Quantifying the Benefits and Costs of Energy Audits Based on Measurements with an Energy Monitoring System of the Relevant Electricity Consumers of Industrial Sites Compared to Classical Audits

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Abstract. We have developed a methodology that utilizes electricity metering during energy audits. Our approach keeps costs low by lending metering devices to companies, utilizing wireless technology, and automating data collection and report generation. The generated report supports energy consultants in their analyses. In the 17 audits where we applied this methodology, we discovered that most energy efficiency measures were related to process installations. The savings potential achieved through metering increased the saved energy by nearly 70% for the total sample. For individual sites, the impact of monitoring varied significantly, ranging from 5% to 100% of the total savings. The additional costs associated with metering were recouped in less than one year for 14 of the sites. Our field study demonstrates that integrating metering into energy audits not only increases the number of energy-saving measures found but also enhances the precision of estimated energy gains while being profitable in most cases. Furthermore, measuring electrical drives provides valuable insights into sizing quality and future optimization opportunities.
Keywords: Energy Efficiency, Energy Audit, Digitalization.

1 Introduction

Improving energy efficiency is crucial for achieving a sustainable future and combating global warming. Energy audits aim to identify energy efficiency measures, assess their costs and benefits, and calculate the financial outcomes to determine their return on investment. In Switzerland, energy efficiency is one of the pillars of its "Energy Strategy 2050". To support the implementation of the Swiss energy policy, the following frameworks, subsidies and programs have been developed. EnergieSchweiz [1] is a program of the Swiss Federal Office of Energy (SFOE) designed to facilitate the implementation of the Swiss energy policy through the promotion of voluntary measures. In this framework specific programs with subsidies and knowledge transfer targeting specific sectors were developed such as INCITE [2] and TOPMOTORS, which target electrical drives. The PROKILOWATT [3] program subsides investment for non-cost-effective electricity saving actions. The PROANALYSYS framework (detailed analysis of electric drives) and PINCH ANALYSIS programs subsidise the analysis and measurements.

In Switzerland, the EED Directive (EU) 2023/1791 and the EA/EMS obligation of Art. 11 [4] does not apply. Nevertheless, in most Swiss cantons, sites with high energy consumption (typically with an electrical consumption exceeding 0.5 GWh/y or thermal consumption exceeding 1.5 GWh/a) are obliged to undergo an energy audit. The target agreement is a frequently utilized framework for the fulfilment of this policy. Two agencies, EnAW and ACT, are tasked with providing support to companies in the creation and subsequent annual review of these agreements. In a target agreement, a company's sites engage an agreement with the Confederation and the Canton with the objective of achieving a specified target for energy efficiency and CO_2 reduction over a period of ten years. The target is defined by the cost-effective energy actions that are planned or collected during an initial energy audit, which is performed by an energy consultant from one of the two agencies. Furthermore, the framework permits the reimbursement of CO_2 tax. In Switzerland, over 4,000 large energy-consuming companies have already conducted an energy audit for their target agreements [5]. A significant proportion of these target agreements are due for renewal in the next three years. Consequently, there is a need to identify additional unidentified energy efficiency measures that were not discovered during the initial audits and to reduce the cost of energy audits. Furthermore, smaller energy consumers are now being encouraged or required to perform energy audits [6, 7].

A typical approach to conducting an energy audit is to base the audit on a site's monthly energy consumption data. For the different energy consumers, the nominal power and, in most cases, estimated operating hours are employed. Given the limited data available, it is challenging to determine the energy distribution among the largest energy consumers and to evaluate estimated energy savings with precision. At present, an increasing number of companies are utilizing stationary metering systems to obtain more precise energy consumption data, for example, 15-minute energy consumption of various users or processes. Such data is also employed during an energy audit. Nevertheless, most companies have not yet implemented such a system.

The rapidly developing sensor and Internet of Things fields has led to a reduction in the costs of energy metering systems. Planair, an energy consulting company, has developed a methodology that uses energy metering devices and data analysis to improve the results of energy audits.

