A standardized energy audit tool for improved energy efficiency in industrial SMEs

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Abstract

Despite extensive attention given to energy efficiency, research states that a majority of available cost-efficient energy efficiency improvement measures are not implemented due to the existence of various barriers to energy efficiency, in particular information-related barriers. Energy audits, and energy audit programs, are one of the most widespread and used instruments to overcome barriers to energy efficiency and promoting energy efficiency in industry. Despite the importance of energy audits, and the fact that a large number of energy audit programs are in operation in the EU and across the world, there is a considerable lack of so called energy audit tools, i.e. a standardized tool to conduct the actual energy audit. The aim of this paper is to present an energy audit tool for industrial SMEs (small- and medium-sized enterprises). The tool is based on more than three decades of research and teaching in the area of energy auditing in industry, covering more than 300 energy audits, primarily conducted in Sweden. The developed tool uses unit process categorization, which enables energy auditors and energy program administrators to conduct energy audits in a standardized way. The data collection is facilitated by a set of forms. The noted data is automatically summed at different levels of detail and summarised in sheets. The auditor can suggest measures, and the expected energy balance with all the measures implemented can be displayed. According to the available literature on energy audit programs, program success means more than just performing energy audits. The current presentation of the Swedish energy audit tool, SVEA, is one such means to achieve more effective energy audit programs.

Introduction

Improved energy efficiency in industrial energy systems is of importance as a way to reduce greenhouse gas emissions and reduce energy costs (IPCC, 2007). The energy efficiency potential in European industry is stated by the European Commission to be 25 percent, where the majority of the measures are found in pumps, fans and lighting (EC, 2006). Despite extensive attention given to energy efficiency, research states that a majority of available cost-efficient energy efficiency improvement measures are not implemented due to the existence of various barriers to energy efficiency, in particular information-related barriers (Fleiter et al., 2011, Trianni and Cagno, 2011, Schleich and Gruber, 2008). However, research states that the potential for industrial SMEs[1] (small- and medium-sized enterprises) may be higher than the 25 percent stated by the Commission (Backlund et al., 2012).

Energy audits, and energy audit programs, are one of the most widespread and used instruments to overcome barriers to energy efficiency and promoting energy efficiency in industry (Price et al. 2011). This is in particular true when related to support technologies and industrial SMEs (small- and medium-sized enterprises) (Thollander and Palm, 2012). Despite the importance of energy audits, and the fact that a large number of energy audit programs are in operation in the EU and across

1. I.e. a firm with about 10–250 employees. For micro firms, i.e. below 10 employees the tool may be less useful as the energy system then is less complex.

the world (e.g. Price et al., 2011), there is a lack of so called energy audit tools, i.e. a standardized tool to conduct the actual energy audit (Väisänen, 2003). In an evaluation of 42 energy programs, only two programs, the Finnish and the French programs, used an energy audit tool within the program (Väisänen, 2003). The aim of this paper is to present an energy audit tool for industrial SMEs. By presenting the basic components of the energy audit tool, and its underlying logics, together with suggested areas of improvement, it is the author's intention that the development of future programs, Swedish and international, may be improved. The tool is based on more than three decades of research and teaching in the area of energy auditing in industry at the Division of Energy Systems, Department of Management and Engineering, Linköping University, covering more than 300 energy audits, primarily conducted in Sweden (Wetterlund, 2012, Svensson, 2011, Difs, 2010, Rohdin, 2008, Thollander, 2008, Trygg, 2006, Sandberg, 2003, Karlsson, 2002, Nilsson, 1993, Björk, 1987). The developed tool uses unit process categorization, which enables energy auditors and energy program administrators to conduct energy audits in a standardized way.

Energy efficiency and energy performance ratios

There are different ways to categorize energy end-use use and energy efficiency indicators. Jagemar (1996), defines energy efficiency as "a measure of the balance between the energy gained and the sacrifice necessary to bring about this gain". EC (2006) defines energy efficiency as "a ratio between an output of performance, service, goods or energy, and an input of energy" (EC, 2006). An energy-efficient energy system is a system that provides its function with the lowest possible energy end-use at a reasonable cost. Abel and Ekberg (2002) outlines the importance of two aspects when implementing energy efficiency improvement measures: the implementation of an energy efficiency improvement measure should not have a negative effect on the building and its function; and the primary use of resources when implementing an energy efficiency improvement measure should be related to the total energy reduction as a result of the measure. Both of these requirements must be fulfilled in order for the measure to be categorized as an energy efficiency improvement measure. This distinguish measures where the function of the building, such as indoor environment issues and production-related deficiencies, is altered in a negative way, or when the measure itself results in a use of resources not in proportion to the reduction of energy use.

