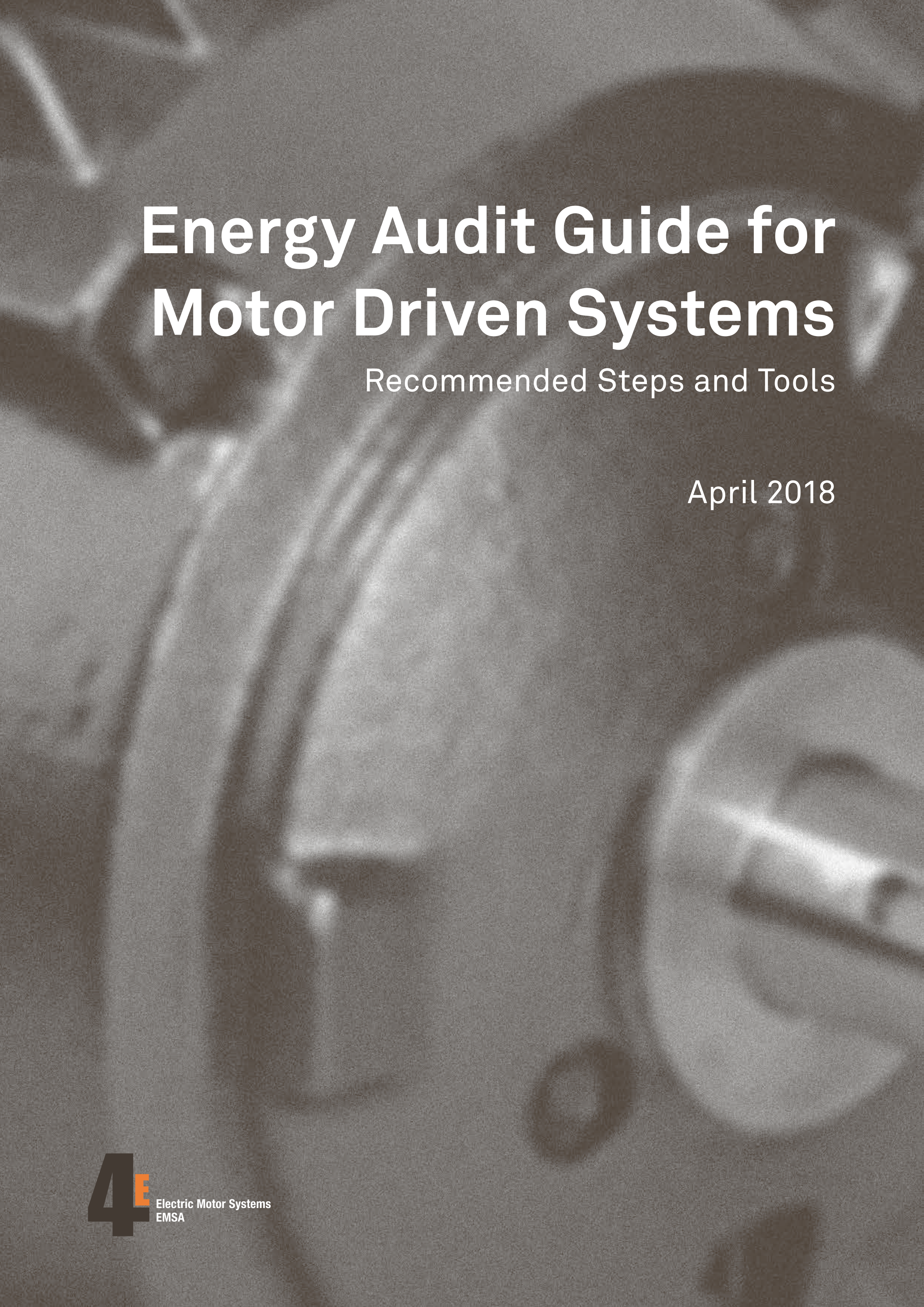

Energy Audit Guide for Motor Driven Systems

Recommended Steps and Tools

April 2018

4E Electric Motor Systems EMSA

Energy Audit Guide for Motor Driven Systems

Authors

- Konstantin Kulterer, Austrian Energy Agency, EMSA Task Leader Energy Audits for Motor Systems
- David Presch, Austrian Energy Agency

Reviewers

- Gilbert McCoy, Washington State University
- Maarten van Werkhoven, TPA Advisors, EMSA Operating Agent
- Rita Werle, Impact Energy, EMSA Coordinator
- Rolf Tieben, Impact Energy

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4E Electric Motor Systems Annex (EMSA)

Electric motor systems in industrial plants, infrastructure applications and buildings that drive pumps, fans, compressors and other equipment, are responsible for 45% of the world's total electricity consumption. New and existing technologies offer the potential to reduce the energy demand of motor systems across the global economy by 20% to 30%. The know-how to realise energy savings exists but is not widely applied.

The 4E Electric Motor Systems Annex (EMSA) promotes the opportunities for energy efficiency in motor systems by disseminating best practice information worldwide. It supports the development of internationally aligned test standards and regulations to improve the energy performance of new and existing motor systems.
Between 2008 and 2018, EMSA has:

- Contributed to the development of internationally aligned, globally applicable technical standards for motor systems. EMSA participates in relevant International Electrotechnical Commission (IEC) standards committees and contributes independent research results.
- Established a global network of testing laboratories.
- Contributed to the SEAD Global Efficiency Medal Competition for Electric Motors.
- Helped to disseminate the messages of the IECEE (Worldwide System for Conformity Testing and Certification of Electrotechnical Equipment and Components) Global Motor Energy Efficiency Program.
- Expanded the Global Motor Systems Network to 5500 contacts from 85 countries. Members include representatives of governmental bodies, international organisations, standards developers, researchers, motor systems efficiency experts, utilities, industrial end-users and manufacturers. Members receive the EMSA Newsletter in English, Chinese, Japanese, Spanish, with updates on national and regional policy initiatives and EMSA's activities.
- Developed the Motor Systems Tool for engineers. The Motor Systems Tool helps to optimise the energy efficiency of a complete motor system.

The following reports related to motor systems have been published:

- EMSA Motor MEPS Guide (2009)
- EMSA Motor Policy Guide – Part 1 (2011)
- EMSA Policy Guidelines for Electric Motor Systems –Part 2 (2014)
- 4E Energy efficiency roadmap for electric motors and motor systems (2015)
- 4E EMSA Policy Guidelines for Motor Driven Units – Part 1 (2016)
- 4E EMSA Policy Guidelines for Motor Driven Units – Part 2 (2018).

Further information on EMSA is available at: www.motorsystems.org

4E Electric Motor Systems EMSA

Table of Contents

1 Introduction and Objective

More than half of the electricity consumed worldwide is used in electric motor systems. A total of 30% (6,000 TWh) of the global electricity consumption is used in industrial systems. By 2040, increased industrial activity would double global electricity use for motors (IEA/OECD, 2016, p. 283).

In industry, motor systems are responsible for 70% of electricity consumption. These include, for example, material conveying, pumping, fan, refrigeration, and compressed air systems. Improvements of older motor driven systems (MDS) have the potential to save between 10% and 30% of energy consumption and running costs, thus offsetting the investment for high efficient components within three to five years (Waide et al., 2011; Brunner et al., 2013).

Energy audits are an important instrument for increasing the efficiency of motor driven systems:

An energy audit is a systematic analysis of energy consumption within a defined system in order to evaluate opportunities for improved energy performance. It is therefore an effective instrument to detect optimisation potentials for existing in-service motor driven systems. A comprehensive audit should expose over-sized, old and inefficient equipment, equipment without proper control or operating with a wrong control strategy, leakages, and inappropriate applications or end uses. Furthermore, reducing running time or turning equipment off when not required can often provide significant energy savings.

This guideline gives a systematic and comprehensive overview on how to use available standards and tools for a motor system audit. This will help energy auditors to identify and calculate the most important energy-saving potentials in these systems by considering all relevant standards. The present document aims to help energy auditors, energy consultants, energy managers, and engineers to achieve their goals of saving energy in motor driven systems in industrial companies. However, many recommendations of the guideline are applicable to other sectors, e.g. municipal waste water plants or irrigation pumping systems.

This document is structured along the stages of an energy audit according to ISO 50002 and includes organisational and technical tasks to be performed during the audit. For each step, it refers to the relevant standards and tools.

In addition, it includes the following information:

- Technology-specific key indicators for determination of appropriate energy-saving measures
- Saving calculation methods

This audit guideline for motor driven systems was developed within the task “Energy Audits for Motor Systems”, which was performed by the Austrian Energy Agency within the framework of the Electric Motor Systems Annex (EMSA) of the IEA Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E). The goal of the Electric Motor Systems Annex is to raise awareness on the large savings potential in motor systems, while showing the realization method of such a path. The goal of the task was to collect already existing requirements for energy audits in motor driven systems as well as information to be considered or to be referred to during an energy audit in this field.

The following chapter covers an overview of the audit steps, whereas chapters 3 through 9 comprise the main part of this guide: Detailed information for each step to be made in the audit are given, starting from “Step 1: Acquisition and Energy Audit Planning” to “Step 9: Connection to Energy Management”. The comprehensive Appendix includes a checklist for audit planning, data collection sheets for the various technologies, an overview on possible measurement points, indicators and calculation formulas for the most important energy-saving measures, and an overview of the elements of a plan for the measurement and verification of energy-saving measures.

2 Audit Methodology

This chapter defines the main roles of the persons involved during the energy audit and gives an overview of the proposed steps of the audit methodology.

2.1 Definition of Roles

The present guide is written from the perspective of an external energy auditor but can also be used by internal energy managers or technicians:

An energy auditor is an individual or a team of people conducting an energy audit. An energy audit is a systematic analysis of energy use and energy consumption within a defined energy audit scope in order to identify, quantify, and report on the opportunities for improved energy performance (ISO 50001).

Usually, for several reasons, not all tasks can be performed by an external auditor. Also, energy auditors can be specialized on particular organisational or technological topics. Therefore, they can either work in an energy audit team and/or include expertise of internal personal and external experts via personal meetings or workshops. Some auditors define themselves as moderator leading the internal personal through the recommended steps.

Depending on the company, the main counterpart of the energy auditor in the company is an energy manager or someone who partly fulfils this role. This can be done by various persons, but, frequently, it will be the plant electrician, the head of the technological department, or the environmental, quality, safety manager. Generally, this person knows the main energy consuming processes and/or is responsible for monitoring the energy consumption in the company.

The necessary competencies for the specific energy audit will be defined during the opening meeting.

2.2 Overview on Audit Methodology

Figure 2.1 shows the entire energy audit methodology for motor driven systems. The rectangles in the flow chart stand for the nine steps of the audit methodology, the column next to it shows checklists, tables, and additional information given in the report that will support the auditor during every single step. Furthermore, various tools, which can or should be used during those phases are listed.

The nine main steps of the energy audit methodology for motor driven systems (MDS) are listed below and are described more in detail in the following chapters:

- Step 1: Acquisition and energy audit planning
- Step 2: Opening meeting
- Step 3: Data collection
- Step 4: Measurement plan
- Step 5: Conducting the site visit
- Step 6: Data analysis
- Step 7: Energy audit reporting
- Step 8: Closing meeting
- Step 9: Connection to energy management and motor policy

The descriptions contain the methodology including organisational, management, and technical aspects as well as available tools which can support the energy auditor in the respective step.

Steps	Name of the Step	Tables and Checklists	Recommended Tools
Step 1	Acquisition Planning	Checklist General Information	
	Pre-Screening End	Required Data Input	SOTEA
Step 2	Opening Meeting	Checklist for Opening Meeting	
Step 3.1	General Data Collection	Tables for General Data Collection	ILI+
Step 3.2	Specific Data Collection	Technology Specific Data Collection Sheets	
Step 4	Measurement Plan	Elements of Measurement Plan Measurement Points	
Step 5	Site Visit	Indicators for Saving Potential	
Step 6	Data Analysis	Indicators and Calculation Formulas for Energy Saving Measures	EMSA STR Manufact. Tools
Step 7	Report	Content of Report	
Step 8	Closing Meeting		
Step 9	Connection to EMS		

Figure 2.1: Flowchart for the energy audit method for MDS – including the various tools

3 Acquisition and Energy Audit Planning

In this chapter, the first step of the energy audit methodology is described. It contains information to be collected at the beginning or even before the energy audit, defines relevant questions to be answered during this step, and describes ways to convince top management to start an energy audit. For this chapter, the table "Checklist General Information" in the Appendix 12.1 should be used.

3.1 Acquisition of the Energy Audit

The acquisition or starting phase is generally not considered in the energy audit standards as it is the phase before the actual energy audit, but it is highly relevant for defining the scope of the audit as a starting point. During the acquisition phase, it is necessary to build a strong argument for top management to finance an energy audit and build commitment for investing in feasible energy-saving measures. For this, it is useful to do a preliminary evaluation of the company, investigate its strategic goals, and check how efficient motor driven systems can support these. This information will help energy auditors for the energy audit planning and also during the opening meeting.
The main reasons for an energy audit can be: legal or financial incentives for energy audits or energy management systems, out-phase of refrigerants, down-time that can be attributed to bad functioning of motors, high maintenance costs, quality issues of the product associated with motor control, capacity issues (e.g. too high temperatures in halls, compressed air pressure too low); or expected energy savings.

3.2 Audit Planning

The first step of an energy audit is the energy audit planning. The audit planning can but does not have to be done on site. Especially, if time effort and travel distances are too high, the auditor or the company can prefer telephone and email correspondence to a personal meeting.
In this phase, the energy auditor and the audited company is expected to define the scope of the energy audit and identify the needs and expectations to achieve the audit objectives. The results of this first planning should be written down both to serve as a proposal of the auditor and internally to get approval for the next steps.

One of the most important issues will be the definition of resources, meaning available time for the auditor for completion of the audit. This time is influenced by the particular topics discussed in this chapter. But to get a very rough impression it can range from one day for smaller companies to one week on site for big companies, plus time for analysis, additional visits for clarification of specific issues and reporting. This time is dependent for example on the information available and the expectations. For instance, if a database of motors is already available, more time can be devoted to a more detailed analysis of the systems than if such a database has to be developed from scratch. For a first rough estimation of savings, see the chapters below. For bigger projects, it is recommended to follow a two-staged process, with the first phase assigned to clarifying the available data and making an energy consumption analysis (based-level audit) and the second phase to defining the energy-saving measures (investment-level audit).

Topics to be planned and collected at this stage are:
- the necessary period of time to complete the energy audit,
- necessary and available resources from the organisation (e.g. time and money allocated to the energy audit),
- available data from the organisation (e.g. drawings, historical energy consumption, measurements),
- copies and a summary of completed efficiency measures from previous energy efficiency studies,
- the organisation's representative responsible for the energy audit process.

In addition, an energy auditor can request information to establish the energy audit context, e.g. regulatory requirements; plans for future expansions; equipment upgrades or retrofits that may affect the organisation's energy performance; (EN ISO 50002, p. 6-7).

Other relevant questions to be answered during this step:
- Is the management of the company generally interested in the topic?
- Is an energy audit for electric motor systems in this company useful at all?

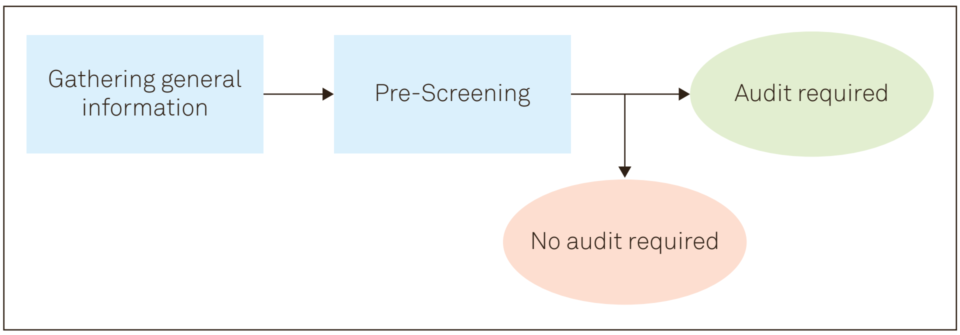

Figure 3.1: Two different parts of the energy audit planning step

- Is there enough energy saving potential?
- Is the company able to support an auditor?
- Which cost-effective or other criteria will be used to rank and/or implement energy-saving measures?
- Are there enough financial resources to implement energy efficiency measures?