This paper describes the results of 17 audits performed in Switzerland, focusing solely on electrical energy. Furthermore, this text presents an estimation of the additional savings potential when using metering in comparison to a classical audit. It also includes a cost assessment. Finally, it demonstrates how the results related to electrical drives can aid in the selection of installations for more detailed analysis.

2 Description of the Audit Methodology

Energy Audits Type. The energy audits discussed in this report were conducted in Switzerland by various energy consultants using the following different frameworks. Each audit comprised one or more on-site visits by the consultant:

New Target Agreement (NTA) energy audit to conclude a new target agreement mostly for companies with an electricity consumption higher than 500 MWh.
Energy Contingency (EC). In response to the potential risks associated with energy shortages in 2022/2023, the Swiss government has called upon companies to develop contingency plans aimed at significantly reducing their electricity consumption in the event of a shortage. This directive and the prevailing high energy prices, led to several energy audits with the objective of providing companies with a plan for optimizing their energy consumption.
Medium Consumer Audits (MCA) prompted by new policies in specific regions, high electricity prices, or financial incentives for sites with electricity consumption between 200-500 MWh/a.

Methodology As is typical in classical audits, an initial meeting and site visit is arranged with the site's energy manager. The identification of the relevant energy consumer will enable the determination of which appliances will be measured in the next stage. Energy metering devices are lent to the company for a period of 2-3 months. Most of the time each installation is measured for one week to analyze consumption during production, night, and weekends. If the consumption is not recurring on a weekly basis, the measurement length must be adjusted, or the consumption should be interpolated. The handling process for metering is simplified, and costs are reduced by implementing the following setup: - The communication between the meter and a gateway is made through utilization of the wireless LoRa (Long Range Wide Area Network)[8] protocol, allowing the meters to be easily relocated to other installations without the need for complex wiring. - Current clamps of 100 A to 600 A (amperemeter) without a voltage probe are used as meter. Therefore, the true power is only estimated using an estimation of voltage and cos Φ. The LoRa gateway, which is responsible for the collection of data from the meters, is connected to a modem, which transmits the data directly to the cloud via the cellular network (LTE/4G). The data is then available to the energy auditor in real-time. **Fig. 1** illustrates the setup. Python scripts [9] and a time-series database are used to automate several steps. The measured data is collected automatically from the cloud via API[1], while other data sources are entered manually. The collected data is stored in the database, and an interactive report in HTML format is generated. The consumption data is interpolated to estimate yearly consumption, and a Sankey diagram is created.

Finally, the report is discussed with the client to identify any irregularities and unnecessary consumption. Measures are then proposed, and their effects estimated. In some cases, further analysis of specific systems may be necessary.

[1] Application programming interface

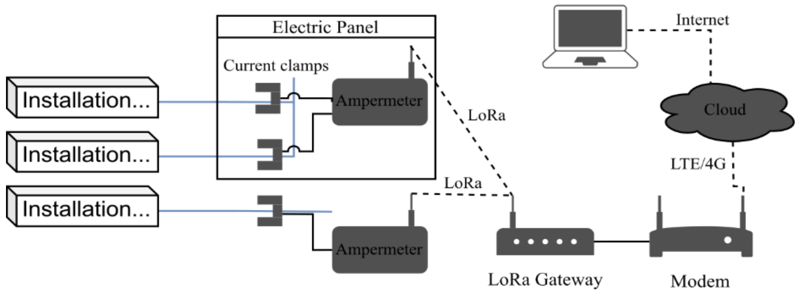

Fig. 1. Sketch of the metering setup

3 Results

3.1 Methodology of the analysis

Audits. The audits are categorized in: - Type of audit (see section 2), - If it was the first energy audit or not (“First audit”, “Not first audit”), - Total electricity consumption of the sites in three categories.

Energy efficiency measures. This analysis only considers electricity consumption and savings. The addition of renewables, such as photovoltaics, was not considered. Each audit corresponds to a specific site.

