IDB

EVALUATION OF WATER PUMPING SYSTEMS

Energy Efficiency Assessment Manual
First Edition

Water and Sanitation Intiative

Sustainable Energy and Climate Change Initiative

Inter-American Development Bank

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Water and Sanitation Initiative
Sustainable Energy and Climate Change Initiative
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PRESENTATION

As part of its Technical Cooperation "Energy Efficiency for Caribbean Water and Sanitation Companies," the Sustainable Energy and Climate Change Initiative (SECCI) of the Inter-American Development Bank (IDB) financed the development of a regional methodology to improve energy efficiency and maintenance of water companies in Latin American and Caribbean countries. This methodology, developed by the consulting firms Econoler International and Alliance to Save Energy, focuses mainly on electromechanical efficiencies of water pumping systems in the Caribbean. This publication presents an energy efficiency assessment manual. The calculation sheet, a guide to the calculation sheet, and a maintenance manual for the evaluation of the systems are also available on the IDB Publications Portal (www.iadb.org/publications) and the Water and Sanitation Initiative Portal: http://www.iadb.org/en/topics/water-sanitation/energy-efficiency-for-utilities,4492.html.

The following people from the Sustainable Energy and Climate Change Unit (ECC) and the Water and Sanitation Division (WSA) supervised the preparation of this manual: Christoph Tagwerker (ECC), Marcello Basani (WSA), Rodrigo Riquelme (WSA), and Gerhard Knoll (WSA). Econoler International and Alliance to Save Energy developed the manual – Arturo Pedraza and Ramón Rosas.

Water and Sanitation Initiative
Sustainable Energy and Climate Change Initiative

ACRONYMS AND DEFINITIONS

The acronyms and definitions below refer to common concepts used throughout this manual.

ACRONYMS

AP	Action plan
AWG	American Wire Gauge units
EEP	Energy efficiency program
Effic	Efficiency
EI	Energy index
HP	Horsepower
Hb	Pumping head
Ia	Electrical current in phase a
Ib	Electrical current in phase b
Ic	Electrical current in phase c
IDB	Inter-American Development Bank
IGEA	Investment Grade Energy Audit
kW	Kilowatt
kWh	Kilowatt-hour
kVA	Kilovolt ampere
kVAr	Reactive kilovolt ampere
LF	Load factor
mwc	Meters water column
mm^2	Square millimetres
Nr	Reference level
Ns	Suction level
$(D_{r\text{-}m})$	Distance from reference level to manometer or pressure gauge
PF	Power Factor
Ps	Suction pressure
Pd	Discharge pressure
Q	Flow of water
R.P.M.	Revolutions per minute
S.F.	Service factor
UCE	Unit cost of energy
WSC	Water and sanitation company
$	Monetary symbol

DEFINITIONS

Active power – power consumed by an electric motor that becomes useful work.

Apparent power – sum of active and reactive powers or the product of current and voltage.

Drinking water – colorless, tasteless, and odorless liquid found in nature or produced through a purification process; used for human and animal consumption.

Electric current – flow of electric charge in ampere (A) that passes through a conductor with resistance (R) under voltage (V).

Electric power – power in watts of energy required by the electric motor attached to the pump and in normal operation.

Electric voltage – difference in electrical tension between two points in a circuit.

Flow – volume of water measured in a unit of time, usually expressed in liters per second.

Friction factor – coefficient of friction of water with the pipe walls. This factor depends on the material that the pipe is constructed of, or lined with; the diameter of the pipe; and water velocity.

Gauging – measurement of the flow of a liquid through a pipeline.

Leaks – escape of water from a water pipeline network.

Net pumping head – algebraic sum of loading gauge pressure measured at the discharge, corrected with the height to the line of the centers of the pressure gauges, the dynamic level, the friction losses in conduction pipelines, and the velocity head.

Power factor (PF) – relationship between the active power and the apparent power; the power factor describes the relationship between the power converted into useful and real work and the total power consumed

Pump – hydraulic machine that converts mechanical energy into pressure, which is transferred to the water.

Reactive power – power consumed by an electric motor to generate the necessary magnetic field for its functioning. In the triangle formed by the active power, apparent power, and electric power, the opposite leg is the reactive power, the adjacent leg is the active power, and the hypotenuse is the apparent power. The angle θ is formed between the apparent power and active power, and the power factor is Cos θ.

Reference level – level selected as a reference for all hydraulic measurements, typically flat bottom mounting of the pumping equipment.

Suction level – vertical distance from the reference level to the surface of the water when pumping equipment is in operation.

Suction pit – additional hydraulic structure of the hydraulic system which serves as a staging for pumping any fluid from a lower to a higher level; used for drinking water, treated water, sanitary drainage, and rain drainage

Velocity head – kinetic energy-per-unit weight of the fluid in motion.

Water source – site which intakes the drinking water to supply to the distribution system.

Chapter 1

INTRODUCTION

The primary role of a water and sanitation company (WSC) is to provide water to the population and play a vital role in water management. Continuous urban growth has led to increased demand and exploitation of water supplies, and therefore an increased amount of energy is used to extract and distribute this vital resource to the population. Limited energy resources and water supply, and a lack of environmental awareness and care in the region have set a challenge for Caribbean water and sanitation companies, where the major task is to increase access to service, while trying to maximize energy and water resources and minimize negative environmental impacts.

The water and sanitation sector in the Caribbean requires constant upgrades in infrastructure as well as adjustments in its operations to promote the efficient use of water and energy in drinking water systems. However, economic resources in the region are scarce, thus preventing the development of a comprehensive, integrated plan to solve the problem.

Energy efficiency measures, when applied to an integrated plan, can defer and in some cases eliminate the need for investment in additional infrastructure. Creating a comprehensive plan for energy efficiency improvements in public water services is a worthy investment because it can yield returns in the form of savings in operational costs by increasing the level of service and giving financial sustainability to the water and sanitation company.

The Inter-American Development Bank (IDB), aware of the problems facing Caribbean countries, has launched the project «Energy Efficiency in Water and Sanitation Companies of the Caribbean,» assisting each country to develop an energy efficiency plan (EEP) with the overall objectives of improving energy efficiency and reducing energy costs in the Caribbean water and sanitation sector.

The specific objectives are to provide a general methodology for Caribbean countries, develop an action plan to increase energy efficiency that helps utilities self-evaluate their facilities, identify and evaluate improvements using available technologies and practices, implement projects, and monitor energy efficiency.

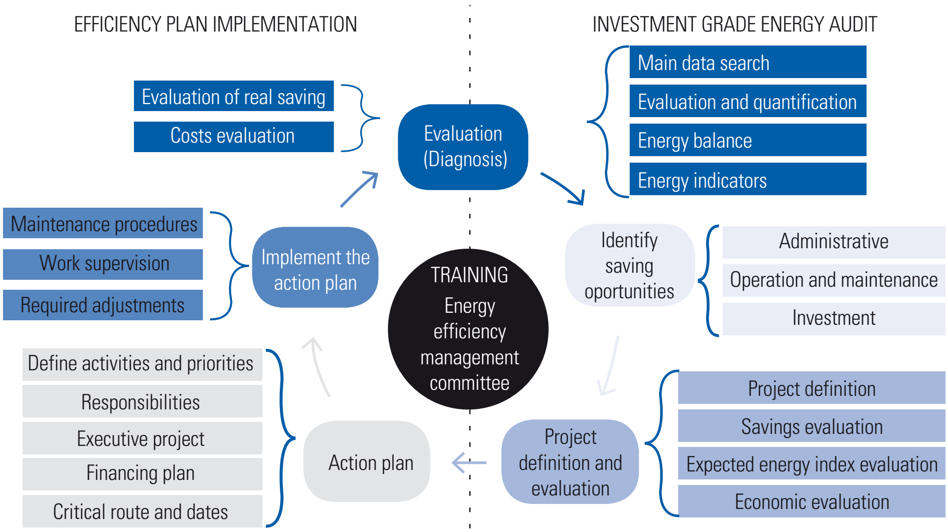
Performing an EEP on a water and sanitation system involves the development of a sequence of phased steps to determine the following: where and how much energy is used in the system, the degree of efficiency, the measures and specific projects needed to reduce the consumption and cost, the cost benefit or cost-effectiveness of such actions, the implementation plan, the methods of evaluation, and the results.

The EEP can be divided into two main activities: an energy efficiency audit and the implementation and monitoring of actions for energy efficiency improvement.

This process involves the following:

a. Securing a real commitment from the WSC, signified by the creation of an energy efficiency management committee.
b. Valuating actual performance in energy consumption, including the relationship between the system's operation and maintenance.

FIGURE 1: Components of an Energy Efficiency Program



c. Determining opportunities for improvement and savings, based on the actual performance evaluation.
d. Evaluating the identified opportunities for improvement to define projects and expected savings.
e. Designing an action plan, which involves defining goals, timelines, policymakers, and the resources to be used.
f. Carrying out the action plan, which involves supervising the defined work, implementation and operating procedures, maintenance deployment, and providing feedback during deployment enhancements.
g. Assessing and monitoring results, which involves periodically measuring the progress of the plan throughout the entire process and the results or real benefits achieved, and identifying improvements to continue the cycle

The implementation of an EEP is a continuous process of improvement that should be considered throughout the lifetime of the WSC, and must be established as a permanent program.

This document is intended to establish the methodology for implementing an EEP and to define each of its components. It is structured as follows. Chapter 2 establishes criteria to form an energy efficiency management committee and the committee's guidelines. Chapter 3 presents the methodology to perform an energy efficiency audit and addresses the assessment of energy efficiency, the identification of opportunities for improvement, and the definition and evaluation of projects for improvement. Chapters 4 to 7 develop the three components of an energy efficiency audit and the principal contents of an audit report. Chapter 8 recommends key points of maintenance practices. Chapter 9 covers the conditions and components that make up the action plan. Chapter 10 describes activities and recommendations for the implementation of the action plan. Finally, Chapter 11 describes the methods and techniques to assess the savings once the action plan is implemented.

Chapter 2

KEY ASPECTS OF ENERGY MANAGEMENT

Successful energy management for a Caribbean water company involves applying the following basic management principles to the energy efficiency field:

1. Administration – effectively administer EEPs and projects.
2. Financing – create short, medium, and long-term financial strategies for energy saving measures and for a quick payback of the investment.
3. Operation – constantly seek better and more efficient ways to deliver low-cost water distribution service to the population; and
4. Revenue – manage the incomes from water sales in order to improve energy efficiency and simultaneously increase profits.

The final objective of energy management should be to improve the balance sheet through structured efforts. It is essential to mobilize human resources to achieve these results with a real plan for follow-up.

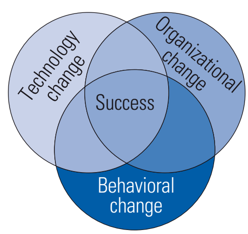
The first step for energy management is for the WSC to make a real commitment to energy efficiency. To do so, all areas of the water company must be involved in effecting a behavioral change. Figure 2 shows how the three major components of a WSC must be interrelated to support this commitment.

Regardless of the its size, the WSC must commit to allocate necessary staff and funding to achieve continuous improvement. The first key step after making this commitment is to establish an energy efficiency committee.

2.1. ENERGY EFFICIENCY COMMITTEE

The energy efficiency committee should consist of a head staff person, known as the **energy champion**, and operations staff. Appointing an energy champion is a critical component of a successful EEP. He or she sets goals, tracks progress, and promotes the energy management program by establishing energy performance as a core value. The energy champion is not always an expert in energy and technical systems; however, to be successful, he or she must understand how energy management helps the WSC achieve its financial and environmental goals and objectives. Depending on the size of the WSC, this

FIGURE 2: Diagram of a Successful Energy Efficiency Management Plan



role can be a full-time position or added to an existing staff person's responsibilities. The energy champion's key duties often include the following:

- Creating and leading the energy efficiency committee
- Acting as the point of contact for senior management
- Coordinating and directing the overall energy program
- Increasing the visibility of energy management within the organization
- Drafting an energy policy
- Assessing the potential value of improved energy management
- Securing sufficient resources to implement strategic energy management
- Assuring accountability and commitment from core parts of the organization
- Identifying opportunities for improvement and ensuring implementation (including staff training)
- Measuring, tracking, evaluating, and communicating results
- Obtaining recognition for achievements

If the energy champion does not report directly to a senior manager, it is often helpful for a member of senior management to serve as an "executive ally." The involvement of upper management is crucial for successful programs. Having an ally provides a direct link to upper management and helps to formalize the commitment to continuous improvement.

In addition to planning and implementing specific improvements, **energy efficiency committee staff** measure and track energy performance and communicate updates to management, employees, and other stakeholders. The size of the committee varies depending on the size of the WSC. In addition to the energy champion and dedicated staff, it is a good idea to include a representative from each operational area that significantly affects energy use, such as engineering, purchasing, operations and maintenance, building/facilities management, environmental health and safety, corporate real estate and leasing, construction management, contractors and suppliers, and utilities/information technology.

2.2. ENERGY EFFICIENCY PLAN

The second key issue of energy management is to establish an EEP via the energy efficiency committee. An energy plan provides the foundation for successful energy management. It formalizes senior management's support and articulates the organization's commitment to energy efficiency for staff, shareholders, the community, and other stakeholders.

A successful EEP must meet the following guidelines:

- State an objective – have a clear, measurable objective that reflects the organization's commitment, culture and priorities.
- Establish accountability – establish a chain of command, define roles in the organization, and provide the authority for personnel to implement the energy management plan.
- Ensure continuous improvement – include provisions for evaluating and updating the policy to reflect changing needs and priorities.
- Promote goals – provide a context for setting performance goals by linking energy goals to the organization's overall financial and environmental goals.

It is important to involve key people in plan development to ensure buy-in. The EEP should be tailored to the organization's culture and be understandable to employees and public alike. Moreover, a successful EEP must consider the skills and abilities of management and employees, and include details that cover day-to-day operations. The head of the WSC should officially issue the plan and encourage all staff to get involved.

2.3. PERFORMANCE ASSESSMENT

Organizations must understand current and past energy use to identify opportunities to improve energy performance and gain financial benefits. Performance assessment is the periodic process of evaluating energy use for all major facilities and functions in the organization and establishing a baseline for measuring future results of efficiency efforts. Assessing energy performance helps to achieve the following:

- Categorize current energy use by fuel type, operating division, facility, product line, etc.
- Identify and replicate facilities with high performance practices
- Prioritize assistance to poorly performing facilities
- Understand the contribution of energy expenditures to operating costs
- Develop a historical perspective and context for future actions and decisions
- Establish reference points for measuring and rewarding good performance

2.4. GOAL SETTING

Performance goals drive energy management activities and promote continuous improvement. Setting clear and measurable goals is critical for understanding intended results, developing effective strategies, and reaping financial gains. Well-stated goals guide daily decision making and are the basis for tracking and measuring progress. Communicating and posting goals can motivate staff to support energy management efforts throughout the organization. Setting goals helps the energy champion achieve the following:

- Set the tone for improvement throughout the organization
- Measure the success of the energy management program
- Help the energy efficiency committee identify progress and setbacks at a facility-wide level
- Foster ownership of energy management, create a sense of purpose, and motivate staff
- Demonstrate commitment to reducing environmental impacts
- Create schedules for upgrade activities and identify milestones

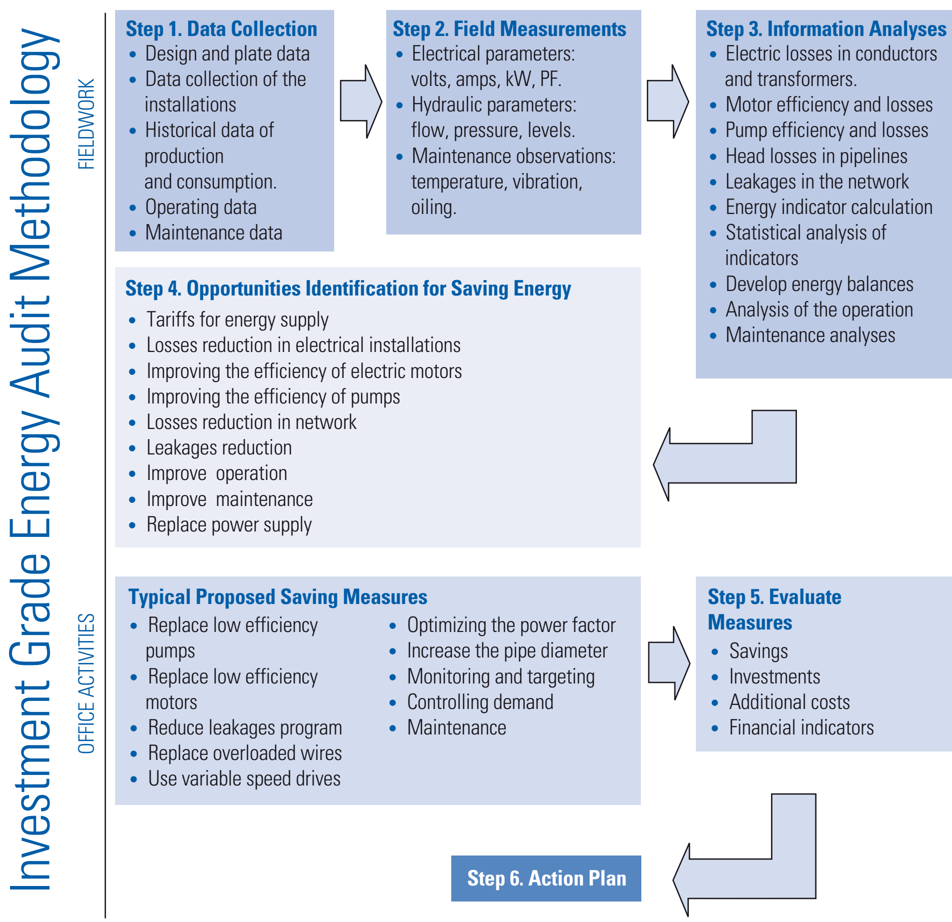
It is important to use the energy efficiency committee's wide range of knowledge to help set aggressive yet realistic goals. Upper management should review these goals to enlist their feedback and support.

Chapter 3

INVESTMENT GRADE ENERGY AUDIT METHODOLOGY

The Investment Grade Energy Audit (IGEA) in a water and sanitation system is the implementation of a set of techniques to determine how and where energy is used and to assess the efficiency of each energy-consuming component of the water and sanitation facilities. The ultimate goal is to identify cost-effective technical and administrative measures for energy savings in the facility as part of the development of a comprehensive plan for energy efficiency. In performing the IGEA, an orderly sequence of activities tends to lead to better results. The suggested sequence requires activities in both the field and the office. Figure 3 summarizes the main activities needed to perform an IGEA in a WSC in the Caribbean.

FIGURE 3. General Scheme of Investment Grade Energy Audit Methodology



FIELDWORK

Step 1 – Data Collection

Collecting data establishes the general operating conditions of a WSC, and helps determine the most effective energy saving opportunities. Data collection should be accomplished in two ways:

a) Prior evaluations – Review any existing reports of the WSC in the following sectors: legal, legislative, social, political, and economic management relating to water and energy. Examine previous audits or evaluations to determine which systems and equipment would benefit from an IGEA.

b) Data needed for an IGEA – Gather basic data from the pumping and distribution systems, motors, pumps, pipes, tanks, electrical and hydraulic plans, conditions of operations, population, and topography.

Step 2 – Field Measurements

a) Planning of field measurements – With the information obtained in Step 1, rank all processes according to their energy consumption levels. A strategy for field measurements that focuses on energy consumption of the highest ranked processes should be developed.

b) Field measurements – Field measurements must be focused on electrical and hydraulic parameters that allow the calculation of an energy balance to determine where the main losses of energy are. With this information, determine the elements and equipment with savings potentials and generate proposals for the corresponding saving measures. Also record temperature readings, excess vibrations, lubrication of mechanical components, leakage in valves, and the state of main discharge pipes and electrical installations to define maintenance actions within the action plan.

OFFICE ACTIVITIES

Once fieldwork is finished, a series of office activities must be completed in order to proceed with the IGEA.

