

CARBON EMISSION EFFICIENCY BEST PRACTICES: A CASE STUDY IN AN INDUSTRIAL SITE

Abstract

Carbon emission efficiency is key in sustainability development such as renewable energies and nuclear. To reach the zero-carbon emission all those levers should be activated. **Carbon emission efficiency** has some advantages over other levers. Renewable energies are inexhaustible resources, but they are not fully available everywhere (it depends on the geographical situation) and the storage of this energy is still to be developed. Nuclear is also an option for avoiding fossil fuels. Nevertheless, the treatment of nuclear waste is still an issue because they are still radioactive and therefore harmful for health. **Moreover, in case of incident the consequences can be huge.**

This article discusses various best engineering practices for reducing carbon emissions. All those best practices have been selected among different practices because they have been successful experiences: tested, reproduced and important CO₂ savings confirmed.

The industrial site of this case study is a pharmaceutical manufacturing in France. Thanks to the implementation of the best **carbon emission efficiency** practices, site's carbon emissions have been reduced by 48% in a decade (from 2010 to 2020).

1. Introduction

Industry represents 18% of world emission carbon. It is the third sector after electricity and heat producers and transport [1].

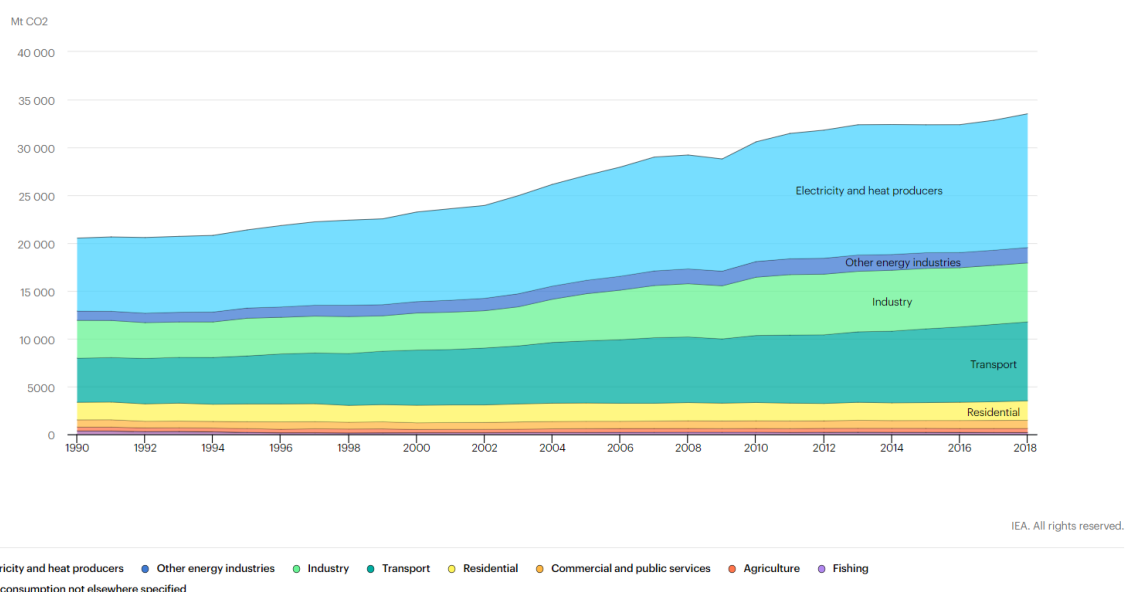


Figure 1. World CO2 emissions by sector [1]

“Energy efficiency simply means using less energy to perform the same task – that is, eliminating energy waste” [2]. “Energy efficiency brings a variety of benefits: reducing greenhouse gas emissions, reducing demand for energy imports, and lowering our costs on a household and economy-wide level” [2].

The definition that applied to this case study is reducing greenhouse gas emissions (i.e. Carbon emission efficiency).

This article is a case study in an industrial site of a pharmaceutical company in west of France. The site is 28 years old, produces yearly 70 million packs of medicine (4 dry oral forms: suspensions, capsules, sachets, and tablets) and employs 400 persons. This industrial site has been selected for this case study because it has various and high consuming equipment. It is also an innovative and a complex site. Nowadays, this type of profile is common (modern industry). Therefore, best practices identified can be applied to similar industries such as food, chemistry, and cosmetics for carbon emission efficiency and energy saving.

The different steps to deliver business needs with minimum energy are the following:

- Clarify past and current site’s performances (collect data etc.)
- Identify potential savings
- Quantify savings
- Agree validation approach
- Deliver savings
- Monitor performance to prove savings

This article contains several major actions defined and implemented for reducing site’s carbon footprint. The site consumes electricity and natural gas and produces secondary utilities such as hot water, chilled water, and compressed air. The utilities represent 80% of site’s energy consumption.

