in many companies in the manufacturing industry. This is an ideal instrument for energy visualization and communication within interdisciplinary discussion of questions and problems from the field of design, technology, production engineering, training and marketing.

Data visualization and process simulation become more important in production development and management of enterprises. Correctly analyzed data can help to find more suitable solutions for existing problems. Most problems need to be solved in teams, involving people with different skills and knowledge with different approaches to define and solve these problems. Those teams include people that are experts for the specific problem and lay people. Therefore data visualization can be used to provide a common understanding and discussion platform. Data visualization should be simplified to be understandable for everyone. This is a main goal of energy visualization for energy management efficiency.

Data will be easily understood by the means of transforming it to suitable diagrams, graphs or schemes. Different approaches are used for different types of data. One of the most applied ways for energy and power flow visualization is the Sankey diagram. Identification of inefficiencies and potentials for saving re-sources is a main task for the Sankey diagram. With this type of diagram it is possible to observe energy flows and energy waste in the best way. The intensity of energy flow is indicated by arrows and theirs width.

The Sankey diagram is an important aid in identifying inefficiencies and potential for savings when dealing with resources. The diagrams frequently focus on energy flow and its distribution to various source or sinks, replaced by arrows, the width of which indicates the amount of energy flow.

Within the recent work, a method was developed to use 3D-Sankey diagrams and virtual machine tools in a virtual reality (VR) environment to enhance the understandability of the visualized energy flow. Afterwards different VR-based methods, including 3D-Sankey, were implemented and then tested regarding user acceptance and usability.

One of the results of that user test was that users would prefer dynamic visualizations that are well arranged and that transport a lot of information without being overloaded.

In addition to those user requirements, the proposed 3D-Sankey method has another drawback when using the dynamic adaption of the branch-thickness for visualization the current quantity of the energy. Especially when the intensity of the energy flow has a great variation, the thickest branches can cover the machine components and the thinnest branches are too small to be clearly visible.

To avoid problems with lack of data was developed new method of energy visualization. This method is based on using particle system as visualization tools for energy consumption. The advantages of this method will be discussed below [36].

6.2 Using a particle system method as visualization tool

The term "Particle System" is well known in the computer graphics. It has been used to describe modeling techniques, rendering techniques and even type of animation. The two main assumptions have to fulfill for existing of particle system:

Collection of particle – A particle system is composed of one or more individual dots, called particles. Each particle has attributes that directly or indirectly affect the behavior of the particle. Often, particles are graphical primitives such a point or lines, but they are not limited for this.

Stochastically defined attributes – the other common characteristic of all particle system is the introduction of some type random element. This random element can be used to control the particle attributes such a position, velocity and color. Usually the random element is controlled by some type of predefined stochastic limits, such as bounds, variance or type of distribution.

Modeling phenomena such a clouds, smoke, water, and fire has proved difficult with the existing techniques of computer graphics. The object, which do not have smooth, well-defined surface are called "fuzzy" objects. Concerning these properties of particle system has made assumption to define electrical current in the machine tools as "fuzzy" object, which does not have any defined surface.

Initially term "Particle system" was used by William T. Reeves to describe the "effect of a bomb explosion on the surface of a planet". This creation was realized in the movie Star Trek II: the Wrath of Khan. Reeves was searching for a realistic method of fire visualization. He understood that a behavior of such a surface is difficult to define. Therefore it would be better to set up dynamic rules for a huge amount of small points. For instance, a fire was represented by thousands of particles [36].

A particle system is basically just a collection 3D points in space. They go through a complete life cycle. As described by Reeves a particle goes through three phase during its lifespan: generation, dynamic and death.

Generation of particles

The generation phase involves the creation of a particle each interaction. Generation occurs by means of controlled stochastic process. One process determines the number of particles entering the system during each interval of time. The number of particles generated is important because it strongly influences the density of the fuzzy object.

Particle attributes

The attributes of the particles are either initialized with fixed or random values. The level of randomness in each attribute is determined by stochastic process. The key aspect of a particle system is its dynamic. That is, how their attributes change dynamically each interaction. A typical structure of a particle in a particle system contains the following common attributes described in Table 3.

Table 3: Attributes of particle system and their description

Particle attribute	Description of function
Color	Sets of different color of particle
Lifespan	Time describing how long a particle will exist within boundary of particle system
Size	Default size of particles
Velocity	Vector direction to decide how fast a particles moves in given direction
Position	The location of particle within three-dimensional boundary
Opacity	Transparency of particle system

In general, the attributes of a particle system can be either static or dynamic. Dynamic attributes change in time, while static attributes remain constant in each iteration.

Particle lifespan

The lifespan of a particle may affect its color, opacity, and size. A particle's color can change constantly with each iteration to create an array of effects. A particle's color can also be combined with its opacity to determine its intensity and transparency. The higher the opacity, the brighter the particle's color will appear while a lower opacity would result in the particle appearing more transparent. The lifespan of a particle coupled to its opacity causes the particle to appear increasingly transparent until it fades away. The particle's size coupled to its lifespan can be used to represent life. For example, particles with full life are represented as large-sized points or objects but as the particle ages; they shrink in size until they die away.

The advantages of particle systems that make them an ideal technique for modeling natural phenomena are three-fold. Firstly, particles are simple primitives and use the simplest of surface representations. As a result, it takes the same amount of computational time to render many primitives to create complex animations. Secondly, a particle system model is defined procedurally. Thus, the behavior of particles can be controlled using various functions and parameters. This reduces the amount of time needed by the animator to create a highly detailed model. Finally, unlike surface-based modeling techniques, modeling the dynamics of particles are easy and thus well suited for complex animations.

6.2.1 Energy consumption visualization using particle system

The idea of visualization of energy consumption consists in using a particle system with several adjustable attributes. If consider an electrical current flow as a fuzzy object then parallel to particle system is obvious. One electron is represented by one particle. The boundary of particle system is a wire within electrical current flow extend. In parallel to the characteristics of electrical energy, it is possible to present energy flow or precisely electrical current like a movement of electrons in a conductor.

The first idea to show different amount of energy is – following the Sankey method – to change the color of the particles. Figure 13 shows a possible division of the color depending on the current energy consumption.

Up to 3kW	3kW-6kW	more than 6kW
Green	Yellow	Red

Figure 13: Dividing energy consumption by color

In addition to the proposed method of just using color coding, the particles themselves can be used to give a clearer understanding about energy movement within the machine tool.

The energy consumption can be represented by changing densities of the particles over the time. Using particles for the visualization of the current energy consumption by letting them flow through the machine tools will help to increase understanding for the main consumers of energy and the behavior of energy within the machine tool.

Particles usually have a sphere shape. Each particle corresponds to certain quantity of power consumption. In case power consumption is low there are only a few particles in a system. If power consumption increases, the quantity of particles increases as well. Figure 14 shows a combination of changing color and density of the particles to represent different energy consumption levels.

