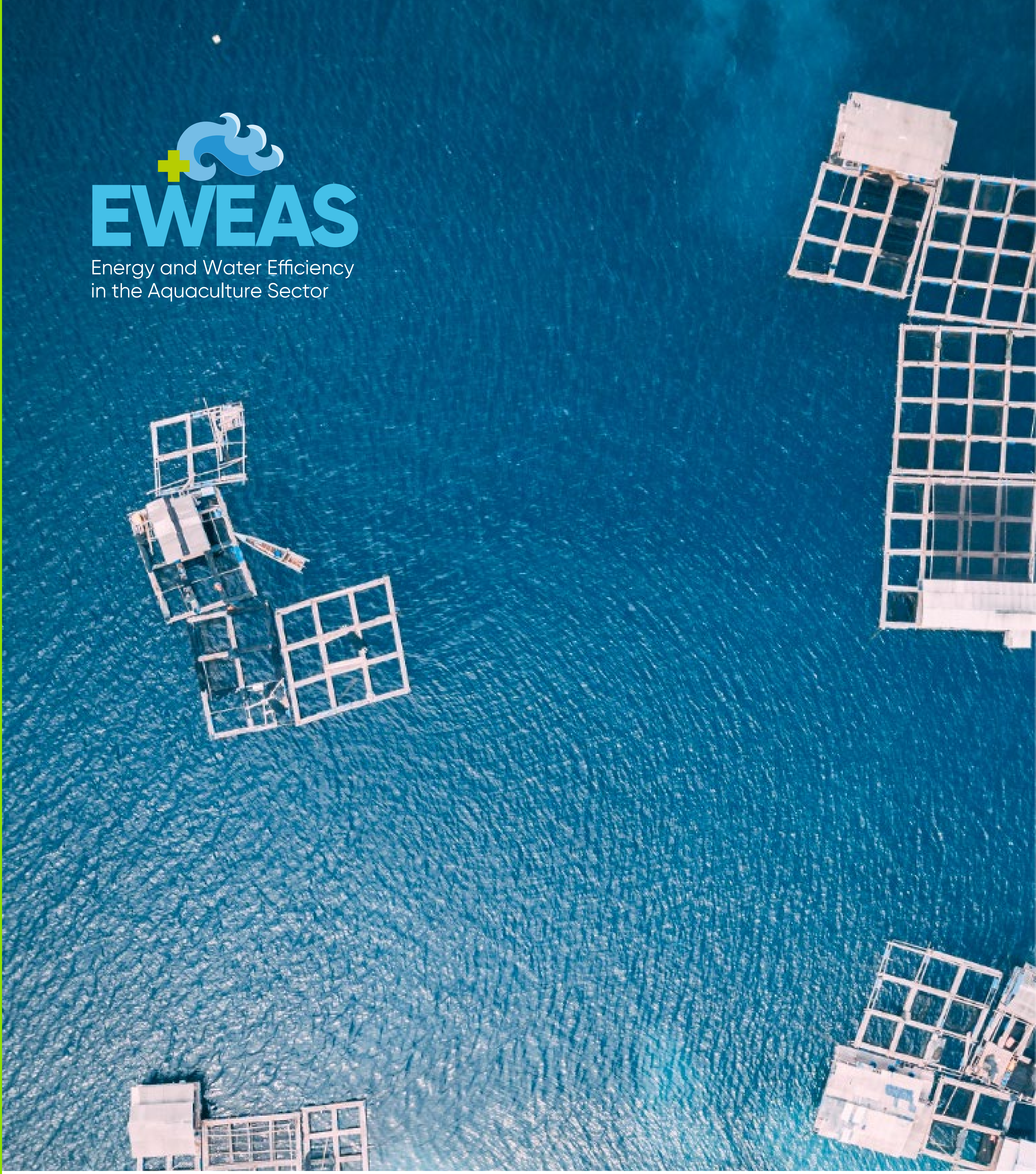

GUIDE FOR THE EVALUATION AND IMPROVEMENT OF THE **ENERGY EFFICIENCY OF INSTALLATIONS IN THE EUROPEAN AQUACULTURE SECTOR**

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AUTHORS

This guide has been developed by Adrian Cano (SGS) and Antonio Dominguez (SGS) in the year 2020 as part of the EWEAS project (Energy and Water Efficiency in the Aquaculture Sector) belonging to the Erasmus+ Programme and formed by a consortium of 5 participants from 5 European countries (Ireland, Italy, Latvia, Slovenia and Spain) coordinated by SGS Tecnos (Spain).

The EWEAS project team consists of a multidisciplinary team with a high degree of experience and expertise in aquaculture, energy efficiency and e-learning.

SGS

Mercedes Rodriguez Caro
Elena Tylko Ausias
Adrián Cano Cabañero
Antonio Domínguez Más

eurofortis

Adela Vitkovska
Vanda Novokšonova
Markuss Jānis Švāģeris

AQUATT

David Murphy
Marieke Reuver
Oxana Sytnik

Kmetijsko gozdarska zbornica Slovenije
KMETIJSKO GOZDARSKI ZAVOD KRANJ

Mitja Kadoič
Miha Štular

API ASSOCIAZIONE PISCICOLTORI ITALIANI

Andrea Fabris
Lisa Rovaglia
Vladimir Kvavadze

In addition, for the Pumping and Hydraulic Distribution section, we have had the collaboration of the Professor Javier Soriano, from the ITA (Technological Institute of Water), of the Polytechnic University of Valencia.

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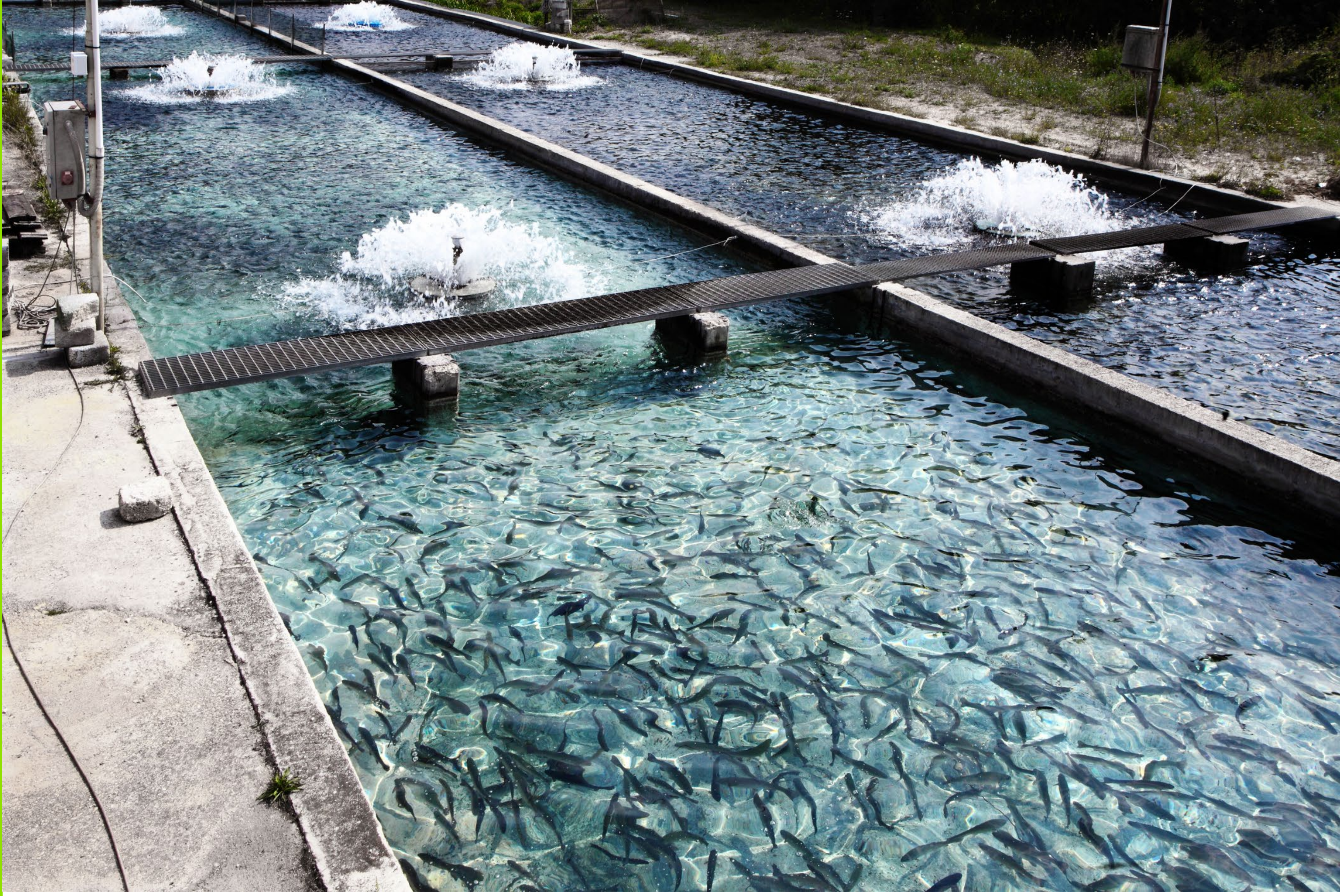


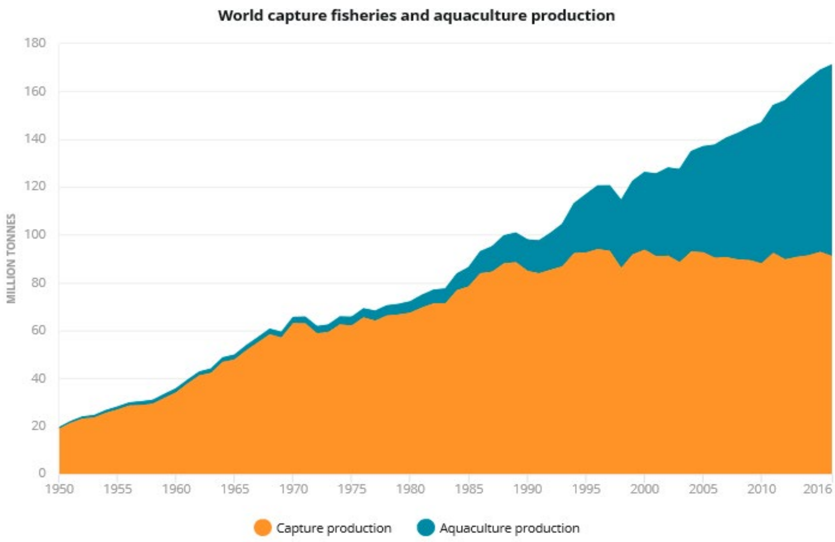
INTRODUCTION

MOTIVATION

By the middle of the 21st century, a human population of over 9 billion people will have to face the challenge of providing food security for its members, in a context of environmental degradation and overexploitation of natural resources and the effects of climate change, which are likely to be severe under the likely trajectory of greenhouse gas emissions.

A portion of 150 g of fish can represent up to 60% of the daily protein needs of an adult, so it is likely that the contribution of fish as a high-quality protein source will become increasingly important over the next few decades. In particular products coming from the aquaculture sector are likely to play an ever-increasing role in the face of the probable ongoing overexploitation of wild marine resources.

Even today, aquaculture is the fastest growing major food production sector, with an annual growth rate of 5.8% during the period 2001-2016, the latter year in which aquaculture production accounted for 53% of all fish destined for human consumption (FAO, 2020).



Img 1. World capture fisheries and aquaculture production FAQ, 2020. (FAO, 2020)

According to the Food and Agriculture Organization of the United Nations (FAO), "aquaculture must fill the growing gap between aquatic food supply and the demand of a growing and more resourceful world population" in the face of the expectation that most fish stocks "will continue to be fished at maximum sustainable levels or overexploited" for at least the next decade. (FAO, 2018).

In response to the disturbing question about where our food will come from in the future, FAO itself states the following:

"Given the limited scope for expanding agricultural use of more land and water resources, the increases in production needed to meet the growing demand for food will have to come mainly from improvements in productivity and resource use efficiency." (FAO, 2020).

OBJECTIVE

To this end, the purpose of EWEAS and this guide is to provide technicians and managers of aquaculture facilities with the necessary tools to maximize their energy efficiency and performance, allowing them to evaluate by themselves the state of their current facilities, as well as the impact on their energy consumption derived from the improvement actions they are considering implementing.

EWEAS focuses on the analysis of widely proven and established technologies that, however, are still often used within inadequate working parameters or inadequately maintained. This training will address the following essential points: Choosing the right equipment to obtain the best performance of their work along with the shortest return on investment; Detecting when inadequate operation is taking place correctly; Evaluating when it is convenient to renew equipment.

This guide will allow professionals who are not very familiar with the field of energy efficiency to discover a range of new possibilities that will contribute to increasing the efficiency of their installations and reducing their production and maintenance costs. In short, the aim is to provide a simple system for evaluating and calculating the most common systems present in aquaculture production plants, accompanied by enough training to enable the aquaculture technician to make their installations more efficient and, therefore, more competitive within today's demanding market.

DOCUMENT LAYOUT

This document consists of different sections related to the most common systems and technologies in aquaculture production. Each section begins with a brief theoretical introduction related to its content followed by the elements of analysis and calculation tools. These will allow the technician or plant manager to evaluate the current situation of the installations and to propose improvement scenarios and that can be used objectively for decision-making in the area of implementing energy efficiency measures.

1. BASIC CONCEPTS

DEFINITION OF ENERGY AND POWER

Energy is the capacity available to perform work and its unit of measurement in the International System of Units is the Joule (J).

The law of conservation of energy (first principle of thermodynamics) indicates that energy remains constant in an isolated system, although it can be transformed into other types of energy from which it follows that energy is neither created nor destroyed. It is transformed.

Power is the amount of work done over a given period of time and its unit of measurement is the Watt (W).

Therefore, one joule is the amount of work that will be necessary to produce one watt during one second. 1 W = 1 J/s

Although the recommended unit of the International System when referring to energy is the Joule, both the Watt hour (Wh) and the kilowatt hour (kWh) are widely used.

Maintaining a power of 1 kW during one hour of time requires an energy of 1 kWh. This is equivalent to, 3,600,000 Joules ($3,6 \times 10^6$ J).).

ENERGY SOURCES

An energy source is any physical phenomenon (wind, tides, solar energy...) or chemical (coal, oil...) that allows us to obtain energy capable of producing a work or provide us a certain utility. Energy sources can be renewable when they allow us unlimited use or non-renewable, when their availability decreases with the exploitation of these.

Renewable energy sources include:

- Solar: Use of energy from the sun to generate electricity (solar photovoltaic) or to harness its heat (solar thermal).
- Wind: Use of wind power.
- Hydraulic: Use of the energy of water flow under gravity.
- Geothermal: Based on the use of the earth's internal heat.
- Biomass: Use of non-fossilized organic matter originated by a biological process.
- Marine: Based on the use of energy from the movement of seawater, such as waves or tides.

Non-renewable energy sources include oil, coal, natural gas, uranium...

Energy sources can be classified as primary, when they are directly available from nature (coal, natural gas, renewable) or as secondary or final energy, when a transformation process is required to obtain them (electricity, diesel oil, etc.).

DEFINITION OF ENERGY EFFICIENCY AND ENERGY AUDITING

Energy efficiency can be defined as the optimization of the energy consumption of an installation, in such a way that to carry out the same operation the energy consumption is reduced without diminishing the quality of the service provided.

Obtaining a greater degree of efficiency in the use of the facilities and with it the reduction of the energy consumption, brings economic advantages, but also environmental ones. In order to adopt the appropriate measures, the energy situation of the company must be known in advance, this is usually done through an energy audit.

An energy audit makes possible to evaluate the components with the greatest impact on energy consumption. In it, a situation analysis carried out that allows detailed knowledge to be obtained about is:

- Mode of operation
- Demand levels of energy-consuming services
- Operation of energy facilities and condition of their components
- Energy consumption and operating costs

In short, to know where, how and for what the energy is used in the company in order to identify improvements that can be made and how much energy could be saved.

Carrying out an exhaustive inventory of consuming equipment and taking consumption measurements during its operating cycles makes it possible to evaluate the level of efficiency of the equipment and to detect opportunities for improvement. It should be noted that the improvement measures do not always have to involve a cost on the part of the company, and there are many possible actions (organisational, change of energy tariffs, etc.). (FEMEVAL y SGS)

Conducting an energy audit is particularly valuable when:

- The energy map, demand, consumption and operating costs are not known.
- Inefficient equipment and installations are used.
- Maintenance is poor.
- Typical consumption habits are not known.

The minimum requirements for energy efficiency at European level are reflected in Directive 2012/27/EU which establishes the common framework of measures for the promotion of energy efficiency within the European Union, although its transposition into the legislation of the different member countries may have led to more stringent measures.

BASIC CONCEPTS OF ENERGY MANAGEMENT

When establishing energy saving objectives and being able to evaluate the energy savings associated with the different energy saving measures to be implemented, it is necessary to have tools that allow the analysis of energy consumption and study its evolution in relation to parameters external to the installations (climate) and internal (occupation, schedules, etc...).

It will not be enough to launch a measure and verify that it is generating the savings expected in the audit and, in the case of proposals with investment, to verify the expected payback periods. It will be necessary to carry out a control over time that will allow us to detect whether that system, initially verified and implemented, continues as planned and continues to produce the expected results.

Normally, experience tells us that, if there is not adequate monitoring and control not only in maintenance, but also in the supervision of the measures, with time, these end up again in their initial situation.

Having a system that allows us to know the daily, weekly, monthly, etc... consumption in real time of those points, sections or proposals that have been implemented, will allow us to know if the forecast is being fulfilled or not. The detection of these deviations will allow us to act and know the reason why it has occurred.

Many times, the deviations are due to human errors. With a consumption detection system, the error is discovered thanks to the overconsumption of energy that the incident entails, allowing immediate action and avoiding the loss of value due to this concept.

Other times, these deviations correspond to failures in equipment that are not detected when other equipment enters in cascade and in this way to replace the incidents. Therefore, this type of system can alert us to possible anomalies since we have defined the working ranges considered normal.

2. LIGHTING

TECHNICAL CONCEPTS

Luminous flux: Magnitude whose unit of measurement is the lumen (lm) and which allows the measurement of the light power emitted by a source.

The luminous flux is defined as the power of visible light radiation emitted by a light source weighted with the spectral sensitivity of the eye. The maximum spectral sensitivity of the human eye is 555 nm (in the green-yellow region of the spectrum.

Luminous efficiency: The relationship between the luminous flux (lm) emitted by a light source and its power (W). The result is an indicator of the degree of efficiency of a luminaire.

$$\eta = {}^{lm}/_{W}$$

Illuminance (E): The ratio of the luminous flux received by a given surface to its area. Its unit of measurement is the lux (lm/m^2).

$$E = \frac{lm}{m^2}$$

Light intensity (I): Flux emitted by a light source in a certain direction defined by the solid angle. Its unit is the candle (cd).

Luminance (L): Ratio of the luminous intensity of an object to its surface. Equivalent to the brightness of the surface. Unit: cd/m^2.

Unified Glare Index (UGI): Index used to quantify the glare caused directly by light sources. It is measured on a scale of 10-31.

Colour temperature: Tone of light emitted. This is the temperature at which the black body has a similar colour appearance.

It is measured in degrees Kelvin and allows us to appreciate variations in the appearance of colour, on a scale that goes from what we call "warm" colour temperature and whose Kelvin value is not very high, to a "cold" colour appearance that corresponds to a higher K.

Img 2. colour temperature: **WARM**

Img 3. colour temperature: **COLD LIGHT**

Colour rendering index: This index allows us to know the capacity of a light source to faithfully reproduce colours. It is measured on a scale from 0 to 100, 100 being the colour rendering that would be obtained from an ideal source of natural light (such as the sun).

IRC value	Evaluation	Associated lamps types
90 < IRC < 100	Excellent IRC level	Incandescent; Halogen; Led
80 < IRC < 90	Good level	Fluorescent; Compact fluorescent
IRC < 80	Poor IRC level	Sodium vapour

The main elements that make up a lighting system are the following:

- Lamps
- Luminaires

According to the definition of the CIE (Commission internationale de l'éclairage), luminaires are devices that filter, distribute or transform the light emitted by one or more lamps and contain the necessary accessories to power them.

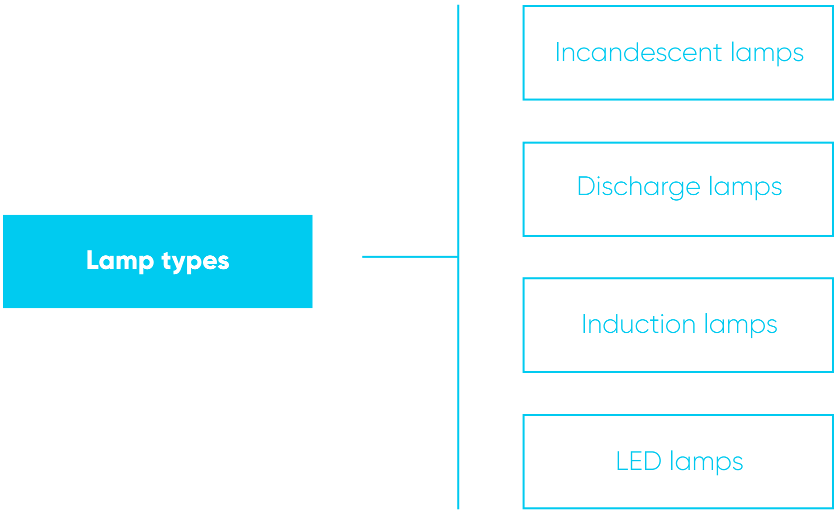
- Auxiliary equipment
- Supports
- Installation and protection elements
- Control panel and protections

Incandescence.
The most inefficient lighting system

The operation of traditional bulbs is based on the emission of energy thanks to a high temperature in its internal filament. The visible part of the emitted radiation is called "incandescence". This type of lighting reached a perfect IRC level of 100.

Lighting systems based on the incandescent principle were gradually withdrawn from the European market at the beginning of the century due to their inefficiency. Only 5% of their energy consumption was used for lighting, with the rest of the energy being dissipated in the form of heat.

LAMP TYPES



INCANDESCENT LAMPS

Non-halogen incandescent: They were the most used in the domestic sector because of their low cost and versatility. Their operation is based on passing an electric current through a tungsten filament. They are currently withdrawn from the market but can still be found working in many installations.

Halogen incandescent: Their duration and efficiency are better, but they have a higher cost, and their use is more delicate. They incorporate a gas to prevent the tungsten from evaporating from the filament and depositing in the bulb, thus reducing the luminous flux.

DISCHARGE LAMPS

The light is achieved by excitation of a gas subject to electrical discharges between two electrodes requiring auxiliary equipment for its operation. In the industrial field they are the most used, being of different types and forms (tubular, cylindrical...) depending on the gas and pressure. The most used in industrial environments as far as their technology is concerned are the following:

- High- and low-pressure sodium vapour lamps
- High pressure mercury vapour lamps
- Fluorescent and compact fluorescent lamps
- Metal halide lamps

All of them share the characteristic of needing auxiliary equipment (ballast or reactance) capable of generating an electric arc that allows the lamp to be turned on and then maintaining it by also limiting the current intensity.

Tubular fluorescent lamps: These are low-pressure mercury vapour lamps of low power, whose traditional application is in interiors of reduced heights (typical "office" lighting system). They have a long duration, a low acquisition cost and present a great variety of colour appearances.

There are two types of power supply system: electromagnetic ballast and electronic ballast.

Traditional (electromagnetic) ballasts increase the energy consumption of the lighting system by around 15 - 20% (depending on the model and power of the lamp) and have therefore been progressively replaced in models of tubular fluorescent lamps by modern electronic ballasts that In addition to not having this disadvantage associated with energy consumption, they have other advantages such as the elimination of the strobe effect, simple regulation of the luminous flux, extension of the life of the lamps, instantaneous ignition and elimination of the annoying "flickering" that occurs both when the lamp is switched on and at the end of its life.

Replacing electromagnetic ballasts with electronic ones in tubular fluorescent lamp models is a very common energy-saving measure with consumption savings of around 20% and reduced payback periods (usually one or two years in working environments and with considerable annual operating hours).

Compact fluorescent lamps: Same operation as tubular fluorescent lamps, although they are small in size as they are made up of one or several bent fluorescent tubes. Many have the auxiliary equipment directly incorporated.

High pressure mercury vapour lamps: They have a higher luminous flux than fluorescence, although their ignition is not instantaneous. Their efficiency is lower, and they have an average cost of acquisition.

Low pressure sodium vapour lamps: They are high efficiency lamps with a yellowish colour. Their traditional use is in highways, industrial areas and public lighting. They have a large size for large powers.

High pressure sodium vapour lamps: They improve the colour rendering of low-pressure lamps, maintaining a high efficiency with respect to the rest of the lamps. They are normally used in industrial installations, both indoors and outdoors.

There is another type with a higher-pressure level called white sodium that provides greater colour rendering.