Step 3 – Information Analysis

In order to identify the elements with a high rate of loss or low efficiency, the data collected from the field must be analyzed based on the following:

- Calculation of energy losses in electrical conductors and transformers, electrical motor efficiency, and pump efficiency; head loss in pipelines; percentage of leakage in water network; and energy indicators
- Analysis of statistical indicators, operations, and maintenance practice
- Elaboration of energy balances

Step 4 – Energy Saving Opportunities

After determining the greatest energy consuming elements, saving measures can be implemented through one or more of the following:

- Changing tariffs for energy supply due to a previous analysis
- Reducing losses in electrical installations
- Improving the efficiency of electric motors and pumps, water systems operations, and maintenance practices, or replacing power supply
- Reducing losses in the network
- Leakage reduction program
- Technology upgrade
- Incorporation of renewable energies

Step 5 – Energy Saving Measures Evaluation

The evaluation of the energy saving measures consists of the following:

- Calculating direct and indirect energy and cost savings and the total amount of investments necessary for implementation
- Estimating additional costs (operating, maintenance, and equipment materials, such as lubricants or gaskets)
- Determining the financial indicators (pay-back, net present value, and analysis of the lifecycle of the project)

Step 6 – Action Plan Implementation

The following chapters develop the theoretical basis, procedures, and specific activities that allow a water and sanitation company to carry out the IGEA in pumping systems.

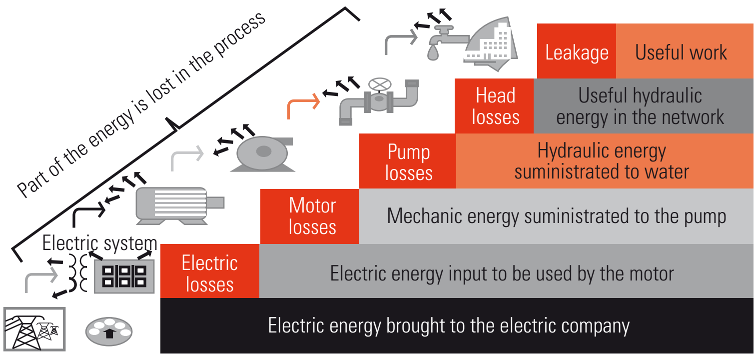
Chapter 4

EVALUATION (ENERGY EFFICIENCY DIAGNOSIS)

In the case of water and sanitation systems in the Caribbean, Figure 4 illustrates the main elements for the supply and transformation of energy through the process of water production. The figure details the equipment chain from the electricity supplier through the corresponding consumption and losses of energy in the transformer and electric control system. This system's elements include the electric motor, the mechanical energy transferred to the pump, the hydraulic power supplied by the pump to the water network, and the remaining energy finally converted to useful work to provide water to the network user.

The following sections describe the procedures necessary to perform the evaluation of the energy consumption and losses described in Figure 4.

FIGURE 4: Typical Energy Consumption and Losses in Water Supply and Sanitation Systems in the Caribbean



4.1. DATA COLLECTION

Before performing an energy audit of the pumping systems, it is essential to investigate the general situation and mission of the WSC, including the water and energy situation of the country where it is based and the main policies of the water and sanitation sector, as well as other relevant aspects to understand any challenges the WSC may face. The application of this methodology can help uncover potential savings opportunities, which should be briefly analyzed during this stage. It is also essential to collect data on the WSC's history in the water and energy sector.

4.1.1. *Water and Energy Sector: National Context*

The investigator must understand the position of the WSC in its country's water and energy sector. To do so, it is important to identify national laws, regulations, statistics, and the role that the company plays in the sector. This requires gathering the following data:

- General population data
- Current energy situation, sources of energy, and consumption of energy by sector
- Energy rate structure
- Particular energy problems
- Types of water companies (public, private, etc.)
- Legal context of water management
- Available water and main sources
- Statistics of water demand and coverage of potable water and sewerage systems
- Problems faced in terms of water supply, including topographical features and distance to water sources
- Legal and institutional framework for energy efficiency

4.1.2. *General Situation of the WSC*

In particular, the initial research of the WSC requires a review of the size of the water utility, the mode of operation, the technology used, and the specific aspects of water and sanitation that the company covers. The following information should be obtained:

- General infrastructure and number and type of facilities
- Impact of the water sector on national energy consumption
- Facilities with the greatest energy consumption and their impact on total costs
- Other pertinent aspects, such as the level of water losses and the energy management structure

Due to the importance of the data in terms of energy consumption evaluation, its analyses enables better initial planning of the pumping systems to be assessed in an IGEA, especially in those pumping systems that have the potential for energy savings.

4.1.3. *Basic Data*

An IGEA cannot be performed without basic data collection. Table 1 illustrates the data required as well as the information sources used to collect them and some general observations.

The information should be as recent as possible and preferably in digital format. Verify the level of data reliability and carry out field tours to gather and confirm the data. It is also appropriate to resort to alternative databases, such as those available on the Internet. Finally, investigate information from national, state, and municipal agencies. Each piece of equipment must be evaluated; in the event the WSC cannot provide all of the necessary data, it must be collected in the field. The fundamental data that must be obtained or confirmed in the field are from the electrical system, electric motor, and pump (see the Appendix for the forms and detailed procedures for this activity).

4.1.4. *Electrical System Data*

The following data of the electrical system must be collected:

Electric diagram – Outline the unifilar diagram connections of the electric equipment, intake, cabling, transformer, main switch, and starter, if applicable.

TABLE 1: Information to Collect from the WSC

WSC area	Information source	Required data	Observations
General	Customer database of the WSC	Number of water service intakes	Classified by type of use and with/out meter
	Water service coverage and viability	Water distribution network and overall coverage	Percentage of area and population served; planned growth areas
	Government records	Population statistics	Last three censuses and national counts
Technical	Water production	System-supplied volumes	Monthly summary for at least one past year; measured in cubic meters
		Flows produced in water sources	Annual average, daily maximum, maximum for summer and winter in extreme weather
		Macro meter characteristics	Type, model, date of installation and calibration, diameter
	Engineering records	Water distribution net maps	Full-scale, geo-referenced, with diameters, materials, roughness and lengths of pipe; topographic dimensions in cruisers; types and locations of wells, pumping stations, tanks, and valves
		Profile drawings of piping	With indications of change in diameter and equipment; locations of air and outlet valves
		Previous capital projects	Additional data, drawings, and measurements
Energy-related	Billing information	General power supply data	Power company name, voltage in volts, rate by time of pumping, monthly billing, maximum demand (kW), consumption (kWh/month), power factor, history (year)
	Plans, equipment inventory, and fieldtrip	Electromechanical infrastructure	Unifilar diagram (caliber, protections, transformers, motors, capacitors, and generators); electrical intake (type, disconnect item, fuse); electrical substation (type, the number of transformers, grounding system); transformers (identification, type, kVA original capacity, age, and transformation relationship); capacitors (location, capacity kVA, bank, element type); measuring equipment
		Electrical motor system stats	Starter (electric capacity type); electrical conductors (number of threads, length, size, material, insulation type); electric motor (brand, type, design power, volts, supply voltage, rated current, number of poles, speed at full load, service factor, original efficiency, aging, number of rewinding, operating temperature in °C
		Hydraulic pumping equipment stats	Pumps (identification, brand, type, model, casing material, driver material, design flow, design head, design efficiency and design power); suction (dynamic level in aquifer and safflower); discharge pipe characteristics; dynamic levels-per-year history
Institutional	Executive reports	Management indicators	Indicators of physical, water, and energy efficiency; historical developments in a year; impacts; benefits and costs
		Feasibility and master plans	Projected programs, investments in short and long term, efficiency in development and yearly goals
		Organizational structure of the institution	Describe functions, staff, and interrelation with other areas
		Inter-institutional programs	State and local institutional programs

Power supply – Record the following information about the electrical service provider and the contract described in Table 1.

- Name of the electrical company
- Contract number on the receipt or electrical invoice for the pumping system
- The key or name of the fare schedule in the contract
- Voltage level of power supply

Transformer – Record the following features of the transformer:

- Type of transformer that feeds the electrical equipment
- Capacity of all transformers (kVA) that provide power
- Voltage input and output of the transformer (V)
- If the transformer has more than one output voltage, the real voltage (the voltage at which the transformer is currently operating)

Main Switch – Record the following data for the main switch, which controls the energy from the transformer or the main power supply:

- Maker or manufacturer of the switch
- Original capacity of the switch (A)
- If the switch is adjustable type, the original capacity where the switch is set in (A).

Starter – If the motor has a starter, record the following information:

- Starter type
- Starter capacity (HP)

Protection – Collect the following starter motor overload protection data:

- Manufacturer of the thermo-magnetic element of the motor protection
- Capacity of the thermo-magnetic element of the motor's protection (A)
- Setting point of the thermo-magnetic element

Capacitors – If the equipment has a capacitor bank, note the total capacity of the bank in kVAr. Also identify the type of capacitors and installation method (e.g., capacitors for single equipment as compared with capacitors for a group of equipment).

Grounding System – Verify whether there is a grounding system and if it is fully separated from the neutral system. Describe the caliber of the cable connected to the ground.

Conductors – Collect the following data about conductors that relate to the size and length of the conductors in two locations: first from the service entrance, either a transformer or a direct entry, to the starter or main switch; second, from the starter or main switch to the motor. In both cases, collect the following information:

- Caliber of the electric conductor (mm^2) or (AWG) (record the data stamped on the lining of the cable)
- Total length of conductors in the described stretch
- Description of how the conductors are grouped

Electric Motor Data

Obtain the following data of the electric motor and the maintenance history:

Name Plate Data – Obtain the following information described in the motor plate (if the plate is unreadable, search the purchase order or the document describing the characteristics of the motor):

- Make of the motor
- Capacity of the motor (HP)
- Speed of the motor (RPM)
- Voltage of the motor (V)
- Current of the motor (A)
- Efficiency of motor (manufacturer or new motor) in percentage (–)
- Type of motor
- Frame type or number of the motor's frame
- Service factor (SF), which is a measure of the amount of overload that a motor can handle without damage. When not shown in the plate, the SF is (1); a factor of more than one indicates that the motor can withstand greater overload.

History – Obtain the following information about the motor maintenance history:

- Age or amount of time in years the motor was used since its first installation
- Average motor working hours in a year (h/year)
- Number of rewindings that have been made to the motor in its service life

Pump Data

The following data about the pump are also required (if field data are not available or the plate of the pump is unreadable, use the documents supplied with the pump at the time of purchase):

Frame – Gather the following data concerning the body of the pump:

- Pump manufacturer
- Type of pump (e.g., submersible, turbine vertical, horizontal, or centrifugal)
- Model of the pump according to the manufacturer
- Age or time in years that the equipment has been in operation since its installation

Impeller – Obtain the following data about the impeller of the pump:

- Type of driving pump
- Impeller material
- Original diameter of the impeller (mm)
- Age or time in years that the impeller has been in operation (data may differ from that of the pump if the impeller has been changed during the life of the pump)

Shaft – Record the diameter and length of the transmission shaft between the motor and pump.

Design Data – Record the manufacturer's model and the point of operation of the characteristic curve of the pump. Also, collect at least the design pressure and the flow capacity.

Fluid Characteristics – Obtain the following characteristics of the pumped fluid, which will depend on whether it is drinking water or sewage:

- Fluid type (e.g., drinking water, raw water, or sewage)
- Operating temperature of the fluid (^{o}C)
- Density of the pumped fluid (kg/m^3)

These base field data must be collected at the same time as the field measurements, which are described in the following chapter (see the Appendix for template to enter data).

4.2. FIELD MEASUREMENTS

Once the base data are obtained, plan and complete measurement of electrical and hydraulic parameters required to audit the electromechanical components of the pumping systems. The electromechanical efficiencies of the joint motor-pump and operating curves of pumping equipment are determined from the field measurements. The measurement campaign is divided into hydraulic activities and electromechanical works in pumping systems (see Table 2).

To make the measurements as accurate as possible and obtain precise efficiency values, surveyors should ensure that *measurement devices are calibrated and in good operation, and that the system being* measured is stable. In the following section, there are important details and recommendations for taking the most accurate measurements so as to avoid spending excessive time recalculating (see the Appendix for templates and detailed procedures for this activity).

4.2.1. *Electrical Measurements*

All measurements should be taken by trained personnel under normal operating conditions (not at pump start-up). To avoid potential hazards, follow the internal safety procedures and the following set-up guidelines and practices.[1]

TABLE 2: Description of Measurement Campaign

Measurement campaign	Activity	Objective	Equipment and tools needed
Electromechanical measurements in pumping equipment	Measurement of electrical parameters	Determine power operation and calculate efficiency	Scanner of power electricity networks or measurement equipment (voltmeter, ammeter, etc.)
	Discharge pump flow measurement	Determine operational equipment flow	Ultrasonic or electromagnetic flow meter
	Discharge and suction pressure measurement	Obtain operational equipment loads	Portable Bourdon gauge
	Definition of baselines in pumps	Obtain load and hydraulic load losses	Electrical probe, tape measure

[1] www.fluke.com/library

` Guidelines:

- Assess the environment before taking the measurement.
- Do not work alone in hazardous areas.
- Wear the appropriate personal protective equipment (PPE) as recommended by local health and safety personnel.
- Make sure your test instrument is rated for the measurement environment.
- Be familiar with and know how to use equipment prior to taking any hazardous measurements.

Practices:

- Measure at the lowest voltage point possible. For example, if you are measuring voltage on a breaker panel, identify the lowest-rated breaker available and make your measurement there.
- Keep your eyes on the area that you are probing and keep both hands free when conditions require.
- For single phase, connect neutral first and hot second. After taking your reading, disconnect the hot lead first and the grounded lead second.
- When testing for voltage, use the following three-point test method to verify your test instrument is working properly—an important part of your personal safety:
    1. Test a similar known live circuit first.
    2. Test the "circuit to be tested."
    3. Retest the first known live circuit.
- When taking measurements in or around high-energy three-phase distribution panels, use test probes with a minimum amount of exposed metal, such as .12 in (4 mm) metal tip probes. This reduces the risk of an accidental arc flash from probe tips.
- If possible, measure with one hand to reduce the possibility of offering a closed circuit between your hands. DO NOT touch any grounded structure while measuring on energized phases.

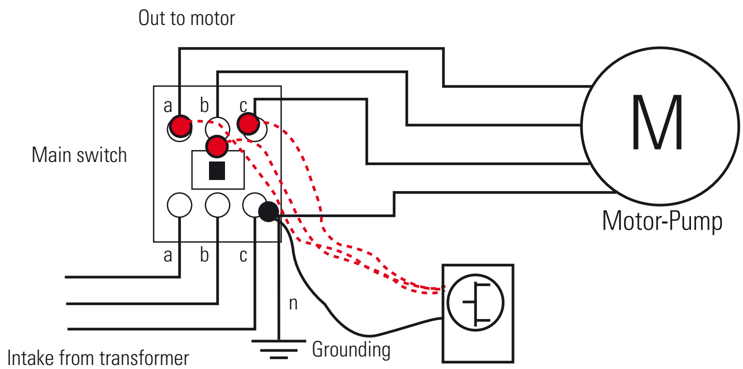
The electrical measurement parameters are voltage, electrical current, power factor (PF), active or real power, and reactive power. To take these measurements, use the appropriate equipment, such as a voltmeter, ammeter, wattmeter, or multimeter. To simplify the process, use an electric network analyzer, which can measure parameters by phases and store data in memory. It can then integrate these measurements directly for three-phase values to determine trends and, in most cases, other electrical parameter measurements. This is important in evaluating the quality of the energy used in the equipment, such as the harmonic distortion, among other specifications.

4.2.1.1. *Voltage*

For the measurement of the electrical voltage in pumping equipment, use a voltmeter. Refer to Figure 5, and proceed as follows:

1. Take the measurement in the emerging voltage wires from the main switch to the motor-pump.
2. Place the red cable of the tester on the tip of the switch output in the "a" line.
3. Place the black cable of the tester on the tip of neutral "n."
4. Register the reading for the "a" phase voltage (Van).
5. Repeat the action, putting the red cable of the tester in output tips "b" and "c" of the switch (with the black connected to neutral ground) and take respective readings of tension (Vbn) in phase "b" and tension (Vcn) in phase "c."
6. When measuring voltage between phases, repeat the procedure above by placing the red wire of the voltmeter on the output switch in point "a" and the black cable into the "b" end; then between "a" and "c"; and finally between "b" and "c."

FIGURE 5: Measurement of Voltage in Pumping Equipment



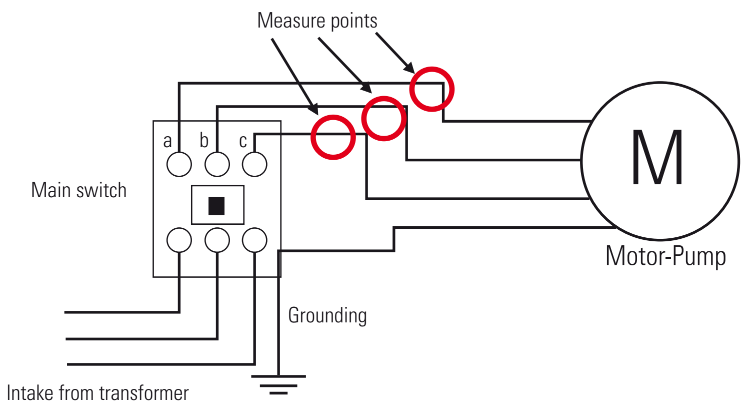
7. The value of the three-phase voltage (V) can be calculated with the average of these three values. Take three readings in each cable to confirm the data. Define a realistic variation range for minimum and maximum acceptable values.

4.2.1.2. *Electrical Current Measurements*

Measure the electric current with an ammeter. Refer to Figure 6, and proceed as follows:

- When using an ammeter, perform single-phase electrical current readings one by one by placing the ammeter in each of the three cables coming out of the main switch or starter and fed to the motor. Readings in each cable shall be flow phases Ia, Ib, and Ic, and the electrical three-phase total current is calculated with these three values. Take three readings in each cable to corroborate the data.
- If you use an electric network analyzer, take electrical current readings individually, but place the three amps simultaneously in each of the cables coming out of the switch and leading to the engine. The electrical currents of each of the cable readings are obtained directly by the online scanner.

FIGURE 6: Electrical Current Measurement



4.2.1.3. *Power Factor Measurement and Calculation of the Electrical Power*

For the measurement of the PF, follow the same procedures as in the measurement of current or voltage, using a process similar to testing the resistance of the electric grills. This method is useful because sometimes there is no wattmeter on hand. In this way, the PF value is obtained using only the ammeter or the voltmeter, and applying mathematical formulas (law of sines and law of cosines).

4.2.1.4. *Active Power*

A wattmeter, which is put in the output switch cable, is used to measure the actual power going to the engine. The procedure for measuring the value of the real or active power is as follows:

1. Put wattmeter on phase “a” wire on voltage terminals.
2. Put another voltage terminal in the neutral wire on “n.”
3. Insert the ammeter hook in the “a” phase wire.

The real or active power registers directly in the wattmeter. Repeat the above process to obtain the real power in phases “b” and “c.” If the pumping equipment has an installed bank of capacitors, take two measurements (see Figure 7 and Figure 8).

The first of these measurements must be downstream of the point of connection to the capacitors bank, drivers, directly submersible pump, or vertical turbines and pumps so that measurements are not influenced by the effect of compensation of the capacitors and reflect the actual situation of the

FIGURE 7: Measuring the Real Power before the Capacitors Bank

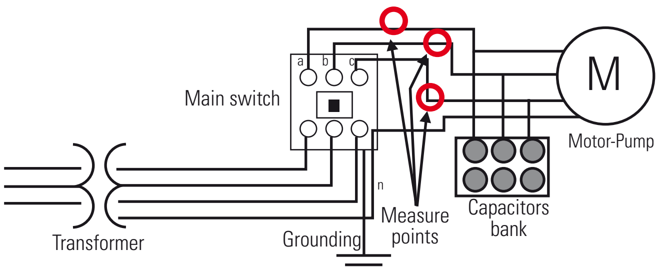
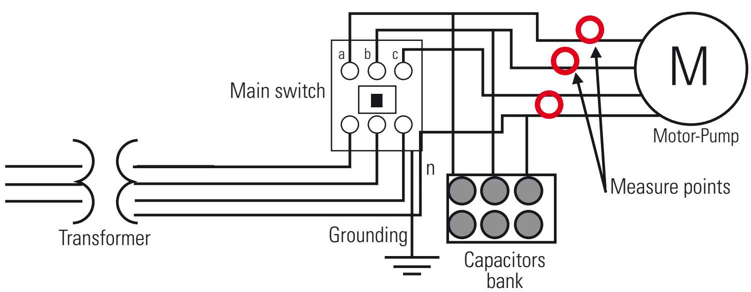


FIGURE 8: Measuring the Real Power after the Capacitors Bank



electric motor in evaluation. The second measurement must be upstream of the capacitor. This measurement will describe the effect of the compensation of the PF on the electrical network.

