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ENERGY CONSUMPTION IN INJECTION MOULDING: A CASE STUDY

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Abstract

Energy consumption is a key parameter to determine manufacturing process efficiency and sustainability, therefore, analysing plastic injection moulding from an energy perspective is fundamental. In this context, this study presents the analysis on an industrial case to produce shoe soles. The daily injection process was monitored with one power quality analyser and the process was observed at the industrial site. Power data were examined in contrast with the PVC products generated by the rotary table injection machine. It was determined that the production method used was a key factor affecting energy consumption, resulting in a non-productive energy as high as 60%. Furthermore, an important amount of energy was not being used in value added activities. The net energy required to produce a product was found to be approximately 72 Wh for a juvenile sole and 160 Wh for an adult sole. Nevertheless, the energy per product increased to 128 Wh for a juvenile sole when the energy of a cycle (a table revolution) was distributed over the generated products. This analysis has provided the company a first approximation to the amount of non-productive energy in a manufacturing cycle.

Keywords: injection moulding; energy consumption; PVC; non-productive energy.

1. Introduction

Currently, there is a search for production processes that are economically feasible and sustainable. Sustainability of a process can be influenced by multiple factors, with energy consumption being a significant variable [1], [2]. In a low-volume manufacturing environment, it is critical for companies to optimise resource utilisation and minimise energy losses. In this regard, [3] suggests that the implementation of lean methodology can be an effective solution to improve operational efficiency and reduce costs associated with inefficient use of resources. The authors proposed a methodology that seeks to identify and eliminate energy inefficient processes, as well as eliminate non-value adding activities (e. g., non-productive energy consumption) with the aim of improving the overall efficiency of the manufacturing process.

A close look at the process is made by [4], which analyses the optimisation of the injection process to reduce energy consumption without reducing product quality. The impacts of cooling time, screw rotational speed, mould temperature and nozzle temperature were studied. The study revealed that the duration of cooling had the most significant effect on energy usage. Specifically, the examination showed that nearly 50% of the total energy consumed was attributed to the chiller. Maintaining the parameters at their minimum values facilitated a decrease in energy using without significantly impacting quality.

A more comprehensive examination of energy usage is available in [5]. The authors examine each stage of the process, from injection to product ejection. According to their findings, the operations that consume the most energy are plasticising and cooling. These findings are in agreement to a certain degree with the outcomes found in [4]. One of the concrete proposals of this study [5] is to reduce the cooling time as much as possible without compromising the quality of the product.

In [6] the configuration of the injection moulding machine was analysed. The study assesses energy consumption based on the power unit used, indicating that choosing the appropriate power unit, at the time of purchase, can significantly decrease energy usage. The limitation of the implicit approach is that it is only suitable during machinery acquisition periods. Nevertheless, it is still crucial to articulate this viewpoint clearly.

A broader look at energy consumption in plastic injection moulding processes is given in [7]. The authors evaluate the plastic injection moulding manufacturing practices of several companies and identify both technical and managerial areas for improvement. Notably, it was found that the measurement and control of specific energy consumption is a weakness within all the companies under examination. This study also compares different machines with respect to specific energy consumption (SEC) and finds that it is depends on the injected mass, the machine output (productivity), and each mould-machine-material combination.

The previous ideas were considered when conducting an analysis of a plastic injection moulding process. Energy and power consumption were monitored during daily operations to gain insight into its behaviour. This study enables the association of energy consumption values with the manufactured component, a practice currently not implemented in the company. Additionally, this study enables the identification of components that can be targeted for implementing energy-efficient measures.

2. Experimental Procedure

In this case study, energy consumption was measured in an injection moulding process to comprehend its behaviour in daily operation. A rotary table injection machine (Desma Werke #1 and #3) was used to analyse,

Fig. 1. Both rotary tables have spaces to fit 10 moulds. In this study, a complete rotation of the table was defined as a production cycle, and products were injected one at a time, resulting in PVC soles as the final product.

