An Approach for Reducing Energy Consumption in Factories by Providing Suitable Energy Efficiency Measures

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Abstract

Energy efficiency has developed into an important objective for industrial enterprises. However, there is still a need for systematic approaches to reduce energy consumption in factories. Existing methods focus on the optimization of manufacturing processes and lack upon considering the entire factory system. Additionally, they are based on a detailed quantitative analysis of processes and thus, they need a high effort during the phase of data acquisition. Therefore, an approach for reducing energy consumption by providing energy efficiency measures to factory planning participants was developed in order to overcome these barriers. The general approach is described in this paper and supported with a use case that demonstrates the required information and possible outcomes in terms of energy efficiency information. Main advantages of this approach are reducing the effort to acquire energy data and the possibility to consider the factory system holistically.

1. Introduction

The importance of energy efficiency as an objective for industrial enterprises increases due to ecological, political and economic reasons. Considering the ecological perspective, the International Energy Agency identified energy efficiency as the most important driver to reduce global greenhouse gas emissions [1]. Political conditions are fixed upon both international and national levels. For example, the European Union drafted a long-term strategy in the “Energy Roadmap 2050”, which includes, among other things, an 80-95% reduction of greenhouse gas emissions until 2050 [2]. From an economic point of view, industrial enterprises have an incentive to reduce their energy consumption because of increasing energy prices, such as the European average prices for gas in industry, which rose by approximately 34% during the last four years [3].

Despite this situation, the implementation of energy efficiency measures has not met the expectations yet. The reasons for the deficits in realizing energy efficiency include lack of time, lacking transparency on energy consumption, lacking capital for investments and divided responsibilities within a company [4].

Different tools and methods have been developed in recent years to support the systematic analysis and optimization of industrial enterprises for reducing their energy consumption. However, the existing methods mainly focus on manufacturing processes and systems. Although these are important aspects of the energy-efficient factory, considering the interrelationships between products, processes and resources in the factory system is essential for a holistic integration of energy efficiency in the enterprise.

Another barrier in implementing methods is the high effort for data acquisition. Therefore, an approach to reduce energy consumption within factory systems was developed that...
provides energy efficiency measures to factory planning participants based on qualitative data [5].

The remainder of the paper is organized as follows: An overview of the state of the art of energy efficiency-oriented factory planning is described in section 2. The overall concept for the methodical approach is presented in section 3. A detailed use case describes the implementation of the approach in section 4. Section 5 summarizes the results and gives an outlook on future research work.

2. State-of-the-art

In general, existing tools for considering energy efficiency of manufacturing systems can be divided into assessment, monitoring and inventory tools on the one hand while engineering, design and improvement tools on the other [6]. The following discussion is focused on the second group, since the aim is to reduce energy consumption in factory systems.

The existing tools to support energy efficiency-oriented factory planning and management can be divided into energy efficiency guidelines, principles and methods [5]. Table 1 provides an overview on these tools, which are described in detail in the following.

Table 1. Overview on existing types of tools for energy-efficient production.

<table>
<thead>
<tr>
<th>Description</th>
<th>Example(s)</th>
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| Energy efficiency principles | Small number of general approaches for energy efficiency | • substitute energy sources  
• increase efficiency of equipment  
• energy recovery (selected according to [8]) |
| Energy efficiency methods | Systematic approaches to identify and realize energy efficiency improvement opportunities | Energy metering and assessment of manufacturing processes |

Guidelines provide an overview on energy efficiency measures within a specific industrial sector or a specific field of application (e.g. lighting). The guidelines are mainly published by independent institutions or governmental organizations (e.g. [7]). By providing information close to application and including examples of realization within enterprises, the guidelines are suitable for practitioners. However, finding the information that is relevant to a specific use case requires lots of effort and time.