Therefore, in this case study, the bests practices are focused on utilities:

- HVAC (Heating Ventilation and Air Conditioning)
 - Setback mode
 - Fans & motors
 - Temperature mead-bands
 - Air Change Per Hour (ACPH)
 - Air Fresh Unit (AFU)
 - Filters
- Variable Speed Drive (VSD)
- Insulation
- Boiler (hot water and steam)
- Heat pump (heat recovery)
- Site Weekend and Evening Shutdown Plan (SWEEP)
- Compressed air (oil and oil-free)
- LED Light and motion sensor

2. HVAC - Heating Ventilation and Air Conditioning

In industry where environmental condition must be maintained, HVAC - Heat Ventilation Air Conditioning – is widely present. The ventilation and associated equipment of a building represent nearly 60% of its overall energy consumption and are often overlooked.

The site has 42 HVAC for the regulation of temperature, pressure and hygrometry in several area (e.g. for clean room).

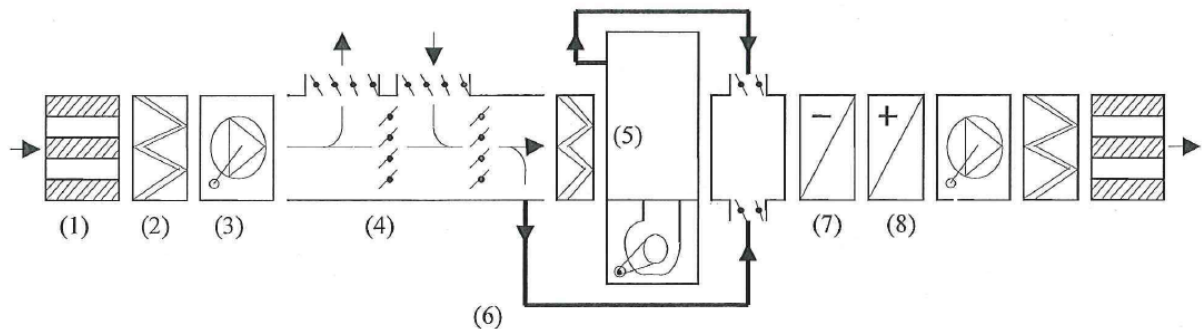


Figure 2. HVAC schematic

Below, a description of the different elements in figure 2:

- (1) A sound trap: It reduces the noise generated by the installation and the air circulation.
- (2) A filter: Its role is to stop the particles circulating in the air.
- (3) A fan: It ensures the continuous flow of air in the distribution and return networks.
- (4) A control flap: It is used to regulate the air flow.
- (5) A dehydrator: It has the function of dehydrating part of the air as needed. The other part is bypassed.
- (6) A bypass: It allows part of the air not to be treated by an element of the plant (here the dehumidifier).
- (7) A cold coil: The function of a cold coil is to cool and dehumidify the air.
- (8) A hot coil: It is used to heat the air.

2.1. HVAC: Setback mode

The 1st action on HVAC is the implementation of HVAC set back mode. It consists of stopping fans or reducing their speed where there is no activity or when activity is low.

Before starting a new week, a specific HVAC functioning planning is established based on the production planning. The number of shifts is also taken into consideration. For example, if a production room will be only in-service during morning shift, the HVAC covering this room will be off during evening and night shifts or fans' speed will be reduced.

All HVAC covering non-critical area (quality or/and EHS) such offices are stopped during out of working hours.

Each HVAC setback mode has been defined following the environmental condition to maintain in the room (airflow, temperature, humidity, and pressure). It is important to not degrade the quality of the products in the area treated by the HVAC.

2.2. HVAC: Fans & motors

Many HVAC on the site have belt drive fans with conventional motors as in the figure 3:



Figure 3. Belt drive fan with conventional motor

All belt drive fans with conventional motors have been changed by direct drive multi grid fans with Electronically Commutated (EC) motors for having a high efficiency at nominal and reduced air flows.



Figure 4. Direct drive multi grid fans with EC motors

An EC motor is a brushless Direct Current (DC) motor utilizing a permanent magnet rotor with a built-in Variable Frequency Driver (VFD) and a DC to AC transformer. The mechanical commutation and the brushes are replaced by an electrical commutation [3].