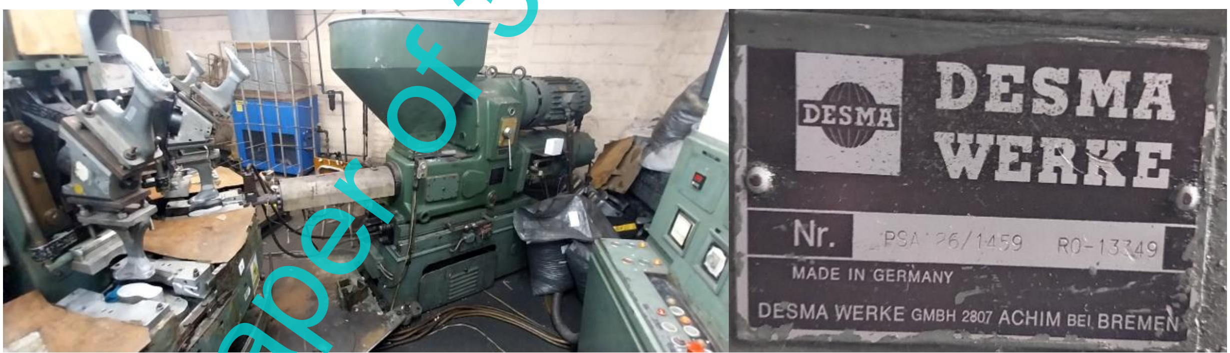

Fig. 1. Desma Werke injection moulding machine

To measure energy consumption and active power, a power analyser (Fluke 438-II) with an acquisition rate of 250 ms was installed in position M3 and M4,

Fig. 2, but in different moment of time. The energy measurement procedure was defined based on the algorithm proposed in [8]. A general measurement was conducted, with the base case being the measurement of injection cycles executed in one rotation of the table. Power profiles were created and analysed to identify power peaks and determine the energy required for product generation.

The case study was approached in two phases. The first phase focused on measuring the energy consumption and active power of the process with position M3 of the analyser,

Fig. 2 and

Fig. 3. a. In the second phase with position M4 of the analyser, the production of the observed period was also recorded,

Fig. 2 and

Fig. 3. d. It was observed that during the cyclical operation of the equipment, not all ten spaces of the rotary table had moulds and some cases PVC was discarded,

Fig. 4. This information was taken into account when analysing the productive and non-productive energy.

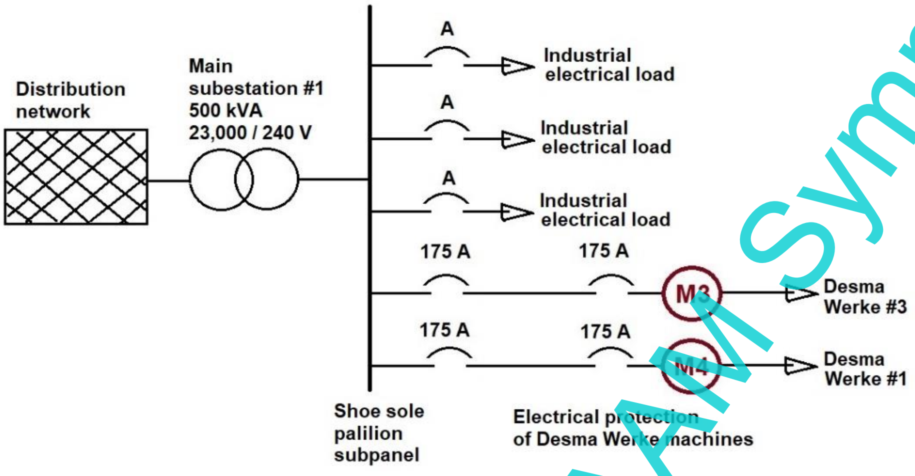

Fig. 2. Single-line diagram of the sole manufacturing pavilion.