4.2.2. *Hydraulic Measurements*

The hydraulic parameters should also be measured with calibrated measuring equipment. The system must not have disturbances when taking measurements. For units such as wells or pumping equipment installations, measurements are made directly in the discharge pipelines. For installations that integrate several pieces of pumping equipment, hydraulic parameters must be measured individually for each piece in its own discharge pipeline.

The operating curve, with flow versus total hydraulic pumping head (Q-Hb), is developed by the measurement of these two parameters and includes a reading of the changes of the operating conditions at each step. The following measurements are necessary to obtain the data and hydraulic parameters:

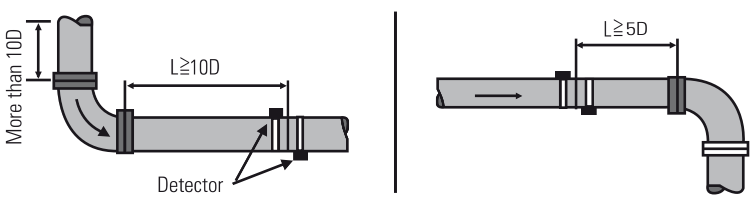
- Flow measurement at the discharge pipeline of the pump (Q)
- Measurement of the pressure at the suction (Ps) and discharge (Pd) gauges
- Definition of the reference level (Nr)
- Measurement of the dynamic level of suction (N_s)
- Measurements of the distances at the center of the gauges ($D_{r\text{-}m}$), including both the suction and the discharge

4.2.2.1. *Discharge Flow Measurements*

Flow measurement is done in each of the water production facilities in the water system in places such as wells, springs, dams, and filter galleries, and should be carried out at the exact point in the piping where it enters the water distribution network. In treatment plants, tanks, or pumping stations, it is of interest to measure the flow only in the discharge pipelines. We recommend taking advantage of the flow meters installed in the water system, but it is important to obtain the accuracy errors of this equipment prior to taking measurements. When there is no flow meter on the site, use a portable ultrasonic or electromagnetic meter certified by an accredited testing laboratory, which provide high levels of accuracy and versatility.

The position of the flow meter in the piping should be in a straight section of the piping and preferably horizontal. There should be no obstacles before or after the meter. These include elbows, valves, reductions, enlargements, and pumps, which distort the velocity of the water in the test section. Any bends should be at least 10 diameters upstream and 5 diameters downstream of the meter axis (see Figure 9). However, there are meters currently on the market that can reduce these distances according to the respective manufacturer catalogs.

FIGURE 9: Position of the Flow Meter



Flow measurement may be carried out in a short period of 15 to 30 minutes. If flow variations are less than ±5 percent in the course of a full day, the average flow value is recorded. If the flow fluctuation is greater than this percentage, continuous testing should be carried out for at least 24 hours to establish an average flow value.

4.2.2.2. *Suction and Discharge Pressure Measurement*

For the measurement of suction (Ps) and discharge (Pd) pressure, use Bourdon type gauges (see Figure 10), preferably those that contain glycerin. Also, ensure good calibration and choose gauge ranges so as to measure in the middle third of the scale where accuracy is optimal.

FIGURE 10: Pressure Measurements with a Bourdon Type Gauge

For practical purposes, head load pressure calculations should be expressed in meters of water column (mwc), although the gauges normally have scales in (kg/cm^2) or (PSI). The equivalence formulas of these units are:

- 1 kg/cm^2 = 10.3 mwc
- 1 PSI = 0.7031 mwc

Suction and discharge pressure measurements must be taken as close as possible to the pump. If it is not possible to take a suction pressure measurement because it is a submersible pump or because there are no available measuring points, make note of this in the measurement log forms. It is essential, however, to measure the pressure in the discharge pipeline.

4.2.2.3. *Reference Level Definition*

In calculating the total hydraulic pumping load, set a reference from which the other levels can be measured. Typically the reference level is located on the engine mounting board (see Figure 11 and Figure 12), but in the case of submersible pumping equipment, the reference level is usually the well discharge head pipeline (see Figure 13).

FIGURE 11: Measurement for Pressure Gauge in the Discharge

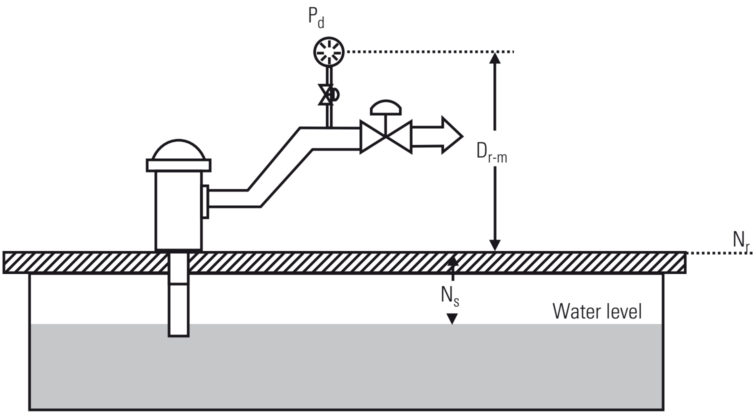


FIGURE 12: Measurement of Pressure When Gauges in Suction and Discharge Are Available

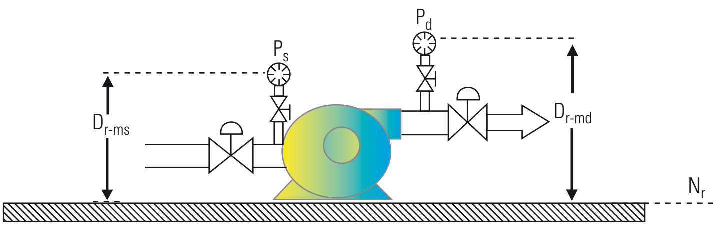
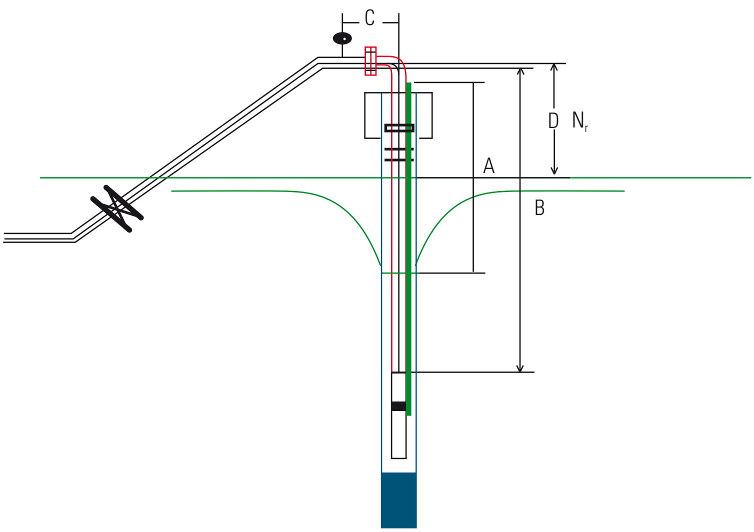


FIGURE 13: Submersible Pump Level Measurement



4.2.2.4. *Dynamic Level Measurement*

The suction level (Ns) is the vertical distance between the reference level and the water surface from which water is being pumped in normal and stable operating conditions. Take measurements with a probe-level or a flex meter. When taking measurements from a pump with a suction pit or a low-level water tank, the dynamic suction level is the level of the surface of the water within the suction pit or the water tank. In the case of a well, suction level corresponds to the dynamic level in the aquifer. The images in Figure 14 and Figure 15 show the measurement of dynamic levels with an electrical probe.

FIGURE 14: Measurement of the Dynamic Level of a Pumping Suction Pit

FIGURE 15: Measurement of the Dynamic Level of a Low-Level Water Tank

If the level changes position significantly while measuring in a suction pit or water tank, it is important to take simultaneous measurements of flow, pressure, and electrical parameters. The value can be negative or positive, depending on whether the level is below or above the reference level.

4.2.2.5. *Measurement of Levels to Manometer Centers*

Figures 11 and 12 on page 22 illustrate how to locate levels to the gauges' centers. If the pressure of the discharge is only measured, this level will be designated as Dr-md. In the event that both the discharge and the suction pressure loads are measured, the level of the discharge manometer shall be appointed as Dr-md and the level of the suction manometer as Dr-ms.

4.2.2.6. *Determination of Total Hydraulic Pumping Head*

Levels described in paragraphs 4.2.2.2 to 4.2.2.5 and pressure measurements are used to calculate the total hydraulic pumping head (Hb), which is made up of the sum of several measured values that depend on the pump type and the pumping array. Table 3 describes the calculation process and parameters to be considered in determining the total hydraulic pumping head, depending on the type of equipment and the application of the parameters.

TABLE 3: Calculations for Total Hydraulic Pumping Head and Measuring Parameters

Case	Formula	Parameters
Only when the discharge pressure is measured	$H_b = p_d + N_s + D_{r-m} + h_{fs} + h_v$	H_b = total hydraulic pumping head (m) P_d = discharge pressure (mwc) N_s = dynamic suction level (m) D_{r-m} = distance from reference level to gauge (m) h_{fs} = suction head losses due to the flow friction and accessories in the suction pipeline (m) h_v = velocity head (m)
When the discharge and suction pressures are measured	$H_b = p_d - p_s + D_{r-ms} + D_{r-md}$	P_d = discharge pressure head (mwc) P_s = suction pressure head (m) D_{r-ms} = distance from reference level to suction gauge (m) D_{r-md} = distance from reference level to discharge gauge (m)

4.2.3. *Temperature Measurements*

Temperature measurements provide additional information on the system's conditions and indicate whether maintenance must be performed in the electrical system. Temperature measurements should be taken for the control equipment, motor, and transformer.

CONTROL EQUIPMENT – Take the following temperature measurements to determine if conductors are overloaded or if screws and conductor terminal fasteners need to be adjusted:

- Terminals of the conductors coming from the transformer to the main switch in each of the phases A, B, and C
- Terminals of the main switch towards the motor output in each of the phases A, B, and C
- Terminals in the starter's entry in each of its conductor phases A, B, and C
- Conductors to output terminals along the motor's starter in each of the phases A, B, and C

MOTOR – The motor temperature can determine lack of maintenance in the motor and indicate whether the shaft is unbalanced. The housing and bearings should be measured.

TRANSFORMER – Similar to temperature measurements in the control equipment, measuring the transformer temperature determines possible overload in conductors and indicates the need to adjust conductor terminal fasteners or to perform other maintenance. Measure the temperature in the following areas:

- At the terminals of the electric feeder that connects to the transformer on the side of high tension in each of the phases X_1, X_2 and X_3
- At the transformer on the low voltage side, both in the neutral terminal output X_0 and in each of the phases X_1, X_2 and X_3
- On the top and bottom of the frame to determine the temperature of the work of the transformer and reveal possible overloading
- Both at the top and bottom of the radiator to determine the transformer oil temperature differential

4.2.4. *Measurements and Observations for Maintenance Audit*

Temperature measurements provide additional information about the operation of the electrical and pumping systems, and indicate the need for maintenance. Other types of observations for maintenance will be described in Chapter 8 of this document.

4.2.5. *Field Data Log Templates*

It is important to use field templates for registering both the electromechanical system and pumping equipment so as to keep their original values and the data in the same measurement campaign. Table 4 is an example of the form suggested for the registration of the electromechanical system and original pump data and engine characteristics. Table 5 is an example that can be used in hydraulic and electrical variables of pumping equipment measurements.

4.3. INFORMATION ANALYSIS AND EFFICIENCY ASSESSMENT

The next step is to analyze the data measurements. This evaluation determines the energy losses and the efficiency of the various components of the pumping system. Based on the distribution of losses described in the beginning of this chapter, the energy audit in a drinking water system should include an analysis of the following systems, in order of importance:

1. Electric supply, including the characteristics of the supply contract
2. Electromotive system, including the transformer
3. Motor-pump set, including efficiencies, conditions of operation, and maintenance aspects

Although there are many perspectives to analyze, for the purposes of the IGEA, electrical systems are emphasized because they contribute mainly to the energy analysis. This section describes the most important features and main aspects to evaluate, as well as the methodology to calculate the energy efficiency of each component of the energy chain of a typical drinking water and sanitation system. An installation audit will be useful for developing a power saving project.

TABLE 4: Data and Characteristics of the Electrical System Catalog Form

Energy Audit of Pumping System

Site: ______________________ Date: ______________

UTILITY: ______________________

SYSTEM: EQUIPMENT:

1.1. ELECTRICAL SYSTEM

POWER SUPPLY:

Supplier:	NEC BS
Service No.:	D-3364605
Contract Tariff:	3

TRANSFORMER:

Type:	Pole-mounted three phase
Capacity:	3 x 25 kVA
Rated Voltage:	13,800/440 V

MAIN SWITCH

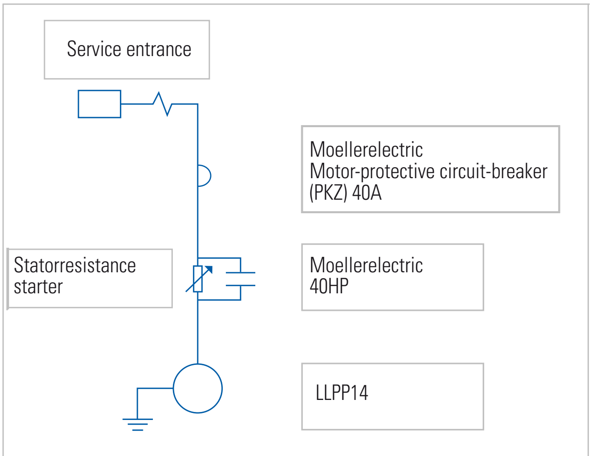
Make:	Moeller electric
Capacity:	40A
Setting:	32-40A

STARTER:

Type:	Stator Resistance Starter
Capacity:	40 HP

PROTECTION

Make:	MOELLER ELECTRIC
Capacity:	32-40A
Setting:	37 A



CAPACITORS

Capacity: — kVAr

GROUNDING SYSTEM

Is there a grounding system?	YES	NO	
Separated neutral and ground?	YES	NO	
Grounded transformed?	YES	NO	Caliber:
Grounded starter?	YES	NO	Caliber: 6
Grounded motor?	YES	NO	Caliber:

OBSERVATIONS:

CONDUCTORS

Service entrance – Starter

Caliber:	10 mm^2
Length:	15 m
Grouping:	

Starter – Motor

Caliber:	12 AWG
Length:	53 m
Grouping:	3W/Conduit

1.2 NOMINAL MOTOR DATA

Nameplate Data:

Make:	GRUNDFOS	Voltage:	440 V	Type:	SUBMERSIBLE
Capacity:	10 HP	Current:	15.0 A	Frame:	
Speed:	3,450 RPM	Efficiency:	79.0%	SF:	0.85

HISTORY:

Age: 1 years # of rewindings: 0 Operation: 8,760 hrs/year

OBSERVATIONS: The motor has been overloaded and stopped five times this year for a period of 2 hours

1.3 NOMINAL PUMP DATA

FRAME		IMPELLER	
Make:	GRUNDFOS	Type:	closed
Type:	SUBMERSIBLE	Material:	SS
Model:	Sp 45-4N	Diameter:	m
Age:	1 years	Age:	1 years

SHAFT: Diameter: inches Length: m

DESIGN DATA: Design head: 22 m Design flow: 18.61 l/s

OBSERVATIONS: The pump has been stopped for 24 hours. There are no records of the pump's age.

TABLE 5: Hydraulic and Electric Measurements Catalog Form

1.4. FLUID CHARACTERISTICS

Fluid: water | Temperature: 21 °C | Density: 1,000kg/m³

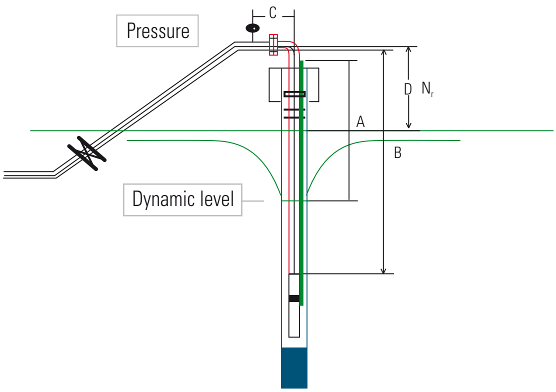
OBSERVATIONS:

2.1. HYDRAULIC MEASUREMENTS

LEVELS:

Tank suction level (A): 32.42 m | Suction pipe length (B): 39.95 m

Distance of discharge pressure gauge (C) 0.28 m | Height of gauge (D): 0.98 m



	Diameter (m)	Material	Pressure (kg/cm²)	Flow (l/s)	Speed (m/s)
Suction	0.1	SS		4.70	0.598
Discharge	0.1	SS	1.3	4.70	0.598

TOPOGRAPHY: Elevation of the pump site: 1,045 masl (meters above sea level)

Elevation of the highest delivery point: 1,047masl

OBSERVATIONS: The well is deviated, so the pump must be submersible.

2.2. ELECTRICAL MEASUREMENTS

VOLTAGE IN PHASES:	Van:	260.4	Vbn:	261.9	Vcn:	255.8
CURRENT PHASE:	Ia:	13.92	Ib:	14.14	Ic:	12.93
ACTIVE POWER:	Pa:	2.92	Pb:	2.86	Pc:	2.61
POWER FACTOR	PFa:	0.806	PFb:	0.774	PFc:	0.791
HARMONIC DISTORTION:	THD-V:		THD-I:			
MEASUREMENTPOINT:	Main circuit					
CAPACITOR CHECK:	Ia:		Ib:		Ic:	
GROUND SYSTEM:	Continuity:	YES / NO	Current:	A	Resistance:	?

OBSERVATONS: Did not find continuity in the grounding wire, so no measurements were made of current and resistance

2.3. TEMPERATURE MEASUREMENTS

Control equipment	Switch input			Output switch			Starter input			Starter output		
	A	B	C	A	B	C	A	B	C	A	B	C
	40	41	39	53	49	40	46	44	52	43	42	54

MOTOR			TRANSFORMERS										
Housing	Bearings		Feeder terminals			Low voltage terminals				Frame		Radiator	
	Upper	Lower	X1	X2	X3	X0	X1	X2	X3	Upper	Lower	Upper	Lower
42	48	40	38	39	39	36	40	38	39	41	40	41	39

OBSERVATIONS:

4.3.1. *Calculation of Electricity Losses in the Electrical System*

4.3.1.1. *Calculation of Losses in Electrical Conductor*

The set consisting of drivers, controls, transformer protections, starters, and other elements that provide energy to the equipment that transform electrical energy into mechanical energy (motor) is known as the electromotive system (see Figure 16).

FIGURE 16: Typical Electromotive System Components in a Pumping System

The main aspects to observe and evaluate during an energy efficiency audit of the electrical system are the losses in the electric conductors caused by the high resistance of copper contained in the conductor's resistance. Electric conductors behave as a pure resistance; that is, they absorb power according to the following expression:

$$P = R * I^2$$

Where:

P is the joule effect losses (W)
R is the conductor's resistance (Ω)
I is the electrical current circulating through the conductor (A)

This resistance generates a voltage drop, which is calculated based on the current. Calculating the losses in the conductor is part of the energy efficiency assessment.

Example: Calculate losses in an electrical conductor that feeds a 150A motor connected to a submersible pump. The caliber of the installed conductors is 1/0 with four wires to 440V. The cable is 130m long. Calculate the joule effect losses in the conductor that feeds the submersible pump at 440V and 150A.

Table 6 presents the calculation of loss and voltage drop for different sizes of conductors and losses for the distance and amperage in the example above.

