ENERGY EFFICIENCY IN WSS UTILITIES CAPACITY-BUILDING PROGRAM

WORLD BANK

EE Program Manual

August 2015

ABBREVIATIONS

AP	Action plan
AWG	American Wire Gauge Units
$(D_{r\text{-}m})$	Distance from reference level to manometer or pressure gauge
EEP	Energy efficiency program
Effic	Efficiency
EI	Energy index
Hb	Pumping head
HP	Horsepower
Ia	Electrical current in phase a
Ib	Electrical current in phase b
Ic	Electrical current in phase c
LF	Load factor
mm^2	Square millimetres
mwc	Meters water column
Nr	Reference level
Ns	Suction level
Pd	Discharge pressure
PF	Power Factor
Ps	Suction 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

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.

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1 ENERGY EFFICIENCY ASSESSMENT METHODOLOGY

This manual provides a general methodology to help utilities self-assess the efficiency of their facilities (both water and wastewater) for them to identify and adopt the best available technologies and practices.

Performing an Energy Efficiency Program (EEP) on a water and wastewater system involves the development of a sequence of phased steps to determine where and how much energy is used in the system, the level of efficiency, measures and specific projects to implement to reduce consumption and cost, the cost benefit or cost-effectiveness of such actions, an implementation plan, and methods to evaluate and monitor results.

An EEP can be divided into two main activities, including: an energy efficiency audit and the implementation and monitoring of actions for energy efficiency improvement. Figure 1 outlines the components of the EEP.

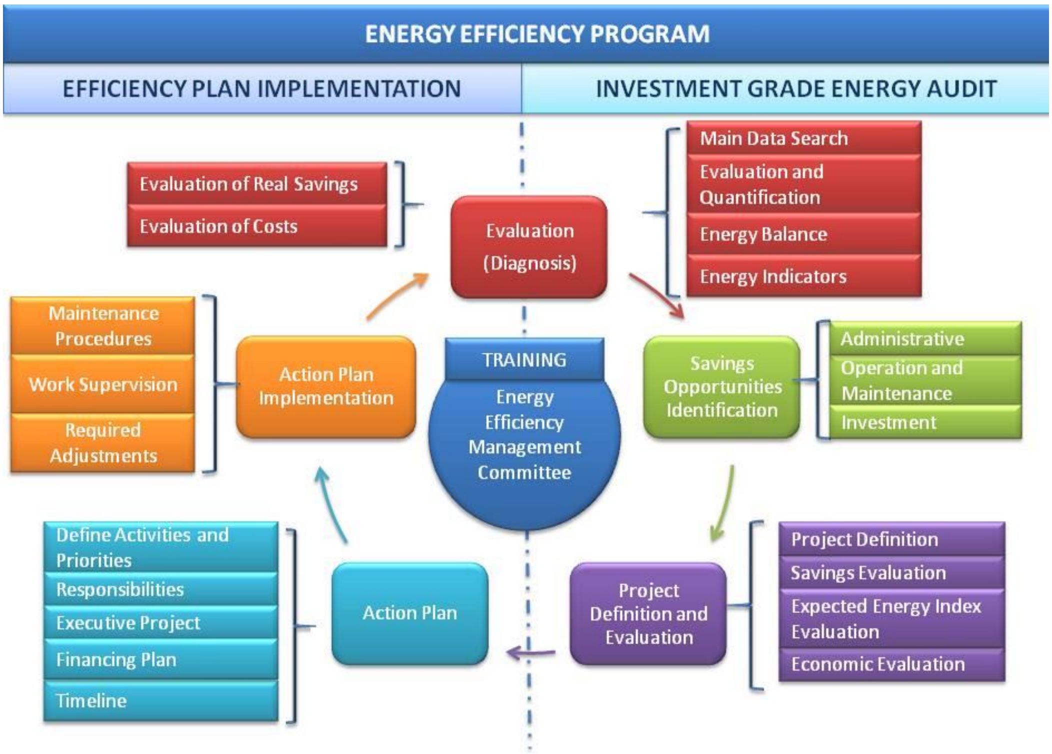

Figure 1: Components of an Energy Efficiency Program

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

The purpose of this document is to establish a methodology for implementing an EEP and define each of its components with a focus on the energy audit. In performing an EEP, an orderly sequence of activities tends to lead to better results. The main activities needed to perform an EEP at a water facility include the six steps described below.