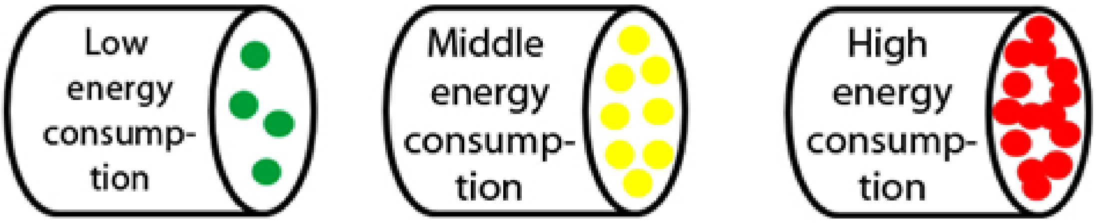

Figure 14: Rendering energy consumption by changing density and color of the particles

In addition to color and density, the live span of the particles is another attribute that can be used to even better visualize energy flows.

In principle the particle system has three stages: generation, dynamic changes and death.

A lifespan begins with the generation of the particles in an emitter. The emitter can be a single point or different types of surfaces (circle, rectangle, square, undefined surface). The emitter controls global settings of particles: number, speed, and direction in which they should be emitted. The particles are generated in an emitter and die, when lifetime reaches zero. In addition particles will die if they leave the set boundary of diffusion. In case a particle reaches a consumer (spindle, CNC controller, pumps, etc.) it will disappear.

In case of line losses (heat), there are no defined energy consumers in the machine tools. By using particles property to die when they are leaving the boundary of diffusion, it is possible to show this kind of energy losses.

It is complicate to show all energy consumers in a machine tool. Taking into account that different elements in machine tools consume various amounts of energy, it is possible to split the total amount of emitted particles accordingly. Almost 41 % of energy goes to the servo unit drive during operation. This means the major part of the particles will be directed to the spindle and to the X, Y, and Z axes. The rest of the particles will be directed to other elements, according to their energy consumption. Nevertheless it is necessary to simulate all energy consumers. Energy consumers which require a little amount of energy but consist of different components will be present like one block with one branch.

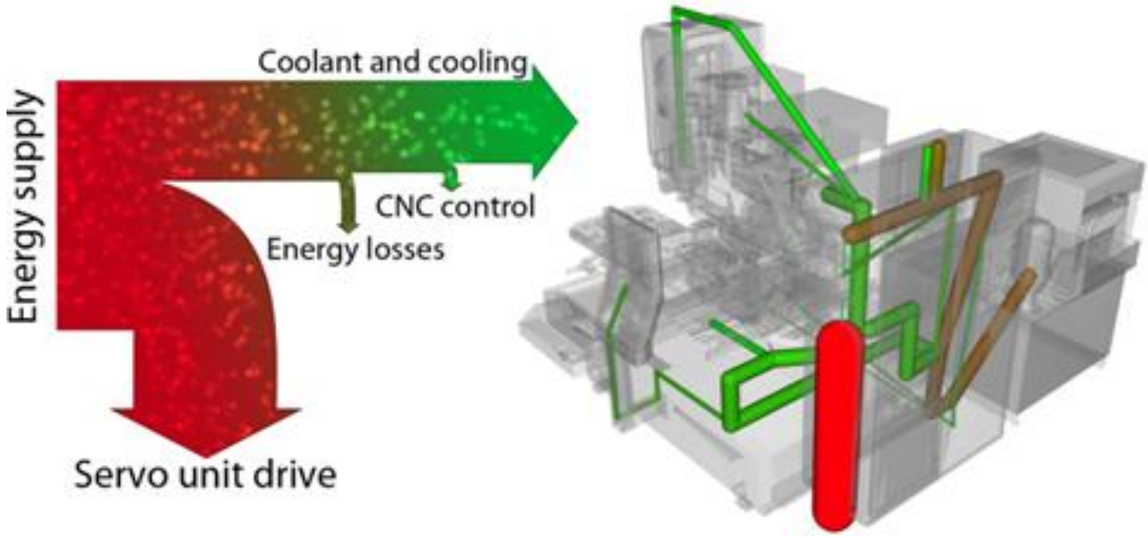

Figure 15: Framework of machine tool and boundary of particle diffusion

Figure 15 shows the main energy consumers and the power supply unit. The power supply unit can be used as the emitter of the particle system. Coming from this emitter, one thick main branch represents all necessary energy needed by the machine tool. After entering the machine the main branch is divided to different smaller branches. Each branch should be connected to an energy consumer (e.g. spindle, axis, and pump). The branches represent the boundaries for the particle system. The particles are moving through a machine from emitter to consumer simulating flowing energy. When particles reach the consumer they die and in the same time new ones appear from emitter.

6.2.2 Mathematical basis of particle movement

The primary idea of using particle system is to show dynamic changes of energy consumption over the time. This demonstration should not be very difficult, but first of all more intuitive and usable for understanding.

If an emitter of a particle system is not one single point, but a complex surface (rectangle, circle), the creation of the particles and their movement to the consumer can be represented by the following equations. The trajectory of particle movement is a simple line, which is described by vector-parametric equation line in space:

$$\vec{r} = \vec{r_0} + \vec{v}t \quad (6)$$

where, $P_0(\vec{r_0}) = P_0(x_0; y_0; z_0)$ are the points in a line; $\vec{v}(l; m; n)$ is a direction vector of this line.

In suggested system the direction of particle changes. For describing the behavior of all particles in a system, a set of equations depending on direction and time should be developed. In a scenario (energy flowing from emitter to consumer along branches 1- and 2) a particle changes direction one time. That means energy came from the power supply unit and then part of it went to one element (for instance X-axis). The description of particle way will be:

$$W_1(t)\begin{cases} P_1 + a_1(t)\vec{v}_1 \\ P_2 + a_2(t)\vec{v}_2 \end{cases} \qquad \begin{cases} t \in [0;10] \\ t \in [10;20] \end{cases} \tag{7}$$

where, P_1 is an initial point of a system and P_2 - the point, where particle changes the direction and t is a time.

The coefficient $a(t)$ should fulfill the followings condition:

$$a_i(t) = t - t_{io};\ t_i \in [t_{io}; t_{i1}] \tag{8}$$

The following equation represents scenario 1-3-8:

$$W_2(t)\begin{cases} P_1 + a_1(t)\vec{v}_1 \\ P_3 + a_3(t)\vec{v}_3 \\ P_8 + a_8(t)\vec{v}_8 \end{cases} \begin{cases} t \in [0;10] \\ t \in [10;20] \\ t \in [20;30] \end{cases} \tag{9}$$

The realization of the method is presented on the Figure 16.

