ENGINEERING TOMORROW

Danfoss

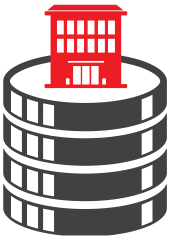
Danfoss – your energy efficiency partner of choice for the hospitality industry

Energy saving in hotels: a treasure hidden among the installations

Reconsidering efficiency in hotels

Reconsidering energy efficiency in hotels and the hospitality industry

In a highly competitive market like the hospitality industry, cost control is a vital factor for successful businesses. Margins and profits have a decisive impact on the management of activities, including the quality of services for guests. With energy costs typically representing up to 10% of operating costs (the second largest item after personnel costs), it's no wonder hospitality companies are on the lookout for savings opportunities



Energy costs may represent up to **10%** of operating costs

the **2nd** item after personnel costs

About **60%** of energy costs are attributable to heating, cooling and hot water production

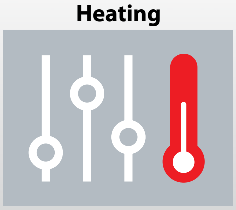
Energy plays a key role in ensuring adequate levels of comfort and service for guests. Furthermore, there is a clear trend in this sector that aims to reduce both energy consumption and water usage. Together with growing demand for certified environmental sustainability, this requires increasingly efficient components, systems and installations – and more effective building management too.

Technical building systems (**TBS**) are a fundamental element of the energy efficiency of hotels. These systems are linked, for instance, to the operation of heating, air-conditioning, ventilation, hot water and lighting installations. Danfoss has the right technologies and proven experience to make your buildings more efficient.

Almost 60% of energy costs result from heating, cooling and hot water production, providing plenty of scope for potential improvements in energy efficiency in these areas. Combining the latest HVAC (heating, ventilation and air conditioning) technologies (including automatic hydronic and thermal balancing, variable speed compressors and speed-controlled pumps) with advanced TBS building automation enables more granular control of areas and rooms within the hotel – delivering both greater comfort and efficiency.

Technical systems: possible improvements

Heating

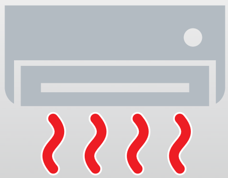


Individual checks per room; automatic hydronic balancing; speed-controlled pumps

Domestic hot water

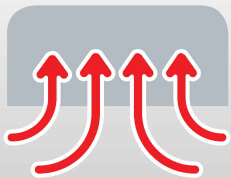
Automatic thermal balancing

Air-conditioning



Checks for each single room; variable speed compressors

Ventilation



Speed control of the fan motors

Table of contents

Executive summary 5
Chapter 1 - **Introduction** 6
Available spaces: the most precious resource in the nZEB era 6
A new energy parameter: the equivalent photovoltaic surface 7
Chapter 2 - **Energy simulation of a building for hotel use** 8
Chapter 3 - **Influence of endogenous loads** 10
Requirements without endogenous loads 10
Requirements with endogenous loads 11
Conclusions 12
Chapter 4 - **Influence of orientation** 13
Conclusions 14
Chapter 5 - **Influence of thermal insulation on energy requirements** 15
Conclusions 17
Chapter 6 - **Influence of intake of external air** 18
Influence of the regenerator's efficiency on consumption 18
Influence of the injected air temperature on the power required to the terminals 19
Total power required to the regenerators 19
Energy requested by the AHU (Air Handling Units) fans 20
Conclusions 20
Chapter 7 - **Influence of thermal insulation on the air temperature in the rooms** 21
Air temperature in the occupied rooms 21
Consequences on the plant management 22
Conclusions 23
Chapter 8 - **Comparison between maximum design powers and maximum powers in the standard average year** 24
Load on the batteries of the air handling unit 24
Fan Coil in heating and cooling 24
Total annual load on hot and cold circuits 25
Consequences on the flow in the terminals 26
Conclusions 28
Chapter 9 - **Theoretical advantages of variable water flow circuits** 29
Power required to move a water flow 29
When the power varies with the cube of the pump rpm 29
Limits of traditional two-way valves 32
The risk of hunting 38
The risk of starving 40
Conclusions 41
Chapter 10 - **Advantages of pressure-independent valves Danfoss AB-QM** 42
How the pressure-independent valve Danfoss AB-QM works 42
Resolution of the overpressure issue on the control valvethanks to the use of Danfoss AB-QM valves 43
Resolution of the risk of hunting issue thanks to the use of Danfoss AB-QM valves 46
Resolution of the starving issue thanks to the use of Danfoss AB-QM valves 48
Simplification of the installation and reduction of installation and commissioning times 50
Conclusions 52
Chapter 11 - **Advantages of variable air flow in hotel rooms** 53
Variation of air flow during the day 53
Effects of the air flow on the energy required to the generators 54
Energy Consumed by AHU fans 55
Conclusions 57

Chapter 12 - Reduction of energy consumption and management costs with variable flow Danfoss solutionsin installations with boiler and refrigerating unit 58
Retrofit of building with year 2005 thermal insulation type 58
Efficiency improvement of installed equipment 59
Improvement of thermal insulation 60
Use of Danfoss solutions for variable flow installations 60
Economic benefits retrofit of building with year 2005 thermal insulation type 63
Retrofit of building with year 2010 thermal insulation type 64
Efficiency improvement of installed equipment 64
Improvement of thermal insulation 65
Use of Danfoss solutions for variable flow installations 65
Building design with year 2021 thermal insulation type 66
Use of Danfoss solutions for variable flow installations 66
Economic grounds 67
REconomic savings on retrofit of building with year 2005 insulation type 67
Economic savings on retrofit of building with year 2010 insulation type 68
Economic savings on retrofit of building with year 2021 insulation type 68
Conclusions 69
Chapter 13 - Advantages of Danfoss solutions in other hotel areas 70
Restaurant and Spa premises 70
Dining area and Breakfast Room 70
Spa premises 72
Conference Room 73
Savings obtainable by taking into account bedrooms, common areas and additional rooms 74
Chapter 14 - Danfoss MTCV multifunctional thermostatic circulation valves 75
The recirculation ring 75
Difference between static balancing valves and thermostatic valves 76
The versions of the Danfoss MTCV valves 76
Calculation of the water flows for the balancing valves MTCV 82
Estimates of obtainable saving 82
Conclusions 83
Chapter 15 - Use of new Danfoss compressors 84
Volumetric compressors and centrifugal compressors 84
Limits of traditional scroll compressors 84
Scroll compressor IDV with Intrinsic Variable Volume 86
Centrifugal turbochargers 89
Adjustment of power at constant rpm 90
Centrifugal turbochargers: performance when revolutions vary 91
Optimum operation of a centrifugal turbocharger with inverter 93
Savings obtainable by using the inverter 94
ITurbocor® compressor 94
Conclusions 97
Chapter 16 - Efficiency improvement of cold food management installations 98
Chapter 17 - Conclusions 99
Index of Figurees 101

Executive Summary:

A study on the energy consumption of hotels, and analysis of the potential energy and economic savings obtainable with the implementation of modern technologies in technical installations for air conditioning, domestic hot water and refrigeration.

This study has been undertaken with a view to highlighting and quantifying the potential energy savings in hotel buildings. The influence of various design choices on the energy consumption of a hotel were assessed, and it was shown that the use of Danfoss advanced technologies in installation planning enables not only the ability to achieve ever more stringent efficiency goals and energy savings imposed upon commercial buildings through European directives, but also provide swift return-on-investment – both in existing buildings and newly constructed ones.

The results that emerged from the study can help designers and industry professionals better comply with regulatory limits, more easily reach the energy efficiency targets for nZEBs (nearly zero energy buildings) and reduce reliance on the spaces necessary to exploit the sources of renewable energy (such as photovoltaic panels), which aren't always readily available.

The study shows investors and hotel managers how it is possible to make considerable savings on energy management costs, while ensuring maximum comfort and a high level of service for customers, all with full regard for the environment, and with very low initial investments that guarantee extremely fast return-on-investment.

Chapter 1: Introduction

The analysis reported in this study is aimed at calculating and evaluating the various thermal loads of the building (including endogenous, by radiation, of heating, cooling and domestic hot water production systems), by calculating the related energy consumption – and by highlighting the savings obtainable through the use of Danfoss solutions for variable flow installations.

The analysis took into consideration a building for hotel use located in the geographical area of Milan (Italy), with a rectangular ground plan, either oriented north-south or east-west. A sensitivity analysis was performed in order to estimate the influence of the orientation of the building on the energy requirements and the related consumption, in addition to the potential savings and economic return-on-investment.

To evaluate the effect of the structure's thermal insulation, and the performance of the refrigeration equipment installed, three types of hotels were taken into consideration, featuring average structural thermal insulation types equivalent to the typical techniques of the years 2005, 2010 and 2021 respectively, refrigeration equipment and electric motors, both high efficiency and low efficiency ones, and installation with boiler plus refrigerating unit, and with heat pump only.

All simulations were performed using the EnergyPlus software, by assuming standard occupancy conditions according to the ASHRAE criteria, and the presence of two types of HVAC installations: at full air, and with fan coil plus primary air.

The domestic hot water production system was also included in the analysis of consumption and related efficiency improvements, as it proved to have a significant impact on the hotel's overall energy consumption.

Upon completion of the simulation, the influence of the type of compressors deployed in the refrigeration equipment was then taken into consideration, which showed how Danfoss' high efficiency and high performance technologically advanced solutions for scroll and centrifugal compressors can further help to reduce electricity consumption.

Finally, once the study was completed, the importance of using design solutions which can guarantee maximum comfort and continuity of service for hotel guests was demonstrated.

The design solutions suggested are easy to implement, require low initial investment, which is lower than other solutions for energy saving, such as structural interventions on the building or alternative generation systems, and guarantee swift return-on-investment. Furthermore, they contribute to support environmentally friendly policies and the prestige of the hotel, and are already ready to interface with current and future technological solutions for building automation, which is developing strongly at present.

Available spaces: the most precious resource in the nZEB era

We are living at a time in which the world is finally becoming aware of how fundamental it is to reduce energy and water waste to safeguard our planet.

Maintaining correct temperature and air quality levels represents the main item of energy consumption inside buildings. Heating, cooling and ventilation systems, commonly referred to by the acronym, HVAC (heating, ventilation and air conditioning), are used to maintain a comfortable environment inside buildings. Incorrect installation or non-optimised operation of HVAC systems involves higher CO_2 emissions, deriving from increased energy consumption.

Europe has set itself important goals to address global warming and reduce carbon dioxide emissions.

The next important goal to be achieved under the 20-20-20 Plan (reduce greenhouse gas emissions by 20%; increase the share of energy produced from renewable sources to 20%; and bring energy savings to 20%) is the implementation of the European Energy Performance of Buildings Directive, which requires all new public buildings to be "Nearly Zero-Energy Buildings" (nZEB) by 2018.

Assuming that the only renewable source accessible everywhere is solar energy (since the use of other sources is closely linked to the specific characteristics of the territory), we will necessarily have to face the problem of what spaces are available for solar panel installations.

In the case of buildings mainly developed horizontally, or in areas with low density of housing, such as in open countryside or in peripheral urban centres, it is easy to find the necessary spaces for photovoltaic installations, while in the case of purely vertical constructions, art heritage cities, or renovations in historic centres, it often becomes virtually impossible to find suitable spaces for solar panel installations.

Therefore, the real challenge is to find suitable spaces for solar installations that can supply sufficient energy for the buildings' requirements. Every 1000 kWh/year saved corresponds to about $7m^2$ of solar panels installed.

It can therefore easily be inferred that the real alternative is intelligent use of the advanced technologies currently available for installation design, in order to deliver high efficiency, low energy consumption and low environmental impact buildings.

A new energy parameter: the equivalent photovoltaic surface

In recent years, more professional profiles interested in building consumptions have emerged, each having different cultural origins. Therefore, it is not easy to understand the extent of energy savings when you do not speak the same language. You need a simple parameter, which can be understood by anyone.

This parameter has been identified by AiCARR (the Italian Association of Air Conditioning, Heating and Refrigeration) as the equivalent photovoltaic area, which can be defined as the surface of a photovoltaic field needed to bring to zero budget the annual self-generation of electricity and the installation's overall consumption, including auxiliaries.

The reference photovoltaic field comprises crystalline silicon panels with an electrical efficiency of 14.4%, south-facing and with an inclination equal to 40%, so that the estimates of solar power generation of the European Commission Joint Research Centre (JSR) of Ispra can be applied. With this kind of yield, 7m^2 of panel surface are necessary to obtain 1 electric kW-peak, with an irradiation of 1000 W/m^2.

In the budget, the methane used by the boilers is deemed to be able to produce electricity with a 55% yield, equal to the maximum value available with current technologies.

The equivalent photovoltaic surface, expressed in m^2, is given by the following formula:

$$\text{EqPPV} = 7 \cdot \text{PeakPPV} = \frac{\text{TotEC} + (9{,}6 \cdot \text{TotMC} \cdot 0{,}55)}{\text{EstimSPG}}$$

where:

PeakPPV is the peak power required to the photovoltaic plant to produce all the energy needed to bring the consumption of the plant and its auxiliaries to zero budget;

TotEC is the total annual electricity consumption of the plant, comprehensive also of the auxiliaries (pumps and fans), expressed in kWh;

TotMC is the annual methane consumption of the boilers, expressed in m^3;

EstimSPG is the estimate of annual solar power generation of the JSR of Ispra for 1 kW-peak photovoltaic systems, expressed in kWh: it is 1060kWh in Milan, 1180 kWh in Rome and 1260 kWh in Bari;

7 is the surface necessary to reach the peak power of 1 kW with the reference photovoltaic panel (ηPV= 14,4%), expressed in m^2;

9,6 is the lower heating value of methane, expressed in kWh/m^3;

0,55 is the reference electrical efficiency of the best system of power generation running on methane.

In a nutshell, the equivalent photovoltaic surface parameter expresses the photovoltaic surface necessary to bring the system to zero energy consumption. The lower the value, the more efficient the building-plant system is.

The parameter has the advantage of being mediated in the climate where the building is placed, and of immediately giving a very precise value to anyone, because it gives an indication of the spaces and the investments necessary to bring at least the mechanical installations of a building to zero consumption.

Thus, energy savings can be related to the amount of photovoltaic surface saved, or to the saved power of the same plant, as better explained in Chapter 12.

Chapter 2: Energy simulation of a building for hotel use

The simulation and analysis were carried out on a building used as a hotel, with a rectangular ground plant, located in Milan. The following are the main hypotheses considered in the analysis:

Data of the building

- City Milan
- Use: Hotel
- Shape: Rectangular
- Orientation: north-south or east-west
- Structure: 9 above ground floors, 1 reception and bar, 8 with rooms
- Rooms: 20 double rooms per floor, 10 per facade
- Capacity: 160 total rooms
- Dimensions: 4,500m^2 of air-conditioned surface (13,500m^3)
- Occupancy aspects: according to the ASHRAE's definitions (American Society of Heating, Refrigerating and Air-Conditioning Engineers)
- Occupancy: 80% average occupancy
- Other areas: additional underground areas taken into consideration where the influence of thermal insulation of the building itself and of the other areas (restaurant and breakfast room, spa, conference room) is negligible.

