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A Complex Approach to the Energy Efficiency of Buildings and Processes in Industrial and Municipal Areas

Vítězslav Máša*, Petr Stehlík, Martin Havlásek

Institute of Process Engineering, Faculty of Mechanical Engineering, Brno University of Technology, Technická 2, 616 69 Brno, Czech Republic
masa@fme.vutbr.cz

This contribution discusses the energy efficiency of buildings and processes in industrial and municipal areas. Standard procedures in energy management have proved insufficient for many industrial facilities and the benefits of implemented energy saving measures are rather limited. There is a lack of procedures for identifying and implementing optimal saving measures in commercial and mid-size industrial facilities, with input from dozens of kW to units of MW. Effective procedure must be valid for a wide rangeof energy systems whilst keeping its practical applicability. Such procedures are difficult to find in the literature. This article provides a complex approach to energy saving projects and thus contributes to closing the existing gap. The complex approach targets three levels: (1) the technological level: all buildings and processes involved in the production and consumption of energy, (2) the time level: in respect to the dynamic behaviour of the systems, and (3) the methodological level: a systematic approach from the initial analysis of the system to the design of the energy saving measures.

The article stresses the analytical phase of the project, which deals with acquiring qualified data. Reliable experimental and operational data lead to the use of mathematical models that increase the quality of the final results. The complex approach was applied on various case studies. Its implementation creates new, efficient way to conduct research projects on energy savings.

1. Introduction

Mid-size industrial facilities and municipal buildings usually utilize energy systems that consume power and/or thermal power ranging from dozens of kW to units of MW. These energy systems are usually local boilers and boiler houses in close vicinity to the place of consumption. Heat from central heating systems can be an alternative. External contractor provides power supply or the supply may come from in-house power production. There is a big potential to decrease the primary energy sources consumption (Backlund et al., 2012). Real-time evaluation of energy intensity, wide use of mathematical modeling and detailed consumption analysis are among the current trends of increasing the energy efficiency (Zhou et al., 2016). More complex and detailed analyses of facilities' energy intensity have a positive impact on accuracy of the developed mathematical models but they are rather time consuming. Owners of energy systems face a difficult task of selecting and implementing a concrete saving measure. Figure 1 shows typical energy saving measures used in commercial and mid-size industrial facilities as well as in municipal areas. These measures are commonly combined to maximize the effects of a particular energy system (Sorrell, 2015).

Owners of the energy systems, buildings and various industrial processes are generally aware of the fact that increase in energy efficiency has a potential for their business. However, they often postpone application of the changes, which may have the following causes:

- Lack of knowledge of available solutions and lack of trust in real benefits of the saving measures
- Conservative approach to application of results of R&D compared to “tested solutions”
- Fear of a negative impact that the changes may have on reliability of their facilities
- Energy cost is part of the overhead; overhead is only a small percent of the total operating cost
- Lack of investments

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All of these leads only to partial solutions to energy efficiency. There have been various tools and methods developed in recent years which should make it easier to selectg a saving measure. The so far published methods may be beneficial in the initial part of the project which aims to define current state of the energy system. However, the methods present no procedures for identification or implementation of suitable saving measures; if any procedures are discussed, they concern very specific case studies (Krones and Müller, 2014). Most of the methods focus on the building sector (Sesana et al., 2016). The only method describing a concrete procedure for industrial facilities was published by Smith and Ball (2012) and concerns production processes. The literary search has proved that there is a lack of practical procedures how to increase energy efficiency in day-to-day operations of various facilities. This gap may be filled by the complex approach which is presented in the following chapters.