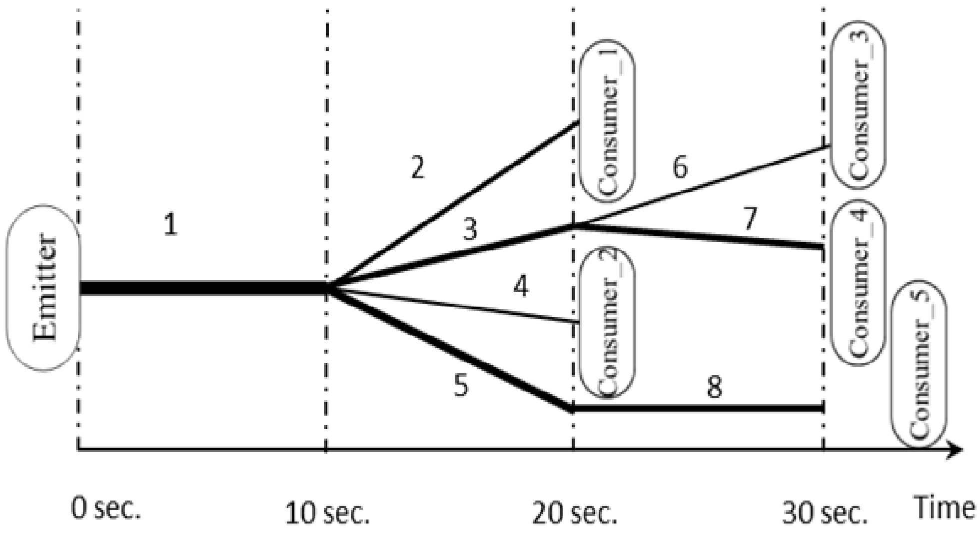

Figure 16: Basis of the particle system methods

6.2.3 Particle system background

The goal is to implement a particle system to be able to visualize the energy flow and its changes over time in-side of a machine tool represented in a 3D model.

To achieve this goal it is necessary to develop and implement a model by which the energy flow, by other words electric current, inside a machine is visualized in 3D Space by a representation of energy flow with a particle system. This has done by implementing some ideas in C++ and visualizing it via an OpenGL template at first. The plan for the realization of that goal contained following steps:

1. Design and implementation of a model for pathway and flow value description in C++;
2. First visualization and testing with OpenGL;
3. Design and implementation of an energy flow model;
4. Design and implementation of a model for describing particle behavior;

Design and implementation of a model for pathway and flow value description in C++

As a first step, a model (simplified description) of how energy flows inside a machine had to be found and implemented.

Assumptions:

- the paths inside the machine are described with a **graph**

- the **energy source**, the **junctions** to several pathways and the **energy consumers** are
- represented by the **graph nodes**
- the connections are represented by **parent/child relationships** between the nodes
- the nodes have **flow values**, which represent the energy passing through it
- for each graph there can only be **one source**, but **several consumers**, making it a **tree**
- graph

Implementation:

The graph was implemented in two C++ Classes:

Class PowerTree

This class represents a complete tree graph. It contains the further parts of the graph:

- root node
- container with all nodes of the graph

class PowerTreeNode

This class represents a node of the graph. It works as a junction, from which the energy gets divided between its children nodes.

- parent node (can be nonexistent, making it a root)
- container with children nodes (can be zero, making it a leaf/power consumer)
- coordinates in 3-dimensional space
- a flow values, representing the energy which flows through the node

As in a tree graph every node has only one parent, the properties of the connection to it is also described in this class:

- length of the connection leading to it (Euclidian distance to parent node)

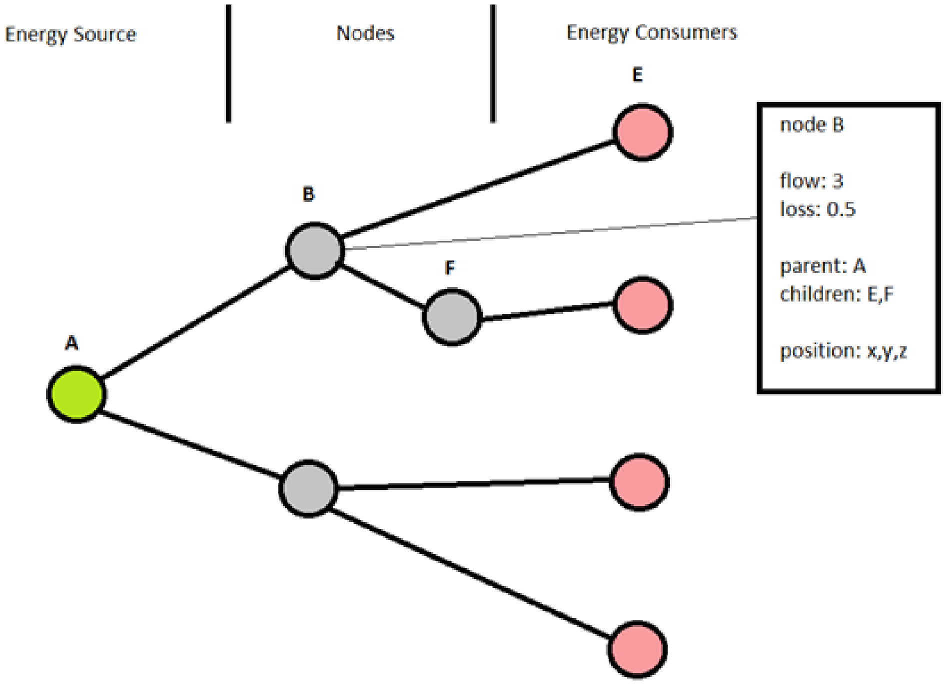

Figure 17: Energy flow tree graph

First visualization and testing in with OpenGL

For first testing and visualization, a simple OpenGL Template was used:

- nodes are shown as spheres
- connection between nodes are represented by lines between them

Some first visual properties were added:

PowerTreeNode

- colour
- size
- name

for example the root, junctions and energy consumers are distinguishable.

PowerTree

The ability to load testing graphs from a simple file that contains all node information is added:

- loadTreeDataFromFile()

Design and Implementation of an energy flow model

The next step was to find a way to divide the particle flow among all tree nodes/connections as the energy would in the real machine.

Assumptions:

1. there are given flow values for the energy source and the energy consumers (for example from measurements);
2. overall energy loss is calculated: ***flow(source) – sum flow(consumers);***
3. the resulting energy flow and loss are divided onto the single nodes (and connections).

by following assumptions:

- every path loses energy constantly along its way
- the longer the path, the more energy is lost
- the higher the energy flow on a path, the more energy is lost

In order to achieve this, a number of functions were added to the classes:

PowerTree

Function that reads measurement data for the root and leaves from a file:

-readMeasureDataFromFile()

Function that initializes the (re)calculation of all flow values:

-calculateFlow()

PowerTreeNode

Several functions are calculated and divide the measured flow and the calculated loss among the graph nodes/connections. Detail calculation of nodes is described below.