Metal halides: Its composition includes metal halides which considerably improve colour reproduction. Its acquisition cost is high, and its duration is average.

Mixing lamps: These are a combination of high-pressure mercury vapour lamps and incandescent lamps, together with a phosphorescent coating. They do not need a ballast for their operation and have a poor light efficiency and colour rendering. They are currently in disuse.

INDUCTION LAMPS

Although its operation is based on the principle of gas discharge at low pressure, it has the characteristic of dispensing with electrodes. Its useful life is very long.

LED LAMPS

With a much longer average life than other lamps and very high efficiency, this type of lamp is based on the use of semiconductor materials capable of directly transforming current into light. The market share of these highly efficient lamps has grown considerably over the past decade as the cost has progressively decreased and so they have become increasingly competitive.

Below is a table with approximate average values of characteristics for the most common lamp technologies on the market:

	Power (W)	Useful life (h)	Efficiency (lm/W)	Tª colour (K)	IRC (%)	On (minutes)
Incandescent	25 ~ 2.000	1.000	8 ~ 21	2.700	100	0
Halogens	40 ~ 100	2.000	15 ~ 27	2.800	100	0
Fluorescents	16 ~ 65	5.000	48 ~ 80	2.700 ~ 6.000	70 ~ 98	0
Compact fluorescent lamps	7 ~ 50	8.000	57 ~ 65	2.700 ~ 6.000	85	0
Mix	160 ~ 500	6.000	19 ~ 28	3.600	60	2
High pressure mercury	50 ~ 2.000	24.000	32 ~ 60	3.500 ~ 4.500	40 ~ 70	4
Metal halide	70 ~ 3.500	10.000	75 ~ 105	3.000 ~ 6.000	80 ~ 90	3 ~ 10
Induction	70 ~ 150	60.000	80	3.000	80	0
Low pressure sodium	18 ~ 180	6.000	100 ~ 200	1.800	~	15
High pressure sodium	35 ~ 1.000	8.000	60 ~ 130	2.000	25 ~ 50	5 ~ 10
White sodium	35 ~ 150	12.000	40 ~ 50	2.500	85	12
Led	1,5 ~ 50	50.000	60 ~ 120	2.500 ~ 8.000	70 ~ 98	0

CALCULATING THE ENERGY CONSUMPTION OF A LIGHTING SYSTEM

The main factors that influence the consumption of a lighting system and that are decisive for its consumption are the following:

- Installed power
- Hours of operation
- Desired lighting level
- Lamp performance
- Luminaire efficiency
- Regulation and control devices

The energy consumption of a lighting installation is directly related to the installed power and the number of operating hours. Thus, let us take as an example an installation in which there is a total of:

- 50 traditional incandescent lamps of 60W of power per unit. These lamps work outside at night, approximately 10 hours a day, all year round.
- 30 LED lamps of 15W of power each. These lamps installed in the common areas of the building work an average of 5 hours a day from Monday to Friday throughout the year.
- 10 fluorescent tube screens (conventional ballast) of 2x36W of power. They are installed in the offices and work 8 hours a day from Monday to Friday all year round.

The annual consumption for incandescent lamps will be:

Installed power = 50 units x 60W = 3.000W = 3 kW

Operating time = 10 h/day x 365 days = 3650 hours

Energy consumption = 3 kW x 3,650 hours = 10,950 kWh

The annual consumption corresponding to the LED lamps will be:

Installed power = 30 units x 15W = 450W = 0,45 kW

Operating time = 5 h/day x (365 - 52 days) = 1565 hours

Energy consumption = 0.45 kW x 1565 hours = 704.25 kWh

The annual consumption corresponding to the LED fluorescent tube screens will be:

Installed power = 20 units x 36W x 1.2 = 864W = 0.86 kW (see notes 1 and 2)

Operating time = 8 h/day x (365 - 52 days) = 2,504 hours

Energy consumption = 0.86 kW x 2,504 hours = 2,163.45 kWh

- Note 1: As indicated in the statement, there are 10 luminaires of 2x36W, that is, two fluorescent tubes for each luminaire. Total 20 units.
- Note 2: The unit power increases (x 1.2) because, as seen in previous sections, fluorescent tubes are discharge lamps (such as sodium or mercury vapor lamps, among others) that need a ballast to cause them to light up. Traditional ballasts increase lamp consumption by around 20% (depending on their power and manufacturer).

The total annual energy consumption of the installation will be:

10,950 + 704.25 + 2,163.45 = 13,817.7 kWh/year

Which, considering an average price in Europe for electricity consumption of 0.1251 euros/kWh (data corresponding to the first half of 2019 for medium-sized non-household consumers (EUROSTAT, 2019)) gives us a total annual cost of 1,728.59 euros.

CURRENT TECHNOLOGIES: REPLACEMENT OF LIGHTS BY OTHERS WITH HIGHER EFFICIENCY

The tables below indicate different options for the replacement of lamps of different technologies and wattages, which could be replaced without a decrease in lighting conditions.

Thus, for example, looking at table 1 we can see how it is feasible to replace a 60 W incandescent lamp with an 11 W compact fluorescent lamp and that this would mean energy savings of around 82%.

Equivalence between incandescent and compact fluorescent lamps

Incandescent	Compact Fluorescent	Energy Saving
15 W	3 W	80 %
25 W	5 W	80 %
40 W	7 W	82 %
60 W	11 W	82 %
75 W	15 W	80 %
100 W	20 W	80 %
150 W	23 W	84 %

Equivalence between halogen dichroic and led lamps

Dichroic	Led	Energy saving
35 W	4 W	89 %
50 W	5,5 W	89 %

Equivalence between incandescent and LED lamps

Incandescent	Led	Energy saving
32 W	6 W	81 %
40 W	8 W	80 %
48 W	9,5 W	80 %
60 W	12 W	80 %
75 W	17 W	77 %

Equivalence between conventional and energy-saving fluorescent lamps

Conventional fluorescent	Energy saving fluorescent lamps	Energy saving
18 W	16 W	11 %
36 W	32 W	11 %
58 W	51 W	12 %

Replacing conventional lighting systems with LED technology lighting means considerable savings, although these vary - to a greater or lesser extent - depending on the starting technology. The estimated average savings by switching to LED in different technologies can be seen in the following table:

Existing technology	Estimated savings after switching to LED
High pressure sodium vapour	60 %
Low-pressure sodium vapour	20 %
Metal halide	40 %
Mercury vapour	40 %
Incandescent	15 %
Halogen	15 %
Fluorescent	50 %

LIGHTNING MEASUREMENT: 9 POINTS METHOD

In order to know the existing lightning level in a determined installation a Lux meter is to be used. This equipment is reliable, affordable and easy-to-use. It has been used routinely by professional (lighting experts, energy auditors among others). The lux meter will allow us to quantify a series of parameters to ensure enough lightning in the installations. The key points of lightning efficiency are:

- Sufficient light: Availability of adequate light levels, according to the nature of the visual task.
- Uniform Lightning: A general lighting with a high degree of uniformity guarantees total freedom when locating the machinery or the working teams.
- Good vertical lighting: where necessary light should reach high points in the room.
- Light sources well screened: proper screening ensures that light I directed to where it is needed without dazzling people.
- Balance brightness: It provides a comfort sensation.
- Pleasant light colour: A source with a pleasant colour and a good colour performance.
- Low maintenance cost: it is as important as the modern machinery and personally driven.

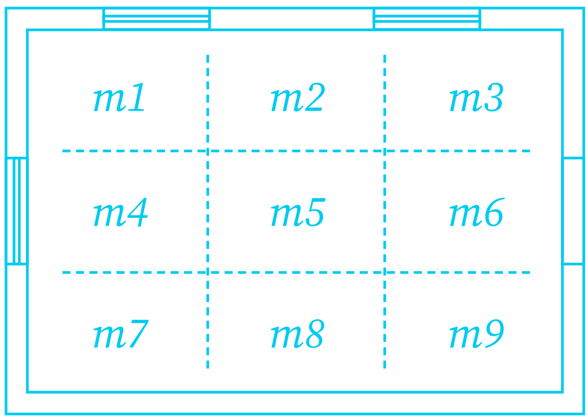
As we will see further on, the EU normative that regulates the minimum necessary level of lightning for each type of work is norm EN 12464 (parts 1 and 2). It must be taken into account that in a firm itself many different jobs are being developed (room storage, offices, production areas...) and each of them has different lightning, uniformity and glare needs that are regulated in the already mentioned norm. Is due to this fact that measurements must be carried out in each of the premises in order to verify that necessary conditions for the type of work developed are correctly fulfilled.

HOW TO DEVELOP THE MEASUREMENTS

The measurement we obtain from the Lux meter will be much higher directly underneath the light source and it will progressively decrease as we move away from it. Furthermore, other factors such as the walls' colours and reflectivity can also influence the result. We need, hence, a method that allows us to obtain a value measured for the whole room.

It is widely established than measurement at 9 points (so called nodes) spread evenly across the room is sufficient to calculate a representative average illuminance in a room. The part of the room that each node represents is called its domain. The total illuminance is calculated by a weighted average (Equation below).

The numeric method of the 9 points is a methodology widely accepted that establish-es that it is sufficient to measure representative points, the so-called nodes, each of them corresponds to a domain. The total illuminance is calculated as a weighted average of from the illuminances of each domain:



$$Em = \frac{m1+m3+m7+m9}{16} + \frac{m2+m4+m6+m8}{8} + \frac{m5}{4}$$

Even though norms must be followed both at a national and local level, according to the guidelines of norm EN 12464 for each task or specific job post, it can be considered that a value Em = 100 lux can result appropriate for light visual tasks, while a value Em = 300 lux is necessary for a receptionist office desk.

Em = 500 lux would be used for normal visual tasks (as reading or writing) and a value Em = 1000 lux or superior would result appropriate for high visual requirements, as inspection of colours in determine industries or exam chambers in sanitary facilities.

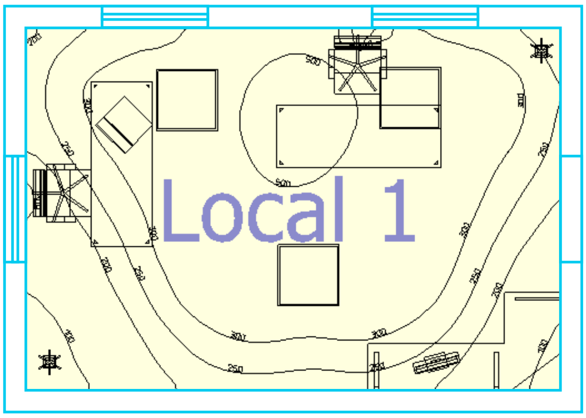
It Is convenient to keep in mind that the value obtained as of method of the 9 points of average illuminance (E) can be enough for our needs, and yet, have a bad lighting in the premises due to the deficient location of the luminance. The average uniformity (U) is the value that allow us to acknowledge if the distribution of lighting systems is correct or, if, on the contrary, they produce shade areas between one light source and another.

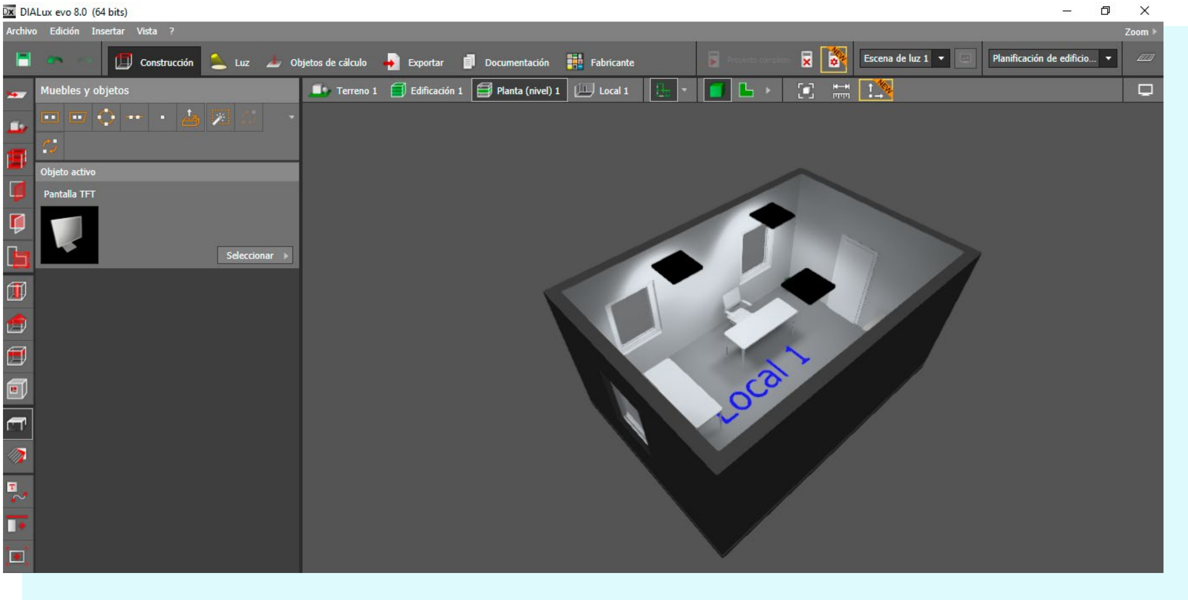
The Average Uniformity (Um) is calculated as the ratio between the minimum value obtained in the measurements and the average illuminance (Em).

$$Um = E(min) / Em$$

The Um value is better the closer to the unit. As an example, a Um value of 0.40 is suitable for office file locations, while it would be necessary to reach an Um value of 0.60 for classrooms or reading rooms in educational buildings.

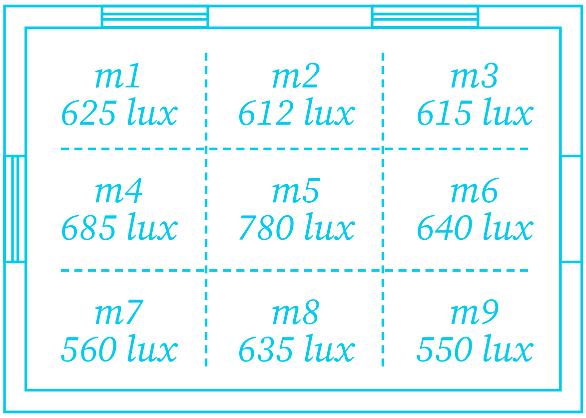
Another way to obtain these values is by using stimulation software, which allow us to model premises with all the necessary constructive and lightning parameters. The following images correspond to a calculation simulation performed, as an example, with a version of the free DIALux software.





EXAMPLE OF LIGHTING LEVEL CALCULATION IN A VENUE

Suppose we have made all nine measurements with a lux meter in office premises and that we have obtained the following results:



m1 (Lux)	m2 (Lux)	m3 (Lux)	m4 (Lux)	m5 (Lux)	m6 (Lux)	m7 (Lux)	m8 (Lux)
625	612	615	685	780	640	560	635

As we can see, the lowest value is obtained at the measuring point m9 with 550 lux, while the highest value is obtained at the measuring point m5 with 780 lux. From the obtained values we calculate the Em and the average uniformity.

$$Em = \frac{m1+m3+m7+m9}{16} + \frac{m2+m4+m6+m8}{8} + \frac{m5}{4}$$

$$Em = \frac{625+65+560+550}{16} + \frac{612+685+640+635}{8} + \frac{780}{4}$$

$$Em = 663{,}38$$

$$Um = E\,(min) / Em$$

$$Um = 550 / 663$$

$$Um = 0{,}83$$

As it is an office premises, as indicated in the example, and after consulting the corresponding section of EN 12464-1 for lighting in workplaces, we can see that the completion of most of the office's own work requires a minimum Em level of 500 lux (write; read; CAD; conference and meeting rooms; typing), while for some tasks even lower values are required. Thus, for files only between 200 and 300 lux (as the case may be) and for 300 lux reception desks. For technical drawing works, however, a value greater than 750 lux is required, this being the only case for which the lighting of our example would be insufficient.

The uniformity value obtained from Um s 0.83 is also considered good enough to pre-vent the appearance of shadow areas between lighting bulbs.

Finally, it should be noted that EN 12464-1 also indicates the glare rate and the degree of colour reproduction (Ra) required for the different premises and that, for aquaculture facilities it should not be less than 80. This data should be taken into account when purchasing replacement lamps and performing maintenance.

UTILITY OF AVERAGE ILLUMINANCE MEASUREMENTS

From the information provided by the measurement of lighting conditions, different measures can be taken for the reduction of consumption or improvement of production processes, such as:

- Decreased lighting level

In premises where the level of lighting is found to be higher than necessary for the tasks being carried out there (over-illumination), it is possible to reduce consumption through actions such as:

- Replacing existing lamps with lower power lamps.
- Selective shutdown of some lighting points.
- Sectoral switches for the shutdown of areas during hours when external lighting is available.
- Installation of photocells that control the electric lighting depending on the level of natural light (in cases where the over light situation occurs by a light supply from the outside during the daytime period, through skylights, windows, etc...).

- Adapt environmental conditions

Bearing in mind the importance of lighting control in aquaculture for both smoltification and the growth rate of specimens, having as accurate data as possible where the installation of automatic control elements is not feasible can be a significant competitive advantage.

LED lighting, increasingly present in all areas, allows for quality lighting, with good colour reproduction and very low consumption compared to traditional lighting systems. It also allows the regulation of its light intensity in a simple way and even the variation of colour which is interesting from a productive point of view in aquaculture installations.

Effects of green and blue LED lighting on fish stress.

A study conducted by scientists at Korea Mari-time and Ocean University showed the influence of various wavelengths of light on physiological stress caused by water temperature changes in Korean rock fish (Sebastes schlegelii). The paper, published in Fisheries Science in 2017, points to the influence of green and blue LED lighting on the recovery of physiological damage in fish.

(Cheol Young Choi, 2017).

LIGHTING IN WORKPLACES

European standards governing workplace lighting conditions are EN 12464-1 (for in-door workplaces) and EN 12464-2 (for outdoor workplaces). These standards, where the visibility and comfort conditions of a wide range of workplaces can be found, also provide recommendations on good lighting practices. National or local standards may also apply on top of these regulations.

Although there is no specific section related to aquaculture in that standard, some of the tasks referred to in the following table may serve as guidance for their similarity in the tasks or activities to be carried out.

Areas, tasks or activities		Em (lux)
12464-1 Indoor workplaces		
Agriculture	› Loading, operations with items, handling equipment, machinery, veterinary rooms, barns for pairing, food preparation, emptying and washing utensils	200 lux
Food	› General working areas › Critic workplaces (slaughterhouses, mills, butchery, filtering…) › Laboratories	200 lux 500 lux 500 lux
Traffic zones and common areas	Circulation areas and hallways › Resting areas Changing rooms, cleaning rooms Material and mechanism rooms	100 lux 100 lux 200 lux 200 lux
Offices	› Archive, copies, etc › Writing, type writing, reading, data processing › Technic drawing › Job posts CAD › Conference and meeting rooms › Reception desk › Archives	300 lux 500 lux 750 lux 500 lux 500 lux 300 lux 200 lux
EN 12464-2 Outdoor workplaces		
Farms	› - Corral › - Area of animal classification	20 lux 50 lux

In any case, it must be taken into account that these European norms, as it is high-lighted in paragraph 1 "Object and field of application "do not specify requirements of lightning in what respects to security and health of workers at the workplace, even though they usually satisfy their security needs.

3. ELECTRIC MOTORS

THEORY:

EFFICIENCY OF AN ELECTRIC MOTOR

An electric motor is a machine that transforms electrical energy into mechanical energy. Heat losses occur in the transformation process. There are motors powered by both DC and AC power:

	ADVANTAGES	DISADVANTAGES
DC powered motors	Easy regulation of speed (through voltage control)	High acquisition cost High maintenance cost (Its design includes the use of brushes to transfer energy to moving parts, which have an important weathering)
AC powered motors	Lower cost of acquisition Simpler design Larger availability of power sources of AC	Fixed operating speed (Require inverter)

AC motors can be:

- Synchronous: Where the rotation speed matches the frequency of the alternating current.
- Asynchronous: Where the rotation speed can differ from the magnetic field of the stator.

The main parameters of a motor, which can be easily found on the equipment's nameplate are as follows:

- Voltage (V)
- Nominal and starting current (A)
- Nominal power (kW or CV): Useful power output on the shaft when the motor is operating on normally (not to be confused with the power drawn from the electrical supply).
- Power factor: Frequency and voltage function ($P = I \times V \times \cos \phi$)
- Turning speed: Power grid frequency function (rpm)
- Load factor: Index indicating the percentage of engine capacity being used.
- Electrical performance: Power obtained on the axle compared to power absorbed from the grid.

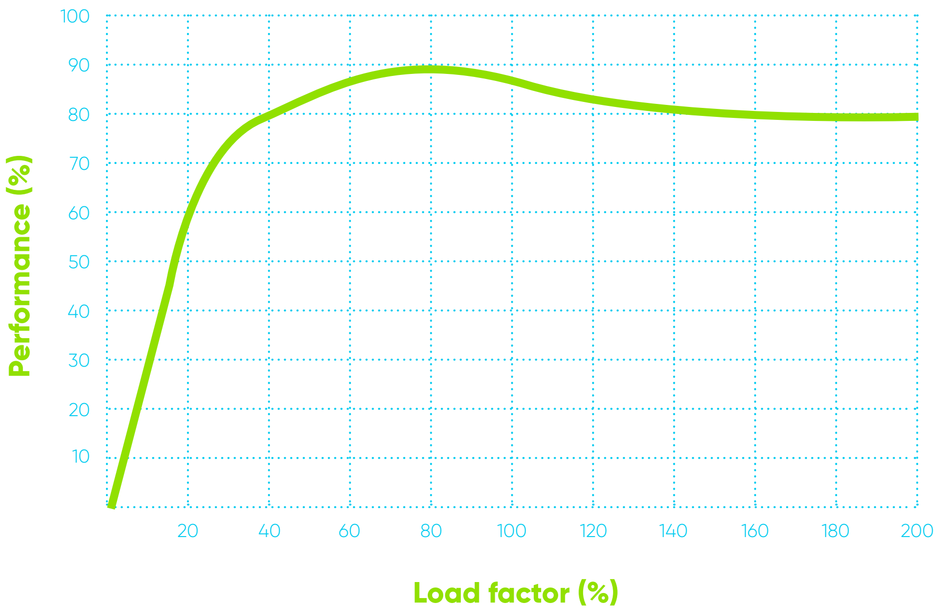
The motors have different types of losses during operation:

- Electrical losses: Depend on engine working speed (load factor). They are presented in both the rotor and the stator and are reflected as heating through the winding.
- Mechanical losses: They are divided into friction and ventilation losses. The former occurs due to friction between the rotor and the stator and the friction of the shaft bearings. The latter are the result of friction of moving parts with air.
- Core Losses: Represents the energy required to magnetize the core. It is independent of the load.

OPERATIONAL ANALYSIS

Unlike other equipment - such as lighting - where energy consumption depends mainly on operating time as its power value remains stable, in electric motors consumption has a direct relationship with the workload to which they are subjected. Therefore, it is important to select motors that are appropriate to the workload you are performing.

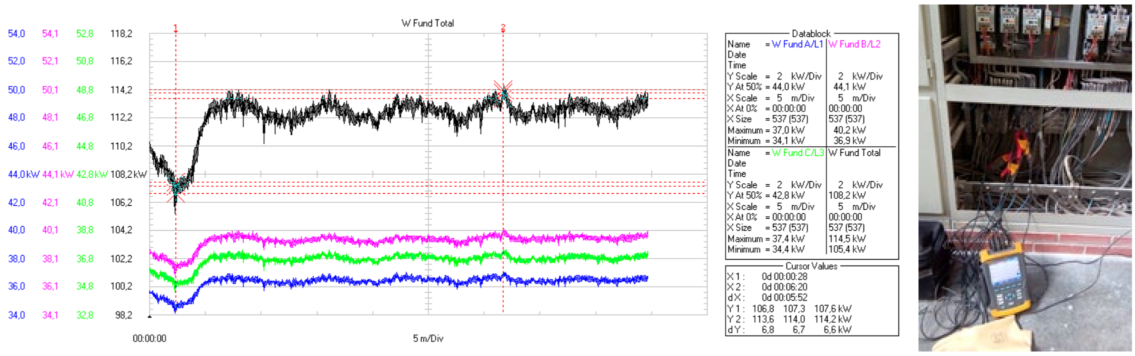
The following graph shows a typical engine performance curve relative to its load factor. It can be seen how the highest performance is obtained around 75% load factor while below 25% engine performance plummets.



It is easily apparent from the graphic that the use of motors at a high workload is preferable than the use of large engines operating at low capacity.

The best way to know the load on a motor in an operational setting is to install a network analysis measurement equipment that monitors its operation over a long period of time. This allows you to analyse the periods of time when the engine is subjected to different workloads.

They are shown, as an example, the results obtained from a measurement of an engine, through the use of a net analyser Fluke 434.