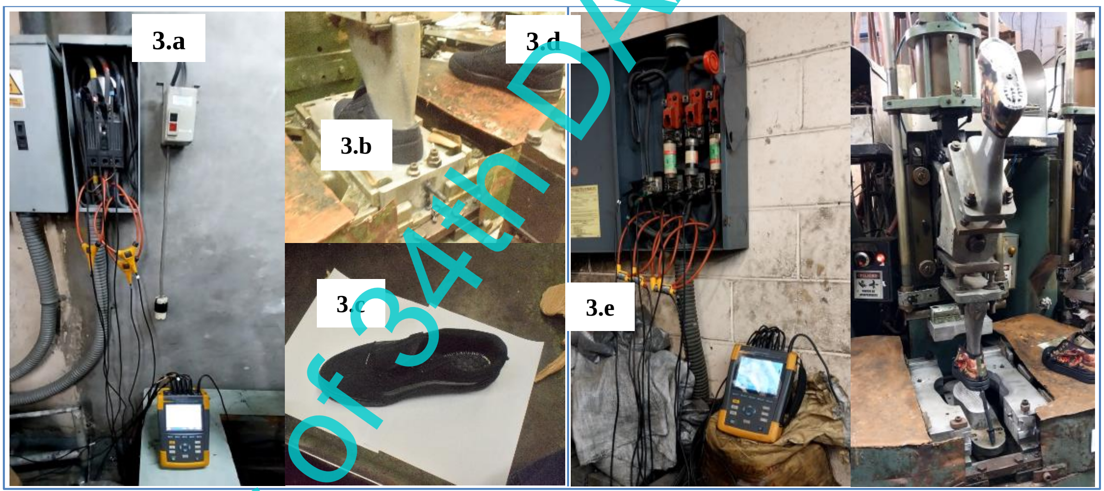

Fig. 3. a) installation of Fluke 438-II for measuring Desma Werke #3, b) moulding of adult sole in Desma Werke #3, c) final product of adult shoes, d) installation of Fluke 438-II for measuring Desma Werke #1, e) moulding of children sole in Desma Werke #1.

Fig. 4. PVC discard

The data for this study were collected in the plant during a daily production day, Desma Werke #3, under normal working conditions in the company,

Fig. 3. b, c. In the second phase, Desma Werke #1, the production of the observed period was closely monitored, and the number of products produced during the measurement period was recorded,

Fig. 3. e. This comprehensive data collection allowed for a thorough analysis of the energy consumption and production efficiency of the injection moulding process.

Overall, the methodology used in this case study provided a systematic approach to measure and analyse the energy consumption of the injection moulding process,

Table 1. By considering both the energy consumption and production data, a comprehensive evaluation of the process's energy efficiency was obtained.

Date of visit	Machine measured	Electric variable	Rate of measurement	Other measurement
June 30th	Desma Werke #3	• Energy consumption, kWh • Active power, kW	250 ms	-
August 16th	Desma Werke #1	• Energy consumption, kWh • Active power, kW	250 ms	Video to record the production of soles and PVC discard.

Table 1. Methodology of measurements of energy consumption and active power.

3. Results and discussion

3.1. Phase 1: Power and Energy Consumption

Power monitoring allows observing, as expected, a cyclical behaviour,

Fig. 5. It was observed that the highest power peak was required at the time the plastic was injected into the mould. Therefore, each injection is shown on the graph as a power peak. The power profile also shows other peculiarities. The baseline machine power consumption is around 20 kW. This baseline appears to rise to 80kW, but the change is caused by the activation of the chiller used to cool the mould. This suggests that attention should be paid to other elements in addition to the injection moulding machine, as they significantly increase the power demand. This observation is consistent with what [4] discovered concerning the influence of the chiller. However, a more detailed analysis is required to assess the influence of this element in this case. The baseline value found is a first approximation that can be taken into account by the company when determining the costs linked to non-productive time.

The

Fig. 5 shows regions where no power peaks are observed (around 1280 and 1420 s). This is due to the fact that no material injection was performed. These areas appear in a non-systematic way as the operator determined, for example, whether an out-of-mould injection was necessary to prevent the material from overheating. This highlighted the necessity to monitor whether a product was being produced in order to determine the consumption of non-productive energy. Therefore, recording was employed as a tool for process monitoring in the second phase.