3 thermal insulation levels of the building:

- Average insulation (year 2005 type)
- Current insulation (year 2010 type)
- High insulation (year 2021 type)

Set-point temperature in the rooms:

- Heating 20°C
- Cooling 26°C

Comparison plant type:

- Fan coil + primary air
- Boiler + Air cooled refrigerating unit

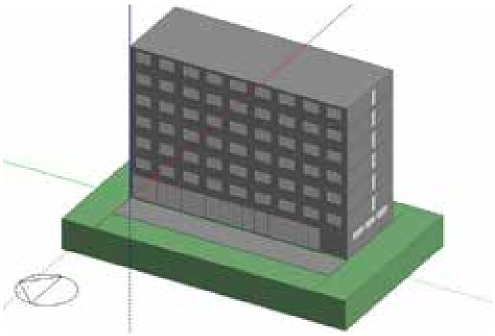
Size of the building:

- Long sides:
  - glazed surfaces = 110 m^2
  - opaque surfaces = 250 m^2
- Short sides:
  - opaque surfaces = 113 m^2
- Roof: 500 m^2

Main characteristics of the insulations considered:

	Medium insulation 2005	Medium insulation 2010	Medium insulation 2021
Opaque wall transmittance	0,46 [W/(m^{2}K)]	0,34 [W/(m^{2}K)]	0,22 [W/(m^{2}K)]
Shell transmittance	0,43 [W/(m^{2}K)]	0,30 [W/(m^{2}K)]	0,15 [W/(m^{2}K)]
External ceilings and floor on the ground transmittance	0,43 [W/(m^{2}K)]	0,33 [W/(m^{2}K)]	0,20 [W/(m^{2}K)]
Fitting transmittance	3,5 [W/(m^{2}K)]	2,2 [W/(m^{2}K)]	1 [W/(m^{2}K)]
Window solar factor	0,55	0,55	0,55

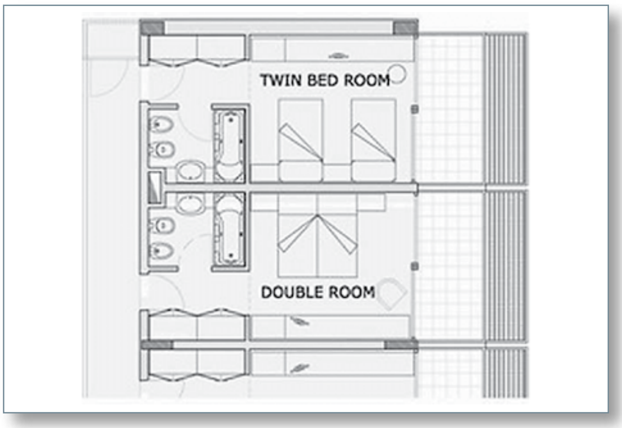
Hotel design, as built on Energy PLus

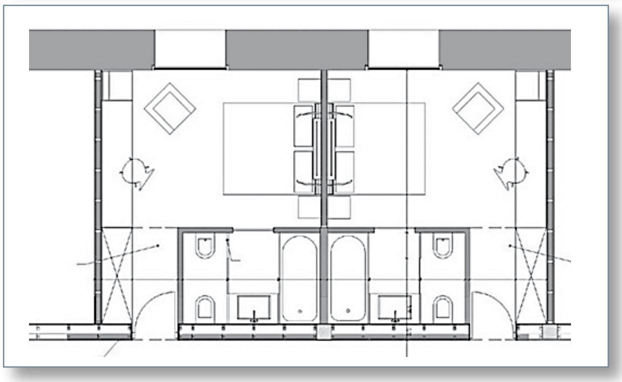


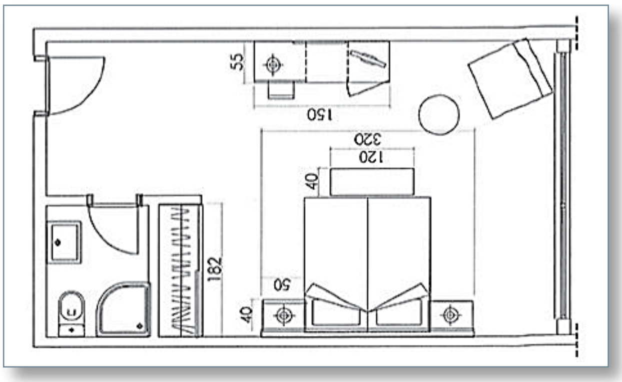
The study began by trying to reproduce an actual hotel project, starting from the dimensions and configurations of standard rooms.

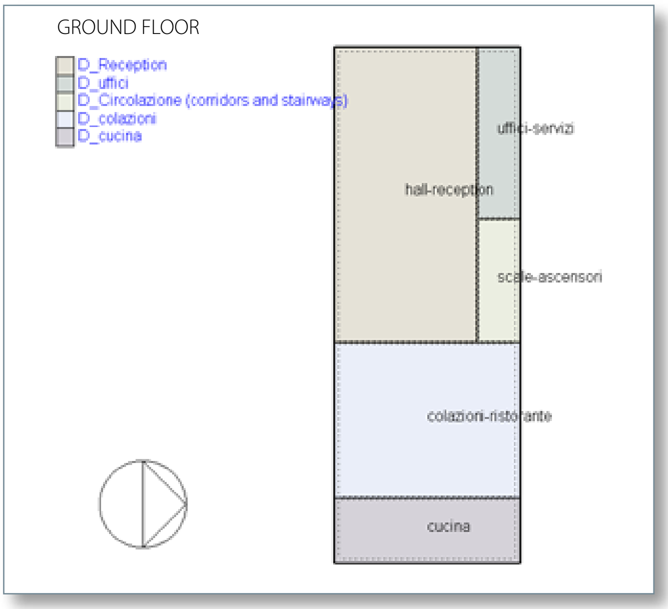
The floor plans obtained are reported as legible from the EnergyPlus simulation model.

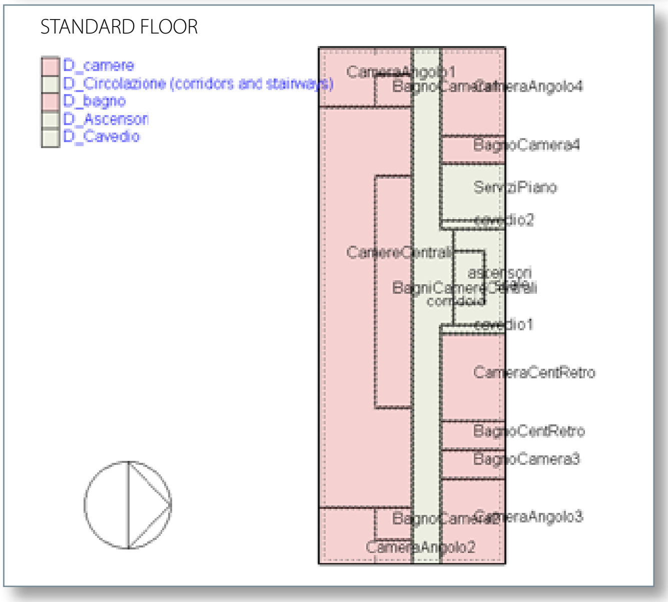
Hotel room configuration











Chapter 3: Influence of endogenous loads

The aim of this chapter is to show the effect of endogenous loads on the thermal loads required in the rooms. The analysis was performed by taking into consideration the rectangular building, with north-south orientation, and a medium type of insulation (as per 2010).

The hypothesis is to introduce primary air always in neutral conditions. Obviously, this is not the case in practice, but the variations will be analyzed in the following chapters.

Requirements without endogenous loads

If the endogenous loads within the room are not taken into account, the rooms to the north have to be heated from approximately mid-October to mid-April, while they should be cooled from approximately mid-June to mid-September.

The rooms facing south, instead, have to be heated from the end of October to mid-March and cooled from mid-April to approximately the 20th of October.

As can be seen from the graphs, where the annual heating and cooling requirements are reported for the rooms on the northern and southern face, even without endogenous loads, the rooms to the south require, for cooling, virtually the same amount of energy required for heating.

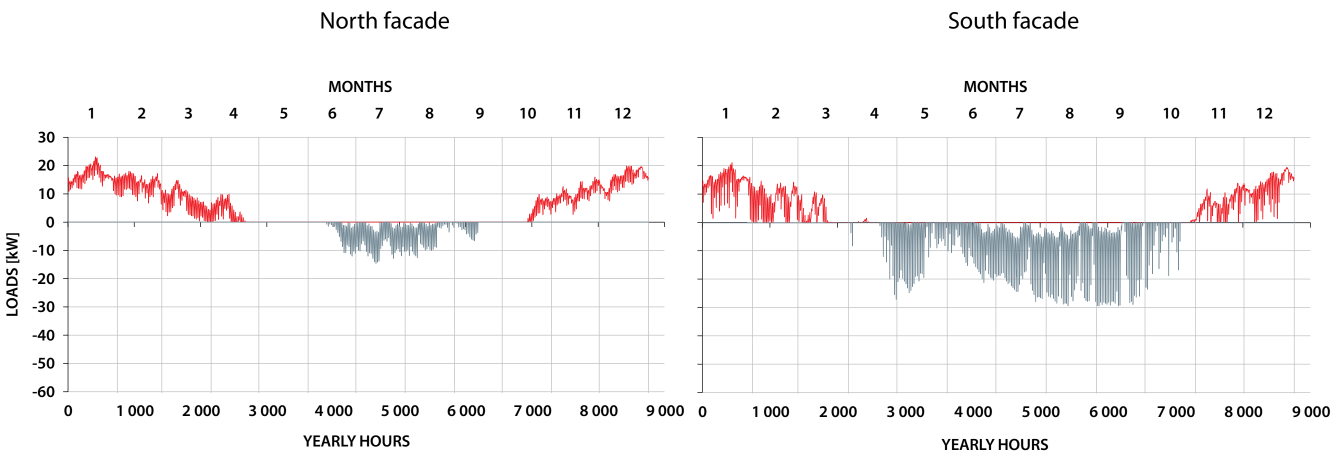


Figure 3-1: Trends in heating and cooling requirements for north and south facades

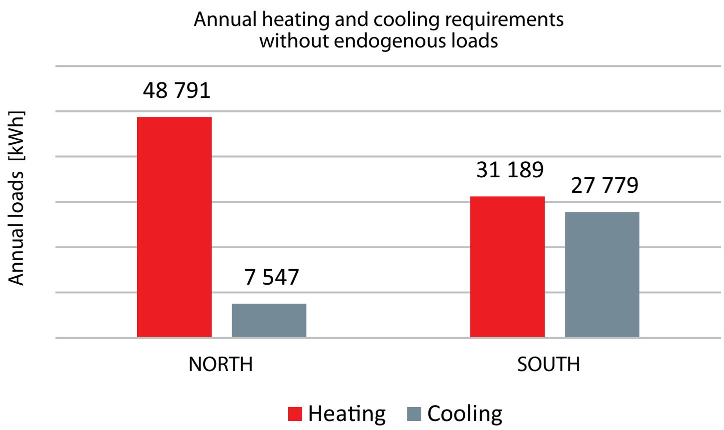


Figure 3-2: Annual heating and cooling requirements for north and south facades without endogenous loads

Requirements with endogenous loads

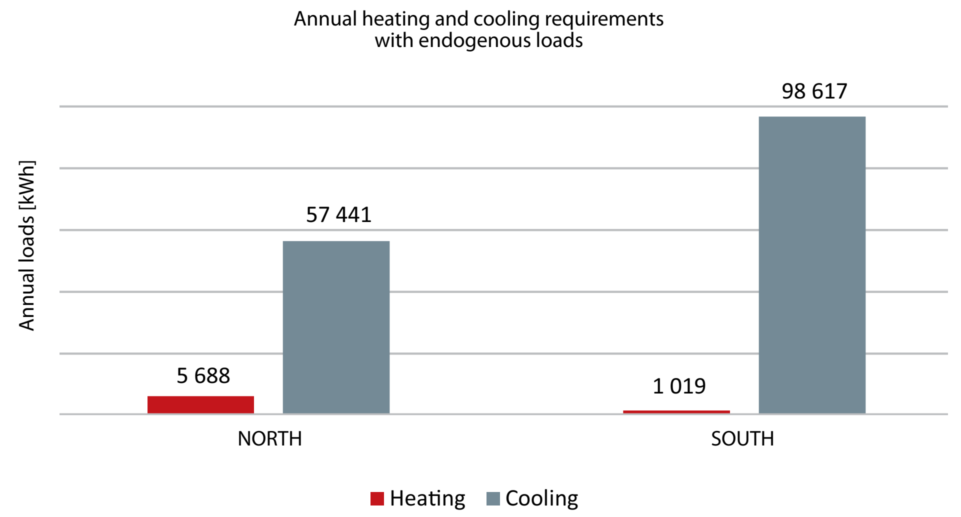


Figure 3-3: Annual heating and cooling requirements for north and south facades with endogenous loads

Furthermore, when endogenous loads are present in the rooms to the north, the heating period is reduced by about two and a half months, while that of cooling increases: without endogenous loads, it is limited to the summer months, whereas when considering the endogenous loads, it goes from early April to the whole of October.

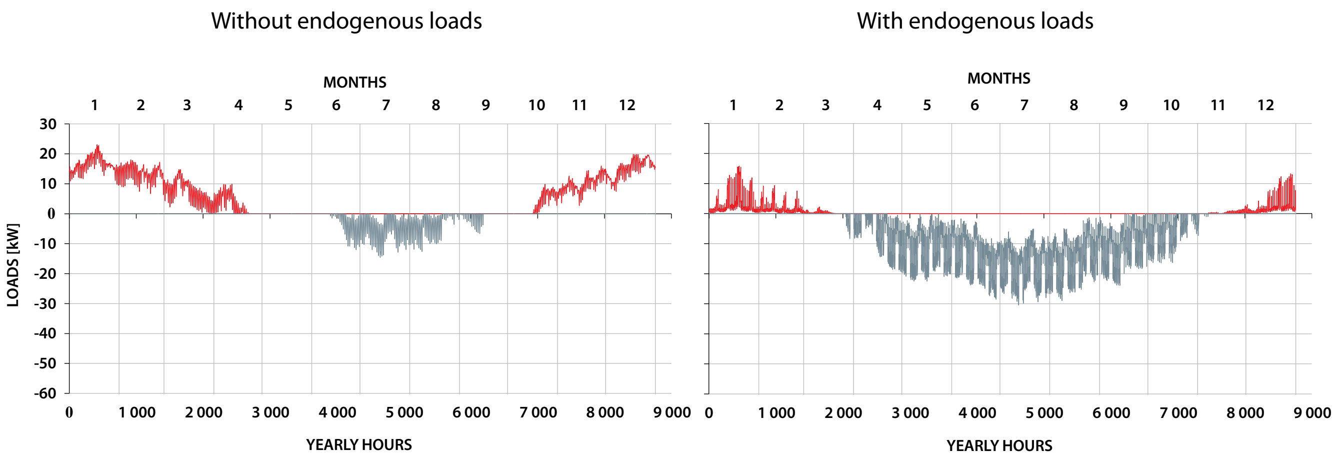


Figure 3-4: Trends in heating and cooling requirements for the north facade without and with endogenous loads

The effect is even more evident in the rooms to the south. The heating requirement is limited to a few hours a year, while that for cooling increases. The fact that it is at its peak during the months of March, April, September and October depends on the orientation: on a south-facing vertical wall the irradiation is maximum during these months.

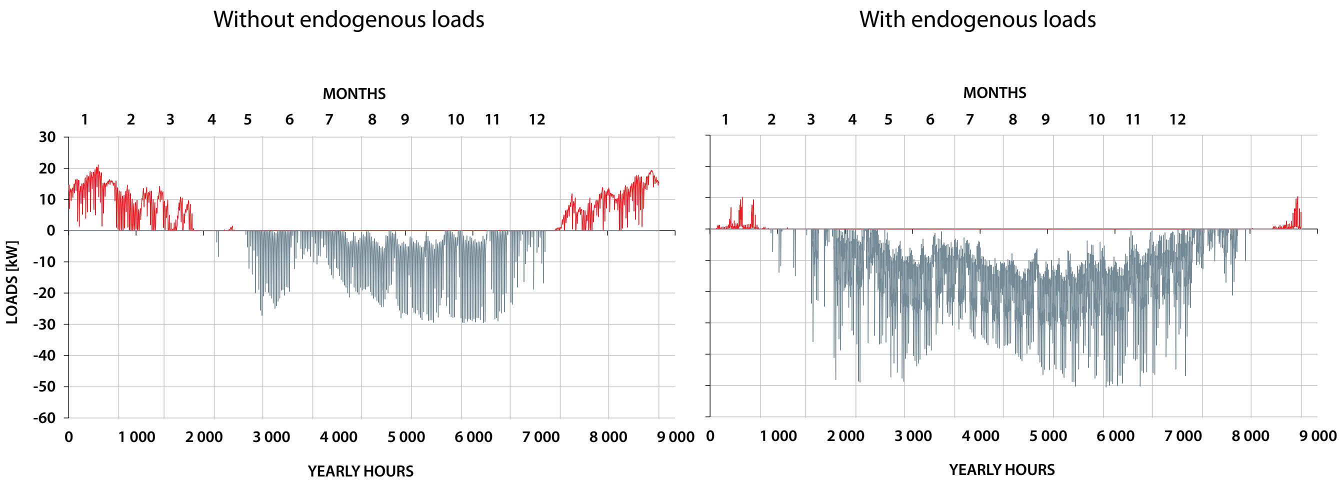


Figure 3-5: Trends in heating and cooling requirements for the south facade without and with endogenous loads

Conclusions

2010 Building - Rectangular plan - North/south-facing

Without endogenous loads, the rooms facing north would require 6 months of heating and 3 of cooling, with a heating power about 7 times higher than the cooling one; the rooms facing south would require about 5 months of heating and 7 of cooling, with very similar powers for hot and cold.

