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Introducing Load Management Analysis and Measures in Manufacturing Companies

Steffen Nienke, Jan Hicking, Günther Schuh
Institute for Industrial Management
at RWTH Aachen University (FIR)
Aachen, Germany
E-mail: {Steffen.Nienke, Jan.Hicking, Guenther.Schuh@fir.rwth-aachen.de}

***Abstract*—In order to introduce load management in the manufacturing industry, some obstacles need to be pointed out. This paper presents a feasible approach on how to implement load management measures in companies. To this end, load management and energy management are explained and distinguished in a first step. Subsequently, the implementation method is introduced. Therefore, by means of this paper, companies will be enabled to use load management measures and significantly reduce their energy costs. In the second part of the paper, the introduced approach will be applied. Hence, a use case of a manufacturing company is described. Alongside energy analyses with consumption data, specific measures are presented.**

Keywords - Load management; Energy management; Energy Monitoring; Manufacturing industry; Renewable energies.

I. INTRODUCTION

This paper ist an extended version of [1]. For the majority of companies in a continuously changing production environment, the ability to stay competitive depends on the production price of a product [2–4]. The ability to produce a product at lower costs can lead to a significant market advantage. Therefore, the ideal adjustments of essential target values like occupancy, timelines, or process costs are crucial for a company's success [3]. However, the costs for resource, energy and production utility have been raised dramatically in the last decades [5].

In particular, the price for electrical energy in Germany has risen severely over recent years. This development is connected to the increasing expansion of renewable energy [2]. Due to the implementation of the priority access of renewable energy, the prices for electrical energy rose [6]. This development refers to the fact, that the EEG-allocation (EEG: German Renewable Energy Sources Act, legislation to foster the use and invest in renewable energies) increases in the amount of expanding renewable energies in Germany [7]. As a result of the expansion of renewable energy generation capacities, the grid stability is endangered [8]. The priority access of volatile renewable energy leads to a decrease in energy supply reliability, which is one of the most important location factors for the German manufacturing industry [9].

Rising energy prices, as shown for Germany in Figure 1, promote a significant competitive disadvantage for the manufacturing industry [6]. Moreover, a growing scarcity of resources pushes energy prices [2]. Especially the scarcity of resources has increased environmental awareness in society and industry in the past [3, 10].

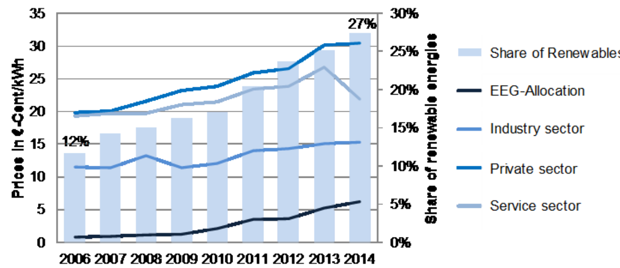

Figure 1. Development of energy prices [11]

In order to guarantee the grid security and create a greater environmental compatibility, Germany set a target to develop the most energy efficient and environmentally friendly economy in the world [12]. The focus of this program is the expansion of renewable energy. To compensate the incoming side effects like increasing energy prices, flexibility mechanisms are even more relevant. To stabilize the electrical grid, load management can be realized by using flexibility potentials in manufacturing industry. The identification of those potentials is very important. Hence, the survey of process-specific energy data in the manufacturing industry is necessary to point out any potential [13–15]. In this context, the gathering of information can be done by continuous energy monitoring of manufacturing companies [3]. Many companies are struggling to identify information relevant for load management as well as possible collection strategies. Apparently, a structured approach on how to create the information base to achive energy transparency as a first step to load management is missing. The presented approach focusses on the manufacturing industry, as literature research confirms that this area has the greatest potential for load management. However, the concept can easily be adopted to other application areas (e.g., office buildings).

In Section II, this paper describes fundamentals of load management concepts. In Section III it then focusses on the implemention of load management in the manufacturing industry. Considering, among other things, organisational requirements as well as the necessary transparency of the energy system, this paper develops a general approach to introduce load management in manufacturing companies. Finally, in the last section, the approach is applied to a specific use case that evaluates the described method.

II. Definitions and Fundamentals

Describing basic concepts and distinguishing several terms within the field of energy management, load management, and energy efficiency is essential in order to understand work at hand. In contrast to conventional base load power plants like lignite-fired power plants or nuclear power plants, the sustainable generation in renewable energy plants usually cannot be controlled. These circumstances lead to a discrepancy between feed-in time and amount of fed-in power of renewable energy technologies like wind and solar systems [8, 16, 17]. To gain a more profound understanding of this, Figure 2 visualizes a comparison of installed and generated power of renewable energy technologies. The Figure displays the discrepancy of installed and generated power of renewable energy technologies in January, May and June. Biomass and hydropower are not volatile. Therefore, the loads are nearly constant or were reduced by demand side management. The behaviours of Solar and Wind plants are quite different. The strong volatility of solar can be seen in the difference between January and May. Wind, on the other hand, covers 70% of the installed load in January, but drops the production close to zero in June.