Img 4. Slope of network analyzer load

However, network analysers are expensive equipment that requires technical knowledge for connecting and analysing the results, so generally, to be able to know approximately where an engine is running, the engine board data is often used together with measurements that maintenance personnel can perform by means of a simple clamp meter.

The value can get quite close to reality in engines that work without large variations in their workload (or with varying degrees or stable workload "steps" over certain periods of time, which would require measurements for each of those periods).

The calculation of AC motors is obtained based on:

$$P\ abs = \frac{\sqrt{3}\ x\ V\ x\ I\ x\ Cos\Phi}{1.000}$$

$$\eta\ elect. = P_N / P\ abs$$

Being:

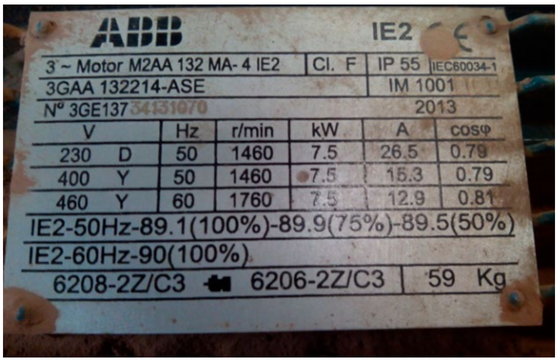
$P\ abs$ = Absorbed power (kW)

V = Supply voltage (V)

I = Intensity (A)

$Cos\varphi$ = Power Factor

PN = Nominal power (kW)



Img 5. Example of an engine plate

It can be seen that the motor nameplate has the necessary data for the calculation, for which it is necessary to keep in mind the network frequency (50 Hz in Europe) and the type of motor connection (Y/D).

EXAMPLE OF CALCULATING ENGINE CONSUMPTION

Calculate the rated performance of two electric motors connected to a 380 V low voltage network that record the following parameters:

Motor 1	PN = 2 HP	Cosϕ = 0,75	I = 3,9 A
Motor 2	PN = 10 HP	Cosϕ = 0,85	I = 15,5 A

	$P\ abs = \frac{\sqrt{3} \times V \times I \times Cos\Phi}{1.000}$	$\eta\ elect. = P_N / P\ abs$
Motor 1	$P\ abs = (\sqrt{3} \times 380 \times 3{,}9 \times 0{,}75) / 1000$ $P\ abs = 1{,}93\ kW$	$\eta\ elect. = (2 \times 0{,}736) / 1{,}93 = 0{,}76$
Motor 2	$P\ abs = (\sqrt{3} \times 380 \times 15{,}5 \times 0{,}85) / 1000$ $P\ abs = 8{,}67\ kW$	$\eta\ elect. = (10 \times 0{,}736) / 8{,}67 = 0{,}76$

Note: HP x 0,736 = kW

EXAMPLE OF CALCULATION FOR CORRECT POWER SELECTION. ENGINE REPLACEMENT

In this case we will carry out the study on a pumping facility in which a 10-kW motor is being used, however the useful power demanded by the pump is only 4 kW. The motor performance for a load factor of 40% is 0.56.

Calculate

1 - Calculation of profitability if we replace the engine with a 5-kW engine that has a yield of 0.75 to a load factor of 80%.

2 - Calculation of the single return period, if the cost of the complete engine change is 1500 euros and the engine operates 20 h/day, 300 days per year and the average electric cost of the kWh is 10 c/kWh.

	Existing motor	Proposed motor
Nominal power	10 kW	5 kW
Useful power	4 kW	4 kW
Load factor	40%	80%
Performance	56%	75%

Annual working hours = 20 x 300 = 6.000 hours
Electric average cost of kWh = 10 c€/kWh

Motor 1	Motor 2
$P\ abs = P_N / \eta\ elect.$ $P\ abs = 4 / 0{,}56$ $P\ abs = 7{,}14\ kW$	$P\ abs = P_N / \eta\ elect.$ $P\ abs = 4 / 0{,}75$ $P\ abs = 5{,}33\ kW$
Consumption = P abs x h/year Consumption = 7,14 kW x 6.000 h = 42.857 kWh	Consumption = P abs x h/year Consumption = 5,33 kW x 6.000 h = 32.000 kWh
Cost = 42.857 kWh x 0,1 €/kWh = 4.286 €	**Cost = 32.000 kWh x 0,1 €/kWh = 3.200 €**

Period of simple return for the investment (PRS)
PRS = Cost / saving
PRS = 1.500 / (4.286 – 3.200)
PRS = 1,38 years

DECISION FACTORS FOR MOTOR REPLACEMENT

When a motor fails, there is often a choice between repair or replacement with new equipment, especially if it is an old and in-efficient engine.

Decision factors to consider when replacing a damaged engine with new equipment are:

- The cost of repair vs the price of a new engine. As a general rule, replacement is recommended when the repair cost of an engine is more than 50% of the cost of new equipment.
- It is generally recommended not to repair engines with power below 40 hp that are more than 15 years old.
- The loss of performance caused by rewinding should be taken into account.

One option to consider is the acquisition of high-efficiency engines. This type of engine has a special design and construction that favours lower losses than standard engines, which is especially interesting when you consider the cost-sharing over the life of an engine.

- Cost of purchase: 1%
- Energy cost: 95%
- Maintenance cost: 3%
- Cost of engineering. and logistics: 1%

The decision to make a greater economic outlay to acquire a better energy efficiency engine should also consider sustainability and environmental factors, as well as the likely future increase in energy supply costs.

It is important to consider that in some cases the motors will be placed in wet and salty environments, which can suppose a shortening of their lifetime. The economic analysis must take into account the mean replacing time of the motors and make sure that is greater than the payback period of the improvement.

Equipment prior to the emergence of IEC 60034-2-1:2007 and 60034-30:2008 standards that harmonized the engine efficiency measurement criterion and resulted in new performance ratings are still installed. To avoid the confusion that, even today, continues to occur with engine efficiency class nomenclatures, the following table is attached showing the equivalence between the old and modern classification (for low voltage motors > 1000 V):

Previous efficiency classes	EFF3	**EFF2**	**EFF1**		
New efficiency classes		**IE1**	**IE2**	IE3	IE4

less efficient → **more efficient**

Improved engine efficiency

It should be noted that since 2021 Regulation (EU) 2019/1781 establishing eco-design requirements for electric motors enters into force. As of July 1, 2021, power engines between 0.75 kW and 1,000 kW must have a minimum level of class IE3 efficiency.

ENERGETIC EFFICIENCY

There are different strategies for energetic efficiency for its application in electric motors. Up next, the most usual are described, and so are their advantages and disadvantages.

USING HIGH-EFFICIENCY ENGINES

As mentioned in the previous section, high-efficiency engines are an attractive option when it comes to replacing existing equipment with breakdown, as their special design and construction favour lower losses compared to standard engines.

Among their main advantages are greater robustness, which means lower maintenance costs and better efficiency, which reduces operating costs.

However, they encounter limitations when operations are required at higher speeds when carrying an increase in load. They also require higher starting currents for their operation.

High-efficiency motors are especially interesting for the following cases:

- Engines between 10-75 hp when > 2,500 h/year
- Engines <10 hp and >75 hp when > 4,500 h/year
- When replacing oversized motors
- When applied in conjunction with inverters

USE OF FREQUENCY DRIVES

The control of the speed of a motor allows us to adapt its operation to the productive needs of each moment thus avoiding working at a higher than necessary speed and the increase in associated energy consumption.

Alternating Current motors are robust but rigid in terms of speed. The best option to be able to control its speed is to act on the power supply frequency. Changing the engine feed frequency controls the speed adapting its working regime to the needs of each moment and avoiding unnecessary energy overconsuming.

Other advantages of using drives are the reduction of reactive energy consumption, vibrations and cavitation's in hydraulic pumps, as well as a smoother start of the engines. All of these factors allow for reduced maintenance costs and increased equipment life. Although the installation of drives requires qualified personnel, their lower cost and the energy savings they provide make it possible for the payback of the in-vestment to be achieved in a few months. Frequency drives find application in different elements such as pumps, fans, compressors, etc.

TRANSMISSION OPTIMIZATION

The transmission elements are responsible for transmitting the torque. Depending on the type of coupling it is recommended that:

- Direct coupling: A correct coupling must be ensured.
- Straps: Use V-bands and preferably toothed.
- Reducers: They should be suitable depending on power and speed ratio.
- Chains: Recommended for high loads.

4. PUMPING AND HYDRAULIC DISTRIBUTION

This section provides tools related to pumping and hydraulic installations, essential on aquaculture farms, so that managers of the same can estimate their current level of efficiency and implement energy saving measures. The contents of this section are based on the methodology developed by the Institute of Water Technology (ITA) of the Polytechnic University of Valencia, with the support of Professor Javier Soriano.

THEORY: PRESSURE AND OPERATING CURVES

A pump is a hydraulic machine that converts mechanical energy (movement) into pressure energy of a fluid, that is, to increase its pressure.

Pressure is the amount of elastic energy stored in a fluid and can be calculated as:

$$P = \frac{Force}{Surface}$$

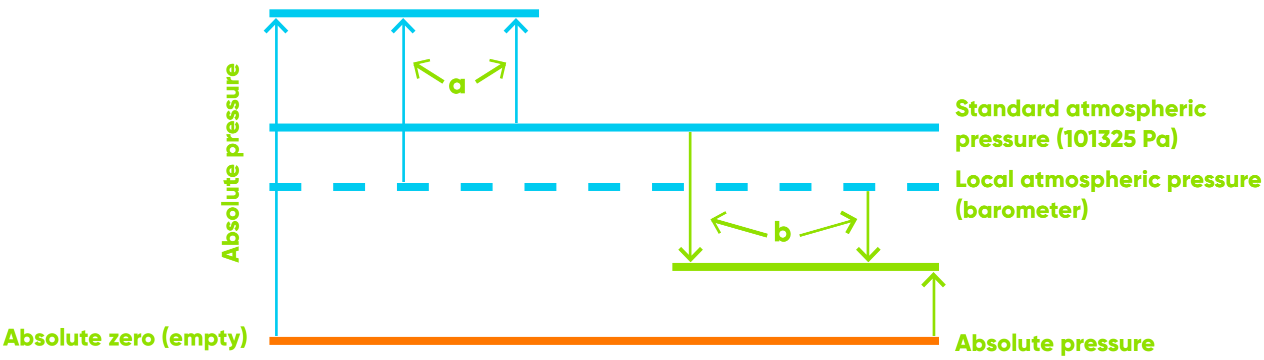
In the International System it is measured in Pascales (Pa), but other units are generally used for handling. The most common are:

- Bar. 1 bar = 100000 Pa
- kp/cm2. 1 kp/cm2 = 0.981 bar = 98100 Pa
- Meters of Water Column (mWC – Equivalent pressure that would exert a certain height of water due to its weight). 1 mWC = 9,806.38 Pa
- Atmosphere (atm – Average atmospheric pressure at sea level). 1 atm = 101,325 Pa = 10.33 mWC

HOW TO INTERPRET THE PRESSURES OF A SYSTEM?

Pressure is measured with devices called pressure gauges. The measured pressure is called manometric pressure. Manometric pressure is the pressure difference between absolute pipe pressure and actual atmospheric pressure (101,325 Pa).

This manometric pressure can be positive (absolute pressure greater than atmospheric pressure) or negative (absolute pressure lower than atmospheric pressure). For this reason, when we talk that the pressure at some point in the system is X Bar, we are talking about its manometric pressure, and consequently, according to this reference the manometric pressure of the atmosphere is 0.



a, b - Manometric pressure

To be able to design these systems correctly it is necessary to explain certain theoretical concepts.

ENERGY BALANCE OF A PIPE

In hydraulic conduction energy is transformed in three ways:

- Kinetic energy: the energy due to the speed of the fluid circulating through the pipe.
- Potential energy: the energy due to gravitational potential, which depends on height relative to the ground.
- Pressure energy: the elastic energy accumulated in the fluid by increasing its pressure.

By the principle of energy conservation, in an ideal case, if there are no external inputs or load losses, the sum of these three energies must be equal at any point in the pipe. This is the theoretical basis of the famous Bernoulli Equation or energy balance of the pipe:

$$Total\ energy = z + \frac{P}{\gamma} + \frac{v^2}{2g}$$

And therefore, in any two points (1 and 2) of the pipe, it is equal:

$$z_1 + \frac{P_1}{\gamma} + \frac{v_1^2}{2g} = z_2 + \frac{P_2}{\gamma} + \frac{v_2^2}{2g}$$

Where:

Z is height in regard to the floor in m

P is pressure in Pa

V is speed in m

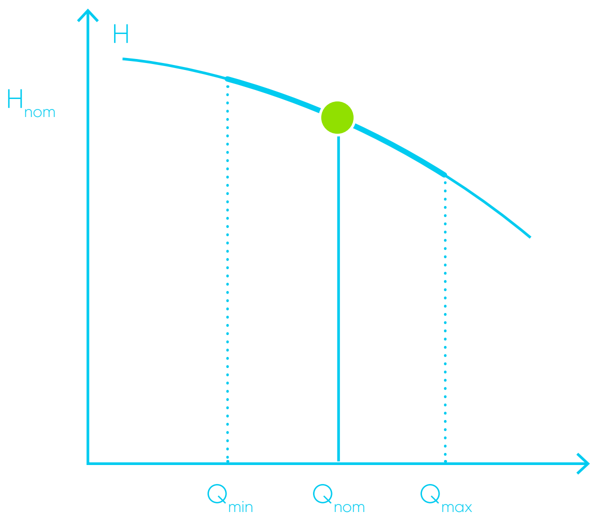
g is acceleration of gravity = 9,81 m/s2

γ is the product of density for g = 1000 kg/ m3 . 9,81 kg/(m.s2)

And the 6 terms of the equation are expressed in meters in the water column (mWC).

CHARACTERISTIC CURVES OF PUMPING:

The operation of the pump is represented by a graph where the working flow rates are located on the X axis and on the Y axis, the pressures. It is very common for pressures to be represented in mWC (water column meters). In this way, a typical curve of a pump looks like this:



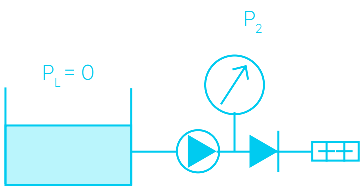
As it can be observed, it is an inverted parabola, where the more given flow, the less height (pressure) it is capable of providing.

The characteristic curve of operation is generally represented with the expression:

$$H_p = A + BQ + CQ^2$$

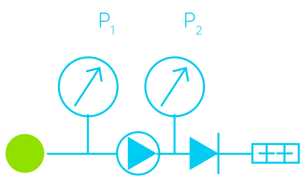
The height or pressure that the pump provides is represented by Hp, and it is the difference of pleasure between its exit and entrance, depends on the connection type (INDIRECT or DIRECT CONNECTION).

Indirect aspiration



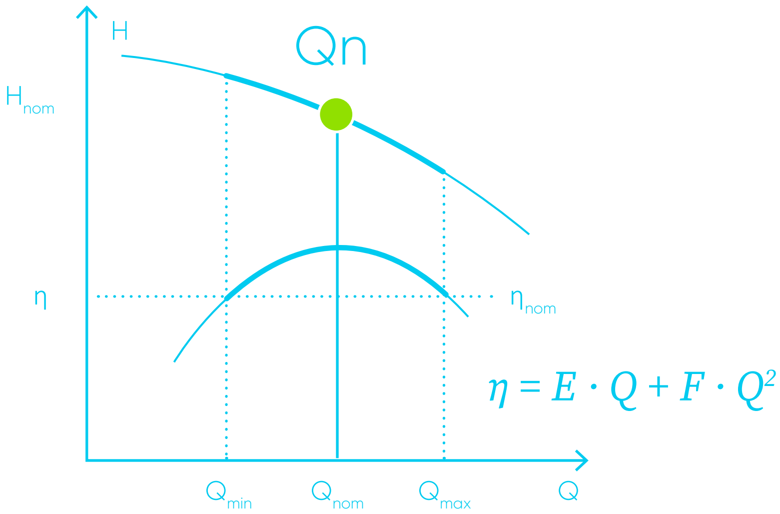
$$\longrightarrow \quad H_p = \frac{P_2}{\gamma} - \frac{P_1}{\gamma} = \frac{P_2}{\gamma}$$

Direct aspiration



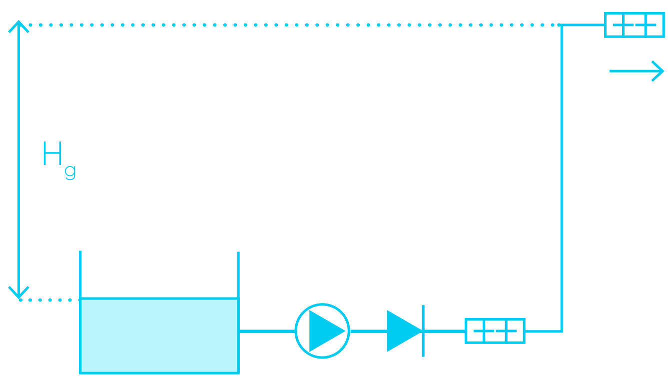
$$\longrightarrow \quad H_p = \frac{P_2}{\gamma} - \frac{P_1}{\gamma}$$

On the other hand, the PERFORMANCE CURVE shows the relation between the flow and the performance for each point of operation. Of the entire curve, the useful area is defined as the one in which we want it to work (with acceptable values). The following image shows curves of performance and flow together.



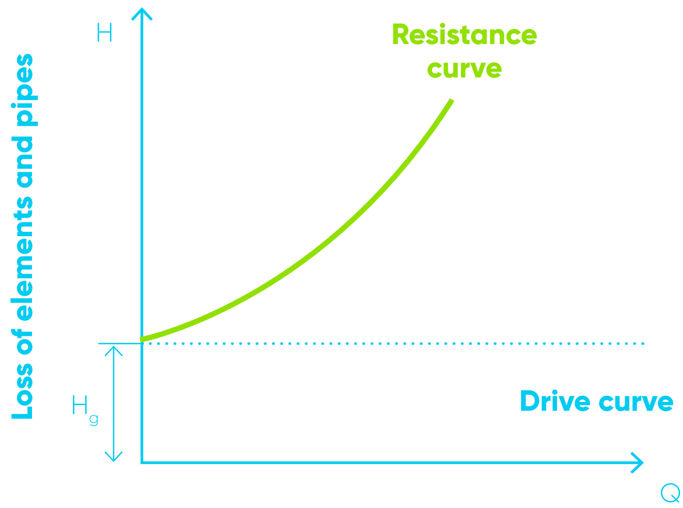
The curve of performance has likewise an inverse parabolic form and it is represented generally with the expression.

$$\eta = E \cdot Q + F \cdot Q^2$$



The resistance curve represents the conditions of operation imposed by the installation. It takes into account both the pumping slope (Hg) and the load losses (in pipes and elements).

The resistance curves present the following appearance, generally:



In general terms, the resistance curves are represented with the expression:

$$h_r = H_g + K \cdot Q^2$$

Where:

K Loss coefficient in pipes + elements (valves, elbows)

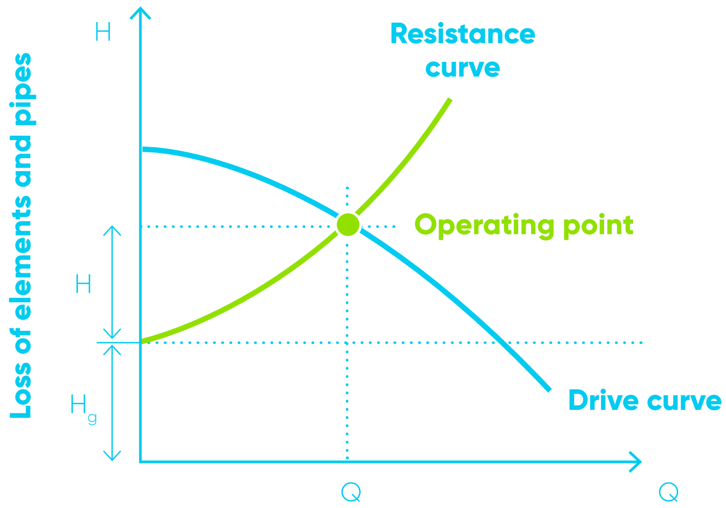
h_r Total resistence pressure

H_g Height difference between pump and point of use

Q^2 Flow

Consequently, the pressure that a pump must apply to move water between 2 points is the sum of the pressure required to overcome any height change due to slopes in the pipework and the hydraulic losses (i.e., resistances) in the circuit.

The point of operation represents specific conditions of the pump functioning, where it provides a determined flow and the correspondent pressure. It is the intersection be-tween the pump slope and the resistant curve of the installation.



The slope of the green curve will be bigger as the losses increase in the installation. On the other hand, the slope will be lower (flatter) when the losses decrease.

POWER CONSUMED BY A PUMP:

As previously explained, the pump is a device that converts mechanic energy (motion) in pressure energy. Generally, that mechanic energy stems from an electric motor that converts electrical energy to motion.

Taking this into account, the power consumed by a pump can be expressed:

$$P\ (kW) = \frac{9{,}81 \cdot Q(m^3/s) \cdot H\ (mca)}{\eta_{engine} \cdot \eta_{pump}}$$

Where:

Q Flow driven by the pump in m3/s

H Pressure provided by the pump in mWc

η_{engine} Efficiency of electric engine (see Operational analysis)

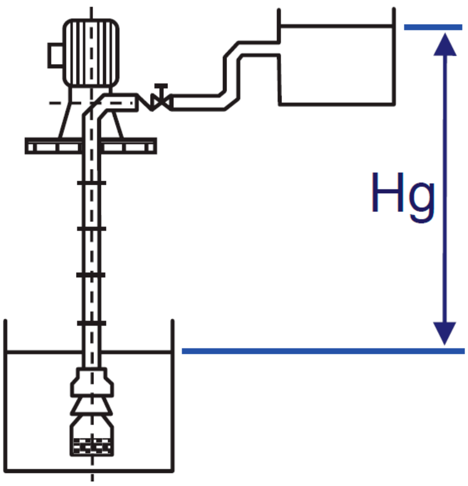
η_{pump} Efficiency of the pump (data from the manufacturer)

SELECTION OF THE OPTIMAL PUMPING SYSTEM

In order to choose the appropriate pump (or pumps) for a particular application first step is to know the needs of pumping, which means, determining the flow and the pressure that the installation requires.

In order to determine the pressure, it is necessary to estimate the hydraulic loss of the installation elements. If this calculation is precise, it will be possible to carry out the proper selection of the pump. On the other hand, if we draw on estimations, we will have to oversize the system in order not to have any trouble with the supply.

Obtaining the losses analytically can be a difficult task. The recommended approach is to estimate them based on an average value of unit losses per pipe km. The usual value is 10 wcm of losses for 1 pipe km



The necessary power of a pump will be:

- If losses are known

$$H_p = H_g + P_{req} + h_{losses}$$

- If losses are not known

$$H_p = [H_g + P_{req}] + 10x \text{ pipes length}$$

Where:

Hp is the pressure of the pump (in wcm)

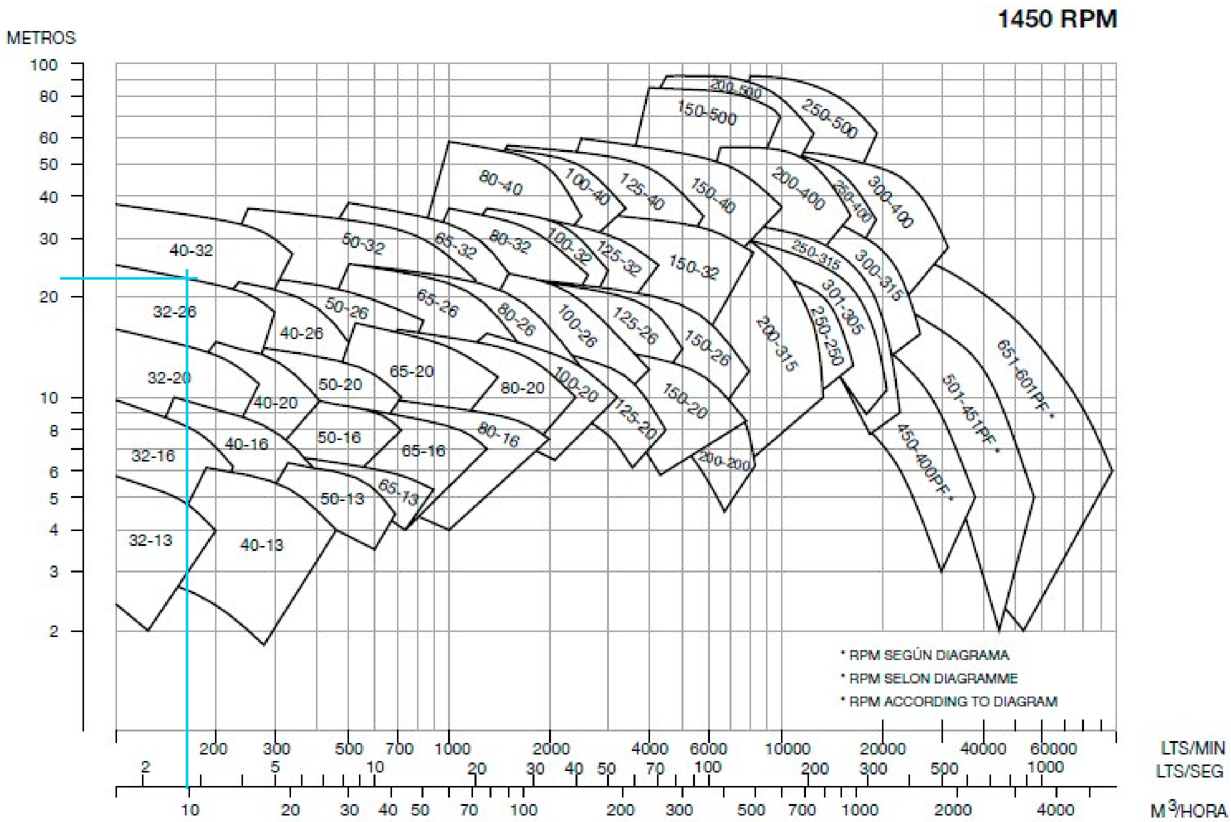
Hg is the height gain in the system

$Preq$ is the required pressure in the use point

Once pressure and pumping flow are calculated, the pump can be selected.