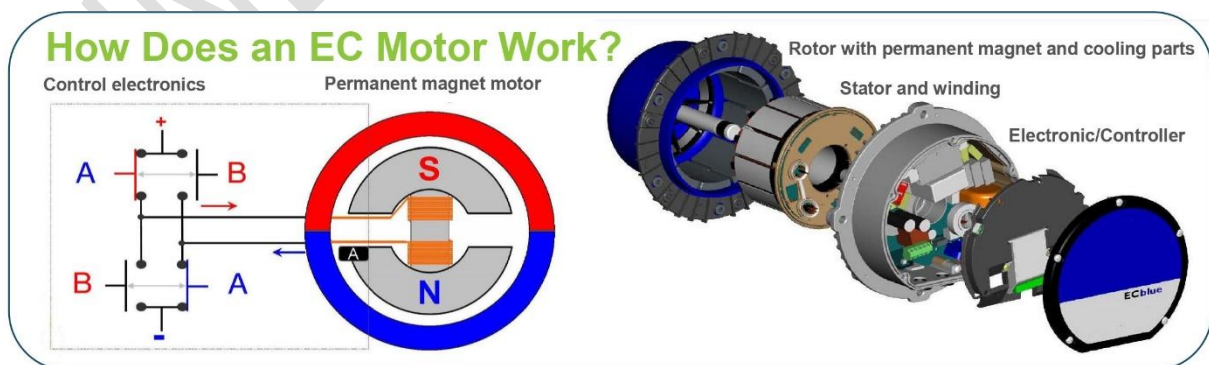


Figure 5. EC Motor functioning [3]

For the speed range 50%-100%, the efficiency of an EC Motor is between 91-92% whereas for an AC (Alternating Current) Motors it is between 84-89% [4].

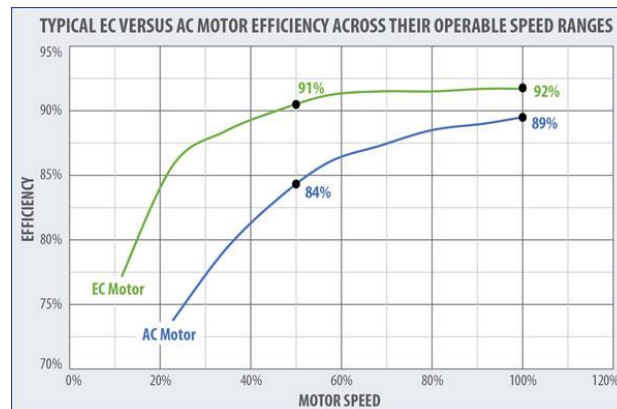


Figure 6. Typical EC Versus AC Motor Efficiency Across Operable Speed Ranges [4]

It is also important to state that this technology has others benefits:

- The redundancy of the system is improved (multi grid).
- The maintenance is easier and maintenance costs are reduced (smaller fan sizes, easy to handle and same fan modules).

2.3. HVAC: Temperature Deadbands

Some HVAC have been fitted with cooling or/and heating coils for maintaining a specific temperature. The main issue is that HVAC is permanently heating or cooling or both.

This method consists of implementing two setpoints. It helps to eliminate unnecessary simultaneous heating and cooling. When value is within range, heating and cooling are off.

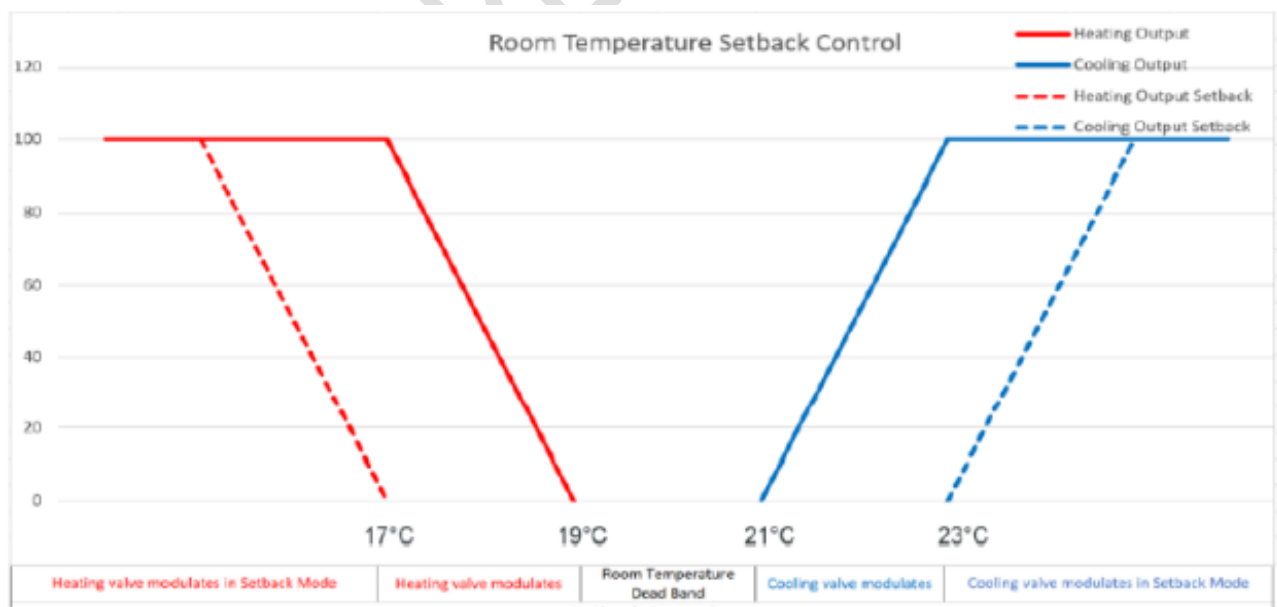


Figure 7. Example of room temperature Deadbands

Most of the time very tight temperature is not really required for product quality or/and for a sure environment (EHS = Environment, Health & Safety).