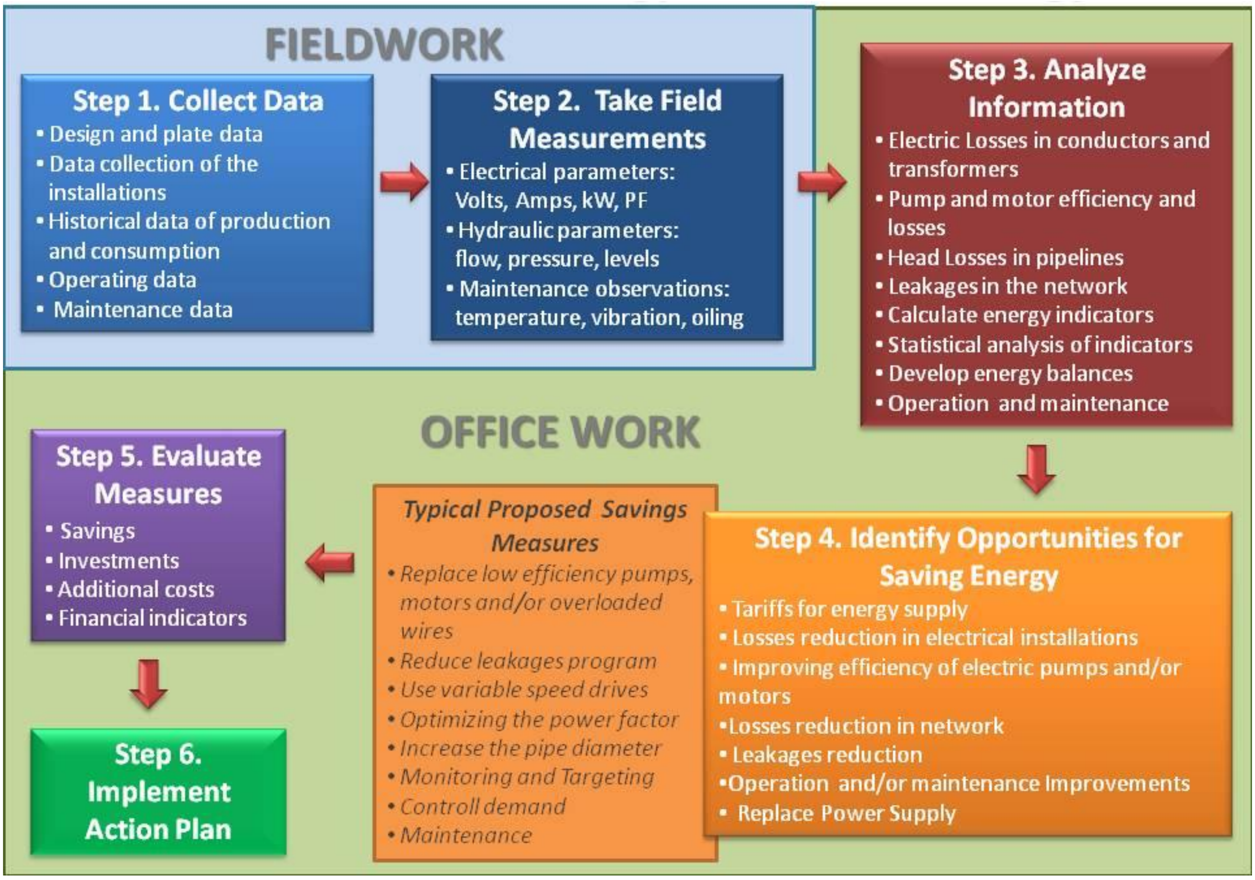

Figure 2: General Scheme of Investment Grade Energy Audit Methodology

The following figure describes the links between the proposed work plan and the set of activities under the Danube Water Program.

Kick-off Meeting

↓

Step 1 – Collecting Data (Related to Assignement 1)

↓

Step 2 – Taking Field Measurements (Related to Assignement 2)

↓

First National Event

↓

Step 3 – Analyzing Information (Related to Assignement 3)

↓

Step 4 – Identifying Energy Savings Opportunities (Related to Assignement 4)

↓

Second National Event

↓

Step 5 – Evaluating Savings Measures (Related to Assignement 5)

↓

Step 6 – Designing and Implementing an Action Plan (Related to Assignement 6)

↓

Third National Event

↓

Financing Plan

Figure 3: EE Program Timeline and Links between Events

The following sections detail the activities to be held under the Danube Water Program.

1.1 STEP 1 – COLLECTING DATA

Collecting data helps establish the general operation conditions of a water and wastewater company and identify the installations with the greatest potential for energy savings. Data should be collected according to the two following steps:

- **Preliminary evaluation** – Reviewing the legal context of water utilities; examining previous audits and evaluations or conducting a walk-through audit to allow identifying the systems and equipment that would benefit from an energy audit;
- **Energy audit data** – After the preliminary evaluation, basic data on the utility's pumping and distribution systems, motors, pumps, pipes and tanks, as well as additional data such as

conditions of operation (flow, pressure), households connected to the plant, and topography must be collected to perform an energy audit

1.1.1 Assignment 1

The first progress report should include an overview of the utility with basic data on pumping and distribution systems, motors, pumps, pipes and tanks, as well as additional data such as conditions of operation (flow, pressure), households connected to the plant, topography and energy billing must be collected.

Data Collection Form

A data collection form based on RETScreen® will be provided to all participating utilities to allow using uniform, relevant data when performing EE calculations. The form will be provided in pdf format; utilities will have to print the form and write down all their information by hand. Many comments and tips will be included on the form to help utilities in collecting the appropriate data.

Audit Report Template

Please use the audit report template provided in the appendix and start building your own audit report using the data you collected.