For buildings in general, the energy performance ratios most commonly applied are often defined in terms of kWh/(m2 and year), kWh/(person and year), kWh/(m3 and year), kWh/(m3/s), and kW/(m3/s). For industrial SMEs, additional ratios are often used, including the amount of energy used per employee, kWh/person or per square meter, kWh/m2, and the index of energy use per unit of product, for example kWh/weight, kWh/volume or kWh/number of produced goods. One single energy performance ratio has not yet been adopted extensively in industry, as it is very difficult to take into account for example, when the production varies over time. It is argued by the authors that the amount of energy per annual production hours (kWh/(ann.prod.hrs)) could be a suitable figure for industry, however used in addition to other performance ratios. In economic terms, an energy cost/unit such as EUR/m2 or EUR/person may be used, or annual energy cost in relation to annual turnover or added value, which is often referred to as energy intensity. All of these ratios are easy to use and have their individual advantages and disadvantages depending on, e.g. how the energy use at a site is composed and what information that is requested. It is important to note that aspects such as an increase in production will decrease specific energy use in kWh/produced ton, if support processes represent a substantial part of the energy use, and thus act as a base load. These indices also often make comparisons between different industrial sites difficult, as there are multiple processes that differ between industrial buildings at different locations.

One way to solve parts of this problem, and to allow easier benchmarking and a more effective structure, is to use the concept of unit-processes first introduced in Söderström (1996). The concept is presented below and is employed by, for example, Nord-Ågren (2002), Trygg (2006), Thollander (2008), and Rohdin (2008), and has been used in a number of auditing schemes throughout Sweden such as Project Highland, which up until 2010 was the largest audit program in Sweden in terms of numbers of companies audited (Thollander et al., 2007).

The unit process concept

The unit process categorization is a way to divide the energy use of an industry into smaller parts, or units. A unit process is based on the purpose of a given industrial process, for example, mixing materials, cooling or drying products, producing compressed air, or carrying goods etc. Unit processes are thus to be considered the smallest parts of an industrial production system and its related energy use. The unit processes are thus general across industrial companies, allowing comparison of specific processes between industrial companies as regards e.g. energy efficiency.

Unit processes are defined by the energy service they perform. Two major categories are found (Söderström 1996):

- production processes – the processes needed to produce products.
- support processes – the processes needed to support the production processes, but not directly needed for production.

As defined by Söderström (1996), the 11 production processes and the ten support processes are presented in Table 1.

These unit processes represent the "building blocks" of energy use, enabling them to be used for comparisons between firms, in both the same and different sectors. The categorization by unit processes also enables further simulation or optimization modelling of industrial energy use and improvement measures, i.e. a Level III audit according to ASHRAE's definition (see, e.g., Söderström 1996; Thollander et al. 2007; Thollander et al. 2009).

Energy audits

In addition to improved energy efficiency from technical energy efficiency measures, there are also load management and conversion measures and procedures, which are in most cases also considered within the framework of an energy audit. An

Table 1. Structure of unit processes categorization according to Nord-Ågren (2002) and Söderström (1996), and further developed.

Production process	Disintegrating	Support process	Ventilation
	Disjointing		Space heating
	Mixing		Compressed air
	Jointing		Lighting
	Coating		Pumping
	Moulding		Tap water heating
	Heating		Internal transport
	Melting		Cooling
	Drying		Steam
	Cooling/freezing		Administration
	Packing		

initial, well-structured energy audit is the first important step in an energy management program in an industrial organisation (Caffal, 1995). Energy audits should thus be considered a mandatory feature in successful management of energy in industry, as the audit represents a starting point for implementing these issues in management procedures (Caffal, 1995). An audit aims at assessing the present energy situation in a building, plant or site.

ASHRAE[2] (2003) presents a commonly used classification of energy and indoor environment audits. This classification involves three levels, defined in Mazzucchi (1992), and is similar to the audit procedure presented in Nilsson (2003). The three levels detailed by ASHRAE (2003) are Level I (walk-through assessment), Level II (energy survey and analysis), and Level III (detailed analysis of capital-intensive modifications). Level I involves assessing the energy cost and efficiency by analyzing energy bills and a brief survey of the site. This first level assessment targets low- or no-cost measures and presents a listing of technical improvement measures that needs to be studied further. The survey also gives an initial judgment of the potential for further cost and energy savings (ASHRAE, 2003). Level I is mainly based on historical data of energy use and often includes a brief walk-through, where representatives at the audited firm are interviewed in an informal manner (Nilsson, 2003). Furthermore, a coarse breakdown of energy use on different processes may be carried out.

Level II includes a more detailed survey and analysis of the studied object. This is typically done by some form of a more detailed breakdown of energy use, either by activities and energy carriers or, as in most cases when related to the research done at the Division of Energy Systems at Linköping University, by unit processes. In this level, potential savings are derived in relation to the owner's constraints and economic criteria. This is accompanied by a discussion and evaluation of how these measures affect maintenance procedures and manufacturing operations. An energy survey analysis should also include a list of potential capital-intensive measures that require more detailed data and measurements, along with a study of their potential costs and savings (ASHRAE, 2003). In some Level II studies, where measures affecting indoor climate or indoor air quality are studied, complaints may be gathered to provide additional information on background problems. More extensive long-term measurements may also be performed and suitable measures suggested (Nilsson, 2003).

