Swiss motor efficiency program EASY: results 2010 - 2014

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ABSTRACT

Investments for systematic retrofits of industrial machines are hampered leading to a low level of efficiency in industrial production systems. Despite minimum energy performance standards for new electric equipment, reinvestments are generally neglected. Financial incentives can help to overcome barriers.

The audit and financial incentive program EASY Efficiency for motor systems (www.topmotors.ch/easy) run in Switzerland from 2010 until 2014. The program used a systematic four-step audit method called Motor-Systems-Check to assess and replace existing motor systems in industrial facilities, infrastructure plants and large buildings. The main barrier to overcome is identifying the most cost-effective energy efficiency measures, bringing the highest savings.

The results of the program:

- More than half of the assessed 4 142 motors and their systems are older than their expected lifetime, on average two times older.
- Only 19.8% of motors are equipped with a variable frequency drive.
- About two thirds of 104 motors measured have an average load factor below 60%.
- In total 2.3 million USD were invested by participating firms, saving 73.7 GWh of electricity calculated over the life time of the newly installed equipment, or 3.9 GWh/a.
- Implemented measures delivered average savings between 20 - 30%.
- The highest share of savings was thanks to efficiency measures improving air compressors systems (60%), followed by fans (23%) and pumps (11%).

The program budget was 1 million USD, financed through public funds (from a grid charge). The cost-effectiveness of the program was 0.014 USD incentive paid per kWh saved during the lifetime of the newly installed equipment.

The lessons learned include that energy efficiency improvements take considerably longer than anticipated, in part due to internal decision making procedures and budget cycles. They have also shed light on a lack of capacities in terms of know-how, financial resources and responsibilities in terms of managing electric energy in Swiss industry. Because of this much more external support was needed by qualified engineers than previously expected, causing significantly higher program management costs.

The lessons learned from EASY led to the build-up of a training program for energy technology and -management in industry, aimed at building capacities of factory operators.

Policy instrument for open tendering

In 2010, the Swiss Federal Office of Energy (the equivalent of the U.S. Department of Energy in Switzerland) introduced a new policy instrument for stimulating electricity savings: open tendering of projects and programs. The open tenders are held annually, inviting market players to submit proposals aimed at reducing the electricity consumption of end-users in households, the services and industrial sectors. From the proposals the most cost-effective are chosen to be financed (within the constraints of the total available budget), thus those delivering the most electricity (kWh) saved at least cost. Further criteria for assessing proposals are the potential for innovation, demonstration effects as a good example for other projects and the risks associated with the implementation of the proposal. The goal of this policy instrument is to let the market compete for savings at the lowest cost. The funds are secured through a grid surcharge on the electricity tariff. The available budget has increased from 9 million USD in 2010 to 42 million USD in 2015, reaching 50 million USD per year by 2020.

Program overview

EASY ("Effizienz für Antriebssysteme": efficiency for motor systems - www.topmotors.ch/easy) is a motor systems audit pilot program of the Swiss Agency for Efficient Energy Use (S.A.F.E.) that ran in Switzerland between 2010 and 2014. The goal of the program was to introduce a method for retrofitting existing motor systems in industrial and infrastructure plants and large buildings. EASY was chosen to be financed through the first round of the open tendering, with a total budget of 1 million USD.

The program followed the Motor-Systems-Check methodology which was developed by S.A.F.E. in the framework of the Topmotors program (www.topmotors.ch) in 2010. The Motor-Systems-Check is a four-step audit process (see Figure 1), comprising the following steps:

- Step 1: assessing the overall efficiency potential of a factory
- Step 2: compiling a motor list
- Step 3: measurements of relevant motors chosen from the motor list on site
- Step 4: implementation of identified and most cost-effective measures.

The first three steps are preliminary analyses, necessary to identify the motor systems that will be retrofitted in the last step (implementation).

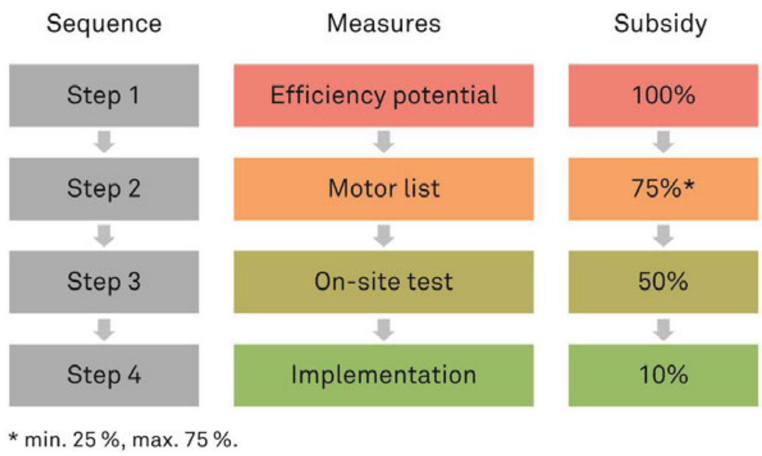

Figure 1. Four-step Motor-Systems-Check methodology and subsidy scheme. Source: S.A.F.E. 2011.