When these values are calculated according to Table 7, the operational loss for 6,000 hours per year, with an average energy cost index of $1.4 /kWh average, is $27,720.

TABLE 6: Example of Resistance to Different Sizes of Conductors and Voltage Drop

Caliber	Resistance			ΔV	
	(Ω/km)	Length (km)	(Ω)	(V)	%
1/0	0.3290	0.13	0.04277	6.42	1.46%
2/0	0.2610	0.13	0.03393	5.09	1.16%
3/0	0.2070	0.13	0.02691	4.04	0.92%
4/0	0.1640	0.13	0.02132	3.20	0.73%
250	0.1390	0.13	0.01807	2.71	0.62%
300	0.1157	0.13	0.01504	2.26	0.51%
350	0.0991	0.13	0.01288	1.93	0.44%
400	0.0867	0.13	0.01127	1.69	0.38%
500	0.0695	0.13	0.00904	1.36	0.31%
600	0.0578	0.13	0.00751	1.13	0.26%
750	0.0463	0.13	0.00602	0.90	0.21%

TABLE 7: Example of Calculation of Energy Loss by Joule Effect

Calculation	Result
Voltage – V =	440V
Current – I =	150 A
Voltage fall – ΔV =	22V
	5.0%
Resistance – R=ΔV/I=	0.1467 Ohms
Losses – Pj = I^2 x R =	3300 Watts
	3.3 kW
Operation =	6,000 h/year
Energy losses	19,800 kWh/year
	$27,720/year

Note: This calculation does not consider the effect of temperature on the resistance of a conductor.

The impact of the PF on the value of the demanded current in the system causes losses principally due to the Joule effect and the voltage drop. Increased losses caused by the Joule effect, which is based on the square of the current, will increase energy losses in electrical conductors from the meter to the main switch, in the windings of distribution transformers, and in operating and protection devices. An increase in the voltage drop results in an insufficient supply of power and a reduction in the power output. This voltage drop increases the apparent power and reduces the capacity of the installed load, which is important in the case of distribution transformers. These losses affect the producer and distributor of electric power. For this reason, some electric companies penalize the user by charging more for their electricity under these conditions.

Regarding an energy efficiency audit, if the electric company measures the PF and applies a fee, or there is a credit, register the statistical value of the PF period evaluated in conjunction with billing statistics to determine the behavior in the PF time and its impact on the cost analysis. Then, measure the actual PF of the audited equipment. If the instrument does not directly register a three-phase PF value, then it must be calculated based on real power and real reactive power values during measurements using the following equation:

$$PF = \frac{Pa}{\sqrt{(Pa^2 - Pr^2)}}$$

Where:

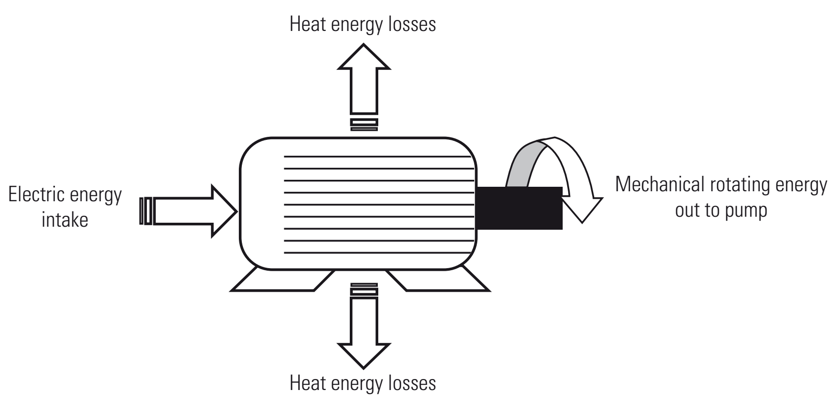
- *PF* is power factor (–)
- *Pa* equals active power measured (kW)
- *Pr* is reactive power measured (kVAr)

Some systems, usually the capacitor bank, can compensate for the PF. See if and where they are installed.

4.3.2. *Calculation of Losses and Efficiency of the Electric Motor*

Electric motors convert electrical energy into rotating mechanical energy, which is then transferred to the pump (see Figure 17).

FIGURE 17: Electric Motor Energy Flow



In water systems, typical electric loads are pumping systems, although there are also other types of loads, such as fans, blowers, agitators, and conveyors used in the treatment of wastewater and in water treatment plants. Out of the different varieties of electric motors, induction motors are the most popular due to their versatility and low cost, and they are often used in centrifugal pumping systems and for municipal water pumping. However, many induction motors are not properly cared for, resulting in high inefficiencies.

4.3.2.1. *Typical Losses in an Electric Motor*

In general, electric motor losses can occur as the following:

- Electrical losses, in the stator and rotor that vary with the load
- Losses in iron (core), which are essentially independent of the load
- Mechanical losses (friction and cooling system if it applies), which are independent of the load, and occur in bearings, fans, and the brushes of the motor
- Loss of load by dispersion, which are made up of several smaller losses from factors such as loss of flow-induced currents of the engine and distribution of nonuniform flow in the stator and rotor

These combined losses constitute up to 10 or 15 percent of the total loss of the motor and tend to increase the load. Under normal conditions of voltage and frequency, mechanical and magnetic losses remain almost constant, independent from the load. This is not the case with power losses, which vary with the power required by the shaft.

4.3.2.2. *Motor Efficiency Assessment*

The efficiency of an electric motor is the measure of its ability to convert supplied electrical power into useful mechanical power. It is usually expressed as a percentage of the mechanical power over electrical power.

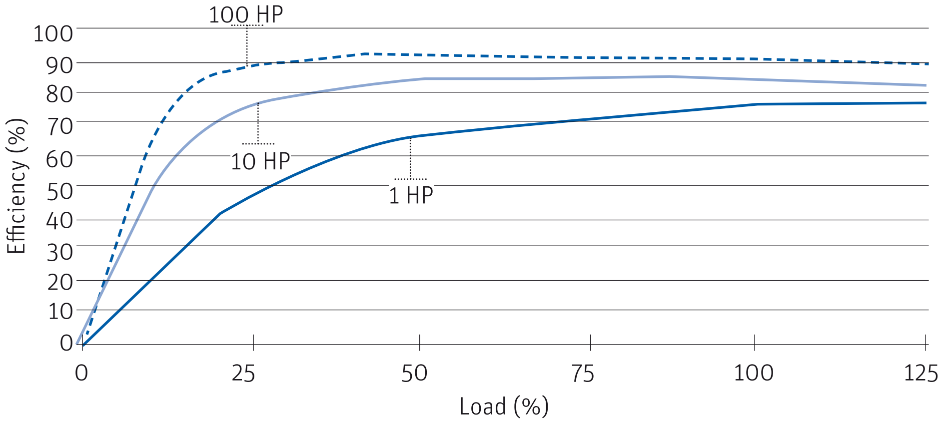
$$\textit{Efficiency} = \frac{\textit{Mechanical power}}{\textit{Electric power}} \times 100$$

All of the described factors influence the real value of the efficiency of an engine in operation, but maximum efficiency generally occurs when operating between 75 and 95 percent of its original design capacity. Figure 18 shows the typical efficiency curve for squirrel cage induction motors of different capabilities, which are also used in the evaluation of the real efficient engine methodology.

As part of the energy efficiency audit, it is recommended to separately assess the efficiency of the motor normally attached to the pump to figure out if energy is being wasted. Evaluating the efficiency of each component separately is useful for making better decisions on actions to incorporate into an energy savings plan.

The methodology focuses on determining the efficiency (η_m) and therefore the level of wasted energy of electric motors. The motor curve method is the most appropriate engineering method to use to determine efficiency. This is an iterative procedure based on the comparison between the calculated efficiency and efficiency curve based on the motor load factor (LF).

FIGURE 18: Typical Efficiency vs. Load Curves for an 1800-RPM Cage Induction Motor



The appropriate motor efficiency curve, identified in Figure 18, is derived from the original design parameters of the motor (HP, RPM, and V). Using the measurement of the active power of the motor, calculate the LF using the following equation:

$$LF = \frac{P_e / \eta_m}{HP_{nom.} * 0{,}746}$$

Where:

LF is the load factor of the motor (–)
P_e is the active power of the motor from the field measurements (kW)
η_m is the actual and real efficiency in which the motor is operating (–)
Hp_{nom} is the original power of the motor (verify it in the motor's plate) (HP)

Check the engine efficiency to see if it corresponds to the LF calculated. If not, repeat the previous step using the efficiency that corresponds in the efficiency curve to the calculated LF until both values match. The last values of efficiency and LF are the real values for the motor. Once the original efficiency and LF are determined, efficiency has to be depreciated according to the following criteria:

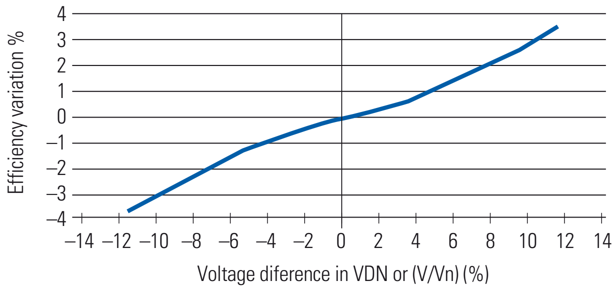
- If the engine is more than 10 years old, depreciate it by a percentage point.
- If the motor has been rewound, depreciate efficiency by two percentage points. If you know the temperature of the motor during the rewinding process, depreciate efficiency according to Table 8.

TABLE 8: Depreciation of the Efficiency of a Motor Rewinding According to Temperature

Temperature (oC)	Efficiency Reduction Value
633	0.0053
683	0.0117
733 (use of welding torch)	0.0250
Use of chemicals	0.0040

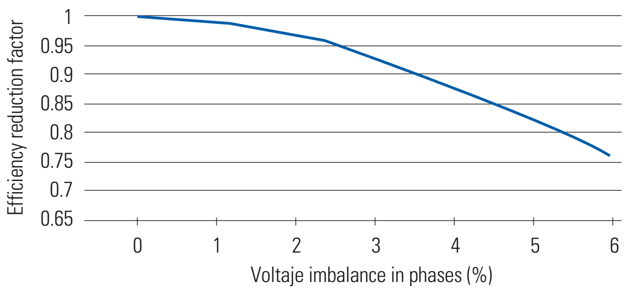
When measured, if the supply voltage to the motor is different from the original motor voltage (in the plate), apply an efficiency reduction according to the curve shown in Figure 19.

FIGURE 19: Efficiency Variation Based on the Difference with Respect to the Original Voltage in an Electric Motor



If there is an imbalance in the supply voltage, apply the adjustment to the efficiency according to the curve in Figure 20.

FIGURE 20: Reduction in the Capacity of an Electric Motor Based on the Voltage Imbalance



Use the equations to calculate the imbalance of the voltage and current, and the voltage difference to the original motor.

Voltage Imbalance D_{BV}

The voltage imbalance is calculated from voltage measurements between phases using the following equation:

$$D_{BV} = \max((\max(V_{A-B}, V_{B-C}, V_{C-A}) - V_{avg}), (V_{avg} - \min(V_{A-B}, V_{B-C}, V_{C-A})))$$

Where:

D_{BV} is the voltage imbalance (–)
V_{A-B} is the voltage between the phases A and B (V)
V_{B-C} is the voltage between the phases B and C (V)

V_{C-A} is the voltage between the phases C and A (V)
V_{avg} is the average voltage between phases (V)

Current Imbalance D_{BI}

The current imbalance is calculated from current measurements in each phase using the following equation:

$$D_{BI} = \max((\max(I_A, I_B, I_C) - I_{avg}), (I_{avg} - min(I_A, I_B, I_C)))$$

Where:

D_{BI} is the current imbalance (–)
I_A is the current in phase A (A)
I_B is the current in phase B (A)
I_C is the current in phase C (A)
I_{avg} is the average of the current in the three phases (A)

Voltage Difference to the Original Motor VDN

The voltage difference to the original motor is calculated in percentage by the following equation:

$$VDN = (V_{avg} - V_{Plate}) / V_{Plate} * 100$$

Where:

VDN is the difference to the original motor voltage or V/Vn (–)
V_{avg} is the average voltage in phases (V)
V_{Plate} is the value of the original intake voltage of the motor, indicated in the motor's plate (V)

4.3.3. *Calculation of Losses and Efficiency of the Pump*

One of the greatest points of energy loss occurs when the electrical energy is converted to mechanical energy by means of the pumping system and transmission to the fluid in the form of power gauge transformation. It is important to diagnose various aspects that may cause excessive energy consumption, while at the same time seeking low-cost savings opportunities. The main aspects to diagnose in pumping systems are:

1. Actual electromechanical efficiency
2. Operating conditions of the system
3. Characteristics of the installations and energy lost in the conduction system

4.3.3.1. *Calculation of Efficiency and Pump Losses*

Pumps have natural losses during operation as a result of the interaction of the flow with the frictional mechanism that occurs inside and outside of its components. To understand where the losses come from during operation, review the different types of losses that occur in pumps, which are classified as internal or external.

Internal Losses

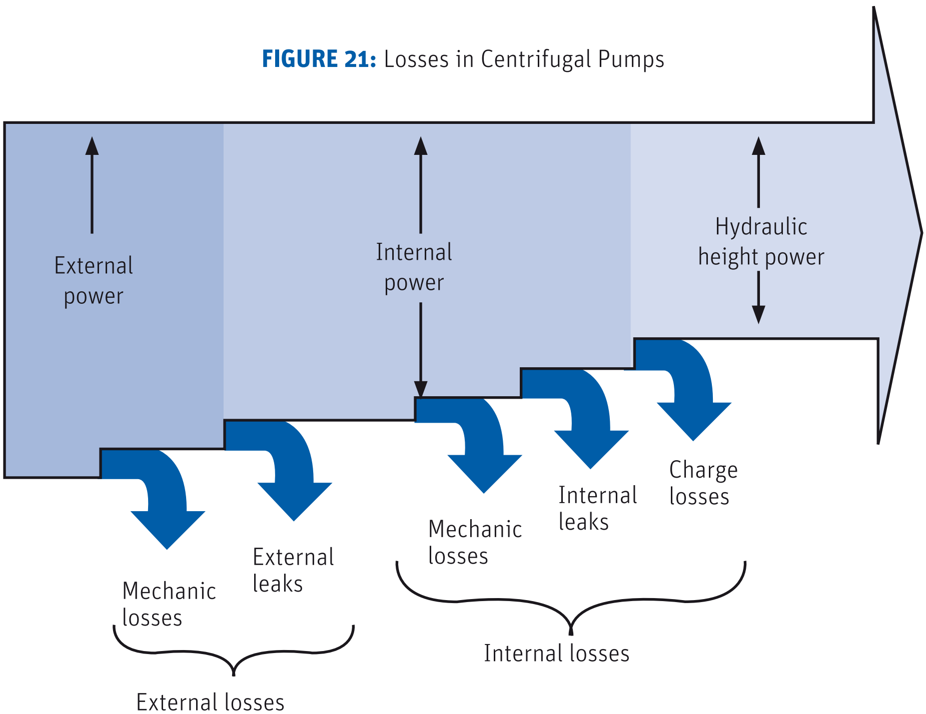
- Load losses: caused by the viscosity and the turbulence of the fluid. An example is the shock at the entrance of the diffuser.
- Leakage losses: caused by the gap that necessarily exists between moving parts and fixed parts.
- Internal friction losses: a centrifugal pump impeller has inactive surfaces, independent of its work to transmit energy to the fluid, causing a rise of the viscous friction. This leads to internal friction losses in the fluid.

External Losses

- External leakage: takes place where the shaft crosses to the housing of the machine. A part of the flow entering the pump is diverted from entering the driver and is lost.
- External friction losses: caused by mechanical friction in the packing in the shaft or pump bearings.

Figure 21 presents the flow of losses and the performance of a typical centrifugal pump in a Sankey diagram.

FIGURE 21: Losses in Centrifugal Pumps



The overall efficiency of the operating pump is then calculated as the total output power P_s (pressure in the output gauge) divided by the mechanical power absorbed P_m, identified in Figure 21 as external power. The efficiency formula is as follows:

$$\eta_b = \frac{\textit{Output total Power Gauge } (P_s)}{\textit{Absorbed Mechanical Power } (P_m)} \times b$$

Where:

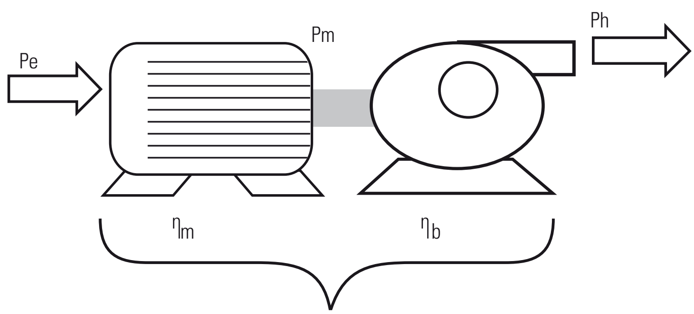
η_b	is pump efficiency in percentages (–)
Ps	is Q ρ g Ht / 746 (HP)
Pm	equals absorbed mechanical power by the pump in HP
Q	is flow (m^3/s)
r	is pumped water density (kg/m^3)
g	equals acceleration of gravity (m/s^2)
Ht	equals total pumping head (mwc)

Because of the difficulty of measuring the mechanical power separately and then determining the efficiency of the pump, it is recommended to evaluate the electromechanical efficiency of the motor-pump assembly.

4.3.3.2. *Evaluation of Electromechanical Efficiency*

Electromechanical efficiency corresponds to the efficiency of the joint motor-pump (see Figure 22).

FIGURE 22: Efficiencies that Comprise the Electromechanical Efficiency



First, calculate the gauge power using the following equation:

$$P_h = H_t * Q * \gamma * g / 1000$$

Where:

P_h	is the gauge power (kW)
H_T	is the total pumping head (mwc)
Q	is the flow (m^3/s)
γ	is the specific weight of water (kg/m^3)
g	is the acceleration of gravity (m/s^2)

The Q value is based on measurements acquired in the field. The γ and g values are almost constant in the typical operating temperature range and generally take the values 1 and 9.81 respectively. The total pumping head is a combination of different partial loads calculated.

Calculation of the Total Pumping Head H_T

Depending on the type of measurements made, the total pumping head shall be calculated as follows:

• If the suction pressure was measured, as is recommended in pumping systems, use this equation:

$$H_t = (P_d - P_s) * 10.3$$

Where:

H_b equals total pumping head (mwc)
P_d is the measured discharge pressure (kg/cm^2)
P_s is the measured suction pressure (kg/cm^2)

• If the suction pressure was not measured, which is the case with deep wells or where the suction pressure cannot be measured for the pumping systems, use this equation:

$$H_t = (P_d * 10.3) + N_s + D_{r-m} + h_v + h_{fs}$$

Where:

H_t	equals total pumping head (mwc)
P_d	is the measured discharge pressure (kg/cm^2)
N_s	is the suction level *measured from reference level Nr* (m)
D_{r-m}	is the distance between the reference level and the center of the gauge (m)
h_v	is the velocity head (m)
h_{fs}	are the friction losses in the suction and discharge pipes (m)

Velocity Head Hv

Velocity head is dependent on the diameter of the pipe. Calculate the area of the cross section (A) of the discharge pipe as follows:

$$A = \pi * D^2 / 4$$

Where:

A	is the area of the cross section of the pipe (m^2)
D	is the diameter of the pipe (m)
π	Pi, which is equal to 3.1416

Based on this result, you can calculate the fluid velocity (v) with the following equation:

$$\nu = Q / A$$

Where:

v	is the velocity of the fluid (m/s)
Q	is the flow from field measurements (m^3/s)
A	is the area of the cross section of the pipe (m^2)

Next, use these values to calculate the velocity head as follows:

$$h_v = \nu^2 / (2 * g)$$

Where:

- h_v is the velocity head (mwc)
- ν is the velocity of the fluid (m/s)
- g is the acceleration of gravity, 9.81 (m/s^2)

Friction Losses in Suction and Discharge Pipes H_{FS}

Suction and discharge piping also generates energy losses due to the friction of the fluid on the walls and is calculated by the following equation:

$$h_{fs} = f * (L/D) * (\nu^2/2*g)$$

Where:

- f is the friction factor (–)
- L is the pipe length – suction and discharge with the same diameter (m)
- D is the pipe diameter (m)
- ν is the fluid velocity (m/s)
- g is the acceleration of gravity, 9.81 (m/s^2)

The friction factor (f) is obtained either from the Moody diagram (see Figure 23) by entering the value of the relative roughness and the value of the Reynolds number, or by using the following Colebrook-White equation:

$$\frac{1}{\sqrt{f}} = -2 \log\left[\frac{\varepsilon/D}{3.71} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right]$$

This equation is implicit and the value of the friction factor has to be obtained by iteration. Alternatively, the following formula can be used, which is explicit (thus no need for iteration) and uses the same parameters:

$$f = \frac{0.25}{\left[\log\left(\frac{\varepsilon/D}{3.7} + \frac{5.74}{\mathrm{Re}^{0.9}}\right)\right]^2}$$

Source: Guerrero O. (1995). "Ecuación Modificada de Colebrook-White." *Revista Ingeniería Hidráulica de México* X: 43–48, January-April.