Level III focuses on capital-intensive measures found in the Level II analysis. Level III provides detailed evaluations of costs and savings that can be sufficiently used as decision support for a major capital investment (ASHRAE, 2003). This generally involves a detailed study of the effects of specific measures by using specialized software and simulations, and extensive measurements. In the third phase, aspects such as indoor environment are often included next to economic considerations and other management issues (Nilsson, 2003).

Thus, an energy audit, depending on which type (level) of that is carried out, may take one or two days, up to several weeks or even several months to accomplish. The method may in general be executed in six steps (Thollander et al., 2008):

1. First, a meeting is held with representatives of the industry in question and the conductors of the audit (either by phone or on-site). Requirements and delimitations are formulated if needed.
2. An on-site visit (walk-through) is made, where quantitative data are collected through metering, etc.
3. The collected data are compiled into, for example, unit processes, which in turn are split into production processes and support processes such as lighting, ventilation and compressed air. The data are analyzed and confirmed.
4. Complementary calculations and, if needed, additional measurements are made in order to compile a sound analysis of the present energy use.
5. A meeting is held (either by phone or on-site) between representatives of the industry concerned and the auditors about the proposed energy efficiency improvement measures and the analysis of current energy use.

2. American Society of Heating, Refrigerating and Air-Conditioning Engineers.

6. The audit is compiled into a two-part report that includes current energy use and proposed energy efficiency measures.

It should be noted that an energy audit tool cannot replace the skill of an energy auditor when it comes to proposing measures for improvements. Between step 4 and 5 above, there is a thorough amount of work done by the auditor which is very much dependent on his or her skills, i.e. engineering background, previous experience etc. As will be outlined later, providing a database with previously proposed energy efficiency improvement measures could enhance the energy audit quality, ensuring the actual proposed measures to be more reliable, and thus the provide a more valid energy audit report. The industrial energy audit may be divided into three main parts: the survey, the analysis and the proposed measures. The expected result of the energy audit is an energy balance of the system, i.e. the supply and the demand of different energy forms are expected to be in balance. Thereafter, it is expected to find a number of measures that will improve energy efficiency, switch from non-renewable to renewable sources, and decrease the energy use of the company, preferably using a systems perspective (Churchman, 1968).

To be able to create an energy balance and a power balance data collection is needed and the purpose is to give basic data on relevant unit processes. Another purpose is to get enough data to be able to suggest adequate measures for technical energy efficiency improvements, conversion and load management measures etc. The origin and quality of information can vary greatly.

The data collection procedure could be carried out in the following way:

- Step 1: Gather statistics: electricity, district heating, fuel, water, production rate etc. Gather drawings and plans
- Step 2: Visit the company during operating hours
- Step 3: Visit the company during non operating hours
- Step 4: Create the power balance and the energy balance and allocation of energy use.

Thollander et al. (2008) outline a number of important factors for effective energy audits: auditors well skilled in engineering and also having high social capabilities, clear and concise information in the energy audit reports, and credibility and trust in the auditor. Also, the need for an energy audit tool is found to be crucial. The main idea of an energy audit model is to support Step 4. Below follows a presentation of SVEA, an energy audit tool. The tool involves some general opportunities for suggesting improvement measures but, as stated above, generally is supporting the auditor in conducting the energy balance for the energy audit.

SVEA (System Tool for Energy Analysis)

The energy audit tool, SVEA, originated in 2004 as an excel-based tool named EnSAM (Energy System Analysis Method) (Franzen, 2005). In 2011, a project was initiated with the intention of creating a java-based energy audit tool, based on EnSAM, and by so move away from the slow, excel macro-based EnSAM to a version independent on operation system. In late 2011, an initial version of the energy audit tool SVEA was presented, available in Swedish and English language. Below follows a brief presentation of the tool.

The graphical interface provides a number of sheets:

- Overview
- Support processes
- Production Processes
- Result graph
- Results.

See figure 1 for a presentation of the Overview sheet where one fills out annual energy use of various energy carriers, type of company, etc.

See figure 2–4 for presentations of a filled-out Support Process sheet where one has filled-in specific data for the different support processes ending up in an annual energy use of various energy carriers for the different processes.

In figure 3, the support process ventilation sheet enables the auditor to fill in data on the company's ventilation fans. The sheet enables the auditor to type in the power in Watt for the various fans together with the specific power factor (if only apparent power is avaliable), and then fills in the specific operation time. This way, a room, and in turn the whole site, with various ventilation installations, is easily mapped.