1.2 STEP 2 – TAKING FIELD MEASUREMENTS

Field measurement of electrical and hydraulic parameters must be made to enable an energy balance calculation, which will in turn serve to determine the main energy losses. With this information, the elements and equipment with significant energy savings potential will be identified and the corresponding energy efficiency measures will be proposed. This step should also include maintenance observations, such as: temperature readings, excess vibrations, lubrication of mechanical components, leakage in valves and main discharge pipes, and cleaning of electrical installations. This process is necessary to define maintenance actions within the Action Plan. Equipment needed for the field measurement activities will be discussed during the kick-off meeting.

1.2.1 Assignment 2

The second progress report should include field measurements of electrical and hydraulic parameters and maintenance observations, such as: temperature readings, excess vibrations, lubrication of mechanical components, leakage in valves and main discharge pipes, and cleaning of electrical installations. Equipment needed for the field measurement activities will be discussed during the kick-off meeting.

Training Materials

Please refer to Module 2 in the appendix of the training materials for a comprehensive review of measurement equipment to use.

Audit Report Template

Please use the audit report template provided in the appendix and start building your own audit report using your field measurements.

1.3 STEP 3 – ANALYZING INFORMATION

Once field data are collected, an analysis must be performed.

The analysis proposed in this methodology refers to loss calculations and involves the following:

- Analysis of energy indicators based on historical data;
- Calculations of energy losses in electrical conductors and transformers, electrical motor efficiency, pump efficiency, head losses in piping, and leaks in water network;
- Analysis of operations as well as maintenance practices;
- Development of energy balances.

These analyses identify items with a high rate of losses or low efficiency, allowing to determine savings measures likely to improve upon them.

1.3.1 Assignment 3

The third progress report should include an analysis of energy indicators based on historical data; calculations of energy losses in electrical conductors and transformers, electrical motor efficiency, pump efficiency, head losses in piping, leaks in water network; analysis of operations as well as maintenance practices; and the development of energy balances. These analyses will identify items with a high rate of losses or low efficiency, therefore allowing to determine savings measures likely to improve upon them.

Training Material

Please refer to Module 2 in the appendix of the training materials for a comprehensive review on how to analyze collected information.

Audit Report Template

Please use the audit report template provided in the appendix to continue building your own audit report.

RETScreen® Tool

Please use RETScreen® to analyze information collected during Steps 1 and 2.

1.4 STEP 4 – IDENTIFYING ENERGY SAVINGS OPPORTUNITIES

After analyzing and evaluating the largest energy-consuming elements, savings measures for the proposed action plan are determined within one or more of the following categories:

- Achieving savings by changing energy supply tariffs;
- Improving electrical installations (transformers, capacitors, etc.);
- Improving the efficiency of electric motors or pump operations within water systems, and maintenance practices;
- Reducing losses in the distribution network;
- Implementing leakage reduction programs;
- Considering renewable energies.

1.4.1 Assignment 4

The fourth progress report, which will be handed out immediately before the first national meeting, should include the savings measures for the proposed operation and investment plans.

Training Materials

Please refer to Module 3 in the appendix of the training materials for a comprehensive review on how to identify energy savings opportunities.

Audit Report Template

Please use the audit report template provided in the appendix to continue building your own audit report.

RETScreen® Tool

Please use RETScreen® to identify energy savings opportunities.

1.5 STEP 5 – EVALUATING SAVINGS MEASURES

Evaluating savings measures is a crucial step in an energy audit. Such an evaluation consists of the following:

- Calculating direct and indirect energy and cost savings to be achieved with identified measures;
- Estimating implementation cost for the measures (detailed design, equipment, installation, field supervision, security, storage, shipping and commissioning);
- Estimating additional operation costs (operation, maintenance and equipment materials, e.g., lubricants or gaskets) associated with the measures;
- Identifying financial indicators (pay-back, net present value and analysis of project lifecycle).

1.5.1 Assignment 5

Following the first national event, the fifth progress report should include the evaluation of the savings measures, consisting of the direct and indirect energy and cost savings to be achieved with the identified measures, estimated implementation cost of the measures (detailed design, equipment, installation, field supervision, security, storage, shipping, commissioning), estimated additional operation costs (operation, maintenance and equipment materials, e.g., lubricants or gaskets) associated with the measures and the financial indicators (pay-back, net present value, and analysis of project lifecycle).

Training Materials

Please refer to Module 4 in the appendix of the training materials for a comprehensive review on how to evaluate savings measures.

Audit Report Template

Please use the audit report template provided in the appendix to continue building your own audit report.

Action Plan Template

Please use this information to start building your action plan with the template provided in the appendix.

RETScreen® Tool

Please use RETScreen® to evaluate savings measures.

1.6 STEP 6 – DESIGNING AND IMPLEMENTING AN ACTION PLAN

Once all the possible energy efficiency measures are evaluated and the most interesting ones are selected by company senior management, the action plan is ready to be designed and implemented. First, the total energy savings and the resulting cash flow should be recalculated to provide a complete overview of the project. The implementation of the action plan consists of the three following main sub-activities:

- Project implementation
- Activities and critical path identification
- Financing plan
- Commissioning

1.6.1 Assignment 6

The last assignment, which will be handed out immediately before the second national event, should include an action plan with sections on the identification of activities and priorities, identification of responsibilities, and an implementation timeline. This progress report will be critical to the local consultant to prepare adequately for the last national meeting.