Relative roughness is defined as the division between absolute roughness (ε) and the pipe diameter (D) in mm. Absolute roughness is a characteristic of the pipe's material. Table 9 provides the values for different pipes.

TABLE 9: Values of Absolute Roughness (ε) for Different Pipe Materials

Pipe Material	ε (mm)
Steel	0.9–9
Concrete	0.3–3
Cast iron	0.25
Galvanized iron	0.15
Forged asphalt iron	0.12
Forged iron	0.046
(PVC)	0.0015

The Reynolds number (Re) is calculated by the following expression:

$$Reynolds = \upsilon * D * \rho / \mu$$

Where:

- υ is the velocity of the fluid (m/s)
- D is the internal diameter of the pipe (m)
- ρ is the density of the fluid (kg/m3)
- μ is the dynamic viscosity of the fluid, which comes from tables in function of the fluid temperature

Water viscosity values are shown in Table 10.

TABLE 10: Dynamic Viscosity of Water

Temperature (°C)	Viscosity (mPa·s)
10	1.308
20	1.002
30	0.7978
40	0.6531
50	0.5471
60	0.4668

Electromechanical Efficiency Calculation η_{EM}

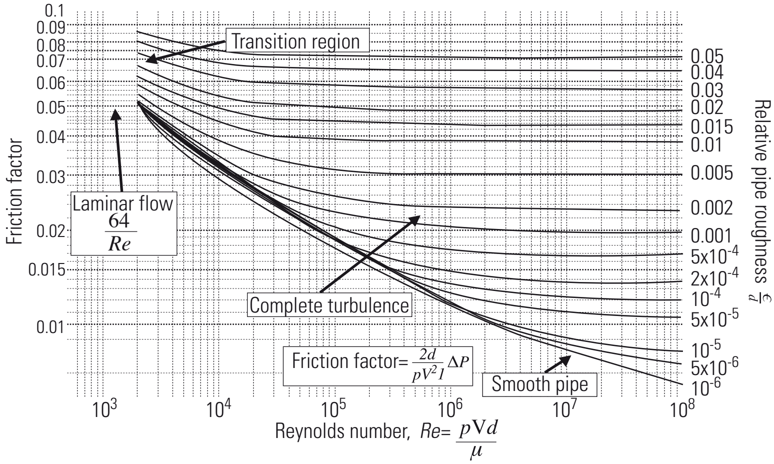
With the value of P_h calculated and the active motor power measured in the field, the value of the electromechanical efficiency is calculated with the following equation:

$$\eta_{EM} = P_h / P_e \times 100$$

Where:

- η_{EM} is the electromechanical efficiency (–)
- P_h is the gauge power (kW)
- P_e is the electric power input to the motor already measured (kW)

FIGURE 23: Moody Diagram



Material	ε (mm)
Concrete, coarse	0.25
Concrete, new smooth	0.025
Drawn tubing	0.0025
Glass, plastic, perspex	0.0025
Iron, cast	0.015
Sewers, old	3.0
Steel, mortar lined	0.1
Steel, rusted	0.5
Steel, structural or forged	0.025
Old	1.0

Pump Efficiency Calculation η_P

Once the electromechanical efficiency $\eta_{EM,}$ is calculated and the real motor efficiency η_M has been evaluated, the pump efficiency η_P can be calculated as follows:

$$\eta_B = \eta_{EM} / \eta_M$$

This value is calculated for all the pumping equipment to be audited and is used as a basis for the development of an energy efficiency plan.

4.3.4. *Calculation of Losses in the Distribution Pipe Network*

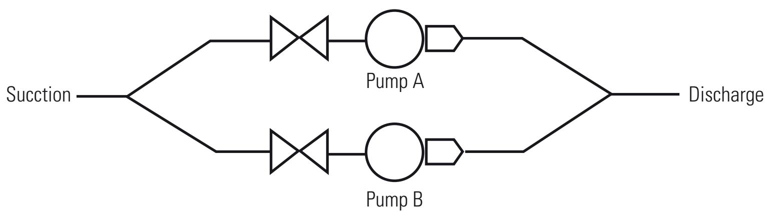
Excessive energy is often consumed in the pumping installations, particularly the water pipe network associated with each pumping system. Key points of the pumping systems evaluated during the energy efficiency audit include the physical configuration of pipes from wells and water conduction systems to the pumping stations or in the surface source pumping systems, such as river intakes, springs, dams, or filter galleries.

The main points to note are the suction conditions and pipe system characteristics. On many occasions, the system's efficiency is reduced due to insufficient liquid suction force at the intake of a pump, a concept known as net positive suction head (NPSH). During the energy efficiency audit, it is important to verify that the adequate NPSH requirements are met.

It is common to find low carrying capacity at the discharge pipelines of the pumping systems. This is reflected in three typical problems that must be identified during the energy efficiency audit in order to issue relevant recommendations.

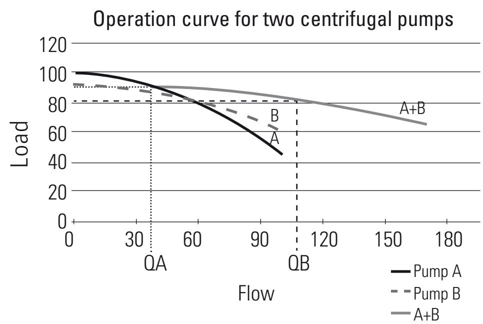
The first problem is back pressure caused by flow coming from an additional connected source or pumping system. This happens when more than one source feeds water into the same pipeline but at different pressures. The second problem is a reduction in the expected discharge capacity of pumping trains. This problem occurs frequently in systems where two pumps or more operate in parallel with the expectation of delivering additional flow to the network without ensuring each individual pump's ability. When this happens, the equipment does not provide the expected flow and has significantly reduced efficiency (see Figure 24).

FIGURE 24: Centrifugal Pumps Operating in Parallel



Erroneously, the operation curve for the situation in Figure 24 is conceived by simply adding the capabilities of each pump for equal load conditions. The result is shown in Figure 25.

FIGURE 25: Load Capacity of Centrifugal Pumps Operating in Parallel



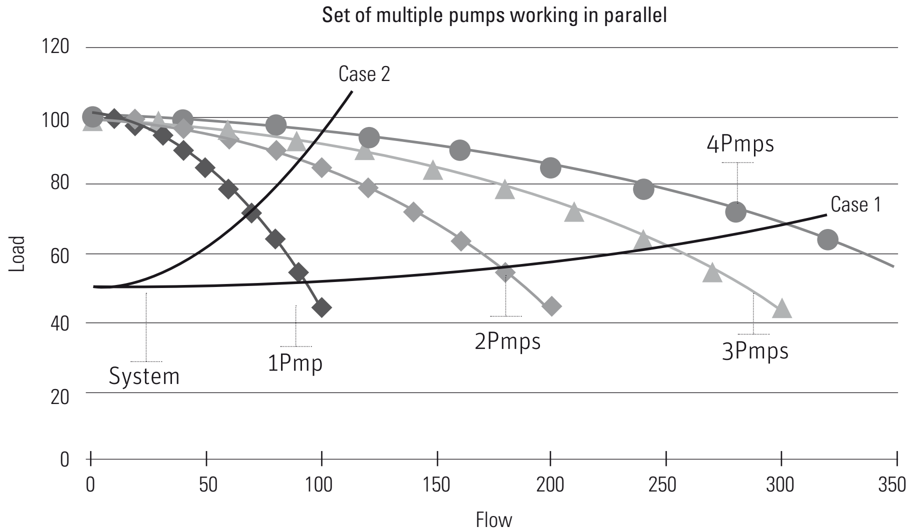
The load capacity equation then supposes that: $Q_{AB} = Q_A + Q_B$

Where:

Q_{AB}	is the resulting flow from parallel operation of pump A and pump B
Q_A	flow of pump A
Q_B	flow of pump B

A further misconception is that adding another pump will increase the flow twofold, a third pump will increase the flow threefold, and so on with each new pump. When you have a flow increase through the same pipe network, the head loss will also increase. The effect of each additional pump results in reduced flow from the individual pumps. Figure 26 illustrates this effect with two different cases. In the first case, the curve of the system is fairly flat for four pumps. Adding more pumps increases the flow, but the load has no significant change. In the second case, the curve of the system is not as flat as in the first case. Adding a fourth pump does not increase the total flow but splits it between four pumps. Neither case demonstrates a simple linear relationship between number of pumps and the resulting discharge flow.

FIGURE 26: The Effect of Several Pumps Working in Parallel on the Conduction System



Another problem is excessive energy lost due to the low capacity of the existing water conduction systems. In some distribution systems, energy losses by friction in pipelines are significant. To assess this possibility, perform the following procedures during the energy efficiency audit:

1. With the data collected during the measurement campaign and field inspection, evaluate the velocity of the fluid in the primary conduction pipes in the supply and distribution networks.
2. In conduction pipes where the fluid velocities are greater than 2.0 m/s, evaluate the energy lost. Integrate this information later into the portfolio of proposed energy efficiency projects.

The following are options for performing an assessment of friction losses in conduction pipes:

a. Calculation based on hydraulic modeling pipeline analysis methods, which requires the construction of such a model before this assessment
b. Conventional procedure for a rapid assessment of the potential savings in the early stages of the plan to prevent having to wait for access to the simulation model

   For analysis by the conventional method, follow this procedure:

   i. Calculate primary friction losses (straight pipe) in the current pipeline:

1. Calculation of the friction factor
   a. The friction factor coefficient is determined by the Moody diagram and from the values of the Reynolds number and relative roughness that were described in section 4.3.3.2 of this document.
2. Calculate the friction losses load h_{fr} (mwc) with the following equation:

$$h_{fr} = f * \left(\frac{L}{D}\right) * \left(\frac{v^2}{2 * g}\right)$$

Where:

f	is the friction factor from Moody diagram (–)
L	is the total length of the conduction pipe (m)
D	is the diameter of the pipe (m)
υ	is the velocity of the fluid (m/s)
g	is the acceleration of gravity, 9.81 (m/s^2)

ii. Calculate secondary losses by valves and fittings in the pipeline.

Several methods can be used to determine secondary losses. The present document mentions only the equivalent straight pipe length method, which assesses the pressure drop generated by a pipe accessory and determines the equivalent length of straight pipe with the same pressure drop.

Figure 27 shows a nomogram for various pipe accessories and consists of three scales. Draw a straight line connecting the left scale, which describes the pipe accessory, to the right scale, which corresponds to the inside diameter of the pipe accessory. The point of intersection of this line with the central scale tells us the equivalent length of a straight pipe for the accessory.

Once the equivalent length of all accessories is determined, calculate the pressure drop or secondary losses using the following equation:

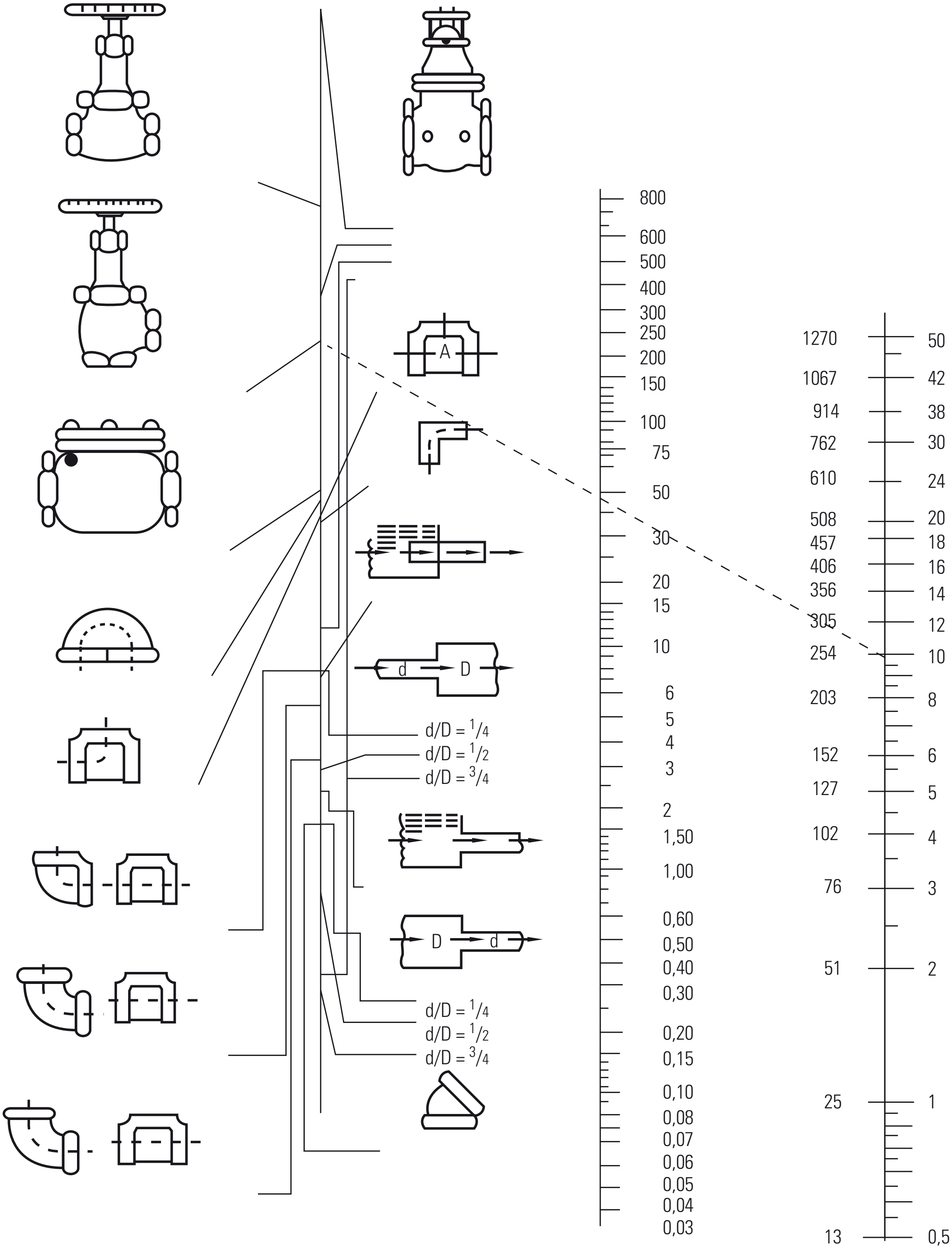
$$h_{fa} = f * \left(\frac{\sum L}{D}\right) * \left(\frac{v^2}{2 * g}\right)$$

Where SL is the sum of all equivalent lengths of accessories within the same diameter. The values for the equivalent length of accessories are standard common values. In fact, the pressure loss values of the accessory will depend on the particular design of the manufacturer. **The total losses will be the sum of the primary and secondary losses**.

iii. Once total losses by friction are calculated, calculate the electric power needed to offset the friction losses. This is the end point of the evaluation of losses during the energy efficiency audit. Calculate the required electric power with the following expression:

$$P_e = \frac{(h_{fr} + h_{fa}) * Q * 9.81}{\eta_{EM}}$$

FIGURE 27: Nomogram for the Calculation of Equivalent Length in Pipe Accessories



Where:

P_e	is the electric power needed to compensate the losses (kW)
hfr	are the friction losses in the straight pipeline (mwc)
hfa	are the friction losses in accessories (mwc)
Q	is the flow (l/s)
η_{EM}	is the electromechanical efficiency of the motor-pump arrangement in decimals (–)

Commonly, when there is insufficient water conduction ability, the electric power needed to compensate is a significant percentage of the power demanded by the pumping system. This is an essential calculation for the energy saving measures in the efficiency plan.

4.3.5. *Calculation of Energy Indicators*

There are a large number of indicators to measure the effectiveness and efficiency of a water system, but in terms of energy efficiency, tracking the energy index *EI* (kWh/m^3) and unitary energy cost indicator *UEC* ($/kWh) is essential. It is important to measure, register, and analyze these indicators continuously in water and sanitation companies, as the results can reflect the progress achieved and help establish further policies and programs to increase energy efficiency.

4.3.5.1. *Energy Index EI (kWh/m³)*

The energy index represents the relationship between the energy used by the pumping system in a drinking water system and the total volume of water produced and supplied to the distribution network. The volume of water produced is expressed in cubic meters per year. The amount of energy consumed in the pumping system is determined from past billing statements of the local electricity company. The consumption in kilowatt-hour (kWh) is totaled on a yearly basis. The energy index is calculated as follows:

$$EI = \frac{\textit{Total energy consumed by the equipment } (kWh)}{\textit{Total water produced and supplied to the system } (m^3)}$$

There is no energy index baseline value because this value depends on the type of water source available in the water supply system and the topography of the city. Systems located in hilly topographies that supply water by using pumping stations only will have higher energy index values. Also, systems with many leaks in the network will show an increase in the production and supply of water, and thus greater consumption of energy. On the other hand, a water company's energy index will go down by installing more efficient pumping equipment and minimizing the leakage in the network.

4.3.5.2. *Unitary Energy Cost Indicator UEC ($/kWh)*

The cost per unit of energy consumed depends on several factors, such as the type of electricity tariff contract, specific load factor (reflecting actual operation hours with respect to fulltime operating of 24 hours a day), and other factors affecting energy such as penalties or billing credits due to the PF of the electrical installations. Unitary energy cost (UEC) is calculated based on the total annual consumption of energy (kw/year) and the total of the energy bills ($/year) collected by the water company over the year.

$$UEC = \frac{Total\ energy\ billed\ (\$/year)}{Total\ consumption\ of\ energy\ (KWh/year)}$$

Like the energy index, there is no average reference value. These indicators are based on the electro-mechanical infrastructure and respective costs and have to be set for each water company.

4.3.6. *Actual Energy Balance*

Once the energy efficiencies of the pumping system components are evaluated, the actual energy balance of the equipment must be determined. The actual energy balance is an indicator of the elements of the pumping system that consume the most energy and serves as a basis for planning savings measures.

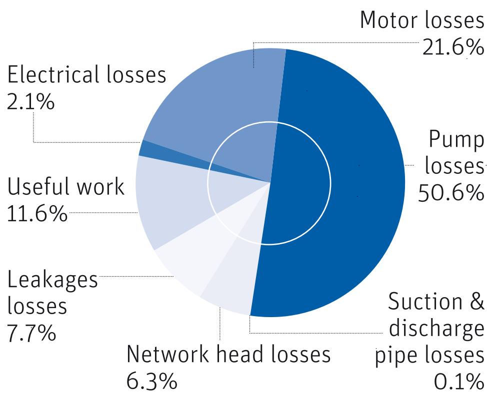
The most significant value obtained with this indicator is the breakdown of all the energy lost in the supply and use of energy by distinguishing it from the useful work, which is the energy actually used by the system for water pumping. Anything that is not useful work is lost energy. The balance makes it possible to distinguish the difference between the two. It indicates the distribution of energy and where it has the greatest impact, and where the major energy saving opportunities can be found.

The actual energy balance calculates the energy losses and efficiencies of all the pumping system components according to the sections 4.3.1 to 4.3.5 of this document. The energy losses and efficiencies are shown in Table 11, where the value of each element of energy consumption is then broken down into the actual energy balance.