2.4. HVAC: Air Change Rate

By reducing air change rate of an area, we reduce the speed of a fan and therefore its energy consumption [5]. Settings of many HVAC have been changed for reducing the Air Change Rate in areas treated by those HVAC, but we make sure to still maintain environmental conditions and particulate.

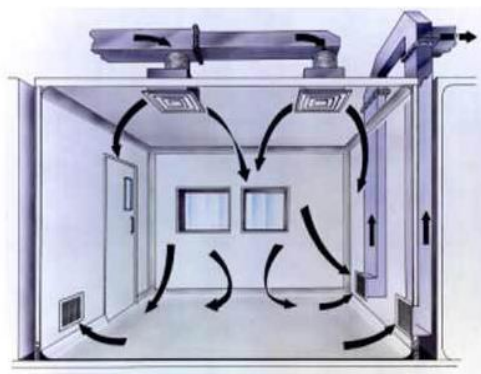


Figure 8. Typical air flow in a room

Air changes rates are influenced by:

- Initial design
- Heat gains in the room
- Containment between rooms (pressurization)
- Make up air for local extract (or fume cupboards)

All air change rates have been calculated by excluding large fixed vessels/isolators from room volume.

Table 1. Example of previous and new Air Change Rate

HVAC identification	Air Change Per Hour Before	Air Change Per Hour After
HVAC A	12	10
HVAC B	7	5
HVAC C	15	12

2.5. HVAC: Dehumidifiers

Several HVAC have dehumidifiers because products manufactured are sensitive to relative humidity. Different dehumidifier technology exists but this study is only about wheel dehumidifier [6, 7].

The humidity setpoint of all dehumidifiers have been reviewed and increased when possible and by considering quality and EHS requirement.

The regulation of all dehumidifiers has also been optimized when possible thanks to automatism and electrical revamping (implementation of new elements for allowing regulation improvement).

All dehumidifiers are fitted with a technology named Power Purge® and developed by Munters company (dehumidifiers manufacturer).

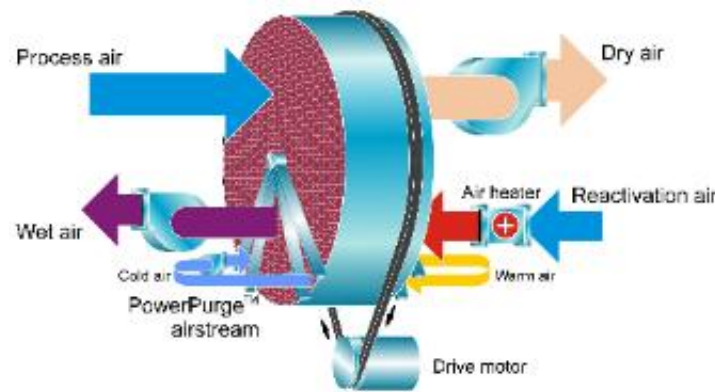


Figure 9. Munters rotor principle with Power Purge® [8]

This type of dehumidifier permits to save energy because it recovers waste heat of the wheel and used it for the reactivation of the air.

2.6. HVAC: Filters

Filtration is key in HVAC as it retains particles for maintaining indoor air quality. Filters are broadly used in industrial, commercial, and residential HVAC applications.

A filter spends on average 1700 kWh/year. For example, it is:

- 3 times more than a dryer,
- 5 times more than a class A refrigerator,
- 13 times more than an iron, ...

It should also be remembered that a high efficiency filter will certainly create good air quality, but also pressure drops synonymous with energy expenditure (1 Pa = 1 €).

A global, energetic, and environmental reflection is conducted. It is possible to save energy but not at the expense of filtration efficiency. An adapted filtration strategy will greatly extend filters life, reduce energy consumption, maintenance & disposal costs, and energy costs [9].

The filtration strategy in this case study is the following:

- Maintain/improve current filtration air quality
- Change to low energy filtration
- Remove low-capacity panel filter
- Consider removing panel filters and just having bag filters large capacity
- Add pressure/volume control

3. Variable Speed Drive (VSD)

“VSD increases efficiency by allowing motors to be operated at the ideal speed for every load condition. In many applications VSDs reduce motor electricity consumption by 30–60%” [10].

In this case study, variable speed drive has been generalised and in priority in equipment that consume a lot of energy.

The 1st main action has been to buy and implement a new 160 kW oil free compressed air with a variable speed drive integrated [11]. The 2nd main action has been to modify a chiller for adding a variable speed drive (chiller cooling capacity = 937 kW). The last main action has been to change direct pumps on the hot water system by 4 new pumps mounted with variable speed drive (15 kW each).