German electricity transmission system operators compensate the incoming volatility by using control energy. Within this concept, controllable power plants like gas turbine plants or pumped-storage power plants are usually used [18]. The control energy concept leads to dealing with peak loads or loss of loads properly [19]. In summary it can be said that through expanding renewable energy in the electrical grids the supply reliability cannot be guaranteed. So secure the network, control energy uses load flexibilities. This is necessary to maintain the critical success factor of low energy prices for a society with a manufacturing industry as leading edge. However, energy prices are rising. Therefore, load management is one possible opportunity to compensate increasing energy prices.

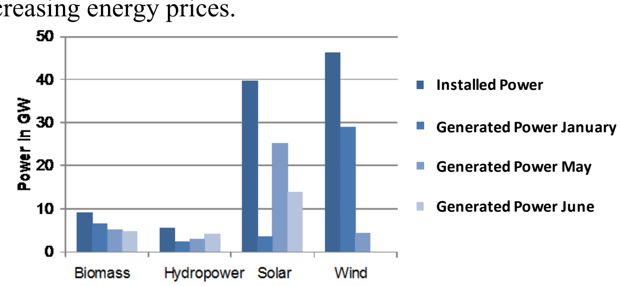

Figure 2. Renewable energy volatility [20]

A. Definition of Energy

Energy is a fundamental factor. Several types of energy can be transformed into each other, but neither be created nor exterminated [8, 15, 21]. Energy is used to heat buildings or to warm up process fluids to a high temperature (space or process heat). Apart from that, energy is used to drive engines within machines or vehicles. In this context, energy is called mechanical energy or electrical energy.

B. Definition of Energy efficiency

The term "efficiency" follows its Latin origin "efficientia", which means efficacy [22]. Energy efficiency is the relation between benefit and initial energy input [23]. Energy efficiency also describes an intelligent usage of the initial input aiming to use the available energy as efficient as possible [14]. Following this definition, energy efficiency is increased by reducing energy consumption while (simultaneously) keeping the energy benefit constant [24].

C. Definition of energy management

The introduction of energy management in the manufacturing industry will have an impact on increasing sustainability and lowering energy costs [10, 25–27]. Energy management is defined as an instrument of coordination aiming at an ecological and economical satisfaction of energy requirements in companies. This goal is realized by a predictive, organized and systematic approach of energy production, procurement, storage, distribution and usage [28, 29].

Energy management can be considered from two perspectives. There is a technical perspective dealing with energy monitoring, analysing the energy data and deriving plans of action to achieve defined goals. Furthermore, there is an organisational perspective, which follows a holistic view of energy consumption and usage in processes, proceedings and procedures in the manufacturing industry [10]. To achieve goals, such as raising energy efficiency or reducing energy costs, energy management uses approaches like investing in new technologies, changing behaviours and identifying energy saving opportunities [30]. Referring to the identified approaches and goals of energy management, load management describes one aspect of energy management.

D. Definition of load management

First, load management must be distinguished from demand side management (DSM), since both terms are easily mixed up. Demand Side Management is a generic term for different approaches of systematically switching loads. It contains load management, energy saving approaches, fuel substitution and load optimisation [31–33]. Load management, however, describes the way to achieve the goal of changing the point of time and amount of load that is required [32]. Hence, load management describes the temporal relocation of energy consumption [13]. In addition to that definition load management is defined as switching loads on and off [14]. Therefore, load management focuses on internal processes, to reduce load peaks and thus reduce energy costs [34]. Examples of load management are described in the following section.

E. Measures of load management

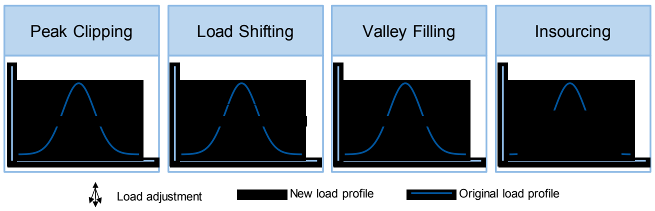

Figure 3. Load management measures

To avoid energy costs due to load peaks, load management focuses four different types of measures as shown in Figure 3 [31–33, 35]. In the following, the different types are explained. "Peak Clipping" describes the immediate handling of peak loads. Thereby peak loads are reduced by a specific amount, which reduces the energy costs significantly [31–33]. It is achieved by ejecting loads to prevent a significant peak load [36, 37]. Using energy storage technologies are another opportunity to prevent peak loads by feeding-in energy at the point a peak load would occur [38].

"Load Shifting" also describes the immediate handling of peak loads. However, in this case, technologies are introduced to reduce peak loads. Energy storage technologies enable companies to temporarily switch production processes. The change of organisational or production processes can lead to a reduction of peak loads. Although energy is not saved, energy costs are significantly reduced. The energy consumption of several production procedures is not saved but switched to a point in time when there is no risk of a peak load [31–33].

"Valley Filling" describes a load management measure, which lifts the base load of a company to cut the average electricity price. This measure goes with a change of energy contract of the energy supplier. Because the total energy consumption is increased, the load profile is polished. Any energy supplier prefers a polished load profile and will remunerate those profiles. Another use case is a loading of electric cars in the night. The raised load in off-peak times polishes the whole load profile.

The last measure of load management is named "Insourcing". It describes the reduction of energy purchase. Unlike "peak clipping", "insourcing" reduces the load profile holistically. There is no need for a specific peak load analysis. Companies reduce the energy purchase by producing a specific energy amount themselves. Achieving this goal, companies need new energy production technologies like cogeneration units or PV-plants in combination with an energy storage.