By introducing endogenous loads, the situation changes completely, resulting in, on one side, far fewer months of heating and much lower thermal loads thereof, which are almost non-existent in the rooms facing south, since the period of use is limited to a couple of months, and, on the other, additional months of cooling and power requirements thereof.

Chapter 4: Influence of orientation

The effect of the different orientation of the building, north-south compared to east-west, on the thermal loads and on related cooling and heating requests has also been analyzed.

The difference in the rooms' thermal requirements is determined mainly by the solar gains through the facade windows, which are very different from one another. While with orientation to the east and west the maximum irradiation on vertical surfaces is reached in the summer months, in the south orientation it is reached in March, April and from August to October.

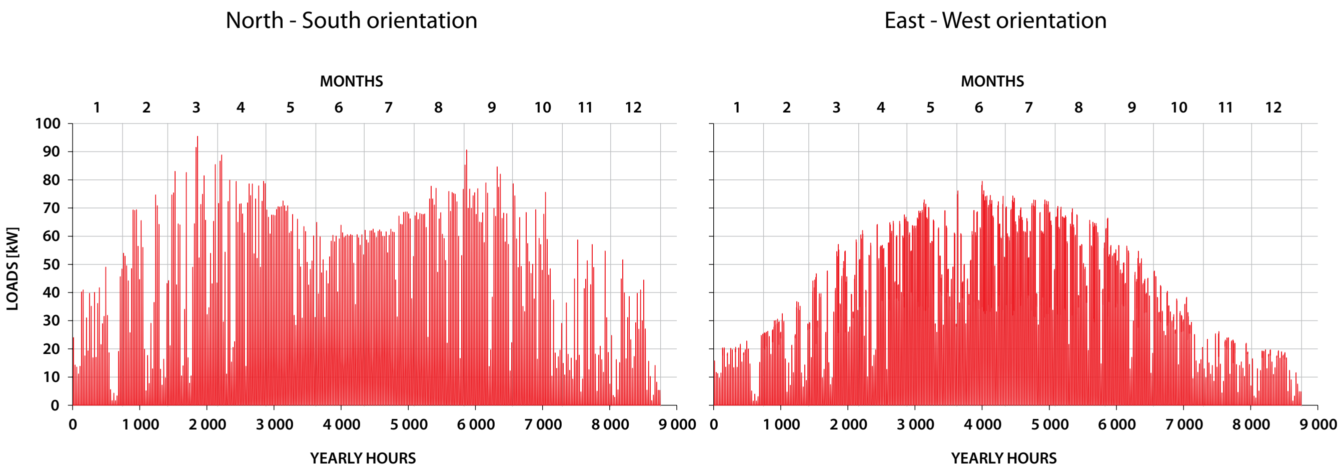


Figure 4-1: Trend of solar gains with north-south and east-west orientation

In overall energy terms, the differences are limited. The approximately 8,000 kWh per year of greater solar gain with orientation east-west translate into an annual requirement of 3,000 kWh more in heating and 13,000 kWh more in cooling.

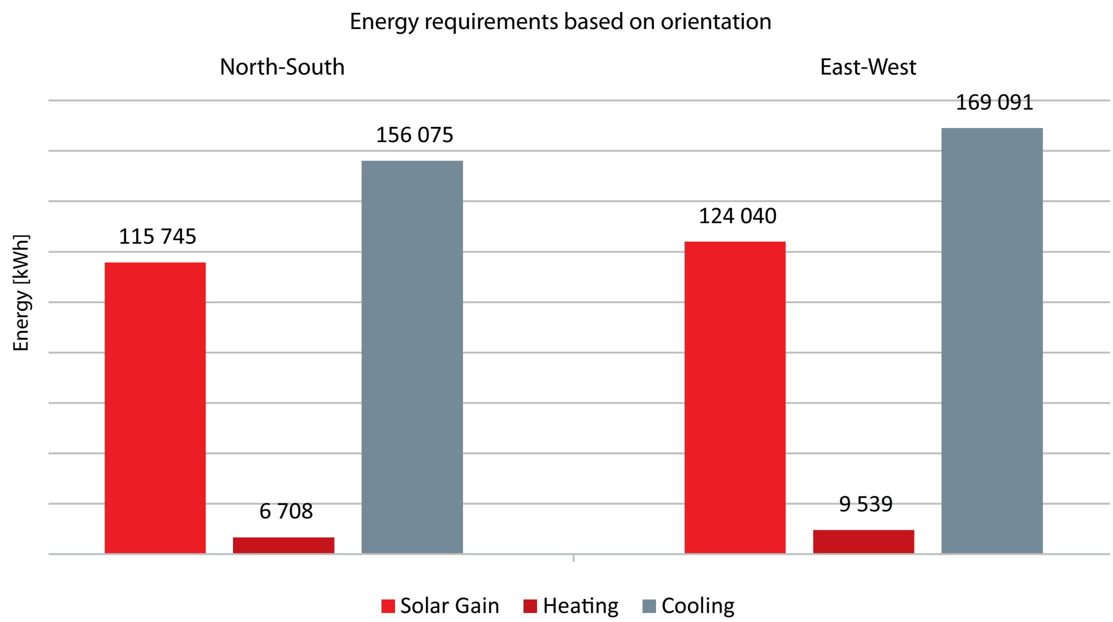


Figure 4-2: Energy requirements based on orientation

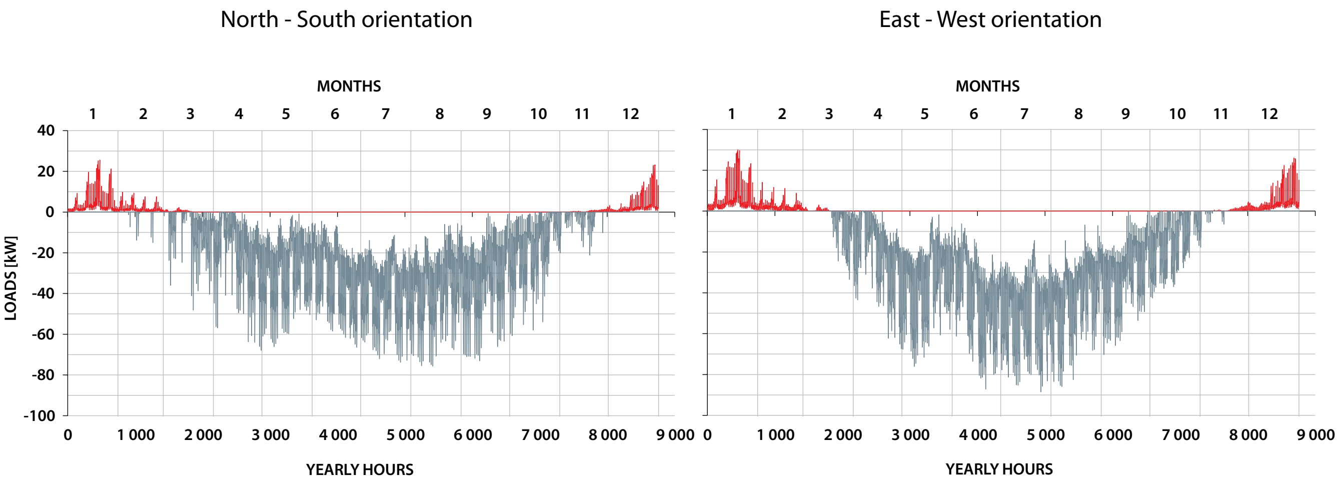


Figure 4 3: Energy requirement trend based on orientation

The difference in thermal requirements is above all at the temporal level. The north-south orientation requires more power and energy for cooling in mid-seasons, when it is possible to mostly exploit free-cooling.

The diagrams show the differences between heating requirements (left) and cooling requirements (right). Positive values mean greater requirements for the north-south orientation, while negative ones indicate greater requirements for the east-west orientation.

The east-west orientation always consumes more heating-wise, while for cooling, it is the north-south orientation in mid-seasons, and the east-west orientation in the summer months.

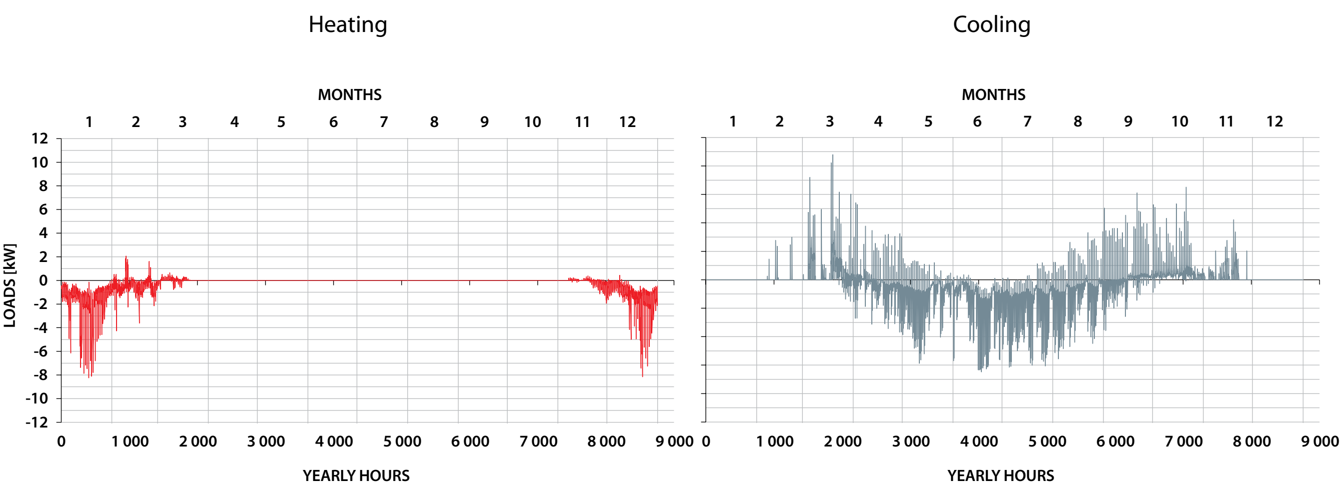


Figure 4-4: Requirement difference between north-south and east-west orientations

Conclusions

The orientation influence simulation shows that about 8,000 kWh/year of gain are achieved in irradiation with an east-west orientation, which translate into a greater consumption in heating (+42%) and, especially in summer, in cooling (+8.35%).

The north-south orientation consumes more in cooling in mid-season periods, where, however, it is possible to mostly exploit free cooling.

Chapter 5: Influence of thermal insulation on energy requirements

In the previous chapters, we analyzed how the presence of endogenous loads and the orientation of the building affect the conditioning energetic loads. In this chapter, an additional variant is introduced to the simulation: the influence of the building's thermal insulation.

In overall energy terms, the differences are limited, especially in cooling.

Three different types of thermal insulation have been taken into consideration, which refer to the techniques used in different time periods: medium thermal insulation (year 2005), current thermal insulation (year 2010) and high thermal insulation (year 2021).

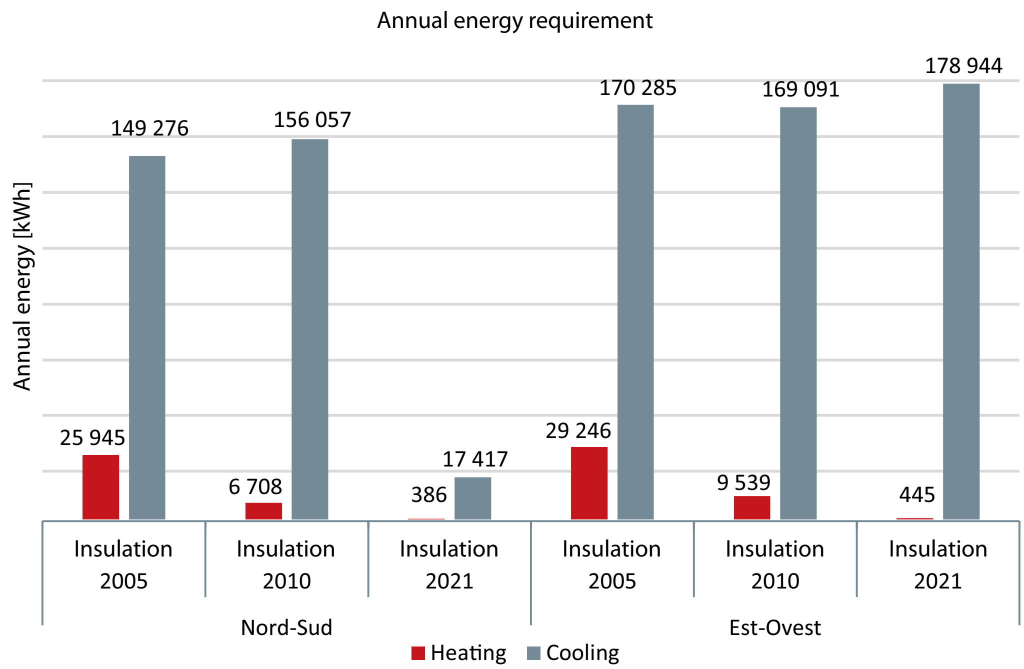


Figure 5-1: Annual energy requirement based on the type of insulation and orientation

Regardless of the orientation, lesser insulation always requires a greater heating requirement, and a greater maximum power also for cooling, despite having a different time distribution.
A higher thermal insulation in fact requires cooling for several months a year, starting already in February until November.
It can also be noted that, in buildings with year 2021 insulation type, there is almost no heating demand when compared to the demand from older buildings, and also in relation to cooling demands.