4. Insulation

Building Insulation is a key action and should be among the first action to realize [12, 13]. Whether it is to heat or cold an area, a suitable and robust insulation, will reduce thermal lost. It is sometimes not a site priority. Most of the time it is not complex and can contribute greatly to reduce carbon emission.

The first step is to perform a thermal insulation. Thanks to this survey all insulation gaps will be precisely identified and evaluated (thermal lost and cost).

In this case study, the insulation of large area such as the 2 main warehouses for raw materials and finished products (5 500 m²) has been improved with rockwool.

Insulation applies also to pipes and pipes accessories (filters, valves etc.). Like for building, a thermal survey has been conducted and all gaps identified have been fixed as soon as possible.

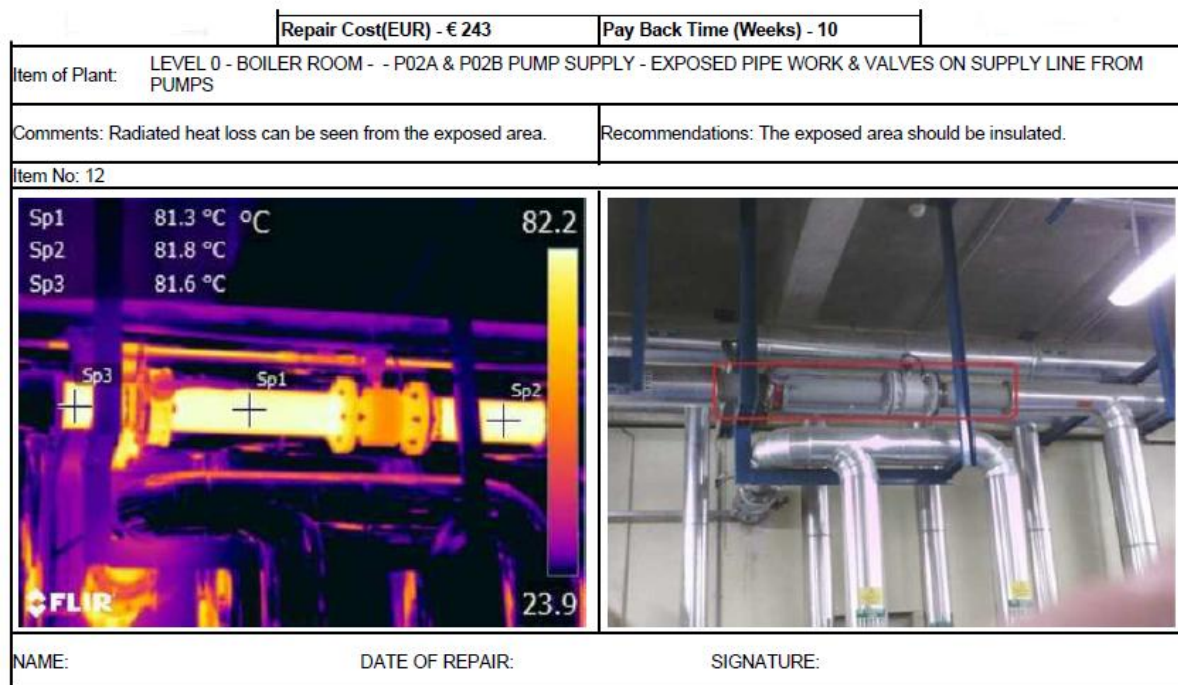


Figure 10. Example of thermal result on hot water network

5. Boilers

5.1. Hot water boiler

The site has 3 hot boilers: 2 for the production building (2 MW and 2,5 MW) and 1 for the administration building (300 kW). The boilers are supplied by natural gas.

The first action consists of changing the burner of production building boilers by a new technology of burner with electronic modulation. The following action in those boilers is to optimize the regulation by taking more account of several parameters such as external temperature.

The main action in the administration building boiler is to add the boiler on the BMS (Building Monitoring System). BMS offers many advantages. For instance, a setback mode has been implemented (boiler stop during the night and the weekend when building is empty).

There is an action also on the accessories and more precisely on hot valves. Hot water 3 port valves have been changed by 2 port valves for reducing hot water consumption.

5.2. Steam boiler

The site has 1 steam boiler (capacity = 7000 kg/h) supplied by natural gas. The steam boiler is fitted with an economizer: Placed downstream from the boiler on the combustion products circuit, an economizer is an exchanger that recovers part of the heat contained in the combustion products for preheating the generator feed water [14, 15]. The feed water, coming from the tank, circulates against the current in the exchanger. The flue gas temperatures initially between 180 and 260 ° C are thus lowered to a value of 110 to 130 ° C.