The Motor-Systems-Check is applied to firstly identifying factories with high energy efficiency potential and secondly finding the motor systems with the highest energy savings potential within the factory in a systematic manner. With the Motor-Systems-Check, the most cost-effective improvements in rolling stock can be identified. Based on this, a systematic annual retrofit program can be designed.

The preliminary analyses and the implementation of efficiency measures were supported by qualified energy efficiency engineers. EASY also aimed at training internal factory technical staff to continue implementing systematic improvements of motor systems with the help of the Motor-Systems-Check after the end of the financial incentive program period.

EASY gave financial incentives to participating firms (including consultants performing the audits) at each step (see Figure 1). To help companies overcome the barrier of the preliminary analyses in the first three steps - which manifested itself in lack of time, financial resources and technical expertise at the factories - financial incentives were high for preparatory engineering analysis and on site measurements. For the implementation of improvement measures financial incentives were low, as payback times below three years could usually be achieved.

Program focus

In the last two decades, Swiss industry efficiency programs have successfully focused on fossil energy efficiency. The CO_2 emissions were reduced by concentrating on industrial boilers, steam production and heating facilities operated mainly by natural gas and heating oil. A systematic thermal analysis (Pinch analysis: http://pinch-analyse.ch/index.php/en/) for heat recovery in industrial processes was developed and introduced by EnAW (Energie-Agentur der Wirtschaft: www.enaw.ch) a decade ago. These activities were supported by a national CO_2 tax on heating oil and gas as well as by several subsidy programs for buildings.

Energy efficiency in electricity use in industry has been widely neglected in the last decade in Europe and Switzerland. Between 2007 and 2010, S.A.F.E. analyzed the electricity consumption of 25 Swiss factories and found that motor systems had an 87.8% share within the factories' total electricity consumption (see Figure 2). This has defined the focus of EASY on pumps, fans, compressors and industrial transport and process systems.

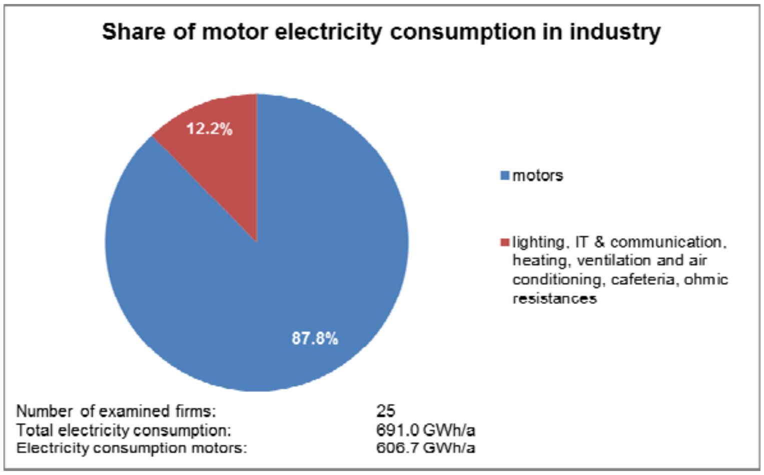

Figure 2. Share of motor systems electricity consumption within 25 Swiss factories.
Source: S.A.F.E., 2013.

The EASY program focused on mid- and large-size factories with an electricity consumption starting at 10 GWh per year, equivalent to 1.2 million USD electricity cost per year (at 0.12 USD/kWh). These mid- and large-size factories were chosen as having the best cost-benefit ratio for on-site engineering audits. The engineering cost for improving the efficiency in smaller factories would not have been easily paid off by possible savings. For smaller factories a short walk through audit and check lists with standard improvement measures are a more cost-effective choice.

Analysis

S.A.F.E. assessed 4 124 separate motor systems in 18 factories during step 2 (compiling a motor list) of the Motor-Systems-Check. This first analysis looked at the motor system's application, age, annual operating time, and use of VFD.

The analysis has shown that the highest share of energy consumption can be attributed to fans and pumps respectively, followed by different kinds of rotating machines and compressors for air and cold (see Figure 4).