More motor-specific questions for understanding plant practices are for example (Gilbert McCoy, personal communication 2017):
- Does the facility maintain an electronic database of in-service and spare motors? If yes, request a copy.
- Does the facility follow a preventative or predictive maintenance approach?
- Are all new or replacement motors purchased from one manufacturer?
- Has the facility created a repair/replace policy for motors at their time of failure?
- Are failed motors repaired on site or sent out to a preferred repair shop? If sent out, are repair best practices followed?
- Are new equipment specifications developed by on-site staff or staff at a parent company?
- What is the serving utility and under what rate schedule is power and energy supplied?
- Does the utility offer any audit assistance or incentives for efficiency measures?
- Does the facility operate a combined heat and power plant?

The energy audit planning phase can be structured in two different parts (see Figure 3.1):

3.3 Gathering General Information about the Company

Firstly, general data of the company has to be collected. In the Appendix 12.1, a checklist summarizes the most significant information: company address, sector, number of employees, purpose for which motors are used, operating times, name and function of contact person. Most questions can be answered through web-research by the auditor themselves or with a short phone call with the respective company.

3.4 Pre-Screening

If finding energy-saving potential will be the main issue, this should be estimated on a very rough level based on the amount of electricity used in the company, the electricity price, and total electricity costs. The share of electricity used by electric motors can give an estimate about how much money is necessary to run electric motors in this company. 70% of total electricity demand is used on average in production companies by electric motors (IEA, OECD, 2016), on national basis this may be even higher, e.g. in Austria 75%. For different branches, these values have a higher range (see Table 3.1 for the national example of Austria). The share can be quite low if other processes consume a lot of electricity, e.g. metal casting, ovens.

The second indicator is the number of motors and their age. This can be answered by questions, such as: When was the plant or were specific parts of it built, when was the last major renewal of the electric machinery (Topmotors, 2015)? Other sources may be the analysis of the identification numbers (ID) of motors. Some plants assign this numbers chronologically, some plants use the ID number of a failed motor to the new replacement motor, which makes the motor population characterization more difficult (Gilbert McCoy, personal communication 2017). Based on this information, the possible saving potential can be roughly estimated.

Especially for this step, “SOTEA” (topmotors.ch, 2015a), a free software tool, was developed by Topmotors in Switzerland. Table 3.2 illustrates the required data.

After the data entry, SOTEA is able to calculate and estimate the consumption and energy efficiency potential of electric motor systems in the respective company. Based on this information, the energy auditor and the company can decide if they want to proceed with the energy audit.

Branches	Share of total electricity consumption consumed by electric motors
Wood	93%
Chemical and Petrochemical	92%
Pulp and Paper	90%
Food and Tobacco	80%
Textile	80%
Mining	76%
Other Production	75%
Iron and Steel	68%
Automotive	65%
Stone, Earth, Glass	62%
Machinery	54%
Construction	47%
Non-Iron Metal	33%

Table 3.1: Share of total electricity consumption consumed by electric motors in various branches in Austria (Statistik Austria 2017)

Required Data	
General	
Tool language	English
Currency	EUR
Turnover	
Total number of workplaces	
Share of office workplaces	
Electricity	
Use of electricity	[kWh/a]
Average price of electricity (present)	[EUR/kWh]
Annual costs of electricity	[EUR/a]
Last major renewal of the electric machinery	

Table 3.2: Required data input for SOTEA

4 Opening Meeting

In this chapter, the second step of the audit, which consists of the opening meeting, is discussed in detail. It includes a checklist for topics to be discussed during this meeting and recommendations of whom to invite to this meeting and how to convince top management.

If the energy saving or efficiency potential in the field of electric motors is considered high enough, the technical and financial scope of the energy audit can be defined. Frequently, the opening meeting will be the first personal encounter between the energy auditor and the representative of the company. In other instances, as stated before, the auditor may have already visited the company during the audit-planning phase. If that is the case, this first meeting can be used to clarify several points, raised in this chapter.

In this step, the energy auditor should inform the interested parties about the energy-saving potential of the electric motor systems, the defined audit scope, the boundaries and methods. Table 4.1 is a checklist for the meeting to be discussed in the following section.

For the opening meeting, the **following persons** should be invited to ensure commitment:

- Top management or head of the company
- Chief financial officer or head of controlling
- Experts on the industrial processes in the company
- Energy manager of the company or person responsible for energy issues within the company

The task of the energy auditor is to **convince top management** of the advantages of an energy audit and of providing the financial and personnel resources for carrying out an energy audit. Furthermore, employees will apply their best efforts to an energy audit only if their management displays awareness of the audit's importance.

For this purpose, a rough estimation of the current energy costs for running electric motors, the saving potential, and a list of references can be very helpful. In addition, the auditor should assess how the efficiency of electric motor systems can contribute to the company's strategic goals and why energy efficiency, therefore, is a strategic issue. Optimised efficient motor systems can contribute on a broader scale to the success of a company with less risk of down-times (if an important motor fails), better control of production processes, lower maintenance, electricity and fuel costs, reduced carbon dioxide emissions, and a better working environment with less noise and lower temperature. These additional benefits are called non-energy benefits or gains and may be the main reason why an energy audit is conducted.

The main points which have to be discussed in the opening meeting are the **scope, the boundaries and methods** of the energy audit. Examples of objectives of an energy audit can be:

- Determine the current energy consumption of specific motor driven systems
- Define the energy efficiency potential of the various electric motor systems
- Identify performance improvement opportunities in this area

With respect to the boundary of the energy audit, it is highly relevant to identify the category of motor systems, the system border (e.g. motor, drive, distribution system, end user of the system), and the physical part of the company where the motors are analysed. Defining what the boundaries are is dependent on the needs, expectations, and financial resources of the company as well as on the possible data available before the start of the energy audit, e.g. drawings, manuals, test reports, historical utility bill information, computer monitoring and control data.

For the level of detail, the company can choose between the based-level audit (called level 1 audit in ISO 50002) and the investment-level audit (called level 2 or 3 audit in ISO 50002). An investment-level audit generally requires more time for data collection, measurement, and higher qualified persons than a based-level audit. In addition, the costs will depend on the accuracy and duration of measurements of power, flow, and pressure, and any third-party contractors that are required to undertake measurements. For a based level-audit, the measurement and reporting requirements will be significantly less and, thus, the energy audit costs will decrease accordingly (EMANZ, 2017, p. 7-8).

Before the meeting	
Invite responsible representatives to the opening meeting	☐
Preparation of documents for the meeting	☐
During the meeting	
Convince top management	☐
The energy auditor shall request the organisation to:	
Define scope, boundaries, and methods of the energy audit	☐
Assign personnel to assist the energy auditor	☐
Ensure the cooperation of the affected parties	☐
Confirm any unusual conditions	☐
The energy auditor shall agree with the organisation on:	
Arrangements for access	☐
Requirements for health, safety, and security (e.g. safety training, steel-toed boots)	☐
Availability of financial resources	☒
Requirements and procedures to be followed for installation of measuring equipment (e.g. certified plant electrician, arc flash protective clothing)	☐
After the meeting: action plan	
An action plan for the assessment shall be developed	☐
Agreed by the assessment team and top management	☐

Table 4.1: Checklist for the opening meeting (based on EN ISO 50002, 2014, p. 7)

The following points should be considered:
- For the goals defined: review with respect to relevance, cost effectiveness, and capacity to produce the desired results before starting with the audit
- For the energy-saving measures: define the criteria for evaluation and ranking
- For the report: finalize the format and process (e.g. reviewing by internal persons)

To have the necessary competencies available in order to achieve the defined objectives, the **assessment team** (internal and/or external) should include or have access to the following individuals (EN ISO 14414, 2016, 4.2):
- An assessor who has the electric motor system analysis competencies
- The host organisation representative who has overall responsibility and ownership for the assessment
- Experts on the processes and the function of the system (rather persons with overall responsibility than operators)
- Experts on the maintenance practices of the electric motor systems (persons with overall responsibility)
- Experts who can provide the team with cost data (financial officer of the company, equipment suppliers, etc.)

The best guides for the energy auditor during a motor driven system audit may be the plant electrician or a knowledgeable person from the mechanical maintenance group (Gilbert McCoy, personal communication 2017).

The energy auditor should **confirm any unusual conditions** that may affect the energy audit or energy performance, i.e. maintenance work, special visits (customer, regulatory, etc.), significant changes in production volume, and others. In this way, possible risks can be identified and the energy auditor will be better prepared in these special cases (EN ISO 50002, 2014, p. 7). Furthermore, the influence of such events on the energy consumption data and on the appropriate measurement time has to be considered.

The energy auditor and the assessment team should have access to:
- Facility areas and electric motor systems required to conduct the assessment
- Facility personnel (engineering, operations, maintenance), their equipment vendors, contractors and others, to collect information pertinent and useful to the energy audit activities, such as costs for new motor of a high efficiency class, such as IE3 or IE4 and costs of repair (bearing change-out, rewind)
- People responsible for the analysis of data which will be used for the preparation of the report
- Other information sources, such as drawings, manuals, data sheet, maintenance records, test reports, historical utility bill information, computer monitoring and control data, electrical equipment panels and calibration records (EN ISO 14414, 2016, p. 9).

The energy auditor and their assessment team have to follow the **safety instructions** to avoid injuries of the personnel and destruction of the measurement equipment.

For the **installation of measurement equipment**, several requirements and procedures have to be followed. It is highly recommended to let authorized (in-house) staff install the devices. In any case, these persons should attend the measurements.

The following questions referring to measuring equipment should be discussed in the opening meeting:
- Is the chosen measuring method the appropriate one?
- Are special circumstances to be considered, e.g. may production be interrupted, does insulation has to be removed to measure hot fluid flows?
- Is special measuring equipment required due to dangerous measuring environment?
- Which measuring accuracy will be required for the energy audit process?

The energy auditor and the assessment team should take notes during the opening meeting to transform the discussed topics into a meaningful **action plan**. This plan should include all the planned activities of the energy auditor and the assessment team but also activities which the company has to carry out during the energy audit process. A well-designed and comprehensive action plan can simplify the following steps of the energy audit. In addition, it helps the people who are involved in the energy audit process to understand the processes and the structure of the audit in a more efficient way.

The last point of the opening meeting is dedicated to the management's commitment to the energy audit. As far as possible, all points mentioned above, should be clarified and agreed upon.

5 Data Collection

In this chapter, the third step of the methodology is described. It includes a two-staged process consisting of general data collection and technology-specific data collection. The Appendix contains data collection sheets for the various technologies.

5.1 Possible Data Sources, Overview on Data Collection

Before starting the data collection, it is recommended to check the information already available within the company, e.g. from the energy management system or maintenance information. Useful facts can be (based on ISO 50002, 2014, p. 8):

- List of energy consuming processes, systems, and equipment (e.g. motors, pumps, fans)
- Information on spare motors or driven equipment held on site
- Historical and current energy performance
- Relevant variables influencing the energy consumption
- Previous energy audit studies
- Monitoring equipment and measurements
- Design, operation, and maintenance documents
- Training requirements for relevant personnel
- Decision process of implementation of energy-saving measures

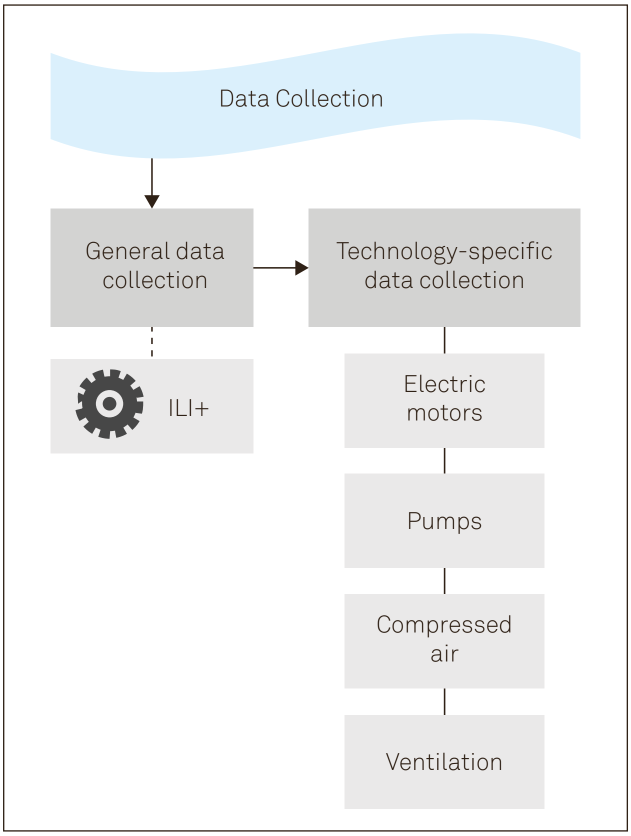

Figure 5.1: Overview of the data collection in two stages

Concerning electric motors and energy management, it should be checked if the company has already implemented elements of a motor policy (e.g. purchasing criteria, inventory list, requirements for repair and maintenance).

The step "Data Collection" of the energy audit methodology can be divided into two stages (also see Figure 5.1):

- Stage 1: the technology-independent or general data collection of electric motor driven systems
- Stage 2: the technology-specific data collection for in Stage 1 selected systems

5.2 General Data Collection for Electric Motor Systems

The first step in data collection is to carry out a rough analysis of the existing data referring to electric motor driven systems. Therefore, the general data should be collected for each motor, for example in an Excel spreadsheet.
Although this is the focus of the technology-specific data collection, it may be useful to collect, already at this first stage, all data on the motor nameplate: enclosure type, mounting configuration, voltage rating, full-load amps and full load efficiency (if no rating is present, then the energy efficiency class of the motor corresponds to IE1 or IE0). Also, any special features such as high-torque motor or flame-proof motor should be compiled.
The next step is, first, to rank the motors according to energy consumption and, second, to select old motors with high energy consumption without control for a more detailed analysis.

Ranking of motors

The motors in the list will be ranked according to a mixture of the following criteria:

- Motor age (e.g. above 10 years)
- Motor nominal power (e.g. focus on AC motors in 37 to 375 kW size range)
- Running time (e.g. above 3,000 h)

Required Data	Example
Number of the motor (No.)	1
Year of manufacture, purchase or installation	1999
Operating hours	3,000
Frequency converter available	no
Mechanical nominal power	100 [kW]
Number of poles	4
Driven equipment	Conveyor belt

Table 5.1: General data to be collected as a minimum for all motor driven systems

Intelligent Motor List

For the analysis of the existing electric motor driven systems with the focus on energy efficiency and potential for improvement measures, the "Intelligent Motor List" (ILI+), developed by Topmotors, available on www.topmotors.ch, can be used. In addition to the information given above (Table 5.1), the energy auditor has to define the following criteria:

- Rate of realization of the maximal saving potential in % (e.g.: 50%)
- Age, older than x years (e.g.: 15 years)
- Operating hours per year > x hours (e.g.: x = 3,000 h)
- Nominal power of motors > x kW (e.g.: x = 10 kW)
- Motors without frequency converter (e.g.: "yes" – when there is no frequency converter)
- Application (pump, ventilator, compressed air system, cold system, others, etc.) (e.g.: yes)

The ILI+ tool lists the most relevant motor driven systems based on the above-mentioned criteria.

5.3 Technology-Specific Data Collection

The selection of the systems for which more detailed data will be collected is based on the first stage, but, in addition, several other technology-specific criteria can be considered. In this chapter, for each technology these criteria are specified and the specific data is defined.

The technology-specific data collection is divided into the following technologies:

- Electric motors
- Pump systems
- Ventilation systems
- Compressed air systems

It is important to note that data collection for the different systems can be very time-consuming and not all data will be available. One task of an energy auditor is to identify and recommend the most important energy-saving measures for further "targeting" even with a lack of data as this will always be the case. If for lack of data it is impossible to continue the work, sub-meters have to be installed, and probably, the audit has to be postponed. So it is always a balancing act between what the auditor wants to know and what data the company can deliver within a reasonable time frame and with reasonable effort.