For natural gas, each 20 °C reduction in the temperature of the combustion products increases the efficiency by 1 point. Thus, the combustion efficiency generally goes from 90 to 95% (Net Calorific Value) thanks to the economizer. In this case study, the installation of an economizer has permitted to achieve a gain of around 5 points in combustion efficiency.

5.3. Steam trap annual audit

Maintaining steam traps is essential for the proper functioning of the steam network. Leaking traps induce considerable losses in energy consumption, which has the effect of increasing gas consumption and CO2 emissions. An annual survey is carried out and detailed report is established: number of leaking steam trap, steam trap to be replaced, losses due to leaks in kilogram of steam etc.

Changing defective traps greatly improves the energy performance of the network.

5.4. Heat recovery

The purpose of a blowdown valve in the upper level of a steam boiler is to reduce the concentration of dissolved salts present in the water and which are gradually concentrated in the boiler. The heat of the extracted water is recovered and directed to an exchanger to preheat the softened water.

The condensates from steam trap are also recovered to save energy, water, and chemical products. They are sent directly to the water feeder tank [16].

6. Heat pump

“Heat pumps are efficient and reliable devices to heat and cool useful media” [17].

“Heat pumps (vapor compression heat pumps) transfer heat by circulating a phase changing substance called a refrigerant through a cycle of evaporation and condensation” [18].

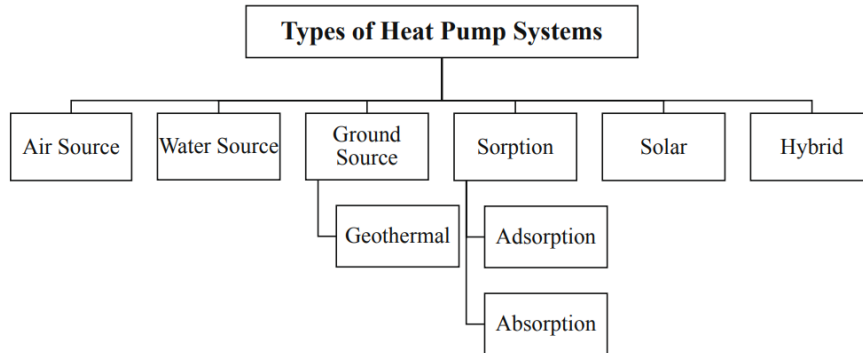


Figure 11. Heat pumps categories [19]

First, a Heat Pump study is carried out to identify initial energy reduction opportunities available. The site, in this case study, has a central chilled water system and a central hot water boiler system.

The chilled water system comprises: 4 chillers, 3 primary pumps, 3 condenser water pumps, 2 cooling towers and secondary distribution pumps supplying chilled water to equipment. The chillers are run with a set point of 4°C.

The hot water system comprises: 2 boilers and 13 pumps. The hot water system is run at different temperatures depending on the day of the week and the season. During the week the hot water system is run at 84°C and out of production hours (i.e. all the weekend) the systems water temperature is reduced to 70°C.

The heat pump will recover the heat lost on the chilled water system and distribute it to the hot water system. The heat pump will supply nearly 70% of site need on hot water.



Figure 12. Rear view of the Heat pump & Production Skid

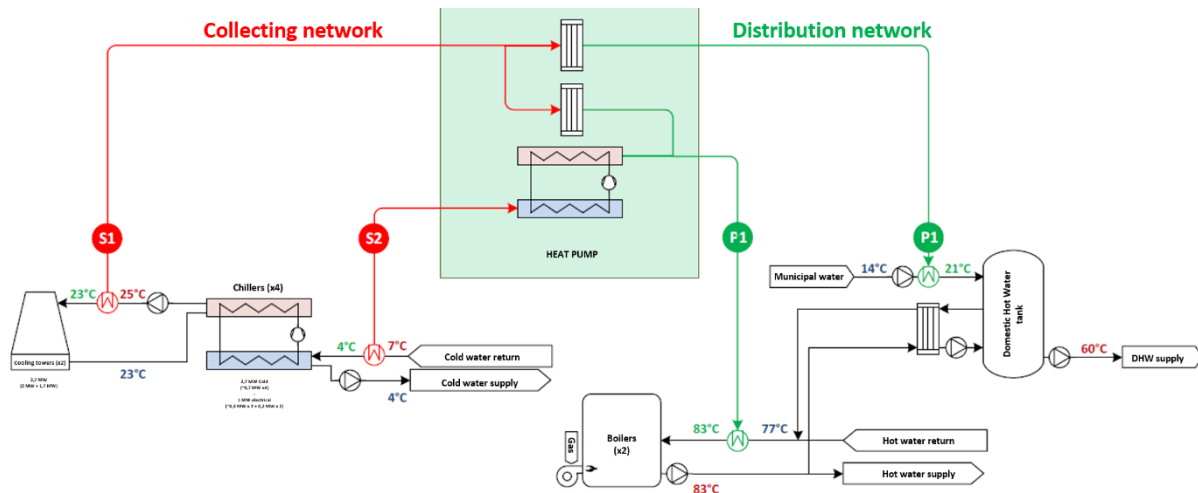


Figure 13. Heat pump P&ID

Several equipment/elements have been installed in addition to the heat pump itself: A production Skid; A new electrical supply cabinet; A water tank (7 m³); Pipes network and insulation etc.