North - South orientation

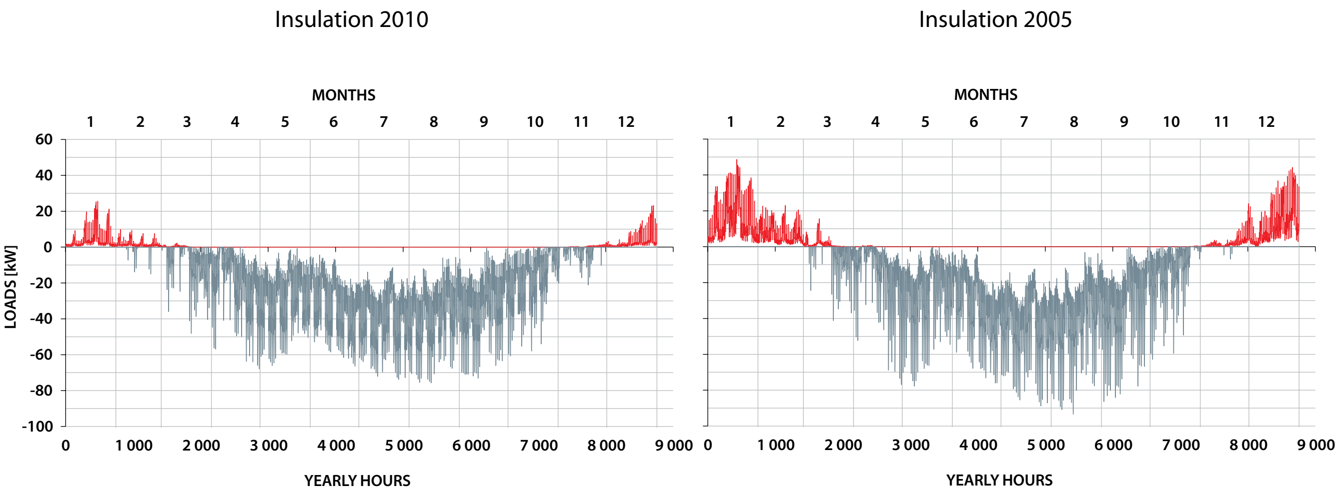


Figure 5-2: Energy requirement trend with north-south orientation and years 2010 and 2005 insulation types

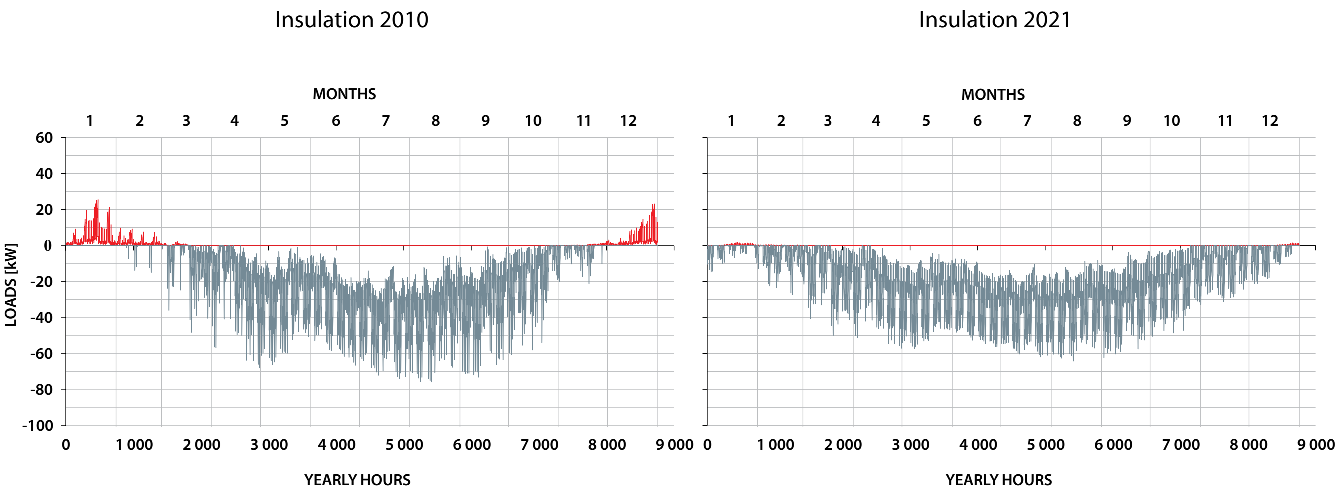


Figure 5-3: Energy requirement trend with north-south orientation and years 2010 and 2021 insulation types

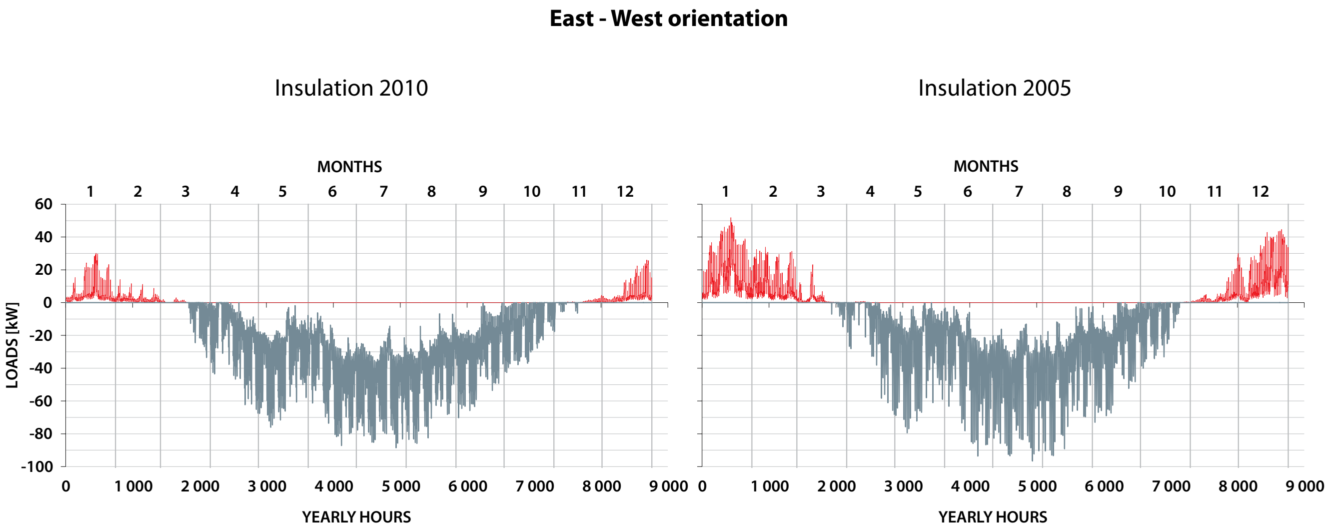


Figure 5-4: Energy requirement trend with east-west orientation and years 2010 and 2005 insulation types

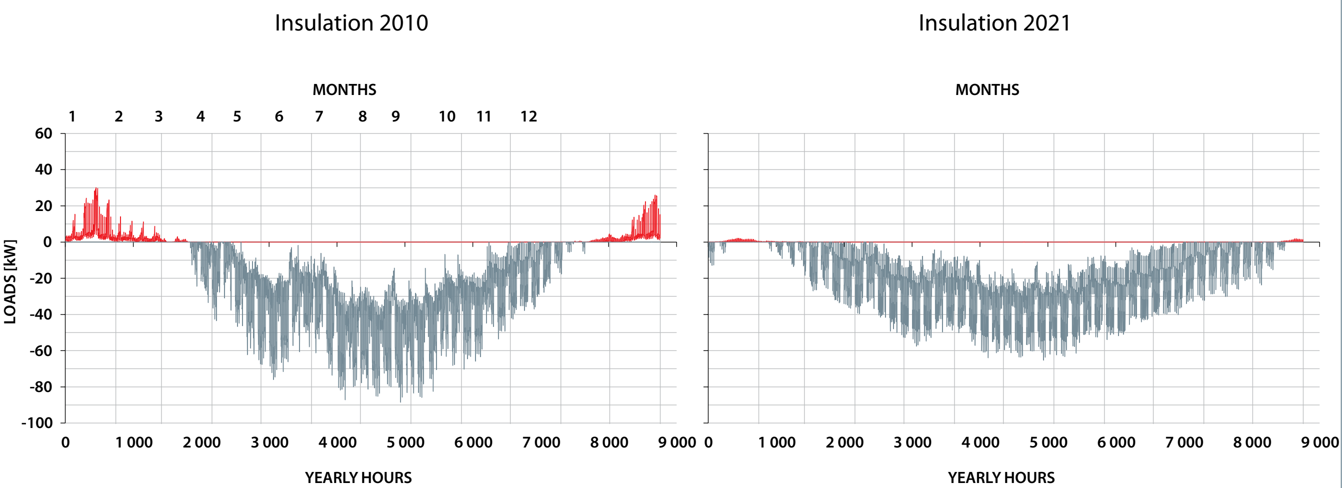


Figure 5-5: Energy requirement trend with east-west orientation and years 2010 and 2021 insulation types

Conclusions

Regardless of the building's orientation, lesser insulation always requires a greater heating requirement, and a greater maximum power also for cooling, despite having a different time distribution.

A higher thermal insulation in fact requires cooling for several months a year, while in buildings with year 2021 insulation type, the heating demand becomes almost negligible.

Chapter 6: Influence of intake of external air

In this chapter, the effect of external air intake is analyzed, assuming the use of a regenerator from the air expelled and the intake of air at a temperature other than neutral.

The air flow rate considered is 80 m³/h per room + 1,600 m³/h in the hall and in the common areas, for a total air flow injected of 12,800 m³/h and extracted of 9,800 m³/h.

The case of a building with orientation north-south and with year 2010 insulation type was initially analyzed by taking into consideration an additional variable: the regenerator's efficiency.

Influence of the regenerator's efficiency on consumption

The following figures show the power required by the air handling, in cases where there is a recovery of 50% and a recovery of 75%.

Since the flow of discharged air is equal to 77% of the renewal air, the efficiencies of the regenerator become respectively 38% and 57%.

Higher efficiency greatly affects heating, but much less cooling. In the months from May to mid-October, the heating load, which is almost constant, is due to post-heating necessary for dehumidification.

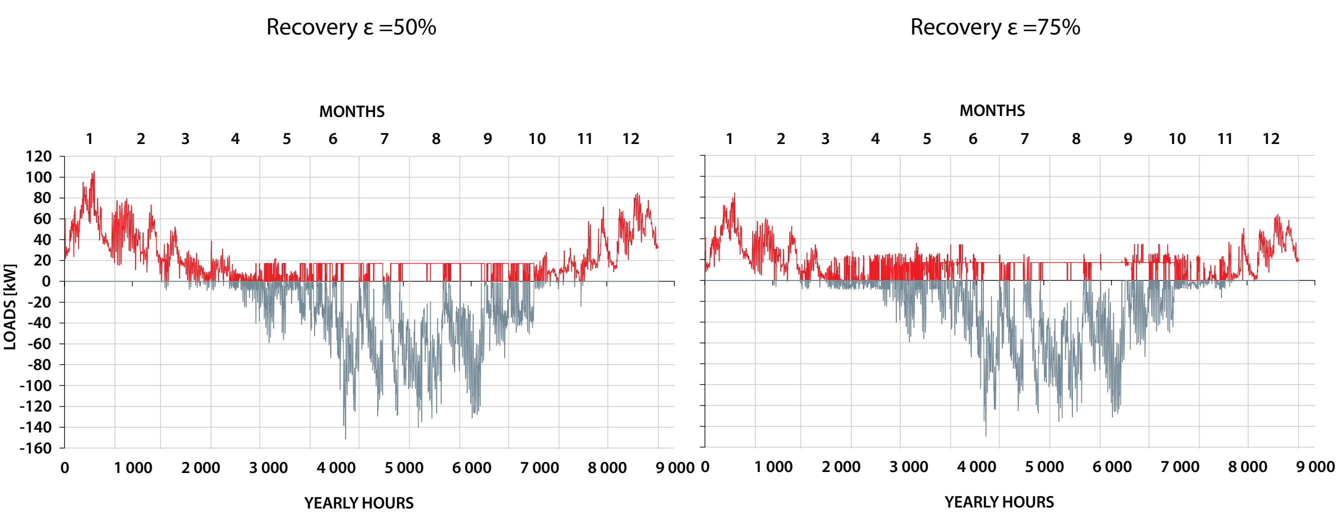


Figure 6-1: Power required by the air handling with regenerator

The regenerator has a significant impact on consumption, particularly in heating. In fact, when there is a certain increase of the efficiency of the regenerator by 50% (i.e. passing from a regenerator with 50% efficiency to a regenerator with 75% efficiency), this produces a 26% saving on the heating demand, and only 2.4% on the cooling demand, while it leaves the post-heating consumption completely unaffected.

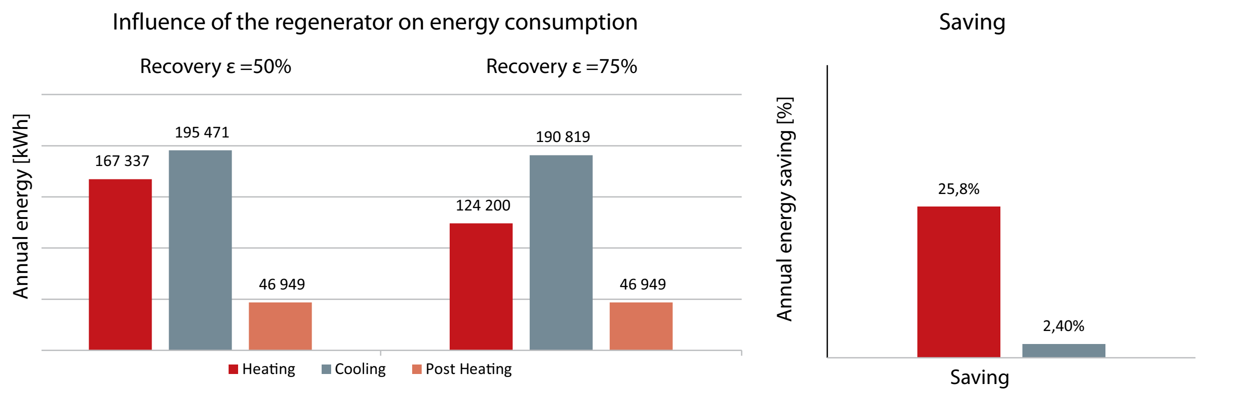


Figure 6-2: Influence of the regenerator on energy consumption

Influence of the injected air temperature on the power required to the terminals

Injecting air at a lower temperature than that of the room changes the terminals' requirement in the room, increasing it in heating and decreasing it in cooling.

The hypothesis is to introduce air at 18°C throughout the year, with specific humidity of 4.8 g/kg in winter and 9.9 g/kg in summer.

Nothing changes from the point of view of the energy required to the generators, but the water flows through the fan-coil batteries vary greatly.

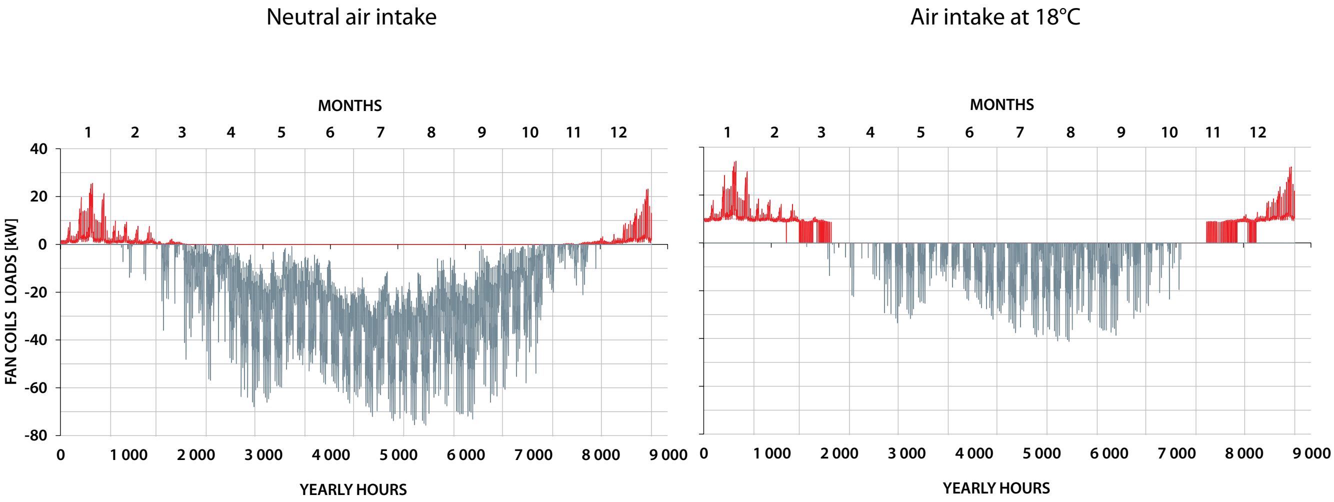


Figure 6-3: Power required to terminals based on the temperature of the air supplied

Total power required to the generators

The sum of the thermal loads of the ambient and air terminals produces the load required to the generators.

The figure shows the case of the regenerator's efficiency equal to 75%.

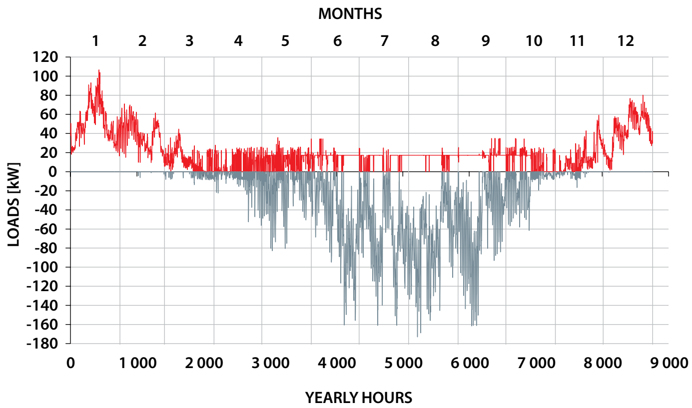


Figure 6-4: Total power required to the generators

Energy requested by the AHU (Air Handling Units) fans

For an equal volume flow of injected and expelled air, the power depends on fan efficiency and load losses.