In order to summarize and classify these findings, the following Figure 4 explains in several layers how terms like energy and load management relate. The top layer represents the concept layer. As described earlier, operational energy management is the primary term. Energy management comprises several goals and measures.

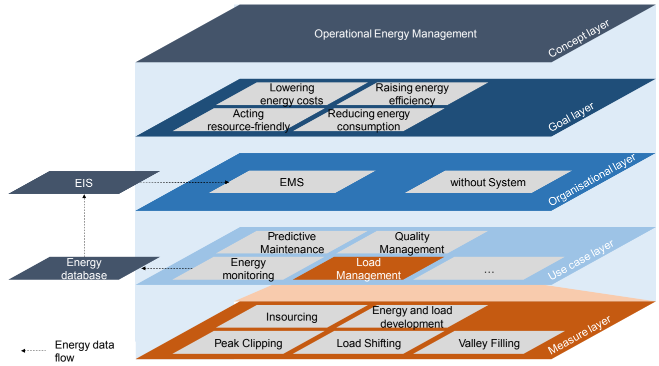

Figure 4. Content of operational energy management

Hereafter follows the goal layer. In this layer, all goals of energy management are summed up. It starts with lowering energy costs, raising energy efficiency, acting resource-friendly and finishes with reducing energy consumption. These goals, which have their origin in the operational energy management, can be achieved by various actions. The organisational layer describes two typical types of how energy management topics can be addressed. On the one hand, companies can implement a holistic energy management system (EMS) that is standardized by a German, European or international institutions. On the other hand, a not standardized solution to achieve the formulated goals can be realized without using such a system. In this case, the organisation of the individual solution falls in the responsibility of the company. For the appropriate application of an energy management system, the information flow must be organized properly. Therefore, an energy database for continuous memorizing energy data would be crucial. Thus, the measured data is always ready for a delivery on demand. For a company, it is important to receive data and information to the exact right point of time, spot and quality. To achieve this, the introduction of an energy information system (EIS) is necessary. The combination of an energy management system, energy information system and energy database is the best way to deliver information and data in the desired quality as explained above. The use caser layer describes different applications within the energy management context. The focus of this paper is on the field of load management, but it is worth mentioning, that use cases like predictive maintenance, quality management and energy monitoring can also achieve energy management goals. All aspects have in common that they collect data, which must be memorized for later use.

The last layer is the measure layer. This layer contains all load management approaches. In principle, all terms of the layer above have their own measures on the layer below.

III. Implementation of Load Management in the Manufacturing Industry

The following approach should support companies to introduce load management. It should give answers to questions such as: how can load management be implemented holistically? What are the benefits?

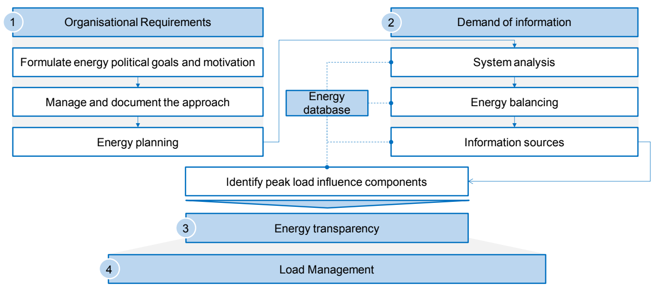

Figure 5. Load management introducing approach

The approach in Figure 5 contains four essential steps. First, companies must meet the organisational requirements. Second, companies must fulfil the demand of information. Third, when the demand of information is accomplished, the required energy generation/consumption transparency can be achieved. Fourth, once all required foundations are provided, load management can be introduced by implementing load management measures.

A. Organisational requirements

The reduction of energy consumption is a long term process. Therefore, it is recommended that the introduction of load management must be well organized and controlled. The organisational requirements are basically described by the DIN EN ISO 50001:2011. But not all requirements to introduce load management are addressed in this standard. First, it is important that companies create an energy policy. A policy in this context must contain energy long-term goals. Furthermore, it must contain a motivation that is communicated within the company, because the employees shall live and realise those policies. The policy must be formulated close to reality, comprehensible and goal-orientated. Moreover, a company must implement a process of documentation. Besides that, a company has to develop an energy plan to summarize all goals, approaches and review processes. Within an energy plan, a company determines, which energy data must be collected, how data can be collected, how a data working process looks like and how a company would work with the flows of information. Those steps are important to lay the foundations for the introduction of load management.

B. Demand of information

Every measure within the context of load management works with real time data. Collecting those data is therefore a necessary requirement. To acquire the required information in a continuously changing environment, data must be collected in various dimensions of the company, e.g., company's location, buildings, rooms, production processes and energy sources. This kind of consideration is called system analysis. The objective is to create a holistic flow sheet of all forms of energy and its use locations. Assuming an overall system, to achieve a holistic flow sheet, it has to be broken down to its source elements.