Below some keys data:

- Combustion efficiency = 93%
- Distribution efficiency = 95%
- Distribution efficiency of the recovery network = 98%
- GCV (Gross Calorific Value) / NCV (Net Calorific Value) = 1,11
- Heat pump power = 680 kW
- Installation COP (Coefficient of performance) = 2,8
- Temperature regime: 90/80 °C

Moreover, a dedicated supervision is used for a continuous monitoring the status and performance of the heat pump.

The following figure illustrates the savings: carbon emission, water consumption, and cost reduction.

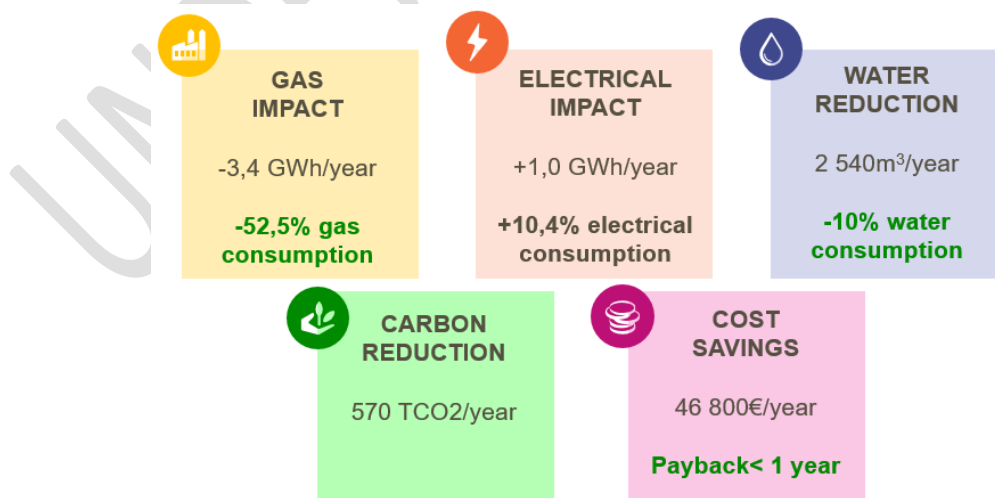


Figure 14. Heat pump savings

Savings are significant. Site carbon footprint was divided by nearly two thanks to this key project.

7. SWEEP - Site Weekend and Evening Shutdown Plan

The goal is to give information to all users on how and where to stop equipment. It is not a complex and expensive action. Moreover, it involves every user. The energy wardens also play a leading role in delivering this initiative. This help to ensure that area performance is maintained.

The SWEEP system is used to standardize the shutdown procedure for all areas of site including manufacturing areas, laboratories, and office areas. Separate sheets can be developed for extended shutdowns, break shutdowns and changeovers. Start-up procedures for each area can also be developed.

It is similar to the 5S standards in production areas [20].

It will typically consist of a single page split into 2 sections containing:

- A layout drawing of the area, showing key equipment & being color coded as required
- An action list of things to be done at the end of the working shift or week e.g. switch off PC's, switch off equipment, shut windows or doors, turn off lights
- Indicate who is responsible for carrying out the SWEEP
- Indicate on the plan where switch off points are if it is not obvious
- Detail equipment that should not be turned off

Management of SWEEP are as follow:

- Be displayed visibly in the area
- Be implemented and owned by the area owner and his team member
- Deviations from the standard are reported to the area owner and the site Energy Manager