TABLE 11: Example of Energy Balance in a Pumping System

ACTUAL ENERGY BALANCE

Parameter	Unit	Amount
Energy consumption	kWh/year	73,651
Motor efficiency	%	77.92%
Pump efficiency	%	33.72%
Leakages losses	%	40%
Useful head	mwa	35
Electrical loses	kWh/year	1,538
Motor losses	kWh/year	15,920
Pump losses	kWh/year	37,242
Suction & discharge pipe losses	kWh/year	52
Network head losses	kWh/year	4,652
Leakages losses	kWh/year	5,698
Useful work	kWh/year	8,548



The elements that compose the actual energy balance are:

Energy consumption – total electrical energy consumed by the pumping system during a full year of operation (kWh).

Motor efficiency – the real motor efficiency (–).

Pump efficiency – the pump efficiency (–)

Leakage losses – an estimate of water lost through leaks in the distribution network, according to previous studies of the network (–).

Useful head – the pump load due to the physical and topographic elevations and the vertical distance between the suction and highest point of delivery, expressed in meters of water column (mwc).

Electrical losses – energy losses in electrical items, in this case, due to the conductor's energy losses.

Motor losses – energy losses in the motor based on real motor efficiency.

Pump losses – energy losses due to pump inefficiency.

Suction and discharge pipe losses – energy losses caused by friction of the fluid in piping suction and discharge.

Network head losses – total pumping load losses calculated by the difference between the net pumping head and the corresponding pressure gap.

Leakage losses – energy losses estimated from the fluid leaks in the distribution network, calculated based on the leakage factor.

Useful work – real work expressed in units of energy actually needed by the pumping system or, in other words, the energy that is actually used in the pumping system to deliver the fluid.

Once the losses are calculated for each of the elements of the pumping system, a pie graph can be made, as in Table 11, to give a better perception of the actual energy balance.

4.3.7. *Analysis of Operating Conditions*

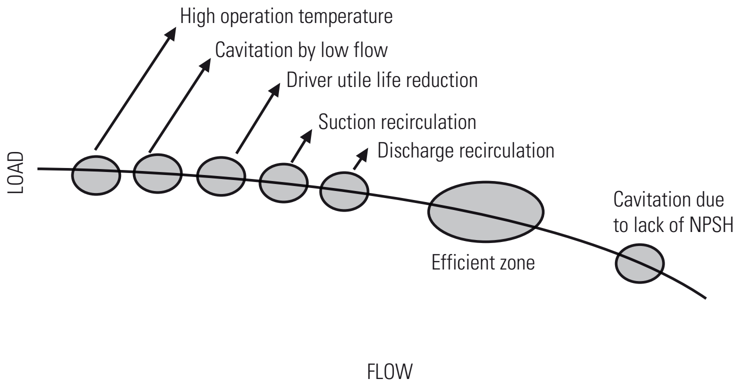
In doing an analysis of operating conditions, there are two important observations to make. The first is the real load-flow operating conditions of the pumping systems to see whether they are constant or if they change by a period of time. The second is the regulation of water levels in suction pits and regulation tanks.

According to their design, all pumps have an optimum load-flow point of operation called a duty point, where all losses described in previous sections are minimized. If the pump is operating out of its duty point, it may be due to:

- Low energy efficiency
- Worn components, particularly drivers and wear rings
- Cavitation by low suction
- Other operating conditions than those present when the pump was designed

Figure 28 presents the typical problems caused by operating a pump out of its duty point.

FIGURE 28: Problems of a Pump Working out of Its Duty Point



Pumping systems commonly operate at different conditions than those for which they are designed. The causes of this problem include the following:

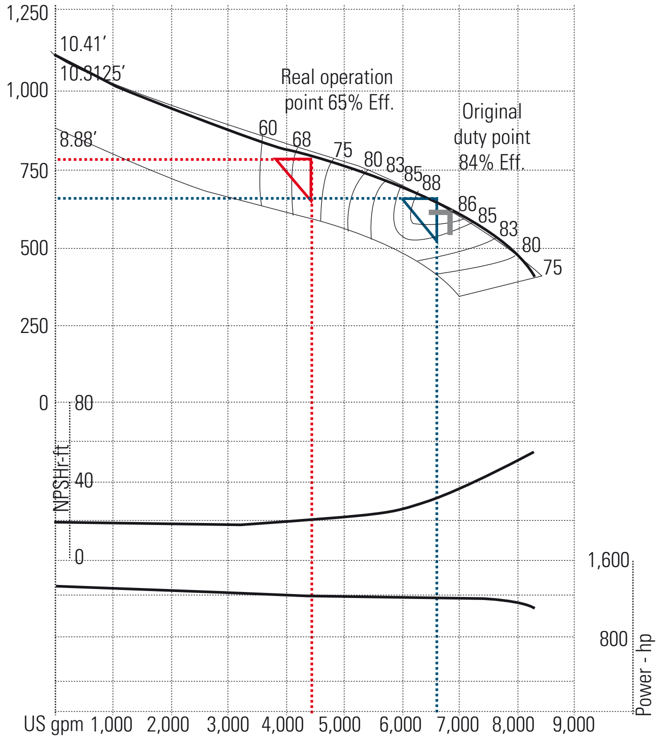
- **Discontinuous supply** – It is common to find pumping systems that supply to different points or areas of the distribution network, even on the same day. A typical discontinuous supply operation supplies directly to the network one day, and the next day it supplies to a tank or another area of the population.
- **Emergency repairs** – Due to the lack of preventive maintenance, urgent repairs are often needed, but the companies lack the correct components required to effectively perform repairs or replace equipment. Instead they use the components available to them, but in most cases these were designed for other operating conditions.

Figure 29 shows that a significant head-flow variation in the operating conditions can affect the pump efficiency up to 20 percent.

The next observation is to determine the method used to control suction and discharge water levels of tanks related to the pumping system. Commonly, the water levels in suction pits are measured manually, which causes inefficiencies such as spills in the tanks. As a result, equipment ends up operating for long periods in unfavorable load conditions, and thus directly affecting the electromechanical efficiency. In this situation, it is very important to carry out the following tasks during the energy efficiency audit:

1. Clearly identify the operating conditions of the equipment, which includes load-flow operating conditions for different periods of the day or every week.
2. Obtain the design parameters or, if possible, the original design curve of the equipment installed in order to provide appropriate recommendations in each situation.

FIGURE 29: Pump Operation and Efficiency Affected by Variations in Operating Conditions



Chapter 5

IDENTIFYING ENERGY SAVING OPPORTUNITIES

Based on the analysis of the information obtained during the energy efficiency audit, including the findings on operating conditions and maintenance, define a portfolio of possible projects to cover all energy and economic saving opportunities, including measures of low to high investment. For projects that require higher investment, evaluate the cost-benefit from either a payback analysis of the investment or a detailed analysis based on the net present value and the lifespan of the purchased good, which will be seen later herein. In general, the actions identified in each project are intended to control and optimize the variables affecting consumption and cost of energy. In this manual, saving measures are classified into the following groups:

- Measures related to the energy rate
- Loss reduction measures in electrical installations
- Measures to increase the efficiency of motors
- Measures to increase the efficiency of pumps
- Head loss reduction
- Leakage reduction
- Operating improvements
- Electric power supply source replacement
- Maintenance (see Chapter 8)

A detailed description of each savings measure, its respective technical basis, and the criteria used for the implementation of these measures are described in the following section.

5.1. MEASURES RELATED TO THE ENERGY RATE

5.1.1. *Electrical Service Rate Optimization*

An attractive savings opportunity in pumping systems is to find a cheaper rate with a different electric power supply company. In order to do so, it is important to undertake a study of the rate structure during the energy audit.

Electricity fees for water and sanitation companies may vary according to agreements established with the supply companies. To find the best rate, first identify the tariffs in each and every one of the water and sanitation company's services, as well as the demand and consumption for each facility. Then do an assessment of the potential savings in the cost of electricity with different tariffs. Compare the amounts that would be paid by using each rate. It is important to consider all the costs associated in each price. For example, if you are going to change from low-voltage to medium- or high-voltage supply, consider the tariff change as well as costs of investments required to purchase and install the electrical transformers as well as the costs associated with the maintenance of such transformers.

5.1.2. *Electricity Demand Control*

In most Caribbean countries, the cost of electricity varies depending on the time of day that electricity is used. The type of fee that is often used in the service contract of water and sanitation systems is referred to as an hourly fee. In this type of rate there is a time known as peak demand time, where the unit cost of energy is usually much higher than during the rest of the day.

In facilities where this rate is used to supply electricity, compare alternatives for implementing a measure that manages consumption when demand is at its peak. This is known as a demand control scheme, which is based on decreasing the hydraulic operation and thus electricity load during peak hours. As a result, the total cost of electricity supply drops. Demand control can be put into place through the following:

a. Modification of operating procedures to reduce consumption during the peak demand time.
b. Installation of timers to stop certain equipment before the start of the peak demand time and programs to restart it again at the end of peak demand.
c. Introduction of a system to automatically cut off equipment of significant electrical size to control global facility power demand (mainly during peak hours), without affecting the process parameters, such as pressure or level in tanks.

5.2. LOSS REDUCTION MEASURES IN ELECTRICAL INSTALLATIONS

5.2.1. *Improve Cooling in Transformers*

If the temperatures recorded in the transformer are high or remaining in an out-of-normal range during the field measurements, it can lead to a significant loss of electrical power. In this case, the cost of correcting the failure should be assessed.

Situation observed during audit: Determine if the electrical losses in the transformer represent more than 2 percent of total energy consumption during the audit.

Recommended measures: Depending on the particular problem, apply actions listed in Table 12.

TABLE 12: Recommended Actions to Improve Conditions in a Transformer

Observed condition	Recommended action
The transformer has many been in operation for many years and/or is in bad shape.	Practice general maintenance on transformer and, in case of irreversible damage, replace with a new low-loss transformer.
The transformer has a high temperature due to lack of ventilation in the room where it is installed.	Improve the ventilation in the room where the transformer is, either by installing extractors or by opening windows for ventilation of the room.
The temperature of the transformer is high during operation due to the high ambient temperatures.	Install a transformer-forced ventilation system.

5.2.2. *Upgrade Electrical Conductors*

If the caliber of conductors does not meet the requirements of the pumping equipment, select a conductor that not only meets the international standard but also saves energy.

Situation observed during audit: The electrical conductors are in poor condition and/or are overloaded and near their capacity limit.

Recommended measures: Replace current conductors with higher caliber conductors that comply with international and safety standards.

5.2.3. *Optimize Power Factor*

The objective of this measure is to eliminate the problems caused by a low PF. If the value is less than 90 percent, improve the PF to maximize unit's capability.

Situation observed during audit: The PF in pumping equipment is less than 0.90 or 90 percent.

Recommended measures: If the low PF is caused by an oversized or poorly working motor, replace it with a new high efficiency motor with a capacity of operation of around 75 percent of its load.

Once the problems of motors are solved, compensate the PF with capacitor bank with the following actions:

1. Measure the PF
2. Propose the installation of a capacitor bank in order to achieve a PF of 0.97
3. Install the proposed capacitors downstream of the motor starter so they only remain in operation when the motor is on

5.3. MEASURES TO INCREASE THE EFFICIENCY OF MOTORS

5.3.1. *Correct Voltage Imbalances*

Situation observed during audit: The motor is working with suboptimal efficiency due to a voltage imbalance in its electrical supply.

Recommended measures: Depending on the source of the voltage imbalance, actions to be implemented are outlined in Table 13.

TABLE 13: Recommended Actions to Correct the Voltage Imbalance in Electric Motors

Source of voltage imbalance	Corrective actions
Imbalance in electric current demanded by the motor, which produces a drop in voltage at each phase and therefore an imbalance in voltage.	Perform regular motor maintenance. If the damage is irreversible, replace the motor with one that has higher efficiency.
Imbalance of energy source at the power supply company.	Request that the energy supply company correct the problem.
Imbalance caused by the substation's own transformer.	Perform regular transformer maintenance. If the damage is irreversible, replace with a new low-loss transformer.
Imbalance caused by uneven transformer workloads.	Balance the transformer workloads.

5.3.2. *Replace the Electric Motor with a High Efficiency Motor*

If the motor breaks and repair is needed, replace it with a high efficiency motor. These motors differ from standard motors based on the following characteristics:

• Made of top-grade magnetic steel and insulating materials
• Reduction in the spaces between internal steel and rolling thickness spaces, which lowers possibility of internal losses
• Increase in the caliber of drivers
• Use of fans and more efficient cooling systems

5.3.3. *Optimize Motor Efficiency*

The energy efficiency audit will calculate the operating efficiency of the electric motors. Table 14 outlines the recommended corrective actions to take if there are abnormal findings.

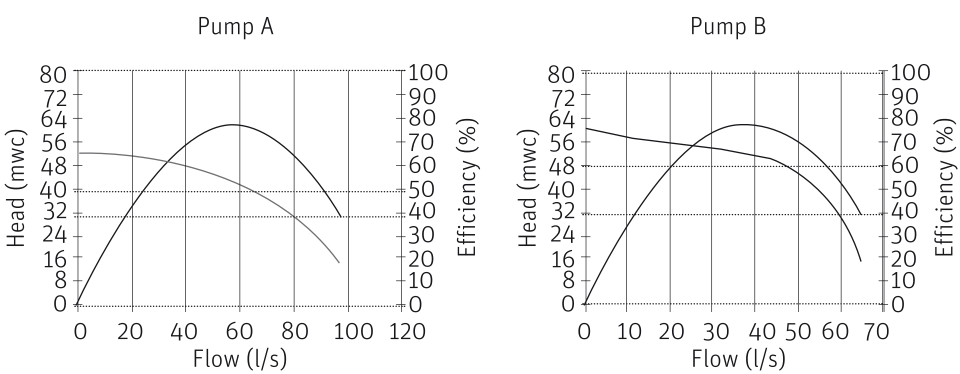
Implementing these actions can substantially improve motor efficiency and thereby reduce energy losses. For example, a 30 percent reduction of losses in a 10HP engine with 82 percent efficiency increases its value to 87 percent, which can also represent an increase in energy savings.

5.3.4. *Replace the Motor-Pump Set*

This measure is recommended when the mechanical efficiency is substantially lower than the optimum, and the potential for energy savings is more than 20 percent. Potential savings are higher with commercially available equipment. It is also important to separately review the real and estimated efficiency values for electric motors. The general approach is that if the potential for improving motor efficiency exceeds 5 percent, thus increasing potential savings, the motor-pump should be replaced. To increase the chances of success in energy efficiency and energy savings, select a pump using the following recommendations:

• Do not calculate unrealistic safety factors or include inappropriate information in the specification.
• If the pump will operate in more than one point of head-flow, select it so that both points present a "reasonably high efficiency." Figure 30 illustrates this recommendation using two pumps with different H-Q operations. Pump B has a flat curve and is adequate for frequent changes in the dynamic level, while Pump A would be more favorable when the dynamic level is more stable.

FIGURE 30: Typical Curves of Two Pumps with Different H-Q Operation



Once the pump is installed, verify the operation point and make the necessary adjustments.

TABLE 14: Recommended Actions to Correct Inefficient Operating Conditions In Electric Motor

Observed condition	Diagnosis	Corrective action
Power voltage lower than the original.	The voltage at the supplier connection point is below the original.	a) Correct the transformer voltage adjusting devices or TAPs of the transformer. (The TAPs are used to adjust the voltage transformation relationship and adjust the output voltage to the motor to absorb the variations of the supplier/ changers handling components.)
		b) Ask the supplier to fix the problem.
	The voltage at the supplier connection point has variations higher than 5 percent.	Ask the supplier to fix the problem.
	The voltage at the point of supplier connection is the same as the original of the motor and has no significant variations.	a) Correct the TAPs of the transformer.
		b) Diagnose and administer maintenance to the transformer.
Voltage imbalance in the motor's power supply.	The voltage at the supplier connection point is unbalanced.	Ask the supplier to fix the problem.
	The in voltage is balanced and the out voltage is unbalanced.	Diagnose and maintain the transformer as needed.
	The voltage at the terminals of the secondary transformer is balanced and power to the motor is unbalanced.	a) Review the grounding of the transformer and the motor connection. Correct problems where detected.
		b) Review the control motor center, starter and motor, and connections. Correct problems where detected.
Imbalance in power demanded by the motor.	Imbalance in power is inversely proportional to the imbalance in voltage.	Correct the imbalance in voltage.
	The imbalance is produced by a power demand unbalanced by the phases of the motor.	a) If the imbalance is less than 5 percent, perform motor maintenance
		b) If the imbalance is greater than 5 percent, replace the motor with a high efficiency motor.
The speed of the motor operation is under original full load speed.	Problems with bearings.	Lubricate and replace components that create problems.
High temperature and/or high vibration in bearings		
The motor has standard efficiency and has been in operation more than 10 years.	Low motor efficiency.	Replace the current motor with a new high efficiency motor that operates at around 75 percent of capacity.
The motor has been repaired (rewound) more than twice.	Depreciated motor efficiency.	
The motor is currently working on a load factor of less than 45 percent.	Low motor efficiency.	
The motor is currently working on a load factor of greater than 100 percent.	Low motor efficiency.	

5.4. MEASURES TO INCREASE THE EFFICIENCY OF PUMPS

5.4.1. *Adjust the Pumping Equipment to the Actual Operating Conditions*

Define at least two points of the head-flow curve where the pumping equipment is operating. Assess the characteristics of the installed equipment in terms of whether they meet the real operating conditions required; for example, reduce the number of bowls, adjust impellers, change impellers, or replace pumping equipment. Table 15 lists appropriate actions that can be taken to increase the efficiency of the pump based on observations.

TABLE 15: Recommended Actions to Adjust the Pumping Equipment to the Actual Operating Conditions

Pump type	Operation point position	Actions
Vertical multi-stage pump	Above pump's curve.	Increase stages of the pump until the curve adjusts to the operating conditions.
		Replace impellers with new ones of a greater diameter.
	Below pump's curve.	Decrease stages of the pump until the curve adjusts to the operating conditions.
		Shorten the impellers so the pump's curve adjusts to the operating conditions.
Horizontal	Above pump's curve.	Replace impellers with new ones of a greater diameter.
	Below pump's curve.	Shorten the impellers so the pump's curve adjusts to the operating conditions.

5.4.2. *Adjust Impeller Position in Open Impeller Turbine Pumps*

This measurement applies only for open impeller turbine pumps with low operating efficiency.

Adjust the shaft with the impellers in the bowl section of the pump by lifting or lowering the shaft with the adjustment nut. Figure 31 shows the impeller array within the body of the pump bowls. This impeller setting is calibrated with the shaft under the manufacturer's specifications at the time of installation. Improper positioning of the impellers at the time of installation or natural shifting over time will cause lower pump efficiency.

The following steps should be taken to adjust the shaft to its design position:

Step 1: Remove the vertical motor cover to reveal the shaft adjustment nut (see Figure 32).

Step 2: Dismount the security screw that prevents the nut from moving.

Step 3: Once the nut is free, move it until it is not supporting the weight of the shaft. At that point, tighten it by hand until it is fixed, and then measure the length of the shaft that is above the level of the nut.

Step 4: Lift the shaft by tightening the adjustment nut until it reaches the upper rim of the bowl. Take the corresponding measurement from the adjustment nut to the top of the shaft. The distance measured is the current total impeller space between the body of the bowls. If the distance does not match the value supplied by the manufacturer, the impellers are worn.

Step 5: Loosen the shaft until the impellers reach the top of the bowl. After doing this, tighten the nut to adjust the shaft according to the distance specified by the manufacturer, which depends on the diameter of the shaft and the hydraulic head.