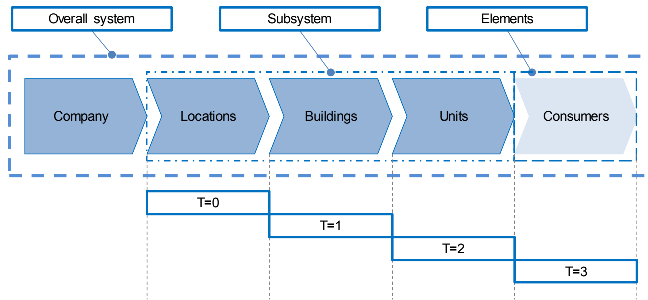

Figure 6. System analysis [23]

Figure 6 represents a typical construct of a company in the manufacturing industry. Dividing this construct in three types of system elements, it is shown that there are different degrees of depth. Starting with the overall system, which contains all given components, a company has its locations (T=0). The location level is the first layer. Diving in the subsystem, a location contains at least one building (T=1). The building level is the second layer. Each building contains at least one unit of its company, for example production, supply, quality management or services (T=2). The unit level is the third layer. The deepest layer represents the energy consumers (T=3). For example, there are machine tools, cooling energy generation or printers. The consumer level is the last layer. In order to achieve energy transparency in a company, a system analysis is fundamental. The concept of balancing is close to a system analysis. The goal of both concepts is to disperse the areal boundaries of energy consumers in a company for transparent visible consumer structure.

Once all energy consumers in a company have been identified, the next step would be to determine where they are located, what form of energy they are using and when they are consuming how much energy. Consequently, an energy monitoring system must be implemented to collect the real-time consumption data. The collected real-time data must be memorized in a database. But there are circumstances, for example, financial barriers, which inhibit a company to implement an energy monitoring system. In this case, there are different options to collect data. Literature has shown that there are just few energy consumers in the manufacturing industry with high impact on peak loads. By comparing the main energy consumers and the main energy conservation potentials in the manufacturing industry, a measurement priority listing can be determined:

1. Compressed air generation
2. Energy generation for cooling purposes
3. Ventilation system
4. Machine tools
5. Electrical system

6. Pumps

Influences to peak loads due to illumination or information and communication technologies are usually neither significant nor manageable. The list above shows which consumers in the manufacturing industry must be prioritised when collecting real-time data.

C. Energy transparency

Collecting real-time data is a fundamental component to achieve energy transparency in a company. Real-time data is required to implement an autonomous load management in the future. The needed data acquisition is a separate challenge, which is discussed in other publications. In addition, the issue of IT security must be considered. The acquired data is now used to identify specific components of the maximum load peak of a company's load profile. Figure 7 presents an activity diagram, which contains an approach to identify specifics peak load components.

Deriving essential elements of the diagram, it is noted that load profiles of energy consumers and the main load profile of a company are required. Furthermore, the specific consumer load profiles must be inspected for load peaks to the point of time when the main peak load occurs. After this step, all specific loads are summarized and compared with the amount of the main peak load. If there is a difference (<<if(n)>>) it must be ensured, that the data set is complete as possible. If there is no difference (<<if(y)>>) a visualisation of the result should be created. The next question to be asked is whether the result is detailed enough or not. To answer this question, a company's layer must be determined. As explained before, a company has several layers. Load management requires information about the peak load components in sufficiently detailed depth. The ideal case would be at plant level (T=3). When including these last steps, energy transparency is guaranteed. The described steps enable companies to get a detailed view over their energy consumption and which kind of consumer has the highest impact on the total consumption. Another advantage of implementing the whole energy monitoring process is that the result can be used to identify energy wastage.

This procedure was validated at a company. The energy transparency was established and it was shown that the energy generation for cooling purposes had a peak load share of 20%. This transparency allowed counter-measures to be implemented.