Energy efficiency principles contain a collection of a small number of general approaches to increase energy efficiency. They are identified by generalizing energy efficiency measures and are mainly published by research institutions or consultancies. One example is distinguishing between substitution of energy sources, reduction of energy demand, increase efficiency of equipment, reduction of process losses, energy recovery and direct use of losses for heating [8]. Further examples can be found in [5].

Energy efficiency methods describe a systematic approach on the identification and realization of energy efficiency improvement opportunities. There are varieties of energy efficiency methods available in scientific literature, from which only a selection is presented in the following. The majority of energy efficiency methods focuses on manufacturing processes and identifies measures based on a detailed quantitative analysis of the underlying processes, whereof mainly manufacturing processes are considered (e.g. [9, 10]). Some contributions describe the implementation of analyses with regard to the requirements of a specific sector [11]. Other publications expand the approaches in terms of other objectives (e.g. resources, waste) and to a wider system definition (e.g. factory level) [12, 13]. There are also methods that do not require a quantitative analysis but lack to provide methodical support for the deduction of appropriate energy efficiency measures. The main focus of these methods is to create transparency within the process (e.g. [14]).

In general, the existing energy efficiency methods can be described by the general scheme to define a system, analyze the processes within the system by means of energy measurements, prioritize sub-systems and deduce energy efficiency measures. By using the measurement results, the expected savings of energy efficiency measures can be assessed quantitatively.

However, this state-of-the-art approach requires high efforts during the analyzing phase in order to acquire the relevant data. Another barrier lies in the necessity of expert knowledge for the deduction and description of energy efficiency measures since the existing methods do not describe this step detailed enough to enable practitioners to transfer it to another application on their own.

Thus, there is need for research for developing an approach to systematically identify suitable energy efficiency measures for a defined project task without the high effort of acquiring energy consumption data. The deduction of measures should be transparent in order to make the approach understandable and manageable.

3. Methodical Approach

The two most important requirements for the methodical approach are the systematic procedure and the reduction of effort for system analysis. The systematic procedure needs to ensure that information to factory planning participants is provided in a structured way (compared to energy efficiency guidelines, where there is no guidance for practitioners to find the information that is relevant for their specific situation). The reduction of effort for system analysis increases the applicability of the methodical approach since high effort for data acquisition without the possibility to forecast the results in energy savings is a high barrier for industrial application.

Based on these requirements, a general concept has been developed to systematically guide a factory planning participant from his or her project task to appropriate energy efficiency measures. The goal is to provide suitable energy efficiency approaches in order to increase the efficiency of...
The approach consists of four major steps, which are explained in the following (Figure 1).

The starting point for the approach is the definition of the project task or planning situation by the factory planning participant (user input). The most important parameters to describe the task are object level, system process, part of the energy chain, energy form, planning case and user’s role. According to their background, the first four parameters are defined as technical parameters and the last two as organizational parameters.

The object level describes the level of abstraction of the considered system (e.g. factory, building, plant area, single machine). The system process defines the process of the enterprise to which the considered system belongs to (e.g. assembly, logistics). The part of the energy chain describes whether the system performs energy generation, conversion, distribution, storage or use, since factories increasingly integrate several of these functions [15]. The energy form defines the types of resources that are used within the considered system (e.g. electricity, water). The planning case comprises the extent to which changes are possible in the system; planning a new system has the highest degrees of freedom, whereas operating the existing system equals the system; planning a new system has the highest degrees of freedom, whereas operating the existing system equals the system; planning a new system has the highest degrees of freedom, whereas operating the existing system equals the lowest degree of freedom. Finally, the user’s role defines the perspective of the user (e.g. factory planner, worker).

When applying the method, not all of these parameters need to be specified. The user can choose which parameters to specify; however, if the number of specified parameters is too small, the user may receive too unspecific results and needs to repeat the approach with changes in the input.