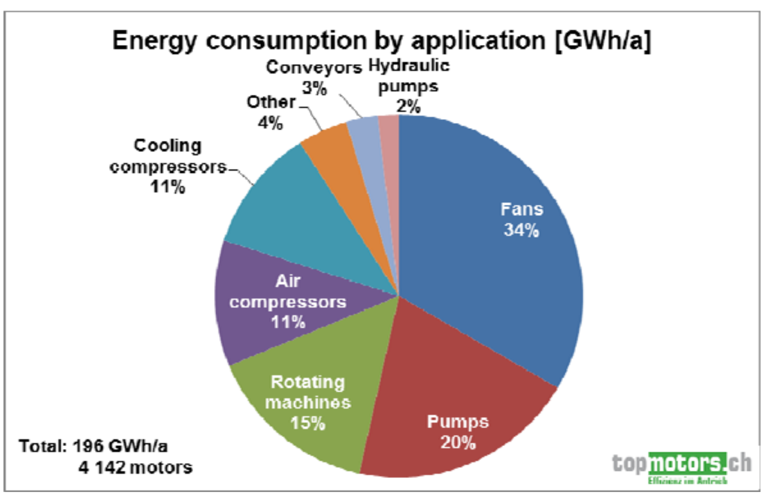

Figure 3. Share of electricity consumption according to application. Source: S.A.F.E. 2015.

Furthermore, the analysis has shown an age problem: 56% of all motors and their respective systems were older than their expected operating life time of 10 to 20 years (depending on output size - see Figure 4). This shows that there was no systematic improvement of motor systems or a continuous renewal program in place. Older motor technologies are still in use, lower efficiency machines are still in operation and the evidence shows that the systems were not regularly checked and adapted during these years for the actual required operation and load.

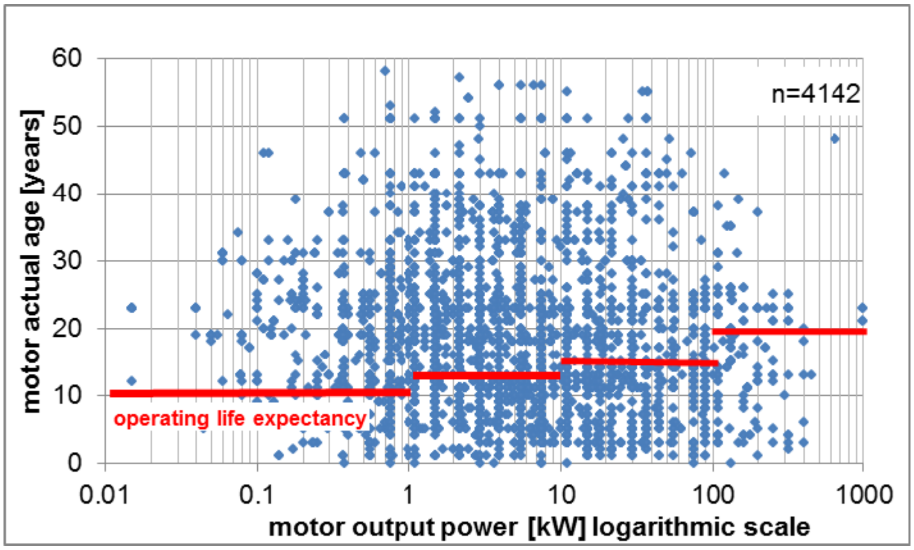

Figure 4. Motor systems by output power and age: Motors are too old. Source: S.A.F.E. 2013.

S.A.F.E.'s analysis of 104 motor systems measured on site (see Figure 5) during step 3 (measurements of relevant motors chosen from the motor list on site) shows that oversizing is still a common problem in industry today. Machines with an average annual load factor below 60% are considered oversized. Machines operated at partial load below 50% work with considerably lower efficiency. When determining the adequate motor size for the required load, special attention has to be given to the starting conditions which can be handled well without oversizing the motors. Here, short term load measurements had to be complemented by analyzing whether the system had also special starting and load conditions that needed to be taken into account for proper sizing.