Training Materials

Please refer to Module 5 in the appendix of the training materials for a review on how to build an action plan.

Action Plan Template

Please use the action plan template provided in the appendix to build your own action plan.

2 STEP 1 – COLLECTING DATA

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.

2.1.1 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

2.1.2 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 energy audit, especially in those pumping systems that have the potential for energy savings.

2.1.3 Basic Data

An energy audit cannot be performed without basic data collection. 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.

2.1.4 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

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.

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):

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 (ºC)
- 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).

3 STEP 2 – TAKING 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 1).

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.

3.1.1 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 setup guidelines and practices.[1]

Table 1: 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
	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

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:
  - Test a similar known live circuit first.

[1] www.fluke.com/library

- Test the "circuit to be tested."
- 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.

Voltage

For the measurement of the electrical voltage in pumping equipment, use a voltmeter. Refer to Figure 4, 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."

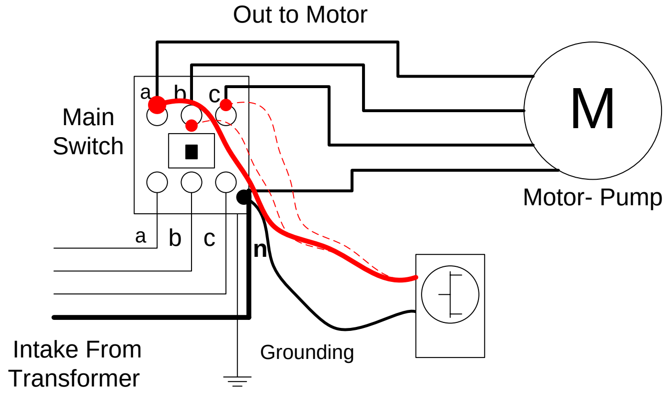

Figure 4: Measurement of Voltage in Pumping Equipment

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.

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.
- f 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.

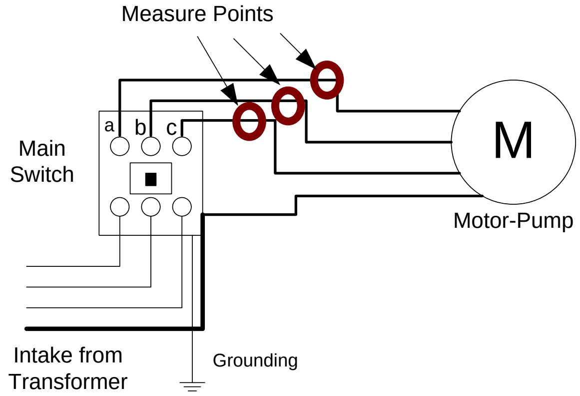

Figure 5: Electrical Current Measurement

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).

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 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.

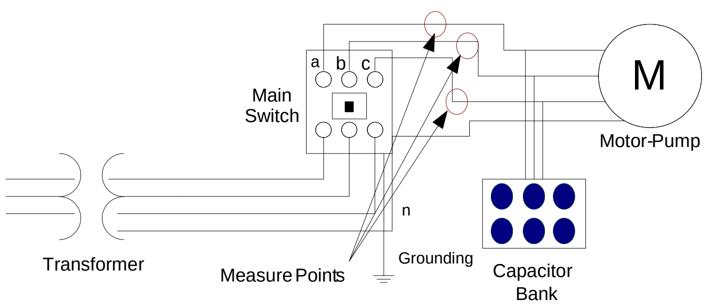

Figure 6: Measuring the Real Power before the Capacitors Bank

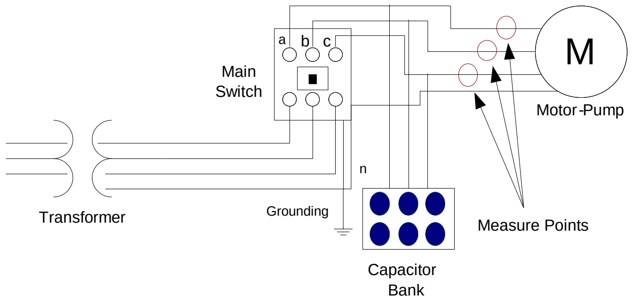

Figure 7: Measuring the Real Power after the Capacitors Bank

3.1.2 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 (Ns)
- Measurements of the distances at the center of the gauges (Dr-m), including both the suction and the discharge

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.

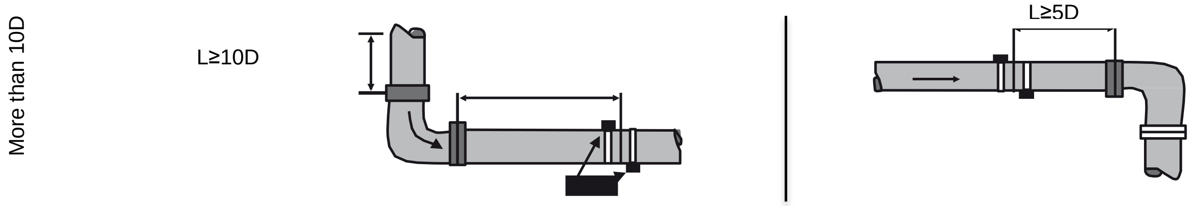

Figure 8: Position of the Flow Meter

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.