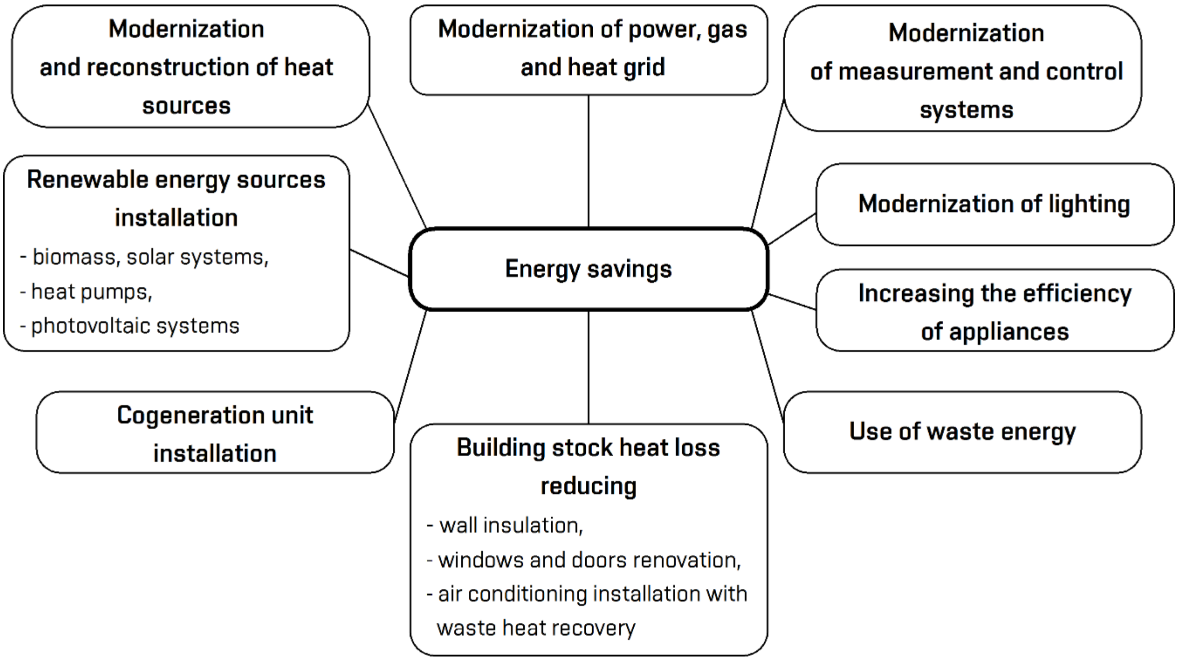

Figure 1: Overview of the usual energy saving measures for the commercial and mid-size industrial facilities

2. Current state of energy management in practice

The most used practical methods for energy savings are the energy management (EM) and energy performance contracting (EPC). EM is a general tool that enables to effectively manage and reduce energy consumption. Benefits of EM for energy savings are substantiated by various scientific papers (Lee and Cheng, 2016). The savings may be attributed to the fact that the facilities' owners, for the first time, have begun to take into consideration the energy efficiency of their businesses. EM systems do not provide specific saving measures that would best suit a particular energy system. Implementation of an EM system usually does not require any special investments; however, rigorous application of the system is an organizational and management challenge, as documented in many scientific papers discussing EM in industrial facilities. Though the papers mostly present case studies describing concrete saving measures, the benefits of the measures are not evaluated or only on a short-term level (Schulze et al., 2016).
The other method for energy consumption decrease is EPC. The EPC is a very effective method that helps decrease the operating costs; it has been around since the 1970s and has stood the test of time. At the core of the EPC method is a mechanism that finances saving measures and helps refurbish the energy system, thusly decreasing the energy consumption very quickly. The EPC focuses mainly on economic benefits of the implemented measures. The savings should cover the initial investments and provide profit for both contracting parties. The contractor (Energy Service Company, ESCo) is responsible for the planned savings.
If the ESCo fails to achieve the guaranteed savings, they must compensate the facility owner for the financial loss. The financing of the investments may come from internal sources of the ESCo, the customer or an external source, such as a credit loan. EPC is a complex service that includes initial energy analysis of the facility, draft of concrete saving measures, financing of the project, implementation of the work, and training of service personnel. The EPC hasn’t been entrenched in the industrial sphere yet. This may be assigned to a rather

problematic justification of the investments and long payback period (Pätäri and Sinkkonen, 2014). Energy systems in industrial facilities nowadays encompass various technologies and processes that necessitate high level of expertise. The energy systems include mutual interactions of particular elements, accumulation of heat, exothermic processes, etc., and optimal solution requires more than just a common approach.
These projects call for sophisticated tools that perform system analysis and come up with an optimized solution. Any attempt for the most efficient operation in this field can be labelled as R&D activities and are usually outside the scope of the ESCo or pose a serious risk for the ESCo.