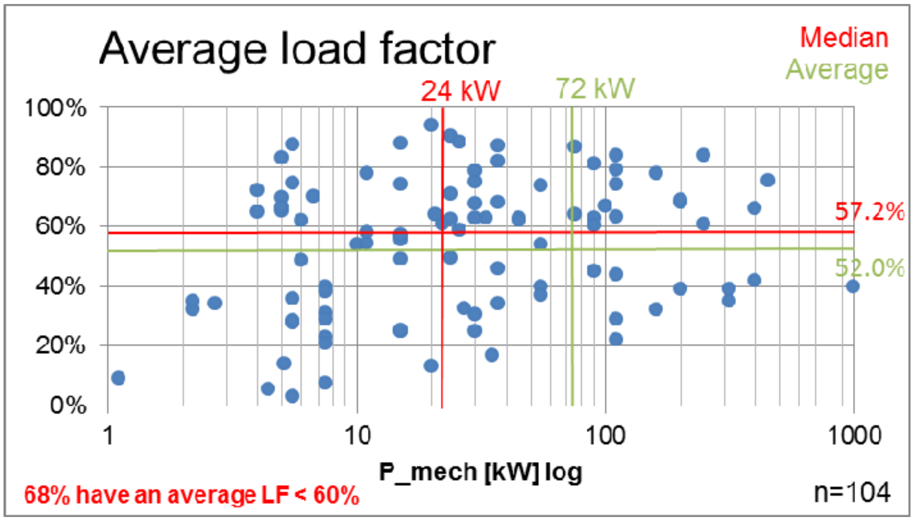

Figure 5. Motors are oversized. Load measurement results of 104 motor systems. Source: S.A.F.E. 2013.

Based on the experience of the EASY program, energy efficiency measures for motor systems are most cost-effective for:

- Machines older than 20 years of age (see Figure 4: age of motor systems)
- More than 4 000 hours of annual operation time
- Systems without variable frequency drives (see Figure 6)
- Motors with output power of 10 kW and larger, also series of same size and type of smaller machines.

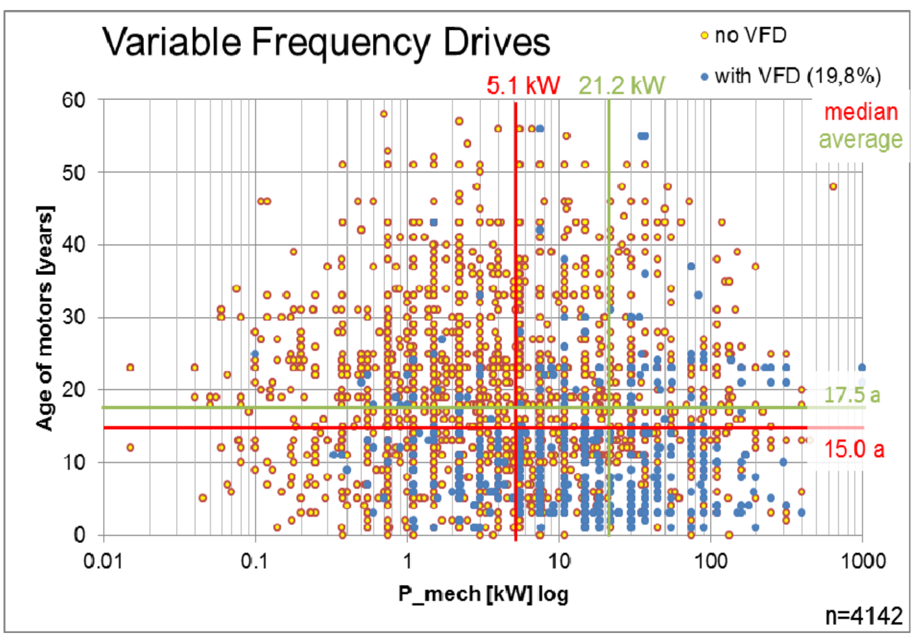

Figure 6. 19.8% of the listed 4 142 motor systems are equipped with a variable frequency drive. Source: S.A.F.E. 2013.

Large savings in the system

Simple motor exchanges 1:1 (an old inefficient motor is replaced by a new premium efficiency motor of the same size, type and speed) tend to have low energy savings only. In small power ranges (below 10 kW) the savings can be 3% to 10%; in larger power ranges (above 100 kW) it will only be 2% to 5%. Attention has to be given to using higher efficient motors that typically have lower slip and thus slightly higher rotating speed. This can cause adverse effects on energy savings when higher volumes of water and air are transported unnecessarily.

Large electricity savings always are achieved by addressing and improving the entire motor system (see Figure 7) starting from the power input from the grid to the power output into the process and the handling of the process itself. With optimal configurations of all the components of the system and adaptation to the necessary load and use time electricity and energy cost savings around 30% are typical, 50% to 80% are frequently achieved.