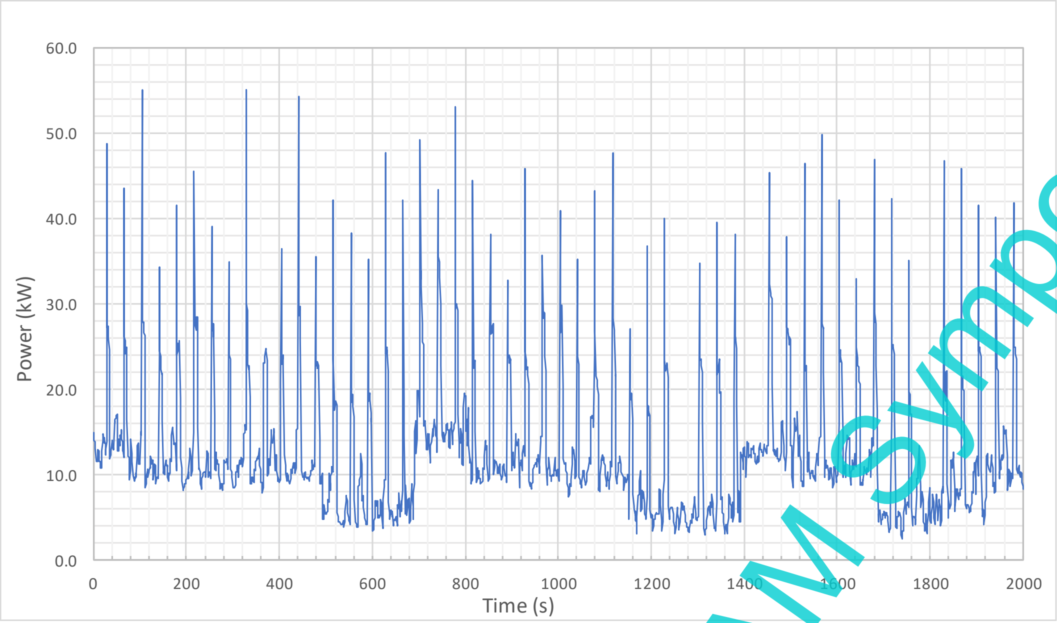

Fig. 5. Active power profile in Desma Werke #3

The energy consumed is shown in

Fig. 6, presented in two formats: as energy consumed per second and as the cumulative value of these amounts. As anticipated, the energy curve for every second displays a corresponding pattern to the power graph, with the latter showing an upward trend. A comprehensive analysis of injecting a product enables an assessment of energy consumption. In this context,

Fig. 7 has provided valuable insights. Consider the four injections that were carried out. The energy required for each injection was approximately 174.2, 164.7, 140.3 and 161.1 Wh. The corresponding average was 160.1 Wh. For each product, the energy consumptions corresponding to the abrupt power increases due to the injection represented 62.3, 76.0, 64.4 and 71.6 Wh. In terms of percentage, each product required injection of between 36% and 46% of the energy, with an average of 43%.