In hotels, the air handling units traditionally run constantly, 8,760 hours a year; therefore, the energy load of the ventilation fans is very high.

The power required by the fans of an AHU is given by the formula:

$$q_V = \frac{Q_{ren}\,\Delta l_{ren}}{\eta_{ren}} + \frac{Q_{ex}\,\Delta l_{ex}}{\eta_{ex}}$$

where:

Q_{ren}; Q_{ex} = volumetric air flow rates, of renewal and expelled, respectively [m^3/s];
Δl_{ren}; Δl_{ex} = load losses of the regenerator and its accessories, if any, on the renewal air flow and on the flow of expulsion air, respectively [Pa];
η_{ren}; η_{ex} = efficiency of the fans that move the respective air flows.

The European Directive ErP (energy related products) has modified the design criteria for electrical appliances and fans, which has greatly improved their efficiency.

In the AHU fans, the average performance of 50% has increased to 70%.

Furthermore, the directive has imposed much lower speeds in the AHU. Manufacturers have complied by reducing, as far as possible, the load losses of internal devices (batteries, filters, regenerators) and by increasing the efficiency of heat exchangers.

Two types of AHUs were taken into consideration to perform the simulation - one prior to the introduction of the ErP 2018 rules and the other subsequent. The fan powers, in operating conditions, are as follows:

- pre-ErP AHU = total power 10.5 kW
- ErP 2018 AHU = total power 5.0 kW

Therefore, the annual energy consumed by the fans is:
- AHU pre-ErP = total power 92,369 kWh
- AHU ERP 2018 = total power 43,591 kWh

Conclusions

The increase in efficiency of the regenerator has a positive impact on consumption related to heating only, while it has no effect on consumption related to post heating, and it impacts only marginally on the cooling demand.

A 50% increase in the efficiency of the regenerator leads to about 26% savings on the heating demand, and only 2.4% on the cooling demand.

Injecting air at a lower temperature than that of the room then changes the terminals' requirement in the room, increasing it in heating and decreasing it in cooling.

Nothing changes from the point of view of the energy produced, but it varies a great deal from the point of view of the water flows.

To achieve the total load required by the generators, the thermal loads of the ambient and air terminals must be added up.

For an equal volume flow of injected and expelled air, the power depends on fan efficiency and load losses.

In hotels, the air handling units traditionally run constantly (8,760 hours per year); therefore, the energy absorption of the ventilation fans is very high.

With the introduction of the European Directive ErP, the average performance of 50% in the AHU fans has increased to 70%, and heat exchangers with much higher efficiencies have been implemented.

With reference to the case analyzed, the effect of the ErP2018 directive has led to a reduction of over 52% of annual electricity consumption of the AHUs, from around 92 MWh to around 43.9 MWh.

Chapter 7: Influence of thermal insulation on the air temperature in the rooms

In Chapter 5, we analyzed the impact of thermal insulation on energy consumption. However, such an assessment is not exhaustive if it is not also accompanied by the evaluation of the correspondent effects on the temperature of the air in the rooms, in particular at night, when they are certainly occupied.

The energy analysis was conducted by hypothesizing that the air conditioning is turned on when ambient air is 26°C, even if many guests from the United States or the Middle and Far East usually require temperatures lower than 23°C in their room yearlong. As can be seen from the following analysis, excess heat insulation can give rise to excessively high room temperatures even in the middle of winter.

Air temperature in the occupied rooms

Regardless of the orientation of the building, in spite of the introduction of primary air in an 18°C environment, the greater thermal insulation, the higher the temperature inside the occupied rooms.

With the orientation to the south and the type of insulation planned for 2021, the temperature remains permanently above 24°C, excessive to sleep well. Even with the 2010 insulation type, the temperature rises above 22°C from February to mid-December. The north wall is always in the shade, thus temperatures remain lower.

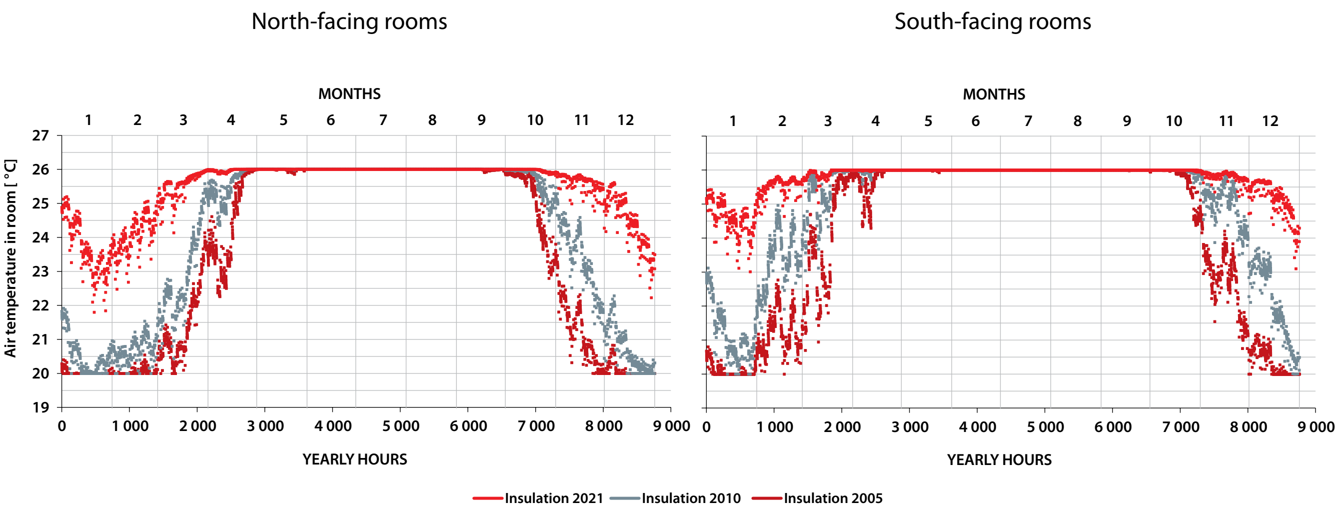


Figure 7-1: Temperature trend in the north and south-facing rooms

With east-west orientation, the temperature trend is very similar between east and west-facing rooms. The differences of temperature trends between the different orientations are obviously more marked in the event of low thermal insulation.

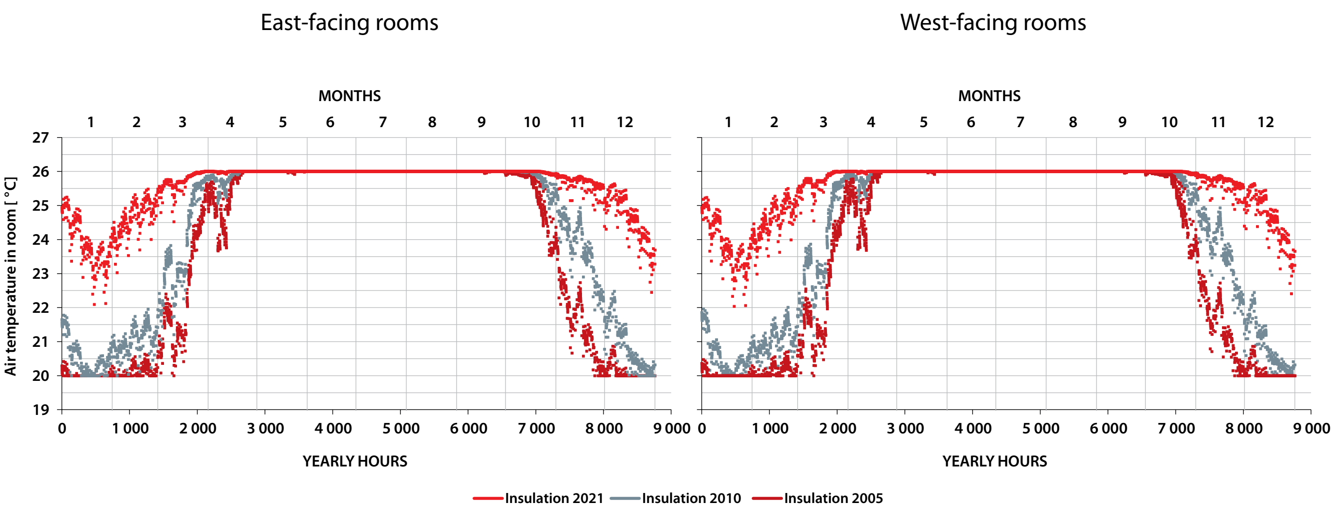


Figure 7-2: Temperature trend in the east and west-facing rooms

Consequences on the plant management

In higher class hotels, from 4 stars upwards, it is now necessary to provide air conditioning throughout the year.

Some guests may want ambient air temperatures different from those seen previously, warmer or colder, depending on of their habits. It is therefore necessary to envisage a four-pipe system.

The increased use of air-conditioning necessarily impacts the building's energy consumption. It is interesting to observe the impact on the annual energy and on the maximum power required to the generators in a case, quite realistic, where the ambient temperature is always maintained at 23°C.

The hypothesis has been developed by taking into consideration the north-south orientation.

Maintaining the temperature at 23°C throughout the year increases the energy demand for the generators in every season.

The power for summer post-heating also increases, because in order to maintain 23°C, even with RH = 60%, you must humidify more compared to 26°C with RH = 55%. Also, the maximum power required to the generators is greater.

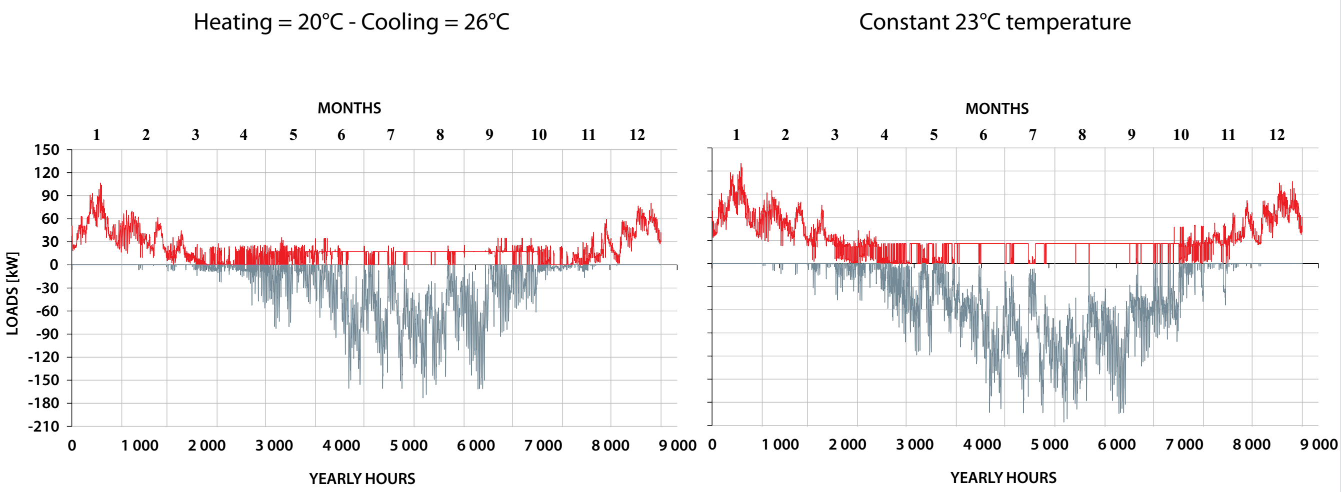


Figure 7-3: Total building requirement based on the required room temperature

Maintaining the temperature at 23°C throughout the year leads to an increase in the maximum power of the system and to an increase in the energy demand for the generators throughout the year.

However, while the increase in maximum power is quite limited, hence any system is able to guarantee 23°C in most of the year, the increase in energy required is instead very high, and should be avoided as far as possible. In heating, in percentage terms, the greater increases, the greater the thermal insulation is, while in cooling, they are substantially similar.

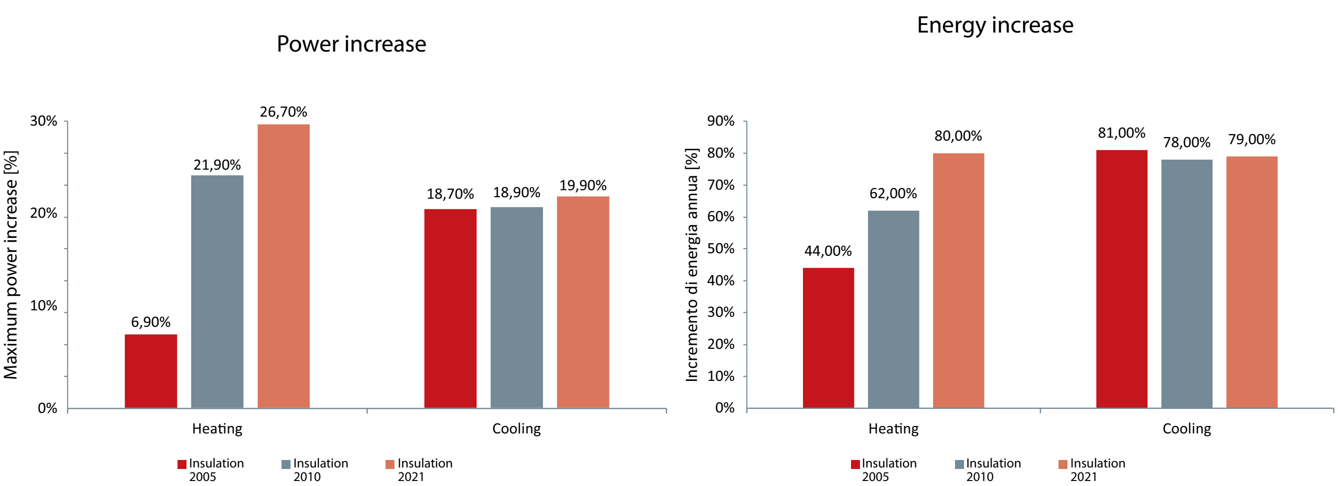


Figure 7-4: Increased power and energy required to maintain 23° in the room all year long

Conclusions

Excessive thermal insulation generates ambient temperatures that are too high even in the middle of winter. Despite introducing ambient air at 18°C, the higher the insulation, the higher the temperature inside the occupied rooms; in the case of the year 2021 insulation type, the temperature is maintained above 24°C almost throughout the year, with consequent use of the air-conditioning.

In case of high thermal insulation, the orientation of the rooms has little influence, rarely bringing the temperature below 23°C.

It therefore becomes necessary, especially for higher class facilities, to provide air-conditioning throughout the year and, above all, envisage a 4-pipe system which makes it possible to manage simultaneously, and more effectively, heating and cooling requests in the different rooms.

The greater use of air-conditioning impacts on the building's energy consumption, increasing the demand in terms of energy and power. But while the maximum power demand could suffer relatively low increases, the increase in the energy required is instead very high and should be avoided as far as possible. In heating, in percentage terms, the greater the increases, the greater the thermal insulation is, while in cooling, they are substantially similar.

Chapter 8: Comparison between maximum design powers and maximum powers in the standard average year

The plant design is obviously always carried out by considering the most critical conditions, which rarely occur and not every year.
In the following paragraphs, it is shown how, during a standard average year, the power required by the plant equipment is always lower than the design's maximum. The analysis was performed by considering a rectangular building with orientation north-south, and year 2010 thermal insulation type.

Load on the batteries of the air handling unit

The batteries are not influenced by the ambient temperature and, as you can see from the diagrams, the AHU hot and cold batteries work for a few hours a year above 50% of their power. In fact, they are generally designed to cope with the loads expected in critical conditions, which nevertheless occur rarely, almost never in an average year.