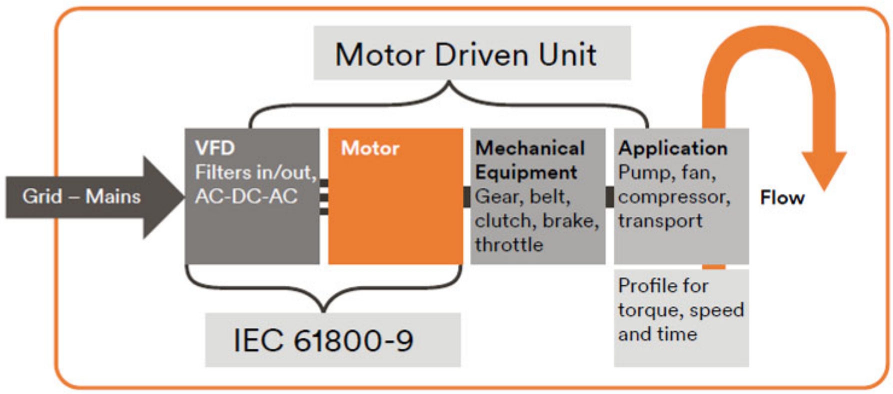

Figure 7. The components of a motor system. Source: EMSA, 2014.

Implemented measures and savings

During the limited project period efficiency measures were implemented and completed by 8 participating firms, saving in total 3.9 GWh/a (see Figure 8). This corresponds to total savings of 73.7 GWh during the expected life time of the newly installed equipment (see Table 1).

All participating firms invested in total USD 2.3 million, 21% of this amount into analyses (steps 1 - 3) and the remaining 79% into investments for efficiency improvements of the motor systems (step 4).

The total financial incentive paid to the firms amounts to 418 k USD from which 60% was given for engineering analyses (steps 1 - 3) and 40% for the investments in new machinery itself (step 4).

The total cost-effectiveness of the program is based on the total life time of the implemented improvement measures. It was calculated by the financial incentive given per kWh electricity saved over the expected life time of the measures. In EASY it resulted in a very favorable value of 0.0136 USD.

Table 1. Cost, incentive, savings and cost-effectiveness of implemented measures. Source: S.A.F.E. 2015.

EASY RESULTS 31.12.2014	Cost Steps 1-3 [k USD]	Cost Step 4 [k USD]	Cost Total [k USD]	Incentive Steps 1-3 [k USD]	Incentive Step 4 [k USD]	Incentive Total [k USD]	Savings [MWh/a]	Savings [GWh/ life	Cost -effectiveness [ct./kWh]
Factory A	34	66	100	21	7	28	150	2.1	1.30
Factory B	59	382	441	37	38	75	511	8.8	0.85
Factory C	62	68	130	13	-	13	-	-	-
Factory D	52	291	343	34	29	63	400	7.5	0.84
Factory E	87	180	267	53	12	65	172	2.4	2.68
Factory F	48	11	59	11	-	11	5	0.1	16.71
Factory G	21	-	21	9	-	9	-	-	-
Factory H	42	621	663	28	62	90	2'050	41.0	0.22
Factory I	30	180	210	22	18	40	656	11.8	0.34
Remaining fact.	39	-	39	26	0	26			-
Total	**474**	**1'798**	**2'273**	**252**	**166**	**418**	**3'944**	**73.7**	**1.36**

Not all participating firms went through all the four steps of the program. Those who stopped prematurely did so mostly after step 1 due to a number of reasons: they were not ready to start further analyses, they were not convinced by the eventual outcome of the program or they did not have the necessary capacity available to go through the in-depth analysis of steps 2 and 3.

The highest share of savings was thanks to efficiency measures improving air compressors systems (60%), followed by fans (23%) and pumps (11%) - see Figure 8.

The high share of savings related to air compressors can be explained by the fact that a large share of the total savings can be attributed to one large air compressor system in a wastewater treatment plant where the higher level control of the system was optimized (details below: EASY example: Sewage treatment plant near Geneva). Another significant share of the savings can be attributed to improvements in fans and pumps which correlate well with the upfront observations, namely that these applications are responsible for most of the electricity consumption in the assessed firms.