For most support processes, there is also an option of filling out time reduction, space reduction etc. as generic general energy efficiency improvement measures.

For one support process, lighting, a slightly different structure is provided, see figure 4. In figure 4, the support process lighting sheet enables the auditor to fill in data on the company's various armatures. The sheet enables the auditor to type in type armature. The rated power in Watt is then outlined, and the auditor then fills in the number of armatures for that specific room, and the specific operation time. This way, a room, and in turn the whole site, with various armature installations, is easily audited.

See figure 5–6 for a presentation of a filled-out Production Process sheet where one has filled-in specific data for the different support processes ending up in an annual energy use of various energy carriers for the different processes.

In figure 6, the production process coating sheet enables the auditor to fill in data on the company's coating equipment. The sheet enables the auditor to type in the fixed power in Watt for the various coating machines together with the specific power factor (if only apparent power is avaliable), and then fill in the operation time. This way, a room, and in turn the whole site, with various coating processes, is easily audited.

For the other production processes, a similar means to fill out data as for coating are given. For the production processes, there is also an option of filling out time reduction, and power reduction etc. as generic general energy efficiency improvement measures.

Finally, in the result graph and result sheets, the results from the energy audit are outlined. In figure 7, the result sheet is presented.

Except for the overview sheet, the sheets presented in figure 2–7 have underlying linear equations such as power multiplied by the time etc., for each unit process.

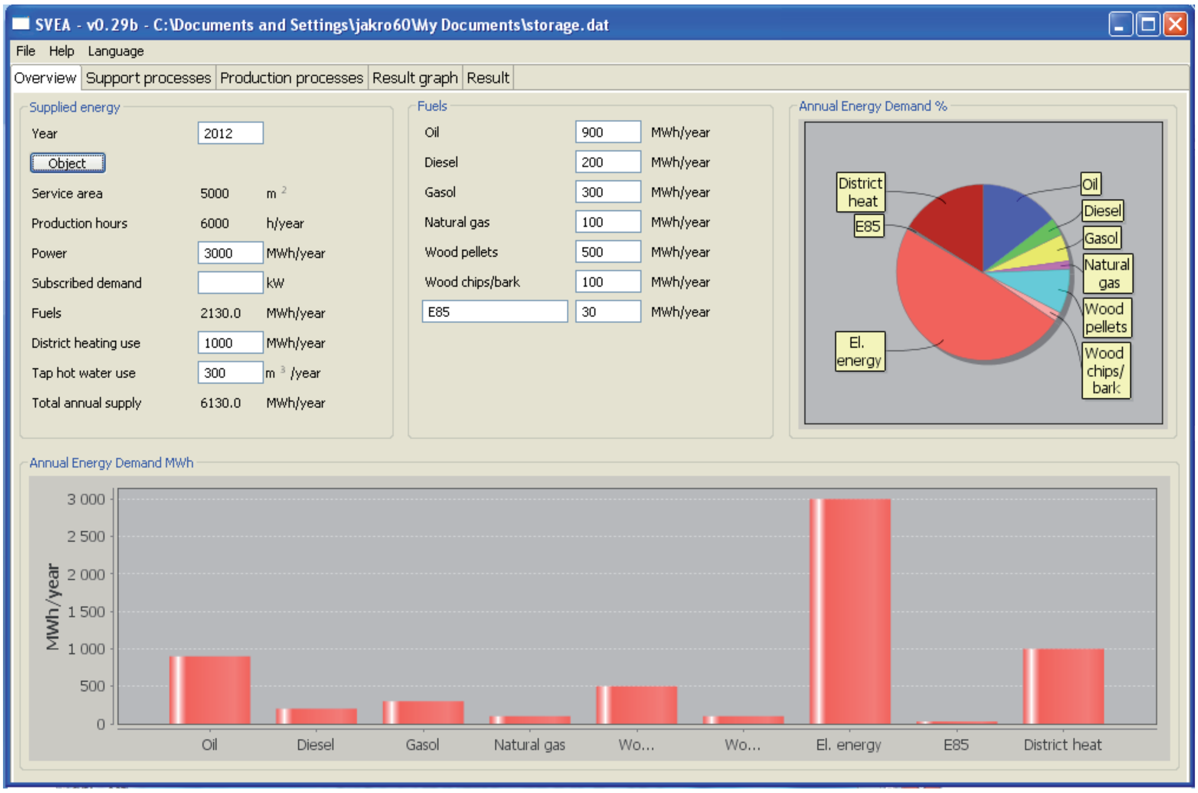

Figure 1. Overview of the audited company's energy use categorized between energy carriers such as electricity and oil etc., power subscription etc. There is also an object button where data on the specific company, name of the auditor, date, etc. is filled out.