3. Philosophy of the complex approach

The complex approach as a whole entails scientific procedures which are applied on real projects (Figure 2). New methods and tools are the final product of research work and at the same time also an instrument that helps systematize the work and make it more efficient.

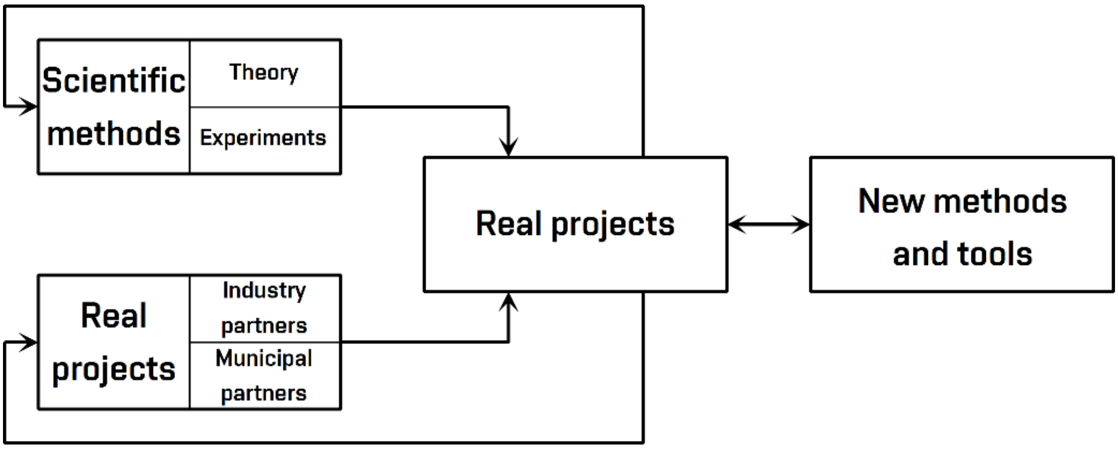

Figure 2: The complex approach for energy efficiency of buildings and processes in industrial and municipal areas

The complex approach targets three levels of application:

1. The technological level: all buildings and processes involved in the production and consumption of energy
2. The time level: in respect to the dynamic behaviour of the systems
3. The methodological level: a systematic approach from the initial analysis of the system to the design of the energy saving measures

Utilization of particular elements must be carefully considered and modified according to a specific project's requirements.

3.1 Technological level

Technology behind the complex approach encompasses analysis of the system as a whole; this means analysis of system's particular elements, their interactions and all external factors affecting operating properties of the system. General assignment of energy saving projects must be materialized into concrete saving measures. Knowledge from process engineering comes into play as this discipline is based on tailor-made solutions which go from the common into more specific.
The mass and energy balance calculations are a basic tool for analysis and optimization of energy systems. A complete balance model of a system, presented in the form of a process flow diagram (PFD) with energy sources and all appliances, is based on operational data and subsequent balance calculations. The model may be implemented into a software, and various options of saving measures may then be simulated (Figure 3).