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 9: 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/cm2 = 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 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.

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).

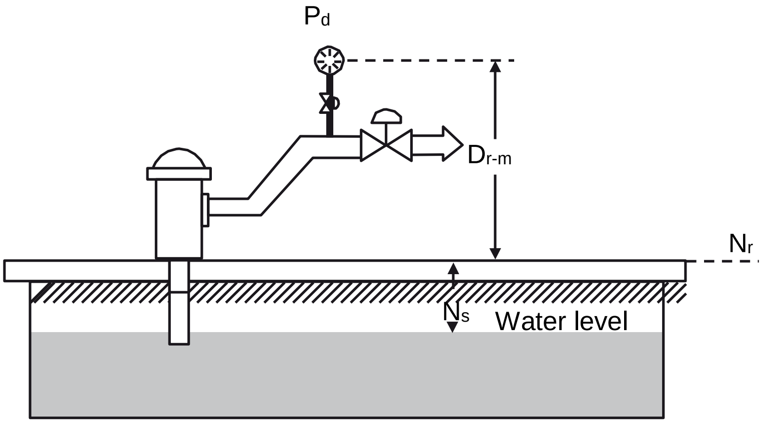

Figure 10: Measurement for Pressure Gauge in the Discharge

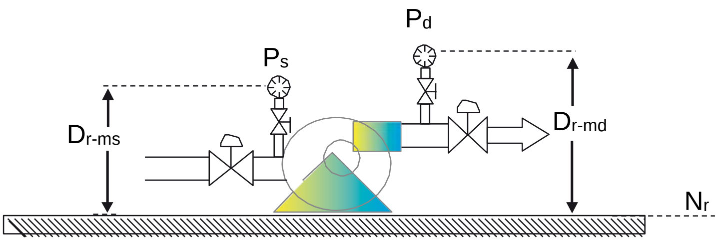

Figure 11: Measurement of Pressure When Gauges in Suction and Discharge Are Available

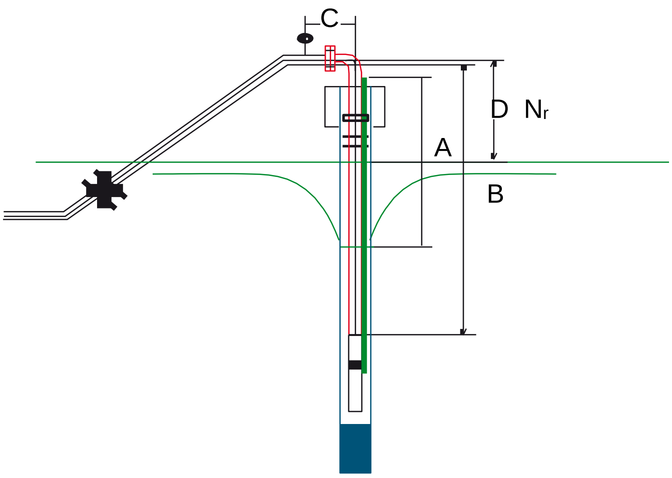

Figure 12: Submersible Pump Level Measurement

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.

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.

Measurement of Levels to Manometer Centers

Figure 10 and Figure 11 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.

Determination of Total Hydraulic Pumping Head

Levels 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 2 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 2: Calculations for Total Hydraulic Pumping Head and Measuring Parameters

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

4 STEP 3 – ANALYZING INFORMATION

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 last 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 energy audit, 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.

4.1.1 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 13).

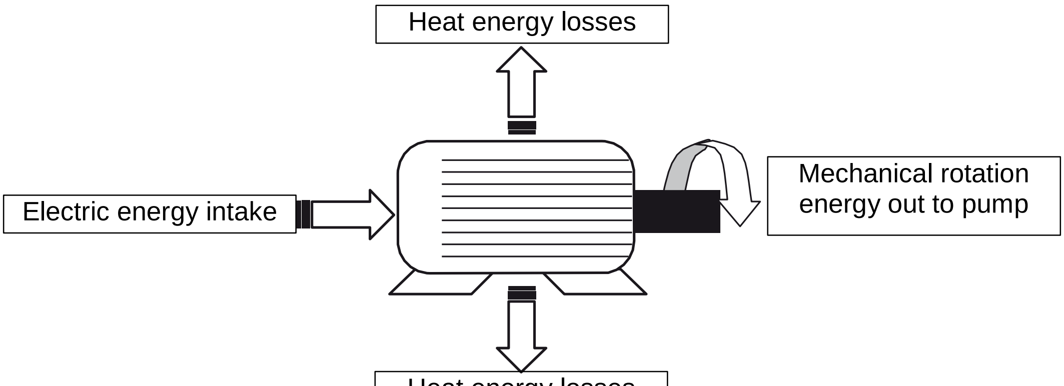

Figure 13: Electric Motor Energy Flow

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.

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 non-uniform 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.

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.

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

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 14 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 (ηm) 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).