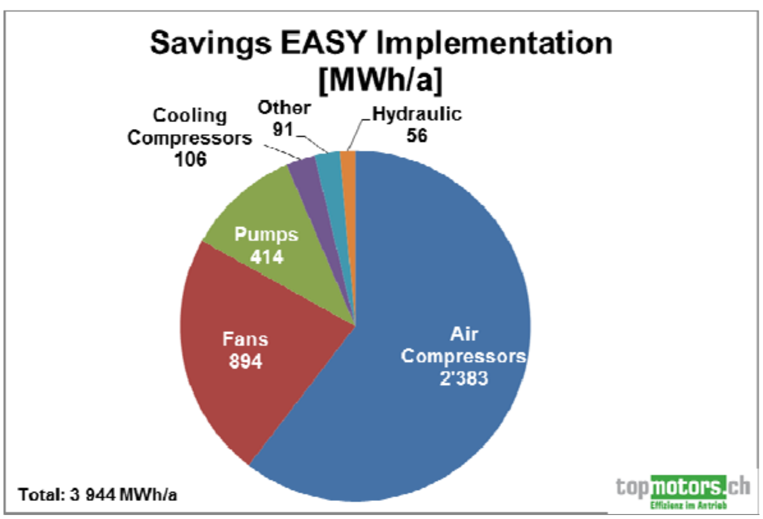

Figure 8. Electricity savings according to applications. Source: S.A.F.E. 2015.

Typical measures

All improvement measures were aimed at optimizing the whole motor system and not just exchanging individual components. Typical measures included:

1. Downsized motors and applications, adapted to the real needs of the production, based on the results of the measurements on site (observing the start and regular operation of the motor systems).
2. Adapting flow rate, pressure, temperature and time of operation to real needs.
3. Introducing electronic load control systems with variable frequency drives, especially for systems with square torque (pumps in closed loops, fans, etc.).
4. Introducing factory automation systems: installing and optimizing higher level controls for complex motor systems with multiple parallel machines and with controls for the entire line of machines in one process; coordinate and optimize the necessary operation time and load.
5. Installing highly efficient and state of the art mechanical equipment like transmission belts and gears and using state of the art technology for pumps, fans, compressors for cold and compressed air, designed to operate at the effective duty point.
6. Installing highly efficient electric motors (IE3 or IE4).

Overall, the average savings achieved lie between 20% and 30% (see Figure 9).

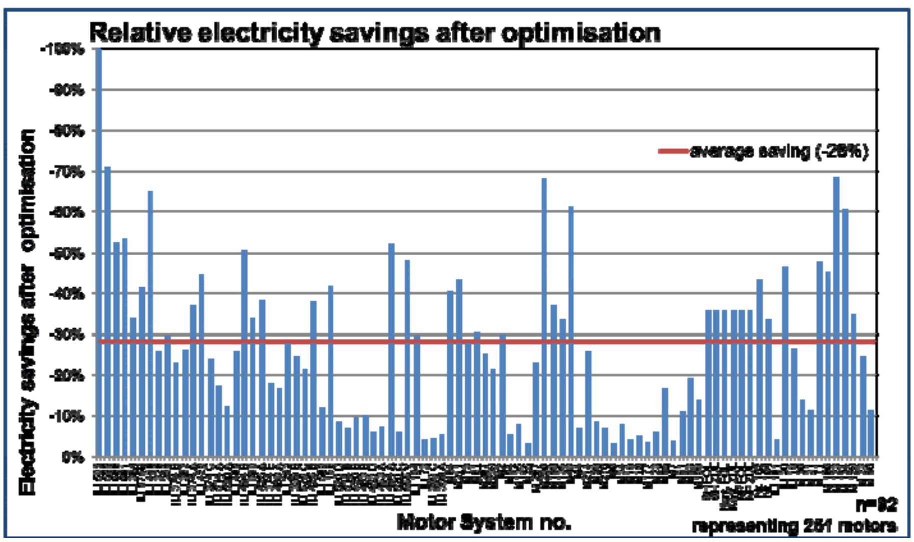

Figure 9. Average savings per improvement measure. Source: S.A.F.E. 2014.

EASY example: Sewage treatment plant near Geneva

The detailed analysis of the sewage treatment plant for 600’000 inhabitants (equivalent) with 40 GWh/a total electricity consumption was addressing all major electric systems (pumps, fans and compressors). The sewage plant uses for the third water cleaning step within the biological treatment plant an aeration system. 25 sewage water basins are aerated by a turbo compressor and air distribution system. The four equal-size turbo compressors are operated by four motors with a total output power of 2.4 MW. This motor system was identified as having the most cost-

effective improvement potential within the entire program, with a financial incentive of around 0.002 USD per kWh. An in-depth analysis of the necessary air input, aerating operation and cleaning cycles, the variations of water input temperatures and concentration of waste content provided the basis for a new operating model with coordinated variable flow cycles. The controls are based on a fuzzy logic model of the entire plant that anticipates the next hours of operation based on past experience and current data.
The newly installed and tested operating system has reduced unnecessary operating times of the machines and with this the electricity consumption by 15.7%. With an investment amount of 620 k USD savings of 2.1 GWh per year were achieved. The resulting payback is 2.06 years.