There are two different data available, for each of which several sources are possible:

- For the check of construction and design data: nameplate, technical data sheets, online databases of manufacturers, design documents, drawings
- For the check of the current use of in-service equipment: inspection and commissioning protocols, maintenance records, monitor and control system data, sub-meter data, building control system, piping and instrumentation diagram, measurement protocols, operating data (e.g. available at equipment panels), process flow diagrams, oral information of operators

5.3.1 Electric Motors

The detailed data collection should concentrate on motors with the following characteristics as those units will be checked specifically during the site visit in cooperation with the relevant contact person of the company, e.g. facility management (UNIDO, 2015):

- Motors with high energy consumption
- Old motors
- Motors with high maintenance requirements
- Motors with varying duties but fixed speed
- Support equipment
- Inefficient drive systems
- Motors with the possibility to replicate recommended efficiency measure

In addition to the general data, additional specific data should be collected.

Three types of data are necessary (see Appendix 12.4.1 for tables for data collection):

- General motor data (e.g.: coupling type, motor type (AC or DC), manufacturer)
- Specific/technical data of the electric motor system (e.g.: synchronous speed, full load efficiency, full load amperage, enclosure type, full load power factor, etc.)
- Operating profile of the electric motors

5.3.2 Pumping Systems

The detailed data collection should concentrate on pumps with the following characteristics (ISO 14144, 2016):

- Pumps running independent of demand
- Pumping systems where throttling takes place
- Pumping systems with recirculation of flow used as a control scheme
- Pumping systems with large flow or pressure variations
- Systems with multiple pumps where the number of operating pumps is not adjusted in response to changing conditions
- Systems serving multiple end uses where minor user sets pressure requirements
- Cavitating equipment
- High vibration and/or noisy pumps, motors or piping
- Equipment with high maintenance requirements
- Systems for which the functional requirements have changed with time but the pumps have not
- Worn, eroded, corroded, distorted, or broken impellers/vanes or wear rings
- Low pumping system efficiency indicator
- Clogged pipelines or pumps
- Seized valves or leaking recirculation valves
- Sealing systems, esp. high temperature, requiring cooling
- Available pump curve

The following type of detailed data is necessary for further analysis (see Appendix 12.2.2 for tables for data collection):

- Motor data (e.g.: coupling type, motor type (AC or DC), efficiency, manufacturer),

- Pump and control data (manufacturer, model, flow, shaft power, static or variable flow, type of control)
- Distribution system, (diameter, material, built-in fittings)
- Liquid properties, (name, temperature, density, viscosity, occurrence of solids)
- Data of consumers (pressure, flow requirement)
- Operating profile (hours per day, days per week, percentage of load, etc.)

5.3.3 Ventilation Systems

The detailed data collection should concentrate on fans and ventilation systems with the following characteristics:

- Running without need
- Variable demand
- Significant changes to the system since installation (e.g. change of flow rate by more than 20%)
- Flow control using inlet or discharge dampers
- Worn, eroded, or broken blades
- Pressure loss across filters
- Air is extracted from the whole hall (instead of specific location)
- No maintenance plan, or maintenance plan indicates problems
- Available fan curve

The following type of data is necessary (see Appendix 5.3.3 for tables for data collection):

- Motor data (e.g.: coupling type, motor type (AC or DC), efficiency, manufacturer)
- Fan data and control information (manufacturer, model, efficiency lass, nominal flow, fan diameter, kind of control, static pressure)
- Coupling (driver coupling, pulley diameter, measured fan speed)
- Distribution channel (length, diameter, material)
- Air characteristics (temperatures, air quality, ingredients)
- Consumer (name of process/area, total flow requirement, total pressure requirement)
- Operating profile
- Maintenance information

5.3.4 Compressed Air Systems

Usually, there are not that many air compressors installed within a company as there are pumps, fans or motors. Therefore, if the general data collection based on installed electric capacity and running hours shows that compressed air system is a significant end user, then all compressors on site should be included in the detailed analysis as compressed air systems typically consist of multiple compressors. Even smaller compressors currently not in use can contribute to energy savings if they are connected to the system.

For a special compressed air audit the annexes of ISO 11011 provide very detailed data sheets for analysis of a compressed air system, including air treatment. For a first evaluation of the most important saving opportunities, the data listed in Appendix 5.3.4 should be collected. Examples are:

- Compressor data, pressure level (manufacturer, model, compressor type, drive motorpower rating (kW), max. operating pressure)
- Flow control type (modulating, load/unload, multi-step, variable displacement, frequency converter)
- Piping system information (material, diameters, length, system pressure drop)
- End-use information (name of process, flow rate, pressure-regulated use)
- Operational profile (hours per day: for weekdays per shift and for weekends)
- Dryer type (refrigerated or cycling refrigerative, twin-tower dessicant type)
- Receiver or storage volume
- Type of condensate drains
- Compressor heat recovery
- Information on leakage detection and elimination programme

6 Measurement Plan

In order to complete an energy audit, on-site data measurement might be necessary. In this chapter, the third step of an energy audit is described. Reasons for the measurements are given and specific aspects to be considered before starting with the measurement plan are specified. The measurement plan itself will be then described, followed by an overview of the measurement process and selection criteria for measurement equipment.

6.1 Selection of Systems to be Measured

It is impossible to measure all systems within a company. To assess the energy-saving potential, it is therefore necessary to carefully select these systems and verify the issues listed in this sub-chapter. Then, the auditor will stepwise further detail the data needed until the presentation of the final proposal in the audit report.

After the step "General Data Collection", in which nameplate data and estimated running hours have been analysed, measurements should be used to determine/verify the most important energy users, thereby examining energy flows within a plant, as many plants do not have sub-meter installed. The most energy-intensive processes likely offer the greatest savings.

Measurements are also useful when "targeting" potential energy-savings opportunities. For electrical equipment, prioritisation is definitely necessary. Criteria are defined in steps "Data Collection" and "Conducting the Site Visit", and often plant staff will also help by identifying equipment that is old and might need to be replaced, or that is known to be "problem" equipment. Equipment recently optimised with – perhaps – an installed frequency converter will not be measured.

Measurements are necessary to verify the baseline energy consumption and the performance (efficiency) of the corresponding system, including average load and running time, to build the basis for the energy-saving calculation.

Furthermore, for a more detailed understanding of the system to be optimised, measurements are required

- to verify assumptions, e.g. spot input kW measurements on systems with constant operating conditions;
- to check if the equipment is matched to load requirements (maximum and average load point, incl. starting torque);
- to identify operating points on a pump or fan curve;
- to examine annual operating hours or to verify information given by operators with respect to systems with constant operating conditions but with on/off control;
- to understand how to improve component sizing, performance, and efficiency and how control strategy influences energy demand with respect to systems with variable flow;
- to understand weekday versus weekend or holiday operation, or first and second shift hourly energy use versus e.g. cleanup shift in a food processing plant;
- to determine air leakage rate with respect to compressed air systems during plant downtime;
- to determine if electrical demand limiting might yield significant benefits at a facility;
- etc.

6.2 Before Measurements

Before proceeding to the actual measuring, the energy auditor or energy manager should collect all current measurement points. In addition, the following points should be considered:

- Sub-meter data or data from a monitoring or control system may already include the relevant data.
- It is recommended to ask plant staff if they routinely monitor any equipment. Companies with predictive maintenance programmes often take and trend field measurements for motors or other equipment.
- Controls for some equipment may have "data historian" features; e.g. in refrigeration systems where operating conditions are routinely monitored and retained in storage.
- Sometimes, measurements are available for the asking.

6.3 Elements of a Measurement Plan

If it is decided to take measurements and dependent on the effort needed, it is recommended to establish an agreement of a measurement plan between the auditor and the organisation. This plan is contingent on the target of the measurement. The two following topics should be the starting point of the measurement plan in addition to the elements of a measurement mentioned further below:

- Definition of the scope and purpose of the measurement (e.g. current energy use of a motor or to evaluate a specific saving measure)
- Definition of the system boundary (e.g. only electric motor of pump)

After that, the parameters to be measured, calculated or estimated, the measurement instruments and their accuracy as well as the appropriate time period can be chosen. Generally, it is recommended that measurement (placing measurement equipment) should be done by internal personnel, especially plant electricians. For instance, for insurance reasons, most factories in the U.S. require that electrical metering equipment be installed by certified plant electricians protected in arc flash protective clothing, with face shield, and lineman's gloves. This calls for developing a detailed monitoring plan as numerous power loggers and other devices must be launched, connected, and then disconnected (Gilbert McCoy, personal communication 2017).

According to ISO 50002, the measurement plan should include the following points, for each of which a short explanation is given:

- List of current measurement points (see Appendix Table 12.32 to collect this information)
- Identification of any additional measurement points: This is depending on the purpose of the measurement (see Appendix Table 12.33 with different possible measurement points at supply, distribution network, and end-consumer of a system).
- Associated measurement uncertainty: This is described by a precision and a confidence level. Precision refers to the error bound around the true estimate (range around the estimate). Confidence refers to the probability that the estimate will fall in the range of precision. Unless stated otherwise, the confidence of meters stated is likely to be 95%. Some meters give the precision relative to maximum reading, therefore the precision of the actual metering might be lower.
- Measurement duration: When considering the duration of baseline measurement, all typical periods of operation shall be measured (ISO 11011, 2013, 7.7.2). The measurement should be done during a period where all other influence factors are known (e.g. production rate, temperature inside and outside the building, employees in the building) and should include situations with highest load (esp. starting conditions). In some cases, instant measuring can be enough; in most cases, however, a measurement period of one week or ten days (to verify the first-weeks data) can be recommended.

In practice, the operating profile of the motor driven system has to be clarified with the operator to ascertain all possible influence factors that have influence on the load. Data logging time and sampling interval have to be established.

For systems that are dependent on the outside temperature (e.g. HVAC or chiller systems), a measurement period during times with a wide range of outside temperature should be chosen to model all-year consumption (based on outside temperature). Usually, such calculations are done in calculation programmes with pre-defined models, measured values are then used to calibrate the baseline of the model. For all these cases, also other existing data sources should be checked for historical operating information (e.g. control systems, load analysis of the utility).

- Data interval: Where dynamic events have to be recorded, a data interval of at least an order of magnitude less than the duration of the event being measured shall be applied (if a dynamic event in the system has a duration of one second, the data interval would have to be no greater than one tenth of a second or less, to characterize that event) (ISO 11011, 2013, 6.2.3).
- Representative time period: The required time period will vary according to the energy uses and processes involved (ISO 50002, 2014, A.4.2). Typical periods are representative for planned or unplanned changes in production. Changes can be seasonal, based on the day of the week, market conditions, and the availability of raw material (ISO 11011, 2013, 7.7.1). "If the operating conditions of the system are constant or only vary minimally in time, a snapshot of the operating conditions may be enough to assess the system. If the system demand varies over time, the assessment team shall determine if the system needs to be monitored over time and what time period is reasonable to get a representation of all operating conditions" (ISO 14414, 2016, 5.6.2).
- Relevant variables are quantifiable variables that impact energy performance. Examples are production parameters (production volume, production rate, or for motor systems: pressure, flow rate, temperature), weather conditions (outdoor temperature, humidity), operating hours, operating parameters (ISO 50006, 2014). Where appropriate, these data have to be provided by the organisation. Other information necessary is e.g. the damper position. To select relevant variables, regression analysis can be helpful (see for example EVO, 2012).

For the following projects, changes in power drawn should be measured: replacement of motors, fans and/or pumps, installation of frequency converters, reduction of pressure loss in distribution systems. For changes in control (e.g. installation of sensors to control pump and fan operation) and reduction of running time, operating hours should be measured. Power drawn can be estimated on the basis of supplier data in this case. This refers to Option A according to EVO, 2012.

- The responsibilities of the measurement should be clarified: In principle, the auditor is responsible for the measurement. For the installation of the meters, other persons can be involved (e.g. as specialized skills are required).
- According to ISO 11011, measuring equipment shall be calibrated, verified or both at specified intervals or prior to use against measurement standards. If no standards exist, the basis used for calibration shall be recorded (ISO 11011, 2013, 6.2.2.). All instruments used for measurement shall have a record of the most recent calibration information, the accuracy details should be mentioned in the report. The auditor has to have access to calibration records of the company, the measurement plan should include calibration of the equipment (if practicable and feasible).

6.4 Measurement Process

For the measurement itself, there are three important stages during the implementation of the measurement plan, which are mentioned in the Annex of ISO 50002 and shown in Figure 6.1. This figure can be used as a checklist for planning the measurement.

6.5 Choice of Measurement Equipment for Motor Driven Systems

The selection of the right measuring instrument is another important point of the measurement plan. Table 6.1 includes recommendations for measurement equipment for all motor driven systems (fan systems, pump systems, compressed air systems, and electric motors) which are discussed in the audit methodology.
In general, safety has highest priority when determining energy consumption of motor driven systems. To determine the load of motor systems as well as voltage unbalance and power factor, voltage and current measurements are necessary. But due to adherence to safety practices and requirements, and also to the inaccessibility of electrical lines and the size of a current transducer, this may be not possible or too time-consuming. For motors that are constantly loaded above 50% of their rated load, voltage compensated current measurements may be adequate to estimate motor load. For measurement of power, the power meter should have the following features to produce relevant results:

- A true root mean square (RMS) meter should be used to measure distorted current waveforms as drawn by non-linear loads like adjustable frequency drives. An RMS meter provides the real effective value of an AC current.
- The crest factor is a factor describing the shape of a current waveform, dividing the peak value of the cur-

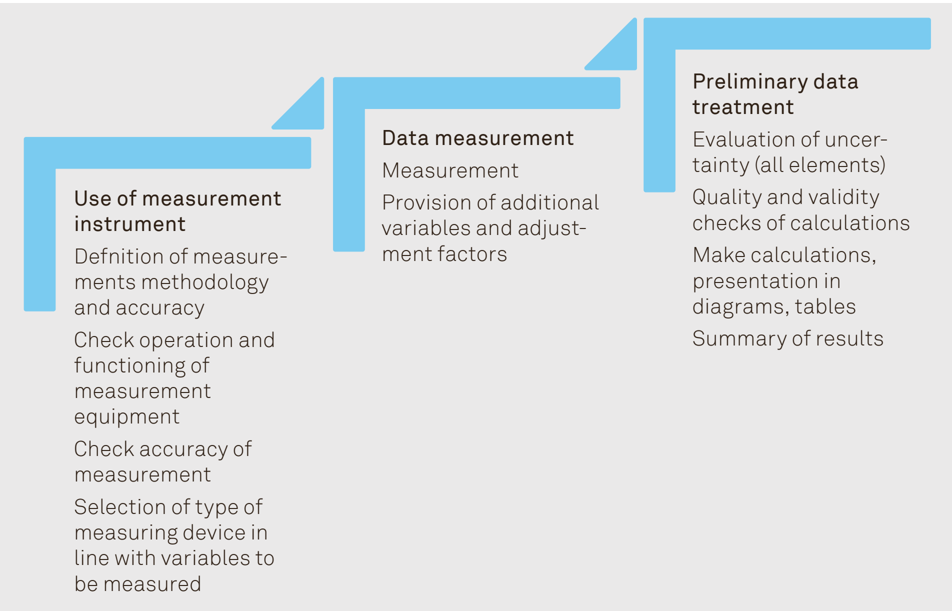

Figure 6.1: Stages of the development and implementation of a measurement plan (ISO 50002, Annex A7)

Application	Recommended measuring system (portable)	Recommended measuring system (stationary)
Electric motor	Electrical power consumption: Power meter	Electrical power consumption: Power meter
Fan system	Flow: ▮ Vane anemometer Electrical power consumption: ▮ Power meter	Flow: ▮ Differential pressure measuring method ▮ Vortex measuring method ▮ Hot-wire anemometer
Pump system	Flow: ▮ Ultrasonic flow measuring method (Clamp-on system) Electrical power consumption: ▮ Power meter	Flow: ▮ Differential pressure measuring method ▮ Electromagnetic measuring method
Compressed air system	Electrical power consumption: Power meter	Flow: ▮ Hot-wire anemometer Pressure: ▮ Manometer ▮ Thermic pressure transmitter

Table 6.1: Recommended measuring systems

rent by the effective true RMS value. For a perfect sinewave, the crest factor is 1.414. A power meter with a crest factor of 3 is recommended.
- “The bandwidth refers to the range of frequencies of the current within which the meter is capable of making accurate measurements” (Fluke, 2017). A distorted waveform consists of several sinewaves with frequencies which are multiples of 50 Hz. A meter with a bandwidth of 1 kHz is adequate in most commercial and industrial power systems.