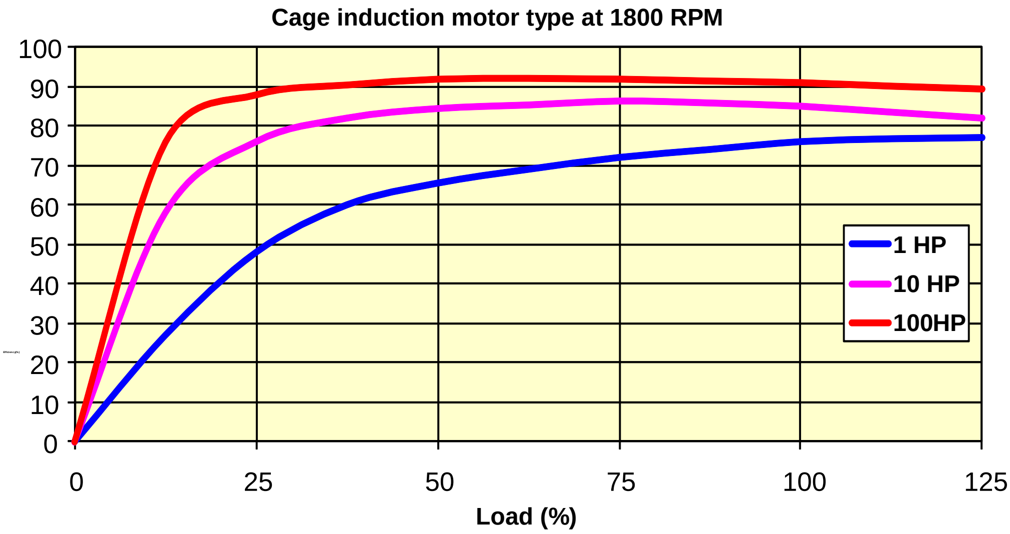

Figure 14: Typical Efficiency vs. Load Curves for an 1800-RPM Cage Induction Motor

The appropriate motor efficiency curve, identified in Figure 14, 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:

$$F.C. = \frac{P_e / \eta m}{HP_{nom} * 0.746}$$

Where:

LF is the load factor of the motor (–)

Pe 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 3.

Table 3: 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 16.

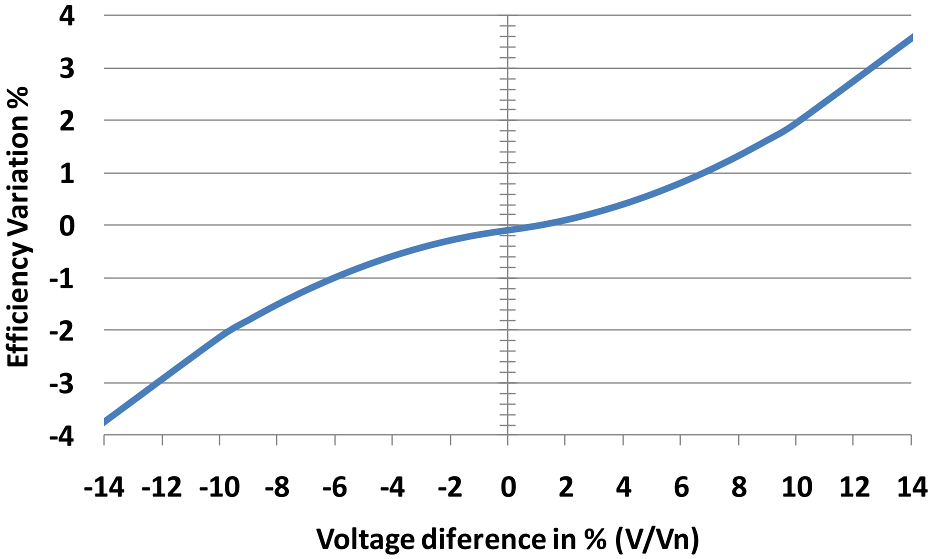

Figure 15: Efficiency Variation Based on the Difference with Respect to the Original Voltage in an Electric Motor

If there is an imbalance in the supply voltage, apply the adjustment to the efficiency according to the curve in Figure 16.