Figure 10. Biologic sewage water cleaning step.

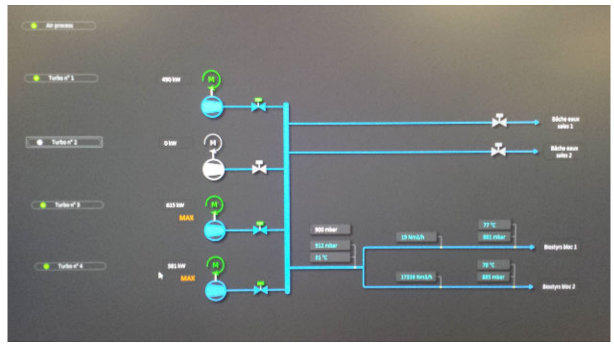

Figure 11. Control scheme of the four turbo compressors.

Figure 12. Motor system for turbo compressor.

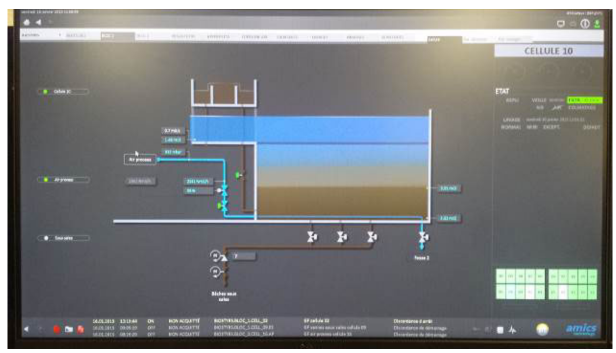

Figure 13. One sewage water basin.

Source: Sewage treatment plant near Geneva. S.A.F.E., 2015

Planning versus implementation

While significant resources were invested in making precise recommendations of cost-effective improvement measures, the participating firms did not always choose to follow them to a full extent.

The improvement proposals were handled in many different ways:

- **Executed fully**, subsequently put into operation, tested and monitored. Some of these cases delivered higher savings than anticipated.
- **Abandoned**, due to various reasons, mostly because priorities changed affecting the sequence and timely implementation of the proposed improvement measures. Examples include:

- Unexpected disruptions in the production process and their remedy tied down the resources of the factory personnel and there was simply no more time left for the implementation of the improvement proposals.
  - The necessary budgets were not readily available.
  - Mid-term planning did not allow guaranteeing the continuous operation of the equipment in the future.
- **Executed only in part** because the improvement proposals were either not fully understood or considered not feasible on the short run.
- **Some additional measures** were implemented concerning motor systems that were not identified as part of the program because during the course of the program changes in the production process shifted priorities.

Regarding measurement and verification, a strict regime for verifying the performance and energy savings achieved was defined at the outset of the EASY program and implemented until its completion. It included measurements before and after the improvements. The consumption ex ante was analyzed with the Standard Test Report[1] (STR) where the efficiencies of all components of a system were matched with the measured total electric input. Then, the improved efficiency of each component was introduced into the calculation and so the savings calculated on a conservative basis. For complex systems the Motor Systems Tool (MST) can be used to optimize the combination of VFD, motor, transmission and load and to estimate its combined efficiency.

In order not to overload the entire efficiency program with unrealistic long periods for control after completion and high cost for detailed verification measurements systematic check tests were made. The tests were supervised by the EASY team and consisted of detailed reports of the performance of all new components and measurements of one or more motor systems per factory in each participating firm. Only successful implementation results aimed at system savings were incentivized by the program. The few non-successful implementation results were analyzed as to their cause and origin. Generally, the ex post savings were matching or surpassing the previously estimated electricity savings. This has confirmed that a robust method for estimating the savings was used ex ante.

Lessons learned

The necessary time for implementing **energy efficiency improvements** in industrial factories from the first contacts until the actual implementation of measures **takes considerably more time than anticipated**. Internal decision making and budgeting cycles added many delays to this process.

Industries tend to be cautious concerning external engineers auditing their factories. Even if confidentiality agreements are drawn up with all participating firms, building up trust between internal staff and external experts needs time.

The **internal factory staff capacity and capability** is not oriented towards energy efficiency but towards the core business: a smoothly running production process, satisfactory volume and quality of products.[2] Efficiency potentials are often not recognized.

[1] www.topmotors.ch/download.php?file=standard_test_report_2.0.zip

[2] Cooremans (2012) shows that if investments into energy efficiency do not have a strategic character, i.e. a link to the core business of a company, they are often hampered.

Internal **communication between technical level staff and management level**, responsible for investment decisions, **is a challenge**. The main investment assessment criteria are pay-back time. A more comprehensive analysis based on life cycle cost assessment was applied only by one program participant.