FIGURE 31: Turbine Pump with Open Impeller Diagram

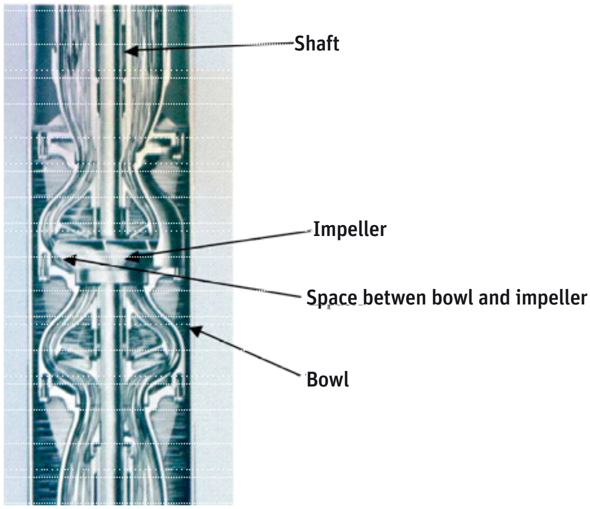
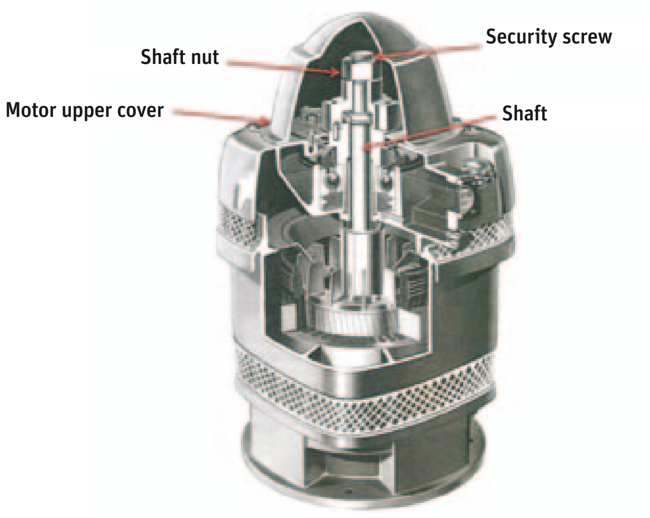


FIGURE 32: Diagram of a Hollow Shaft Motor Attached to a Turbine Pump*



Source: Byron Jackson Manual for Turbine Pumps.

5.5. HEAD LOSS REDUCTION

5.5.1. *Correct Defects in the Discharge Piping Configuration and Operation*

If the audit determines that there is a problem in the discharge pipeline configuration and it is causing lower efficiency in one of the pumps, correct the discharge piping configuration and operation. This measure should be applied in pumping systems when there are unnecessary back pressures or to prevent flow recirculation from the pumping equipment. In this case, make changes to the discharge pipe or primary pipe configuration to avoid the problems mentioned above.

5.5.2. *Reduce Friction Losses in Conduction Pipes*

Losses caused by water friction on the walls of the pipe can reach up to 30 percent of the power demanded by the pumping equipment in some cases, especially in pipes with high water velocity. The recommended fluid speed in a pipe is less than 2.0 m/s. If the fluid velocity is above this value, some actions must be taken to reduce the fluid speed in pipes.

Evaluate the following actions and choose the most cost effective ones:

a. If the pipeline has already been in operation for several years and is in bad condition, replace the current pipe with one of a larger diameter that can achieve fluid velocities between 1.0 and 1.5 m/s.
b. If the pipe is in good condition, analyze the next two options:

    1. Install a pipeline parallel to the current one whose diameter is such that velocity is reduced to a value of 1.0 to 1.5 m/s in both pipelines.
    2. Replace the current pipeline with a one that has a larger diameter and achieves water velocity between 1.0 and 1.5 m/s.

5.6. LEAKAGE REDUCTION

5.6.1. *Implementation of a Leakage Detection and Repair Campaign*

The objective of leakage control is to minimize the time between the emergence of a leak and its subsequent repair, as well as to contribute to continuous improvements in the conservation and maintenance of the distribution network.

Controlling leakage is a continuous activity that relies on monitoring the water network, gathering reports of leakage detected by users, systematic searches for hidden leaks, and regular evaluation of flow balances and testing. Using a sampling of recent data and field statistics, evaluate the losses and create a water balance to estimate the percentage of water consumption that can be lowered by reducing leakage.

1. Collect information and data describing the current efforts to reduce leakage, such as information on staff, budget, procedures, equipment, results, and indicators.
2. Analyze data and plan short- and medium-term actions. The causes of water loss can be determined and addressed with proper equipment and human resources.
3. Establish a program to control and eliminate leakage, which should include general and prioritized activities, scheduled costs and benefits, and funding sources.

4. Implement short-term actions, such as the development of a leakage control department, investigation of leaks reported by the public, purchase of equipment, and staff training.
5. Monitor performance and keep records of operations.
6. Compute a water balance each year and periodically evaluate it by benchmarking the percentage of potential leakage and the cost-benefit relationship of leakage control.

5.7. OPERATING IMPROVEMENTS

5.7.1. *Installation of Frequency Invertors*

The use of variable speed drives in pumping equipment is recommended for systems in which water is supplied directly to the distribution grid, water demand is variable, and an evaluation indicated a high potential for energy savings. This measure consists of implementing a pressure-flow control system that uses an electronic variable speed drive to control the electric motor speed. Take the following steps to properly implement this measure and calculate the subsequent savings:

Step 1: Select viable equipment and consider its energy consumption while operating without the variable frequency drive. Also consider pressures and flow rates for 24 hours and record data of discharge pressure (kg/cm^2), flow (m^3/s), and electric power demanded by the motor (kW) on an hourly basis (see Table 16).

TABLE 16: Sample Energy Consumption Chart

Date	Time hh:mm:ss (at least 24 hours)	Pressure (kg/cm^2)	Flow (m^3/s)	Electric power (kW)

Step 2: Select the optimal operating pressure for each water distribution system based on the following:

i. Optimal operating pressure is the lowest pressure at which the system could operate to provide service at any point in the network, and is usually the lowest value registered during the monitoring. This value must be verified in the field or with a hydraulic simulation model to check if water is still being provided to the highest points in the network.
ii. If the minimum pressure recorded in the monitoring is enough so that water reaches all points in the network, it is the optimal operating pressure.
iii. If the minimum pressure recorded in the monitoring is not enough so that water reaches all network points, pressure should be increased until water reaches all points of the network.

Step 3: Calculate the energy savings in accordance with the following:

i. For each of the records obtained during monitoring, calculate the decrease of discharge pressure using the following equation:

$$If\ p_{op} > p_r \rightarrow \Delta p_r = 0.0$$

$$If\ p_{op} < p_r \rightarrow \Delta p_r = p_r - p_{op}$$

Where:

p_{op}	optimal operation pressure (kg/cm^2)
p_r	registered pressure during monitoring (kg/cm^2)
Δp_r	pressure decrease in the specific register (kg/cm^2)

ii. For each of the records obtained during the monitoring, use the following equation to calculate the power savings with the variable speed drive installed to keep the pressure at the optimal level obtained in the previous step:

$$\Delta P_e = \frac{\Delta p_r * Q * 9.81}{\eta_{em}}$$

Where:

ΔPe	electric power saved (kW)
Δpr	decrease of discharge pressure (mwc)
Q	flow (l/s)
ηem	electromechanical efficiency of the pump-motor set (–)

iii. Calculate the energy saved using the following equation:

$$E = \sum_{i=2}^{n_{lm}} \left[\frac{(P_{e,i} + P_{e,i-1})}{2} (h_{r,i} - h_{r,i-1}) \right]$$

Where:

ΔE	energy saved in the monitoring period (24 hours) (kWh)
$\Delta Pe,I$	electric power saved in the register i (kW)
hr,I	time at the register i (h)
nim	number of registers in the monitoring time
h	hours or time period in monitoring (h)

iv. Once electrical energy savings are estimated, calculate the amount of investment necessary to implement this savings measure and the economic assessment of the project.

5.7.2. *Installation of Regulation Tanks*

The installation of a regulation tank may reduce the required peak capacity of the pumping system when water is pumped directly to the network, therefore reducing the average electrical power demand. If this measure is applied, in addition to the energy savings achieved by reducing the power necessary to supply the water peak demand, more energy savings is possible if the capacity of the new or regulating tank is enough to reduce the operating time of the pumping system. This allows users to manage the power needed in peak hours when the electricity cost may be higher.

To evaluate the energy saved by implementing this measure, calculate the new quantity of electric power needed by the pumping system to supply the regulation tank with the following equation (use the same units for each of the products of Htmb*Q):

$$P'_{eQm} = \frac{H_{tmb} * Q}{(H_{tmb} * Q)'} * P_{eQm}$$

Where:

P'eQm	electrical power expected with the new average flow
PeQm	electrical power demanded with the actual average flow
Htmb*Q	actual product of the hydraulic head multiplied by the actual average flow
(Htmb*Q)'	expected product of the hydraulic head multiplied by the new average flow

5.8. ELECTRIC POWER SUPPLY SOURCE REPLACEMENT

5.8.1. *Utilization of Renewable Energy Sources*

Renewable energy sources can be divided into two categories. The first includes sources where energy is harvested directly from natural resources such as sunlight, wind, and hydropower. The second includes sources where energy is harvested from organic matter or biomass, which can be used directly as fuel (wood or other solid vegetable material) or converted in bioethanol or biogas through organic fermentation processes, or in biodiesel through transesterification reactions.

In drinking water systems, energy can be harvested from water treatment and purification plants in the form of methane, produced by anaerobic decomposition processes of sludge. The following natural resources provide renewable energy sources:

- The sun: solar energy
- Wind: wind energy
- Rivers and freshwater flows: hydropower
- Waves from seas and oceans: tidal energy
- The heat of the earth: geothermal energy
- The use of salinity gradient power of fresh water and salt water through osmosis, often called blue energy

There are several applications of solar and wind energies in water distribution systems, including solar photovoltaic pumping systems or wind-powered pumping systems used in rural and remote areas, such as farms.

Solar Energy

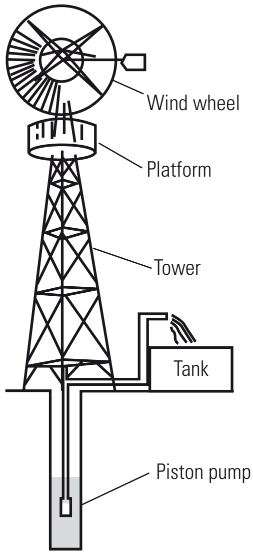
There are a number of systems and subsystems that can use solar energy in drinking water systems. Some examples are automatic isolation and control valves, pressure and water quality monitoring, and small drinking water pumping systems in rural areas or remote electric power networks.

Wind Energy

Wind energy can complement existing power grid lines or allow for nonconventional energy systems to power drinking water systems in rural communities. In some communities, a hybrid energy solution for rural water projects with a wind array and backup diesel generators is highly attractive and cost-effective. These options are complementary, not only in reducing costs, but also by increasing the energy security of the system. Wind energy has low maintenance costs, therefore water production costs decrease significantly. Many systems that are currently in operation have high, costly energy needs and could satisfy part of these needs with wind energy. If these systems are in areas of significant wind potential, it would be easy and inexpensive to implement a hybrid system in their facilities and reduce production costs.

To significantly reduce size and cost, a wind power system should be implemented in a site with high wind potential. Reliable winds must then be properly assessed to determine average wind speeds. The wind information must be gathered directly at the potential site using anemometers or wind sensors for a minimum period of six months.

FIGURE 33: Operation of a Windmill to Extract Groundwater



Windmills or wind turbines are very simple machines that transform the mechanical energy of wind into mechanical power for a pump. For a pumping system, wind energy is very efficient because it does not require conversion to another form of electrical energy. Ensuring an efficient, economical, and stable energy supply is achieved through the use of accumulation ponds whose volumes are determined by the study of winds and estimated consumption. They are very simple low-cost systems that use piston-type pumps and require minimal maintenance. For example, a complete system (not including the well) to pump a flow rate of 1 l/s costs around US$3,400.[2]

Small wind turbines produce between 1 and 10 kW, and allow users to supply electricity to waste water management projects for treatment and their own functioning processes. The cost of the installation varies, mainly depending on the remoteness of the site. The cost of the tower is approximately 50 percent of the total value of equipment. Current fees are between US$2 to $6 per installed watt.

[2] This estimate is based on 2010 costs.

5.8.2. *Production and Utilization of Biogas in Wastewater Treatment Plants*

Biogas is a combustible gas containing mainly methane generated in natural environments or in specific devices by the decomposition reactions of organic material through the activity of microorganisms—specifically bacteria methanogens—in the absence of air (i.e., in an anaerobic environment). When organic matter decomposes in the absence of oxygen, biogas is produced. This reaction takes places in the biodigester.

Implementing biodigesters in water systems achieves two results: the decontamination of wastewater reaching and exceeding the international standards and the production of biogas as an additional product. This biogas can be used for heating purposes, in internal combustion engines to directly drive pumps, or for the production of electricity through a generator.

Chapter 6

ASSESSMENT OF SAVINGS MEASURES

6.1. ENERGY SAVINGS EVALUATION (EXPECTED ENERGY BALANCE)

Once energy savings proposals have been identified, the equipment change specifications and activities, including the new efficiencies, losses, and energy balance, should be evaluated again to determine the potential savings expected once the plan has been implemented. The new assessment should be carried out according to the process described in Chapter 4 of this manual by updating or replacing equipment data and improving operating conditions.

According to the assessments of the motor, electrical conductors, and specifications proposed, and assuming that the pump will work within the efficiency range of the head-flow curve, a new expected energy balance may be calculated to reflect the pump's operation with the proposed savings measures. This calculation is performed in the same way as described in Chapter 4 of this manual. In this case, the expected balance depicts the percentage of savings that the measures will have when implemented. The energy savings in the expected energy balance are calculated using general electricity costs and evaluated according by the following terms:

Unitary energy cost (UEC) – overall cost of electrical energy is obtained in local currency units or ($/kWh).

Direct savings – savings expected in reducing energy losses from the new energy balance by implementing the savings measures suggested for each pumping system. The savings from the expected energy balance are expressed per year (kWh). Total of savings is obtained by multiplying the energy saved by the cost of energy.

Additional savings – savings that are estimated based on the optimization of the PF and installation of a capacitors bank, which reduces losses in conductors and other electrical system components.

However, when operations with low power factors result in fines from the electricity supplier, these fines may be added to this figure in the last year of operation.

Total savings – the sum of direct and additional savings.

$$\textbf{TOTAL SAVING } (S_{ECO}) = \textbf{DIRECT SAVINGS + ADDITIONAL SAVINGS}$$

Since savings proposals involve the purchase of equipment, materials, and additional labor, consider the corresponding investment for each of the pumping systems in your calculations. Investment calculations must take into account all of the costs of the energy savings plan, breaking down each proposed element into purchase, installation, and labor.

6.1.1. *The Rate of Return on Investment Analysis*

Finally, an analysis of the rate of return on investment in the proposed energy savings plan must be conducted. Calculate the simple payback period using the following equation:

$$n_{ri} = \frac{I_{mae}}{S_{eco}}$$

Where:

n_{ri}	payback period (years)
I_{mae}	total investment to implement the savings proposals in dollars or local currency
S_{eco}	total economic savings in dollars or local currency per year

After calculating the savings and the rate of return on investment, prepare a summary of the total conventional energy savings measures or fast deployment and long-time investment measures (see Table 17 for an example spreadsheet).

TABLE 17: Example Energy Savings Summary

Description of the saving measure	Actual consumption		Savings (1)		% (2)	Investment (3)	Payback years (4)
	Energy kWh/year	Energy bill ($/year)	Energy (kWh/year)	Expected bill ($/year)			
Total savings (5)							

Legend:

1. *Annual energy savings and costs for each savings measure resulting from the summation of both economic and energy savings of each pumping system and the rest of equipment, where each measure is applied.*
2. *Percentage of savings by type of measure, calculated by dividing annual energy savings by annual consumption for each measure.*
3. *Estimated total investment cost for each measure.*
4. *Estimated time of simple return on investment, or payback, calculated by dividing the investment value by the annual energy cost savings in years.*
5. *Total savings and percentages obtained by either the summation of all the measures or by type of measures, to distinguish energy-saving measures from energy savings arising from hydraulic operation.*

Chapter 7

ENERGY AUDIT REPORT

The final step in the energy efficiency audit is to prepare a report containing the comments and conclusions of the audit, with an emphasis on energy savings opportunities and the necessary actions for their implementation. This sections describes the information needed for a good report.

7.1. EXECUTIVE SUMMARY

The executive summary enables senior management of the WSC to view and analyze important results of the audit, as well as to have an indication of the costs and benefits of the recommendations. An executive summary is normally two to five pages long, and should contain the following components:

- Both cost and energy savings of all pumping systems and equipment where the measure can be applied, which includes blowers, lighting systems, and other related equipment
- The percentage of savings by measure (calculated by dividing annual energy savings by annual consumption for each measure)
- The investment cost for each measure
- Profitability of investments conveyed by at least a simple payback time of return on investment (found by dividing investment value by annual cost savings)
- Total economic energy saving and its percentages, which helps to distinguish the additional savings achieved with conventional measures from the savings resulting from hydraulic operation
- Summary table (e.g., Table 17)

7.2. EVALUATED FACILITIES DESCRIPTION

An assessment of the situation of the WSC's installations should be made at the time of the audit, and should contain a summary of the following basic data:

- General data for the electromechanical installations (equipment and conditions)
- Overview of the production and distribution system of drinking water and sanitation (acquisition and distributions: well tank, combined system well drawn charges, etc.)

7.3. ANALYSIS OF ENERGY CONSUMPTION

Present the data collected and analyzed with reference to energy consumption in all facilities. The description of the energy situation should be accompanied by graphics for better understanding and should include the following:

- Energy consumption per year, including electrical demand from all facilities and services contracted by the company
- Electricity rates
- Total energy balance of the water company
- Monthly changes in energy consumption and production costs
- List of indicators that are applicable on the basis of the results of the analysis

7.4. RECOMMENDATIONS OF SAVINGS MEASURES AND THEIR COSTS

Submit a general assessment of the conditions found in the company's electromechanical systems and observations of the equipment audit. Note any problems found in installations and maintenance. Then recommend savings measures using the following reference points:

- **Recommendation** – Provide clear and concise descriptions of the actions to be taken to realize the expected savings.
- **Savings evaluation** – Describe the assumptions and calculations made to reach the estimated savings opportunities.
- **Investment evaluation** – Explain the assumptions and calculations made to reach the investment required to implement the recommendation.
- **Financial analysis** – Explain how the plan is cost effective; include the period of return on investment and, if necessary, use the methods of the net present value and the internal rate of return.

Chapter 8

MAINTENANCE: KEY ASPECTS

A preventative and predictive maintenance program should be part of the energy savings plan. A maintenance program is composed of inventory of equipment and facilities, activities and frequency of execution, and a maintenance program schedule. The major benefits of an efficient facility maintenance program include the following:

- Increased pumping capacity
- Increased equipment reliability
- More efficient and better-planned operation
- Better service to the population
- Less stress for personnel
- Lower costs of operation and management
- Longer useful life of equipment
- Decrease in investment and maintenance costs
- Energy savings
- Economic savings

8.1. INVENTORY OF EQUIPMENT AND FACILITIES

Develop an inventory of the equipment and facilities that contains the following information:

Electrical installations

- Unifilar diagram: provide a new or updated version.
- Electric conductors: include information about the length and size of electrical conductors in each section, as well as whether they are in conduit or tray and the number of conductors that are in the system.
- Transformers: identify each processor as well as include all information on its data plate.

Electric motors

- Motor identification number (ID)
- Plate data
- Historic data including age, number of rewindings, and description of the repairs
- Type of bearings and the date they were most recently changed
- The control system, including data on the starter, switch, and protections specification

Pumps

- Pump ID number
- Specification of the pump (brand, model, material, speed of operation, and characteristic curves)
- Data design (head and flow)
- Impeller specifications (type and diameter) and date on which it was installed
- Specifications of bearings, gland, and mechanical seals, including date they were last changed
- Diagram of the hydraulic arrangement and discharge pipelines

Tanks

- Tank ID number
- Dimensions and water volume capacity
- Age and construction material
- Maps and diagrams of the tank

Water Distribution Network

- Diagram of the hydraulic network, indicating length, diameter, and pipe material, as well as the location of the valve boxes
- Age of the pipe and failure statistics
- Inventory of valves, indicating the specifications and locations of each

8.2. ACTIVITIES AND FREQUENCY OF EXECUTION

Identify the frequency with which different activities will be performed in both preventive and predictive maintenance, which will be based on the experiences of the maintenance personnel and the equipment suppliers' recommendations. Use Table 18 as a guide to summarize the data and adapt it to the specific conditions of the company and the equipment.