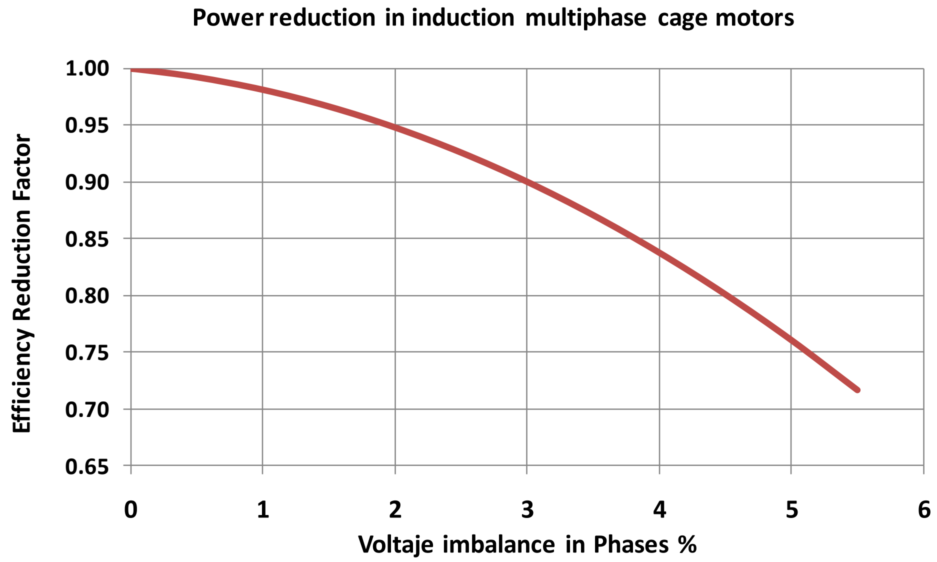

Figure 16: Reduction in the Capacity of an Electric Motor Based on the Voltage Imbalance

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:

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

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 DBI

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

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

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:

$$VDN = \frac{(V_{avg} - V_{Plate})}{V_{Plate}} \times 100$$

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)

4.1.2 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

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

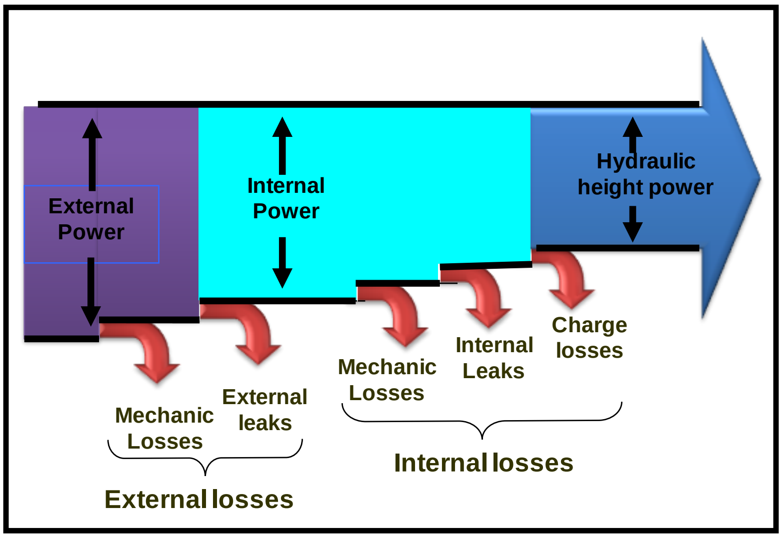

Figure 17: Losses in Centrifugal Pumps

The overall efficiency of the operating pump is then calculated as the total output power Ps (pressure in the output gauge) divided by the mechanical power absorbed Pm, identified in Figure 17 as external power. The efficiency formula is as follows:

$$\eta_b = \frac{Output\ total\ Power\ Gauge\ (P_s)}{Absorbed\ Mechanical\ Power\ (P_m)} \times 100$$

Where:

η_b	is pump efficiency in percentages (–)
Ps	is Q r g Ht / 746 (HP)
Pm	equals absorbed mechanical power by the pump in HP
Q	is flow (m3/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.

Evaluation of Electromechanical Efficiency

Electromechanical efficiency corresponds to the efficiency of the joint motor-pump (see

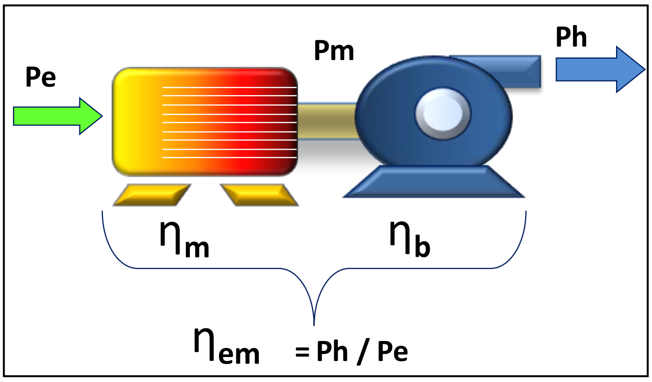

Figure 18).

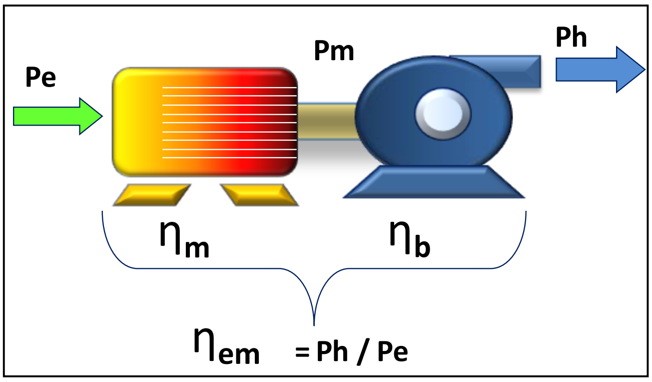

Figure 18: Efficiencies that Comprise the Electromechanical Efficiency

First, calculate the gauge power using the following equation:

$$P_h = \frac{H_T * Q * \gamma * g}{1000}$$

Where:

Ph is the gauge power (kW)

HT is the total pumping head (mwc)

Q is the flow (m^3/s)

Y 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 HT

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:

Hb equals total pumping head (mwc)

Pd is the measured discharge pressure (kg/cm^2)

Ps 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:

$$v = Q / A$$

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:

$$h_v = v^2 / (2*g)$$

Where:

H_v is the velocity head (mwc)

v is the velocity of the fluid (m/s)

g is the acceleration of gravity, 9.81 (m/s^2)

Electromechanical Efficiency Calculation ηEM

With the value of Ph 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)

Pump Efficiency Calculation ηP

Once the electromechanical efficiency η_{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.