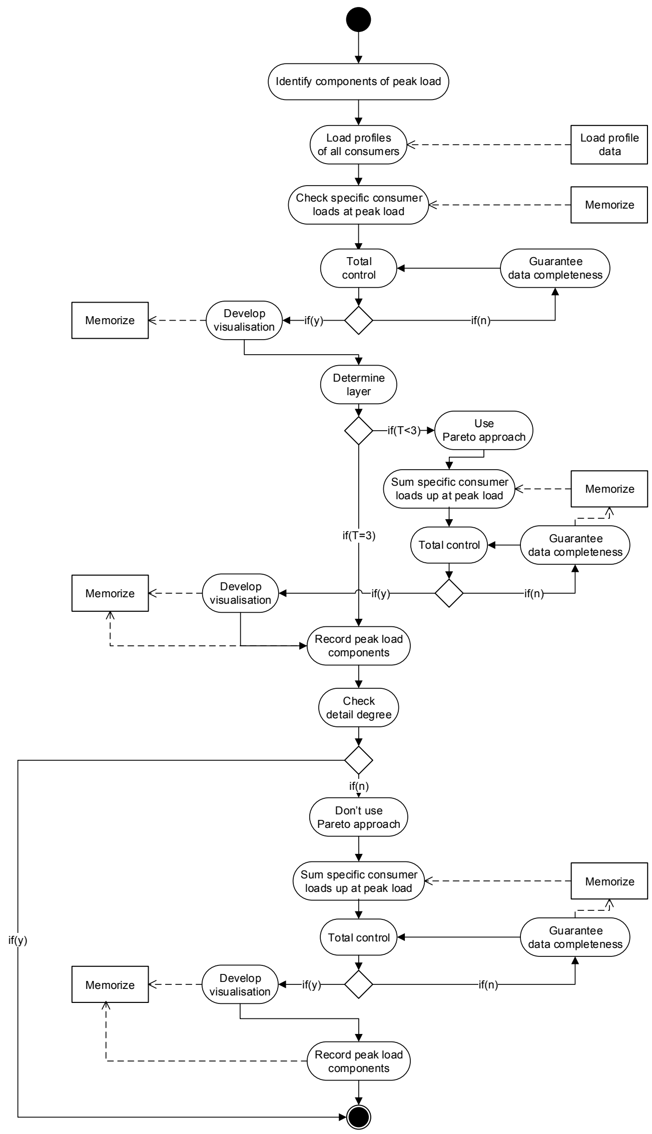

Figure 7. Identification of peak load components

IV. Applying the Approach

To validate the proposed model, it has been applied within use cases in companies. One example is described in the following section. First, the setting and circumstances of the considered company are described. Subsequently, the measurements are visualised and described. Finally, the possible measures to implement load management are introduced.

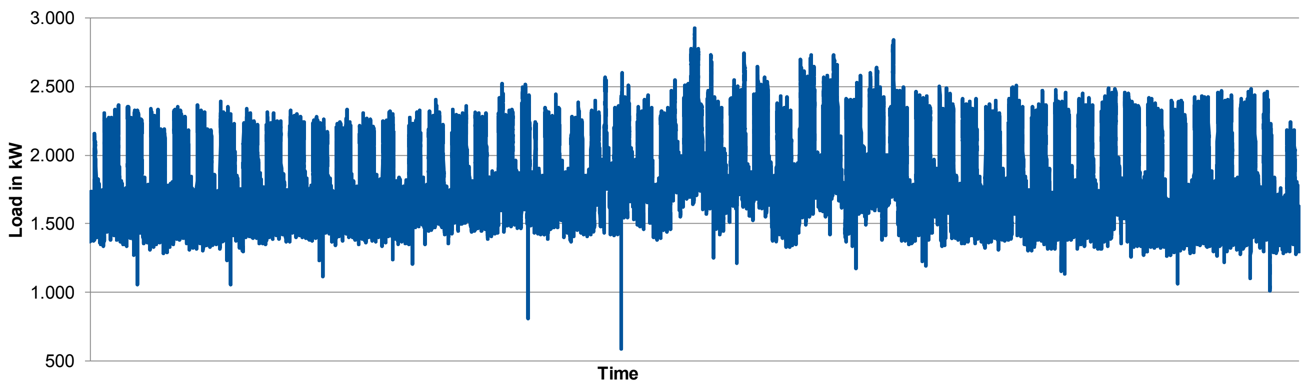

Figure 8. Anual Load Curve of the whole company

A. Setting

The considered measurements could correspond to a classic manufacturing company in Germany with more than 500 employees. Such a company is considered to be a large company according to EU definitions and is due to German regulations consequently obliged to carry out energy audits according to DIN EN 16247-1. The production usually runs in two shifts. The two shifts run from 8 am to 10 pm. Furthermore, a seven-day workweek is also considered. The load curve is characteristic for a company is in the metal sector, e.g., a company producing body parts for the automotive industry.

B. Measurements

This section displays and analyzes the measured data. Various statistical and non-statistical methods are used for the analysis. Figure 8 shows the overall consumption of the company. The resolution of the measured data is 15 minutes and thus contains 34050 measurement points. There is an increase of the minimum and maximum load during summer between the beginning of June and the middle of September. During winter and early spring, the loads are at a constant level of 2350 kW. The load profile suggests that the increase in power consumption in the summer is attributable, for example, to cooling. However, this cannot be confirmed by only considering the consumption of the whole company. The minimum loads are within a range of 1300 to 1700 kW, with few exceptions. The peak load was 2930.48 kW and occurred on July 2, 2015 at 12 am.

Figure 9 shows the annual load duration curve of the measured values. This shows that the load demand decreases rarely below 1300 kW over the entire year. There are a few points in time at which the load is less than 1000 kW. As seen in the earlier figure, there is a night reduction as well as a weekend lowering of the load.

If the median over 24 hours is considered, it is noticeable that between 8 am and 4 pm the load reference is constant. Between 4 pm and 10 pm, it decreases. From 0 am to 5 am in the morning, the load is almost constant 1500 kW. Thus, during 5 hours a day the load has decreased to 1500 kW. As a result, a high load reference is recorded for 19 hours over 365 days a year. The basic load can therefore be seen at 6935 hours (365 days * 5 hours / day). It has to be noted that the basic load is more than 50% of the peak load.

Figure 8 also shows the weekly load cycle at the time of the peak load. It should be noted that the basic load in this week is about 100 kW higher than the basic load of the annual load duration curve. It should also be noted that the peak load