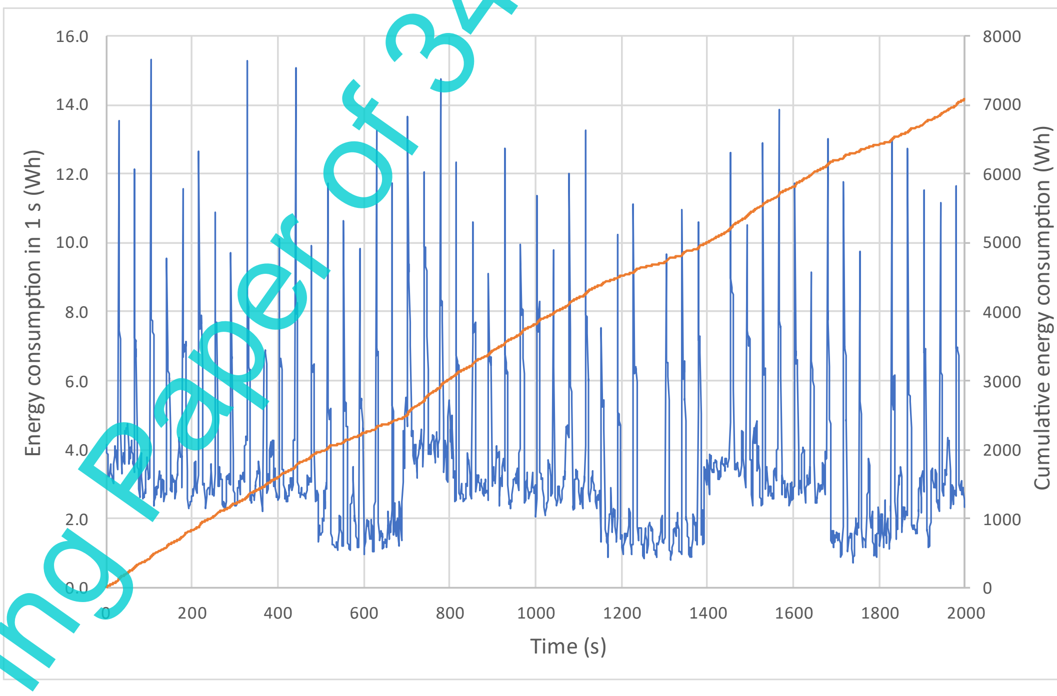

Fig. 6. Energy consumption in Desma Werke #3.

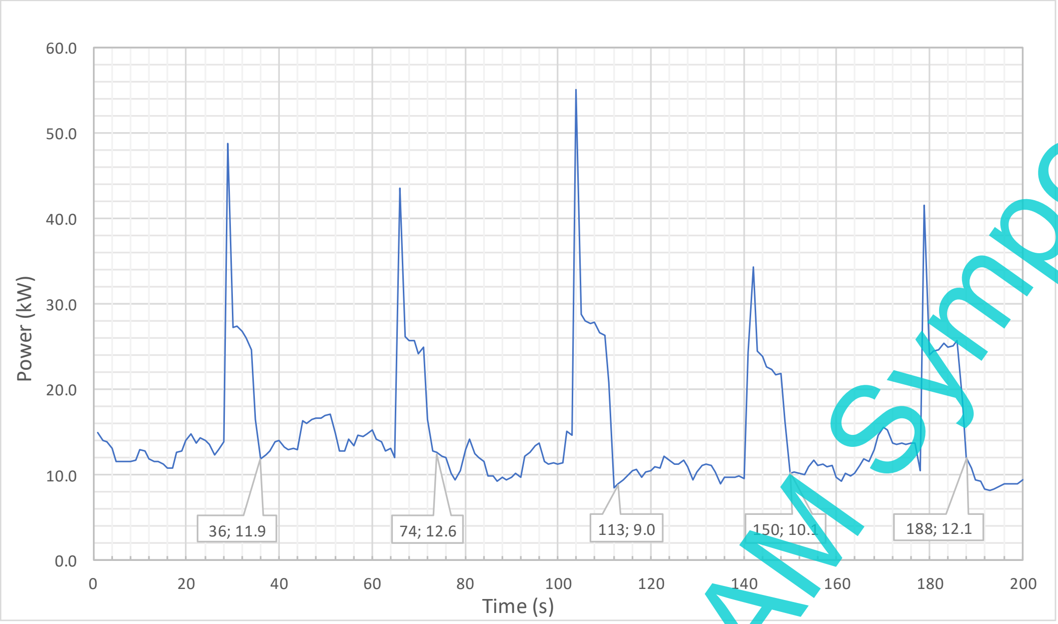

Fig. 7. Detail of the power profile in 5 injections in Desma Werke #3. For each ordered pair, time and power are indicated.

3.2. Phase 2: Power Consumption and Production

The power profile for phase two is displayed in
Fig. 8, revealing six peaks that correspond to six injections. Only the required sole sizes are injected according to production plans, although the rotary table, which can hold ten moulds, must complete its rotation, resulting in higher energy consumption. This information highlights the necessity of considering the work method when examining energy consumption.