4.1.3 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/m³) 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.

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:

$$EI = \frac{Total\ Energy\ consumed\ by\ the\ equipment\ (kWh)}{Total\ water\ produce\ and\ supply\ to\ the\ system\ (m^3)}$$

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.

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.

5 STEP 4 – IDENTIFYING ENERGY SAVINGS 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

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 some 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:

- Modification of operating procedures to reduce consumption during the peak demand time.
- 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.
- 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 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 4.

Table 4: 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 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 19 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.

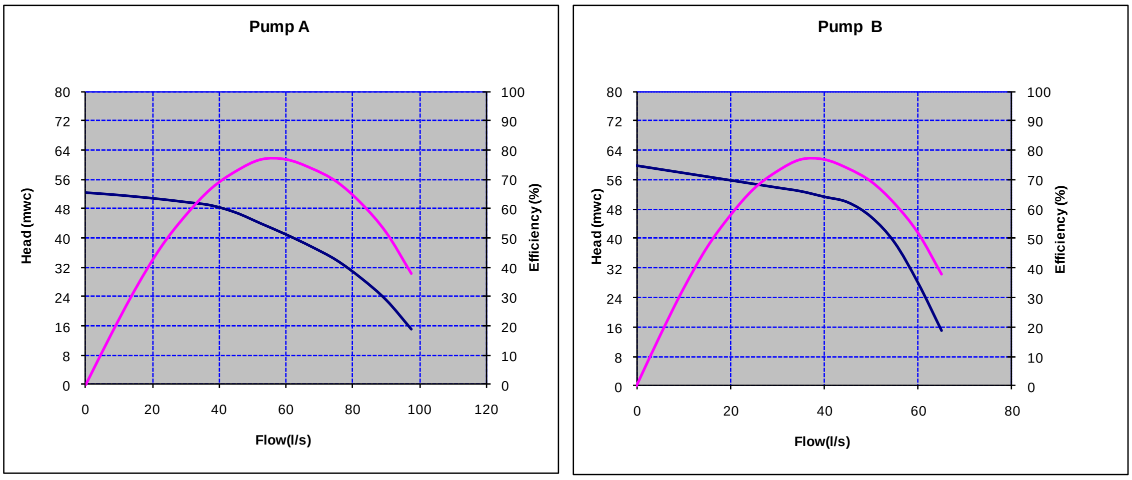

Figure 19: Typical Curves of Two Pumps with Different H-Q Operation

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

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 5 lists appropriate actions that can be taken to increase the efficiency of the pump based on observations.

Table 5: Recommended Actions to Adjust the Pumping Equipment to the Actual Operating Conditions

Pump Type	Operation Point Position	Actions
Vertical multistage 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 21).

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.

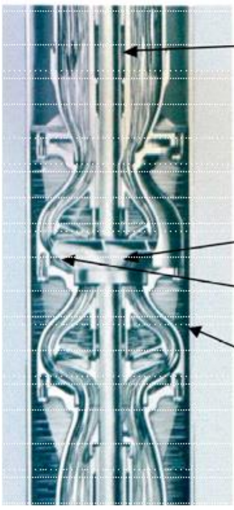

Figure 20: Turbine Pump with Open Impeller Diagram

Source: Byron Jackson Manual for Turbine Pumps

Figure 21: Diagram of a Hollow Shaft Motor Attached to a Turbine Pump

5.5 OPERATING IMPROVEMENTS

5.5.1 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 6).

Table 6: 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:

- 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.
- 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.
- 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:

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

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

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

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)

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 (–)

Calculate the energy saved using the following equation:

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

Where:

ΔE energy saved in the monitoring period (24 hours) (kWh)

ΔPe,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)

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

6 STEP 5 – EVALUATING SAVINGS MEASURES

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.

Total Saving (Seco) = 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 7 for an example spreadsheet).

Table 7: Example Energy Savings Summary

Description of the Savings 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

6.2 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.

6.2.1 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

6.2.2 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.)

6.2.3 Analisis 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

6.2.4 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.

7 STEP 6 – DESIGNING AND IMPLEMENTING AN ACTION PLAN

Once the energy audit 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 energy audit, three main components make up the basic starting point for creating a plan: executive projects, activities and a critical path, and a financial plan.

7.1 EXECUTIVE PROJECTS

The scope of the energy efficiency project depends on the savings measures previously defined in the energy audit. 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.

7.2 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.

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

7.3 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 should be recorded in the timeline of the energy efficiency action plan.

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