1. Calculate lossless flow

$$flowLossless(leaf) = measuredValue(leaf) \tag{10}$$

$$flowLossless(node) = \sum flowLossless(children) \tag{11}$$

2. Calculate overall loss

$$overallLoss = \frac{flowLossless(root)}{measuredValue(root)} \tag{12}$$

3. Calculate distance of every connection (Euclidian distance node - parent)

$$length(node) = \sqrt{(x(parent) - x(node))^2 + (y(parent) - y(node))^2 + (z(parent) - z(node))^2} \tag{13}$$

4. Calculate path length for every node (path = way of connections from root to node)

$$pathLength(node) = length(node) + pathLenght(parent) \tag{14}$$

$$pathLength(root) = 0$$

5. Calculate how which percentage of the total flow falls on every path

$$energyFlowPercentage(path) = \frac{flowLossless(leaf)}{\sum flowLossless(leafs)} \tag{15}$$

6. Calculate how much energy loss for path of every leaf depending on its energy flow:

$$energyLoss(path) = overallLoss * energyFlowPercentage(path) \tag{16}$$

7. Calculate loss for every node and connection on every path to leaf for every path:

$$loss(node) = loss(node) + energyLoss(path) \times \frac{length(node)}{length(path)} \tag{17}$$

8. Calculate real (loss) energy flow for every node

$$flowReal(node) = \sum(flowReal(children) + loss(children)) \tag{18}$$

$$flowReal(leaf) = flowLossless(leaf)$$

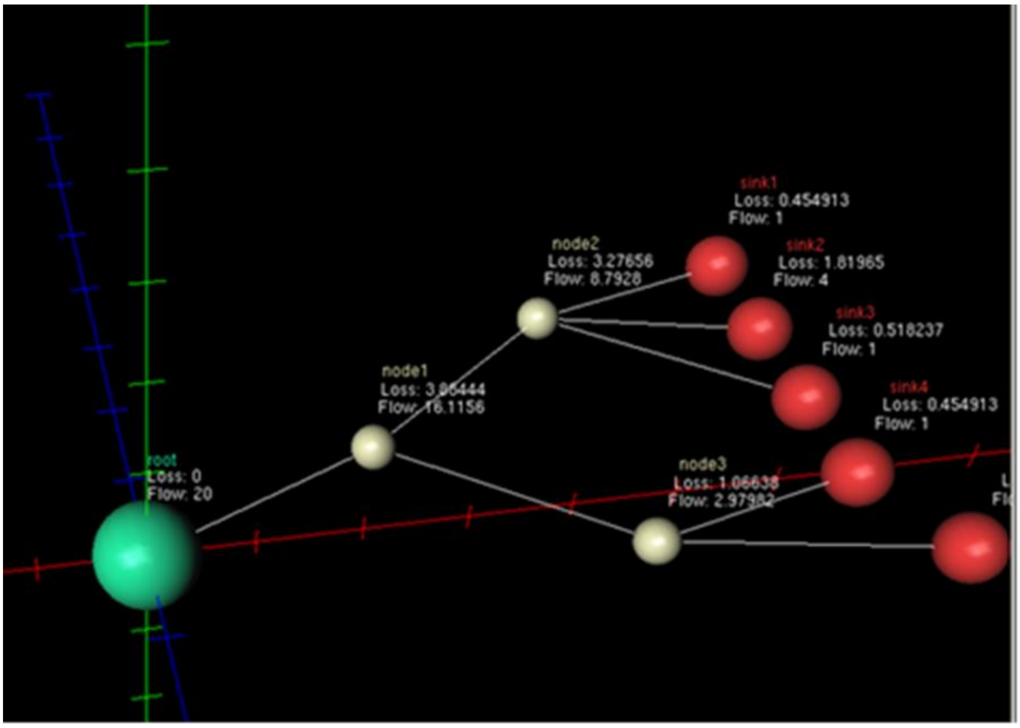

Figure 18: Test graph in OpenGL with calculation results on every node

Design and implementation of a model for describing particle behavior

To represent **energy flow** values with particles, following assumptions were made:

- higher energy flow is represented by a higher density of particles
- particle move on a linear way from random points inside node 1 to node 2, with a fixed speed
- particles move only from one node to another and are then deleted, the
- impression of a continuous flow through the graph is still given due to the high
- number of particles overall
- therefore, a certain amount of particles has to be recreated every frame and for

Every node is depending on:

- current flow value
- passed time since the last frame
- particle speed

The method of creating a dynamic (randomized) amount of particles every frame allows to change/recalculate the flow values on the graph during runtime. Also some other ways of visualizing flow data had problems to clearly show big energy flow differences on different paths (some paths could get really small in comparison to others). To address this problem, different kinds of particles were introduced:

- three different kinds of particles represent different amounts of energy flowing through the system
- the difference between the particles is shown in different sizes and colors
- every path has only one kind of particles on it, depending on its energy flow values

For the **energy loss** on the connection, particle gets the following behavior:

- loss is visualized by some particles disappearing along the way

The particles are also represented in a C++ class:

- position (3D coordinates)
- direction of movement (normalized 3D vector)
- movement speed
- life (remaining lifespan)
- energy content
- boolean if particle is dead

To calculate the next position of the particle depending on how much time passed. If a particles life gets zero, it is marked as “dead”. To manage the creation of particles, following functions were added:

PowerTreeNode:

Function to create on particle for the node:

createParticle()

- start/target points are chosen randomly inside of the start/target node
- from that, the normalized movement vector is calculated
- speed is the fixed overall speed in the tree
- the lifespan = the length of the connection the particle is on
- the particle has a chance to die earlier:
- p(particle dies) = loss / flow
- if a particle dies earlier, its life is multiplied by $random[0-1]^2$ to set an leaving point

- has the option “first initialization”, which already positions the particle on a random point on the connection, to crowd the graph already on program start.

Function to create particles every frame:

onFrame()

calculate number of particles to create:

1. length of connection
2. flow value
3. time passed since the last frame
4. particle speed
5. energy content of the particles

PowerTree:

Function, to create particles on program start:

initializeParticles()

- creates an amount of particles on program start with createParticle () and “first initialization” activated

Energy loss in paths between energy consumer elements is visualized by some particles leaving the scene/ their linear path earlier (see red particles in Figures 19 and 20).

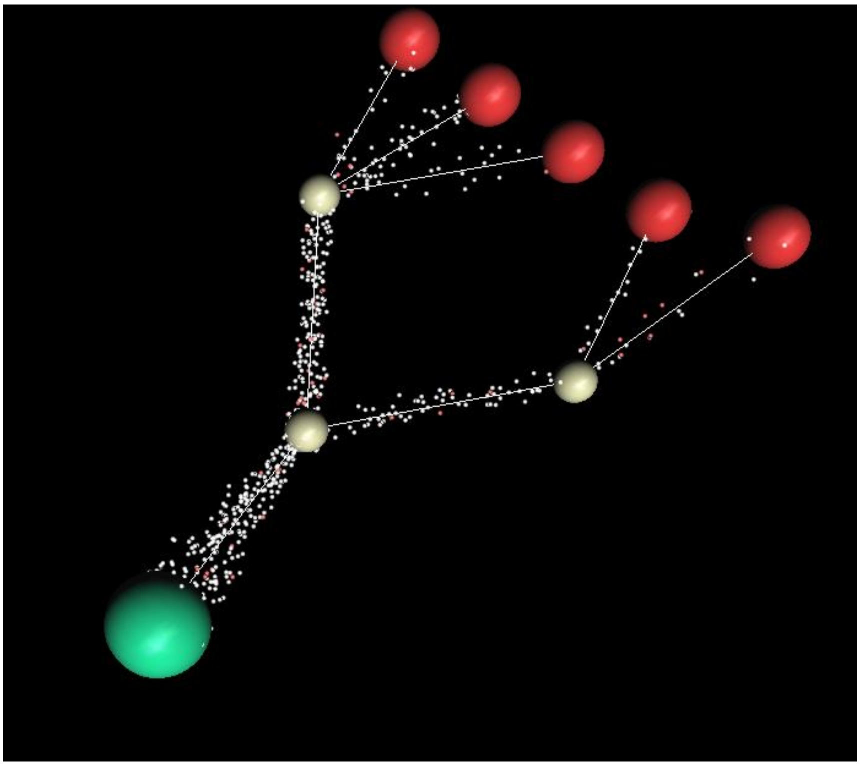

Figure 19: Particles divide among the paths differently, creating the impression of a continuous energy flow