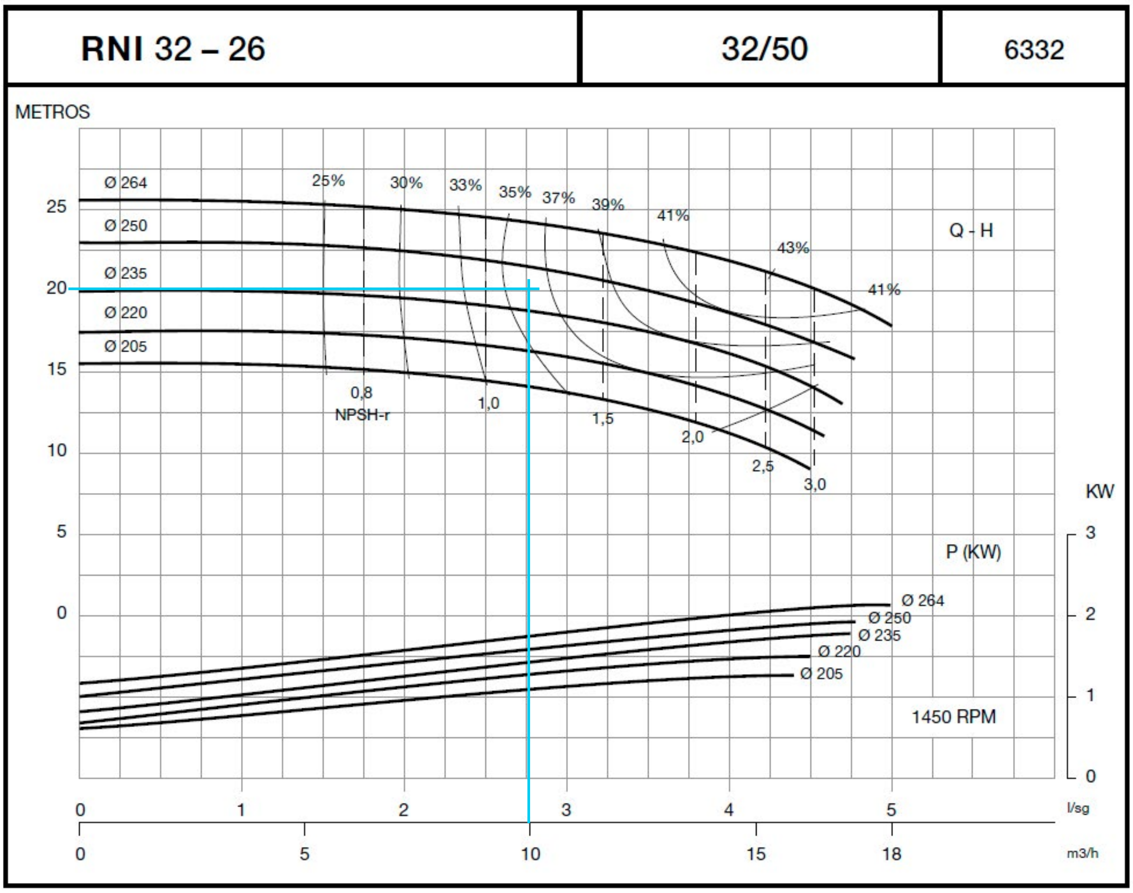
In order to do so, the manufacturers include in their catalogue the Work's Range (or Works field) for every series of pumps.

For example, for conditions Hp = 20wcm & Q = 10 m3/h.



As a result, we have the working field 32-26 for 1450 rpm.

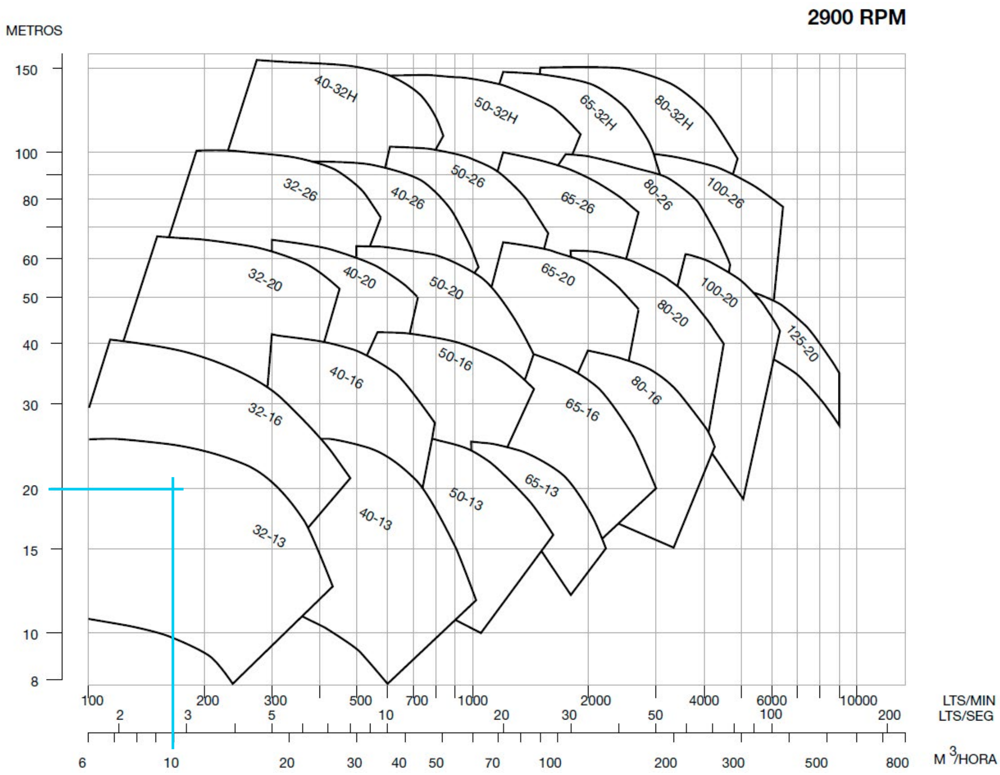
After this, it is necessary to consult the family of pumps that are within this field of work. In this case it is as follows:



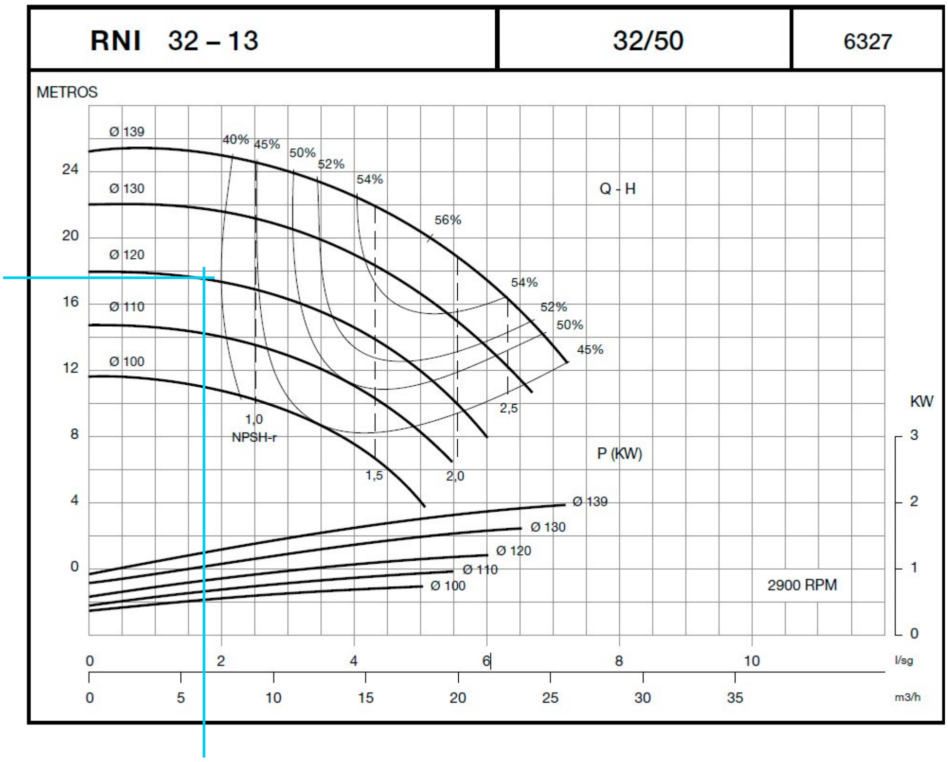
With this choice of working field, we should choose the 250-diameter pump, since with the 235 we would not have enough pressure. With the 250, as you can see in the blue line, for a flow rate of 10 m3/h we will have a somewhat higher pressure, 22 wcm, and a efficiency of only 36%, which is very low. Pumps can work at optimum points of between 40 and 60% of efficiency.

Therefore we can choose this pump or we can consult other pumps or other manufacturers.

Testing with these criteria in other fields of work of the same manufacturer we obtain:



Obtaining the Working Range 32-13.



For the latter selection we must go to the diameter 130, with which we have an operating point of 10 m3/h and 21 mca, with a performance of 47.5% (10 points above the previous one).

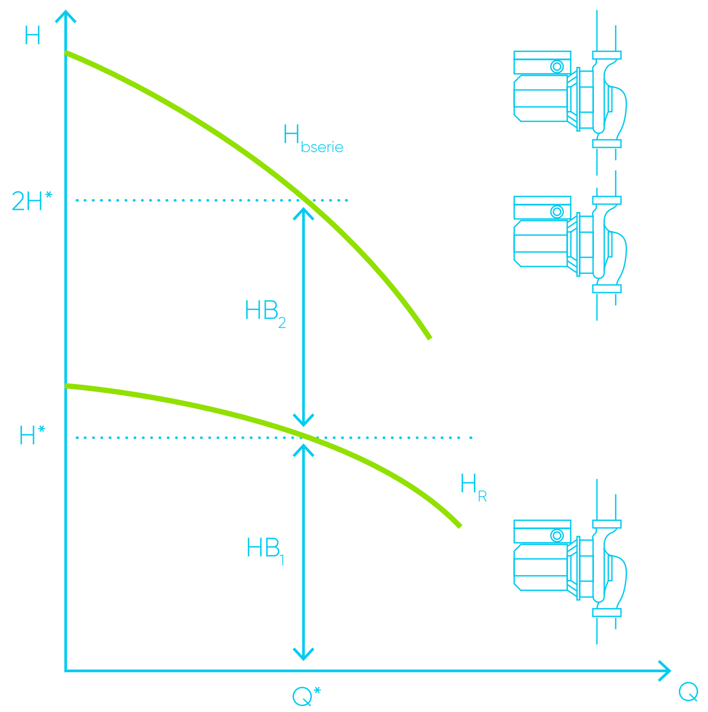
SERIES-PARALLEL PUMP ASSOCIATION

Several pumps can be connected to achieve different operating curves and therefore resulting curves that provide a higher pressure or higher flow rate. This association can be in series or in parallel.

In the case of serial association, the output of the first pump is connected to the inlet of the second pump. This combination allows for higher pressures at the same flow rate. The serial partnership complies with:

- Total pressure (Total head) = H1 + H2
- Total flow rate = Q1 = Q2

To obtain the operating curve of the pump association, the pump heights must be added for each flow rate:



The analytic expressions for the case of obtaining n identical pumps series are:

$$H_p = n\,(A + BQ + CQ^2)$$

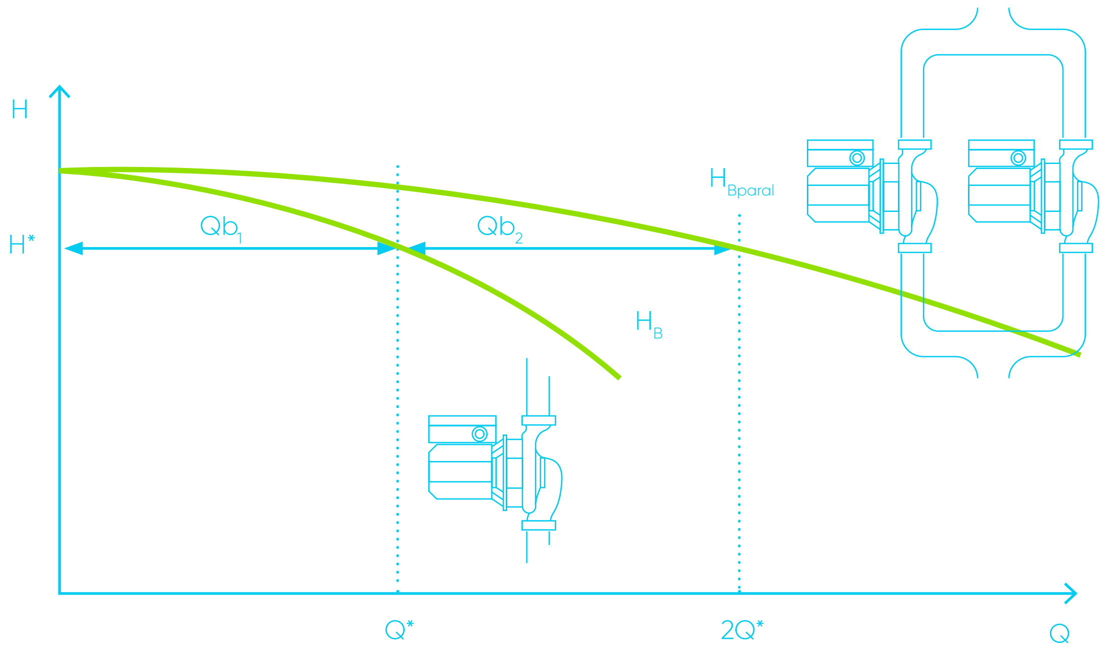
$$\eta = E \cdot Q + F \cdot Q^2$$

In parallel association, pump suction is connected in the same manifold, just like drive connections. This solution achieves higher flow rates while maintaining the height of each pump constantly. The parallel association complies with:

- Total pressure (Total height) = H1 = H2
- Total flow rate = Q1 + Q2

This is a very common association in facilities. The pumps are placed in parallel on the same bench, sharing suction and drive. This configuration allows the pump to start and stop depending on the needs of the installation.

To obtain the operating curve of the pump association, the pump flow rates must be added for each height:



The analytic expressions for the case of obtaining n identical pumps inn parallel are:

$$H_p = A + B\left(\frac{Q}{n}\right) + C\left(\frac{Q}{n}\right)^2$$

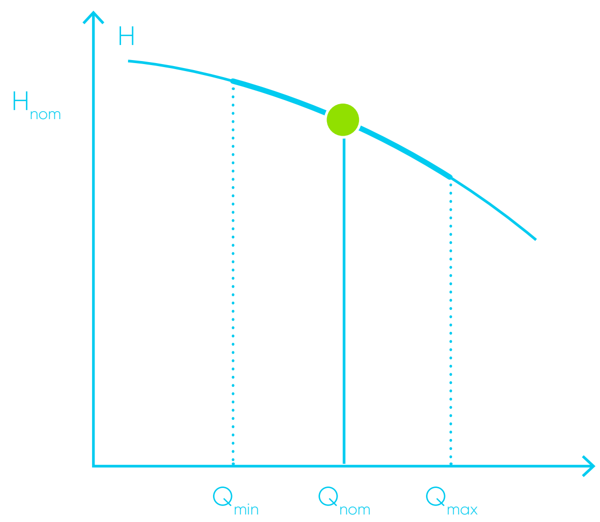
$$\eta = E\left(\frac{Q}{n}\right) + F\left(\frac{Q}{n}\right)^2$$

SIMILARITY LAWS

Similarity laws are mathematical instruments used to characterize the characteristic curves of pumps in situations such as changing their speed with a frequency inverter or changing the diameter of the impeller (or impeller) of the pump. In this way, it is possible to predict the behaviour of these 'altered pumps' knowing their operation at normal speed.

Variation in turning speed

Depending on their turning speed, the pumps can be fixed speed or variable speed. Fixed speed pumps either rotate at 100% of their rated speed or are stopped. Therefore, the operating points of the installation are always located on the nominal curve of the pump.



Variable speed pumps are equipped with a frequency inverter (see Energy efficiency section), which allows to modify the rotation speed of the pump, modifying the characteristics of the electric wave that reaches the motor of the pump.

For operation, a set point pressure is set on the equipment and, with the reference pressure from a pressure sensor, the pump's turning speed is corrected (if the reference pressure is lower, the pump increases its speed). The pump will vary its turning speed adapting the pressure to its output and the driven flow rate.

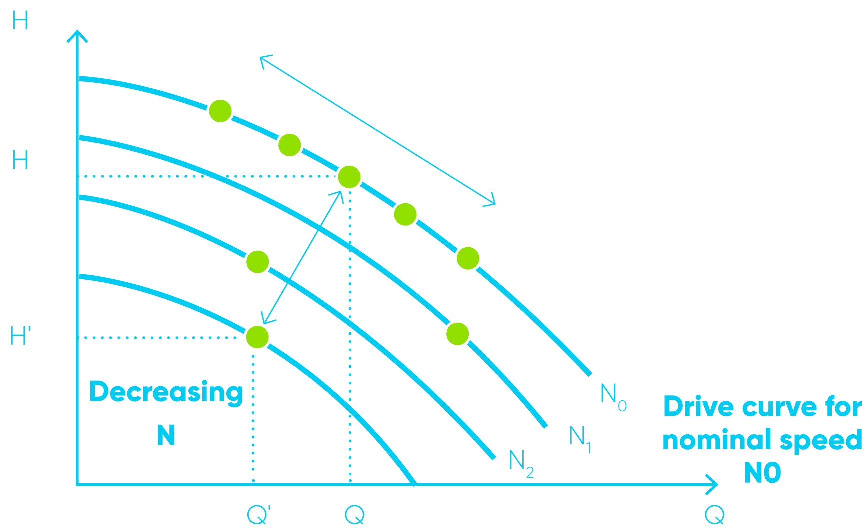
The nominal turning speed of a pump is given by the characteristics of the associated engine. This is calculated using the expression:

$$N_s\,(rpm) = \frac{60 \cdot f}{p}$$

Where f is the frequency of the electricity supply (usually 50 Hz) and p is the number of pairs of motor poles. The usual speeds are 2,900 rpm and 1,450 rpm.

This nominal turning speed is called N0.

The inverter allows you to go from having a single characteristic curve to having a curve for each turning speeddown to a minimum:



The final result is that, for example, at lower flow demand it is no longer necessary to supply such a high-pressure value, but that the required flow rate can be reached with a lower pressure input, and therefore energy.

The parameter commonly used to designate the modification of the turning speed is α, α=N'/N0, N' being the speed pursued and N0 being the nominal speed of the pump.

The corresponding Similarity Laws for pumps using frequency inverter are:

$$H_p = A\alpha^2 + B\alpha Q + CQ^2$$

$$\eta = \frac{E}{\alpha} Q + \frac{F}{\alpha^2} Q^2$$

Impeller trimming

Impeller trimming is a reduction of the outer diameter of the impeller by machining it, keeping the pump the same body. Generally, this machining is carried out directly by the manufacturer for economic reasons of production the reduction results in a de-crease in pump capacity (in height and flow), thus reducing the drive curve.

In this case the parameter to designate the clipping is λ, with λ=r2'/r2 being r2 the original radius and r2' being the trimmed radius. The reduction is usually limited to $\lambda < 12\%$.

The corresponding Similarity Laws for pumps using impeller trimming are:

$$H_p = A\lambda^2 + BQ + \frac{F}{\lambda^2} Q^2$$

$$\eta = \frac{E}{\lambda^2} Q + \frac{F}{\lambda^2} Q^2$$

LEAKS IN HYDRAULIC NETWORKS

In this section we offer an overview of water losses in hydraulic networks, in order to understand their origin and the basic strategies in order to minimize their impacts. The content of this paragraph is based in the article AN APPROACH TO THE TROUBLE ON WATER LEAKS IN URBAN NETWORKS (Marcet).

Leaks are a loss of a determined volume of water through nonintentional openings, between the supply point and the demand point. The losses depend on the state of the network, the pressure and the average time elapse from the moment the leak starts until it is repaired. For this reason, the strategies aimed to improve the state of the networks point in three directions.

Larger leaks, due to large defects, are easily detectable while low flow leaks are more complex to locate. It is very common for small leaks to involve a higher volume of leaked water than large ones, because they are difficult to detect and last for much longer periods than larger leaks. There are numerous studies on the approximate lev-el of leakage based on network age and maintenance, but there is nothing as reliable as installing distributed meters on the network and monitoring consumption. Clearly, when higher than expected flow rates are recorded at times where the expected flow rate is well known, the increase is due to leakage.

A good exercise in detecting them is to see how consumption evolves when all water demand points are closed. If there is no demand, but consumption is recorded, this consumption is because of leaks. Similarly, if a pipe is pressurized, and the demand points are closed (consumption 0), if the pressure of the pipe decreases, it is also be-cause of leaks.

STRATEGIES TO FOLLOW TO REDUCE LEAKS

As mentioned above, the main strategies for minimizing leaks are pressure control, decreased leakage time, and trying to prevent further leakage.

Pressure control

Pressure control is especially important when elastic pipes are available, where higher pressure means that the surface area of leaks is increased, to a greater or lesser extent, depending on the elasticity of the pipe.

Excessive pressures should be avoided through a correct design of the network and pumping station, but it is also important to correctly manage sudden variations in pressure, which over time contribute to increased leakage especially in joints.

Active leak control and quick replenishment

Active leak control tries to establish strategies to detect leaks and repair defects in the shortest possible time. As explained above, it is small, low-flow leaks, which are difficult to detect, that involve a higher volume of leaky water. Many times, these small leaks do not communicate, causing repair times to increase considerably.

Leak control can be performed visually, with acoustic sensors or by installing flow meters distributed through the network. It is the latter option that offers the best result for detection. After detection there should be a clear procedure of action, determining who to warn, how to proceed and who is responsible for repairing the defect.

Infrastructure management

Finally, one of the essential actions to improve the level of network leaks is the re-placement or rehabilitation of pipes. It is very common to have a network with old pipes and whose design is no longer correct for the current application.

The economic aspect has a substantial importance in this infrastructure management, due to the fact that it exists a compromise between the losses of the network and its renovation. This is commonly known as the "economic level leaks". Approaching its calculation exceeds the scope of this guideline, but it is essential to understand the concept.

5. HEATING AND REFRIGERATION SYSTEMS

THEORY OF AIR CONDITIONING SYSTEMS

Conditioning consists of creating for a closed space the temperature conditions, relative humidity, air quality, and sometimes, also pressure, necessary for the wellbeing of people and/or the process' quality.

The thermal load, or the quantity of energy for time unit, of a room is due to thermal outdoor conditions change with annual seasons altogether with:

- The situation of the space and its enclosures (orientation, glazed facades, degree of thermal insulation...)
- Occupancy schedule
- On-site activity
- Existing facilities on-site

Determining the correct air conditioning for a premise must take into account its thermal load. For example, a premise with a high number of people or that has numerous electronic equipment emitting heat, will have a higher thermal load.

Coefficient of performance (COP): is the relationship between the useful energy (heat supplied by the Heat Pump) and the electrical energy consumed (the energy used to run the compressor). The global COP of the Heat Pump takes into account auxiliary energies and integrates energy consumption loses.

COP - Heat power generated / Absorbed electric power

Energy Efficiency Ratio (EER): Represents the energy performance of the heat pump when it is cooling mode. It measures the relation between the electric consumption (power) needed in order to produce cold, and the cold power generated.

EER = Cold power generated / Absorbed electric power
Absorbed electric power = Pm + Pcont

Where:

Pm = the power absorbed by the compressor or compressor motor.

Pcont = the power absorbed by the control and safety devices.