For choosing the correct flow meter, the following parameters play an important role:
- Aggregate state
- Properties of the fluid to be measured
- Corresponding pipe diameter and material
- Pressure loss
- Operating pressure
- Operating temperature
- Reynolds number
- Inlet and outlet sections
- Flow direction
- Explosion protection
- Tubing
- Installation location (proper number of pipe diameters downstream from elbows, control valves, or other devices than can affect flow profiles)

Based on these criteria, the appropriate flow measurement method for the specific applications can be selected using Table 12.34 in the Appendix 12.3.3.

7 Conducting the Site Visit

This chapter describes how to conduct the site visit and, mainly, lists conditions that are often associated with inefficient system operation to be checked during the visit.
The site visit enables the energy auditor to evaluate the energy consumption according to the energy audit scope, boundary, audit objectives and agreed methods. In this phase, the energy auditor also generates preliminary ideas, possibilities, operational changes, or technologies that can lead to energy performance improvement.
During the field work, the energy auditor observes the energy uses within the organisation and compares them to the information gathered in the phase “Data Collection”. Very often not all information is available or not known to the company representative. Especially these areas should be checked on site. Processes for which additional information is needed should be listed. The auditor should ensure that measurements and past data are representative for normal operation, information on operational control and behaviours can be collected during the on-site visit.

During the site visit, the measurement or monitoring equipment should be installed and access to relevant documents should be provided (ISO 50002, 2014, chapters 5.6.2., 5.6.3).
While visiting the site, the energy auditor checks the criteria for motor systems to be further analysed and completes the data collection sheets for the appropriate systems. If general data collection showed that compressed air compressors are relevant, compressed air systems should be investigated in any case.

Motors	Pumps	Fans
▮ Motors with high energy consumption ▮ Old motors ▮ Motors with high maintenance requirements ▮ Motors with varying duties but fixed speed ▮ Undervoltage operation ▮ Voltage unbalance ▮ Support equipment ▮ Possibility to replicate recommended efficiency measure ▮ Inefficient drive systems (check couplings, gearboxes, belts)	▮ Pumps running independent of process requirements ▮ Pumping systems where significant throttling takes place ▮ Pumping systems with recirculation of flow used as a control scheme ▮ Pumping systems with large flow or pressure variations ▮ Systems with multiple pumps where the number of operated pumps is not adjusted in response to changing conditions ▮ Systems serving multiple end uses where minor user sets pressure requirements ▮ Cavitating equipment ▮ High vibration and/or noisy pumps, motors or piping ▮ Equipment with high maintenance requirements ▮ Systems for which the functional requirements have changed with time, but the pumps have not (pump no longer matched to system requirements) ▮ Worn, eroded, corroded, distorted or broken impellers/vanes or wear rings ▮ Indication of low pumping system efficiency (some systems do have a low efficiency because they have to pass solids) ▮ Deposit buildup within pipelines or pumps ▮ Seized valves or leaking recirculation valves ▮ Sealing systems, esp. high temperature, requiring cooling	▮ Running without need ▮ Variable demand (control strategies, e.g. CO_2 monitoring possible?) ▮ Significant changes to the system since installation (change of flow rate by more than 20%) ▮ Constant throttling ▮ Worn, eroded or broken blades ▮ Pressure loss across filters ▮ Air is extracted from whole hall (instead of specific location) ▮ Maintenance plan indicates problems

Table 7.1: Indicators for saving potential to be checked during on-site visit (UNIDO, 2012, ISO 14144, 2016)

8 Data Analysis

Step 6 of the audit comprises three activities:

- Analysis of current energy performance: establishment of baseline annual energy use and energy use per unit of production
- Identification of improvement opportunities
- Evaluation of improvement opportunities
- For the most important energy-saving measures per technology, criteria, descriptions, and formulas are given in the Appendix 12.4.

During these steps, in which the energy auditor evaluates the validity and availability of the data provided, he or she is required to use transparent and technically appropriate calculation methods. He or she has to document the various methods used and the assumptions or estimates made during the execution of their calculations. In this way, transparency is ensured and possible future corrections can be done more easily. Furthermore, the auditor should ensure that the indicators that affect measurement uncertainty and the effects of the measurement results have been taken into account (ISO 50002, 2014).

8.1 Analysis of Current Energy Performance

The determination of the current energy performance is the basis for evaluating improvements. Thus, the energy auditor carries out an evaluation of the existing energy performance indicators and suggests new indicators. The current energy performance of electric motor systems can be evaluated mainly by the following indicators (ISO 50006, 2014):

- Energy use, e.g. compared to other motor systems installed, can be used to identify significant energy users. It does not measure energy efficiency as it considers total energy demand only.
- Specific energy: The disadvantage of this indicator is that it does not take account for base-load effects while considering only one variable); therefore low load points have higher specific energy demand. On the other hand, this indicator can show that the control strategy for this motor system can be improved or that the driven equipment is oversized relative to process requirements.
- Relationship of the energy consumption or power demand to other relevant indicators, e.g. the pump/fan flow rate

The following indicators can be used for on-site measurements and monitoring of energy performance (see Table 8.1).

The first general analysis for motor driven systems was already described in the step of the data collection: The energy consumption of the various motor systems on site was calculated by using running hours and nameplate data. Further indicators can be derived sometimes by using manufacturer, planning and operational data. For several indicators, measurements are necessary. This process is sometimes time-consuming and includes not only measurements of power but also other indicators (flow, pressure), and therefore is not possible for all audits.

8.2 Identification of Improvement Opportunities

The energy auditor should start with determining the needs of the system and, then, should evaluate the design and configuration options to address these needs accordingly. Information gathered during the data analysis (operating lifetime, condition, operation and level of maintenance of the audited objects) are crucial factors in this phase. The energy auditor should also consider the future energy use and the possible changes in operation of the audited object, company, or process.

	Indicator	Source, state of the art
Compressed air	P_{el}/Flow [kW/Nm³] [Wh/Nm³]	ISO 50006, 2014 Value should be below 120 Wh/Nm³ Very good systems have values of 80-100 Wh/Nm³ For "normal" 7 bar systems, without extensive air treatment (Kulterer et al. 2015)
Pumps	P_{el}/Q [kW/(m³/h)] Efficiency of pump $\eta_P = \frac{\rho \cdot g \cdot Q \cdot H}{P_{el} \; 367000 \cdot \eta_M}$	ISO 14144 (2016) Own source (deviated formula) for pump efficiency (hydraulic power/power input to shaft)
Fans	$P_{SFP} = \frac{P_{el}}{\dot{V}_{Net}} = \frac{\Delta p}{\eta_{Ges}}$	Specific fan power in [W/(m³/s)] Value should be SPF class 4: 1,251-2,000 [W/(m³/s)] (Gerstbauer et al., 2017) Old systems: 5-10 W/(m³/s)
Cooling systems	[kWh/MJ]	ISO 50006, 2014

Table 8.1: Examples of indicators for current energy performance of motor driven systems

When identifying opportunities, the following measures should be considered (according to EN 16247-3):

- Measures in order to reduce or to recover the energy losses (e.g. reduction of leakage of compressed air, waste heat recovery)
- Replacement, modification, or addition of equipment (e.g. variable speed motor)
- More efficient operation and continual optimisation (e.g. set point adjustment, maintaining)
- Behavioural change and improvement of energy management (e.g. metering)

The following table gives an overview of possible/the most important technical energy-saving measures in the field of motor driven systems. For the most important energy-saving measures per technology, criteria, descriptions, and formulas are given in the Appendix 12.4.

Motor driven system	Most important saving measures
Motors	▮ Switch off ▮ Installing frequency converter ▮ Replacement of motor (correct sizing, adapted to load) ▮ Replacement of transmission system
Pumps	▮ Reduction of running time ▮ Optimised control of pumps ▮ Motor-, pump replacement ▮ Reduction of static head ▮ Reduction of dynamic head (improving of distribution network) ▮ Reduction of flow ▮ Improved maintenance procedure
Fans	▮ Reduction of running time for fans ▮ Flow rate adjustment ▮ Installing frequency converter ▮ Motor-, fan replacement ▮ Replacement of transmission system ▮ Heat recovery ▮ Maintenance, reduction of pressure loss
Compressed Air	▮ Reduction of leakages ▮ Optimisation of system pressure ▮ Change control strategy/reduction of idle part ▮ Shut down of compressors ▮ Heat recovery ▮ Alternatives for inappropriate end uses

Table 8.2: Most important saving measures for motor driven systems (see Appendix 12.4 for details with respect to applicability of saving measure)

8.3 Evaluation of Improvement Opportunities

The evaluation of the energy-saving measures includes the impact on the energy performance, the potential energy and financial savings, calculation of life cycle costs including non-energy gains, and the ranking of the opportunities according to the criteria defined together with the company during the opening meeting (EN ISO 50002, 2014, p. 10-11).

The financial evaluation of the energy-saving measures usually includes estimates of the energy auditor based on their experience, taking into consideration discounted list prices of suppliers or specific offers. Experienced auditors try to get in contact with suppliers already during other audit steps (Data Acquisition, Data Analysis, On-Site Visit) to get prices and collect information on hourly rates for installation costs.

Usually at this stage, companies have already defined how they want the financial evaluation of energy-saving measures to be done.

In Europe, the EU Efficiency Directive (EU 2012/27/EU, Annex VI]) supports life-cycle cost analysis to be used instead of Simple Payback Periods (SPP) in order to take account of long-term savings, residual values of long-term investments, and discount rates.

According to the ISO 50002, non-energy gains (other benefits than energy savings) should be considered. Energy-saving measures can contribute to the following topics: energy, maintenance, quality, productivity, financial (sales), environmental, health, and safety. Table 8.3 shows non energy-gains which can be relevant for motor driven systems. These non-energy gains should be evaluated, if possible quantified together with the company representatives and included in the life-cycle cost assessment.

ISO 50002 stipulates to recommend measurement and verification methods for use in post-implementation assessment of the proposed energy-saving measures. In

Waste	Emissions	Operation and maintenance
Use of waste heat (e.g. chillers, compressed air, motors)	Reduced CO2 emissions, (because of less electricity consumption)	Reliability Reduced wear and tear on equipment Reductions in labour requirements
Production	**Working Environment**	**Other**
Increased product output Improved equipment performance Shorter process cycle times Improved product quality, air quality	Reduced noise levels Improved temperature control Improved air quality	Decreased liability Improved public image, supporting sustainability goals Reducing capital expenditures Improved worker morale

Table 8.3: Non-energy gains relevant for motor driven systems (Worrel et al., 2001)

addition to the parameters associated directly with the system and the saving measure (power and running time), other parameters have to be measured or estimated as well (see Table 8.4, EVO, 2012, and NSW, 2012 for further details). This approach can be very useful in some cases, examples are:

- For contracting projects
- For the evaluation of the saving measure afterwards, e.g. when energy-saving measure is planned to be replicated several times in the same plant
- When utility conservation savings must be validated to count towards meeting goals set by state regulatory bodies
- Measures can be sold afterwards within a White Certificate programme

8.4 Tools for Data Analysis

An electric motor system consists of several components which must be coordinated with one another. Not only the determination the efficiency of an existing, old electric motor system, but also the assessment of the effects of increased energy efficiency during a new installation requires extensive calculations. In order to assist technicians and energy auditors in system optimisation, several international tools exist (see Table 8.4 for an overview of tools available in English language).

The EMSA Motor Systems Tool is able to calculate the efficiency factor of various motor systems and provides technical support in selecting the optimal components. It dynamically calculates how the change in speed, operating point, or other elements affects the overall system efficiency. In addition, the tool contains models for pumps,

Parameters	Examples
Independent variable	Operating time, production, required flow and pressure Outside (or inlet air) temperature and humidity
Static factors	Number, capacity and usage model of all systems supplied (if relevant: production speed and production mix, system pressure change) Standard requirements for air quality (for fans)

Table 8.4: Additional parameters to be measured or estimated for measurement, and verification of energy-saving measures in the field of motor driven systems (NSW, 2012)

Name and link	Description
Motor Systems Tool https://www.motorsystems.org/motor-systems-tool	Developed by the Danish Technological Institute within the Electric Motor Systems Annex, the Motor Systems Tool calculates the efficiency of a complete motor system (motor plus VSD, gear, transmission and driven equipment like pump, fan, compressor, other). It is intended to assist engineers, machine builders, machine component suppliers, energy consultants and others working on optimising machine systems to benefit from reduced electricity consumption. More information on the Motor System Tool is included in Appendix.
Topmotors Software Tools www.topmotors.ch/Tools	The Excel-based software STR (Standard Test Report) developed by the Swiss Topmotors programme of S.A.F.E. is a standardised template for a motor systems analysis protocol and helps to summarise motor test results and proposed motor systems efficiency measures together with the expected costs and savings.
AIRMaster+ http://www.energy.gov/eere/amo/articles/airmaster	AIRMaster+ is a free online software tool that helps users analyse energy use and savings opportunities in industrial compressed air systems. It can be used to benchmark existing and model future system operations improvements, and evaluate energy and dollar savings from many energy efficiency measures. AIRMaster+ provides a systematic approach to assessing compressed air systems, analysing collected data, and reporting results. AirMaster+ also incorporates interactive effects between multiple measures into its analysis methodology. It does not indicate cost-effectiveness of the saving measure.
Pumping System Assessment Tool (PSAT) http://www.energy.gov/eere/amo/articles/pumping-system-assessment-tool	PSAT, distributed by the U.S. Department of Energy (DoE), helps users assess energy-savings opportunities in existing pumping systems. It relies on field measurements of flow rate, head, and motor power or current to perform the assessment. Using algorithms from the Hydraulic Institute and standards and motor performance characteristics from the U.S. DoE Motormaster database, PSAT estimates existing pump and motor efficiency and calculates the potential energy/cost savings for a system optimised to work at peak efficiency. It does not indicate cost-effectiveness of the saving measure.
Fan System Assessment Tool (FSAT) http://www.energy.gov/eere/amo/articles/fan-system-assessment-tool	FSAT is a free online software tool that helps industrial users quantifies energy use and savings opportunities in industrial fan systems. It can be used to calculate the amount of energy used by a fan system, determine system efficiency, and quantify the savings potential of an upgraded system. The tool also provides a pre-screening filter to identify fan systems that are likely to offer optimisation opportunities based on the system's control, production and maintenance and effect. FSAT estimates the work done by the fan system and compares that to the system's estimated energy input. Using typical performance characteristics for fans and motors, indications of potential savings (in energy and dollars) are developed. It does not indicate cost-effectiveness of the saving measure.

Table 8.5: Examples of public, independent tools for the evaluation of motor driven systems (IEA-4E, 2016; Topmotors, 2014; US DOE, 2008, 2010a, 2010b)

fans and compressors, electric motors, as well as transmission types such as V-belts and frequency converters and other combinations of those (see Appendix 12.5.1 for details).

Another tool which can support the energy auditor in the energy analysis is called "Standard Test Report" and was published by topmotors.ch. This tool is used for standardised documentation of the actual and the target state (before and after the implementation of improvement measures) of motor driven systems. In the Appendix, the main function and features of the STR tool is described.

The U.S. Department of Energy developed motor system tools that model the whole system including the demand side for pumps, fans, cooling systems and compressed air. As an example, AIRMaster+ is a free online software tool that helps users analyse energy use and savings opportunities in industrial compressed air systems. The following saving measures can be evaluated with this tool:

- Reduced air leaks
- Improved end-use efficiency
- Reduced system air pressure
- Use of unloading controls
- Adjustment of cascading set points
- Use of automatic sequencer
- Reduction of run time
- Adding of primary receiver volume

These calculations rely on acquisition of hourly power data for each compressor and the identification of typical operating "daytypes". The software tool uses this information, along with a library of default compressor performance (by compressor type, size, air flow control type, and pressure setpoint) to develop an hourly baseline air flow profile for each daytype. The tool user can then implement measures that either reduce the air demand requirements or improve the efficiency of providing needed air flow. In this manner, the tool can be used to analyse both supply and demand side measures. Note that measurements taken when the plant is not in operation but with trim compressor running can be used to determine rates of compressed air leakage.