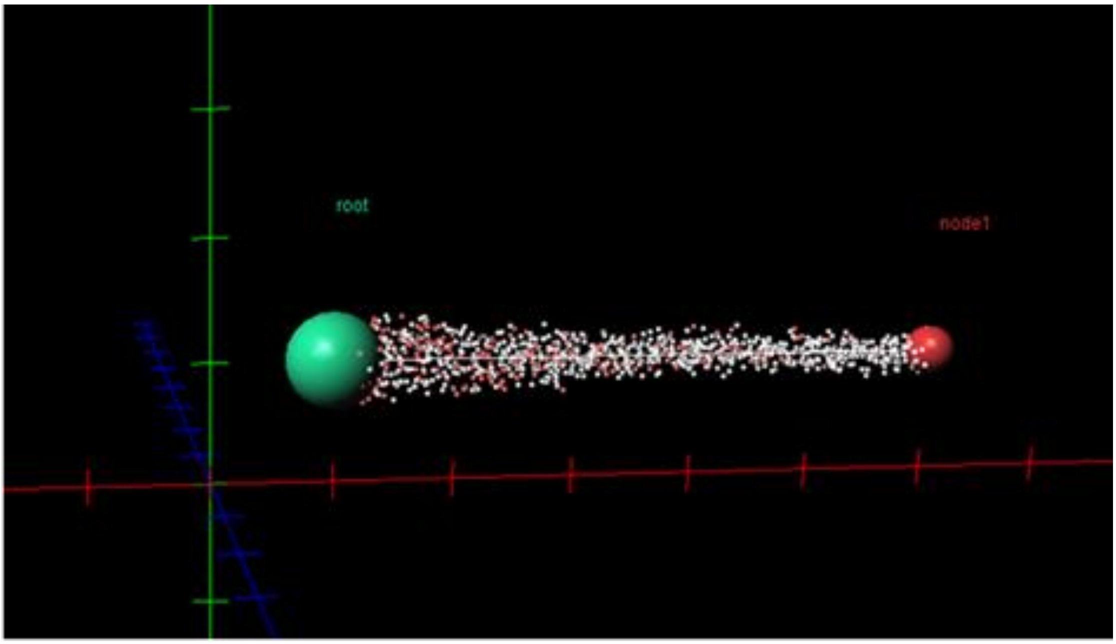

Figure 20: Test graph, where part of the particles get lost (red)

6.3 Implementation of the particle system

The introduced particle system was implemented for testing and evaluating purposes for the VR software Instant Player which allows visualizing x3d graphic files. The developed solution uses to different interfaces to create and control the virtual particles. To gain a good flexibility, the description of the particle tree and the definition of the measurement values are saved in external files (e.g. Tree.txt and Measurement.txt). A plugin reads in the needed data from the files and creates the mathematical particle system model. All presented calculations are done within this plugin. The result is a set of attributes for each particle (position, color, size). Based on this attributes a script creates and controls spheres in the VR environment. Therefore, the functional interaction of the plugin and the script enables the system to show a particle system.

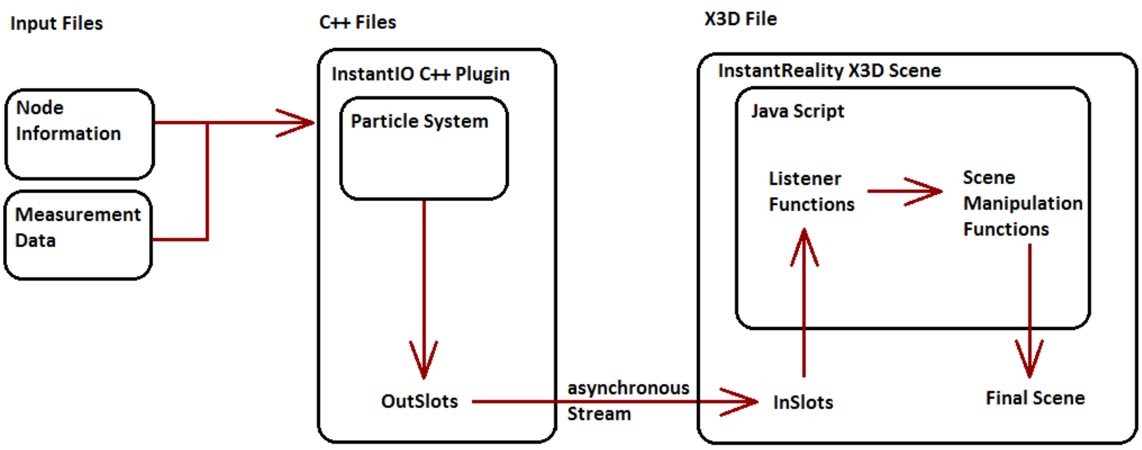

Figure 21: Dataflow in the current system

The final step in developing a particle system for energy consumption visualization was to make the current state in development visible via an InstantReality Scene. This is achieved by changing the C++ code of the particle system into a C++ InstantIO Plugin. Then an X3D Scene was created, which is able receiving data from the C++ Plugin and displaying it via an X3D Scene in InstantPlayer.

Next step of particle system development method was realization implementation of CAD model of machine tools N20 combining with particle system to virtual reality environment. Due to wide adjustability of implementation of particle system it is now difficult to create the same energy visualization flow system for different CAD models. Current status of implementation particle system is presented on the Figure 22.