TABLE 18: Recommended Frequency for Different Maintenance Activities

Subsystem	Equipment	Recommended action	Maintenance frequency				Upon failure
			Daily	Weekly	Monthly	Annually	
Electrical	Transformer	Equipment cleaning with dielectric solvent			■		
		Cleaning the area		■			
		Tightening of nozzles and mechanical terminals			■		
		Purification and filtration of dielectric oil, including centrifuging, filtrating, dehydrating, and degassing the contents of the transformer				■	
		Measurement and analysis of electric parameters			■		
		Physicochemical analysis of oil				■	
		Transformer connection testing (TTR)				■	
		Electrical testing (Megger)				■	
		Thermographic analysis				■	

(*continued on next page*)

TABLE 18: Recommended Frequency for Different Maintenance Activities (*continued*)

Subsystem	Equipment	Recommended action	Maintenance frequency				Upon failure
			Daily	Weekly	Monthly	Annually	
Electrical	Motor control center	Cleaning panels with dielectric solvent				■	
		Cleaning and lubricating electric drives (springs, button panels)				■	
		Tightening hardware at electrical circuit ends and connections				■	
		Measurement and analysis of electric parameters			■		
		Electric resistance tests in ground networks				■	
		Continuity tests in ground networks				■	
		Thermographic analysis				■	
	Motor	Wire coil cleaning with dielectric solvent				■	
		Lubrication of bearings		■			
		Change axle bearings				■	
		Cap adjustment				■	
		Sanding and painting equipment encasements				■	
		Measurement and analysis of electrical parameters		■			
		Measurement and analysis of mechanical vibrations				■	
		Testing for damage to insulation				■	
		Resistance testing for wire coils				■	
		Thermographic analysis			■		

(*continued on next page*)

TABLE 18: Recommended Frequency for Different Maintenance Activities (*continued*)

Subsystem	Equipment	Recommended action	Maintenance frequency				Upon failure
			Daily	Weekly	Monthly	Annually	
Mechanical	Pump	Lubrication of bearings and bearing carriers		■			
		Lubrication of top shaft		■			
		Replacement of intermediate bowls hub					■
		Adjustment of bowls' intermediate seats				■	
		Replacement of suction cup bearings					■
		Adjustment of shaft alignment					■
		Replacement of bearings					■
		Manufacture of towing hub					■
		Adjustment of shaft bowls				■	
		Measurement and analysis of mechanical vibrations				■	
		Measurement and analysis of pump input and output pressure			■		
		Measurement and analysis of flow			■		
		Monitoring of towing hub			■		
		Monitoring of towing pressure	■				
	Discharge main	Cleaning and painting of discharge main components		■			
		Replacement of broken packaging in coupling joints, valves, and gauges and checking of pressure sustainability				■	
		Replacement of valves					■
		Inspection and recalibration of macro gauges			■		
		Inspection of chlorination equipment			■		
		Cleaning of actuator and air expulsion valves			■		
		Measurement and analysis of mechanical vibrations			■		

(*continued on next page*)

TABLE 18: Recommended Frequency for Different Maintenance Activities (*continued*)

Subsystem	Equipment	Recommended action	Maintenance frequency				Upon failure
			Daily	Weekly	Monthly	Annually	
Mechanical	Valves	Cleaning and evaluation of diaphragm		■			
		Cleaning and evaluation of diaphragm actuator spring			■		
		Replacement of O-rings				■	
		Cleaning of dust seal				■	
		Lubrication of bearing shaft			■		
		Cleaning of valve body		■			
		Cleaning of actuator				■	
		Replacement of electric conductor controls					■
		Measurement and analysis of mechanical vibrations			■		

8.3. MAINTENANCE PROGRAM SCHEDULE

After taking inventory of the equipment, the next step is to create a maintenance schedule, which is a chart with dates on one axis and activities on the other. It is important to indicate the responsible party for each of the activities and to keep a record of completed activities; this will serve as a basis for improvement. Table 19 provides a sample maintenance schedule.

TABLE 19: Sample Maintenance Schedule

Facility	Equipment	Activity	Responsible party	Date					
				Week 1	Week 2	Week 3	Week 4	Week 5	Week 6

8.4. MONITORING EQUIPMENT SUGGESTED

In the development of an effective preventive maintenance program, there must be equipment available for monitoring the suggested parameters. The core activity of the maintenance program is to undertake the actions recommended in Table 18, and then to use the measurements to make decisions. Create graphs with the data, and then analyze the trends to detect significant changes in the values of the parameters before a failure occurs or the efficiency drops. The following is a suggested minimum equipment kit for completing the needed measurements:

Portable measuring equipment:

- Flow meters: the most commonly suggested technology is ultrasonic or insertion electromagnetic flow meter.
- Electric parameters meter: it is recommended to use an electrical net analyzer, which is able to take one and three phase measurements and the necessary parameters; in addition to measurements such as voltage, current and PF, it can measure other parameters related to power quality, such as harmonic distortion.
- Thermographic camera: a technology that can detect abnormal "hot spots" in electric installations, which allows users to detect failing contacts or points where potential damages must be corrected.
- Vibration meter: this equipment detects trends in the vibrations level of the motor pump sets, and allows users to investigate the causes and prevent unexpected damage of the equipment if vibration levels increase.
- Ground tester: this equipment allows users to monitor the functioning of the grounding system in all the electrical and mechanical facilities.

Chapter 9

ACTION PLAN DESIGN

Once the IGEA has been completed, the WSC is now poised to develop a roadmap to improve energy performance. Successful WSCs use a detailed action plan to ensure a systematic process that is regularly updated, most often on an annual basis, to reflect recent achievements, changes in performance, and shifting priorities. While the scope and scale of the action plan is often dependent on the energy efficiency measures evaluated in the IGEA, three main components make up the basic starting point for creating a plan: executive projects, activities and a critical path, and a financial plan.

9.1. EXECUTIVE PROJECTS

The scope of the energy efficiency project depends on the savings measures previously defined in the IGEA. As a rule, an engineering project is broken down into design and construction phases. The outputs of the executive project are drawings, technical records, and all other design documentation necessary to carry out the project.

Project Drawings

The drawings should accurately and unambiguously capture all the geometric features of the required products or components of the energy efficiency measures. They should also convey all the required information that will allow those responsible for the implementation (construction) of the saving measures to execute them correctly. The drawings must be used to fully and clearly convey the following critical information:

- Geometry: the shape of the object represented as views, such as how the object will look when it is viewed from various standard directions, such as front, top, and side.
- Dimensions: the size of the object, expressed in accepted units.
- Tolerances: the allowable variations for each dimension.
- Material: what the item is made of.
- Finish: specifies the surface quality of the item, either functional or cosmetic. For example, a mass-marketed product usually requires a much higher surface quality than a component that goes inside industrial machinery.

The required sizes of features are conveyed by marking dimensions. Distances may be indicated with standardized forms of dimension.

Technical Record

Along with drawings, the project must be accompanied by a technical record that integrates all additional calculations, technical specifications, and detailed information on the energy efficiency project, including where it involves changing pumping equipment, calculations, and new information, such as the data sheet from the manufacturer of the proposed pumping equipment and its new head-flow curve (see Figure 34 for an example).

FIGURE 34: Manufacturer Data Sheet of Submersible Pumping Equipment

15B233A6 SP 46-6-A 60 Hz

Input		**Sizing result**	
Parameter	Groundwater supply	Type	SP 46-6-A
		Quantity * Motor 1 * 13kW, 380V	
Overview mode	No	Flow	54.3 m^3/h (+1%)
Select Type of Installation	Well installation, no tank	H total	74.9 m
		Power P1	18.2 kW
Installation Type	Bore hole	Power P2	15.2 kW
Your Requirements		Current (rated)	34 A
Allowed flow oversize	30%	Current (actual)	33.1 A
Allowed flow undersize	0%	Cos phi (actual)	0.83
Flow	53.7 m^3/h	Eff pump	72.7%
Head	74.9 m	Eff motor	83.9%
Maximum water temperature	288 K	Eff total	61.0% = Eta pump * Eta motor
Operating hours per day (low)	10 h	Flow total	196005 m^3/year
Speed regulation	No	Max. pressure	734 kPa = during operation in the load profile
Configuration		Spec. consumpt.	0.3379 kWh/m^3
Motor selection	Grundfos standard motor		4.6 Wh/m^3/m
Pump material	GG 0.6025 or 1.4301 (AISI 304)	Consumption	66222 kWh/year
		Price	On request EUR
		Energy cost	3311 EUR/year
		Total costs	On request EUR/15 years

Operational Conditions

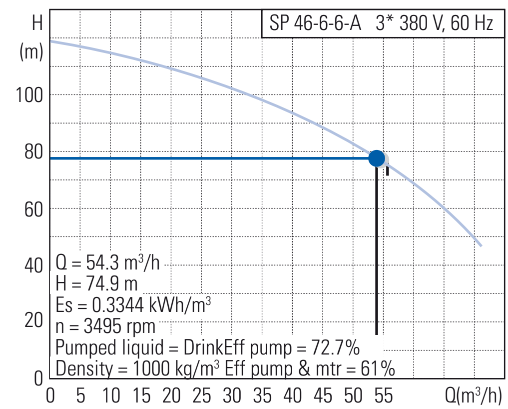
Calculation period	15 years
Energy price (high)	0.15 EUR/kWh
Energy price (low)	0.05 EUR/kWh
Energy price (medium)	0.1 EUR/kWh
Evaluation criterion	Price + energy costs
Frequency	60 Hz
Increase of energy	6%
Phase	3
Starting method 3-phase	DOL
Voltage	380 V

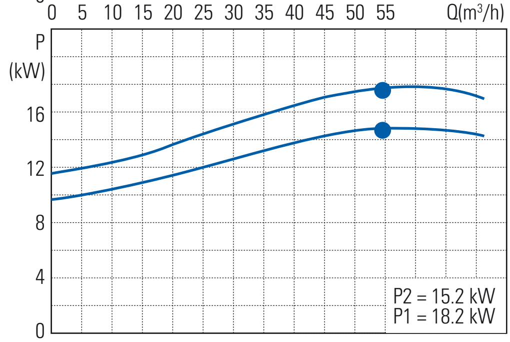
Hit List Settings

Maximum number of results	20
Pumps per product proup	1

Load Profile

	1	
Flow	100	%
Head	100	%
Time	3650	h/year
Consumption	66222	kWh/year





9.2. ACTIVITIES AND CRITICAL PATH

There are a number of approaches to managing project activities, including flexible, interactive, incremental, and phased approaches. Regardless of the methodology employed, careful consideration must be given to the overall project objectives, timeline and cost as well as the roles and responsibilities of all participants and stakeholders.

A project's critical path contains a method for planning and management that puts clear emphasis on the resources (physical and human) needed to execute the energy efficiency project tasks. The goal is to increase an organization's project completion rates. The system constraints and the resources for each project are identified. To work within the time constraints, tasks on the critical path are given priority over all other activities. Finally, projects are planned and managed to ensure that the resources are ready when the critical path tasks must begin, subordinating all other activities.

Regardless of project type, the project plan should undergo resource leveling and the longest sequence of resource-constrained tasks should be identified as the critical path. In multi-project environments, resource leveling should be performed across projects. However, it is often enough to identify (or simply select) a single "drum" resource—a resource that acts as a constraint across projects—and stagger projects based on the availability of that single resource.

Once all the activities and the critical path for each project of all of the energy saving measures are defined, the energy efficiency action plan (EEAP) can be developed by defining prescribed activities in an abstract. Figure 35 shows an example of an EEAP abstract. For this abstract, classify and categorize the energy efficiency activities, measures, and projects into the following categories:

- Short-term low- or noninvestment structural actions
- Short-term investment structural actions
- Short-term low- or noninvestment projects
- Short-term investment projects
- Medium-term investment projects
- Long-term investment projects

9.3. FINANCING PLAN

In general, the energy efficiency financing plan is the budget for the investment in the savings measures. This plan allocates future investment and income to various types of expenses, such as the purchases of equipment and the installation and construction activities required to implement the savings measures. The plan finances those investments under various assets or projects expected to produce future income by savings on energy costs.

The financing plan usually refers to the means by which cash will be acquired to cover the investments, for instance by using cash saved by implementing energy efficiency projects. A financing plan should implement all the defined energy efficiency saving measures through a similar format as the action plan, using the same type and classification of the energy efficiency activities, measures, and projects so that the action and the financing plan can be seen together as a whole. To do this, the amount of cash needed to cover a specific action can should be recorded in the timeline of the energy efficiency action plan (see Figure 36).

FIGURE 35: Example of an Energy Efficiency Plan

Measure		Month																																			
#	Description		2		4		6		8		10		12		14		16		18		20		22		24		26		28		30		32		34		36
Immediate implementation																																					
1	Energy management committee																																				
	Structure definition	■	■																																		
	Write a Policy	■	■	■																																	
	Formalize operation			■																																	
2	Improve the maintenance and measuring practices																																				
	Implement a predictive and preventive maintenance plan			■	■	■	■																														
	Capacity building				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Purchase of portable measuring equipment				■	■	■																														
3	Improve the hydraulic operating scheme																																				
	Hydraulic efficiency project including hydraulic modelling of xxx				■	■	■																														
Short-term implementation																																					
4	Improve the electromechanical efficiency in A									■	■	■	■	■	■	■	■	■	■	■	■	■															
5	Improve the electromechanical efficiency in B				■	■	■	■	■	■	■	■	■	■	■	■																					
6	Improve the electromechanical efficiency in C								■	■	■	■	■	■	■	■	■	■	■	■																	
7	Improve the electromechanical efficiency in D						■	■	■	■	■	■	■	■	■	■	■	■	■																		
8	Improve the electromechanical efficiency in E				■	■	■	■	■	■	■	■	■	■	■	■	■																				
9	Improve the electromechanical efficiency in F							■	■	■	■	■	■	■	■	■	■	■	■	■																	
10	Improve the electromechanical efficiency in G									■	■	■	■	■	■	■	■	■	■	■	■																
Medium-term implementation																																					
11	Improve the electromechanical efficiency in H																			■	■	■	■	■	■	■	■	■	■	■	■	■	■				
12	Improve the electromechanical efficiency in I																			■	■	■	■	■	■	■	■	■	■	■	■	■	■				
13	Improve the electromechanical efficiency in J																■	■	■	■	■	■	■	■	■	■	■	■	■								
14	Improve the electromechanical efficiency in K																■	■	■	■	■	■	■	■	■	■	■	■									
15	Improve the electromechanical efficiency in L																	■	■	■	■	■	■	■	■	■	■	■	■								
16	Improve the electromechanical efficiency in M																		■	■	■	■	■	■	■	■	■	■	■	■							

FIGURE 36: Example of a Financing Plan

	Measure		Savings		Investments	Payback
Num	**Description**		**kWh/year**	**USD/year**	**USD**	**Years**
Immediate implementation						
1	Energy management committee.					
		Project management (3 years)			32,000	
2	Improve the maintenance and measuring practices					
		Capacity building (3 years)			60,000	
		Purchase of portable measuring equipment			74,000	
3	Improve the hydraulic operating scheme					
		Hydraulic efficiency project including hydraulic modelling of xxx			30,000	
Short-term implementation						
4	Improve the electromechanical efficiency in A		209,098	67,957	13,161	0.19
5	Improve the electromechanical efficiency in B		136,698	44,427	10,401	0.23
6	Improve the electromechanical efficiency in C		86,533	28,123	13,161	0.47
7	Improve the electromechanical efficiency in D		50,853	16,527	11,781	0.71
8	Improve the electromechanical efficiency in E		41,040	13,338	9,711	0.73
9	Improve the electromechanical efficiency in F		47,296	15,371	13,161	0.86
10	Improve the electromechanical efficiency in G		34,636	11,257	11,781	1.05
Medium-term implementation						
11	Improve the electromechanical efficiency in H		46,238	14,737	24,776	1.68
12	Improve the electromechanical efficiency in I		20,574	6,687	11,781	1.76
13	Improve the electromechanical efficiency in J		17,404	5,656	11,781	2.08
14	Improve the electromechanical efficiency in K		14,566	4,734	13,161	2.78
15	Improve the electromechanical efficiency in L		8,003	2,601	10,401	4.00
16	Improve the electromechanical efficiency in M		2,194	713	13,161	18.46
Total:			**715,133**	**232,128**	**364,218**	**1.57**

Chapter 10

ACTION PLAN IMPLEMENTATION

The following two factors have to be taken care of during the implementation of the projects:

- Design data: the design data defined during the project should be recorded in order to ensure the goals of the projects, specifically the expected energy savings.
- Critical path: develop a critical path so that the planned duration cannot be easily altered and to ensure an efficient project schedule and financial performance review.

Developing a proper critical path means making sure resources are available at the necessary stages to avoid lapse in timeline. The goal here is to overcome the tendency to delay work or to do extra work and spend more money than planned. Because tasks are estimated for completion within an estimated timeframe, there is pressure on resources, as well as an incentive to complete critical path tasks as quickly as possible. Therefore, supervision must accompany the action plan's implementation.

10.1. ACTION PLAN SUPERVISION

Supervision is, in some ways, the greatest prerequisite for action plan implementation. Because the difficulty of individual tasks may vary within the estimated duration, flexibility should be given rather than the pressure of completing "on time." Instead, supervision is provided to ensure that the overall project stays within the parameters that were created during the planning stage. A project date plan with an achievements chart or similar graph should be created and posted to show the consumption of resources as a function of project completion. If the rate of spending and resource consumption is low compared to the planned spending and resources consumption, then the project is on target. Otherwise, corrective actions or recovery plans must be developed to recover the loss. When spending and resource consumption rates exceed a critical point, alternative plans need to be implemented.

Supervision is the discipline of organizing and managing resources to bring about the successful completion of the energy EEAP goals and objectives. These processes are performed in order to observe the execution of the EEAP so that potential problems can be identified in a timely manner, and corrective action can be taken when necessary to control the execution of the plan. The key benefit is that the plan performance is observed to identify variances from the original EEAP. Supervising duties include:

- Measuring ongoing EEAP activities ("where we are")
- Monitoring the project variables (cost, effort, and scope) against the project management plan and the project performance baseline ("where we should be")
- Identifying corrective actions to address issues and risks properly ("how can we get on track again?")
- Influencing the factors that could circumvent integrated change control so that only approved changes are implemented.

In multiphase projects, the monitoring and controlling process provides feedback between project phases in order to implement corrective or preventive actions to bring the project into compliance with the project management plan.

10.2. TECHNICAL TRAINING

It is important to develop a permanent training program to strengthen the capabilities of staff to develop the audits, execute and supervise the implementation of projects, and monitor the results. The topics to be included in the program should be divided into two areas, depending on the specialties of the trainees. The two main areas and the suggested topics are as follows:

Technical staff training topics:

- Energy quality assessment
- Maintenance systems
- Electrical installations design
- Motor design and maintenance
- Pumping systems design, evaluation, and maintenance
- Energy audit execution
- Monitoring and measurement technologies
- SCADA systems
- Piping design
- Leak detection management

Managerial staff topics:

- Planning skills development
- Critical path project design
- Leadership skills development

Chapter 11

MONITORING AND EVALUATION

A monitoring program should be put in place with the following goals in mind:

- Assess the achievements of the energy savings projects based on the energy audit and adjust goals as necessary.
- Identify and explain increases or decreases in energy use.
- Predict future potential energy use when planning changes in the business.
- Diagnose specific areas of wasted energy.
- Track energy consumption trends and develop performance targets.
- Manage energy consumption rather than accept it as an uncontrollable fixed cost.
- Link actions and savings.
- Report progress.
- Feedback – evaluation.
  - Address issues
  - What worked?
  - What did not work?
  - What improvements are needed?
- Update information on energy, water, and operation.

The monitoring and evaluation process should be based on indicators. In the case of water and sanitation systems, the main indicators suggested are described in Table 20, divided according to the factor to be evaluated.

TABLE 20: Main Indicators to Monitor in a Water System

Energy efficiency indicators	Hydraulic operation indicators	Environmental indicators
• Energy index (kWh/m³) • Unitary energy cost indicator ($USD /kWh) • Electromechanical efficiency of pumping systems (%)	• Leakage losses index (%) • Unitary water supply per habitant (l/hab-day) • Service continuity index (hours/hab-day)	• Carbon emissions factor (t CO_2/year) • Aquifers exploitation index (%)

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