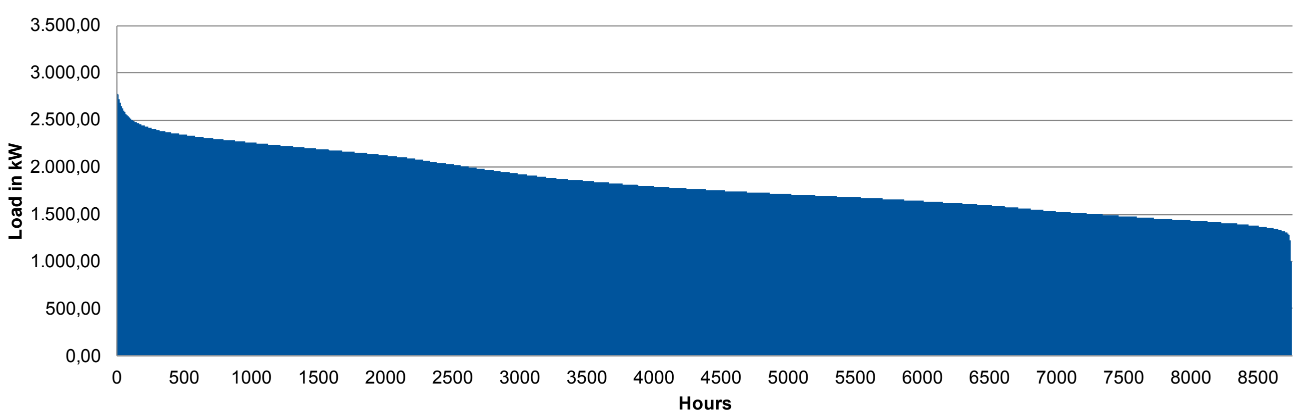

Figure 9. Annual load duration curve

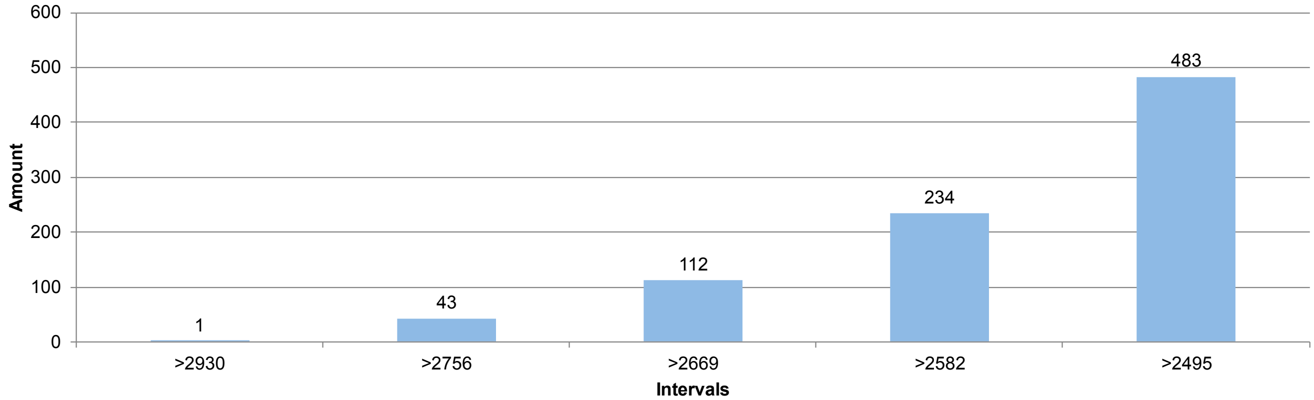

Figure 10. Load Peak Distribution

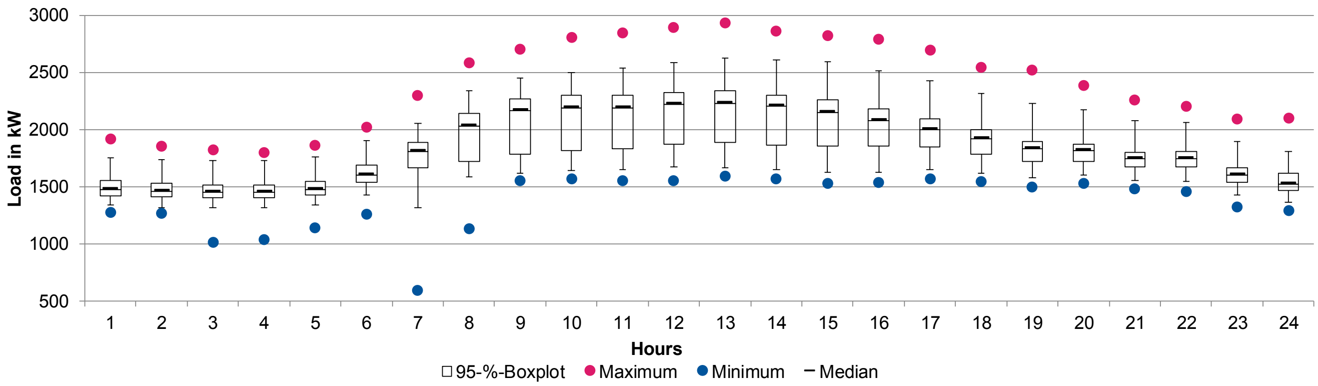

Figure 11. Overall Box-Plot covering the hours of a day

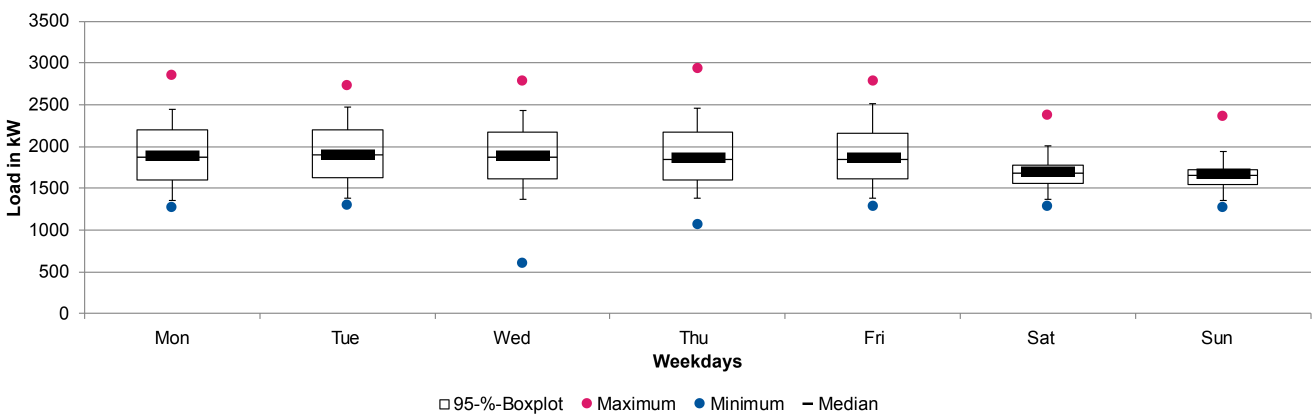

Figure 12. Overall Box Plot covering the weekdays

is not an anomaly, instead the general consumption in this week is very high. The weekends and nights have a reduced load. With regard to the previous assumption that the peak load is due to cooling, it should be noted that July 02, 2015, was one of the hottest days of the month. The maximum temperature was 35.2 ° C.

Figure 10 shows the load peak distribution of the company. The interval lengths are defined by the observation of the top 2.5% of all measured values. If the interval > 2756 kW is considered, it should be noted that less than 50 load peaks are counted in this interval. If the lower bound of the interval is reduced by approximately 100 kW, the number of load peaks triples. The number of load peaks contained in an interval are cumulated in the next interval. Therefore, this visualisation can be used to identify the load management potential. Hence, potential savings can be expected.

Figure 11 shows the box plot covering the hours of a day. It considers all data from the year 2015. Ninety-five percent of all data is located between the vertical upper and lower black lines. Between the maxima (magenta dot) and the upper vertical lines as well as the minima (blue dot) and the lower vertical line 2.5% of all data is located. Based on the medians and the box plots, the nightly reduction of the energy consumption can be identified. The peak load occurs mainly between 8 am and 5 pm.

Figure 12 shows the box plot covering the weekdays. It is noticeable that the median is 200 kW lower on Saturdays and Sundays. The maximum also drops by more than 300 kW. It should be noted that 97.5% of all load points lie between Monday and Friday at a maximum of 2500 kW. An objective of the load management could therefore be to not exceed the threshold of 2500 kW.

The analysis of the measurement presents a strong assumption that the used cooling system is responsible for the measured peak loads. Therefore, the next step would be to break the overall consumtion down to each individual consumer. Since, in reality, it is unlikely to monitor each used consumer, it is usually sufficient to monitor the large consumers and cluster the remaining consumption under "others". In the presented example, the cooling machines can be measured and the share of the overall consumption can be calculated. Figure 13 shows the box plot of the measured cooling machines