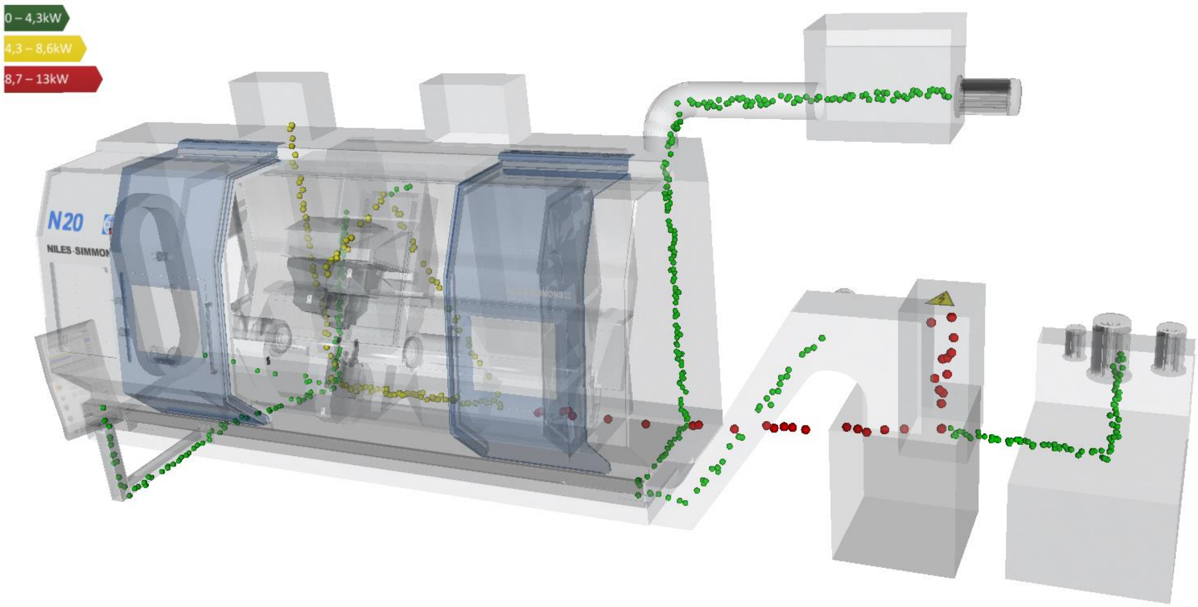

Figure 22: Model of machine tools N20 with particle system implementation

Visualization of data is important because the human eye can process many visual signals simultaneously. Moreover, visualization can be more efficient if the way of data interpretation is chosen correct. Method of energy visualization in virtual reality by using a particle system is described above. The main advantage of the particle system method compared to other existing visualization methods is the dynamic changes of the energy consumption over time.

7 ENERGY SAVING AND ENERGY MANAGEMENT METHODOLOGY

In this chapter is presented entire block diagram of energy savings and energy management methodology with description of each steps. For more clearance major steps of current diagram are colored to corresponded color of general scheme, which is presented on the figure 4 and named «Background of energy savings and energy management methodology».

Introduction to production process – this step is dedicated to introduction of production process, data collection and data analysis of useful information. This information is essential for understanding the problems of energy use and the correct prioritization to achieve the best results of energy audit. Usually data collection has to be done by data energy manager under the control of energy manager.

Mapping of energy consumption – during this step is occur creation and development maps of energy consumption. The most important energy resources and consumers costs have to be defined. For each element of such scheme the flows of energy, raw materials, products, industrial effluents and waste should be identified. Energy auditor or person, who is responsible for energy management system implementation, makes a map of energy consumption. Moreover, distribution on energy consumption for each consumer has to be noted.

Analysis of energy consumption – in order to establish the list of major energy consumers, to identify the most important and prioritize their detailed survey, it is necessary to know their share of the total consumption. After energy investigation it is necessary to concentrate to more detail analyze of the enterprise. For the identification of the main consumers any source of information will help: interviews with staff, process flow diagram, bypassing the enterprise. However, it is possible, if an enterprise has sufficient energy meters and has the necessary statements. But in actual practice it is rare. Map of possible energy consumption is presented on the figure 24

Electrical system/Technological process/Offices and buildings – are three branches of energy consumption in the enterprise, which have to be analyzed and reviewed as major sectors of energy consumption. Different equipment is used for each sector.

Identification of savings potential – during this step is looking possibilities to reducing energy consumption by different methods. Various ways to save energy by implementation new modern technologies have to be considered. Commercial methods can be find by benchmarking another one are given by government in legislatives and directives.

Savings calculation – calculation and analysis of proposed solution for energy saving. Investments to new technology every time have to be calculated and assessment to worth of its implementation. Payback period for different type of process improvements also has to be calculated. It is necessary to observe possibility such a motor management plan for machine tools, production line and other using equipment.

Benefits of applied solutions – analysis of proposed energy savings solutions is necessary. If benefits are negative then proposed energy solutions have to be refused and cycle of energy saving methodology will start again. Otherwise proposed energy savings solutions have to be realized in the production process.

Realization of energy savings solutions – the purpose of this step is a critical analysis of the collected information on the early steps, in order to suggest the ways to reduce energy costs. Proposed solutions can significantly reduce the amount of used energy, while maintaining and sometimes increasing the useful effect of its application. Sources of energy loss can be excessive overheating of the furnace equipment left switched on after hours, leakage in the distribution, excessive pressure steam or compressed air in the system. Low energy conversion efficiency can be caused by poor efficiency of the boiler, air compressor, refrigeration equipment or inefficient exploitation. After identification of the sources of loss and sections of irrational use of energy development of proposals and projects to improve the situation can be suggested.

Data collection for energy visualization – purpose of this step is data collection of all necessary information of implemented solutions. Collected data have to be transformed to suitable form for their next implementation.

Constant monitoring (energy visualization method) – this step is dedicated to continuous monitoring of energy consumption for making next suitable solutions Visualization of consumed energy is necessary to visualized energy consumption for its better understanding. Corrected analyzed and well – presented data can help to find more suitable solution for existing problems. In current work step of constant monitoring is presented by development of new energy visualization system in virtual reality environment by particle system.