Furthermore, major motor manufacturers offer free tools for motor analysis and VSD analysis on their webpage in combination with the access to databases of motors offered by the relevant manufacturer.

9 Energy Audit Reporting

In this chapter, the step “Energy Audit Reporting” is described and the suggested table of contents for this report is given.

In various energy audit standards, the content of an energy audit report is stipulated. Thus, a report should contain the following elements:

1. **Executive summary:** The executive summary shall provide an overview of the whole energy audit process. It is recommended to emphasise the economic benefits.
2. **Introduction and facility information:** This section of the report should include a brief description of the background, the team, and scope of the electric motor system audit.
3. **Description of system(s) studied in assessment and significant system issues:** The report shall include a detailed description of the specific motor systems. Supporting documentation, such as data sheets and handbooks, should be included if necessary.
4. **Assessment data collection and measurements:** The methods used to identify and interview key facility personnel, obtain data, and conduct measurements shall be identified, including an overview of the measurement plan. The following relevant data should be included:
   - Definition of system requirements and a determination of how system operation changes during the year (drawings, system process data)
   - Electrical energy consumption data
   - Other specific data relating to the motor driven systems, such as pump total head, specific fan power, working pressure, flow, etc.
   - Determination of operating hours of the motor systems
   - Performance information of the motor system when available
   - Measurement or estimation of system losses

Also, information about data accuracy and the need for verification before the recommended projects are approved should be given in this section of the report.

5. **Data analysis:** The outcome of the measurements and data analysis should be mentioned in the report. Any significant analytical methods, measurements, observations, and results from the data analysis shall be documented.
6. If sufficient data exist, the assessment report shall contain the baseline of total annual energy consumption.
7. Performance improvement opportunities identification and prioritisation
8. Recommendations for implementation activities
9. Appendices

It has to be noted that the writing of the report can be time-consuming, therefore, it should be defined in the beginning with the company which elements of the report are most important for the company. Some audit companies already have audit report templates, even for major energy-saving measures, where the specific data only have to be filled in.

10 Closing Meeting

In this chapter, the closing meeting is described and some general information of this step is provided.
The final step of the energy audit is the closing meeting. Before the meeting, the report on the energy audit shall be provided to the organisation. At the closing meeting, the energy auditor should:

- Present the results of the energy audit in a way that facilitates decision-making by the organisation. The arguments can be similar to those discussed in the section “Opening Meeting”.
- Be able to explain the results and address questions
- If applicable, identify items requiring further analysis or follow-up by the energy auditor

The aim of the closing meeting is to motivate management to implement the recommended energy-saving measures. For example, it could be helpful to invite stakeholders to the presentation, that profit from the specific saving measures (e.g. installation company, controlling department, energy managers). The probability of the implementation will be even higher if those stakeholders were involved from the beginning and suggested or at least helped evaluating the proposed saving measures.
Therefore, it may be useful to hold meetings several times during an energy audit and summarise the key findings and define further steps. One example could be a presentation after a longer stay at the company, during an exit meeting (Gilbert McCoy, personal communication 2017).

11 Connection to Energy Management and Motor Policy

In this chapter, the last step of the energy audit methodology is described. It contains information on the connection of the audit results to the energy management and elements of a motor policy on company level after the audit itself, including purchasing recommendation and strategies for replacement and repair.

11.1 Connection to Energy Management

The presentation of the energy audit results is the last step of the energy audit, but for the company the work continues with the implementation of the energy-saving measures. The planning of the saving measures may involve further expertise (e.g. concerning subsidies, detailed knowledge on processes and equipment, measurements during additional periods of the year).

A part of the proposed activities, for example, may consist of a better monitoring system for the energy performance indicators. This can involve installation of new, permanent measurement points, visualising software reporting, and evaluation system. Usually, for this process, specific activities and responsible persons have to be specified. When following such indicators, it is possible to set realistic targets for the next year(s).

Other activities can involve the improvement of the maintenance activities, e.g. regular change of filters or regular detection of leakages. Furthermore, to change staff behaviour and operational procedures, internal or external training of employees may be required. Awareness of employees can be increased when suggestion schemes or general motivation events are organised.

All these activities can be structured and coordinated within the implementation of an energy management system according to ISO 50001.

11.2 Motor Policy

The saving potential might be very high in existing systems but most of the energy can be saved during the planning phase of motor systems and their supplied processes. Therefore, the critical point for energy efficiency is the replacement of old and the installation of new systems. The awareness of the involved stakeholders about the process should be high and the information should be ready within the company at this point of time.

Several activities dealing with energy management specific for motor driven systems can be summarised in a motor policy:

A motor policy provides a mid- and long-term strategy for the adoption of efficient motor systems throughout a company or plant, ideally to be integrated into the company's business planning framework. The aim is to achieve the most cost-efficient motor systems justified under the respective economic conditions.

A motor policy typically covers the following aspects, discussed in the following section:

- Process for planning new motor driven systems
- A set of purchasing criteria
- An inventory list
- Requirement for installation or acceptance tests
- Requirements for use of repair and maintenance best practices

11.2.1 Process Definition of New Motor Driven Systems

When replacing an old system or installing a new one, the following points should be determined (calculated, measured) in the beginning:

- Technical parameters for the system/equipment: How much shaft power is really needed for the process, e.g. for delivering defined flow rate, pressure, speed, torque?
- Torque-speed characteristic of driven equipment, e.g. quadratic, linear, constant
- Duty cycle according to IEC 60034-1, e.g. continuous or short time duty
- Definition of load profile, i.e. running hours per power requirement
- Specific characteristic of system/equipment (e.g. static head, programmed soft start necessary, severe-duty application)
- Application-specific characteristic, e.g. motor must withstand hot water sprays during clean up, cleanroom environment, or operation in an environment with the presence of potentially explosive fumes or dust

Based on this information, the responsible technical person can choose a motor, drive, and control system.

11.2.2 Purchasing Criteria

A motor policy extends traditional purchasing criteria to include consideration of life cycle costs, the energy efficiency of the motor, and the expected lifetime:

Selection should be based on life cycle costs. For example, motors with an efficiency class of IE3 (defined by IEC 60034-30) with an annual running time of 2,000 hours have lower life cycle costs than IE1 or IE2 Motors. IE4 Motors have even lower losses. The actual lifetime of a motor can be 20 to 30 years or even longer (see discussion of life time further below). This means that the benefits of high efficiency motors continue long after their payback time. In addition, the track record of suppliers should be taken into account.

Purchasing specifications should include:

- Consideration of modern drives for variable loads (especially for pump and fan applications)
- The selection of high efficient drives (direct drives, high efficient belts), avoiding worm gears
- The provision of technical information, dimensional drawing, installation and user manuals

- Where relevant, specifications should cover the correct installation of the motor according to best practice and commissioning

(Kulterer, Werle et al., 2014)

Specific motor lifetime is dependent upon numerous variables, such as storage conditions, ambient temperature, voltage variation, voltage unbalance, loading or overloading, maintenance and cleaning practices, on-off cycles, insulation class, and enclosure selection relative to airborne particulates and moisture, in addition to the type of VSD used (Gilbert McCoy, personal communication 2017).

11.2.3 Motor List

An on-site motor inventory enables companies to reduce downtime, increase production, and minimise operating costs. A spares inventory may not be required when a major motor distributor operates a supply warehouse within two hours of the company's factory, operates a 24-hour service line, and can, therefore, guarantee delivery of a new high efficient motor within two hours.

Due to the need to maintain operations, failing motors are often replaced by those already in stock, which may not be the most efficient models available. For the quick exchange of old motors with high efficient motors the following steps can be taken:

- Establishing an inventory list of in-service motors
- Creating an inventory of motors in stock (nameplate data and potential application): This inventory should be expanded to include high efficient motor replacements for ratings where multiple identical motors are in-service (i.e. same kW and voltage rating, number of poles, enclosure type).
- Establishing a simple rule to identify when repair or replacement is recommended: The rule can be based according to motor rating (e.g. replace at failure all motors up to 30 kW), and could include consideration of running hours and costs of repair as a percentage of a new motor cost. For developing this rule, costs of replacing the motor, price of electricity, and the efficiency of a high efficient motor and of the old motor after rewind have to be considered.
- Developing a plan for replacing motors, depending on age, size, running time, time for maintenance: If the factory has implemented a predictive maintenance programme, motor performance is trended with the motor scheduled to be exchanged at an opportune moment prior to failure – thus, avoiding costly downtime with associated losses of productivity. This provides an ideal setting for upgrading to a high efficient motor.
- Replacing motors in use (if low efficiency and high energy demand) during factory downtime
- Replacing failed standard motors by IE3 or IE4 motors
- Arranging with the retailer to stock high efficient motors (IE3)
- For several critical motors and motor sizes, it is recommended to keep one's own stock of high efficient motors.

(Kulterer, Werle et al., 2014, adapted by Gilbert McCoy, personal communication 2017)

11.2.4 Requirement for Installation or Acceptance Tests

Failure to pay attention to detail when commissioning electric motors and motor-driven equipment can reduce the efficiency, lead to higher operating costs and an increased risk of early motor or equipment failure.

A thorough commissioning should be done after:

- new equipment is installed,
- existing equipment has undergone significant repair;
- and a considerable change in the operating requirements of a machine has been implemented.

During the commissioning process, the specifications of the supplied equipment should be checked to ensure they follow the process design requirements. It should be verified that the equipment is set up correctly, mechanically, and electrically in accordance with the original manufacturer's specifications, and that the equipment documentation is complete, i.e. installation requirements, operation guidelines, and maintenance specifications (Kulterer, Werle et al., 2014). It is imperative to ensure that operators are provided with training that enables them to know how to operate machinery in the most efficient manner.

11.2.5 Requirements for Repair and Maintenance

Motor rewinding is a common practice in industry as, above a certain size, it can be a cheaper and quicker solution than purchasing a new motor. Depending on labour and motor prices, this size can be, for instance, a 10 or 30 kW for standard motors.

However, the efficiency of an existing motor can be quite low because of its age and rewinding can reduce efficiency even further. Therefore, the economics of replacing a motor with a new model can compare favorably to those of repairing because of the gains in efficiency and higher operating hours. For small standard efficiency and even high efficiency motors, rewinding is usually not the best option because the price of a new motor is cheaper than the price for repairing the old motor.

Nevertheless, motor rewinding is often economical for special purpose motors and AC motors above certain sizes. When rewinding is the selected path, the repair shop should be approved by the ANSI/EASA Standard AR100-2015: Recommended Practice for the Repair of Rotating Electrical Apparatus. The checklist of the EASA Accreditation Programme (EASA accreditation checklist) can be used by the motor repair shop. Core loss tests should be made prior to the repair to ensure that the motor has not suffered degradation, for instance, during prior repairs. A core loss test made after the repair can ensure that no damage occurs during the current motor repair.

12 Appendix

The Appendix gives detailed information on the implementation of the various audit steps. For each part of the Appendix, it will be indicated in brackets to which step that specific part relates.

12.1 Checklist General Information (Step 1: Audit Planning)

Company profile			
Company name:			
Address 1:		Telephone:	
Address 2:		Fax:	
City/Town:		E-Mail:	
Region/Country:			
Post/Zip Code:			
Electric motor system site address (if different than company address)			
Address 1:			
Address 2:			
City/Town:			
Region/Country:			
Post/Zip Code:			
In which industrial sector does the company operate?			
☐ Food	☐ Textile/clothing	☐ Wood/paper/print	☐ Chemical/ pharmaceutical industry
☐ Mechanical engineering/ metal construction	☐ Automotive industry	☐ Electrical engineering/ electronics	☐ Glass/stone/earth
☐ Power engineering	☐ Building technology	☐ Basic materials industry	☐ Rubber and plastic products
☐ Supply/disposal	☐ Others:		
For what are the electric motor systems used? (e.g. for control, power generation processes, chemical processes, …)			
Number of employees		.... employees	
How many shifts are there?		.... shifts	
Working time			
Weekday	Time	Weekday	Time
Mon	From .... to	Fri	From .... to ....
Tue	From .... to		
Wed	From .... to	Sat	From .... to ....
Thu	From .... to	Sun	From .... to ....
.... annual operating hours			
Contact person			
Name:			
Function:			
Address:			
Phone:			
E-Mail:			

Table 12.1: Checklist – general information (VDMA 4370, 2012, p. 16-17; EN ISO 11011, 2013, p. 32)

12.2 Technology-Specific Data Collection Sheets (Step 3: Data Collection)

All tables show the required data for the specific data collection of electric motors in industrial companies as well as examples and the corresponding units. The tables can be used as a check list, which is assumed to help the energy auditor collect the appropriate data in an efficient way. If possible, for the main systems, pictures should be added with name of system, date of visit and name of photographer.

12.2.1 Motor Data

General motor data		
Required data		**Unit**
Coupling type (belt, gear, direct, etc.)		[-]
Motor type (design AC or DC, etc.)		[-]
Motor history (original, rewound or replaced)		[-]

Table 12.2: General motor data (McCoy et. al., 2000)

Specific motor data		
Required data		**Unit**
Manufacturer		[-]
Motor ID number		[-]
Model		[-]
Serial number		[-]
Power		[kW]
Full load speed		[min^{-1}]
Full load voltage		[V]
Full load amperage		[A]
Full load power factor		[-]
Full load efficiency (4/4)		[%]
Part load efficiency (3/4)		[%]
Part load efficiency (2/4)		[%]
Efficiency class (if provided)		[-]
Frame designation		[-]
Unusual operating conditions		[-]

Table 12.3: Specific motor data (McCoy et.al., 2000)

Operating profile motor data		
	Weekdays Days/Year_____	Weekend/Holiday Days/Year_____
Hours per day	1st shift ________ 2nd shift ________ 3rd shift________	________ ________ ________
Annual operating time________ hours/year		
Thereof: Part load________ % Full load ________ %		

Table 12.4: Operating profile motor data (McCoy et.al., 2000)

12.2.2 Pump System Data

Electrical motor/drive data		
Required data		Unit
Manufacturer		[-]
Motor type (design AC or DC, etc.)		[-]
Coupling type (belt, gear, direct, etc.)		[-]
Motor history (original, rewound or replaced)		[-]
Power		[kW]
Motor full load speed		[min^{-1}]
Motor full load voltage		[V]
Motor full load amperage		[A]
Full load efficiency		[%]
Efficiency class (if provided)		[-]
Frequency converter		[-]
Frame size		[-]

Table 12.5: Electric motor data

Specific pump data		
Required data		Unit
Manufacturer		[-]
Pump type		[-]
Shaft power		[kW]
Flow		[m^3/h] or [l/s]
Static/variable flow		[-]
Throttle (pressure side)		[-]
Pump history (original or replaced)		[-]
Operating pressure		[bar]
Operating temperature		[°C]
Suction pressure		[bar]

Table 12.6: Specific pump data

Pump control data		
Variable speed drive (VSD)		[-]
Throttled		[-]
By-pass/recirculation		[-]
On/off		[-]
Pumps in series or in parallel, or split duty		
Not controlled		[-]

Table 12.7: Pump control data

VSD data		
Manufacturer		[-]
Model		[-]
Maximum current		[A]
Description of control parameter		[-]
Power loss		[W]

Table 12.8: VSD data

Transport and distribution system data		
Required data		Unit
Piping material		[-]
Diameter		[mm]
Open/closed system		[-]
Number of installed pumps		[-]

Table 12.9: Transport and distribution system data

Built-in fittings and data of consumers		
Required data		Unit
Name of the process		[-]
Total flow requirement		[m³/h]
Total pressure requirement		[bar]
Simultaneity of the individual components		[-]

Table 12.10: Built-in fittings and data of consumers

Liquid properties data		
Required data		Unit
Name of liquid		[-]
Dynamic viscosity		[mPas]
Temperature		[°C]
Density		[g/cm³]
Presence of solids and their characterisation		[-]
Free gas percentage		[-]
Hazards		[-]
Inflammability		[-]

Table 12.11: Liquid properties data

Additional system data		
Required data	Example	Unit
Unusual operating conditions		[-]
Static head (only for rotor dynamic pumps)	2	[bar]