covering the month. It is noticeable that the median of 1680 kW is almost identical between January and May, and between September and December. During June to August, the median rises to 1900 kW. Peak loads above 2500 kW occur more often during May to August. During summer, the base load and the peak load increases. This proves the thesis that the cooling machines have a mayor impact on the load. After identifying the machine with the largest consumption, load measurements can be implemented.

C. Possible ways to implementation for load management

The following section presents different ways to implement load management based on the measurements done in the previous section. Due to the analysis of measurements, there are several opportunities to reduce the peak load in the considered company. As analyzed, the peak load evolves due to cooling machines, which runs with increased power usage when the external temperatures are high.

1) Insourcing: Combined power and heat station

Reducing the consumed energy by producing energy on company's own, this measure is called "Insourcing". Within this measure the usage of a combined heat and power station is recommended. This technology leads to a massive reduction of the required energy from an energy supplier.

In order to use this technology, several parameters have to be considered. In this context, a combined heat and power unit (CHP) was implemented with these parameters:

- $P_{Power} = 365$ kW
- $\dot{Q}_{Fuel,\ HCP} = 955$ kW
- $\dot{Q}_{Heat,\ CHP} = 478$ kW
- $\omega_{HCP} = 0{,}88$
- $\eta_{Power,\ HCP} = 0{,}38$
- $\eta_{Heat,\ HCP} = 0{,}5$
- $\tau_{v,\ HCP} =$ adjustable

The mode of operation of this CHP unit has been designed to be heat-guided. Due to the high demand for heating available all year round, the CHP is operating at full load all year round. It follows that the heat produced can be reduced at any time. Furthermore, the CHP is designed to be used for the utilization of the energy reduction. The type of design is made by entering the electrical power $P_{Power} = 365$ kW into a year duration line. Following this method the result contains 6620 operating hours of the CHP. It is recommended that the CHP should not run in the partial load effiency as often as in the overall load effiency. A service contract was obtained that effectuates that the CHP is only in maintenance when the energy consumption is relatively low, for example, in the morning or at weekend. In the calculated example, the result of the examiniation of a combined heat and power station with 365 kW electrical power was an annual saving of about 55,000 €. The net present value analyzed over 10 years of the investment in the CHP is ca. 2,600,000 €.