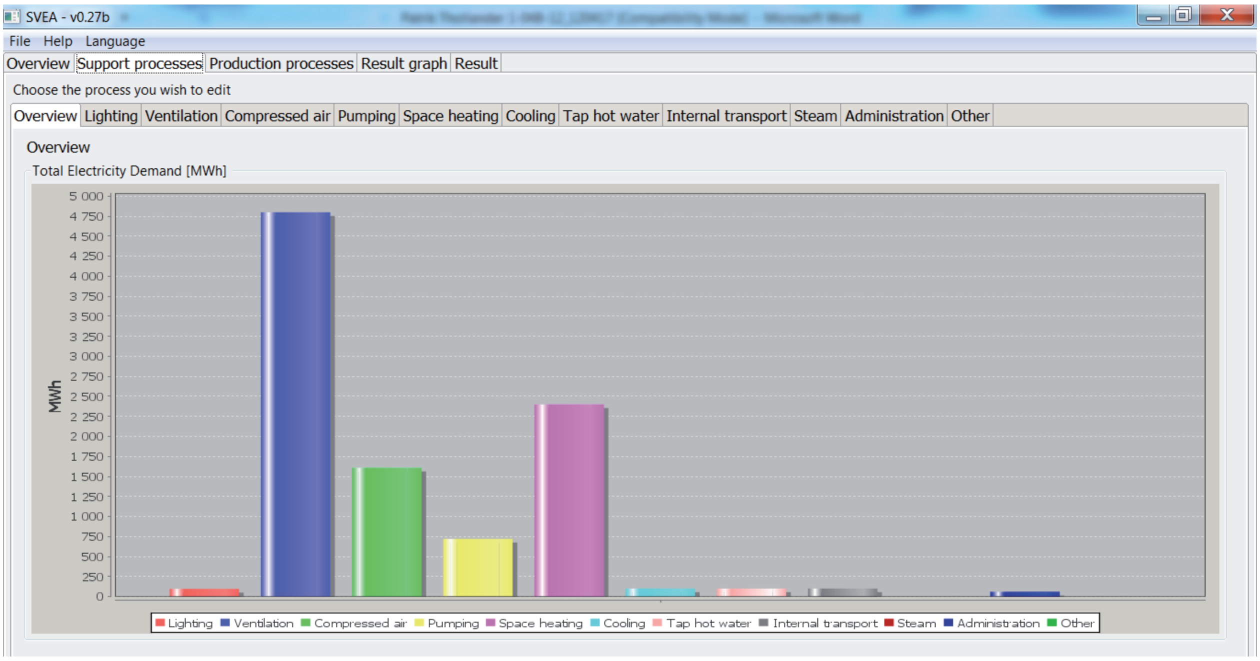

Figure 2. Overview of the audited company's support processes annual energy use.

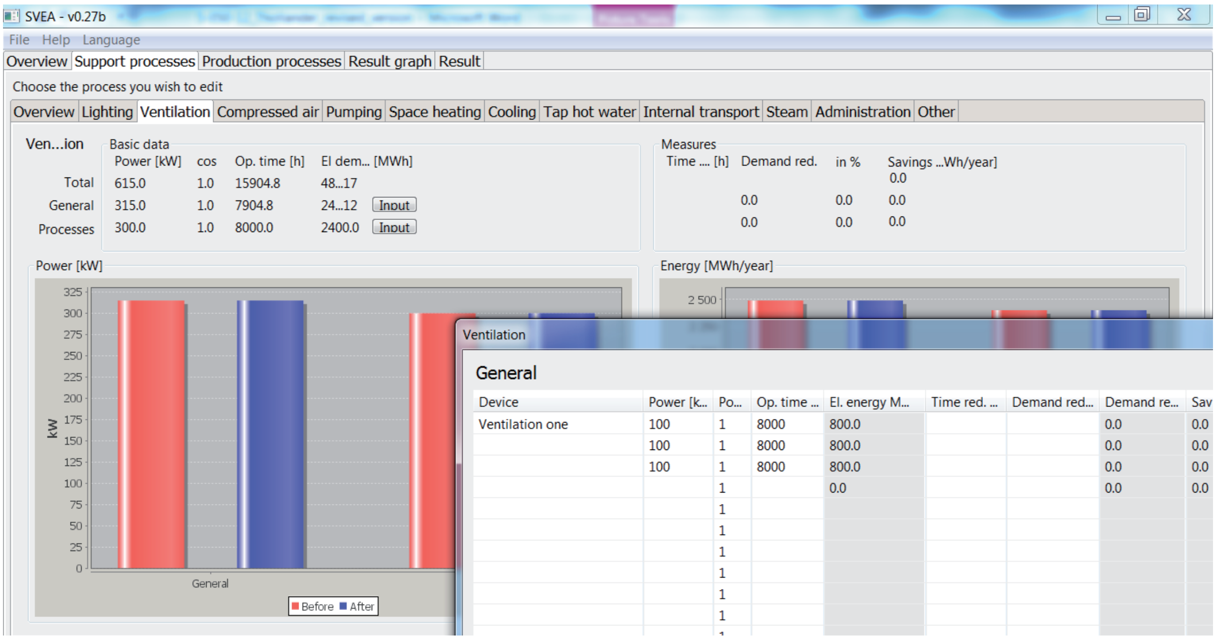

Figure 3. Overview of an audited company's support processes, ventilation, split into general ventilation and process ventilation.