The term “savings” always refers to energy efficiency measures (EEM) determined during the audit with metering. Savings from past audits (for “not first audit” sites[2]) are labelled as “Previous Savings”. All EEMs represent potentials and are not necessarily implemented neither measured. However, we evaluate only those EEMs that are both economically viable and technically feasible. Each EEM is categorized into specific “groups” (i.e. cooling, compressed air, ventilation and other) and is further classified based on its origin:

- “Metering”: EEMs that can almost exclusively be discovered through metering. This category often includes EEMs related to standby reduction in process installations.
- “Metering helped”: EEMs that could have been identified with a classical audit but were facilitated by metering data. It is almost not feasible for an energy consultant to identify all potential EEMs. The use of metering data facilitates a more systematic approach to identifying EEMs.
- “Classical audit”: EEMs that would likely be found even without measurements.

The categorization process is not straightforward and relies on the experience of the authors. There may be some arbitrary components involved.

To evaluate the cost-effectiveness of this methodology, we propose the model outlined in **Table 1**. The price of electricity is set at 18 €/kWh.

2 For those sites, the first audits were always performed without metering.

Table 1. Additional cost model

Description	Cost [€]
Metering Devices: The cost of the modem (4G/LTE), a gateway, and two ammeters with 12 clamps (4 3-phase outputs) are considered and an amortization over 4 audits. The cost may vary depending on the metering material.	1125.-/site
Meter Moving: Each week, the clamps must be moved to a different installation. The company can do this themselves or hire an external electrician, which is more expensive. We take an average use of 15 clamps (5 installations) per weeks and 2 hours at a time rate of 120.- €	$\frac{\#\, measurements}{5} \cdot 120. - \cdot 2h$
Consulting hours: Only the additional costs to classical audits are considered (configuring the material, metering follow-up, and data analysis). These costs depend on the site's complexity and the client's autonomy.	1500.-/site

3.2 Results

The 17 audits that included metering were conducted between 2022 and 2023. The sample was selected based on the companies that had requested the audit and thus could not be chosen. For each site 12 to 60 installations were measured. The activity sectors (NOGA [10]) of the sites are the following: 265 (Manufacture of instruments and appliances for measuring, testing and navigation, watches and clocks), 256 (Metals; machining), 651 (3 sites, only offices) followed by other manufacturing activities 231, 242, 284.

Measures. A total of 175 EEMS were found, representing a potential of 3,800 MWh of electricity savings per year. **Table 2** describes the different group of measures.

Table 2. Description of the EEM types.

Measure group	Examples
Process	Reduce standby mode or pre-heating time, switch off when not used.
Ventilation	Reducing air flows and/or running hours.
Cooling	Changing temperature settings and/or free-cooling setpoints.
Compressed air	Reducing pressure, reduce working hours, leak detection, replacing.
Other optimization	LED refit, reduce working time, switch off completely devices, …

Fig. 2 illustrates the total energy savings for each site as a ratio of the total electricity consumption of the audits supported by metering, differentiated by audit type. The figure also differentiates between audits that were the first of their kind and those that were not. On the right the same savings but with the latter parameter on the x-axis.

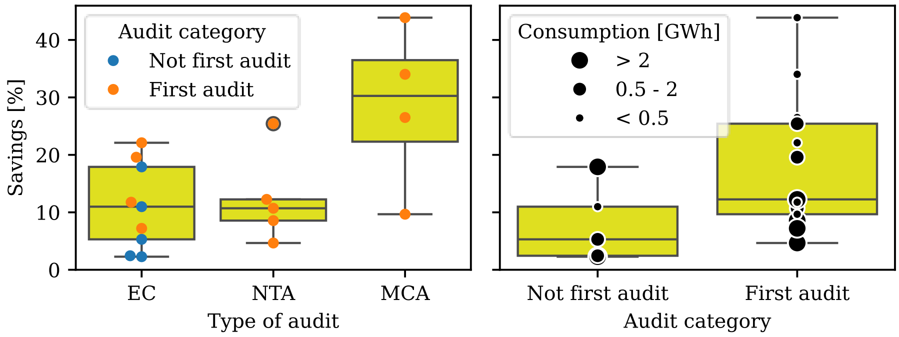

Fig. 2. Left: Total potential energy savings as a function of audit type and audit category. Right: Total potential energy savings for site with first audit or not category.

