Structuring Energy Efficiency Measures in Manufacturing Industry

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Abstract

Energy efficiency is an important objective in manufacturing because of political, environmental and economic reasons. A variety of energy efficiency measures is applicable in factory systems, which makes it necessary to structure the measures. A methodical approach to identify and provide energy efficiency measures in manufacturing industry was developed and is briefly described in this paper. A main prerequisite for applying this approach lies in structuring criteria for energy efficiency information. Therefore, this paper describes structuring criteria for both energy efficiency measures and energy efficiency information based on a literature review. The results form a basis to select appropriate energy efficiency measures in different industrial applications.

1. Introduction

Energy efficiency has developed to an important objective within the last several years. Global ecological developments are leading to increasing energy costs as well as political regulations and goals on national and international levels. Manufacturing industry plays an important role in this context, because it contributes to energy consumption and greenhouse gas emissions to a high extent. Within the European Union, industry accounts for 26 % of the energy consumption [1]. Considered globally, industry causes 39 % of the total greenhouse gas emissions [2].

Despite this situation, the implementation of energy efficiency measures has not met the expectations yet. The reasons are, among others, lack of time, lacking transparency on energy consumption, lacking capital for investments and divided responsibilities within a company [3]. 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 approaches lack upon considering the factory system holistically. Therefore, a methodical approach to reduce energy consumption within factory systems has been developed that provides energy efficiency measures based on qualitative data [4, 5]. A prerequisite for applying this approach lies in structuring the energy efficiency measures for the appropriate assignment to industrial project tasks.

The remainder of the paper is organized as follows: Chapter 2 briefly discusses the state-of-the-art of addressing energy efficiency in manufacturing industry. In chapter 3, the overall methodical approach to reduce energy consumption is described in order to demonstrate the necessity for structuring energy efficiency measures. Relevant definitions are explained in chapter 4. Chapter 5 discusses the criteria to structure energy efficiency information starting with a literature review about this topic. A summary and an outlook on future research are presented in chapter 6.

2. State-of-the-Art: Energy Efficiency in Manufacturing Industry

The importance of energy efficiency in manufacturing industry led to the development of various methodical approaches to support enterprises in increasing their energy efficiency. They mainly differ between their purpose (e.g. analysis, assessment) and the considered system level (e.g. machine, factory).

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The methods for analyzing production systems are used to increase transparency on their energy consumption. The goal is to prioritize the components as starting point for further optimization measures. Smith et al. developed an approach to analyze material, energy and waste flows in factories [6]. These methods can also be extended to a benchmark, i.e. a comparison between the current state of a system and an aspirated state (e.g. best practice, factory with "zero" emissions). For example, Dombrowski et al. described an approach to analyze a factory in terms of ecological, economic, social, technical and logistical objectives in order to identify the difference between the current factory and a sustainable one [7].

Assessment methods also aim at creating transparency but extend their goal beyond a mere analysis. The goal is to compare different approaches, e.g. production technologies [8] or effects of changes in the product spectrum [9], regarding their effects on energy efficiency or environmental objectives.

Methods for the optimization of production systems require an analysis but also describe how the optimization measures are identified. For example, Böhner et al. introduced a classification of measures that is used to identify measures for a specific business case [10]. However, applying these methods needs expert knowledge in terms of detailed knowledge of the measures that may be appropriate in a specific case. Other optimization methods address the perspective of a manufacturer by analyzing a system in detail in order to identify technical measures that improve the efficiency of a system (e.g. tooling machine [11]). This does not necessarily correspond with the efficiency during the operation of this system.

Simulation is a widely used tool to analyze and optimize production processes (e.g. on machine level [12] or on process level [13]). However, detailed data is necessary to generate simulation models, which requires an initial effort for the acquisition of relevant data.