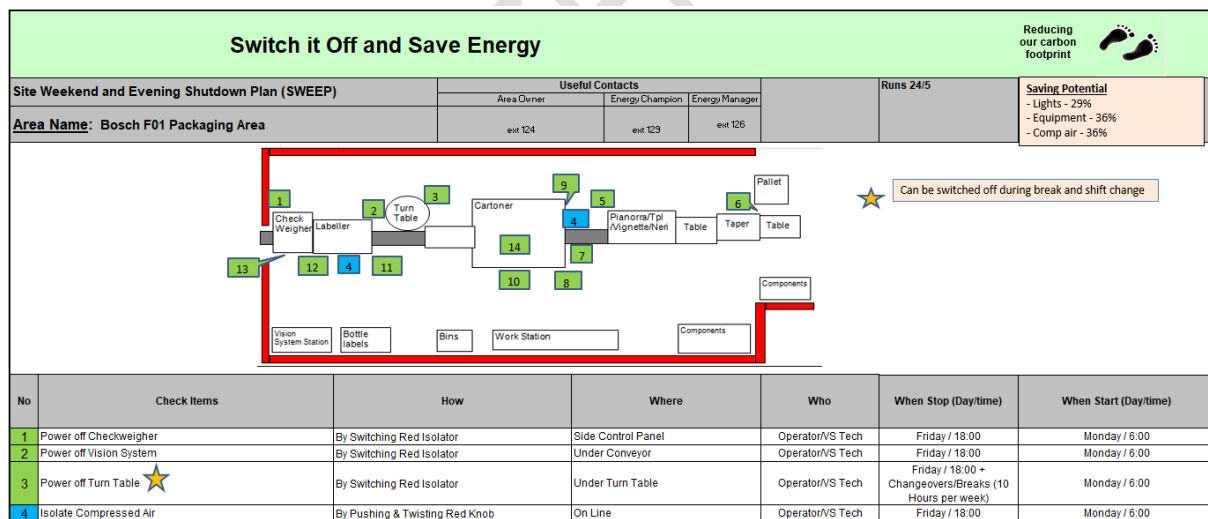


Figure 15. SWEEP example

8. Compressed air

Compressed air is widely used in industrial site. Compressed air is typically one of the most expensive utilities in an industrial facility [21].

8.1. Oil free air compressors:

Site has 4 oil-free compressors to supply pharmaceutical air to production equipment. A compressed air network serves the production equipment around the site. At the points of use of compressed air, there are also several piping accessories that sometimes cause leaks (filters, valves, etc.).

Compressed air represents more than 8% of the site's electricity consumption. The leak rate from the compressed air network is approximately 15%.

We have bought an ultrasonic Detector, done leaks identification campaign and repairs.

Each leak is described in a specific sheet with a picture and all relevant elements. The leaks are managed through a Computerized Maintenance Management System (CMMS).

Site's compressed air pressure has also been reduced from 8,8 to 7,0 Bar. The pressure has been reduced progressively for evaluating impact on equipment.

8.2. Oil lubricated air compressors:

This site has also 2 oil lubricated air compressors for non-critical equipment and a dedicated distribution loop.

Heat recovery takes place at the oil return at the air compressor [22]. The oil which lubricates and seals the various parts on the compressor will also heat up. The oil is then used to transmit heat to a water loop using a heat exchanger. This water loop supplies a domestic hot water installation and heating installations.

9. LED Light and Motion sensor

"Lighting represents almost 20% of global electricity consumption" [23].

In recent years, the site has undertaken to replace T8 and T5 fluorescent lamps by Light-Emitting Diodes (LEDs) in an energy saving process. At the same time, this has made it possible to extend the lifetime of our luminaires and thus make gains in terms of maintenance. The site has also installed motion detectors in an energy-saving approach.

Example of LED light and moving implementation campaign:

- 38 "300 x 600 mm size lighting" integrated into pharmaceutical ceiling in production area remained in T8 (2x58W), i.e. approximately 139W. The retrofit of these lighting consists of replacing the internal part with 36W and 63W LED kits. It is crucial to also consider light color in area where people make precise work like a table in a production room and in an office.
- 17 moving sensors are implemented depending on the characteristics of the areas and the number of people using the premises.

10. Synthesis of carbon emissions reduction per best practice

Energy consumptions have been recorded before and after actions thanks to fixed electrical and gas meters. Moreover, they have been monitored and analyzed through an energy supervision software.

The savings are for a period of 1 year.

Table 2. Carbon emissions reduction of all best practices and complexity level

Best Practice name	Best practice complexity level	CO2 emissions per kWh of electricity (kg CO2/kWh)	CO2 emissions per kWh of gas (kg CO2/kWh)	Electricity Savings (kWh)	Gas savings (kWh)	CO2 emissions reduction in tons (electrical and gas savings * emission factors)
HVAC	HIGH	0,0548	0,1840	1 570 000	908 000	253
Variable Speed Drive	MEDIUM			1 620 000	0	89
Insulation (hot and chill)	LOW			52 000	328 000	63
Boilers	MEDIUM			0	720 000	132
Heat pump	HIGH			-1 000 000	3 400 000	570
SWEEP	LOW			925 000	0	51
Compressed air	MEDIUM			830 000	162 000	75
Led light and motion sensor	LOW			690 000	0	38

11. Conclusion:

This case study shows that carbon emission efficiency can be reached by applying best practices. Those best practices are on high consuming equipment and are mix of innovative and simple action. For example, the heat recovered on the chilled installation with a heat pump has permitted to significantly reduce carbon emissions. Implementation on HVAC of multi grid fans with electronically commutated motors, temperature Deadbands and heat recovery on dehumidifiers are also advanced actions that improved carbon emissions efficiency.

The industrial site of this case study has reduced by 48% in ten years its carbon footprint (from 2 464 to 1 271 CO2 tons with same impact factor such as production volumes and external temperatures).

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly used products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

UNDER PEER REVIEW

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