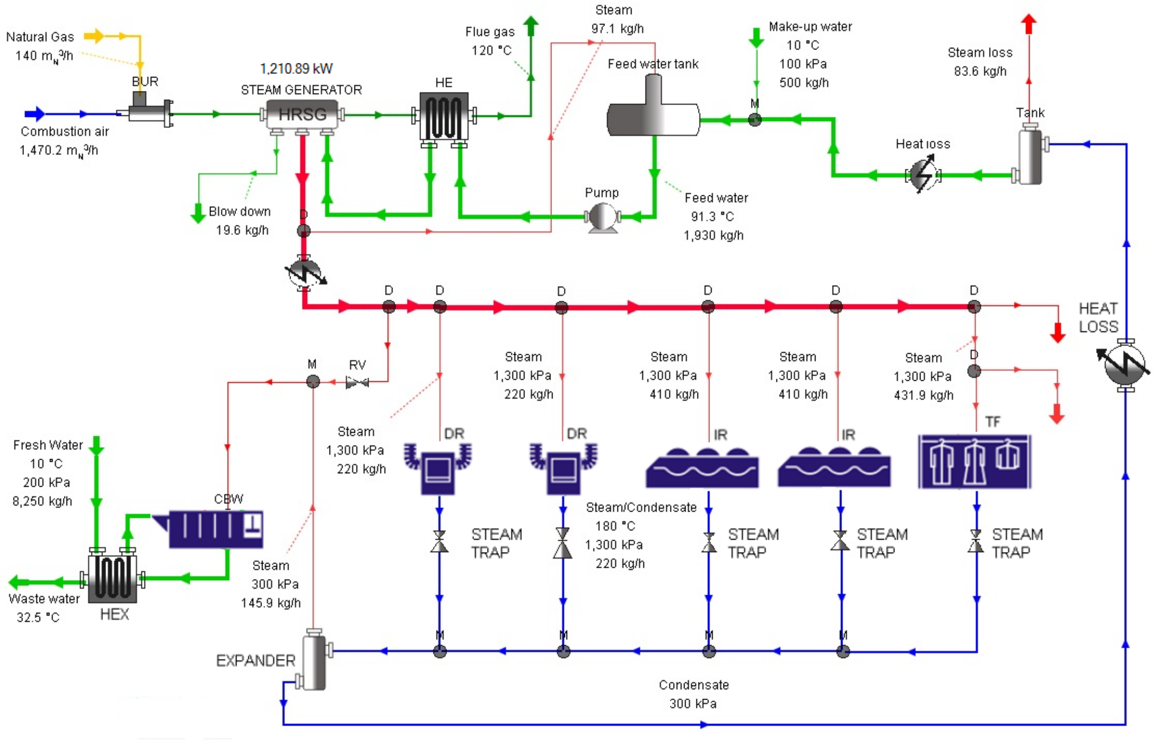

Figure 3: A PFD of a professional laundry care process: a simulation of saving measures (Bobák et al., 2011)

3.2 Time level

Time level works with speed of changes to key quantities over the course of time. Daily heat demand profile (Figure 4a) shows heat demand throughout the day and is used to describe dynamic properties of the heating system in a short-time period. Annual load duration curve (Figure 4b) is another important characteristic describing energy systems. The curve is most useful for designing the heat source. Annual heating load duration curve shows duration of heat capacity in relation to number of working hours of individual sources, and presents changes to heat demands throughout particular year seasons.

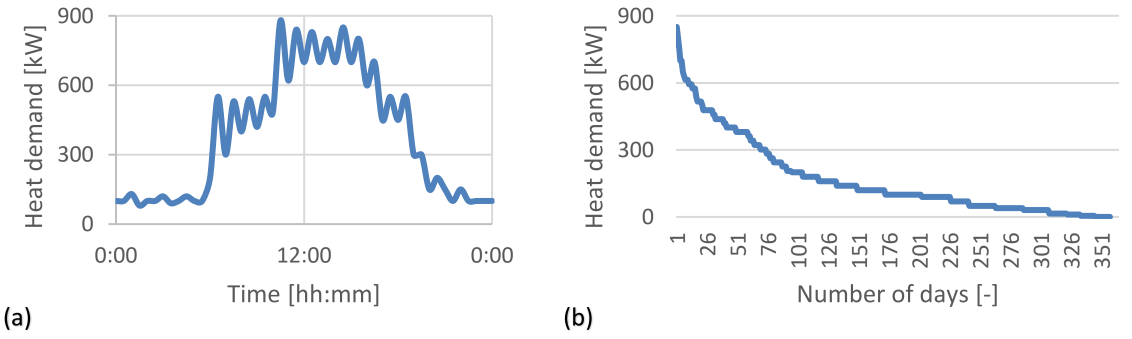

Figure 4: Examples of (a) a daily heat demand profile and (b) an annual heating load duration curve

Many times, a mathematical description of dynamic behavior in real-time relations is necessary. The step response is often used to describe warming of the source, demand changes, etc. With mathematical description of these dynamic properties, it is possible to control the source in compliance with the course of real demands. The transfer function or an ordinary differentiation equation can be used for these purposes. All of the above described options for a dynamic description may be applied to consumption of power, natural gas and compressed air.