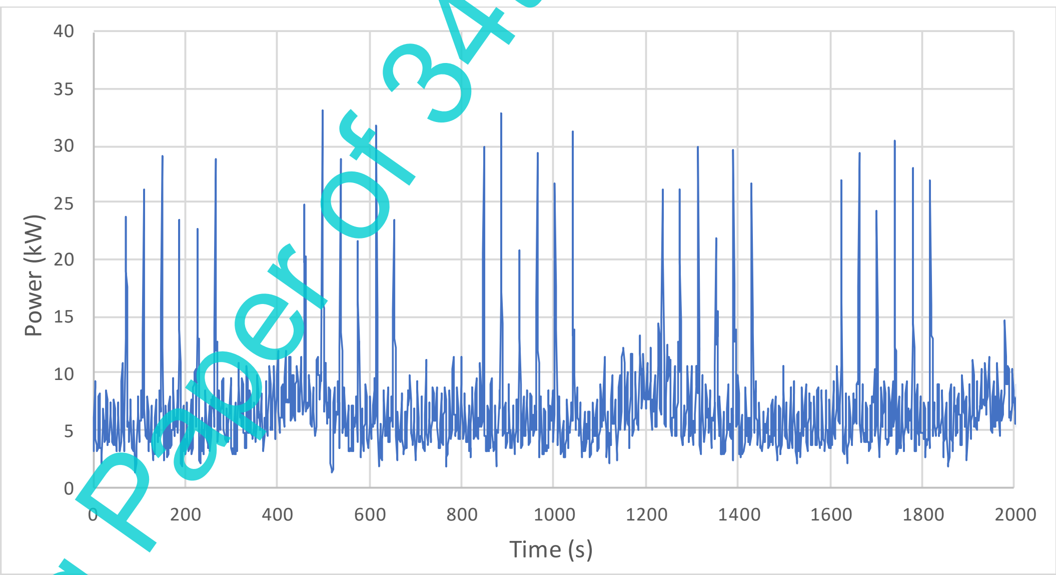

Fig. 8. Active power profile in Desma Werke #1.

Take into consideration a set of six injections, which require approximately 69, 69, 70, 74, 73, and 88 Wh of energy respectively, with an average overall of 73.83 Wh. The abrupt power increase from each injection consumed between 16 and 33 Wh of energy. Each material injection required between 23.1% and 37.5% of the total energy consumption for injection, with an overall average of 34.35%. As mentioned before, in addition to energy monitoring, it is necessary to identify whether the energy is productive or not. In this respect, the observed cycles behave as shown in
Fig. 9, only four of the injections are generating product. In each cycle, two injections are made to discard material.