Table 12.12: Additional system data

Operating profile pump system data		
	Weekdays Days/Year_____	Weekend/Holiday Days/Year_____
Hours per day	1st shift ________ 2nd shift ________ 3rd shift________	________ ________ ________
Annual operating time________ hours/year		
Thereof: Part load________ % Full load ________ %		

Table 12.13: Operating profile

12.2.3 Fan System Data

Electrical motor/drive data		
Required data		Unit
Manufacturer		[-]
Motor type (design AC or DC, etc.)		[-]
Coupling type (belt, gear, direct, etc.)		[-]
Motor history (original, rewound or replaced)		[-]
Power		[kW]
Motor full load speed		[min^{-1}]
Motor full load voltage		[v]
Motor full load amperage		[A]
Full load efficiency		[%]
Efficiency class (if provided)		[-]
Frequency converter		[-]
Frame size		[-]

Table 12.14: Electric motor data

Specific fan data		
Required data		Unit
Manufacturer		[-]
Model		[-]
Serial number		[-]
Year		[-]
Fan type		[-]
Impeller diameter		[-]
Shaft power		[kW]
Efficiency class fan (if provided)		[-]
Specific nominal flow		[m³/h]
Fan diameter		[mm]

Table 12.15: Specific fan data

Fan control data		
Flow control method		[-]
Pressure control method		[-]
Examples:		
Variable speed drive (VSD), which HZ	no	[-]
Throttled, which damper position	Yes	[-]
By-pass/recirculation	no	[-]
On/off	no	[-]

Table 12.16: Fan control data

VSD data		
Manufacturer		[-]
Model		[-]
Maximum current		[A]
Description of control parameter		[-]
Power loss		[W]

Table 12.17: VSD data

Coupling		
Required data		Unit
Driver coupling		[-]
Pulley diameter (motor side)		[-]
Pulley diameter (fan side)		[-]
Estimated efficiency		[%]

Table 12.18: Coupling data

Distribution channels		
Required data		Unit
Length		[m]
Diameter		[mm]
Material		[-]
Filter differential pressure		[MPa]
Type and number of fittings		[-]
Table 12.20: Specific air characteristic		
Specific air characteristics		
Required data		Unit
Temperature inlet/outlet		[°C]
Air quality inlet/outlet		[-]
Hazard ingredients		[-]

Table 12.19: Distribution channel data

Data of consumers and fittings		
Required data		Unit
Name of the process		[-]
Total flow requirement		[m³/h]
Total pressure requirement		[MPa]

Table 12.21: Data of consumers

Additional fan system data		
Required data		Unit
Unusual operating conditions		[-]
Static pressure of the fan system (if provided)		[Pa]
Design minimum velocity for extraction systems		[m/s]

Table 12.22: Additional fan system data

Operating profile fan system data		
	Weekdays Days/Year_____	Weekend/Holiday Days/Year_____
Hours per day	1st shift ________ 2nd shift ________ 3rd shift________	________ ________ ________
Annual operating time________ hours/year Thereof: Part load________ % Full load ________ %		

Table 12.23: Operating profile fan system data

12.2.4 Compressed Air System Data

Compressor data		
Required data		Unit
Manufacturer		[-]
Model/serial number		[-]
Year of construction		[-]
Compressor type		
Reciprocating, rotary screw (oil-lubricated or oil-free), vane, turbo (centrifugal, axial)		[-]
Lubricated (yes, no)		[-]
Coolant (water, oil, air)		[-]
Drive motor power rating		[kW]
Electric power consumption at operating pressure and nominal flow		[kW]
Max. operating pressure		[bar]
Nominal Flow at operating pressure		[m³/min], [l/s] or cfm
Power consumption when unloaded (for rotary-screw compressors)		[kW]
Pressure area: load, unload		[bar]
Full load hours		[-]
Part load hours		[-]
Total running time		[-]

Table 12.24: Compressor data

Control		
Required data		Unit
Type of control		[-]
Automated control		[-]
Speed control, throttling, bypass control		[-]
Modulating, load/unload, multi-step		[-]
Multi-compressor control		[-]

Table 12.25: Compressed air system control data

Dryer information		
Required data		Unit
Manufacturer		[-]
Model		[-]
Year of construction		[-]
Dryer type: refrigerated or cycling refrigerative, adsorption (heatless, heat regenerative), absorption, membrane		[-]
Pressure dew point		[°C]
Air treatment capacity at stated dew point		[m³/h]
Pressure drop		[bar]
Nominal electrical power		[kW]
Control type (VSD, none)		[-]

Table 12.26: Dryer information

Air receiver information		
Required data		Unit
Manufacturer		[-]
Model/serial number		[-]
Year of construction		[-]
Volume		[m³]
Working pressure		[bar]

Table 12.27: Air receiver

Additional compressed air system data		
Required data		Unit
Unusual operating conditions		[-]
Type of condensate drain (manual, level controlled, time controlled)		[-]
Heat recovery (yes/no)		[-]
Leakage detection and elimination programme in place (yes/no)		[-]

Table 12.28: Additional compressed air system data

Piping systems information		
Required data		Unit
Pipe material		[-]
Pipe diameters		[mm] [DN]
Pipe lengths		[m]
System pressure drop		[bar]
Leakage rate		[%]

Table 12.29: Compressed air piping system

End-use applications/Consumer		
		Unit
Name of consumption process		[-]
Flow rate /or intermittent		[l/s]
Current (flowing) pressure		[bar]
Necessary pressure		[bar]
Duration		h/day
Vacuum applications (yes/no)		[-]
Cleaning applications (yes/no)		[-]
Blowing application: Engineered nozzles or air knives installed?		[-]

Table 12.30: End-use data

Operating profile compressed air system data		
	Weekdays Days/Year_____	Weekend/Holiday Days/Year_____
Hours per day	1st shift ________ 2nd shift ________ 3rd shift________	________ ________ ________
Annual operating time________ hours/year		
Thereof: Part load________ % Full load ________ %		

Table 12.31: Operating profile for compressed air system

12.3 Measurement Points and Selection of Technologies for Flow Measurement (Step 4: Measurement Plan)

12.3.1 List of Current Measurement Points

Place of measurement	Measured energy consumer/ processes	Number of measuring equipment	Measurement principle	Interval of meter reading	Last calibration	Accuracy
Compressor room	Work shop	L 47	Meter/electromagnet	monthly	April 2011	5%

Table 12.32: Table for establishing a list of current measurement points (with an example)

12.3.2 List of Possible Measurement Points

In the following table, test points for measurements on site are identified. Not all points are valid for all systems and additional points can be required, therefore, the actual points used shall be identified in the assessment plan (ISO 11011).

	Motors	Fans	Pumps	Compressed air pressure, flow and electrical test points
Supply	Power meter	▮ Fan differential pressure Filter differential pressure ▮ Flow measure-ment	▮ Suction side of pump (pressure, flow) ▮ Discharge side of pump (pressure, flow)	Examples are: compressor discharge, up- and downstream of pressure, flow controls and supply-side treatment equipment
Distribution network		▮ Filter pressure drops ▮ Duct supply pressure	▮ Pressure loss in distribution network	Entrance to distribution piping, up- and downstream of treatment equipment, pressure, and flow controls
End-consumer		▮ Flow and pressure measure-ments	▮ Flow and pressure measurements	Specific point of use up- and downstream of treatment equipment, flow control valves

Table 12.33: List of possible measurement points (IS 14414, 2016; ISO 11011, 2013: C 1, D1, E1; EMANZ, 2017)

12.3.3 Criteria for Selection of Flow Measurement

	Properties of the medium										Properties of the measuring section & instruments										
Measuring Methods	Liquid	Gaseous	Steam	Clean	Dirty/Polluted	Chemically strongly agressive	Solids content	Gas bubbles	No electrical conductivity	Viscosity	Small tube diameter DN 2-25	Huge tube diameter DN 200-2500	Low pressure loss Δp	High operating pressure > 40bar	High operating temperature > 120°C	Samll Re-Numbers (10-10000)	Short inlets and outlets	Dynamic range (mesurement)	Mesurement accuracy	Reproducibility	Explosive environment
Electromagnetic	1	5	5	1	3	2	1	5	5	5	1	1	1	1	1	1	1	100/1	0,2-0,5% m.v.	0,1% m.v.	1
Variable area flowmeter	1	1	4	1	5	3	5	4	1	5	1	5	2	1	1	3	2	10/1	0,5 – 1% FS	k.A.	4
Blind	1	1	1	1	4	5	4	4	1	5	2	3[1]	4	1	1	3	5	10/1	0,6 – 2% FS	0,5% m.v.	5
Venturi-tube	1	5	5	1	2	4	4	n.a.	1	5	2	3[2]	3	1	1	3	5	10/1	0,6 – 2% FS	0,5% m.v.	n.a.
Ultrasonic-run-time	1	5	5	1	5	1	3	5	1	5	3	1	1	1	1	3	4	20/1	0,5% m.v. – 2% FS	0,25% m.v.	n.a.
Ultraschall-Doppler	1	5	5	5	5	1	3	5	1	5	5	1	1	1	1	5	4	20/1	1% m.v. – 2% FS	0,5% m.v.	n.a.
Coriolis	1	1	1	1	2	1	2	3	1	1	1	4	4	1	1	2	1	100/1	0,05 – 0,2% m.v.	0,2% m.v.	n.a.
Vane anemometer	5	1	5	n.a.	n.a.	n.a.	n.a.	n.a.	1	5	1	1	1	n.a.	2	n.a.	n.a.	n.a.	3% m.v.	n.a.	n.a.
Vortex	1	1	1	1	4	5	5	4	1	5	3[4]	3[5]	3	2	1	3	4	10/1	0,5 – 1% m.v.	0,2% m.v.	n.a.
Hot-wire anemometer	1	1	5	n.a.	n.a.	n.a.	n.a.	n.a.	1	5			1	5	2	n.a.	n.a.	10/1	1,5% m.v.	n.a.	n.a.

Rating scale			
Very good	1	[1]	up to DN1000 and > Rating: 5
Good	2	[2]	up to DN4000
Practical	3	[3]	up to DN150
Able	4	[4]	only from DN15, < Rating: 5
Not able	5	[5]	up to DN400, > Rating: 5
Not available	n.a.		
Of full scale	FS		
Of measured value	m.v.		

Table 12.34: Criteria for selection of flow measurement (Kulterer, Presch, 2015)

12.4 Indicators and Calculation Formulas for Energy-Saving Measures (Step 6: Data Analysis)

In this part of the Appendix, the most relevant energy-saving measures for each technology are described roughly in a uniform way: indicators for this saving measure, short description and formula.

12.4.1 Electric Motors

Title	Switch off motors when not needed
Indicators	▮ Running (when not needed) on holidays, weekends, nights, too long before shift, finishes too long after shift, breaks ▮ Running continuously where loads are irregular (batch operations, irregularly used services, switch off one of a bank of machines)
Description	Switch off motors when not needed.
Formula	$\Delta C = P_{el} \cdot (t_{before} - t_{after}) \cdot c(E)_{el}$
Recommended parameters for measurement and verification (M&V)	Measurement of running time and/or current over a representative time period (before and after), keeping other variables constant.

Table 12.35: Switch off motors when not needed

Title	Motor replacement
Indicators	▮ high run-times of the electric motor ▮ high age of the electric motor ▮ low electric motor efficiency ▮ wrong sizing, not adapted to load
Description	Replacing the old inefficient (or oversized) electric motor with a new, more efficient one. The energy-saving potential is depending on the load profile of the motor.
Formula	This calculation has to be done for each load point with the efficiency at the specific load point. $\Delta C = P_N \cdot load \cdot t \cdot \left(\frac{1}{\eta_{old}} - \frac{1}{\eta_{new}}\right) \cdot c(E)_{el}$
Recommended parameters for M&V	Measurement of power drawn over a representative time period (before and after), keeping other variables constant.

Table 12.36: Motor replacement

Title	Drive replacement
Indicators	Old drive belts or gear boxes in place
Description	Replacing the old inefficient drive with a new, more efficient one
Formula	$\Delta C = P_e \cdot t \cdot \left(1 - \frac{\eta_{Drive\ before\ opt.}}{\eta_{Drive\ after\ opt.}}\right) \cdot c(E)_{el}$
Recommended parameters for M&V	Measurement of power drawn over a representative time period (before and after), keeping other variables constant.

Table 12.37: Drive replacement

12.4.2 Pump System Saving Measures

Sources for this chapter are: Hofmann, Kulterer, 2009; ISO 14414, 2016.

Title	Reduction of running time for pumps
Indicators	▮ Running (when not needed) on holidays, weekends, nights, too long before shift, finishes too long after shift, breaks ▮ Running continuously where loads are irregular (batch operations, irregularly used services, one of a bank of supplied machines is switched off on a regular basis) ▮ Systems with multiple pumps where number of operating pumps is not adjusted in response to changing conditions
Description	The first measure to reduce the run-time is to switch off pumps which are not needed. In addition, the operating time of all pumps should be adjusted to the actual required operating time. For example time, temperature, pressure and level control (level indicators) are simple control mechanisms for adjusting the operating time of the pumps to the process.
Formula	$\Delta C = P_{el} \cdot (t_{before} - t_{after}) \cdot c(E)_{el}$
Recommended parameters for M&V	Measurement of running time and/or power drawn

Table 12.38: Reduction of running time for pumps

Title	Optimised control of rotodynamic pumps
Indicators	▮ Demand vary with throughput, temperature, product type ▮ Pumping systems with large flow or pressure variations ▮ Low temperature difference in heating or cooling systems (esp. during spring/autumn) Depending on system characteristics following options are possible: ▮ VSD: variable flow rate with higher variation – optimal control range ▮ 40 to 90% ▮ Parallel pumps: when it is possible to reach variable flows by switching on/off ▮ Impeller trimming: difference of flow rate to design conditions < 40% and flow rate is constant
Description	This measure consists of controlling the pump to adapt the flow according to the need. This can be done by a frequency converter. For old motors, it has to be checked if a frequency converter can be installed to the motor (as the insulation of windings may be inappropriate). The energy-saving potential can be calculated by using the real pump curve and the calculated system curve. For each load (flow) point, this has to be calculated separately. The head is depending on the flow rate: For frequency converters, the head follows the system curve, for throttling, however, it is according to the pump curve. In reality, the frequency converter cannot fully follow the system curve (esp. in part load). For closed systems (only friction head, no static head), the formula can be simpler.
Formula	For the determination/calculation of energy consumption with throttle before optimisation, either measurements, data from the datasheet of the pump, or the following simplified formula for the pumping curve can be used (when throttled, head follows the pumping curve). $H_{Partload} = (H_m/{n_m}^2) \cdot n^2 + (H_r - H_m)/{Q_m}^2 \cdot {Q_{Partload}}^2$ $P_{e\_before} = \frac{\rho \cdot g \cdot Q_{\_before} \cdot H_{\_before}}{367000 \cdot \eta_P \cdot \eta_M}$ Before system optimisation "Q,H_{before}" corresponds to "Q,$H_{Partload}$". When using a frequency converter, the head follows the system curve, specifically, in systems with static head. Therefore, the formula for the head in part load (not full flow) is given. When the frequency converter is used (as suggested) to adapt the flow, the calculation has to be done for each load/flow point.

	$$H_{Partload} = H_s + (H_r - H_s)/Q_r^2) \cdot Q_{Partload}^2$$ Calculation of electric consumption at part load for frequency converter: $$P_{e\_FU\_after} = \frac{\rho \cdot g \cdot Q_{\_after} \cdot H_{\_after}}{367000 \cdot \eta_P \cdot \eta_M \cdot \eta_{FU}}$$ The head is reduced because of using a frequency converter, the flow Q_{after} is the same as Q_{before} when not changed during optimisation. $$\Delta C = (P_{e\ before} - P_{e_{after}}) \cdot t_{before} \cdot c(E)_{el}$$
Recommended parameters for M&V	Measurement of power drawn, measurement of running time or flow delivered.