3.3 Methodological level

The methodological level of the complex approach is a key aspect of project's efficiency. Systematic approach to energy saving projects includes the following steps:

1. Analysis of a current state of the energy system and all appliances
2. Selection of suitable saving measures
3. Support during implementation of the saving measures
4. Evaluation of impact of the saving measures

In-depth knowledge of the specific energy system and all key appliances is very important. Experience proves that owners of energy systems lack this kind of knowledge. Most of them have basic assumptions about total energy costs and expected life time of key pieces of equipment. First goal of the analysis is to get acquainted with technologies of the energy system. It is important to know whether the principles of EM are in place. Scope of available operational data and their reliability must be verified.

Then, modification of the system must be designed. Measures regarding the organization of the facility usually concern energy-conscious behaviour of the service personnel. Typical low-cost saving measure is a recuperative technology for recovery of waste heat from outlet flows (Bobák et al., 2012). Complex investments may include integration of renewable energy sources, complete replacement of heat sources and outdated appliances, or substitution of steam system for hot-water one.

The research team should be able to offer complex services that lead to savings. In terms of investments, this concerns the so called basic design, which is a simple project with new technological scheme, layouts of the premises and a technical report. Basic design may be used in bidding for tender concerning the supply of the technology or energy services. If the energy system is not that large, a competent selection of a particular saving measure and basic recommendations for its implementation are enough. The owner is then responsible for the implementation.

Evaluation of benefits of the saving measure does not stop with a mere statement that savings have been accomplished. The evaluation of the system efficiency must lead to identification of a specific consumptions; this related amount of consumed energy to a unit of a product leaving the process. This unit may have the form of a kilogram of processed material, square meter of finished surface, etc. Specific consumption helps better evaluate the energy efficiency and compare appliances with an identical product. Long-term monitoring of system's operational parameters is necessary for its gradual optimization.

4. Experience from case studies

The complex approach was applied on various case studies. The projects differed greatly in their scope; some researched issues were from the commercial sphere (a modern system of production site heating using biomass (Máša et al., 2011)), industrial and commercial laundries (Máša et al., 2013), energy system in a wood-processing facility (Máša and Vondra, 2015) or water desalination and digestate thickening (Vondra et al., 2016), whereas other projects dealt with issues from the municipal sphere (e.g. the energy system in the Prague National Theatre (Máša et al., 2016). It is obvious that quite different cases are analysed. A first key to implementation of complex approach lies in a qualified data acquisition. If there is no reliable data, initial analysis ends up being an incomplete list of basic drawbacks of the system. The subsequent design falls back on to a conservative solution which does bring a large degree of certainty.

Many promising measures are not considered as there is no way to estimate their impact more accurately, and therefore their potential remains wasted. Other ways for optimization of the facility are also rather limited. A second key to success in more complicated energy saving projects is a mathematical model of the system. A high-quality model developed using high-quality data is an effective tool for evaluation of a large scope of saving measures. A sophisticated analysis of the energy system is time-consuming as well as money-consuming; however, it provides a complex design of savings thanks to simulation of several possible solutions. The owner receives a reliable and grounded proposal. Once the most promising measures have been implemented, the database should be kept updated and the model should be adequately modified. The modified model of the system may be then used for identification of an optimal operating regime with respect to external conditions (defined inputs of the model).

5. Conclusion

Industrial and municipal facilities include a wide array of energy systems, processes and buildings; the owners of the facilities, however, often display distrust to ungrounded solutions. Standard procedures of EM do not bring satisfying results which opens new ways to sophisticated scientific methods. Three key aspect of a complex approach have been identified; these aspects greatly enhance quality of the energy saving measures and bring better results:

- Application of process engineering principles (especially balance models)
- Description of the dynamic behaviour of particular system elements (especially heat demand curves)
- Use of systematic procedure from initial analysis of the system to the implementation of saving measures

If the project is to be successful, the above aspects must be considered in addition to having a high-quality database and a reliable mathematical description of the system. The complex approach provides identification of optimum saving measures for the particular facility and efficient support during their implementation. The outcome of a future work should be a new methodology for energy saving projects in industrial and municipal areas.

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