3. Methodical Approach for Providing Energy Efficiency Measures

Concluding the state-of-the-art, the existing methods to improve energy efficiency in a factory system are mainly based on the approach to analyze a system with the help of energy consumption data acquired by measurements and to prioritize the components within the system. The components with the highest share of energy consumption are selected to apply optimization measures. However, this approach requires high effort during the analysis in order to acquire relevant data. Furthermore, the deduction of optimization measures is mainly not described explicitly. Therefore, expert knowledge is needed to perform this step, which represents a barrier for industrial application [3]. Based on these deficits, a methodical approach to identify suitable energy efficiency measures in a factory based on the qualitative analysis of a project task has been developed [4, 5] and is briefly explained in the following.

Since the goal is to save effort during data acquisition, the starting point of the approach is to analyze the project task in a qualitative way, i.e. by describing it with the help of several parameters. Based on this, opportunities to increase energy efficiency in the considered system are identified in terms of parameters that can be changed to save energy. These parameters are assigned to possible energy efficiency approaches by accessing energy efficiency approaches that are structured according to different criteria. Afterwards, appropriate information towards the implementation of these measures is identified. The basic concept of this approach is presented in Figure 1.

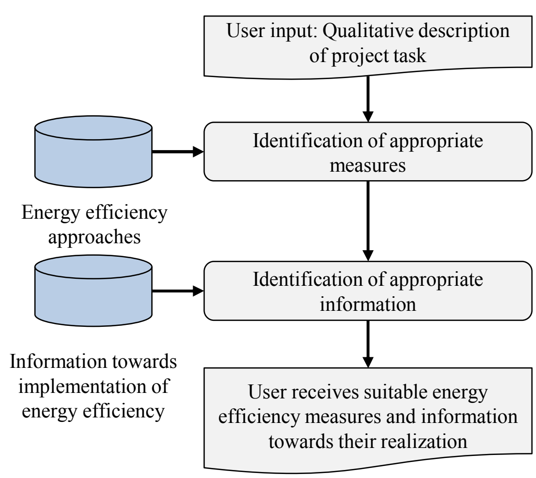

Figure 1. Basic Concept of Methodical Approach for Providing Energy Efficiency Measures.

In summary, the user specifies the respective project task by qualitative criteria and by that, receives appropriate energy information in terms of suitable energy efficiency measures and information on how to realize them. The paper addresses the possibilities of structuring both these energy efficiency measures and the additional information, since this is an important prerequisite for applying the approach.

4. DEFINITIONS

As the paper deals with providing energy information to planning participants, definitions of energy data, energy information and energy knowledge are needed. In general, data is described as a structured fact about any event, which becomes to information by adding meaning or processing it [14]. In contrast, knowledge is a term without a common sense about its meaning. It is used differently depending on the scientific discipline. However, on a generally accepted level, it can be understood as being derived from information and adding understanding to it.

Energy data is described as the result of power measurements at technical products in operation [15]. Both the objects and the extent of data acquisition vary considerably. For example, measurements can be performed at the level of a machine, process chain or entire facility [16]. Energy information, or sometimes called energy-related information, describes the connection between energy data and process data, such as related products, times or process states [17]. This information is used to assess the energy performance of an object, for example in terms of an efficiency indicator. Energy information supports the transparency and energy awareness within a company and therefore helps to identify efficiency potentials. However, expertise is needed to exploit these potentials [18]. The terms energy knowledge and energy efficiency knowledge are rarely used in scientific literature. Dombrowski et al. define efficiency knowledge as knowledge about approaches and energy efficiency measures [19].

For this paper, information is defined as static object, whereas knowledge is created by adding context to the information. The information need of practitioners regarding the developed methodical approach (chapter 3) comprises energy efficiency measures and the information towards their implementation. Both are structured energy efficiency information, since they support increasing energy efficiency of an enterprise. The assignment of energy efficiency information to the project task creates energy efficiency knowledge for the user. A more detailed description of both information objects is given in the following.