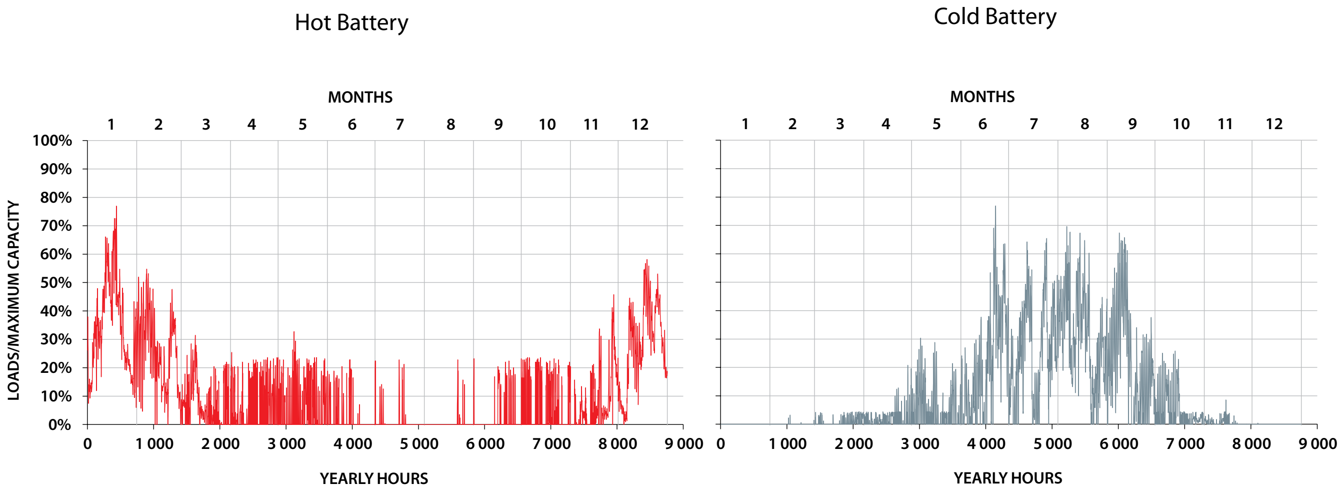


Figure 8-1: Load on the air handling unit batteries

Fan Coil in heating and cooling

In the case of fan-coils, the increase in the temperature maintained in winter inside the room not only increases the percentage of power used compared to the maximum performance, but also extends the period of operation of the fan-coils to over a month, while the decrease in the temperature maintained in cooling not only increases the percentage of power used compared to the maximum performance, but also extends the period of operation of the fan-coils practically to the whole year.

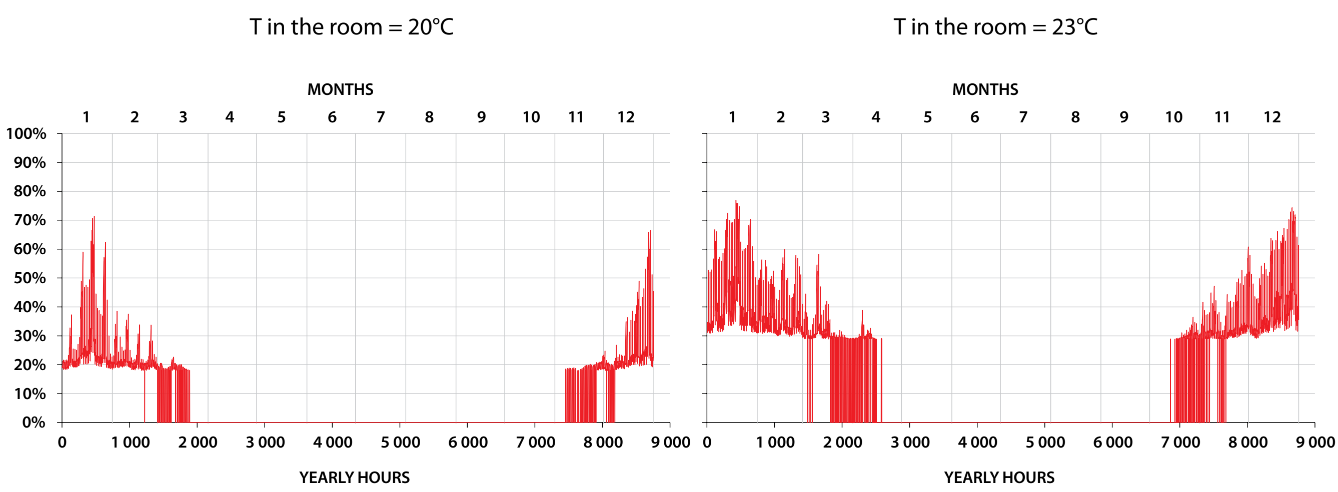


Figure 8-2: Trend of fan-coil load in heating

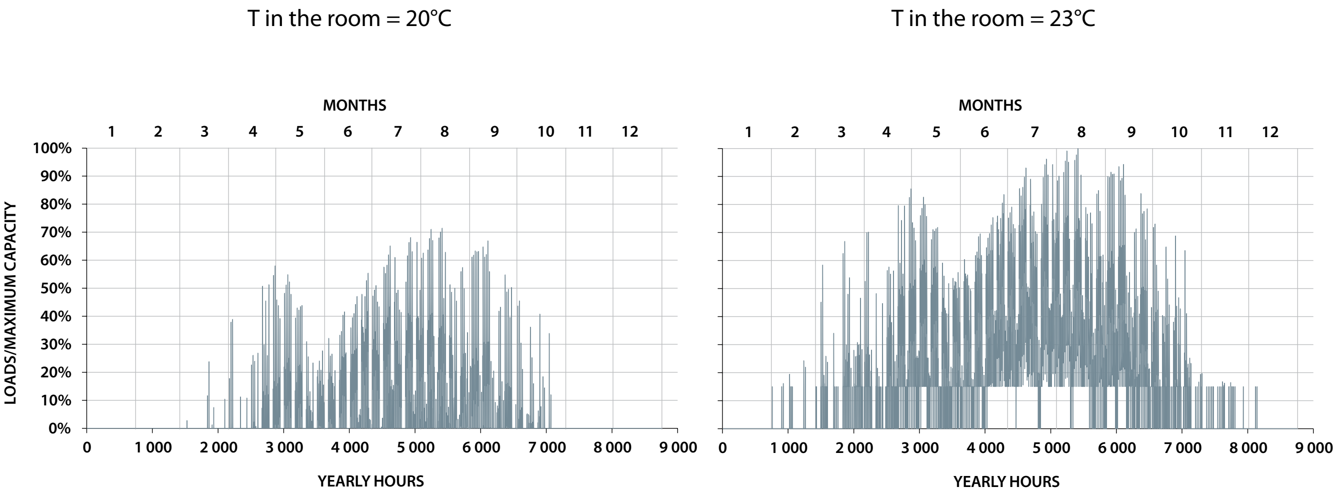


Figure 8-3: Trend of fan-coil load in cooling

Total annual load on hot and cold circuits

The power to be supplied to hot and cold circuits throughout the year corresponds to the sum of that requested by the AHU and the fan-coils. Hot circuits require power all year long (even in summer, for post-heating), while cold ones theoretically don't require power in December and January. However, since it is a facility for hotel use, we cannot exclude that some guests might want to lower the temperature in their room, so, in a hotel of at least 4 stars, even the cold circuits must always be kept in operation.

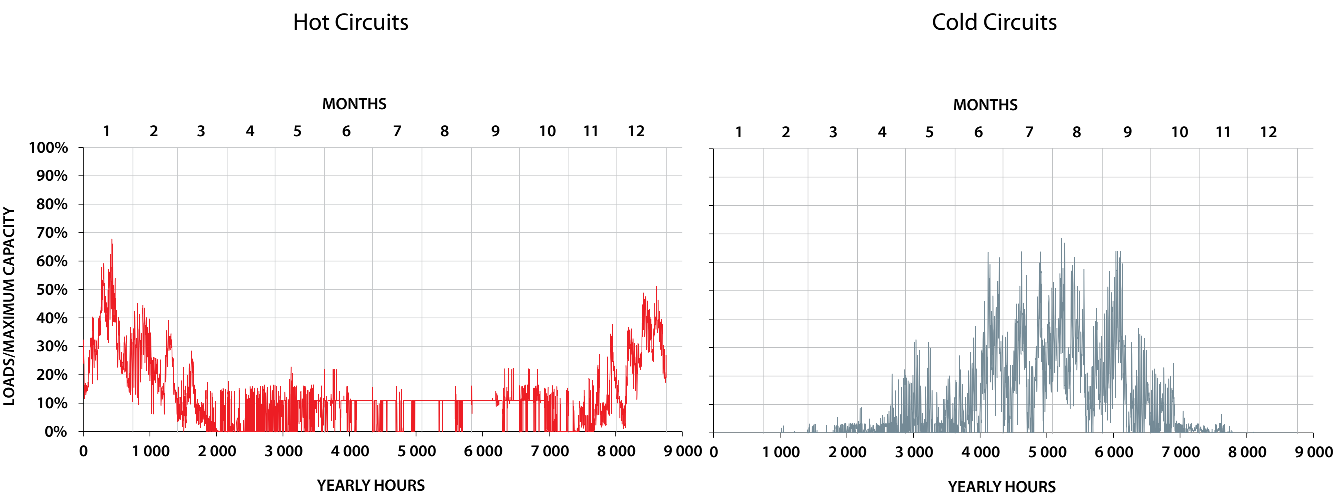


Figure 8-4: Performance of the power to be supplied to the hot and cold circuits

Consequences on the flow in the terminals

The heat exchange batteries of AHUs and fan-coils have a power-flow curve that deviates from linearity.

For example, to get 75% of the power, the flow must be reduced to 50%. With the same temperature of handled air, the power-flow curves vary depending on the inlet water temperature.

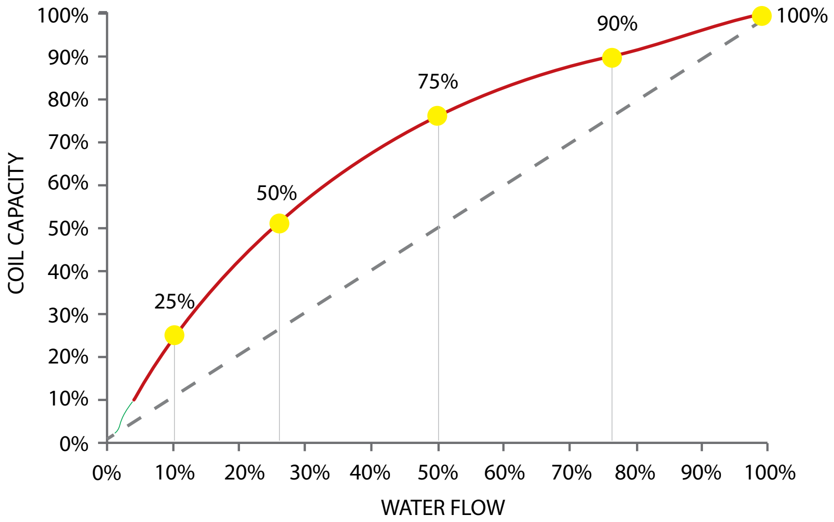


Figure 8-5: Characteristic Power-Flow curve

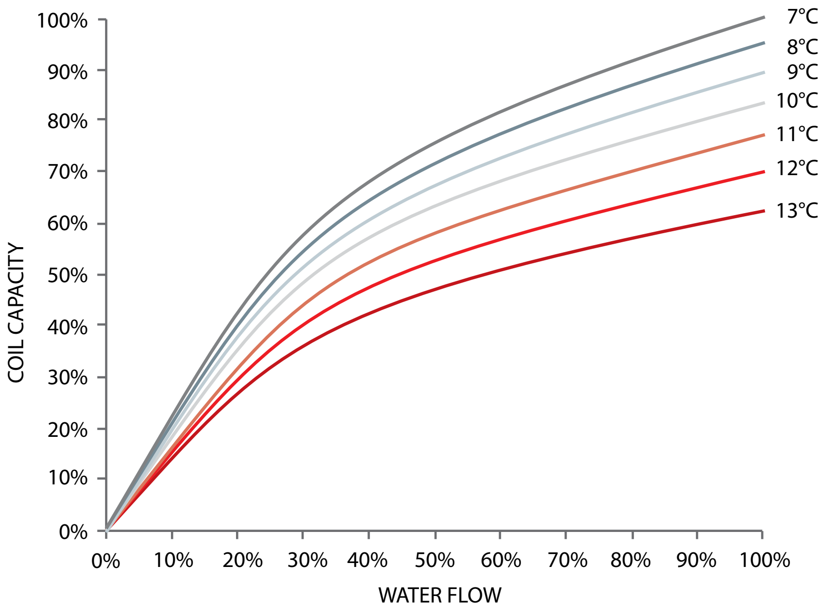


Figure 8-6: Characteristic Power-Flow curves for different inlet water temperatures

From the terminal's point of view, the flow of water that passes through it is always the same, regardless of whether a 3-way valve or a 2-way valve is used. By using a 3-way valve, part of the flow is bypassed on the third way and does not cross the battery, while the flow towards the terminal is always 100%.

With a 2-way valve, however, the flow circulating on the pipe towards the terminal is always equal to the one passing through the battery. Therefore, there is less water flowing on the system and a variable water flow system is obtained.

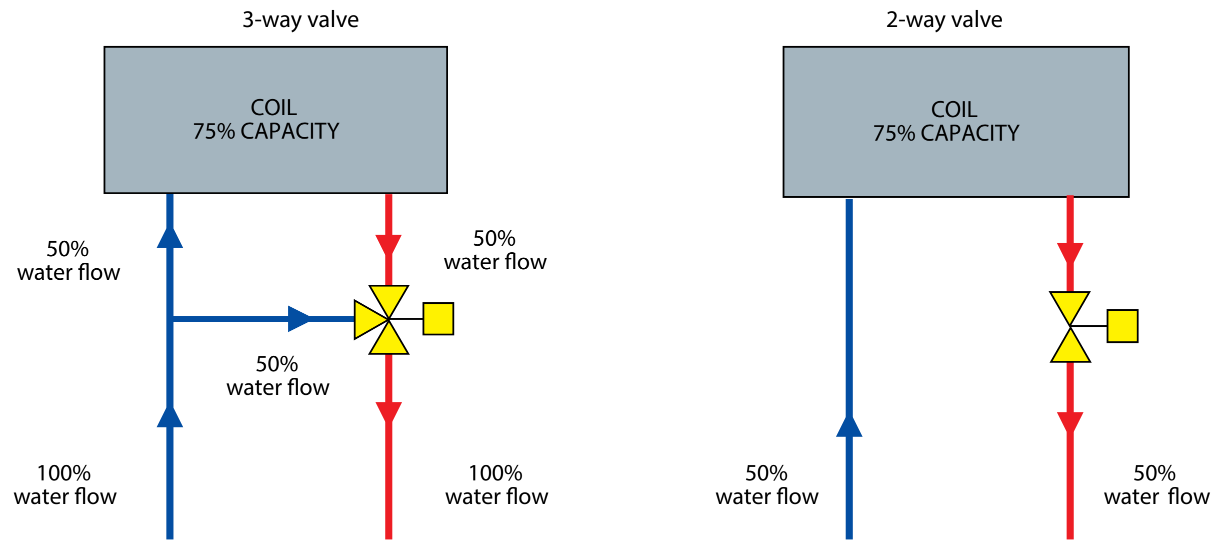


Figure 8-7: Circulation in the coil with a 3-way valve and a 2-way valve

While in circuits with three-way valves, the flow that circulates is always at its maximum (you can disable the pump of the cold battery for a couple of months a year at most, but only if it is separated from that of the fan coil), in circuits with two-way valves, only the water flow shown in the diagrams can circulate. You can easily imagine, therefore, that when adopting two-way valves, it is possible to save a lot of energy, as explained in more detail in the following chapter.

The best way to adjust the number of revolutions of a pump according to the actual requests is to use an inverter.