The thermal conditions of the environment depend on a number of factors:

- Factors that depend on the environment

- Temperature (dry and wet bulb)
- Average air speed
- Average radiant temperature

- Factors that depend on the human body

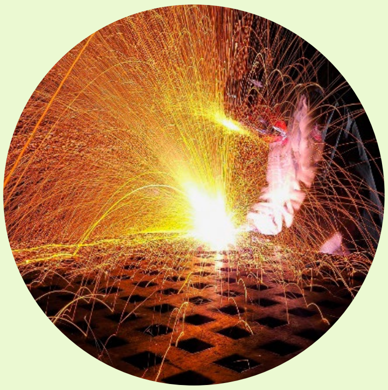
- Metabolism
- Skin temperature
- Skin moisture
- Sweat

- Factors that depend on clothing

- Heat pass resistance
- Resistance to water vapour passage
- Surface increase facto
- Surface emissivity
- Surface temperature

Variation of the thermal load depending on the activity

We have seen the importance that they have over the thermal load of a premises and in its occupation schedule as well as the activity carried out. This is explained by the functioning of the equipment that produce heat (computers, lightning...) and to the heat that people release depending on the activity they perform. This metabolic energy is measured in met.



Some typical values are:

Activity: Lying at rest	0,8 met
Activity: Sitting at rest	1 met
Light sitting activity	1,2 met
Light standing activity (shopping, light industry)	1,6 met
Average standing activity (household chores, machinery)	2 met
Activity: Walking flat at 5 km/h	3,4 met

1 met equals 58,15 W/m^2

AIR CONDITIONING SYSTEMS

Air conditioning systems are applied to achieve determined contains of temperature and humidity in premises and processes. In order to do so, it is necessary, on one side, to arrange equipment that generate cold and warmth, and on the other side, to arrange equipment that deliver heat or cooling to where they are needed.

These two types of equipment are known as outdoor and indoor units. The outdoor units generally use a compressor to carry out the refrigeration/heating cycle, and are the ones that produce cold and warmth. The coolant performs a closed circuit throughout the operating cycle of the equipment in which it is compressed, condensed, expanded and evaporated. Cooling occurs thanks to the physical principle by which a fluid absorbs heat from the medium during an evaporation process. The use of refrigerants is due to the large capacity of these compounds to yield or absorb heat during their state change.

There are several types of outdoor units, which use several different thermal fluids. Depending on the case, the thermal fluid is reached from the outdoor units to the interiors, in different ways. These fluids can be air, water or directly refrigerant.

In the case of air, the indoor unit is nothing more than a diffuser of this air at the correct temperature. In the case of water and refrigerant, a heat exchanger should be available, which moves the heat/cold into the air of the corresponding room.

The choice of these systems also has to consider air quality and health criteria, although this aspect is not covered in this guide.

Some of the most interesting conditioning systems are described in the following lines:

Chillers/Heat Pumps

Water or water chiller cooling systems (in heat pump mode can also heat water) are often used for large surface air conditioning while also simultaneously providing sanitary hot water. It is said that when the machine can reverse the cycle is a heat pump, while if it only produces cold it is a cooler.

These units produce hot/cold water that is distributed to the indoor units.

The interior units most commonly used with such equipment are called fan coils.

A fan coil equipment is a water-to-air air conditioning system whose operation is based on the temperature of the water circulating through ducts inside and through which a fan-driven air current is circulated. The water that reaches the fan coil can be cold if it comes from a cooler or hot. As it enters the equipment, the air cools or heats up to contact with the water conductions. The air then passes through a filter and is then expelled to the premises that intends to be air-conditioned.

We can find two types of facilities with fan coil:

Two tubes: They consist of a one-way conduction and a return conduction. In this type of system, the room will be heated or cooled depending on the temperature that reaches the equipment and that will come from a chiller or boiler depending on the time of year.

Four tubes: The equipment has two independent round-trip circuits so it can produce cold and heat simultaneously for different areas, allowing greater control and comfort.

Direct expansion systems

These equipment have a direct exchange between the air to be conditioned and the refrigerant, without using water as a heating fluid. From the outdoor unit the coolant comes out at the desired temperature and is transferred to the indoor units (evaporators or condensers). The equipment can produce cold only or cold and heat. A very interesting case in this family of equipment are VRVs, Variable Coolant Volume equipment.

VRV (variable coolant volume) systems act on the coolant flow sent to the indoor units, so allow for more precise temperature control and significant energy savings.

Evaporative cooling

It is also a system based on the cooling produced during an evaporation process, us-ing water as a refrigerant. Both evaporative condensers and cooling towers base their operation on this principle, in which a small amount of water evaporates, "stealing" heat from the air and thus getting it cooled. An airflow maximizes time and contact surface with circulating water to promote heat exchange.

APPLICATIONS OF AIR CONDITIONING SYSTEMS IN THE AQUACULTURE SECTOR

Water temperature control is the main application of air conditioning systems in the aquaculture sector, considering that it is one of the main variables for maintaining the optimal range of water quality.

Maintaining the physical, chemical and biological variables of water within the appropriate margins for each species contributes to higher productive performance and improved growth rates by reducing their stress levels and thus the metabolic energy consumption of fish derived from adaptation processes.

In addition to the direct impact of water temperature on fish, the ratio of temperature variations to other parameters such as the presence of ammonia or the availability of oxygen in water should also be considered.

The air conditioning of the rooms in which the tanks are located is also relevant because of the direct influence of the ambient temperature on the water in which the animals are located in different conditions such as:

- Maintenance of water temperature conditions in tanks.
  The exchange of heat between the water of the tanks and the air of the room that houses them is a process closely related to the total area of exchange and the temperature difference between the water and the environment of the premises.
- Evaporation of water from tanks.
  Evaporation is a process that occurs at any temperature, although it increases in relation to it. It has an influence on water consumption and on the maintenance of water quality variables.
- Temperature stratification inside water tanks.
  When temperature variations occur on the surface of the same, due to the processes of thermal exchange with the environment.

CALCULATION OF ENERGY LOSSES IN HEATED WATER TANKS

As mentioned, there is a loss of energy that has been used to obtain the right water temperature conditions. These losses increase depending on the larger exchange area and water temperature of the tanks.

Energy losses in heated water tanks installed inside premises are mainly due to:

- Evaporation losses, which account for between 70% and 80% of total losses.
- Radiation losses, representing between 15% and 20% losses.
- Hydraulic losses are considered negligible.

The calculation of these energy losses can be carried out as follows (IDAE, 2009):

$$P = (130 - 3 \; x \; tws + 0{,}2 \; x \; tws^2) \; x \left({}^{Sw}\!/_{1000} \right)$$

Being:

P = Power Losses (kW)

Tws = Water Temperature (ºC)

Sw = Tank Surface (m2)

Thus, for example, a tank with a water surface of 12 m2 at a temperature of 24 0C has approximate energy losses of:

$$P = (130 - 3 \, x \, 24 + 0{,}2 \, x \, 24^2) \;\; x \left({}^{12}\!/_{1000} \right)$$

$$P = 2{,}08 \; kW$$

Annual energy consumption, taking into account that these conditions are maintained 24 hours a day during all days of the year will therefore be:

$$P = 2{,}08 \; x \; 24 \; x \; 365$$

$$P = 18.206{,}78 \; kWh$$

For tanks or rafts that are installed outdoors, it should be noted that energy losses are due to a considerable number of factors:

- Radiation from water to the atmosphere
- Evaporation of water
- Convection due to wind
- Driving through the tank walls
- By splashing water

An approximate calculation of energy losses in such installations can be made by means of the following expression (IDAE, 2009):

$$P = \frac{(28 + 20 + V) \; x \; (tws - tbs) \; x \; Sw}{1000}$$

Being:

P = Power Losses (kW)

tws = Water Temperature (ºC)

tbs = Air Temperature (ºC)

V- = Wind Speed (m/s)

Sw = Tank Surface (m2)

ENERGY EFFICIENCY IN AIR CONDITIONING SYSTEMS

Some of the usual measures used in air conditioning systems are discussed below to improve energy efficiency:

INSTALLATION OF EXTRACTION AIR HEAT RECOVERY SYSTEMS

Ventilation of the premises involves the extraction of air from them and the air renewal from the outside, which means a loss of heat when evacuating tempered air and additional energy consumption to maintain the comfort conditions despite the continuous supply of cold air from the outside.

Heat recovery systems from the extraction air are air-to-air exchanger equipment that extracts some of the heat contained in the air before its drive and uses it to preheat air that arrives from the outside. The heat exchange process is carried out in such a way that there is no contact between the inlet and outlet airflows.

REGULATION OF THE FLOW RATE (AIR OR WATER) TO BE BOOSTED, BY MEANS OF FREQUENCY INVERTERS.

As seen in the motors section, the frequency inverters allow us to carry out a control of the speed of pumps and fans, allowing to adapt their working regimen to the needs of each moment and avoiding an unnecessary energy use.

SET DIFFERENT SETPOINT TEMPERATURES FOR UNUSED AREAS (OR NOT AIR-CONDITIONED).

The possibility of establishing different temperature setpoints according to the needs and thermal loads of each room is a significant energy saving.

Each additional temperature grade in air conditioning can account for up to 8% more energy consumption.

ACQUISITION OF EQUIPMENT WITH A GOOD COP AND EER

Air conditioning equipment often has a high impact on energy consumption, so good performance means significant savings. It should be noted, however, that these are systems that require significant investment and depreciation periods are often high, so the degree of efficiency should only be seen as another decision-making factor when considering the replacement of obsolete equipment.

The following example shows the calculation required for an estimate of savings for improving the performance of air conditioning equipment:

There is 1 air conditioning equipment of 5.5 kW of cold power and 5.9 kW of heat power that works an average of 8 hours a day, every day of the week. This equipment is used in summer for about 20 weeks and in winter for another 20 weeks. Its COP is 3.15 and its EER is 2.86.

Calculate savings from the replacement of the previous air conditioning equipment, with other equipment of the same characteristics and with the same usage regime, but with a COP value of 5.8 and an EER value of 6.1.

Calculation of the consumption of current air conditioning equipment.

Energy consumption. Use in summer:
8 hours x 7 days a week x 20 weeks a year = 1,120 hours per year for cold production

$$Qs = t \ x \left(Pc / EER \right)$$

Qs = t x [Pc/EER]

Qs = 1120 x (5.5 / 2.86)

Qs = 2,153.8 kWh

Being:

Qs = Energy consumption in summer (cold production) in kWh

t = Annual hours of operation of equipment in cold production

Pc = Cold power

EER = Energy efficiency coefficient in refrigeration

Energy consumption. Use in winter:
8 hours x 7 days per week x 20 weeks a year = 1,120 hours per year for heat production

Qw x 1120 x (5.9 / 3.15) Qw x 2,097.7 kWh

$$Qw = t \ x \left({}^{Ph}\!/_{COP} \right)$$

Qw = 1120 x (5,9 / 3,15)

Qw = 2.097,7 kWh

Being:

Qw = Energy consumption in winter (heat production) in kWh

t = Annual hours of operation of the equipment in heat production

Ph = Heat power

COP = Coeficient of Perfomance

The total annual energy consumption of the equipment currently installed will therefore be:

Q annual = Qs + Qw = 2.153,8 + 2.097,7 = 4.251,5 kWh

Calculation of the consumption of the proposed air conditioning equipment.
For the proposed example all parameters remain unchanged (including equipment power) improving only COP and EER energy efficiency coefficients.

The same calculation is therefore performed, varying only the values mentioned:

Estimated energy consumption in summer	Estimated energy consumption in winter
Qs = 1120 x (5,5 / 6,1)	Qw = 1120 x (5,9 / 5,8)
Qs = 1.009,8 kWh	Qw = 1.139,3 kWh

Estimated total annual energy consumption of the new:
Q annually = 1.009,8 + 1.139,3 = 2.149 kWh

The annual energy savings obtained from the improvement of the energy coefficients of the air conditioning equipment are therefore 4,251.5 – 2,149 x 2.102,5 kWh which equate to about 49% of the total annual consumption.

It should be noted that the calculation considers consumption at a maximum workload of the air conditioning equipment, throughout the operating time. Depending on the environmental conditions and existing thermal loads, the application of some reduction factor to the result of energy consumption calculations could be considered.

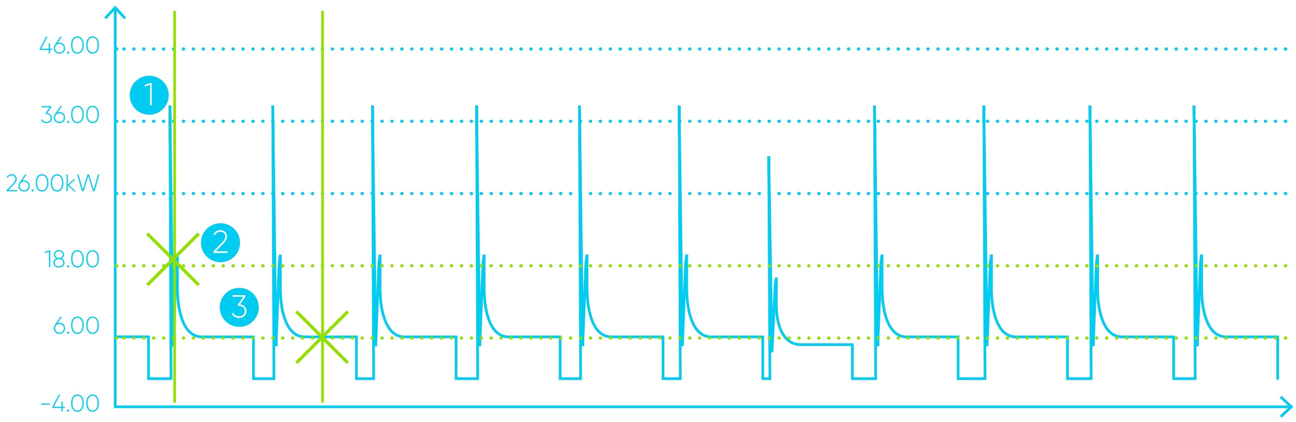
6. COMPRESSED AIR

THEORY: BASIC CONCEPTS

The function of compressed air systems is to provide a certain airflow at a pressure higher than atmospheric pressure, in order to obtain mechanical work. The main parts of a compressed air installation are:

- Compressor: It is the main element of the installation. Increases air pressure mechanically by compression.
- Air storage tank: Allows the storage of pneumatic energy for later use.
- Cooler: Reduces the temperature gained by air during the compression process, thus avoiding the subsequent presence of condensations.
- Dehumidifier: Reduces the presence of moisture in the compressed air supply.
- Distribution facilities: A set of pipes and elements that allow compressed air to reach consumer equipment.

A typical compressor consumption profile can be seen in the image below during a normal operating period:



Source: SGS

The graphic corresponds to a measurement made by means of a network analyser to a compressor of 15 kW of nominal power lacking variable speed system, during a normal period of installations. It is easy to see for each work cycle the start-up of the equipment (1) at which the main peaks in electrical demand are reached, as well as the loading periods (2) where the air compression and discharge work (3) in which the compressor motor is in operation without air production.

Between working periods, the compressor stops its operation which is an advantage at the level of energy consumption if the work cycles are sufficiently separated over time. Otherwise, this working configuration forces constant compressor starts resulting in continuous spikes in energy demand and a decrease in equipment life. For this case it would be advisable to install a frequency inverter.

ENERGY EFFICIENCY IN COMPRESSED AIR SYSTEMS

Compressed air production and distribution systems are often significant energy consumers while facing problems that significantly reduce their level of efficiency. Some of the most common strategies for improving energy efficiency in these equipment are explained below.

INSTALLING COMPRESSOR FREQUENCY AND POWER SCALING DRIVES

As seen in the corresponding section, the most efficient method for controlling the speed of an electric motor is by means of an electronic power inverter.

The installation of a frequency inverter in the compressors allows to minimize the periods of operation in discharge, which do not produce useful work, obtaining energy savings of up to 30%

depending on the operating regime of the compressor. Installing frequency drives is an energy-saving measure with a depreciable investment in a few months. The use of a power inverter also reduces the number of compressors starts, helping to extend its service life.

If high compressed air consumption is necessary, several compressors are ideal, so that the power required for air production is split between several equipment and its operation is controlled by an automatic management system. In this way the compressors work optimally and only those necessary to meet the air demand at all times are in operation.

In this working configuration, one of the compressors usually has a frequency inverter resulting in the desired degree of variability in air production between the different power steps configured.

HEAT RECOVERY

Air compressors are inefficient operating equipment. Of the total energy absorbed by the compressor, only 5% is associated with compressed air production, with the remaining 95% being lost in the form of heat.

This heat stored in the fluid (air or water) used for compressor cooling can be directly exploited through pipelines that conduct the hot air generated by the compressor or indirectly by exchange for the production of hot water, which can be used as sanitary hot water, for office or ship heating or for use in processes that may require it.

The main problem with this savings measure is that the usable heat temperature is not too high, which limits its use and the profitability of the actions implemented.

REMOVING LEAKS IN THE FACILITY

The elimination of existing leaks in the compressed air installation results in a decrease in the operating periods of the equipment used in the production of compressed air and, therefore, a reduction in the electricity consumption associated with this supply.

Leaks in compressed air installations are very common and almost impossible to eradicate in their entirety. In low-maintenance installations it is common to detect that up to 25% or 30% of compressor energy consumption is due to leakage.

Compressed air leaks in a facility can be found both in the distribution networks and in the equipment to which it feeds this supply, so the location and repair of them, has varying degrees of difficulty and need for resources to be used.

The installations should be subject to regular reviews and maintenance operations, in such a way as to avoid or minimize as far as possible, the appearance of new leaks resulting from the inevitable wear and tear caused by the passage of time and the intensity of use of the facilities.

INSTALLING THE COMPRESSOR AIR INTAKE IN COLD AREAS

An increase in air temperature means a reduction in its density so, if the suction air of the compressors is at high temperatures, it increases the energy consumption for the same flow rate and discharge pressure.

It is considered that every 3°C of decrease in the temperature of the aspirated air implies 1% more compressed air for the same energy consumption, so it is highly recommended that compressors vacuum air from the outside at the lowest possible temperature.

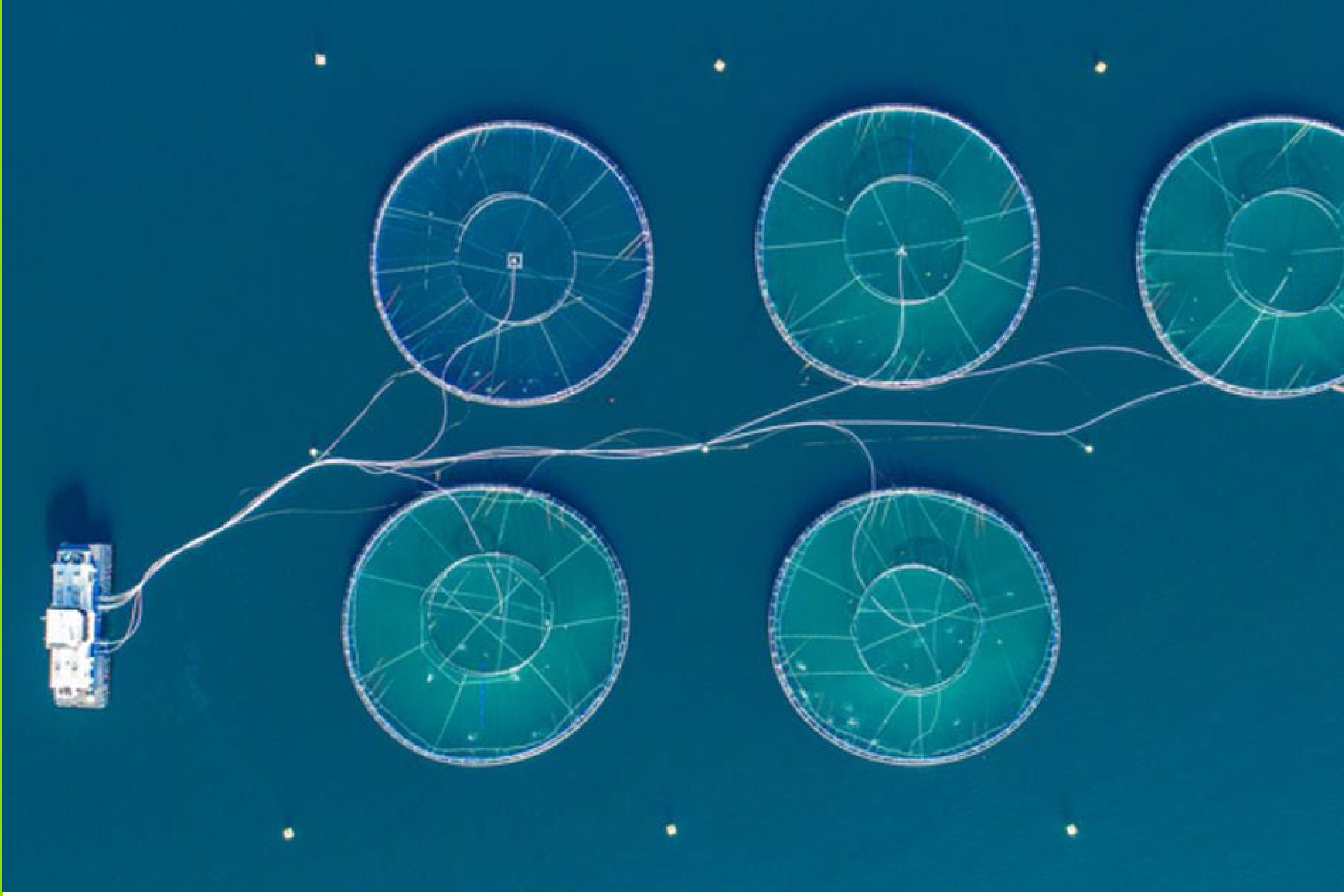
CONTROL, MANAGEMENT AND MAINTENANCE

Stop compressors acting in a vacuum

Compressors can be programmed in many cases to stop after a few minutes of vacuum operation. This measure avoids unnecessary energy consumption, as well as reactive energy consumption. The consumption of a vacuum-working compressor can be around 20% of its consumption during air production.

Decreased pressure in the net

Adjusting the network pressure to the minimum possible to allow the proper operation of equipment that feeds on compressed air, allows a significant decrease in the power required for compression and therefore the consumption of compressors. This measure also achieves a reduction in the volume of leaks that may exist in the installation.



7. BOILERS

THEORY: BASIC CONCEPTS

A boiler basically consists of a heat exchanger in which energy is usually provided by a combustion process, or also by the heat contained in a gas circulating through it. In both cases, the heat provided is transmitted to a fluid, which is vaporized or not, and transported to a consumer, to which that energy is transferred.

Some of the main elements that typically make up a boiler are:

- Burner: Where fuel burns
- Home: It houses the burner inside and in it is made the combustion and generation of hot gases.
- Heat exchange pipes: The flow of heat from gases to water takes place across its surface.
- Liquid-steam separator: Its function is to separate the droplets of suspended liquid water into the steam stream.

- Economizer: Heat exchange equipment to preheat liquid water with still hot gases, before feeding it to the boiler.
- Flue: Exhaust route to the outside of fumes and flue gases after heat has been transferred to the fluid.
- Enclosure: Outer protection of equipment containing the home and heat exchange tube system.

Some energy-saving measures that can be implemented in boilers to improve their energy efficiency are:

- Recovery of heat from boiler fumes.
  Smoke from the combustion of boilers at high temperatures is expelled through the flue into the atmosphere. The temperature of these flue gases can be partially recovered by means of exchangers and used for processes requiring heat, preheating of combustion air or heating of premises.
- Adjustment and control of combustion.
  Poor combustion prevents some fuel energy from being harnessed. Actions such as control over the value of excess air for combustion or proper maintenance that reduces the percentage of burning in combustion, allow to increase the performance of the boiler.
- Replacing old boilers with high-performance boilers.
  Today's boilers have better performance and insulation level, which reduces losses. Modern condensation boilers allow the use of latent water vaporization heat so that their yields exceed values of 100% compared to 70-90% of conventional ones. It should be clarified that values greater than 100% are possible because the traditional performance calculation is based on the heat that can be obtained from combustion, without taking into account the energy of the water for the change of liquid-gas phase, or latent heat.
- Fuel replacement used:
  Fuels can be solid, liquid or gaseous:
  Solid fuels (coal, coke...)
  Liquid fuels (diesel, fuel...)
  Gaseous fuels (natural gas, propane, butane...)

The current trend in the industry is the migration of solid and liquid fuels to the gaseous ones because they provide better equipment performance, as well as for their lower economic cost s/kWh and lower CO2 emissions.

COMBUSTION

According to the definition of the Institute for Energy Diversification and Savings, combustion is "a set of oxidation reactions with heat detachment that occur between two elements: fuel, which can be solid (pellets, coal, wood...), liquid (diesel, ...) or gas (natural, propane, ...) and the oxidizer, oxygen. Its main characteristic, that distinguishes itself from other oxidation processes, is that combustion makes possible to maintain of a stable flame." (IDAE, 2010)

Combustion occurs at very high temperatures and produces heat. For combustion to take place, the existence of a fuel, a reaction trigger and an oxidant is required. Normally this is oxygen, which is found naturally in the air in the atmosphere in a ratio of 21%.