As a first step, a model of the considered system is created in order to identify improvement opportunities (1. analysis of the situation). The required energy form defines the objective as starting point of the analysis (e.g. consumption of electricity). The model of the considered system consists of two parts: The general model is developed depending on the parameter object level, whereas the subordinate system-specific model refers to the system process. The general model contains indicators that can be influenced on the object level. The detailed physical parameters that affect these indicators are specified in the system-specific model.

Afterwards, the organizational parameters of the user input are analyzed in order to identify improvement opportunities for the specific project task (2. identification of influential opportunities). The general possibilities, i.e. the technical improvement opportunities, are limited to the opportunities within the given organizational restrictions. This means that the parameters identified within the general and system-specific model during the situation analysis are examined in more detail. For each of them, it needs to be checked whether the parameter can be influenced in this situation (control factors) or not (noise factors). The control factors that are determined in this step are also referred to as influential opportunities.

The information of the influential opportunities is used in order to search for suitable energy efficiency measures in a database (3. deduction of measures). For this step, the energy efficiency measures need to be structured according to different criteria in order to support the matching between influential opportunities and energy efficiency measures. The existing energy efficiency guidelines and energy efficiency principles (see section 2) need to be integrated in the collection of energy efficiency measures.

In the next step, useful information on the realization of energy efficiency measures is identified (4. identification of realization information). A set of categories was developed to structure this information:

- Basic information: Which basics are relevant to know?
- Relevance: Why is energy efficiency important in this field?
- External requirements and information: Which requirements do exist?
- Principles: How does this measure work?
- Benefit: What is the benefit in realizing this measure?
- Industrial examples: Who applies this measure successfully?

The content provided within these categories is tailored to the user’s situation by using all of the input parameters. For example, the plant engineer receives more information on the functionality of a measure whereas the manager receives more information regarding the economic efficiency.

At this point, the user has the possibility to change the inputs if the results are not yet satisfying. Otherwise, the user receives suitable energy efficiency measures and information towards the realization.
4. Use Case

In the following, a fictive use case for the application of the methodical approach is demonstrated. The necessary information in terms of energy efficiency measures and realization information is provided by a small prototype which was created using a literature review. It includes 35 energy efficiency measures and 80 blocks of realization information. The case is on the object level of a single machine and analyzes a plate conveyor in the final assembly of an automotive assembly line.

The initial situation of this use case is a plate conveyor that is operated within an automotive final assembly line. It transports the finished cars from the wheel assembly to and through the quality assurance at the end of the assembly. For this task, the conveyor needs electricity as energy form. The project task is to redesign the plate conveyor as part of a rationalization measure. The logistics planner wants to know about energy efficiency measures that can be realized in this situation with a moderate budget.

The starting point for the approach is the user input for this specific project task, which is shown in Table 2.

Table 2. Use case machine – user input for methodical approach

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Object level</td>
<td>Machine</td>
</tr>
<tr>
<td>System process – core process</td>
<td>Assembly</td>
</tr>
<tr>
<td>System process – support process</td>
<td>Logistics</td>
</tr>
<tr>
<td>Part of the energy chain</td>
<td>Energy use</td>
</tr>
<tr>
<td>Energy form</td>
<td>Electricity</td>
</tr>
<tr>
<td>Planning case</td>
<td>Retrofit</td>
</tr>
<tr>
<td>User’s role</td>
<td>Logistics planner</td>
</tr>
</tbody>
</table>

In the next step, the technical parameters are used to create a model of the energy consumption in the considered system (Figure 2). As described in section 3, the starting point for the analysis is the required energy form. In this use case, electricity is the only one, so the objective is to reduce the electrical work of the plate conveyor. The next step is to create the general and the system-specific model. The general model depends on the object level “machine”. Thus, the electrical work for the system is divided into the different condition states of the machine, i.e. processing, ready-to-operate and stand-by. The processing state means that the system operates, i.e. transports cars. The ready-to-operate state means that the conveyor is ready to transport cars, which means that the conveyor is moving without any car on it (system waits). The stand-by state indicates that the system is not in movement but not totally switched off. This means, control panels and similar facilities are switched on and it only takes a short time to move the system back into operation.