An energy efficiency approach (EEA) is understood as a possible action to reduce energy consumption for a defined task or to increase the output of this task by maintaining the amount of energy consumption. Since the EEA should be provided to practitioners, they should not be limited to a special technology; instead, they should be general approaches and principles that can be applied to different areas. By describing the project task, the user specifies the application area and therefore receives information that tailors the EEA to the project task. Besides the EEA, the user receives energy efficiency implementation support (EES), i.e. detailed information that helps to analyze and optimize energy efficiency in the considered area. The structuring of both EEA and EES is discussed in section 5.2 after the review of classification approaches for energy information and knowledge in literature (section 5.1).

5. CRITERIA TO STRUCTURE ENERGY EFFICIENCY INFORMATION

5.1. APPROACHES FOR CLASSIFICATION IN LITERATURE

There are only few scientific publications that explicitly address the structure or classification of energy efficiency measures. However, other contributions that provide a methodical approach or decision-making support for industry include the application of different criteria to structure energy efficiency information.

The most general criterion used in literature is the *type* of an energy efficiency measure which describes its pursued goal. A rough classification differentiates measures that need an investment and those that depend on the usage of equipment [20]. Neugebauer et al. divided measures into product-oriented, technical and organizational [21]. Dombrowski et al. distinguished between organization and personnel, infrastructure as well as corporate processes [19]. Fischer developed the characteristics business model, technical material efficiency, organization and personnel development [22].

The *technical principle* of a measure describes how a technical measure works. It describes the type of technical measures in more detail and thus, can be understood as sub-criterion to the criterion “Type”. Commonly used principles are substitution of components, proper dimensioning, appropriate usage of energy and recuperation [23-25].

Many authors differentiate energy efficiency measures depending on the *applied process*, i.e. the process where a measure can be applied. There is a wide variety of possible sub-classifications for this criterion, since there are many possibilities of applying energy efficiency measures. The sub-classifications can be developed by either taking a process-oriented view or an object-oriented view. For example, Thiede et al. described efficiency measures in production planning and production control taking a process-oriented view [26]. In contrast to that, Heinen et al. distinguished the objects within a factory (e.g. compressed air, heating and cooling, drives and pumps) [27].

The *extent of changes* describes the changes that are necessary to implement an energy efficiency measure. Similar approaches are used across literature to describe this criterion. Boehner et al. developed the stairs of innovation, differentiating between the characteristics substitution, upgrading, reengineering, product design and technology management [10]. Whereas these only focus on technical measures, Fleiter et al. provided an alternative approach by distinguishing organizational measures, technology add-ons, technology replacements and technology substitutions [27]. Connected with this criterion is the *implementation time*, i.e. the time that is needed for planning and implementation [22].

The *department* which can influence a measure is relevant for the implementation in enterprises. Fischer provide a classification into management, corporate culture, human resources, research and development, product design, marketing, controlling, procurement, manufacturing, maintenance and cleaning, storage and logistics and packaging [22]. Closely related to the department is the *necessary knowledge* for planning and implementing a measure. Fleiter et al. regarded this criterion in order to describe the adoption rate of energy efficiency measures. They differentiated the criterion into technology expert, engineering personnel and maintenance personnel [28].

A further criterion is the *benefit* that can be gained by enterprises when they implement an energy efficiency measure [28]. They can be described in terms of the effects on economic and ecological objectives or considering their potential to reduce energy consumption. Finally, the *measure duration* describes the lifetime of a measure. Fleiter et al. divided into short-term measures (< 5 years), medium-term measures (5-20 years) and long-term measures (> 20 years) [28].

5.2. Developed Classification Scheme for Energy Efficiency Information

Based on the classification approaches in literature, own criteria were developed to describe energy efficiency approaches with regard to the goal of assigning these suitably to industrial applications. Furthermore, the energy efficiency implementation support, i.e. the information beyond measures that is helpful for analyzing and optimizing energy efficiency in manufacturing industry, were analyzed and structured. The latter one is not yet discussed in scientific literature.