The combustion process generates a considerable volume of gases and, depending on the fuel, solid waste in the form of ash or soot.

SENSIBLE HEAT LOSSES

Sensible heat losses through combustion fumes depend primarily on the following factors:

- The temperature of fumes
- The specific heat of fumes
- Excess air used in combustion, which is manifested in the percentage of CO and affects the mass or volumetric flow rate of fumes.
- These losses are usually between 6% and 10% of the rated power, significantly increasing in the event of poor maintenance.

(IDAE, 2007)

LOSSES FROM INCOMPLETE COMBUSTION

They are mainly due to burning carbon and, along with oxygen, form carbon monoxide (CO). Carbon monoxide is a toxic, colourless, odourless gas and is the product of in-complete combustion. A high concentration of CO can cause death within a few hours.

THEORETICAL AIR AND EXCESS AIR

For combustion to occur, there must be a certain air supply, which provides the amount of oxygen needed to burn the available fuel. The exact amount of air to burn a certain amount of fuel is called "theoretical air" and the combustion obtained is called 'stoichiometric', meaning in the exact proportions predicted by the generalized chemical reaction.

This type of combustion is not possible in practice due, inter alia, to a poor oxygen mixture with fuel, so it is inevitable to contribute more air to combustion than would theoretically be necessary. Excess air is represented as Lambda (λ) and its value will depend on the fuel used.

A value of λ = 1 indicates stoichiometric (!) combustion.

Although the instruments used for measuring combustion parameters usually indicate excess air data, it can also be obtained from measurements of CO2 or O2 content in combustion fumes, from these formulas:

$$\lambda = \frac{CO_2 max}{CO_2} \qquad \lambda = 1 + \left(\frac{O_2}{21 - O_2} \right)$$

ENERGY EFFICIENCY OF BOILERS

IMPROVED COMBUSTION PERFORMANCE: OVER-AIR CONTROL

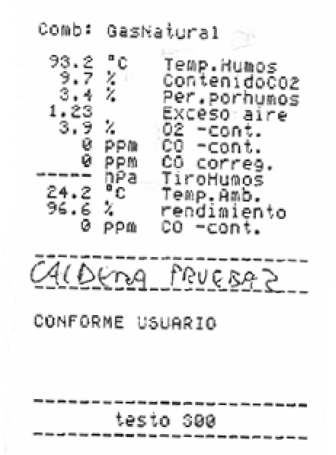
We have seen how greater air intake is needed to perform combustion than would theoretically be necessary. Depending on the amount of air provided for combustion, the following situations may occur:

- Stoichiometric combustion: Exact oxygen ratio for combustion. It is not achievable in practice.
- Excess air: Decreased smoke temperature and presence of O2 in them. Boiler performance decreases.
- Insufficient air: incomplete combustion Production of highly toxic and dangerous carbon monoxide gas (CO).

The air supply for combustion (and therefore excess air) is an easily adjustable parameter for the heating technicians.

The combustion values of the boilers are known from the tests carried out by means of a Combustion Analyser. This equipment, widely used by the technical services and boiler maintainers, provides various data on the content of combustion fumes.

IMG 6. COMBUSTION ANALYZER



Comb: GasNatural

93.2	°C	Temp.Humos
9.7	%	ContenidoCO2
3.4	%	Per.porhumos
1.23		Exceso aire
3.9	%	O2 -cont.
0	ppm	CO -cont.
0	ppm	CO correg.
-----	hPa	TiroHumos
24.2	°C	Temp.Amb.
96.6	%	rendimiento
0	ppm	CO -cont.

CALDERA PRUEBA 2

CONFORME USUARIO

testo 300

IMG 7. RESULTS OF THE COMBUSTION ANALYSIS

The data required for the evaluation of the boiler from an energy efficiency point of view are: Smoke temperature; Combustion air temperature; Oxygen content (O2); Carbon Dioxide (CO2) content; Carbon monoxide (CO) and Excess Air content. The latter data, as we have seen above, can be calculated from the values of O2 or CO2 if it is not available.

The calculation of sensible heat losses is done by means of the following formula:

$$qA = (T1 - T2)\ x \left(\frac{A}{(21 - 0_2) + B} \right)$$

Except for solid fuels, with which the Siegert formula is used:

$$qA = f\ x \left(\frac{T1 - T2}{CO_2} \right)$$

Being:

$T1$ = Combustion gas temperature

$T2$ = Combustion inlet air temperature (default, ambient temperature)

$A,\ B\ and\ f$ = Fuel-specific factors (see table below)

$O2$ = Concentration of O2 as measured by the analyser

Fuel-specific factors (A; B; f) are as follows:

	A	B	f	CO2 max
Fuel oil	0,68	0,007	-	15,4
Gas Natural	0,65	0,009	-	11,9
GLP (butane; propane...)	0,63	0,008	-	13,9
Coke, wood	0	0	0,74	20
Briquettes	0	0	0,75	19,3
Lignite Anthracite	0	0	0,9	19,2
Anthracite	0	0	0,6	18,5
Coke oven gas	0,6	0,011	-	-
City gas	0,63	0,011	-	11,6
Test gas	0	0	-	0

Source (TESTO, 2020)

Take, for example, the following values from a combustion analysis to a boiler, to see how sensitive heat losses can be reduced by reducing the excess air value:

Fuel: Natural Gas - INITIAL TEST	
Smokes temperature	152,4 °C
Combustion air temperature	31,1 °C
Oxygen content (O2)	10,6 %
Carbon Dioxide content (CO2)	5,89 %
Air Excess (λ)	2,02
Carbon monoxide content (CO)	1 ppm

The calculation of the sensible heat losses of this boiler is therefore as follows:

$$qA = (T1 - T2)\ x \left(\frac{A}{(21 - 0_2) + B} \right)$$

$$qA = (152{,}4 - 31{,}1)\ x \left(\frac{0{,}65}{(21 - 10{,}6) + 0{,}009} \right)$$

$$qA = 8{,}98\%$$

Losses reach 8.98% so the current combustion yield in this boiler is: 100% - 8,98% x 91,02%

After the correct regulation of excess air by the technical service the new scenario that we find after a second combustion test is as follows:

Fuel: Natural Gas - TEST AFTER REGULATION OF λ	
Smokes temperature	152,4 °C
Combustion air temperature	31,1 °C
Oxygen content (O2)	2,0 %
Carbon dioxide content (CO2)	10,9 %
Air excess (λ)	1,10
Carbon monoxide content (CO)	1 ppm

The new calculation of sensitive heat losses will be as follows:

$$qA = (T1 - T2)\ x \left(\frac{A}{(21 - 0_2)} + B \right)$$

$$qA = (152,4 - 31,1)\ x \left(\frac{0,65}{(21 - 2)} + 0,009 \right)$$

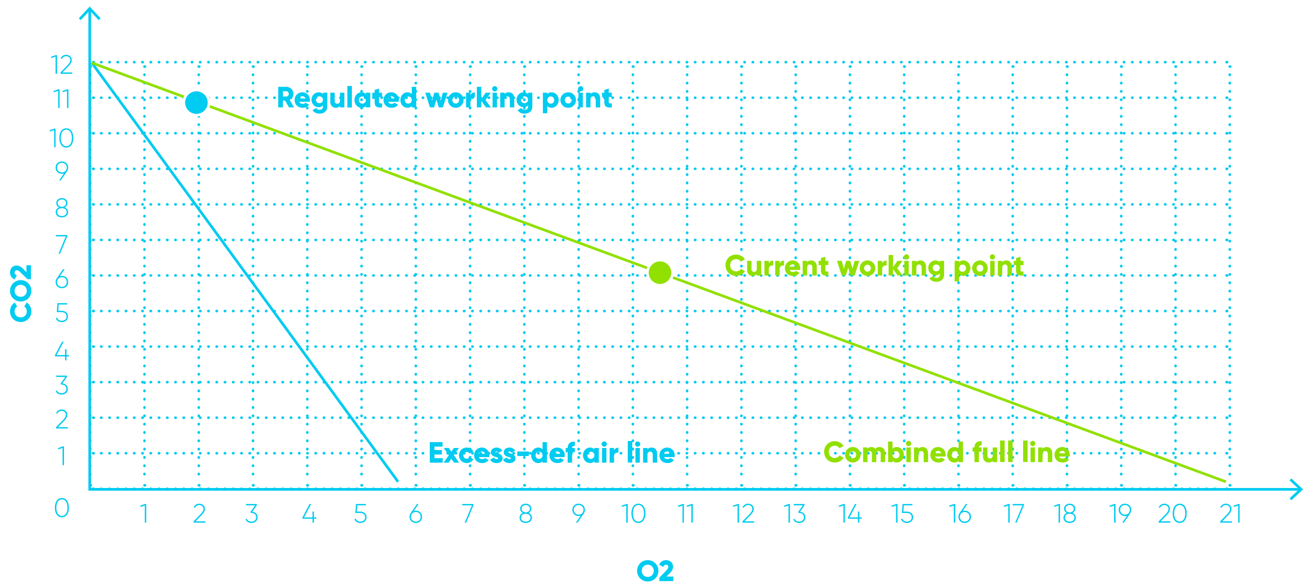
$$qA = 5,41\%$$

Losses reach 5,41% so the current combustion yield in this boiler is: 100% – 5.41% x 94,59%

It has gone from 83.83% yield to 95.01% yield, fuel savings of 3.78%

(94.59% – 91.02%) / 94.59% x 3,78%

The following graphic shows the working point of the boiler before regulation (blue) and after the regulation of excess air (black):



Ostwald diagram

THE IMPROVEMENT OF COMBUSTION PERFORMANCE: LOSSES DUE TO INCOMPLETE COMBUSTION

The quantity of Carbon monoxide (CO) present in combustion smokes is measured in parts per million. Thus, for example, a concentration of 100 ppm equals a volume present of CO of 0,01% in the combustion products, which, in practice, means dividing per 10000.

The formula employed for the calculation of the percentage of losses from incomplete combustion is the following:

$$qi = K\,x \left(\frac{CO / 10000}{(CO / 10000) + CO_2} \right)$$

Being:

CO = Content of carbon monoxide in ppm

$CO2$ = content o carbon dioxide present in combustion smokes

K = Specific combustible factors (see following table)

The specific combustible factors (K) are the following:

	K
Gas Natural	72
Butane	75
Propane	84
Diesel oil	95

Source: (TESTO, 2020)

For example, consider a propane boiler whose combustion analysis showed:

- CO = 500 ppm
- CO2 = 8,27%

$$qi = K\,x \left(\frac{CO / 10000}{(CO / 10000) + CO_2} \right)$$

$$qi = 84\,x \left(\frac{0{,}05}{0{,}05 + 8{,}27} \right)$$

$$qi = 0{,}50\%$$

Losses amount to 0,50% so the current performance of combustion in this boiler is: 100% - 0,50%=99,50%.

Once the proper measures have been taken by the technical service of the boiler in order to count on a correct combustion, the elimination of the carbon monoxide in the combustion products will carry the increase of the performance, with it, the correspondent fuel savings. In the matter at hand: (100% – 99,50%) / 99,5% = 0,50%.

WHAT IS MY BOILER'S PERFORMANCE?

In relation to previous sections, it must be taken into account that the performance depends both on the percentage of losses due to sensible heat (qA), as well as the percentage of losses from incomplete combustion, and so the performance in % of combustion of the boiler would be calculated considering the sum of both as:

$$100\% - (qA + qi)$$

After the correct regulation of excess air and the proper measures taken in order to avoid the presence of CO in combustion, the losses for both qA and for qi would be reduced and as a consequence the performance would increase.

The calculation for the fuel saving would be:

$$(\text{Final performance} - \text{Original performance}\ )\ /\ \text{Final performance}\ )\ x\ 100$$

Finally, it is important to highlight that small losses of heat are being produced through the boiler's own body and these would be larger when the temperature difference between the boiler's body and its surroundings. Therefore, it is important to have the correct thermal insulation both around the boiler and its conduits of vapor or water through the application of the adequate thermal hollows or blankets. Such insulations, manufactured from materials such as rock wool, glass wool or synthetic rubber, have relatively small cost and a high degree of efficacy.

IMPROVEMENT OF COMBUSTION PERFORMANCE: PREHEATING OF COMBUSTION INPUT AIR

As we have seen above, the combustion smoke is expelled at high temperatures to the outside through the boiler flue.

The recovery of this heat to preheat the air supply for combustion is an interesting measure of energy savings that allows us to save fuel because, the more heat available in the air in the inlet to combustion, the burner needs less operation to reach the operating temperature (the thermal jump required is lower).

However, air from combustion products cannot be directly "injected" as input air into the boiler for new combustion because toxic products could be generated.

Therefore, an air-to-air heat exchanger is used to use the heat contained in combustion products that ensures heat transfer without contact between combustion fumes and a new "clean" air that will be heated for input to the boiler.

However, as in any energy exchange, heat transfer is not perfect and some of the existing heat content in combustion products cannot be exploited. Air-to-air heat ex-changer equipment can reasonably expect efficiency between 55% and 70%.

RECOVERING SENSITIVE HEAT FROM BOILER FUMES

As in the previous section, the measure is based on the recovery of heat from the combustion of the boiler that is expelled into the atmosphere through its flue. By using economizers, heat recovery units, regenerators or recovery boilers, the energy contained in this waste heat can be harnessed for use in multiple applications and pro-cesses that require the use of heat such as heating rooms or offices.

Economizers, heat recovery units, regenerators or recovery boilers, are equipment that take the heat of the combustion gases and use it to heat up a fluid. This fluid can be the inlet air for com-bustion, water (for example for sanitary hot water purposes) or others.

The high investment required for heat recovery technologies is interesting only in cases where:

- Heat is required for the process continuously.
- The daily hours of operation of the boiler are high enough to provide us with heat continuously.

PRODUCTION OF SANITARY HOT WATER

The production of hot water can be carried out from different fuels, with different prices per kWh.

In order to assess whether it is interesting to replace sanitary hot water production equipment with other equipment powered by a different energy supply (e.g., replacing an electric thermos with an instant butane or natural gas heater) we need to first quantify our energy consumption.

Take, for example, a facility where 1,000 litres of sanitary hot water are consumed per month, at a setpoint temperature of 60 °C, while the temperature of the supply water arriving at the facility is around 15 °C. The calculation of the energy consumption re-quired to raise the temperature of a water volume of 1,000 litres from 15 °C to 60 °C is as follows:

$$Q = m \times Ce \times \left(T2 - T1 \right)$$

Being:

Q = Power consumption (kcal/h)

m = Mass of the volume of water to be heated (kg). For calculation purposes we will consider 1 l x 1 kg

Ce = Water-specific heat - 1 kcal/kg °C

$T1$ = Incoming water temperature (°C)

$T2$ = Final water temperature (°C)

The energy consumption would therefore be:

$$Q = m \; x \; Ce \; x \left(T2 - T1 \right)$$

$$Q = 1.000 \; x \; 1 \; x \left(60 - 15 \right)$$

$$Q = 45.000 \; kcal$$

$$45.000 \; kcal / 860 = 52{,}3 \; kWh$$

This consumption of 52.3 kWh is the energy consumption necessary to increase the temperature of 1,000 litres of water by 45°C during the month we have considered but, it should be noted that the water temperature of the supply network varies throughout the year so the calculation should be made for each month of the year. The annual energy consumption would be the result of adding up to the 12 results obtained.

The water temperature of the supply network it is an important parameter for a large number of calculations (such as the present or also for sizing calculations of solar thermal installations) so there are tables with local values easily accessible from the internet.

With the consumption data obtained, it would only be necessary to study energy prices at the national level for the different fuels. The savings obtained from the difference in the price of fuels shall be sufficient to amortize within its reasonable period of years the investment involved in the replacement of sanitary hot water production equipment.

- Annual economic savings (€/yr) = (Energy consumption (kWh/yr) x actual fuel cost (€/kWh)) – (Energy consumption (kWh/yr) x new fuel cost (€/kWh))
- Payback Period (years) = Investment (€) / Economic savings (€/yr)

The cost of some fuels may be indicated in consumption-related units (such as liters or kilograms). To perform the conversion to kWh, the Heating Value of fuels are required, which are attached in the table below:

Fuel	Lower heating Value (LHV)
Coal	9,08 kWh/kg
Diesel	10,28 kWh/l
Butane gas	12,73 kWh/kg
Propane gas	12,86 kWh/kg
Natural gas	10,83 kWh/Nm^3

Source: Guía técnica – IDAE (IDAE, 2010)

The amount of fuel needed in kg, litres or Nm3 would be:

$$\textit{Expected energy consumption (kWh) / LHV = Fuel needed (kg; l; Nm}^3\textit{)}$$

8. INSULATION

THEORY OF HEAT TRANSFER

Heat is the process of transferring energy between different bodies or areas of the same body that are at different temperatures, until a thermal balance occurs.

Heat measurement units. The unit of heat measurement (also used as a unit of measurement for energy and work) in the International System of Units is the Joule.

A Joule is the amount of energy to supply to one gram of water at an atmospheric pressure to raise its temperature 0.24 $^{\circ}C$.

Other units of heat measurement commonly used are calorie and BTU.

A calorie is the amount of energy to supply to one gram of water at an atmospheric pressure to raise its temperature 1 $^{\circ}$C, while the BTU (or British thermal unit) is defined as the amount of heat that must be added to a pound of water to increase its temperature by a Fahrenheit degree. It is a widely used unit of measure in the United States and its equivalence is 252 calories.

Thermal balance: Any substance at a temperature above 0° Kelvin (-273,150 Celsius) begins to emit heat and heat to other nearby substances using mechanisms such as conduction, convection and radiation until the temperature of both is equal, producing a thermal balance.

Thermal balance: Is achieved when heat in equals heat out. Thermal conduction: is the process that occurs by thermal contact between two or more bodies, due to direct contact between their particles. Pure conduction is presented only in solid materials and depends to a large extent on the material, its section of its length.

Thermal convection: Is the process of transmission of heat produced in fluids (liquids or gases) that occurs due to its movement.

Thermal radiation: This is the process by which energy is transmitted through electromagnetic waves. It involves double transformation of energy to reach the body to which it will first propagate from thermal to radiant energy and then vice versa.

Dry temperature: This is the temperature of the air, excluding the temperature produced by radiation that can emit the objects that close to that environment. The effects of relative humidity and air movements are also not taken into account. Dry temperature measurement is done with a mercury thermometer, considering that your bulb does not absorb radiation.

Radiant temperature: Takes into account the heat emitted by radiation from the elements of the environment. A bulb thermometer whose mercury tank is installed inside a black sphere is used for measurement to produce as much radiation absorption as possible.

Wet bulb temperature: Is the temperature marked by a thermometer located in a shaded area and with its bulb wrapped in a wet cotton wick and subjected to a stream of air. Evaporation of water results in a decrease in temperature indicated by the thermometer.

Degrees Celsius: The scale was established in 1742 considering the freezing and evaporation temperatures of water, to which the values of 0 and 100 $^{\circ}$C were given.

Degrees Fahrenheit: Proposed in 1724, this scale is established between the temperatures of freezing and evaporation of water, which are 320 $^{\circ}$F and 212 $^{\circ}$F. Its equivalence with the Celsius scale is established by the expression:

$$C=(F-32) / 1{,}8$$

Degrees Kelvin: Coinciding the increase by a degree Celsius with that of a Kelvin, its importance lies in the zero point of the scale: the temperature of 0 K is called 'absolute zero' and corresponds to the point at which the molecules and atoms of a system have zero thermal energy.

$$K = {}^{0}C + 273.15$$

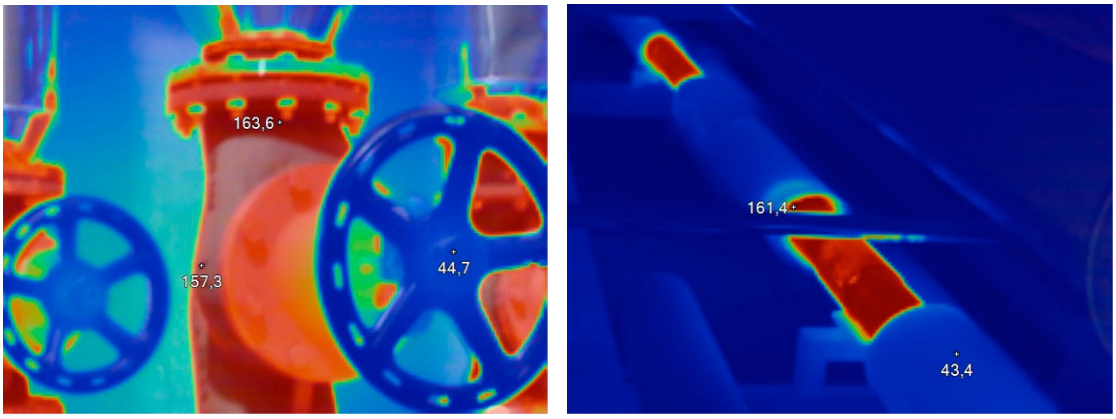
Other scales: Most currently deprecated, are newton, Réaumur, Roemer, Leiden and Delisle.

INSULATION SYSTEMS

LOSSES FROM POOR INSULATION IN PIPES AND CONDUCTS.

Poor insulation or poor maintenance can result in very high energy losses. The greater the area lacking insulation, the greater the temperature difference between the conduction surface and the area of the premises.

The use of a technique such as thermography makes it possible to easily and accurately detect the points where heat losses are occurring.



Source: SGS

Insulation for pipework usually consists of a coating made of materials such as mineral wool or polyethylene, which have a low thermal conductivity with which it is possible to prevent the transmission of heat to the environment. Installing insulation on cold or heat conductions is an effective, inexpensive and easy-to-implement energy-saving measure so investment recovers quickly.

LOSSES FROM POOR INSULATION IN ENCLOSURES AND GLAZING.

Poor insulation of the building's enclosures and hollows (walls, doors and windows) also results in a loss of energy in air conditioning, as well as thermal comfort.

The most common measures of action on constructive characteristics are:

- Improved isolation level.

This consists of separating elements from contact with the exterior to increase resistance to the passage of heat by adding insulating elements and layers in the exterior enclosures and roofs of the building.

- Elimination of thermal bridges.

Thermal bridges are the envelope areas of a building where there is a variation in the uniformity of the building. These points have a lower thermal resistance, so they are the areas where the greatest temperature exchanges occur with the outside.

There are the areas whose isolation should be improved when it is poor. The most common thermal bridges are:

- Pillars integrated into the enclosures of the facades
- Contour of gaps and skylights
- Boxes of blinds
- Front of slabs on facades
- Encounters of interior partitions with facade

- Improved sealing of doors and hollows:

This prevents unwanted infiltrations. Ideally the doors should be made of materials such as wood or agglomerates and incorporate insulating material in their middle part, as well as incorporating tapes or sealants throughout the perimeter of their frame. For windows, the use of double glazing with air chamber between the two is considered an optimal solution. Although the cost is higher than simple glass, it is possible to reduce losses in half. It is currently the most common type of window in new buildings.

- Special glass treatments So you can improve your winter/summer thermal behaviour.

There are different types of glass on the market

- Laminar glass. Multi-leaf compounds that increase insulation capacity.
- Low emissivity glass. They incorporate on their surface a layer of oxides that strengthens their insulation capacity.
- Solar control glasses. These are coloured glasses or with added layers that allow great variety in terms of insulation.

- Installation of additional items.

Fixed sun protections are generally preferable for a south-facing orientation, while for a west and northeast orientation it is recommended that sun protection systems have mobility, for example, through the use of slats. It is interesting to create shadow elements by means of deciduous trees, which allow the passage of light only during the winter period.

TEMPERATURE LOSSES THROUGH ACCESSES.

It is common to have access to communication between air-conditioned and non-air-conditioned premises, which are open almost permanently when high racking between the different areas of the building is required. This leads to a significant loss of conditioned air and a considerable energy cost, so the installation of automatic closing doors or air curtains is often used as a way to reduce energy losses through access.

The installation of an air curtain creates a barrier that effectively separates the interior environment from the outside, significantly reducing energy losses through the door, also providing additional advantages such as avoiding insect entry or avoiding fog that is formed by mixtures of airs. The potential energy saving depends on the height of the door, achieving the best results in accesses up to 3.5 meters high, in which a reduction of energy losses that reaches percentages around 80-90% is achieved.

Below is the calculation that will allow us to know the energy cost lost through accesses. First, the infiltration calculation is performed as follows:

$$V = 0,7 \; x \; W \; x \; H \; x \left(H \; x \left(\frac{1 - (T_{in} + 273,15)}{T_{out} + 273,15} \right) \right)^{0,5}$$

Being:

V - Infiltration (m^3/s)

W - Access Width (m)

H - Access Height (m)

$T \; in$ - Indoor temperature (°C)

$T \; out$ - Outdoor temperature (°C)

Once the data corresponding to the infiltration has been obtained, the value of the energy load that implies the loss of air conditioning through accesses can be established:

$$Q = V \; x \; D_{ext} \; x \left((E_{ext} \; x \; 4,19) - (E_{in} \; x \; 4,19) \right)$$

Being:

Q - Load (kW)

V - Infiltration (m3/s)

$D\ ext\ x$ - External air density (kg/m^3)

$E\ ext$ - Outdoor air enthalpy (kcal/kg)

$E\ in$ - Indoor air enthalpy (kcal/kg)

The values of both enthalpy and air density are linked to their temperature. This data can be found in the table "Properties of dry air at atmospheric pressure" shown on the following pages.