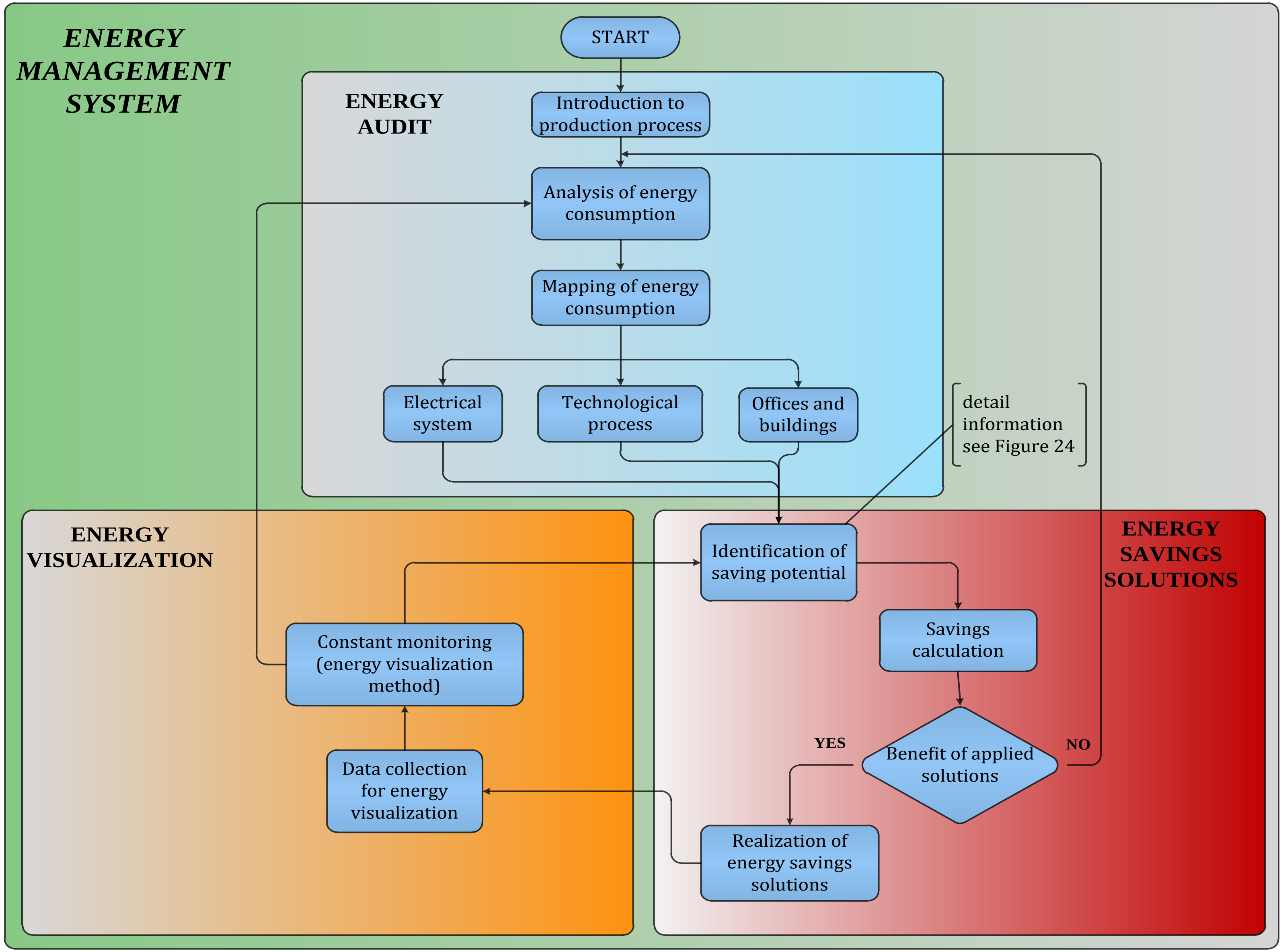

Figure 23: Diagram of energy saving and energy management methodology as implementation of EnMS

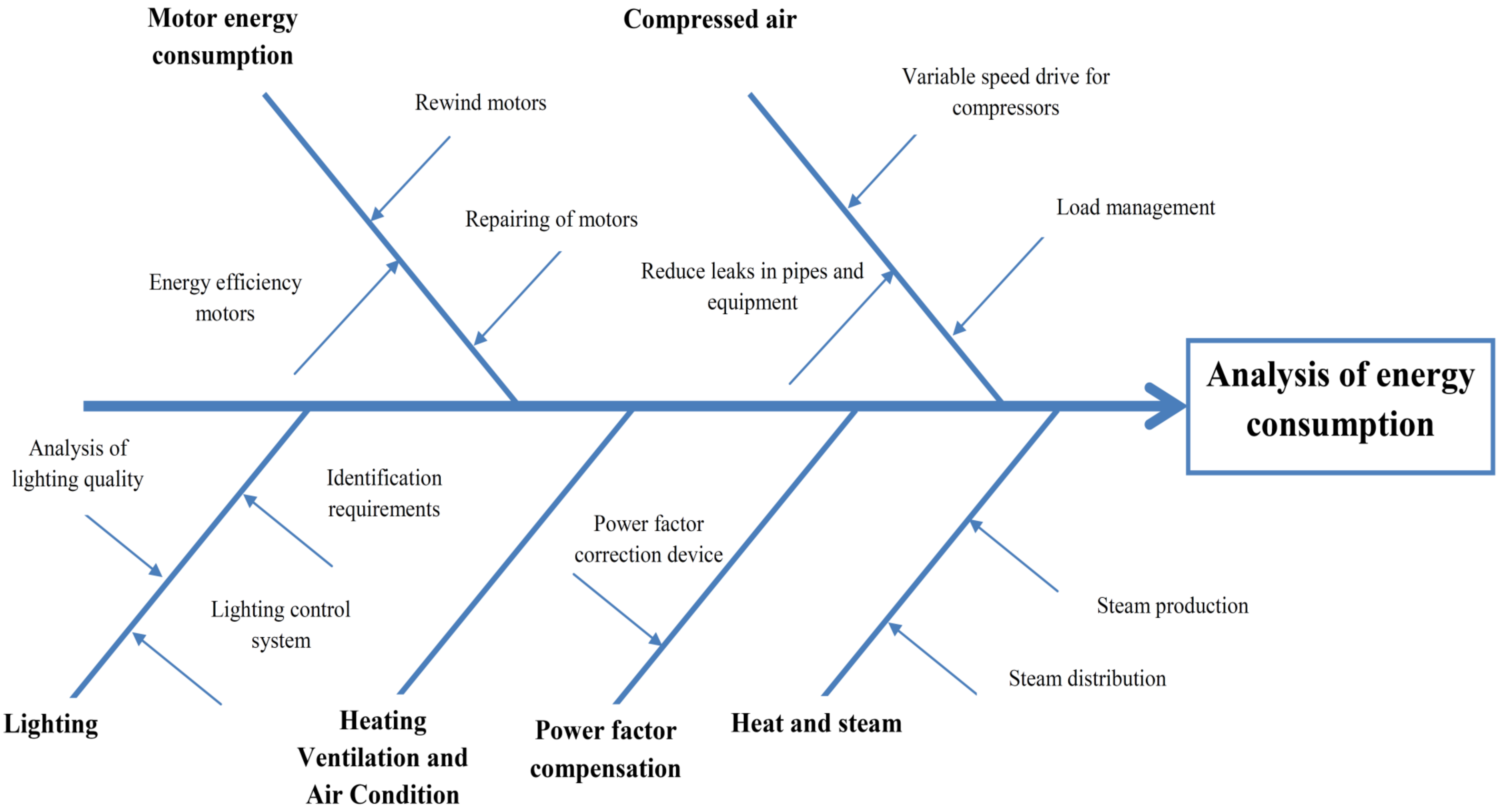

Figure 24: Analysis of energy consumption

8 CONCLUSION

Decrease in supply, increase in costs of energy resources and reduction in energy usage have become an important challenge for the European Union. The Members States establish the target which is directed to reduce annual primary energy consumption by 20% up to 2020. This is one of the main targets jointly described in Communication from the commission Europe 2020 «A strategy for smart, sustainable and inclusive growth» [16].

Saving energy and energy resources play an important role in modern manufacture production. About 37% of the EU's primary energy consumption is related to industry. Improvement of energy efficiency of industrial enterprise is a central target of this work. The most attention is paid to vehicle assembly process and the search of energy potential in this process. It was identified that decrease of energy consumption is possible in two ways. The first way represents systematic implementation and constant execution request of the energy management system, based on EN ISO 50001:2011. And the second way lies in using the newest and modern technology and equipment for increasing energy efficiency of an enterprise.

After analysis of different energy saving potentials and research work in the field of energy consumption in production process the lack of current methodology was identified.

The maps of energy consumption can be developed by enterprise based on the energy audit; and all necessary activities could be accepted. So called «necessary activities» are understood activities for identification of main energy consumers in production process. In vehicle production process the biggest part of energy consumption falls on using the motors of all levels and production of compressed air. The high level of energy consumption by these processes is conditioned by the fact that these processes use motors and drive during their execution. The energy efficiency improvement of motors can significant reduces energy consumption of whole production process. Improving energy efficiency of motors is not only the one activity that can influence energy consumption of an enterprise. Moreover, there are some other manners, which can be recognized by energy audit and energy management implementation. Thus the energy management system is very important for enterprise, which is focused to reduce energy consumption.