The EEA are structured according to the criteria object level, relevant process, part of the energy chain, energy form, extent of changes and participant. In the following, each of these criteria is described including the explanation on the difference to the literature review (section 5.1).

The *object level* defines the level of abstraction at which the EEA is applied. This corresponds to the criterion “applied process” in literature; however, it is realized by a hierarchical approach. Thus, the levels factory, building, plant area and machine are distinguished. This helps to assign EEA to a project task since the task typically refers to a section of the manufacturing enterprise. Technical measures can be easily assigned to the object level. Although there is no such distinction needed for organizational measures, they can be assigned to the level factory in case they are implemented generally.

The *relevant process* distinguishes – in a rough perspective –between core processes (i.e. manufacturing) and peripheral processes (e.g. building services, logistics). A more detailed description of the processes is possible within a specific industrial sector. For example, in automotive industry, the processes body pressing, car body construction, paint shop and assembly are relevant manufacturing processes. The peripheral processes include logistics, liquid medium treatment, compressed air, heat generation, ventilation and air-conditioning technology. Again, organizational measures may not be assigned to a specific process, which needs to be considered when assessing the characteristics of these measures.

Part of the energy chain is an important criterion which is not yet established in literature. Since energy efficiency needs to be considered holistically, it is not possible to just focus on the consumption of energy. EEA rather focus on the generation/conversion, storage, distribution and use of energy. This becomes especially important in the context of an increasing cross-linking between the manufacturing industry and the energy industry [29].

The criterion *energy form* differentiates between the different energy forms or – in a wider sense – energy carriers and media that are used as resources within an enterprise. Examples are electricity, gas, heat, compressed air, water and other liquid media. This criterion is also not mentioned in literature. It is more important for the assignment to a project task than for the description of an EEA itself, because it narrows the possibilities for EEA in case of a considered system that comprises several energy forms.

The *extent of changes* is applied the same way as it is used in literature. The characteristics are chosen similar to [28]: organizational measure (i.e. without investment/changes in hardware), retrofit (changes in the existing system) and new equipment.

The assignment of EEA to project tasks is focused on a user perspective. Therefore, it is important to determine the *participant* that is able to influence an EEA. This is similar to the criterion “Department” in literature but exceeds it by differentiating between various perspectives, e.g. planner and operator.

The criteria “benefit”, “implementation time” and “measure duration” from literature were not adopted because they are hard to assess in general. Especially the benefit varies considerably between different applications, processes and industrial sectors. Due to their importance, they are however included in the EES. The criterion “type”, which is very basic to describe an EEA, is also not used herein. The general approaches that are supported by this criterion, will be included as separate EEA.

Table 1. Developed Classification Scheme for Energy Efficiency Approaches (EEA)—Supported by Examples.

Criteria	**Characteristics**	**Example 1: Adjust Lighting to Needs**	**Example 2: Heat Recovery at Air Compressor**	**Example 3: Substitute Laser Technology**
Abstraction Level	Factory	Not applied	Not applied	Not applied
	Building	Applied	Not applied	Not applied
	Manufacturing Area	Appropriate	Not applied	Not applied
	Machine	Not applied	Appropriate	Appropriate
Relevant Process	Body pressing	Not relevant	Not applied	Not applied
	Car body construction	Not relevant	Not applied	Appropriate
	Paint shop	Not relevant	Not applied	Not applied
	Assembly	Not relevant	Not applied	Not applied
	Logistics	Not relevant	Not applied	Not applied
	Heating, ventilation and air-conditioning	Not relevant	Not applied	Not applied
	Media supply	Not relevant	Appropriate	Applied
Part of the Energy Chain	Energy generation/conversion	Not applied	Appropriate	Not applied
	Energy use	Appropriate	Not applied	Appropriate
Energy Form	Electricity	Appropriate	Not applied	Appropriate
	Gas	Not applied	Not applied	Applied
	Heat	Not applied	Applied	Not applied
	Compressed air	Not applied	Appropriate	Not applied
Extent of Changes	Organizational	Applied	Not applied	Not applied
	Retrofit	Applied	Applied	Hardly applied
	New equipment	Applied	Appropriate	Applied
Participant	Technology planning	Not applied	Not applied	Appropriate
	Factory planning	Not applied	Hardly applied	Applied
	Building and utilities	Appropriate	Appropriate	Hardly applied
	Maintenance	Not applied	Hardly applied	Not applied
	Foreman	Applied	Not applied	Not applied