The total annual energy load (kWh) shall be determined by the value resulting from the calculation of load Q by the number of annual hours in which the infiltration situation occurs between premises.

PROPERTIES OF DRY AIR AT ATMOSPHERIC PRESSURE					
Temperature (ºC)	Density (kg/m³)	Enthalpy (kcal/kg)	Temperature (ºC)	Density (kg/m³)	Enthalpy (kcal/kg)
-15	1,3691	0,6722	18	1,213	8,6372
-14	1,3638	0,9123	19	1,2086	8,8772
-13	1,3581	1,1523	20	1,2044	9,1228
-12	1,353	1,3923	21	1,2006	9,3628
-11	1,3473	1,6323	22	1,1961	9,6028
-10	1,3416	1,8779	23	1,192	9,8484
-9	1,3369	2,1179	24	1,188	10,0706
-8	1,3313	2,3579	25	1,1839	10,3284
-7	1,3266	2,598	26	1,18	10,574
-6	1,3222	2,839	27	1,1763	10,764
-5	1,3173	3,0835	28	1,1725	11,054
-4	1,3125	3,3235	29	1,1687	11,2996

Temperature (°C)	Density (kg/m³)	Enthalpy (kcal/kg)	Temperature (°C)	Density (kg/m³)	Enthalpy (kcal/kg)
-3	1,3072	3,5636	30	1,165	11,5396
-2	1,3024	3,8036	31	1,1611	11,7796
-1	1,2977	4,0447	32	1,1567	12,0252
0	1,2928	4,2892	33	1,1531	12,2652
1	1,2893	4,5292	34	1,1494	12,5052
2	1,2837	4,7692	35	1,1458	12,7564
3	1,2784	5,0148	36	1,142	12,9908
4	1,2739	5,2547	37	1,1382	13,2308
5	1,2693	5,4948	38	1,1343	13,4764
6	1,2645	5,7404	39	1,1308	13,7164
7	1,2605	5,9803	40	1,1273	13,962
8	1,2562	6,2204	41	1,1236	14,202
9	1,2518	6,4615	42	1,1196	14,442
10	1,2476	6,706	43	1,1164	14,682
11	1,2431	6,946	44	1,1127	14,9276
12	1,2381	7,186	45	1,1093	15,1676
13	1,2339	7,3983	46	1,1059	15,4132
14	1,2297	7,6716	47	1,1021	15,6532
15	1,2256	7,9116	48	1,0988	15,8955
16	1,2213	8,1183	49	1,0954	16,14
17	1,2168	8,3972	50	1,0919	16,39

9. RENEWABLE TECHNOLOGIES

BASIC CONCEPTS: PHOTOVOLTAIC, SOLAR THERMAL, HYDRAULIC, WIND

Solar irradiance: Solar power incident per unit surface on plane given in W/m2.

Solar irradiation: Incident energy per unit of surface on a given plane, obtained as integration of irradiance over a given time interval, usually one hour or one day. Expressed in MJ/m2 or kWh/m2.

Direct radiation: this is radiation hitting a surface directly, without interacting with anything and without undergoing changes of direction.

Diffuse radiation: It arrives as a reflection of the solar radiation that is absorbed by dust and air (typical of cloudy days).

Reflected radiation: This is the part of radiation that is reflected by the terrain and other elements -per area unit- and which can be reabsorbed by other objects.

To define the position of the Sun at each moment, two coordinates are used:

- Solar Azimuth: Angle of rotation of the Sun with respect to the geographical south. A value of 0° occurs when the Sun is exactly above the South.
- Solar height: Angle that form the solar rays on the horizontal. It varies throughout the day and year.

To determine the position of an object on Earth, the following parameters are used:

- Latitude: Angle that forms the vertical of a point on the earth's surface and the plane of the equator. It is considered positive in the northern hemisphere and negative in the southern hemisphere.
- Length: Arc of the equator between the meridian of a place and a reference meridian (Greenwich).

SOLAR THERMAL ENERGY: TYPES OF COLLECTORS AND ITEMS IN AN INSTALLATION.

Flat Collectors: It is a device designed to absorb solar energy and transmit it to a carrier fluid, usually liquid, circulating inside. The most commonly used is the glass-covered flat solar collector and its most widespread use is the production of hot water.

The solar uptake system is based on the principle of the greenhouse effect which is that short-wave-length solar radiation passes through the transparent cover and hits the absorber by increasing its temperature. The absorber when heated emits long wave radiation which is retained by the cover, which is opaque to this type of radiation. This produces a build-up of heat that is transferred to the heat-carrier fluid.

The main elements of a flat solar collector are:

- Transparent cover: It is constructed of a material transparent to solar radiation (glass or colourless plastic) and is responsible for retaining heat and isolating the catcher from outdoor environmental conditions. The material that makes up the cover must also meet the following characteristics:
  - Good solar transmission in the short-wave radiation band and opacity to long wave thermal radiation to prevent heat loss. Or stability in time.
  - Coefficient of thermal conductivity for specific specifics.

- Low adhesion to dirt.
- Low dilation coefficient in the working temperature range of the Collector

- Absorber: It is the fundamental element of the flat collector, in which the conversion of solar radiation into thermal energy and transmitted to the heating fluid. It consists of a flat surface attached to a hydraulic circuit through which the heating fluid circulates.

- Housing: External element that protects and supports the elements that make up the system

- Insulation: Insulating material (glass wool, polystyrene, polyurethane foam...) that protects the absorber from the sides and on the back to prevent driving losses.

Tube catchers: These are devices formed by between one and several dozen glass tubes inside which the vacuum has been made. Inside each tube, a rectangular plate absorbs solar radiation and gives heat to the fluid circulating through a copper pipe to which it is welded. Its operation is also based on the greenhouse effect produced when solar radiation passes through a glass.

The fundamental difference is that it does not require insulating material, as the vacuum of the tubes itself eliminates thermal losses to the outside of the glass. Therefore, its performance is higher.

Vacuum pipe collectors perform better and provide higher temperatures than flat plate collectors, as they can reach working temperatures close to 100ºC. Its most common field of application is water heating for industrial processes. They are more expensive, less robust and their assembly is more delicate and laborious.

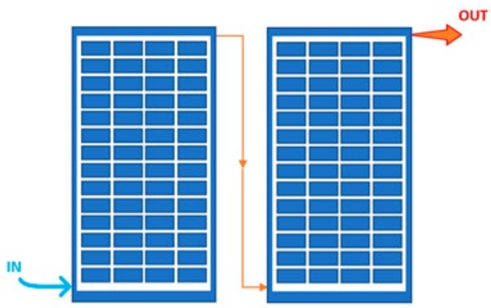
Uncovered catchers: Its only component is the absorber, which has an impact on its low price and ease of assembly compared to other catchers.

These systems have lower performance than flat solar collectors, so they need a larger catchment surface. They also have the drawback of providing small thermal jumps, so their most widespread use is the heating of outdoor pools.

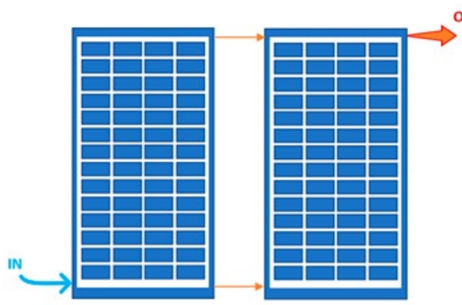
They are normally made of polypropylene, being more mouldable when it comes to adapting them to the roofs.

Catcher connection: The different collectors that are part of a solar thermal installation can interconnect with each other in series or in parallel.

Serial connection. It allows to achieve a higher temperature since the same flow of water passes through all the catchers during its journey, but we sacrifice efficiency since the increase in temperature (difference in temperature between the point of entry and exit of the water to the catcher) is less and less. The parallel arrangement allows us to have greater total flow rates, having the sum of the individual flow rates that pass through each branch of catchers. Load losses must be evaluated and corrected (using flow regulators or reverse return system) to ensure that they are the same in the different water paths, so that the installation is balanced. Connecting serial getters Connecting catchers in parallel. There is also the possibility of a mixed series-parallel connection of the catchers, which allows us to obtain the advantages of both systems.

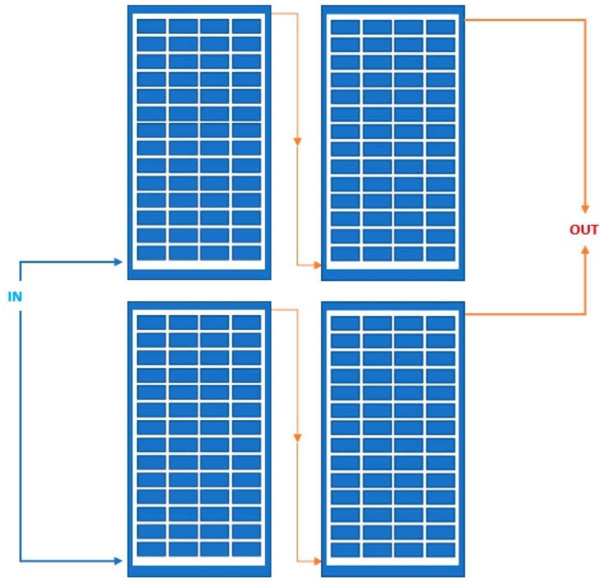


Connection of serial catchers



Connection of parallel catchers

There is also the possibility of a mixed series-parallel connection of the catchers, which allows us to obtain the advantages of both systems.



C Mixed catcher connection

Accumulators: Stores hot water from the collectors for later use.

Its main function being to maintain the thermal energy of the water with the lowest losses and for as long as possible, it is logical to assume that its main characteristic is its level of insulation. It is advisable as far as possible to avoid its installation in outdoor areas, to contribute as much as possible to a lesser exchange of heat with the environment.

As a general rule, an accumulator with an accumulation volume in litres similar to the estimated daily consumption of hot water should be chosen. It is also possible to connect several accumulators to each other, thus achieving greater capacity.

Although the needs of each installation should be calculated, an average value of 70 litres per square meter of solar collector is usually considered as an optimal accumulation volume. In any case, for guidance, different storage volumes are often recommended based on the greater or lesser lag between the time of consumption and the time of capture:

- In case of coincidence between the generation time and the consumption time = from 35 to 50 l/m^2 of solar collectors. This type of offset is typical in industrial environments, offices, schools...
- For offsets less than 24 hours = from 60 to 90 l/m^2 of solar collectors. This is the usual situation that can be found in homes or hotels.
- For offsets greater than 24 hours and lower than 72 hours = from 75 to 100 l/m^2 of solar collectors.

Heat exchangers: Allow heat to transfer between separate fluids without contact between them. This allows the solar collectors to use different fluids from water, for example freezing avoiding fluids.

This system results in a decrease in system performance, resulting from losses in the heat exchange process (lower the more efficient the exchanger) and a higher cost of installation.

To obtain an approximate calculation of the minimum power of an independent exchanger, its working conditions must be considered at the central hours of the day, the existing catchment surface and a conversion performance of solar energy to heat of 50%.

$$P = 1 \times 0,5 \times SC$$

Being:

P = Minimum exchanger power (W)

I = Maximum daily solar irradiance value (W/m^2)

SC = Solar uptake surface (m^2)

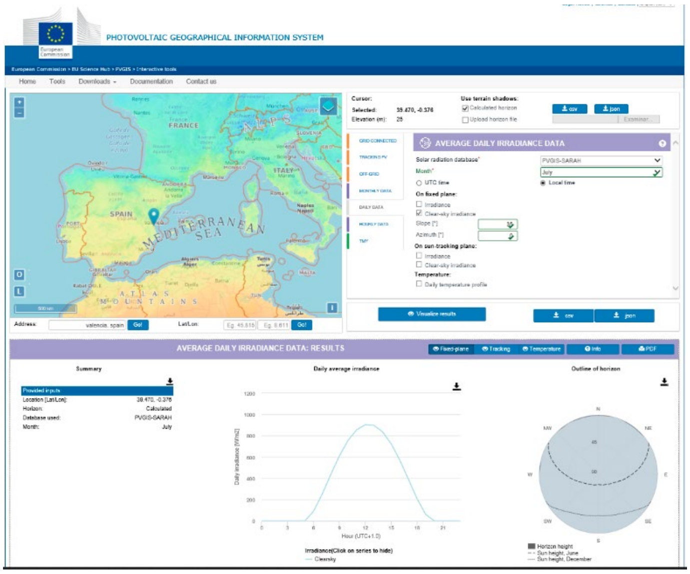
Thus, taking as a reference an approximate solar irradiance value of 900 W/m2 existing at 12:00 noon (July) in sunny city of Valencia (Spain) and a fictitious catcher area for our installation of 50 m2, the ideal minimum power for our exchanger would be:

$$P = 1 \, x \, 0{,}5 \, x \, SC$$

$$P = 900 \, x \, 0{,}5 \, x \, 50$$

$$P = 22{,}5 \; kW$$

The average irradiance values have been obtained through the European Commission's "Photovoltaic Geographical Information System (PVGIS)" online tool, capable of providing numerous valid data and simulations for the planning and performance of solar generation facilities anywhere in Europe. (Joint Research Centre (JRC), European Commission, 2020)



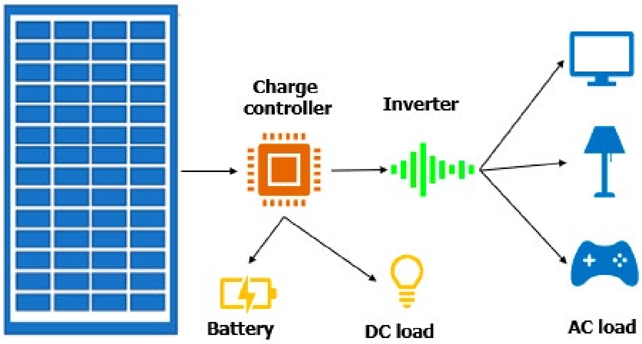
Source: (Joint Research Centre (JRC), European Commission, 2020)

PHOTOVOLTAIC SOLAR ENERGY.

Elements of an installation. The main components of a photovoltaic solar installation are:

- Photovoltaic Generator: Transforms solar energy into electric power.
- Regulator Controls battery charging and unloading processes.
- Battery: Accumulate the energy generated by the FV system to adapt it according to demand.
- Inverter: converts the energy generated in direct current into alternating current.

The photovoltaic panel receives sunlight and transforms it, through the photoelectric effect, into continuous electrical energy. Electricity is driven to the regulator, which decides whether to send it directly to continuous consumption, store it in the batteries or send it to alternate consumptions after passing through the inverter.



A photovoltaic system can be connected to the mains or operate in isolation:

An isolated or autonomous photovoltaic system is a self-supply system that harnesses solar irradiation to generate the necessary electrical energy in the supply of a facility. Some of its most common uses are:

- Telecommunications equipment in hard-to-reach areas away from the electricity grid.
- Maritime and land signage (beaconing on roads, ports...). Feeding of facilities in isolated or protected areas (natural landscapes).
- Power supply for water pumping in wells away from the mains.
- Electrification of isolated homes.
- Street lighting.

A grid-connected photovoltaic system is: A photovoltaic generator coupled to an inverter operating in parallel with the conventional electricity grid, pouring the energy generated into it. This system requires additional components to operate in addition to the photovoltaic generator and inverter:

- Protection box: It serves so that the electrical energy introduced into the grid has all the characteristics required by it, according to the quality conditions imposed. In addition, it prevents the photovoltaic system from affecting the mains in the event of a breakdown.
- Two-way energy counter: Able to measure energy flow in both ways, when the plant generates energy and when it consumes. This provides data on both the energy consumed and the energy available for sale to the electricity market.

Some other concepts and definitions to mention, related to photovoltaic solar generation are:

Solar cell: A device that transforms solar energy into electrical energy. A set of interconnected and encapsulated solar cells for weather protection form a photovoltaic module.

Peak power: Maximum power that a photovoltaic module can deliver under standard measurement conditions (Irradiance 1000 W/m2; Spectral distribution AM 1.5 G; Cell ta 25º C; Normal incidence).

(IDAE, 2009)

BASIC DESIGN OF SYSTEMS

SOLAR THERMAL ENERGY. CALCULATION OF ENERGY DEMAND

The first step necessary for the design of a solar thermal energy installation is, logically, to know the energy needs to be met by installation.

Energy needs shall be determined both by the consumption of water and by the temperature of the water which needs to be reached, depending on the species or the growth phase in which it is located. It is also important to take into account the cold-water inlet temperature, as it will determine the necessary thermal jump and therefore the precise energy supply.

The calculation will be made for each month of the year due to both the different and the possible difference in the temperature of the inlet water.

$$Q = Ce \; x \; m \; x \; \left(t^a out - t^a in \right) \; x \; n$$

Being:

Q = Power consumption (kcal/month) Note: kcal / 860 = kWh

m = Mass of the volume of water to be heated (kg). For calculation purposes we will consider 1 l x 1 kg

Ce = Water-specific heat = 1 kcal/kg ºC

$T^a \; in$ = Inlet water temperature (ºC)

$T^a \; out$ = Final water temperature (ºC)

n = Number of days of the month studied

$T \; out$ = Final water temperature (ºC)

PHOTOVOLTAIC SOLAR ENERGY. CALCULATION OF ENERGY DEMAND AND SIZING

In the case of the sizing of a photovoltaic installation, account must be taken from the nature and magnitude of electricity consumption. The main factors for evaluating are:

Power (W): Obtained from the characteristics of each consumption element. It is also important to know whether or not the load consumes continuously or alternately, as this will depend on whether or not you have an inverter.

Daily hours of operation (h): Multiplying this data by the power we get the watt hours required by the total load over the course of a day.

Expected autonomy: Refers to the days on which it is expected to decrease or there will be no generation by the installation, and which must be taken into account in the sizing of the batteries. The determining factor in the power generation process is the volume of system losses. The main losses are:

- Losses due to non-compliance with the rated power: The rated power of the modules is referred to standard conditions so there is a certain degree of variability. The feature sheet of the manufacturer of photovoltaic modules will inform us of the percentage of variation (in general it is usually less than P±3%) .
- Connection losses: Caused by the connection of photovoltaic modules of slightly different powers.
- Dust/dirt loss: The presence of uniform dirt results in a decrease in current and voltage delivered by the photovoltaic generator, while localized dirt (such as bird droppings) can produce the same effect as connection losses and, in addition, produce what are called "hot spots" in which shaded cells consume some of the power generated by other cells, causing unwanted heating and can break down by overheating, if it lacks protective diodes.
- Angular and spectral losses: During normal operation of the installation neither the incidence of radiation nor spectrum are stable, nor are they maintained in the standard condition values taken into account for the manufacture of the panels. The variation of the solar spectrum at any given time from the normalized spectrum can affect the response of photovoltaic cells resulting in energy gains or losses.
- Wiring losses: Voltage drop losses. They are minimized with proper conductor sizing.
- Temperature losses: About 4% per 100C of operating temperature increase.
- Losses due to inverter performance: Good performance equipment must be selected for operating power.
- Battery performance losses: Energy losses (mainly heat) during chemical charging/unloading processes.
- Losses by orientation, inclination and shadows: (See in later sections)

The total sum of losses implies the non-exploitation of a high percentage of the energy generated. Typical values of installation energy performance or "performance ratio" (PR) are, in systems with inverter PR=0,7 systems with inverter PR-0.7 and in systems with inverter and battery PR-0.6. (IDAE, 2009)

For generator sizing, we can proceed as follows:

Peak power can be calculated as:

$$P_{mp,\,min} \left(E_D \; x \; G_{CEM} \big/ G_{dm} \; (\alpha.\beta) \; x \; PR \right)$$

Being:

$P\ mp,min$ = Minimum peak power of the generator

ED = Consumption expressed in kWh/day

$GCEM$ = 1 kW/m2

$Gdm\ (\alpha.\beta)$ = Incident energy kWh/m2 (See in later sections)

PR = Losses "performance ratio"

In any case, it should be noted that:

$$P_{mp,\,min} = 1{,}2 \; x \; P_{mp,min}$$

For the calculation of the number of panels, depending on the solar peak hours.

$$N = E \big/ \eta comb \; x \; Wp \; x \; HPS$$

Being:

E = Estimated power consumption.

$\eta comb$ = Performance of the photovoltaic installation considering all losses. As seen in the loss section, this value will range from 70% to 75%

Wp = Peak power of the panels considered

HPS = Solar Peak Hours. This value is obtained from the relationship:

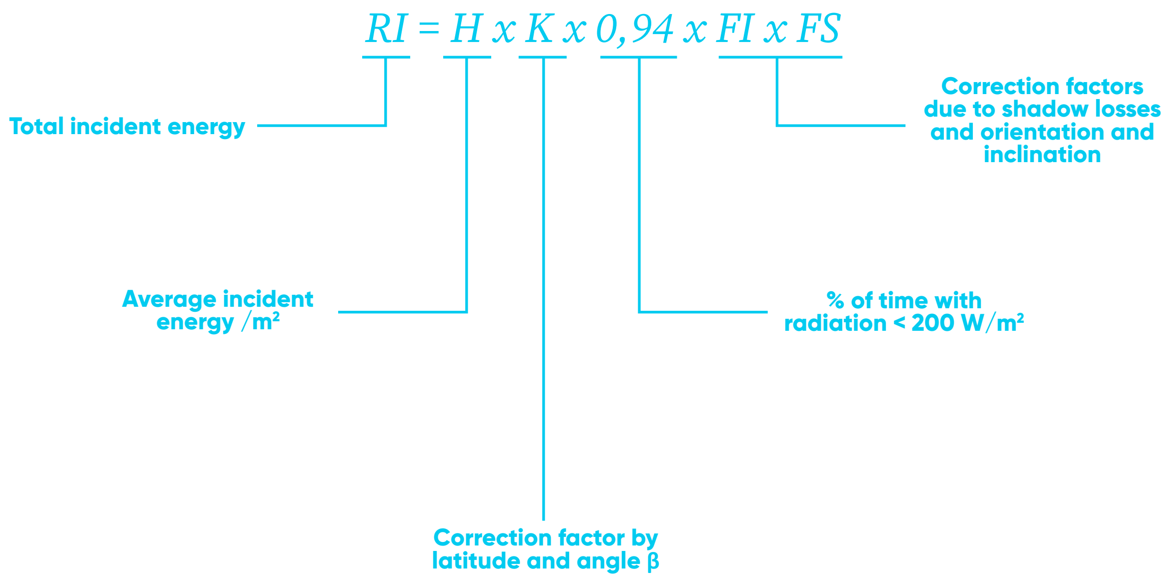
$$HPS = \frac{G_{dm}(\alpha.\beta)}{G_{CEM}}$$

SOLAR THERMAL AND PHOTOVOLTAIC ENERGY. INCIDENT ENERGY ON A SURFACE.

The energy supply of the sun to the system varies depending on the period of the year, the place of placement of the installation (latitude) and the angle of inclination of the catchers. A number of loss corrections should also be considered.

Traditionally, it has been considered that:

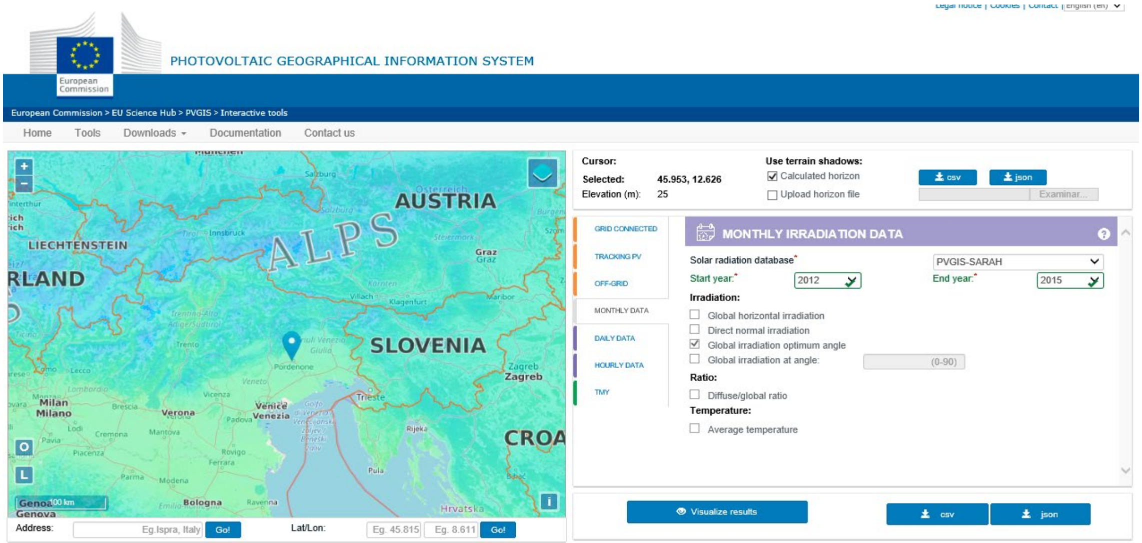
$$RI = H \times K \times 0,94 \times FI \times FS$$



Where Average Incident Energy data per surface was obtained from specific tables for each month and population, as well as the value of the K correction factor that can be obtained for each month of the year from the table corresponding to the latitude at which the facility is located.