An important part of present methodology is development of a new modern monitoring technology of energy consumption. New tool was developed on the base of virtual reality environment. By the means of suggested method it is possible to analyze and discover processes that cannot be seen in reality. Intuitive visualizations are the basis to create understanding for the process itself. Visualization of energy flow in whole enterprise can be easily realized by this new tool due to its flexibility. The main advantage of method's realization lies in using information at all levels of an enterprise. It can be used for more efficient work. If employees from different division can realize, where energy is consumed, how it is flowing through a machine tool or a whole workshop or enterprise, everyone can propose different approaches, in order to work more energy efficient and therefore save energy. By involving all employees in that process other ideas can be found, which might be hidden from expert energy engineers.

Summing up, it is necessary to say that developed methodology has the following advantages:

Contribution to society

- The proposed methodology is developed in accordance with requirements of actual standards and directives of European Union, which set up demands of reducing energy consumption in compulsory way. Directive 2012/27EU establishes compulsory improvements of energy efficiency and decrease of hydrocarbon gas emission by 20% by 2020 year; directive 2009/125/EC establishes obligate environmental requirements in design of products associated with higher energy consumption; new standard EN ISO 50001:2011 Energy Management System establishes requirement for standardization of enterprise in the terms of the system EnMS. Thus, implementation of developed methodology executes established actual requirements and demand of reducing energy consumption of directives and standards EU.
- Utilization of methodology influences decline of harmful impact of CO_2 to environment, which is compulsory required in the directive 2012/27/EU by 20% by 2020 year.

Contribution to enterprise

- Integration of present methodology to production process with implementation of high energy efficiency equipment leads to energy consumption decrease. This energy consumption reduction will have an impact on energy bill reduction and competitiveness of enterprise increase. By implementation of present methodology enterprises will have more competitive product in a short payback period.
- Adaptation to the basic of management system, precisely to PDCA cycle, gives fully and easy integration to any existing management system.
- By using developed methodology in production process it is possible to recognize «weak energy place» in production process. Constant following of methodology gives workers

of an enterprise (energy manager, energy analyst, energy auditor) which are involved in the process of reducing energy consumption, an opportunity to find suitable solution for their problems.

- The usage of a new visualization tool gives opportunity to analyze and discover processes that cannot be seen in reality. By the means of these advantages it is possible to involve employees from different divisions to solve existing problems.

Contribution to research activity

- Present methodology can be used in the next research in the field of integration and implementation of energy management system as a tool for prediction of energy consumption.
- New developed visualization tools can be applied in the next research in the field of Eco design of new machine tools and Life Cycle Assessment implementation.

Thereby, it is significantly beneficial to integrate the present methodology into production process of enterprises, who decide to save energy, improve energy efficiency and decrease pollution of CO_2 emission.

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ANNEX I

Electricity price for companies from ČEZ group in Czech Republic on 1.1.2013

PRODUKTY ROKU 2013	REGULOVANÉ PLATBY ZA DOPRAVU ELEKTŘINY																			SILOVÁ ELEKTŘINA		
	DISTRIBUCE																OSTATNÍ SLUŽBY			OBCHOD		
		měsíční plat za rezervovaný příkon podle jmenovité proudové hodnoty hlavního jističe před elektroměrem													cena za 1 MWh		cena za 1 MWh				cena za 1 MWh	
	odpovídající distribuční sazba	do 3×10 A do 1×25 A včetně	nad 3×10 A do 3×16 A včetně	nad 3×16 A do 3×20 A včetně	nad 3×20 A do 3×25 A včetně	nad 3×25 A do 3×32 A včetně	nad 3×32 A do 3×40 A včetně	nad 3×40 A do 3×50 A včetně	nad 3×50 A do 3×63 A včetně	nad 3×63 A do 3×80 A včetně	nad 3×80 A do 3×100 A včetně	nad 3×100 A do 3×125 A včetně	nad 3×125 A do 3×160 A včetně	nad 3×160 A za každý 1 A	nad 1×25 A za každý 1 A	VT	NT	systémové služby	podpora výkupu elektřiny	činnost zúčtování OTE	pevná cena za měsíc	VT	NT
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	C01d	9,00	14,00	18,00	23,00	29,00	36,00	45,00	57,00	72,00	90,00	113,00	144,00	0,90	0,30	2 810,10	-	132,19	583,00	7,56			
Standard	C02d	42,00	67,00	84,00	105,00	134,00	168,00	210,00	265,00	336,00	420,00	525,00	672,00	4,20	1,40	2 251,54	-	132,19	583,00	7,56	45,00	1 722,00	-
	C03d	519,00	830,00	1 038,00	1 298,00	1 661,00	2 076,00	2 595,00	3 270,00	4 152,00	5 190,00	6 488,00	8 304,00	51,90	17,30	1 072,59	-	132,19	583,00	7,56			
Akumulace 8	C25d	114,00	182,00	228,00	285,00	365,00	456,00	570,00	718,00	912,00	1 140,00	1 425,00	1 824,00	11,40	3,80	1 883,86	60,66	132,19	583,00	7,56	45,00	1 942,00	1 236,00
	C26d	339,00	542,00	678,00	848,00	1 085,00	1 356,00	1 695,00	2 136,00	2 712,00	3 390,00	4 238,00	5 424,00	33,90	11,30	1 202,16	60,66	132,19	583,00	7,56			
Akumulace 16	C35d	402,00	643,00	804,00	1 005,00	1 286,00	1 608,00	2 010,00	2 533,00	3 216,00	4 020,00	5 025,00	6 432,00	40,20	13,40	858,61	60,66	132,19	583,00	7,56	45,00	1 746,00	1 621,00
Přímotop	C45d	405,00	648,00	810,00	1 013,00	1 296,00	1 620,00	2 025,00	2 552,00	3 240,00	4 050,00	5 063,00	6 480,00	40,50	13,50	268,25	60,66	132,19	583,00	7,56	45,00	1 854,00	1 634,00
Tepelné čerpadlo	C55d	50,00	79,00	99,00	124,00	158,00	198,00	248,00	312,00	396,00	495,00	619,00	792,00	5,10	1,70	268,25	60,66	132,19	583,00	7,56	45,00	1 738,00	1 661,00
	C56d	405,00	648,00	810,00	1 013,00	1 296,00	1 620,00	2 025,00	2 552,00	3 240,00	4 050,00	5 063,00	6 480,00	40,50	13,50	268,25	60,66	132,19	583,00	7,56			
Neměřené odběry	C60d	19,10 za každých (i započatých) 10 W instalovaného příkonu nebo 19,10 Kč za odběrné místo (pro odběry s nepatrným odběrem a výjimečným provozem, např. hlásiče policie, poplachové sirény apod.)																			-	-	-
	C61d	22,33 za každých (i započatých) 10 W instalovaného příkonu (pro odběry s konstantním trvalým odběrem, např. pro účely poskytování služby internetu po distribučních sítích)																					
Veřejné osvětlení	C62d	96,00	154,00	192,00	240,00	307,00	384,00	480,00	605,00	768,00	960,00	1 200,00	1 536,00	9,60	3,20	359,40	-	132,19	583,00	7,56	45,00	1 145,00	-