In contrast to the approaches in literature, the different characteristics of a criterion are not exclusive in this developed scheme. This means that it is possible to assess an EEA as applicable in different characteristics. An ordinal scale is used to describe these relationships in the following way: Each EEA is assessed for each characteristic by "not applied", "hardly applied", "applied", "appropriate" or "not relevant" (i.e. the EEA does not depend on this criterion).

Table 1 summarizes the developed classification scheme. The characteristics may be sector-specific and are in this case oriented on the automotive industry. Two examples of different EEA are included to support the understanding of the assessment. It should be noted that this classification is a starting point for the developed methodical approach and may be refined in future research.

The EES provide information that is helpful to analyze and optimize energy efficiency in manufacturing plants. For the first part, it supports the implementation of EEA. Secondly, it also provides basics and information about the relevance of energy efficiency, which also enables the analysis of energy efficiency in a specific context. Table 2 shows the criteria that were developed to structure EES.

Table 2. Developed Classification Scheme for Energy Efficiency Implementation Support (EES).

Criteria	**Criteria Description**	**Characteristics**	**Characteristics Description**
Basics	Which basics are relevant to know?	Definitions	Definition of relevant terms
		Theory	Theoretical basics on energy consumption
Relevance	Why is energy efficiency important in this field?	Share of energy consumption	Share of the considered object area
		Life cycle consideration	Properties of object area relevant to life cycle
		Range	Frequency of energy waste in this object area
Benchmark	How can a need for action be identified?	Theoretical energy consumption	Theoretical energy need for specific task
		Reference value	Usual practical values for energy consumption
		Empirical energy consumption	Empirical example values for energy consumption
External Requirements	Which requirements do exist?	Standardization	Relevant standards
		Legislation	Relevant laws
		Information sources	Relevant external information sources (e.g. manufacturer)
Principles	How does the EEA work?	Effective areas	Components within object area that need to be considered to realize EEA
		Function	Description of the way how the EEA works
Applicability	Where can the EEA be applied?	Application area	Possible application areas for EEA
		Information need	Information necessary to assess EEA's application
Benefit	What is the EEA's result?	Saving potential	Statistical or empirical values on potential
		Implementation time	Time horizon for planning and implementation
		Comparison to reference	Comparison between realized EEA and reference (e.g. state-of-the-art)
		Non-energy effects	Effects on EEA on other objectives (e.g. lifetime)
		Effect on other EEA's	Synergetic effects on other EEA's
		Practical examples	Example of realized EEA in manufacturing industry

6. CONCLUSION

In this paper, a methodical approach for the identification and realization of energy efficiency potentials in manufacturing industry was briefly described. Providing suitable energy efficiency information in terms of energy efficiency approaches and information towards their realization is crucial for applying the methodical approach. After a review of definitions, existing approaches in literature for structuring energy efficiency measures were described. Based on that, a classification was developed to meet the requirements of the methodical approach. Furthermore, criteria to structure the additional information (implementation support) were developed, too, which was not yet part of scientific literature.

The developed structure will be used to implement the presented methodical approach. The next step is to define which information on a project task is necessary to perform the assignment of suitable energy efficiency information. Afterwards, the methodical cross-linking between project tasks and energy efficiency information needs to be described. Finally, the methodical approach will be implemented and evaluated.

ACKNOWLEDGEMENTS

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

European Union

Europe funds Saxony.
EFRE
European Regional
Development Fund

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