Table 12.39: Optimised control of pumps (Kulterer, Hofmann, 2009; da Costa Bortoni et al., 2008)

T itle	Pump/motor replacement
Indicators	▮ Large pumps with long running times ▮ Current flow rate differs more than 30% from nominal flow ▮ Current head differs more than 20% from nominal head ▮ Low efficiency (below 60%, exception: pump systems with solids) ▮ Cavitating equipment, high maintenance requirements, noisy pumps, or piping ▮ Constant throttling ▮ Worn, eroded, corroded, distorted, or broken impellers/vanes or wear rings
Description	In addition, there are several other indicators which can often lead to a replacement of a pump system, e.g. high maintenance requirements (due to cavitation problems), noise emissions and constantly throttled pump system, or a corroded throttle valve. In order to evaluate the pump replacement, the check of the actual efficiency factor of the pump system is crucial. The efficiency of pumps depends on the pump type and the power of the pump and can be gathered from data sheets or the pump curves for the specific pump. The efficiency also depends on the specific operating point of the pump.
Formula	$$\Delta C = P_{el} \cdot t \cdot \left(1 - \frac{\eta_{before\ opt.}}{\eta_{after\ opt.}}\right) \cdot c(E)_{el}$$
Recommended parameters for M&V	Measurement of power drawn, measurement or estimation of running hours.

Table 12.40: Pump/motor replacement (ISO 14414, 2016, authors)

Title	Reduction of flow, if possible (otherwise check adaptation of needs)
	▮ Reduction of static head (otherwise check adaptation of needs) ▮ Reduction of dynamic head (otherwise check adaptation of needs)
Indicators	Reduction of flow: ▮ Differential temperature in heat exchanger applications or heat distribution networks is too low ▮ Flow paths to non-essential equipment, equipment not operating ▮ Flow rate not adjusted to process demand ▮ Reduction of flow to batch process that are fill and drain
	Reduction of head: ▮ Unnecessary throttling/recirculation flows ▮ Heat recovery system not cleaned/maintained ▮ Location of tanks not optimised
Description	Each pump system has to overcome a certain amount of resistance due to the pressure increase which is known as the so-called delivery head. This resistance includes both static and dynamic components. The static lift is determined by the height to which the fluid must be lifted or by the required pressure drops across nozzles. The dynamic portion of the head requirements results from pipe friction losses and the sum of the hydraulic resistances of the built-in fittings. Firstly, the static part of the delivery height should be reduced, for instance, the entire flow volume should not be pumped to the highest level but only to the height required for the particular application. In addition, the position of water tanks and boilers has to be checked. This measure is particularly relevant for plant planning, but it can also play a significant role in case of a larger retrofitting of the plant. Often, pumps systems supply multiple take-offs, which can be located at different elevations or require different operating pressures. In this case, it is necessary to check if the high-pressure consumers can be supplied by a pressure boosting pump so the main network can be supplied at a lower delivered pressure.
Formula	$H_{\_after} = H_{s\_after} + H_{dyn}$ $P_{el\_before} = \frac{\rho \cdot g \cdot Q_{\_before} \cdot H_{\_before}}{367000 \cdot \eta_P \cdot \eta_M}$ $P_{el\_after} = \frac{\rho \cdot g \cdot Q_{\_after} \cdot H_{\_after}}{367000 \cdot \eta_P \cdot \eta_M}$ $\Delta C = (P_{el\_before} - P_{e_{after}}) \cdot t_{before} \cdot c(E)_{el}$
Recommended parameters for M&V	Measurement of total head (before and after) and calculation of power reduction, or measurement of power drawn, measurement of running time.

Table 12.41: Reduction of flow and head

Title	Improving distribution network – reduction of dynamic head
Indicators	▮ Obvious cross-sectional changes or subsequent production expansions with connections of new machines ▮ Unnecessary valves, bounds ▮ Change of pipe diameter ▮ Check suction intake for optimised flow
Description	After reducing static head, the next step is to reduce the dynamic part of the delivery height. The following measures are possible: ▮ Increase pipe diameter to minimize velocity and the pipe friction losses. ▮ Reduce loss of built-in fittings.
Formulas	$H = H_s + H_{dyn}$ $H = H_s + \left(\frac{\lambda \cdot l}{D} + \sum\right) \cdot \frac{v^2}{2 \cdot g}$ $v = \frac{4 \cdot \dot{V} \cdot 10^3}{\pi \cdot {d_i}^2}$ Recommended speed in pumping systems: Water distribution systems (mostly open systems): up to 3.0 m/s depending on application Heating/cooling/ventilation systems (mostly closed systems): Up to DN 32 max. 1.2 m/s DN 40 & 50 max. 1.5 m/s DN 65 & 80 max. 1.8 m/s DN 100 & larger max. 2.0 m/s
	Friction loss of components in pump systems: Fittings Coefficient of loss ζ Pipe bend 90° 0.3 Flap trap 1 to 2 Non-return valve 0.7 to 1.2 Slider 0.2 Pipes 0.0

Table 12.42: Improving distribution network

Title	Improve maintenance procedure
Indicators	No maintenance procedure available
Description	Maintenance costs often account for only 5–10% of the total life cycle costs of a pump system. In turn, however, they have a strong influence on electricity consumption, which accounts for about 85% of the life cycle costs. Therefore, special attention should also be paid to maintenance and repair of pump systems. In order to keep the pump efficiency factor high and the energy costs low, the following points should be included in the maintenance schedule: ▮ Visual checks for leaks depending on the application (weekly to semi-annual): Permissible leakages should be between 2 and 60 drops per minute. ▮ In case of heavy leakage due to high wear, the mechanical seals have to be replaced. ▮ Check the leak-tightness of the re-circulation valves. ▮ Check for cavitation ▮ Lubrication of the bearings should be done according to the manufacturer's instructions. ▮ Increased "clack" noise and unusual vibrations indicate bearing wear (replacement of the bearing if necessary). ▮ Quit running and vibrations: If necessary, correct the orientation of the motor and the pump in order to bring those back exactly into alignment. ▮ Check the insulation of the pump motor. ▮ Built-in filter should be cleaned regularly because from a certain degree of pollution onwards, the pressure loss increases rapidly. ▮ Check the oil level, fittings and instruments.
Recommended parameters for M&V	Measurement of pressure, flow or power reduction.

Table 12.43: Improvement of maintenance procedure

12.4.3 Fans

This chapter contains information about the most effective energy-efficient measures in ventilation systems. However, it should be mentioned that there are several other important measures for ventilation systems which can also help to save energy and costs, for example, humidification and dehumidification, which will not be described in this document because of their complexity.
Sources for this chapter: Gerstbauer et al. 2015; EMANZ, 2017a; topmotors.ch, 2012.

Title	Reduction of running time for fans
Indicators	Running (when not needed) on holidays, weekends, nights, too long before shift, finishes too long after shift, breaks
Description	The first measure for ventilation systems is the reduction of the operating time. This reduction leads to energy savings in the entire ventilation system.
Formula	Ventilation system, unconditioned airflow $\Delta C = P_e \cdot \left(t_{before} -\cdot\, t_{after}\right) \cdot c(E)_{el}$ HVAC Systems (cooling and/or heating): $\Delta C = \dot{V} \cdot (t_{before} - t_{after}) \cdot c(V)_{el,heat,cold,maintenance}$
Recommended parameters for M&V	▮ Measurement of run-time, calculate or estimate power drawn (based on manufacturer data). ▮ Measurement of power drawn over a certain time period (e.g. one week).

Table 12.44: Reduction of running time for fans

Title	Flow rate adjustment
Indicators	▮ Air flow higher than demand (specified requirement) (above 30%) ▮ Demand is not reflected in temperature set points (e.g. water temperature for cooling towers) ▮ Possibility to reduce air flow (reduce specified requirement) ▮ Air supply too high for demand (constantly)
Description	This saving measure reduces the flow (and subsequently the pressure drop) of the fan system. This can be done, for instance, by changing the pulley diameter (for frequency converter see next saving measure).
Formula	$\Delta C = \frac{(\dot{V}_{old} - \dot{V}_{new}) \cdot (\Delta p_{old} - \Delta p_{new})}{\eta} \cdot t \cdot c(E)_{el}$
Recommended parameters for M&V	▮ Measurement of flow rate and pressure, estimate electrical power and running time. ▮ Measurement of power drawn and running time.

Table 12.45: Adjustment of flow rate

Title	Flow rate adjustment with frequency converter
Indicators	▮ Demand varies with throughput, temperature, product type, pollutants, humidity ▮ Systems with large flow variations ▮ Control by damper/bypass flow
Description	Another energy-saving measure is the adjustment of the flow rate of the ventilation system with a frequency converter. For old motors, it has to be checked if a frequency converter can be installed to the motor (as the insulation of windings may be inappropriate). At first, the determination of the actual flow rate before the optimisation is necessary. Then, this is compared to the necessary airflow, the motor speed is reduced in the same proportion. The power decreases in cubic relation.
Formula	Calculation of electric consumption at part load for frequency converter: Formula for part load power consumption in fan systems when using an frequency converter (VSD) $P_{e\_FU} = \left(\frac{\dot{V}_{new}}{\dot{V}_{old}}\right)^3 \cdot P_{e\_old}$
Recommended parameters for M&V	Measurement of power drawn, measurement of running time or flow delivered.

Table 12.46: Installation of frequency converter

Title	Replacement of fan
Indicators	▮ Age of air handling unit (above 10 years) ▮ Significant changes to the system since installation (change of flow rate by more than 20%) ▮ Low efficiency: compared to legal requirements, e.g. EcoDesign or specific fan power (SFP): above 0.5 W/m³/h ▮ Constant throttling ▮ Worn, eroded, or broken blades
Description	Replacement of fan by more efficient one
Formula	$\Delta C = P_{el} \cdot t \cdot \left(1 - \left(\frac{\eta_{old}}{\eta_{new}}\right)\right) \cdot c(E)_{heat,cold}$ $P_{SFP} = \frac{P_{el}}{\dot{V}_{Net}} = \frac{\Delta p}{\eta_{Ges}}$
Recommended parameters for M&V	▮ Measurement of power drawn, measure or estimate running hours. ▮ For efficiency evaluation: measurement of power drawn, volume and total pressure.

Table 12.47: Replacement of fan

Title	Replacement of transmission system
Indicators	▮ Old drive belts in place ▮ Belt drives for fans below 2 kW (topmotors.ch)
Description	Replacement of old transmission system with new, high efficient one (e.g. direct drive that would be combined with frequency converter)
Formula	$\Delta C = (P_{el,old} - P_{el,new}) \cdot t \cdot c(E)_{el}$ OR: $C = P_{el,old} \cdot t \cdot \left(1 - \frac{\eta_{Drive\ old}}{\eta_{Drive\ new}}\right) \cdot c(E)_{el}$ Direct drive: η_{Drive}=1 Single V-belt: for P_{el} < 5 Kw η_{Drive}=0,83 for P_{el} > 5 Kw η_{Drive}=0,90 Multiple V-belt: Each additional V-belt reduces power transmission by 1%! Flat belt: for P_{el} < 5 Kw η_{Drive}=0,90 for P_{el} > 5 Kw η_{Drive}=0,96
Recommended parameters for M&V	Measurement of power drawn, measure or estimate running hours.

Table 12.48: Replacement of transmission system

Title	Heat recovery
Indicators	No heat recovery in place for extract air
	Possibility to exchange heat to the inlet air
Description	Installation of a heat recovery system: For determining the current system costs, you must consider the coefficient of performance (COP) of heat pumps of a chiller and/or the efficiency of a steam or hot water boiler at its load point.
Formula	$P_{extract-air} = \frac{\dot{m}_{extract-air} \cdot c_{air} \cdot \Delta\vartheta}{3600}$ $P_{heat\ recovery} = \Phi \cdot P_{extract-air}$ $\Delta C = P_{heat\ recovery} \cdot t_H \cdot c(E)_{heat,cold}$
Recommended parameters for M&V	▮ Measure heat recovered (if possible). ▮ Or measureement of energy demand for heating system.

Table 12.49: Heat recovery

Title	Maintenance/reduction of pressure loss
Indicators	▮ High-pressure loss in filtration systems ▮ Leakages in the air ducts can cause losses in the flow rate. ▮ Excessive pressure drops in ducting (undersized ducting and poor duct transition design) ▮ Fan inlets and outlets installed close to duct elbows, joints, and tee intersections ▮ Worn blades ▮ Poor lubrication
Description	Improvement of ducting system and filter system reduces leakages and pressure drops.
Formula	$\Delta C = \frac{(\dot{V}_{old} - \dot{V}_{new}) \cdot (\Delta p_{old} - \Delta p_{new})}{\eta} \cdot t \cdot c(E)_{el}$
Recommended parameters for M&V	▮ Depending on saving measurement of: power, pressure, volume ▮ Measurement of power drawn, measure or estimate running hours.

Table 12.50: Maintenance/Reduction of pressure loss

12.4.4 Compressed Air Systems

Sources for this chapter: Kulterer et al. 2015

Title	Reduction of leakages
Indicators	Leakage rate above 10%
Description	One of the biggest energy losses in compressed air systems are caused by leakages in the system. A leakage percentage of 50 % is not unusual, this can be reduced to 10% or even lower. The calculation of the leakage loss can be done by measuring the operating time of the compressors during the operational downtime of the compressed air system, when the compressors cover leakage losses only. Only time in load status has to be considered (total running time minus unload status). Sometimes a load analysis can be enough to identify the leakage rate.
Formula	$\Delta C = Leakage\ losses\ \cdot c(E)_{el} - \cdot E_{tot} \cdot 10\% \cdot c(E)_{el}$
Recommended parameters for M&V	Measurement of flow rate (of all compressors)

Table 12.51: Reduction of leakages

Title	Optimisation of system pressure
Indicators	▮ Pressure level above 7 bar (in most industries) ▮ Pressure loss within compressed air distribution above 0.5-0.75 bar
Description	According to experience, the lowering of the system pressure by up to 1 bar will lead to an energy-saving amount of more than 7% of the total energy consumption of the system. Measures to reach lower pressure level: ▮ Modify high pressure end-use device to operate at lower supply pressure ▮ Installation of a small dedicated compressor (and maybe storage) for high pressure, intermittent loads ▮ Reduce system resistance, optimise components for proper airflow capacity, create piping loop connections. ▮ Maintenance of condensate drains, filters, piping ▮ Check supply-side and point-of-use air treatment (calculate energy demand and pressure loss).
Formula	$\Delta C = E_{tot} \cdot 7\% \cdot (\Delta p_{old} - \Delta p_{new}) \cdot c(E)_{el}$
Recommended parameters for M&V	▮ Measurement of absolute pressure, estimation of electricity demand (based on manufacturer data) ▮ Measurement of average power demand per day or shift, control of pressure

Table 12.52: Optimisation of system pressure

Title	Change control strategy/reduction of unloaded operation
Indicators	▮ Share of part load running hours: 20-50% ▮ No multi compressor controller (for engine rooms with multiple compressors) ▮ Reduction of the original compressed air requirement (standstill of a line, disconnection of a power supply, closure of a production hall) ▮ Oversized compressor ▮ Highly fluctuating compressed air demand
Description	Oversized or poorly controlled compressors often have a load factor of only 50%. As a result, compressed air systems which are not controlled by frequency converters are running frequently in the idle state, the power consumption may reach 20 to 50% (on average about one third) of the full load without delivering compressed air. The target value for the use of peak load compressors should be 70% and above. Controlled multi compressor systems can reach 90%.
Formula	$Idle\ part = \frac{t_{part\ load}}{t_{total}} \cdot 100\%$ $\Delta C = P_{el\_part\ load} \cdot (t_{part\ load_{before}} - t_{part\ load_{after}}) \cdot c(E)_{el}$
Recommended parameters for M&V	Measurement of average power demand per day or shift, control of pressure

Table 12.53: Change of control strategy

Title	Shut down compressors
Indicators	Running (when not needed) on holidays, weekends, nights, too long before shift, finishes too long after shift, breaks
Description	Switching off the compressed air system and the consumers for a while is a very simple energy-saving measure. If there is no compressed air required outside of the operating times, the running time of the system outside the operating times should be checked. Methods include: ▮ Disconnection of unused lines with an electrically operated ball-valve with a time switch ▮ Manual shutdown ▮ Fully automatic switching on/off of the system with an electrically operated ball valve ▮ Switching off unused production machines ▮ Installation of an automatic shutdown timer (the compressor is shut off if it operates unloaded for more than a pre-set period of time)