The inverter manages the rotation of the electric motor by controlling at the same time the speed, the torque, the absorbed current and the voltage: in addition to the flow regulation of the pump, you achieve an important result from the energy point of view. In fact, the inverter makes sure that the pump consumes only the minimum energy needed at a certain speed, without waste. It is important to choose a very high efficiency inverter, because otherwise, there is the risk of nullifying the energy consumption reductions that would be obtained with the speed regulation.

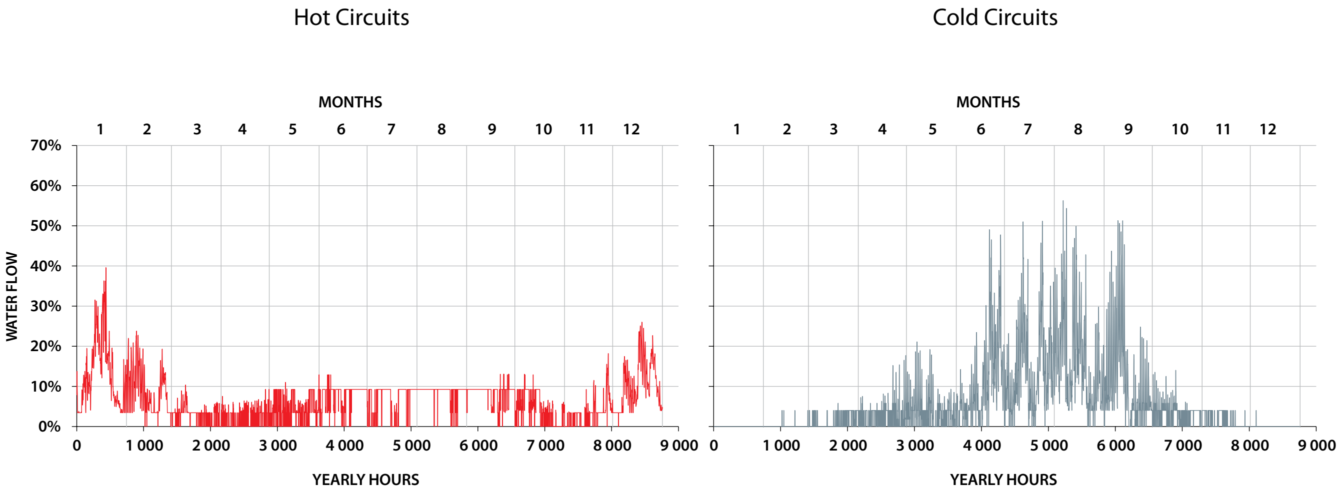


Figure 8-8: Flow rate trend in hot and cold circuits

Conclusions

AHU batteries are not affected by ambient temperature and normally work for a few hours a year beyond 50% of their power. In the case of fan-coils instead, the increase in the temperature maintained in the room in heating, and the decrease in the temperature in cooling, increase the percentage of power used, compared to the maximum performance and extend the period of operation of the fan-coils.

Overall, hot circuits require power all year long (even in summer, for post-heating), while cold ones could theoretically remain switched off from December to January. In practice, however, since it cannot be ruled out that some guests may want a lower temperature in the room, it becomes necessary to also keep the latter always in operation.

If we keep in mind that the curve of the battery power is not linear when the water flow varies, and that lowering the requested power to 75% reduces the flow rate to 50%, we can immediately deduce that in order to reduce consumption, it is necessary to provide a variable flow circuit, which allows only the water needed to satisfy the request of the terminal to circulate.

A variable flow circuit can be obtained by using a 2-way valve, which reduces the flow of circulating water based on the amount that really needs to pass through the batteries.

In a system with 3-way valves instead, the flow of water towards the terminals is always at its maximum and the excess amount is deviated on the third way. In this way, it is clear that no savings can be achieved.

Chapter 9: Theoretical advantages of variable water flow circuits

A variable flow system, that allows only the water needed to satisfy the power demand of the terminals, must be implemented in order to obtain sizeable energy savings.

The following paragraphs expand the theoretical advantages, from the energy point of view, of the variable water flow hydraulic circuits, and try to identify the limits due to the common use of normal 2-way valves.

Power required to move a water flow

The power required by a pump to move a determined flow of water is given by the formula:

$$P = \frac{QH}{\eta}$$

Where:

Q is the flow of water to be moved expressed in m^3/s,

H is the total head of water, expressed in Pa

η is the efficiency of the pump

We also know that the flow rate Q varies linearly with the number of revolutions of the pump, while the total head varies with the square of the number of revolutions. Therefore, it is customary to say that the power varies with the cube of the number of revolutions. However, this statement is not actually correct in a circuit featuring control valves.

When the power varies with the cube of the pump rpm

If there isn't some kind adjuster, the resistive circuit of the system remains constant (red curve) and the pump reduces the number of revolutions in a way linear to the flow rate.

Therefore, the number of revolutions corresponds exactly to the flow rate supplied to the circuit and the pump works at constant efficiency.

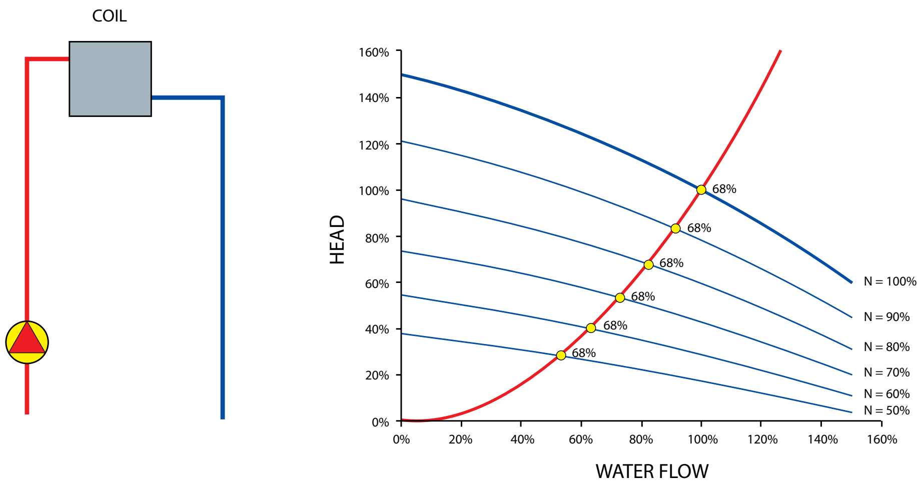


Figure 9-1: Circuit and characteristic curve without adjusters

The presence of 2-way control valves, however, changes the dynamic. When the valves close, the circuit's resistance curve changes and moves to the left. The work point of the pump moves along the curve, and the efficiency also changes. The number of revolutions does not correspond to the flow rate anymore.

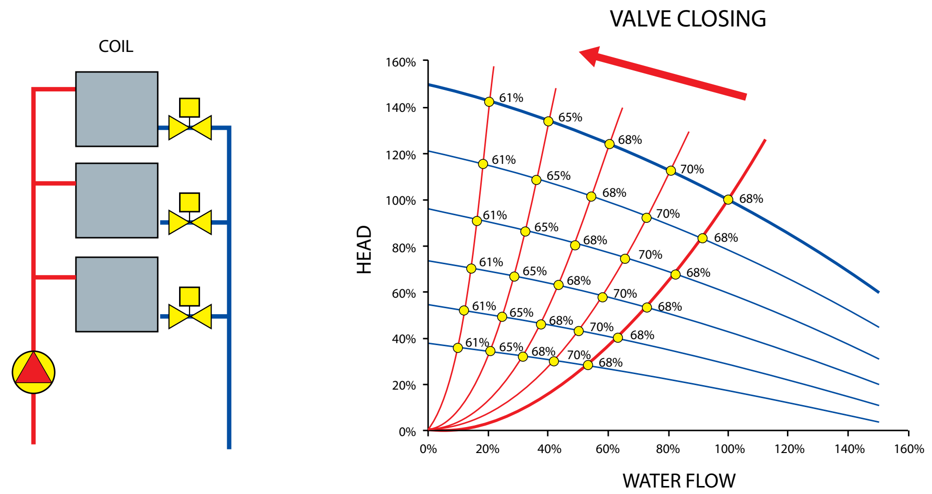


Figure 9-2: Circuit and characteristic curve in the presence of a 2-way valve

At 75% of the load, 50% of the flow is required, which falls to 25% when the load drops to 50%. If the pressure is kept constant at the pump heads throughout the operation, as is generally done, 50% of the flow rate corresponds to 87% of the revolutions and, 25% of the flow rate to 83% of revolutions.

As you can see from the graph in Figure 9-3, the constant pressure pump's efficiency remains at very similar values in the three operating points.

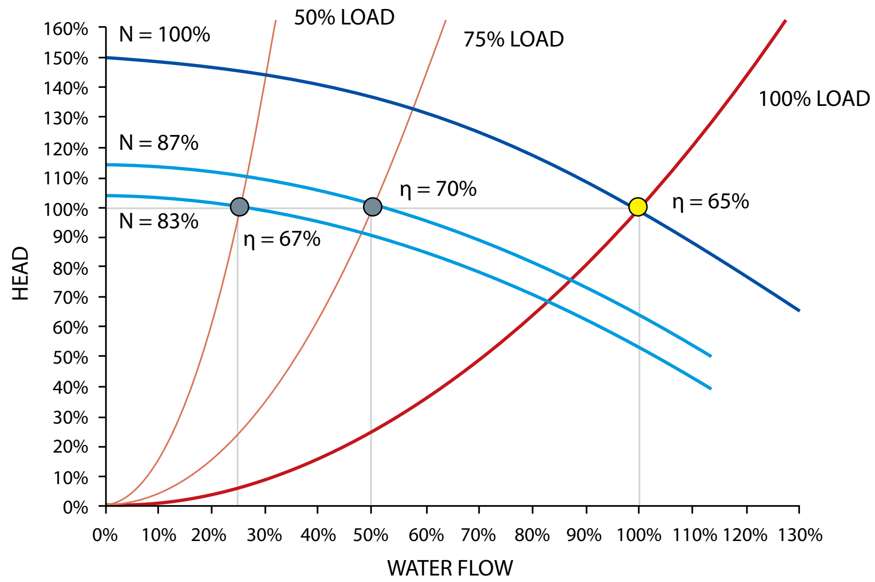


Figure 9-3: The efficiency of the constant pressure pump remains at very similar values in the three operating points

If it were possible to vary the total head and decrease it as shown in the figure (linear trend – grey line – with a total head of 50% at zero flow), the pump would work at higher efficiencies and lower total heads, greatly reducing the power required.

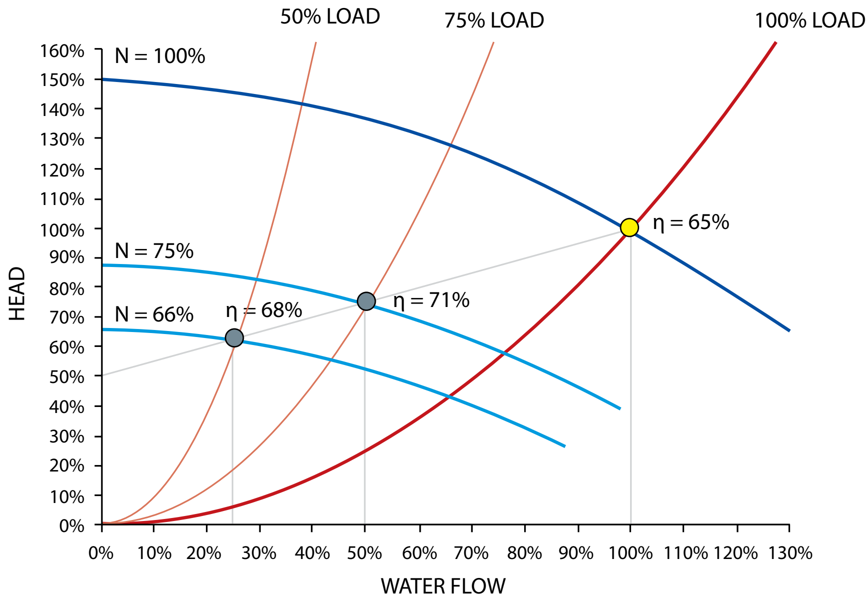


Figure 9-4: If the total head decreased along the grey line, the power required by the pump would decrease

With constant total head, the power varies in a substantially linear way with the flow rate. The small variations are due only to the pump efficiency variations.

If the total head varies with the flow rate, the power reduction is much greater. This condition, however, is difficult to achieve with traditional 2-way valves.

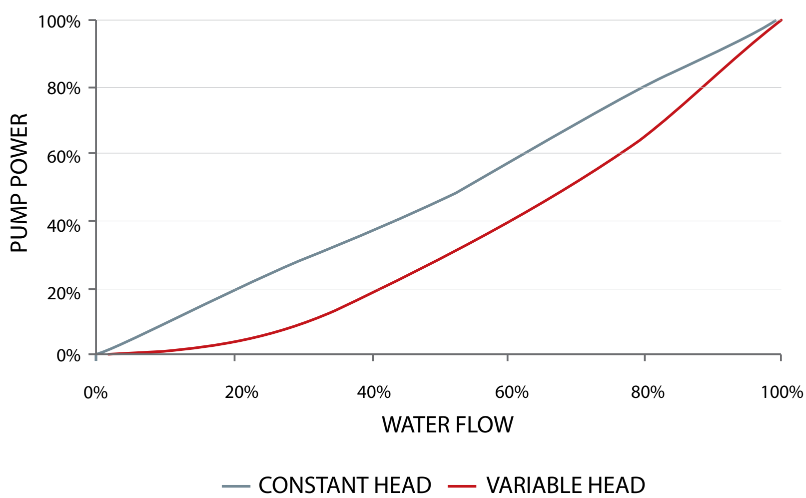


Figure 9-5: Power required by the pump with constant total head and variable total head

Limits of traditional two-way valves

As previously described, the heat exchange battery of an AHU or of a fan coil does not have a linear pattern between water flow and power efficiency; therefore, the water flow must be reduced so much more than the efficiency is reduced.

This poses a problem of adjustment, since the valve stem must receive a linear signal.

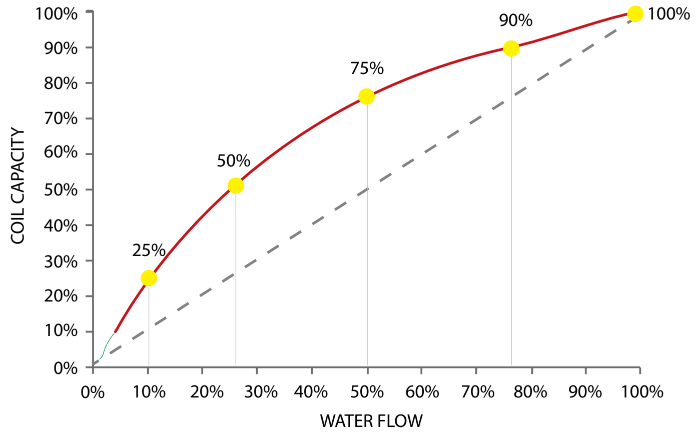


Figure 9-6: Characteristic water Flow-Power output of a fan coil

To overcome the problem, the valve obturators are built so as to compensate for the flow-power of the valve curve.

The best way is to intervene on the obturator curve on the basis of the input signal, so as to compensate for the flow-power curve and obtain linearity between signal and flow (right figure).