Since the work for processing refers to mechanical work rather than electrical work, a conversion of electrical energy to mechanical energy is needed in this system. Therefore, conversion losses are part of the objective electrical work and need to be considered in the general model.

It should be noted that this general model can be used for any considered system on the object level “machine”, i.e. it is only based on the input parameter “object level” but does not depend on the system process. The system process, however, is included in the system-specific model, i.e. in the physical parameters that influence the parameters within the general model.

Using the organizational parameters, the basic influential opportunities are now divided into control factors and noise factors – depending on whether they can be changed within the given restrictions. In Figure 2, the control factors in this use case are formatted bold.

Figure 2. Use case machine – model of the energy consumption for identifying influential opportunities
In the following, each of the influential opportunities is described and the assignment to control or noise factors is explained. It should be noted that the differentiation between control and noise factors is performed on the last stage of parameters, i.e. when there is no further refinement of a parameter.

The general model contains the parameters operating time, waiting time, stand-by time and stand-by power. The planning case in this use case is a retrofit, i.e. no changes in the logistics process are intended. This means that the logistics planner has no influence on the operating time. However, the logistics planner may influence the share of waiting and stand-by times by changing the system control. The stand-by power is influenced by the definition of the components that are operated in stand-by mode. Therefore, the control factors in the general model are waiting time, stand-by time and stand-by power.

The system-specific model comprises the parameters mass of goods, mass of conveyor, friction coefficient, conveyor velocity, power of peripheral components and drive efficiency. As already mentioned, the logistics planner does not intend to change the process, i.e. the mass of the goods and the conveyor velocity cannot be influenced. The mass of the conveyor and the friction coefficient depends on the material and the construction of the plate conveyor. Changing these components would need a high effort in time and cost, which is not possible within this retrofit. The power of peripheral components depends on the control of the plate conveyor which can be changed in a small project. The drive efficiency depends on the choice of motors and gearboxes, which can be changed as part of the retrofit.

Combining the general and the system-specific model, the control factors are waiting time, stand-by time, stand-by power, power of peripheral components and drive efficiency. Using this information of control factors, a database is searched for relevant energy efficiency measures. The result is shown in Table 3.

Finally, the user receives information on the energy efficiency measures which enables him or her to integrate the measures in the planning project. An example of realization information of measure 5 “Use energy-efficient motors” is shown in Figure 3.

As described in section 3, the information is divided into six parts. The content within the categories is adjusted according to the user’s role. For example, the logistics planner does not need to know the details of the principles, i.e. how motors are constructed and developed to reach a higher efficiency. Therefore, the part “principles” is very short in this
case. Furthermore, the content in the realization information can be changed dynamically, i.e. the users themselves can add relevant information, such as their own experiences in implementing the measure.

It should be noted that the primary goal of the approach is to reduce energy consumption. The effectiveness in terms of costs and benefits needs to be estimated by the user with the help of the realization information (especially categories “Benefit” and “Industrial examples”).

5. Summary and Outlook

In this paper, it has been shown that there is a research need in developing an approach for the systematic identification of energy efficiency measures without the high efforts of acquiring energy consumption data. The developed general approach is based on qualitative input information and enables the user to identify energy efficiency measures that are appropriate in his or her planning situation. The use case demonstrated the developed categories for structuring both the planning situation and the energy efficiency information.

Further research will contain expanding the existing approach both in terms of a higher abstract level of the considered system (e.g. factory buildings) and in terms of the considered objectives (e.g. greenhouse gas emissions). Furthermore, additional information needs to be integrated into the realization information (e.g. correlation between measures).

Acknowledgements

The Cluster of Excellence “Energy-Efficient Product and Process Innovation in Production Engineering” (eniPROD®) is funded by the European Union (European Regional Development Fund) and the Free State of Saxony.

References