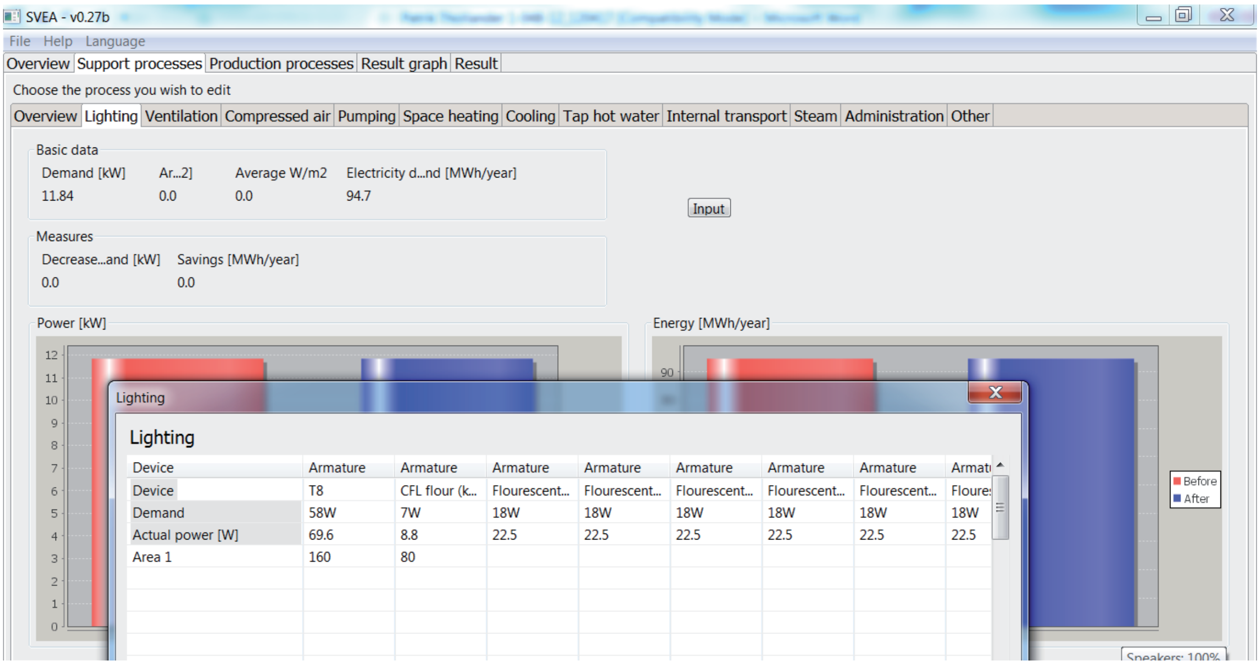

Figure 4. Overview of one of the audited company's support processes, lighting.

Discussion

It should be noted that an energy audit tool cannot replace the skill of an energy auditor when it comes to proposing measures for improvements. Despite the simplicity of SVEA providing linear equations in a structured way, it is evident that apart from actually initiating the use of a standardized tool in the Swedish energy audit program, there also is a large area for improvements of the tool. For example inspired by Trianni and Cagno (2012), one such improvement would be to equip SVEA with a database on energy efficiency improvement measures. There is a thorough amount of work done by the auditor which is very much dependent on his or her skills, i.e. engineering background, previous experience etc. Thus a database with previously proposed energy efficiency improvement measures could enhance the energy audit quality, ensuring the actual proposed measures to be more reliable, and thus to provide a more valid energy audit report. As done by Trianni and Cagno (2012), one means could be to start from the IAC's (Industrial Assessment Center) database with 160,000 measures. Moreover, creating a database from energy audits made using SVEA would enable energy performance ratios on energy use among various unit processes, and also information on energy efficiency improvement measures, to be collected. Creating a Swedish database based on SVEA, would enable benchmarking of energy use, en-