Motor systems are in operation since decades, way over their expected lifetime, while technical motor and system efficiency advancements were made and often the user cycles in a given application changed. These systems were not regularly adapted to such changes which indicates the **lack of a continuous monitoring and improvement process**.

System improvements of old, oversized and not yet load controlled machines could not be implemented in all cases. Some factories chose the replacement of single components, leading to significantly reduced savings.

A certain **dependency on suppliers** was observed. Offers from competing suppliers of equipment were asked only in rare cases, firms tended to stick to their original suppliers who also provide maintenance services of machines. The delivery of more efficient components was delayed in many cases due to a product portfolio at the supplier's side that did not include high efficient products in stock.

The factory staff engaged in the EASY program was challenged by the analysis and the implementation both in their **capacity and competence**.

The extent and complexity of the energy efficiency projects and the design and implementation of the electricity and cost savings requires **an organization with both a strong coordinating leadership and a group of highly qualified energy efficiency engineers**. The recruiting and training of in-house staff, consulting engineers, specialists and factory engineers together with manufacturers' specialists requires a close cooperation and a continuous exchange of experiences.

The **program management costs were significantly higher** at the end of the program as originally planned. Program management comprised administrative tasks as well as effectively accompanying participating firms during the four-step process and supporting them with expert energy efficiency advice. Much more external support and counseling proved to be necessary for firms as originally planned.

Energy technology and management in industry

One main lesson of the program was that internal factory staff lacks the necessary know-how, skills and capacities for implementing efficiency projects improving electric motor systems. Therefore, S.A.F.E. has designed a training program for factory staff on energy management and technology in industry (ET&M). The program is focusing on electricity and in particular, electric motor systems.

The goal of the program is to empower factory staff to initiate systematic energy efficiency programs and to be able to successfully negotiate with external motor experts and suppliers but also with internal staff and especially internal management.

ET&M is planned as a 5-6 day-course, to be potentially extended to 10-12 days. It will consist of the following three modules:

1. Introduction
2. Energy management
3. Energy technology.

Module 1 will give a general introduction on Swiss energy policy, project management, profitability and its assessment criteria.

Module 2 energy management will introduce participants to the concept of continuously monitoring, improving and evaluating the energy performance of the factory. In this module, the communication, negotiation and presentation skills of the participants shall be trained and improved.

Module 3 energy technology will include topics around motor systems, the different applications (pumps, fans, and compressors), use of VFDs, the Motor-Systems-Check method, etc.

ET&M is currently being built up with a first edition planned to be launched in 2015/2016.

Conclusions

EASY was a pilot industry program focusing on electric motor systems in Switzerland. The program aimed at engaging internal technical staff of the factories so that after the initial phase further and regular systematic analyses and improvements could continue without external engineering and financial support.

The main goal of the program has been achieved. The projected energy savings have been secured through efficiency improvements in 8 factories.

Through the program data and insights were gained concerning a number of crucial issues like oversizing machines, overaged equipment, limited use of variable load machines, etc.

The direct contact with the factory management and technical staff showed that the necessary capacities and capabilities are in most cases not available. Staff is hired and trained to operate the machines for the designed product. The energy efficiency of the process, the machines and the operation is mostly not addressed sufficiently.

The electricity cost of the factories that participated in EASY was 1% to 3% in relation to their total turnover. Therefore, the absolute financial gain for the factory through the energy cost savings is small while the relative savings on individual improved systems was large. The additional gain of the renewed systems was of course a trouble free and smooth operation for many years to come.

The program has shown that a systematic approach is necessary in order to find those machines among the hundreds and thousands of motor systems in a factory which can be improved in the most cost-effective manner. The goal is to select these machines within a fairly short period.

EASY has also shown that a financial incentive helps to open the factory doors and it stimulates activities in industry that were dormant and stalled before.

At the same time, it has to be acknowledged that the program also constitutes an administrative burden for companies.

The lessons learned from EASY led to the build-up of a training program for factory operators. The training program includes the Motor-Systems-Check methodology with its analysis tools.

Also drawing from the lessons learned from EASY and based on the research of Cooremans (2012), the Swiss cooperative research project "Management as a Key Driver of

Energy Performance" is investigating whether the level of energy management positively influences investments into energy efficiency.[3]

The EASY program will be followed by the SPEED (www.speed-program.ch) program operated by Planair (www.planair.ch/en), a program partner of EASY.

Acknowledgements

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[3] http://www.nfp71.ch/E/projects/module2/Pages/project-iten.aspx