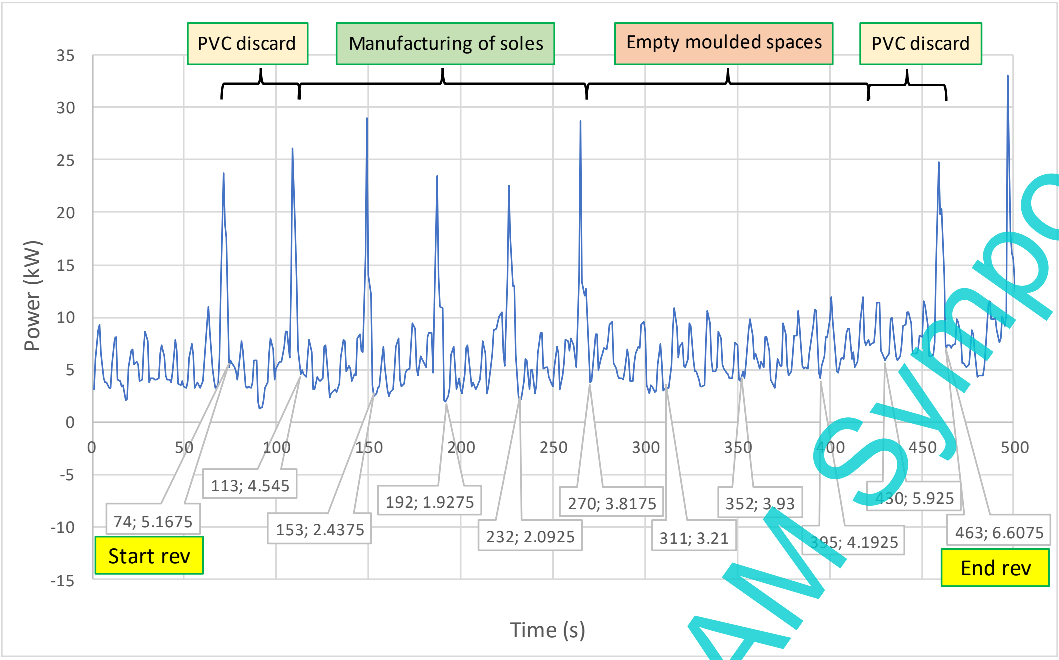

Fig. 9. Detail of the power profile in one revolution in Desma Werke #1. For each ordered pair, time and power are indicated.

The diagram in
Fig. 9, is one of a series of 15 cycles that were observed (with number 16 excluded due to incompleteness). Most cycles follow a similar sequence as shown in
Fig. 10, albeit with some deviations such as in the initial phase. Therefore, this underscores the importance of recording the working method and product generation during energy consumption measurements. For this case study, based on the previous idea, approximately 40% of the energy can be deemed productive.

The above aligns with the suggestions outlined in [9], and identifies scheduling production as another issue to consider in scenarios with low volume. Furthermore, it is recommended to consider scheduling production in low-volume scenarios to reduce energy and resource losses and optimize resource allocation. A careful analysis of challenges and opportunities associated with order scheduling is necessary for this purpose. Additionally, efficient planning can minimize downtime, thus enhancing energy efficiency and profitability of production.

Revolution	space moulds										Pattern
	1	2	3	4	5	6	7	8	9	10	
1	a	a	b	b	c	c	c	c	a	a	Regular
2	a	a	b	b	c	c	c	c	a	a	
3	a	a	b	b	c	c	c	c	a	a	
4	a	a	b	b	c	c	c	c	a	a	
5	a	a	b	b	c	c	c	c	a	a	
6	a	a	b	b	c	c	c	c	a	a	
7	a	a	b	b	c	c	c	c	a	a	
8	a	a	b	b	c	c	c	c	a	a	
9	a	a	b	b	c	c	c	c	a	a	
10	a	a	b	b	c	c	c	c	a	a	
11	a	a	b	b	c	c	c	c	a	a	
12	a	a	b	b	c	c	c	b	a	a	Irregular
13	a	a	b	b	c	c	b	b	a	a	
14	a	a	b	b	c	c	a	b	a	a	
15	a	a	c	c	c	b	c	b	c	a	
16	b	c	a	X							

Color description	
b	PVC discard
c	Manufacturing of soles
a	Empty moulded spaces
X	End of production
	Sample

Fig. 10. Working method in Desma Werke #1 for the period measured.

4. Conclusions

This study presents the analysis on an industrial case to produce shoe soles from an energy perspective. The daily injection process was monitored with one power quality analyser and the process was observed at the industrial site. Power data were examined in contrast with the PVC products generated by the rotary table injection machine. The analysis of the experimental results leads to the following conclusions:

1. When assessing energy efficiency, it is crucial to consider not only energy consumption but also the production process method. This involves calculating the ratio between the total energy used and the energy utilised to manufacture goods.
2. In this case study the net energy consumption was between 74 and 160 Wh, depending on the product. These values should be interpreted within the context of the entire production cycle since the working method may result in doubling the energy per product.
3. The production method used was a key factor affecting energy consumption, resulting in a non-productive energy as high as 60%.

In addition, this analysis has provided the company with a first approximation of the amount of non-productive energy in a production cycle. However, further studies should look more closely at the impact of specific equipment on consumption, the differences that occur between different products, the frequency with which non-energy-efficient working methods occur and their causes, among other things.

5. Acknowledgments

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