The total potential savings per site, expressed as a ratio to the total site consumption, vary from 2% to 43%. For sites that underwent their first audit, the median savings amount to 12%, while for sites with a previous audit, the median is 6%. For sites that were audited previously, the additional saving potentials with metering are slightly lower than for the first audit without metering. However, the potential still ranges from 2% to 18% (relative to the total consumption) for the additional electricity savings.

Fig. 3 illustrates the distribution of energy efficiency measures (EEMs) across various groups and types, aggregated across all audits. Metering (including those helped by metering) significantly augmented the discovered energy savings potential by approximately 70% (passing from 2’263 MWh to 3’813 MWh), compared to classical audits. Most of the energy-efficient measures identified through metering were directly related to processes (i.e production machine).

For the EEMs identified through metering, apart of a few related to industrial ovens, the majority of the remaining EEMs were linked to electrical drives, including oil circulating pumps for manufacturing machines, compressors for compressed air, air fans, hydraulic pumps, and motors driving tools.

In **Fig. 4** (right), the proportion of EEMs discovered thanks to metering relative to the total savings are plotted. The percentages exhibit a wide range, spanning from 5% to 100%. This variability likely stems from differences in audit types, auditor expertise, and client expectations. For instance, some clients prioritize process-related improvements, leading to a focused application of metering.

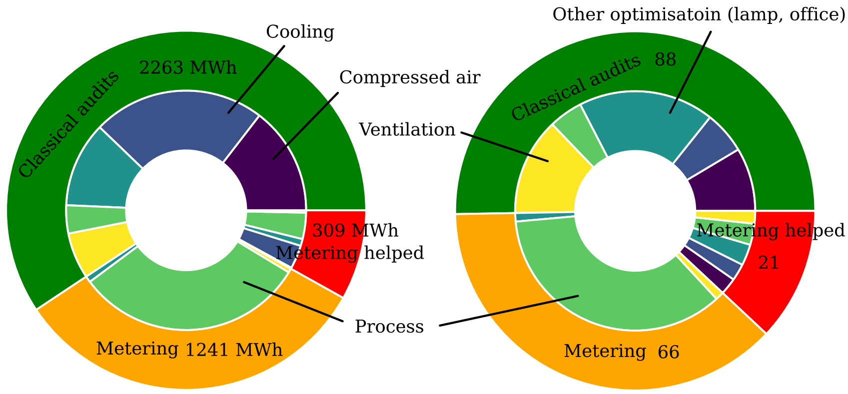

Fig. 3. EEM distribution in energy (left) and in number (right) for the audit with metering. Outer ring classify the EEMs: that can be found with a classical audit (green), were found thank metering (orange), where metering helped to found them (red). The inner ring shows the ratio in EEMs group.

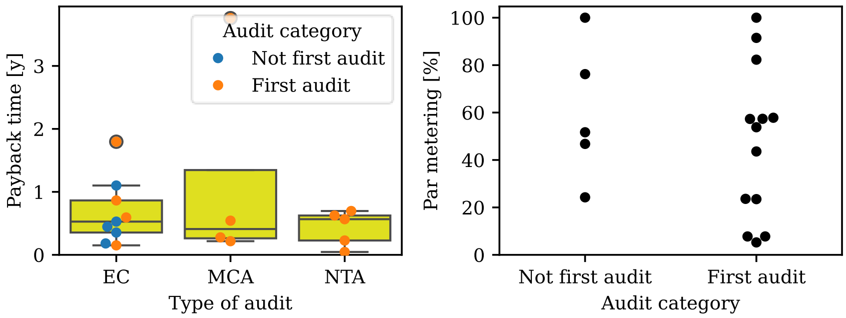

Fig. 4. Left: Payback time of metering by considering the additional investment and savings discovered. Right: The savings from EEM that were likely found as a result of metering (categorised as “Metering” and “metering helped”) regarding the total savings.