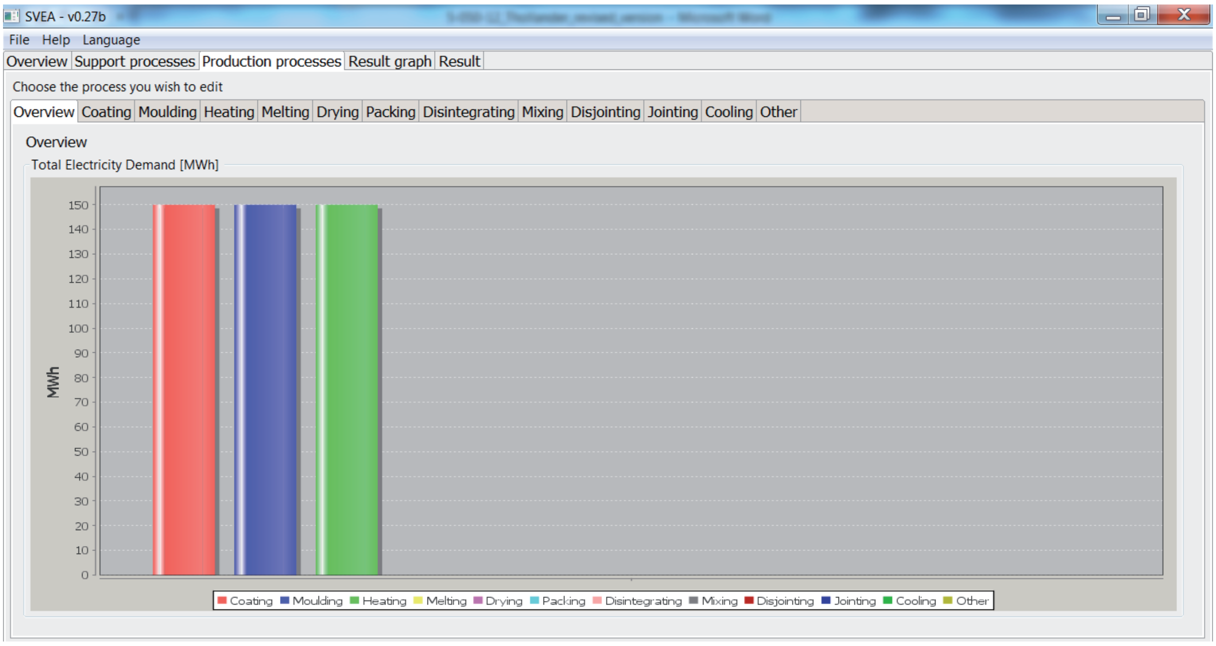

Figure 5. Overview of the audited company's production processes annual energy use.

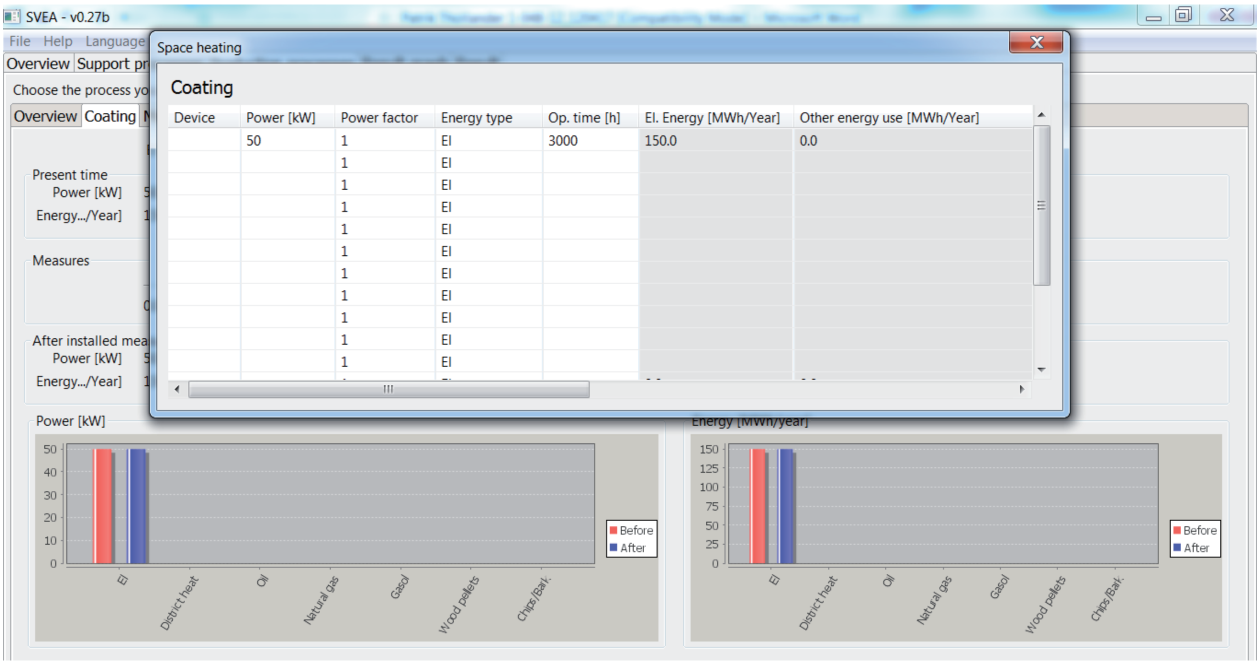

Figure 6. Overview of one of the audited company's production processes, coating.

ergy efficiency improvement measures etc. for industrial SMEs in Sweden. This would be of great benefit for an individual energy auditor, as well as for individual industrial SMEs.