Formula	$\Delta C = P_e \cdot (t_{before} -\cdot t_{after}) \cdot c(E)_{el}$ For the electric power, not the full load power but the average power drawn during the period, when the shut-off is possible, is relevant.
Recommended parameters for M&V	Measurement of power drawn over a longer time period (e.g. 10 days)

Table 12.54: Shut down compressors

Title	Heat recovery
Indicators	No heat recovery is installed.
Description	The amount of useable energy through heat recovery depends on the cooling system of the compressor system. For example, an air-cooled system can provide 80 to 90% and a water-cooled system 50 to 60% of its rated power as usable heat.
Formula	$\Delta C = P_e \cdot HRF \cdot 1/\eta_{HS} \cdot t_{HP} \cdot c(E)_{heat}$
Recommended parameters for M&V	Measurement of fuel demand or energy demand for hot water

Table 12.55: Heat recovery

Title	Alternatives for inappropriate end uses (calculation of net savings)
Indicators	▮ Compressed air used for cleaning, cooling and spraying ▮ Use of vacuum applications ▮ Spray applications without efficient nozzles
Description	The optimisation of the compressed air consumers should be the first thing to focus on when it comes to the optimisation of compressed air systems. It should be noted that compressed air consumers have the highest efficiency potential in compressed air systems (up to 40%). In addition, the compressed air consumers affect all other parts of the compressed air systems. One or more of the following options can be chosen to optimise the compressed air consumers: Maintenance: Pneumatic systems, which wearing parts are regularly inspected and serviced or replaced, do not cause higher compressed air consumption. The result of poor maintenance is the decrease in leak tightness and an higher energy consumption for the compressed air consumers. Replacement of filters where loading causes excessive pressure drops: As a rule, a filter should be replaced once a year or with a pressure drop of 0.35 bar. Blowing applications using nozzles or blow guns (most important air user): Due to the usage of efficient nozzles or blow guns, 15 to 55% of the amount of the compressed air can be saved.
Formula	Difficult to assess: In many cases estimated /average values of suppliers are available.
Recommended parameters for M&V	▮ Measurement of flow at defined measurement point ▮ Calculation/measurement of energy consumption per m^3 ▮ Measurement of average power consumption for compressed air

Table 12.56: Alternatives for inappropriate use

12.5 Tools for the Evaluation of Energy-Saving Measures (Step 6: Data Analysis)

12.5.1 EMSA Motor Systems Tool (MST) for evaluation of energy-saving measures

The tool is able to calculate the efficiency factor of various motor systems and provides technical support in selecting the optimal components. It dynamically calculates how the change in speed, operating point, or other elements affects the overall system efficiency. The MST has built-in automated models for standardised electric motors, asynchronous, permanent and synchronous motors. In addition, the MST can be programmed with models for pumps, fans, compressors as well as transmission types, such as V-belts and others. The MST calculates the total efficiency of combinations of all of the above.

The basic idea of the tool is to map a complete, simplified model of the electric motor system. The tool can be structured into the following sections:

- Section 1: "Load": This section deals with the definition of the load profile of the electric motor system. Here, the user is able to choose different load profiles (linear, square, constant, or reciprocal) referring to the relation between speed and torque.
- Section 2: "Transmission": In the section "Transmission", the specific drive type, e.g. direct drive or V-belt, is selected by defining the adequate parameters in a database, such as pulley diameter, number of belts, etc.
- Section 3: "Motor & Drive": In the third part, the electric motor data is required. If not all motor data are known, predefined standard motors can be selected in the tool. This selection includes both standard asynchronous motors in IE classes from IE1 to IE4, permanent magnet motor technology and synchronous reluctance technology. Finally, there is also a selection for a potential frequency converter.

Figure 12.1 shows the main menu of the motor system tool which includes the three above-mentioned sections:

The basic function of the motor tool can be summarised as follows: The user defines a working point of the electrical motor system, e.g. the speed or the required load. From this point, all efficiency factors can be calculated. The next step involves assessing the efficiency by changing various parameters. The output of the tool is the energy consumption of the defined system.

12.5.2 Standard Test Report

Function of the tool:

The Standard Test Report (STR) tool consists of five parts, which will be described in the following paragraphs:

- Detailed description of the actual state of the electric motor driven system: In this section of the Excel tool, the user can fill in information about the actual state of the electric motor driven system being investigated. All motor system nameplate data must be indicated by the user. The next step deals with the evaluation of plant documents and installation schemes. Relevant data which can be found in these documents, e.g. efficiency and age of the electric motor system, should also be filled in the Excel tool. In addition, also operating data, for example, the operating hours per year of the system, should be known. In the last step of this section, the type of electric motor system should be specified, e.g. pump, fan or electric motor, etc.
- Results of electrical load measurement: The second section of the Excel tool deals with the measurement of the electric motor system. The electric power (motor or motor with frequency converter) is measured at startup and during operation and should be documented together with the information on the actual state. The results are displayed in a graph, and the minimum, maxi-

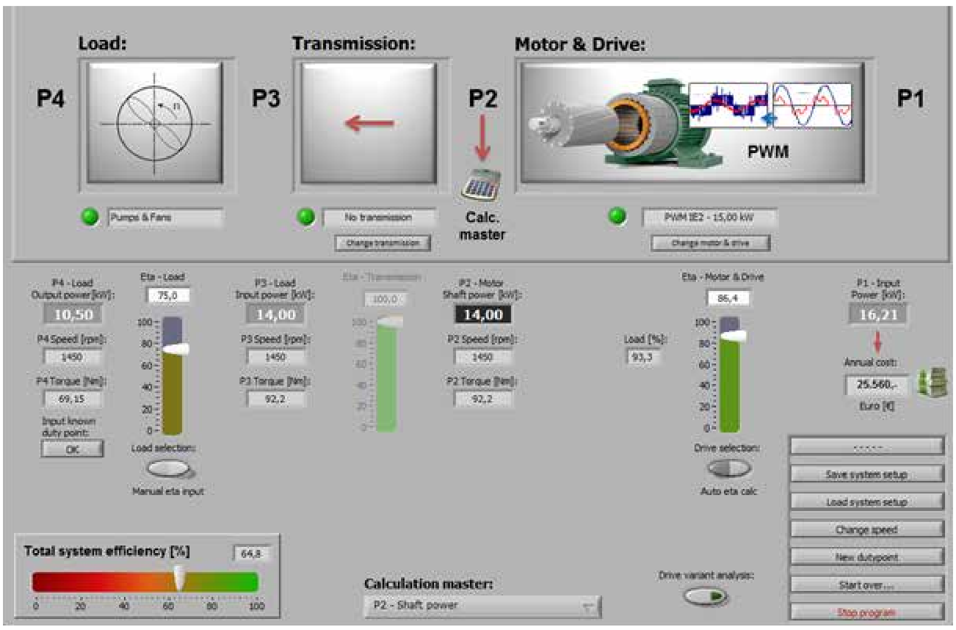

Figure 12.1: Screenshot Motor Systems Tool, www.motorsystems.org

mum and average values of the electrical power will be documented in a table as load factor. Together with the power requirement at the start, the average load factor gives an indication of the under- or over-dimensioning of the system.

- Rough costs of the individual energy improvement measures: The next step in the Excel tool includes a list of the improvement measures as well as the scope and energetic effect of these measures. Furthermore, the user of the Excel tool should fill in the cost estimations of the various measures. The sum of these costs is then used for the cost-benefit and pay-back calculation of the tool.
- Calculation of the energy demand of the total system in the actual and the target status: The main part of the tool deals with the calculation of the energy demand of the total system in the actual and the target status. The tool analyses the measuring results of the actual state and is able to estimate the effective mechanical power requirements of all the components of the electric motor system. Based on this analysis of the actual state, better and adapted components can be evaluated, and the target state can be defined with the new efficiency levels and required power requirements. The result of this calculation is lower energy consumption in the future due to the implementation of appropriate energy efficiency measures.
- Box for additional explanations: The last section of the Excel tool contains a box which can be filled out with additional information, such as:
  - Occurrences or observations during the measurement
  - Detailed information about the process during the measurement
  - Suggestions for further investigations
  - Alternative enhancement variants with higher intervention level
  - General notes and findings on the propulsion system

The basic function of the STR tool can be summarised as follows:

This Excel tool can help the energy auditor to collect the crucial motor system data and is able to analyse the efficiency of the system and its individual components. In addition, the energy auditor can simulate various energy-saving measures and have the programme estimate the costs of the whole motor system in the actual and the target status.

12.6 Plan for the Measurement and Verification of Energy-Saving Measures (Step 6: Data Analysis)

Elements of M&V plan	Further explanation
Scope and purpose	Organisation, reason for M&V, what is being measured, M&V methods used, summary of the data to be collected
Energy performance improvement actions (EPIA)	Description of EPIA, how or why EPIA improves EP (energy performance), responsibility of EPIA, timeframe, locations, costs
M&V boundaries	Determined by scope and purpose of M&V, nature of EPIA, M&V method
Preliminary M&V plan assessment	High level identification of energy systems, data and materials to be used. (e.g. document current energy uses, equipment characteristics, energy consumption pattern; identify representative period of time for conducting M&V; define data needed for data-gathering plan and for energy baseline)
Characterisation and selection of energy performance metrics, incl. EnPI	Quantifying EnPIs (energy performance indicators) is the main purpose of M&V. The characterisation of the EnPI should include mathematical equation to determine energy performance metric. Metrics: e.g. kWh/m², results of multivariant regression analysis
Characterisation and selection of relevant variables and static factors	This should be done in several steps: establishing criteria for relevant variables and identification of relevant variables and static factors (incl. operating range, representative period of time, etc.)
Selection of M&V method	Selection of appropriate methods
Data gathering plan	This plan should describe: name of variable, data source, data quality, frequency at which data will be collected, individuals responsible, preparation of access to measurement points, operating constraints, type of meter (sensor) to be used
Energy baseline establishing and adjusting	Data collected according to data-gathering plan and analysed according to the M&V Plan M&V practitioner can establish the energy baseline after the implementation of EIPA(s) on condition that the data required to establish the energy baseline are available. M&V plan should document how the energy baseline is established (e.g. raw data used, specific time period, process to establish baseline). M&V method can require energy baseline to be adjusted to conditions of reporting period.
Resources required	Statement that resources are appropriate
Roles and responsibilities	Documentation of M&V plan

Table 12.57: Measuring and verification plan (according to ISO 50015)

13 Acronyms

4E	Energy Efficient End-Use Equipment
AC	Alternating Current
ANSI	American National Standards Institute
DC	Direct Current
DoE	Department of Energy
DN	Diamètre Nominal
EASA	Electrical Apparatus Service Association
EIPA	Energy Performance Improvement Actions
EMSA	Electric Motor Systems Annex
EnPIs	Energy Performance Indicators
HVAC	Heating, Ventilation and Air Conditioning
ID	Identification Number
IE	International Efficiency
ILI+	Intelligent Motor List
ISO	International Organization for Standardization
MDS	Motor Driven Systems
MST	Motor Systems Tool
M&V	Measurement & Verification
RMS	Root Mean Square
SOTEA	Software Tool für effiziente Antriebe
SPF	Specific Fan Power
SPP	Simple Payback Periods
U.S.	United States
VSD	Variable Speed Drive
Zip	Zone Improvement Plan

14 Symbol Directory

ΔC	Energy cost savings due to the replacement of the electric motor [€/a]
P_{el}	Electrical power input to the system [kW]
P_N	Nominal power of the electric motor [kW]
P_{Shaft}	Shaft-power of the system [kW]
t	Running time of the system [h/a], if not changed
t_{before}	Current running time of the system [h/a]
t_{after}	Running time of system after optimisation [h/a]
load	Current load of the electric motor [%]
$c(E)_{el}$	Specific energy costs for electricity (el) [€/kWh]
η_{old}	Efficiency factor of the old/inefficient electric motor [%]
η_{new}	Efficiency factor of the new/efficient electric motor [%]
η_{Drive}	Efficiency factor of the drive of the system [%]
$H_{Partload}$	Head of the pumping system at part load [m]
H_r	Rated/nominal (or measured) head of the pumping system [m] (at zero flow)
H_s	Static head of the pumping system [m]
H_m	Maximum head of the pumping system [m] (at zero flow), Shut off head
$H_{(before/after)}$	Head before/after optimisation [m]
Q_r	Rated/nominal (or measured) flow of pumping system [m³/h]
$Q_{Partload}$	Flow at part load [m³/h]
$Q_{before/after}$	Flow before/after optimisation [m³/h]
n_	Speed [RPM] (nominal)
n_m	Speed [RPM] (measured)
λ	Friction factor [-]
l	Length of the tube [m]
D	Outside diameter tube [m]
ζ	Coefficient of loss [-]
v	Flow velocity [m/s]
g	Gravitational acceleration: 9,81 [m/s²]
ρ	Density (e.g. water) [kg/m³]
ν	Flow velocity [m/s]
$\dot{V}$	Flow rate of ventilation system [m³/h]
d_i	Inner diameter of the pipe [mm]
P_{SFP}	Specific fan power [W/m³s]
P_{el}	Electric power of the motor for fans [W]
$\dot{V}_{Net}$	Nominal air volume flow of the fan [m³/s]
Δp	Total pressure increase of the fan [Pa]
η_{Ges}	Overall efficiency (fan, drive, motor)
$P_{extract\text{-}air}$	Power potential of the extract air[kW]
$\dot{m}_{extract\text{-}air}$	Mass flow of the extract air [kg/h]
c_{air}	Specific heat capacity of the air [kJ/kgK]
$\Delta\vartheta$	Temperature difference between room air and average outside temperature [K]
$P_{heat\ recovery}$	Power which can be recovered through a heat recovery system [kW]
Φ	Heat recovery factor [-]
Energy $costs_{actual}$	Energy costs before the reduction of the leakage losses [€/a]
Leakage losses	Energy losses due to the leakages in the compressed air system [kWh/a] OR: E_{tot}·percentage of leakages before leakage detection
$c(E)_{el}$	Specific energy costs for electricity (el) [€/kWh]
E_{tot}	Total energy consumption of the compressed air system [kWh/a]
HRF	Heat recovery factor [%] (60-90%)
t_{HP}	Heating period [h]
$c(E)_{heat}$	Specific energy costs for heating system (e.g. oil, gas) [€/kWh]
$c(E)_{heat,cold}$	Specific energy costs for heating and cooling system [€/kWh]
$c(V)_{el,heat,cold,maintenance}$	Specific volume-related costs for electricity (el), heat, cold and maintenance [€/m³]
η_{HS}	Efficiency of heating systems (%)

15 Literature

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16 Tables and Figures

16.1 Tables

16.2 Figures

The IEA Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E)

4E is an International Energy Agency (IEA) Technology Collaboration Programme established in 2008 to support governments to formulate effective policies that increase production and trade in energy efficient end-use equipment. As the international trade in appliances grows, many of the reputable multilateral organisations have highlighted the role of international cooperation and the exchange of information on energy efficiency as crucial in providing cost-effective solutions to climate change. Twelve countries from the Asia-Pacific, Europe and North America have joined together under the forum of 4E to share information and transfer experience in order to support good policy development in the field of energy efficient appliances and equipment. They recognise the huge benefits for energy security, economic development and greenhouse gas abatement from maximising the use of energy efficiency to meet future energy demand. 4E focuses on appliances and equipment since this is one of the largest and most rapidly expanding areas of energy consumption. With the growth in global trade in these products, 4E members find that pooling expertise is not only an efficient use of available funds, but results in outcomes that are far more comprehensive and authoritative. However, 4E does more than sharing information – it also initiates projects designed to meet the policy needs of participants, enabling better informed policy making. The main collaborative research and development activities under 4E include:

- Electric Motor Systems (EMSA)
- Solid State Lighting
- Electronic Devices and Networks
- Mapping and Benchmarking.

Current members of 4E are:

Australia, Austria, Canada, Denmark, France, Japan, Korea, Netherlands, Switzerland, Sweden, United Kingdom and USA.

Further information on 4E is available at:
www.iea-4e.org

Energy Efficient End-use Equipment
International Energy Agency

Energy Audit Guide for Motor Driven Systems, 2018