However, current online tools such as the European Commission's annotated "Photovoltaic Geographical Information System (PVGIS)" allow us to obtain kWh/m2 irradiation data from the European geographical area that we need to know and with extensive temporary records.

We also have the possibility to select both the degree of inclination that we consider, as well as the optimum degree of inclination for the placement of the catchers. In the images shown below as an example, you can see the incident energy data for a time period ranging from 2012 to 2015, in a location in the Italian region of Friuli-Venezia Giulia.



Monthly solar irradiation estimates

Global irradiation optimum angle

Month	2012	2013	2014	2015
January	125.7	73.63	59.22	100.38
February	133.55	102.3	75.5	110.74
March	197.7	103.16	173.95	153.01
April	138.07	139.63	143.37	177.82
May	197.15	145.16	179.92	170.11
June	180.58	192.05	195.61	187.34
July	212.56	217.86	175.42	222.18
August	210.16	202.1	165.28	196.8
September	148.97	154.55	148.17	154.25
October	108.49	86.55	137.51	116.82
November	76.65	86.07	71.09	99.27
December	84.03	95.74	71.19	97.53

Source: (Joint Research Centre (JRC), European Commission, 2020)

SOLAR THERMAL AND PHOTOVOLTAIC ENERGY. ORIENTATION, TILT AND SHADOWS

Orientation and inclination: In general, the optimal orientation or azimuth for solar collectors that do not have an automatic solar tracking system is considered to correspond to the south-facing orientation (at 0º).

The inclination, however, depends both on the geographical location of the installation and the profile of its use throughout the year. It is generally accepted that for year-round installation use, the inclination must match the geographic latitude of the location where it is installed.

- Use of constant annual installation: Tilt collectors = geographical latitude
  b = latitude
- Preferred use of the installation in summer: Tilt collectors = latitude - 10º
  b = latitude – 10
- Preferential use of the installation in winter: Tilt collectors = latitude + 10
  b = latitude + 10

The percentage of losses a getter has due to its orientation and inclination can be estimated by the following expression:

Losses (%) for $15^{\circ} < \beta < 90^{\circ}$

$$100 \ x \ [1{,}2 \ x \ 10^{-4} \ x \ (\beta - \beta_{opt})^2 + 3{,}5 \ x \ 10^{-5} \ x \ \alpha^2]$$

Losses (%) for $b < 15^{\circ}$

$$100 \ x \ [1{,}2 \ x \ 10^{-4} \ x \ (\beta - \beta_{opt})^2 \ ]$$

Being:

a = Orientation or azimuth of catchers

β = Tilt of the catchers

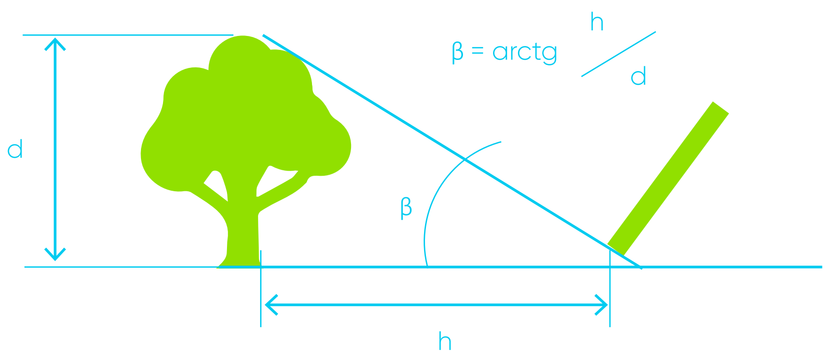
β opt - Optimal inclination of the catchers, according to latitude and usage profile

The existence of any type of shade on the catcher surface is a significant loss of system efficiency. In general, it should be ensured that both the distance to buildings and objects, and the separation between the catchers themselves, will be sufficient to prevent the projected shadow from reaching the beginning of any row of catchers at noon solar on the most unfavourable day (the day with the minimum solar height), the projected shadow does not reach the beginning of any row of catchers.

The procedure that allows to calculate the percentage of losses due to shadows, part of a diagram of trajectories of the sun (specific to each geographical area) on which objects, buildings, etc. that are in front of the catchers and that can prevent the passage of solar radiation at any given time.

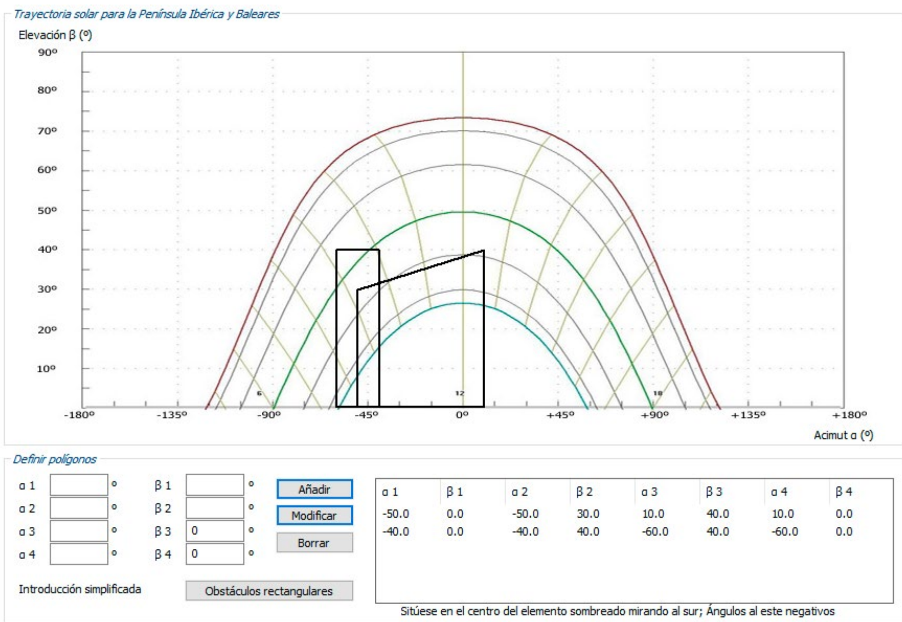
The elevation (β) corresponds to the angle of inclination relative to the horizontal plane while the azimuth (α) indicates the angle of deviation from the south direction, indicated as 00 (the angles to the east correspond to negative values)

To know the elevation angle of the volumes to be drawn on the path diagram of the sun you need to know both the distance in a straight line from the object to be represented, as well as the difference in heights between each point represented and the installation plane of the catchers. The elevation (β) corresponds to the angle of the formed triangle:



Once the elevation angle and deviation from the south (azimuth) are known, the object that can cause shade on the surface of the catchers can be embodied point by point in the sun's path diagram.

As can be seen in the resulting image shown below, the volumes of obstacles reflected on the diagram affect only certain quadrants in whole or in part. Each of these quadrants represents the path of the sun over a given period of time so each of them has a degree of influence or "weight" on total loss.



Source: Software CE3X Energetic certificate for existing buildings v2.3
(Ministry for ecologic transition and demographic challenge, Gobierno de España, 2020)

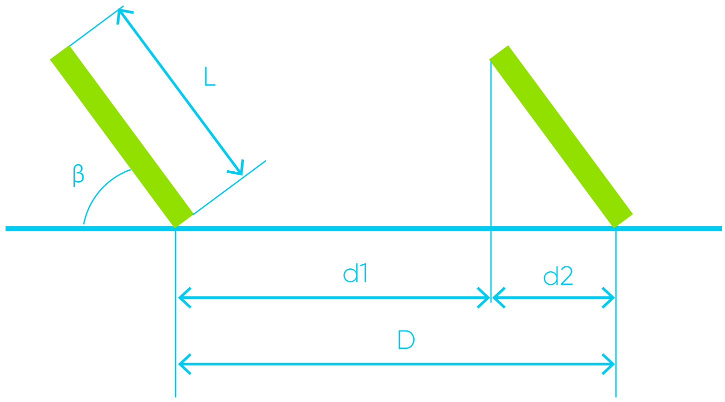
Reference tables (specific to the angle of inclination and orientation in which our catchers are located) are used to determine this weight, with the sum of all those weights being the percentage of shade losses. On the other hand, the presence of objects or the installation of getters in parallel rows can result in shadows being cast on the catchment surface, resulting in a loss of installation performance. To avoid this, the catchers must be sufficiently separated from each other, as well as separated from nearby objects that can cast shadow on them. The calculation for knowing the minimum distance of separation between catcher rows is as follows:

$$d1 = \frac{L\ x\ sen\beta)}{tg\ (Hmin)}$$

$$d1 = L\ x\ cos\beta$$

$$D = d1 + d2$$

Hmin = minimum collar height



Source: (IDAE, 2009)

Data for calculation:

- Catcher height (L) in meters
- Tilt the catchers in degrees (β)
- Profile of use of the facilities (summer, winter or throughout the year):

a) In year-round or winter facilities, the most unfavourable day is December 21, and the minimum solar height at solar noon is:

$$Hmin = 90^{0} - \text{latitude of the place} - 23^{0}27'$$

b) In summer facilities, the most unfavourable days are 21st March and 21st September, and the minimum solar height at solar noon is:

$$Hmin = 90^{0} - \text{latitude of the place}$$

MINI-HYDRAULIC.

The continuous supply of quality running water represents a fundamental need in various types of aquaculture facilities. Thus, for example, for the development of species such as trout it is necessary to have a continuous flow of quality water, which implies having a continuous resource that can be used for the production of hydraulic energy in the aquaculture facility itself.

Mini-hydraulic energy harnesses the potential energy of a water jump to generate electricity through a small turbine. It is common to make an artificial channel for the diversion of a part of the flow and the realization of a small jump, which provide the necessary working conditions to the turbine. Then the water returns to its channel.

Azud: Low-rise wall on the course of the river that causes small backwater of water.

Gross jump: Height between the water intake point of the azud and the discharge point in the river.

Useful jump: Unevenness between the water-free surface in the load chamber and the drain level in the turbine.

Net jump: Net jump is defined as the difference between useful jump and load losses caused by friction, turbulence, steering changes.

Load loss values can be considered between 5% and 10% of gross jump.

Turbine types: There are different types of turbines whose choice will depend on the flow rate and the water jump available, depending on the performance curve of each model. Some of the most common are the following:

- Kaplan Turbines: It is among the most efficient turbine types. They are suitable for small waterfalls and variable flow rates.
- Francis Turbines: Used with medium height jumps and discrete flow variations.
- Pelton Turbines: Suitable for high jumps. The design of its blades or spoons is based on the operation of the old water mills.

Barriers in European Rivers

Despite the undeniable usefulness of artificial barriers to river courses throughout history (Roman reservoirs such as Proserpine in Merida, Spain) still exist, the high number of barriers currently in European rivers (estimated to exceed one million) have a serious impact on ecosystems and species such as Atlantic salmon, sturgeon, or eel. In compliance with the Water Framework Directive (Directive 2000/60/EC) significant efforts are currently being made in river restoration. (MITECO, 2016) European projects such as AMBER (Adaptative Management of Barriers in European Rivers) will allow to know and evaluate thousands of these obstacles generally in disuse and which, in many cases, are not included in official inventories or records. (European Commission, 2019)

Among the advantages of using mini-hydraulic energy are the following:

- It is a renewable resource
- It is constantly available, as long as the flow rate remains stable.
- Low environmental impact

Its disadvantages include:

- Investment and civil works costs
- Administrative and bureaucratic procedures
- Regulatory aspects and conditions of network access

Estimation of installed power

The main parameters for setting the available power are the water flow and the existing jump. The installed power can be set from the following expression:

$$P = 9{,}81 \ x \ Q \ x \ Hn \ x \ e$$

Being:

P - Power in kW

Q - Flow rate in m3/s

Hn - Existing net jump in meters.

e - Efficiency factor of the plant. This factor is obtained from the product of the yields of the equipment involved in the energy production (turbine, generator and output transformer). A value of around 0.85 can be considered for current equipment. The energy production in kWh, provided that the constant flow rate is maintained, is obtained by simply multiplying the installed power by the operating time.

(IDAE, 2006)

For the completion of the above calculation, the value of the water flow is the element that presents the greatest difficulty in terms of its quantification. A rough estimate of the water sheet flow could be obtained from the following financial year:

From a known stretch of distance there is some reference that floats in the water and calculates the time it takes for the object to travel that distance, which gives us the speed at which the water flow runs.

From the data obtained from speed and estimating the cross section, the value corresponding to the flow rate is obtained from the expression: Q (m^3/s) = Cross section (m^2) x Speed (m/s).

WIND POWER

A wind turbine is a team that transforms the kinetic energy of the wind into mechanical energy of rotation through its blades and is used for the production of electrical energy by means of a generator.

A wind turbine requires a minimum wind speed to get up and running and stops for safety reasons when that speed exceeds certain thresholds. The usual use ranges of wind turbines are between 5 m/s and 25 m/s, being able to deliver their rated power with wind speeds around 12 m/s.

Although there are different types of wind turbines, most are currently horizontal and three-blade equipment, although multi-leverage equipment can be found in small production facilities.

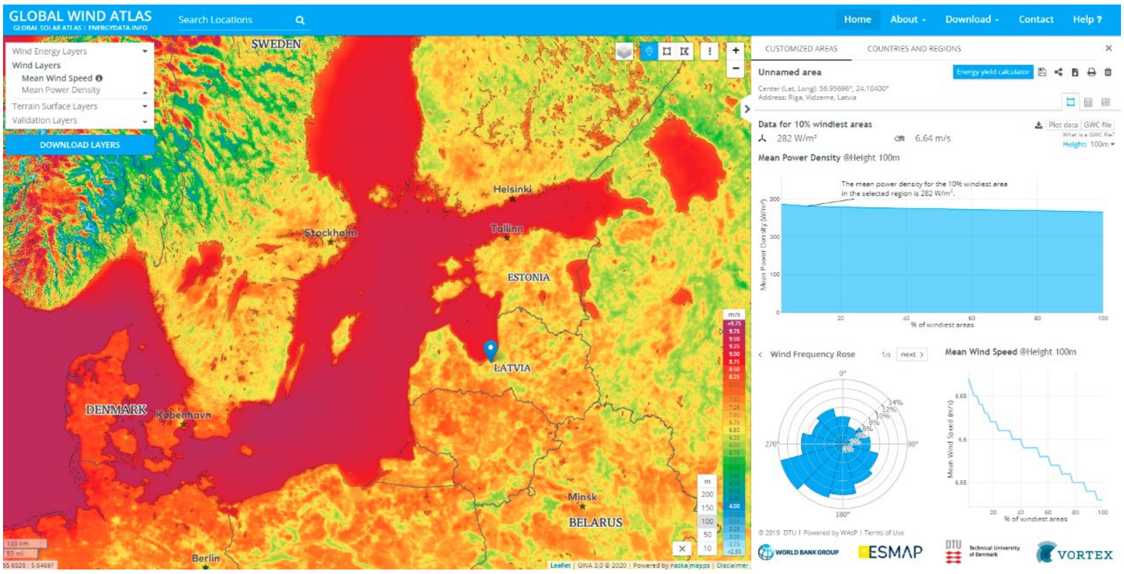
Generally, domestic or microgeneration supply facilities have installed powers of less than 20 kW while power installations greater than 200 kW are mainly located in wind farms. The entire range of intermediate powers (between 20 kW and 200 kW) is made up of so-called mini generation installations, intended for both self-consumption and the production and sale of electricity.

Some of the performance conditions of a wind installation to be known include:

Wind turbine height and geographical location: Considering that the wind speed increases with height and that its distribution varies considerably from one area to another.

Betz Limit: Maximum wind energy transformation performance into mechanics that can be achieved, regardless of turbine design. It is set at 59%.

Weibull Distribution: Statistical distribution of the frequency of wind speeds for a given location. It is represented as a histogram showing the probability of having a wind speed in a given location.



Source: (Global Wind Atlas, 2020) "Global Wind Atlas 3.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info"

10. VIABILITY AND RETURN OF THE INVESTMENT

PRS (Simple Return Period): It is an indicator obtained from the relationship between the investment and the savings obtained. It allows you to know in a simple way the period of time necessary to recover the total of an investment.

NPV (Net Present Value): Represents the value of profits earned throughout all phases of the project. In a simple way, it represents the amount of money that a potential investor would earn today if he decided to undertake the project.

IRR (Internal Return Rate): This indicator provides percentage information about the return on an investment. Example of calculation. Economic feasibility study.

EXAMPLE OF CALCULATION. ECONOMIC FEASIBILITY STUDY

The main starting data are:

- The economic cost of the energy saving measure to be implemented.
- Expected annual energy savings.
- Expected annual economic savings, based on the price of energy.
- The estimated annual increase in the price of energy.
- The discount rates.

Suppose by way of example, the following situation:
it is intended to replace the lighting of a workshop, currently composed of a total of 10 mercury vapor luminaires of 250 W with LED type luminaires of 80 W of power. In the workshop the lighting is in operation around 2,000 hours per year. The cost per unit of the new LED lighting hoods is 100 euros and the price of the electricity kWh is at 0.12 s/kWh.

With this data we determine the energy and economic savings that we could obtain by implementing the savings measure:

Current situation:
10 luminaires x 0.250 kW x 2,000 hours of operation = 5,000 kWh per year
5,000 kWh/year x 0.12 s/kWh x 600 s/year

Expected situation:
10 luminaires x 0.080 kW x 2,000 hours of operation =1,600 kWh per year
1,600 kWh/year x 0.12 s/kWh s 192 s/year

The energy savings are therefore 3,400 kWh per year which translates to 408 euros per year.

Because the investment to be made is 100 x 10 x 1,000 euros, a simple division offers us the simple return period of our investment that is around two and a half years.

PRS = 1,000 euros of investment / 408 euros per year of savings - 2.45 years.

Although this calculation can serve as an approximation, it is excessively simple when it comes to carrying out higher actions. For a slightly more detailed calculation, which we will set as an example over a 10-year horizon, we will also need to have the following data:

- Estimated annual increase in the price of energy. To know this data, we will have to resort to existing forecasts of energy prices in the future. As an example, we will assume an annual increase of 1% in the price of electricity.

- Discount rate. Represents the current value of a future payment. It could be defined as the cost of the financial resources that the investment entails. That is, in the case of financing the investment through a bank loan, the value that we will allocate at the discount rate must be the interest rate of that loan while, if the financing is made with own resources, the value that we should assign to it will be - at least - that of the return we would have obtained from making that investment in other product within a similar timeframe. In our example we will take a value of 4%.

Starting data:

Concept	Valor
Investment cost	1.000,00 €
Energy savings	3.400,00 kWh/year
Economic Savings	408,00 €/year
PRS	2,45 years
Energy annual increase	1 %
Discount rate	4 %

Installation costs and maintenance costs should also be taken into account in the cost section. For our example we will consider a single initial installation cost worth 10% of the total cost of the total investment and maintenance costs (preventive, corrective, cleaning...) of 5% of the total annual investment every two years. The costs are therefore divided as follows:

Year	Investment (€)	Installation cost (€)	Maintenance cost (€)	Total cost (€)
0	1000	100		1.100
1			50	50
2				
3			50	50
4				
5			50	50
6				
7			50	50
8				
9			50	50
10				

The calculation of the revenue earned relates the expected economic savings to the annual increase in the energy price and the discount rate for a given year, as follows:

$$I = A\ x \left(\frac{(E)^{n-1}}{(Td)^{n}} \right)$$

Being:

A = Annual economic savings

E = Annual increase in the price of energy

Td = Discount rate

n = Calculated year

Year	Investment (€)	Installation costs (€)	Costs mtto (€)	Total costs (€)	Income (€)	Balance (€)
0	1000	100		1.100	0	-1.100
1			50	50	392	342
2					381	381
3			50	50	370	320
4					359	359
5			50	50	349	299
6					339	339
7			50	50	329	279
8					320	320
9			50	50	310	260
10					301	301

Therefore, the correspondent calculation for the income column for the fourth year would be as follows:

$$I = A \; x \left(\frac{(E)^{n-1}}{(Td)^{n}} \right)$$

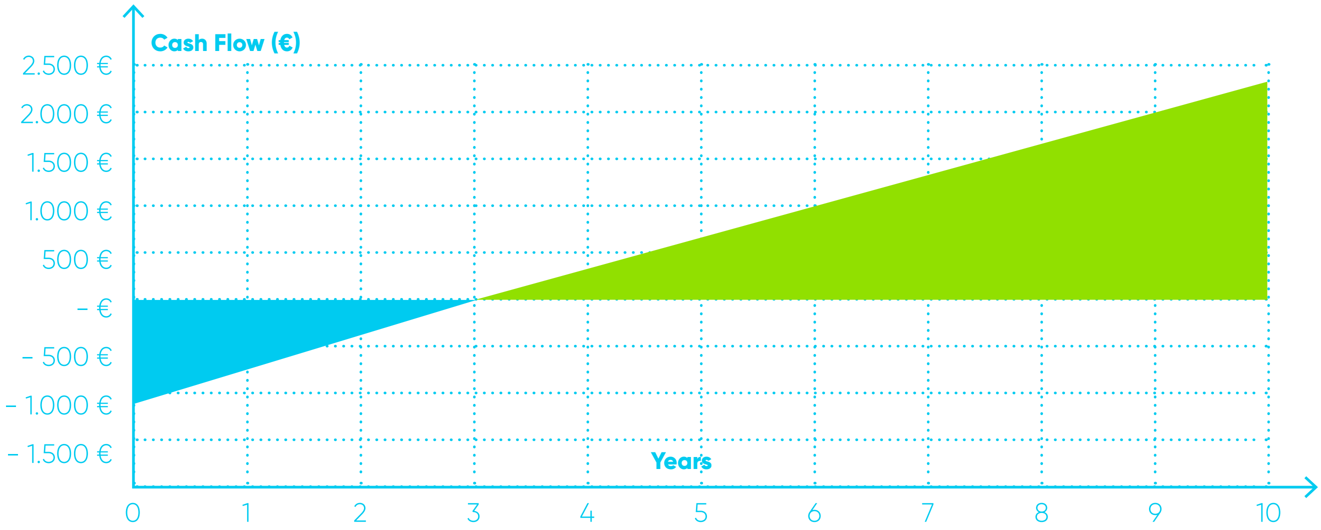
$$I = 408 \; x \left(\frac{(1{,}01)^{3}}{(1{,}04)^{4}} \right)$$

$$I = 359{,}32$$

The balance sheet, on the other hand, is obtained from the simple subtraction between costs and revenues. Finally, the accumulated cash flow will be obtained by the sum of the previous year's cash flow value and the balance sheet value for the current year. The NPV value will correspond to the last cash flow value.

Year	Invest-ment (€)	Installa-tion costs (€)	mtto costs (€)	Total costs (€)	Income (€)	Bal-ance (€)	Accumulated cash flow (€)
0	1000	100		1.100	0	-1.100	-1.100
1			50	50	392	342	-758
2					381	381	-377
3			50	50	370	320	-57
4					359	359	303
5			50	50	349	299	602
6					339	339	940
7			50	50	329	279	1.220
8					320	320	1.539
9			50	50	310	260	1.800
10					301	301	**2.101**
							NPV

As can be seen, the initial investment plus the rest of the costs considered will be recovered from the third year and, after 10 years, the investment will have generated a total of 2,101 euros of net profit (NPV).



DECISION CRITERIA. CALCULATION OF THE IRR.

Both the IRR and the NPV are indicators that will allow us to evaluate the return on an investment, but while the NPV provides us with a net absolute data the IRR offers us a percentage value. It will be desirable to have a high value of the NPV which, of course, must always be above zero for there to be a profitability of the project. The Internal Return Rate (IRR) can be understood as the maximum interest on debt eligible for the financing of a project. In general, the value of IRR should be greater than the value of the discount rate. The value of IRR is complex to calculate so the use of spread-sheets is commonly used. Considering that the IRR is defined as "the discount rate that equals the NPV to zero" and that we know the value of NPV, the calculation becomes an iterative process.

In order to determine that value. For the previous example, the calculation with the aid of a calculation sheet would be the following:

Year	Total cost (€)	Economic saving(€/year)	Cost saving
0	1.100	0	-1100
1	50	408 €	358
2		408 €	408
3	50	408 €	358
4		408 €	408
5	50	408 €	358
6		408 €	408
7	50	408 €	358
8		408 €	408
9	50	408 €	358
10		408 €	408

IRR (value1: value10) = 32,4%

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