Yet another means to develop the tool SVEA would be to further equip the tool with energy simulation calculations, i.e. building envelope and ventilation losses etc. For industrial SMEs in nations with colder climate, such as Sweden, this would provide the auditor and the individual company with a rough heat balance and a rough presentation of energy losses in the company's energy system.

Yet another means to improve the program and spread its use to a wider audience would be to provide yet more language options apart from the current Swedish and English option. For energy auditors and industrial SMEs, it is of great importance that the provided language is the native language.

The tool SVEA uses the unit process categorization. One question that could be asked is if it would be easier for an individual auditor and a company, to instead choose one's own categorization? On the contrary, this would not generate a structured way of collecting data, which in turn is a basis for a database to be created. However, one suggestion for improvement is that the support process categorization remains while the production process sheets are open for name changes. This would on one hand remove data for various production proc-

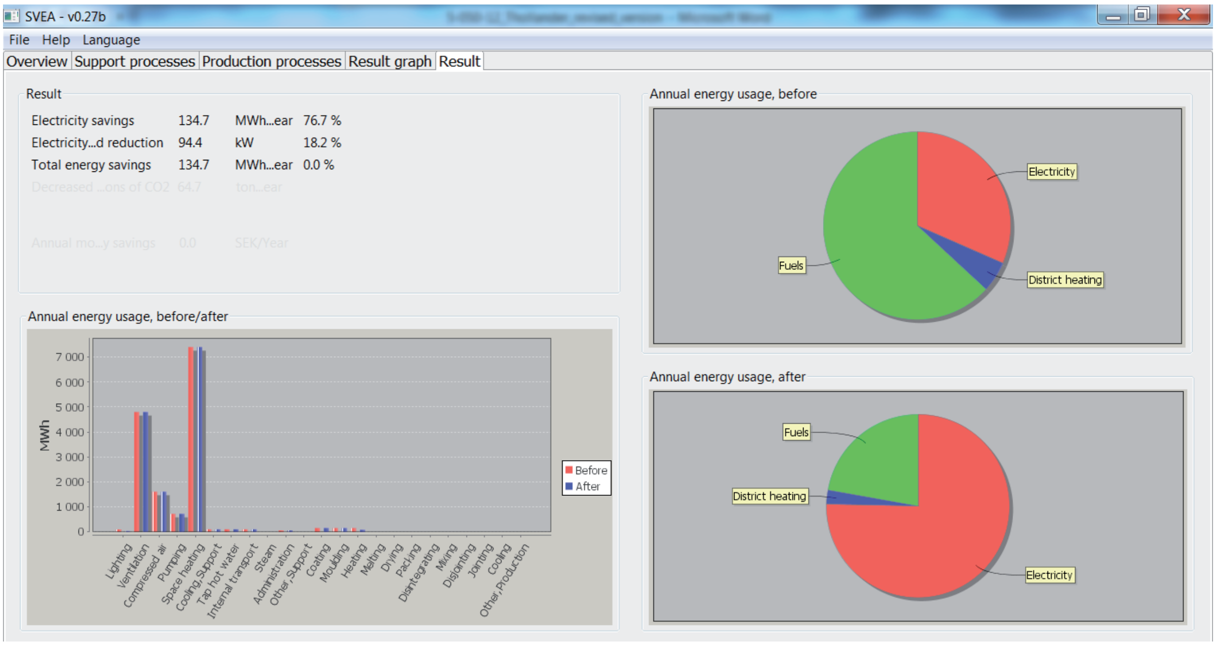

Figure 7. Overview of the energy audit results (energy balance) categorized between the different unit processes, and the current annual energy use and the energy use after all energy efficiency improvement measures are carried out.

esses. On the other hand it would reduce the amount of time for an auditor trying to categorize various processes. Moreover, the support process energy use is typically 50–90 % of the total energy use, and for SMEs the major improvement areas do not lie in the production processes, rather in the support technologies (Gruber et al., 2011, Thollander and Palm, 2012).

According to the available literature on energy audit programs, program success means more than just performing energy audits: "Subsidies for energy audits, training and certification of energy auditors, standardized tools and guidebooks, energy audit databases, post-audit follow-ups and dissemination of case studies are critical to a robust stand-alone energy auditing program." (Price et al., 2011). The current presentation of the Swedish energy audit tool, SVEA, is one such means to achieve more effective energy audit programs.

A suggestion for further research is that an international review is conducted on available country-specific energy audit tools.

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