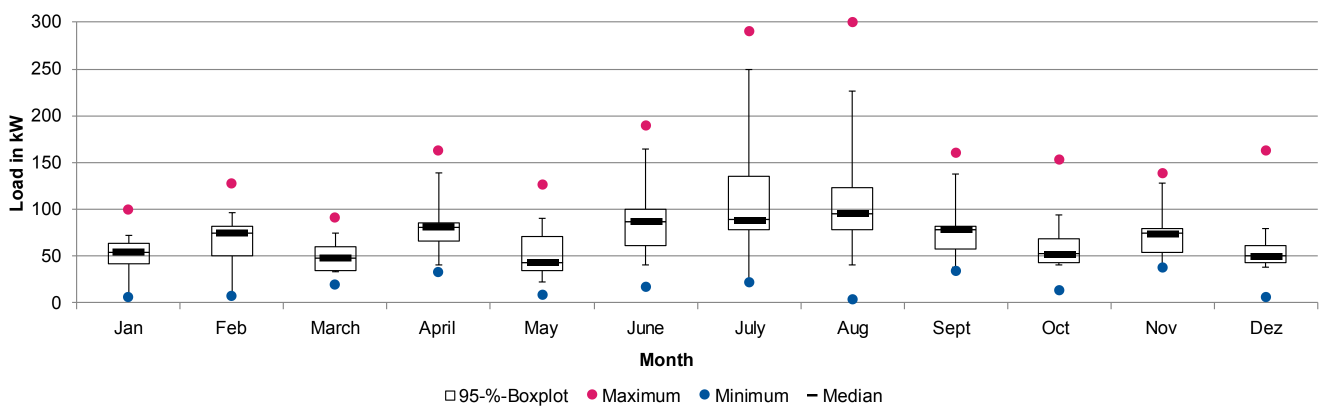

Figure 13. Cooling Machines Box Plot covering the month

2) Insourcing: Emergency power supply

Alternatively, an emergency power supply can used like a CHP. Emergency power supplies are assumed to have a total amount auf 3.5 MW electrical power. In that case, various emergency power supply stations cannot be used parallel since the emergency power supply has to be guaranteed.

In the example calculation, the total annual savings would be more than ca. 60,000 €.

3) Load Shifting: Ice storage

Regarding the definition of load shifting, load intensive processes are identified, which can be shifted in times of lower energy consumption. This approach leads to reduced energy costs. There are two types of cool energy storage technologies: ice storage or cold water storage without icing. Cold water storage technologies have one disadvantage with respect to ice storage technologies. Due to the missing icing process the cold water storage needs much more space to save the same amount of energy. Due to this disadvantage, the ice storage technologie is examined. The relevant parameters of the ice storage are the following:

- $Q_{Storage} = 500$ kWh
- $P_{Peak,\ Storage} = 150\ kW$
- $n_{SP} = 5$

In order to reduce the peak load by 150 kW, an energy storage amount of $Q_{Total,\ Storage}$ = 2427,84 kWh is required.

Figure 14 shows how the usage of the ice storage that reduces the peak load by150 kW. This measure needs five storages to guarantee the load reduction. The calculated potential annual saving in the used example is approximately 15,000 €. Regarding the high cost for investment the net present value is less the net present value of the CHP. In this particular case the net present value of the ice storage would be around 20,000 €.

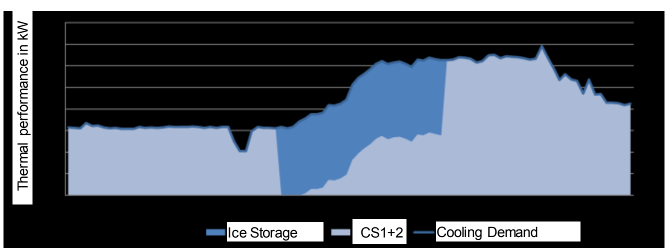

Figure 14. Usage of ice storage

V. Conclusion and Outlook

Load management leads to lower energy costs in companies working in the manufacturing industry. This paper described the requirements that need to be fulfilled to implement load management. With the presented approach, companies are enabled to collect these data and information in a well-structured development. Starting with fundamentals like formulating a company's energy strategy and an energy plan. Furthermore, the company is advised to motivate their employees and to document the whole introduction process.

Besides that, a company must start with a system analysis in order to create a transparent list of all energy consumers. Also, a company must start with measurements in an early stage, to collect necessary data. Energy monitoring systems assist companies in collecting important data and information regarding the energy consumption of machines, etc. Possible circumstances can force companies to reject energy monitoring systems. In this case, the measurement of the energy consumption of prioritized consumers is recommended. This paper presented relevant consumers, which have a high impact on the main peak load in the manufacturing industry. Using these fundamentals and the memorized data and information, energy transparency can be achieved by analyzing collected and memorized data. Therefore, load profiles on all layers, such as buildings, units or consumers must be analyzed following the presented approach.

The application of the approach showed that load measures can lead to lower energy costs. Therefore, the load profiles were analyzed precisely. Due to this analysis, load peaks were identified. Using these results, several load management measures were derived. With a focus on two main measures "insourcing" and "load shifting", two different technologies were introduced to address the measures. On the one hand a combined power and heat station can be used, and on the other hand an ice storage technologies. In the used example calulations, both technologies leads to a annual amount of at least 15,000 €.

Summarizing, load management can be used to reduce energy costs in a company.

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