The payback period is calculated by dividing the additional costs for metering (section 3.1) by the energy savings found for EEMs in the category “Metering” and “Metering helped” multiplied by the electricity price. Given that 96% of the energy savings in this category are related to optimization (i.e. operational EEMs without significant investment), the payback of the measure itself has been neglected. The 52 EEMs with investment, such as replacement with advanced equipment were predominantly classified in the “Classical audit” category. We conclude that metering enables the collection of primarily low-hanging fruits, and that measures with an investment component can generally be identified through classical audits. This is because those EEMs depend more on the characteristics of the equipment (which is collected manually) and not on the operation (where monitoring is crucial).
Fig. 4 (left) shows the payback time as a function of audit type, category and site consumption size. Except for three sites, all payback time values are less than one year.

Therefore, even if only half of the measures are implemented, adding metering is financially beneficial.

The generated Sankey diagram indicates which consumer or consumer categories should be prioritized for initial targeting. The portion of energy consumption dedicated to utilities is frequently compared to the portion utilized for processes in order to benchmark sites.

Electrical drive optimization. Metering results are primarily used to identify unnecessary consumption. However, they can also reveal inefficiencies in operating equipment leading to replacement. For instance, the measured consumption of electrical drives, such as those related to pumps or ventilators, can be compared with the design values (motor nameplates, e.g. nominal power) to provide valuable information about the equipment that requires further analysis. For instance, during the audit of a particular site, the electrical power of a circulation pump with a nominal power of 25 kW was analyzed. The measured values were relatively low, ranging from 8-10 kW, which suggests a possible oversizing issue. The measurement of flow with an ultrasonic flowmeter during a detailed analysis showed that the pump is oversized. Using a smaller pump during low demand could result in potential electricity savings of more than 35,000 kWh per year.

Further studies of similar cases are required to facilitate the drawing of clearer conclusions. Additionally, for this type of analysis, it may be necessary to utilize real power rather than apparent power to gain a comprehensive understanding of the situation. A cost-benefit analysis based on more extensive monitoring data with cos Φ is necessary to clarify.

4 Conclusion

The results of the use case analysis underscore the financial benefits of using metering devices during energy audits. Metering significantly enhances the discovery of energy savings, yielding approximately 70% more identified savings compared to classical audits. Even for sites that have previously undergone an audit, conducting a second audit remains valuable. Additional savings potential exists, as several percentage points of the total energy consumption can be saved. Most EEMs found thanks to metering are related to process (manufacturing). Although the sample size is statistically limited, the results demonstrate a clear trend, which is consistent with previous use cases.

Those EEMs requires low investment in general. It is possible to detect measures such as optimizing ventilation parameters without the use of metering; however, metering facilitates the calculation of savings. For instance, it is challenging to determine the consumption of cooling devices without measurement. EEMs such as replacing the installation, implementing a factory control system, and adding variable speed drives (VSDs) may either be identified through classical audits or were not investigated further by the consultant as the “low hanging fruits” savings were already high.

Further research is needed to determine the role of metering in identifying such measures.

Additionally, a measuring campaign can increase client motivation to implement the proposed measures. The campaign can also provide valuable insights into electricity consumption using a Sankey plot, which can help identify major consumers for further investigation.

These measurements also assist in identifying motor-driven systems where a more comprehensive analysis is necessary in a subsequent step to determine and calculate the EEM (e.g. to ensure accurate equipment sizing). This more in-depth analysis entails measuring the mechanical output as well.

Measuring other energy flows such as compressed air, heat and temperature would be useful for finding more savings. However, implementing these measures can be expensive. Particularly, heat recovery systems require precise monitoring through metering, as they often exhibit operational issues. Furthermore, this study could be extended to other activity sectors. Additionally, it would be interesting to verify the effective implementation of these measures.

In terms of the advantages of the metering approach, we would recommend the following: - Notifying the energy consultant and relevant agencies of the outcomes, - Organizing a training program on this subject, - Including the metering option when offering energy audits.

5 Acknowledgements

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