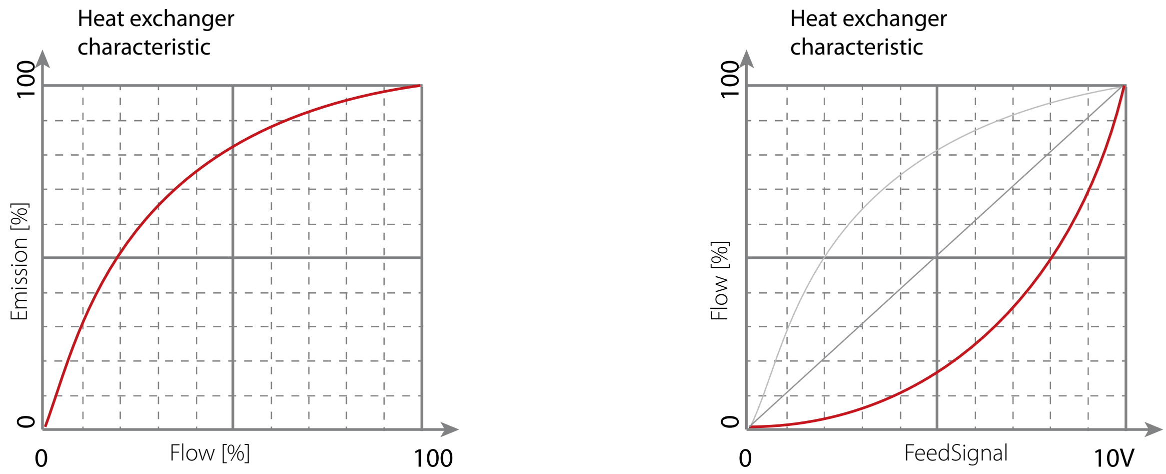


Figure 9-7: Flow-Power of the valve curve (left) and Flow-Signal of the obturator curve (right)

\+

The final result is to obtain a linear characteristic between the valve opening signal and the power output, represented by the red curve: when 50% of the power is needed, the signal will be 5 V (half), thus exploiting the simplicity of the management of a linear signal.

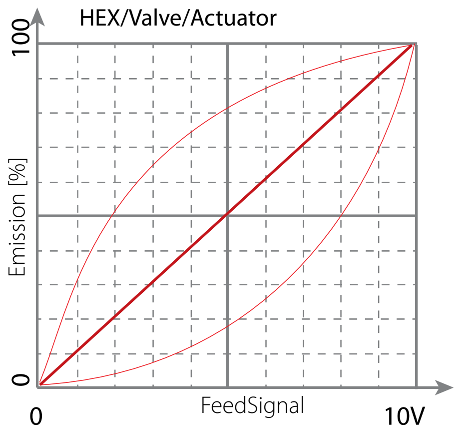


Figure 9-8: Linear characteristic between the valve opening signal and the power output

The effect of the valve opening can be shown in a power output-load loss diagram. The closing of the valve moves the curves to the left.

The prerequisite for obtaining a perfectly linear characteristic between required power and valve opening is that the pressure difference at the heads of the valve itself remains constant (in the figure equal to 100%).

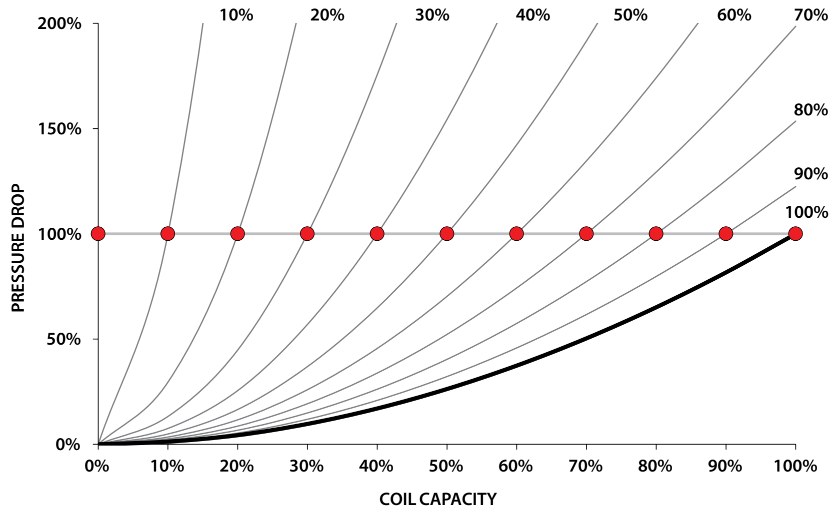


Figure 9-9: Power output-load Loss diagram

In the case of 3-way valves, the difference in pressure upstream and downstream of the valve is always constant, like the flow rate.

If using 2-way valves instead, the difference in pressure changes as the flow varies, causing problems on the adjustment, as will be discussed in the following paragraphs.

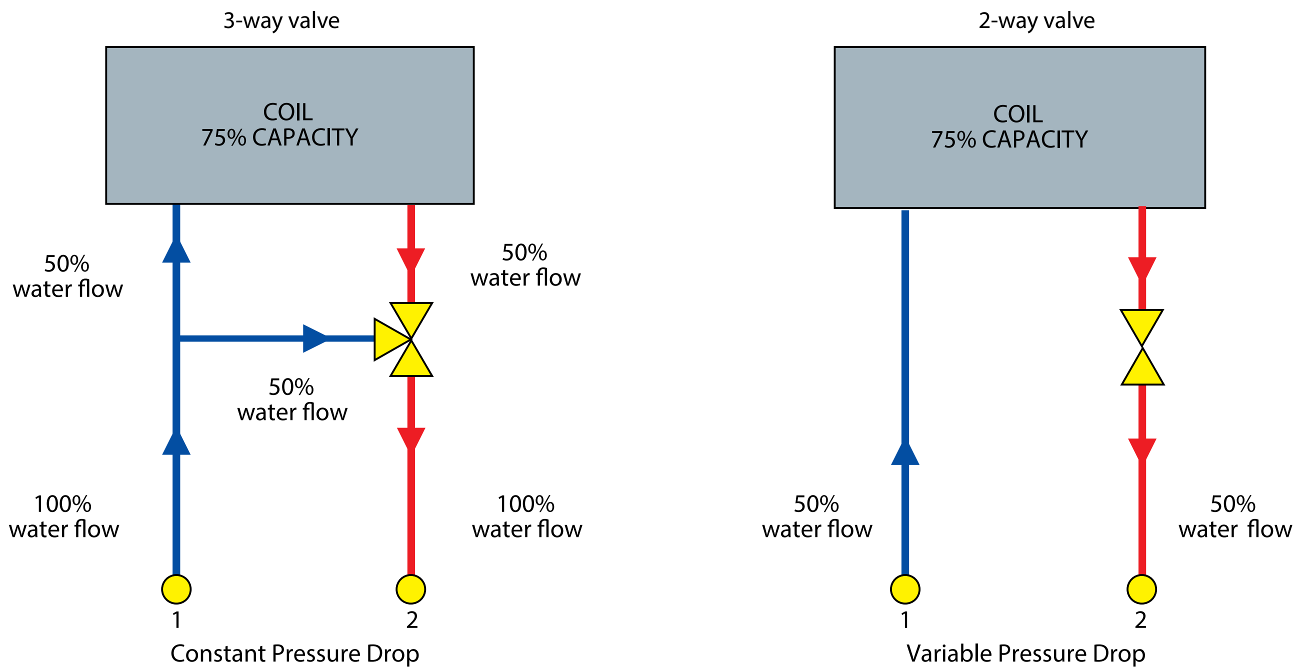


Figure 9-10: Difference in constant pressure and flow with a three-way valve, difference in pressure which varies with the flow with a two-way valve

Suppose that a hydraulic circuit is used, like the one shown in Figure 9-11, with four identical terminals, for example 4 AHUs. The example shows 2-way valves, but the situation would be similar also if using 3-way valves.

At 100% of the load, the flow rate is at its maximum in each common sector of the circuit, thus the ΔP pressure drops at the heads of each terminal are different. To equalize them, calibration valves must be inserted downstream of the control valves.

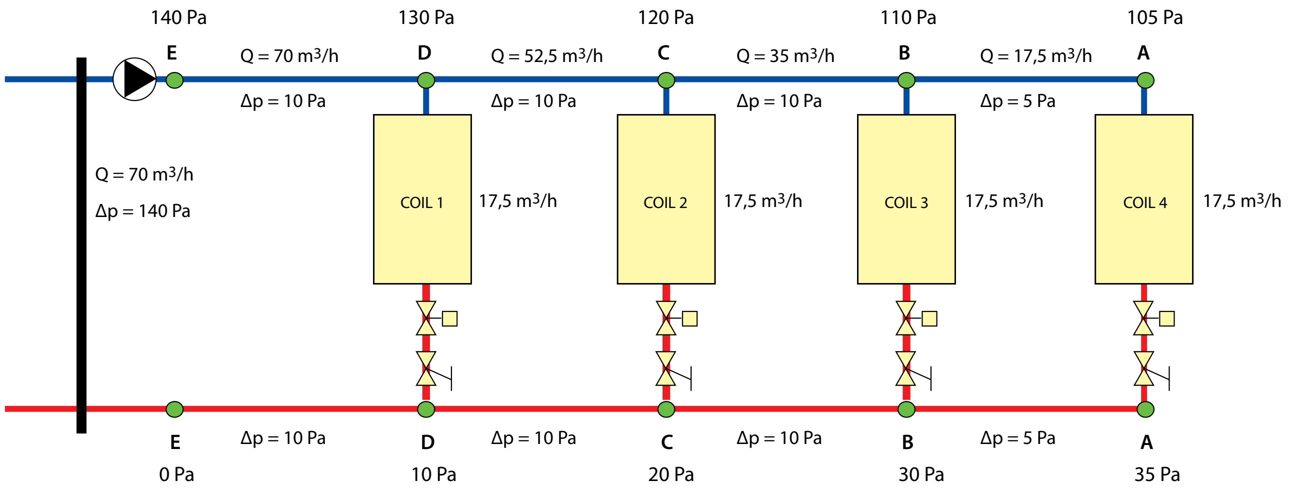


Figure 9-11: Hydraulic circuit with 4 identical terminals

If we observe the progress of the pressures at the heads of the terminals, we see that the pressure drop of the battery is 30 kPa (blue histogram) and that of the valves 40 Pa (red histogram). What changes is the pressure drop of the calibration valves, which in turn depends on the pressure drops of the common delivery and return sections. It goes from 50 kPa of terminal 1. to 0 kPa of terminal 4.

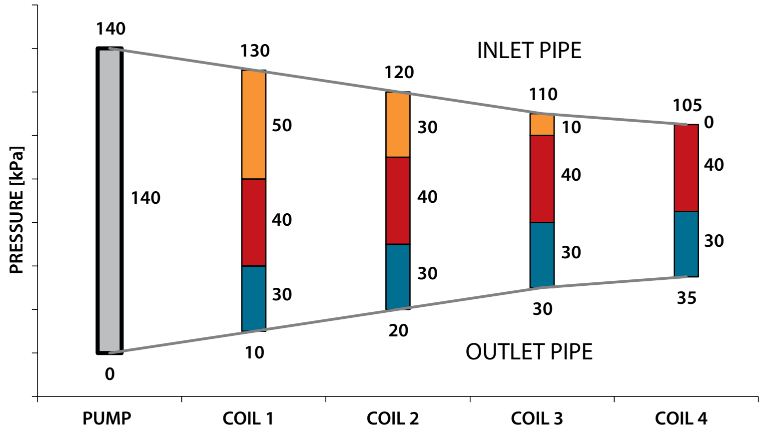


Figure 9-12: Pressure trend in the circuit with 4 identical terminals and calibration valves

Suppose there is a load variation like the one shown in Figure 9-13 in which the water flow in the batteries of the terminals drops, and the load loss drops even more (it varies with the square of the water flow).

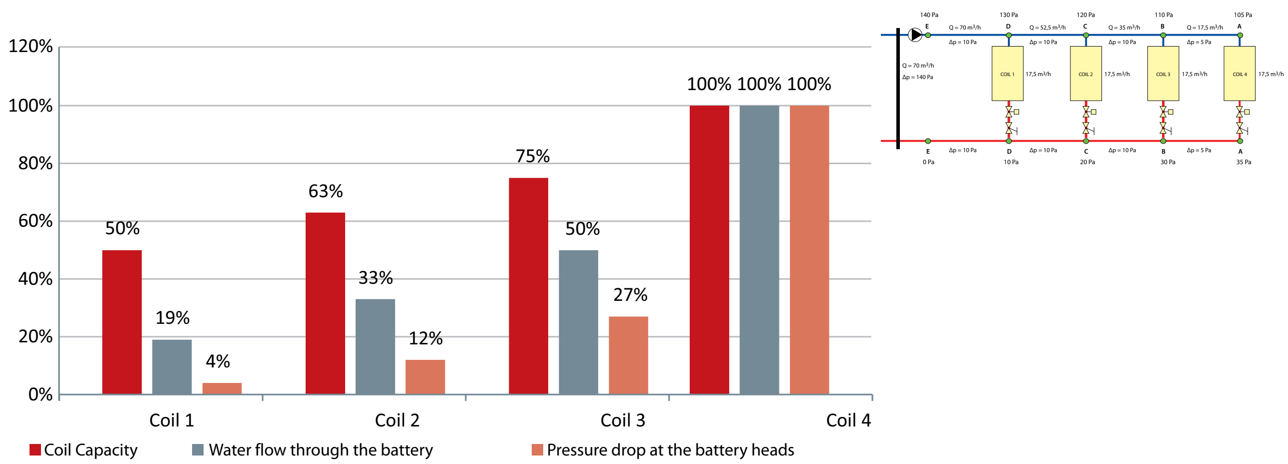


Figure 9-13: Speculated load variation in the hydraulic circuit with 4 identical terminals, from the first to the last the load increases

Compare the different pressure trend in the forward and return pipes in the case of 3 and 2-way valves. In the second case, the hypothesis is to keep the difference in pressure constant at the pump heads.

With 2-way valves, a variable water flow system is obtained. The flow drops in the common sectors between the various terminals and so do the pressure losses as well. For example, at the heads of Terminal 3 there is a ΔP = of 80 kPa with 3-way valves against 114 kPa of the 2-way valves.

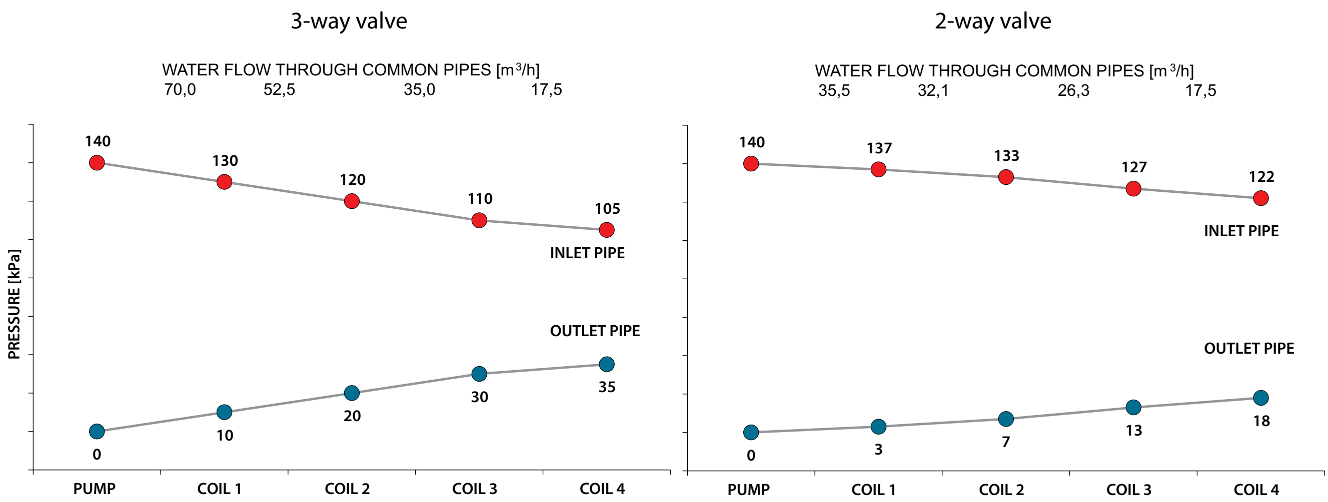


Figure 9-14: Pressure in the hydraulic circuit with 4 identical terminals with 2 and 3-way valves

In the case of 3-way valves, the constancy of the upstream and downstream flow of the valve (red dots in the drawing) and on the calibration valve, means that at the head of the A-C way, the difference in pressure is always constant, equal to 70 kPa.

Generally, the 3-way valves have a greater loss on the C-A bypass way: should it not be enough, a calibration valve should be added in order to equalize the pressure drops between battery + B way and bypass.

The action of the obturator causes a pressure drop in the valve of 22 kPa to compensate for the lower pressure drop of the battery, due to halving the flow. The valve works at a constant pressure difference.

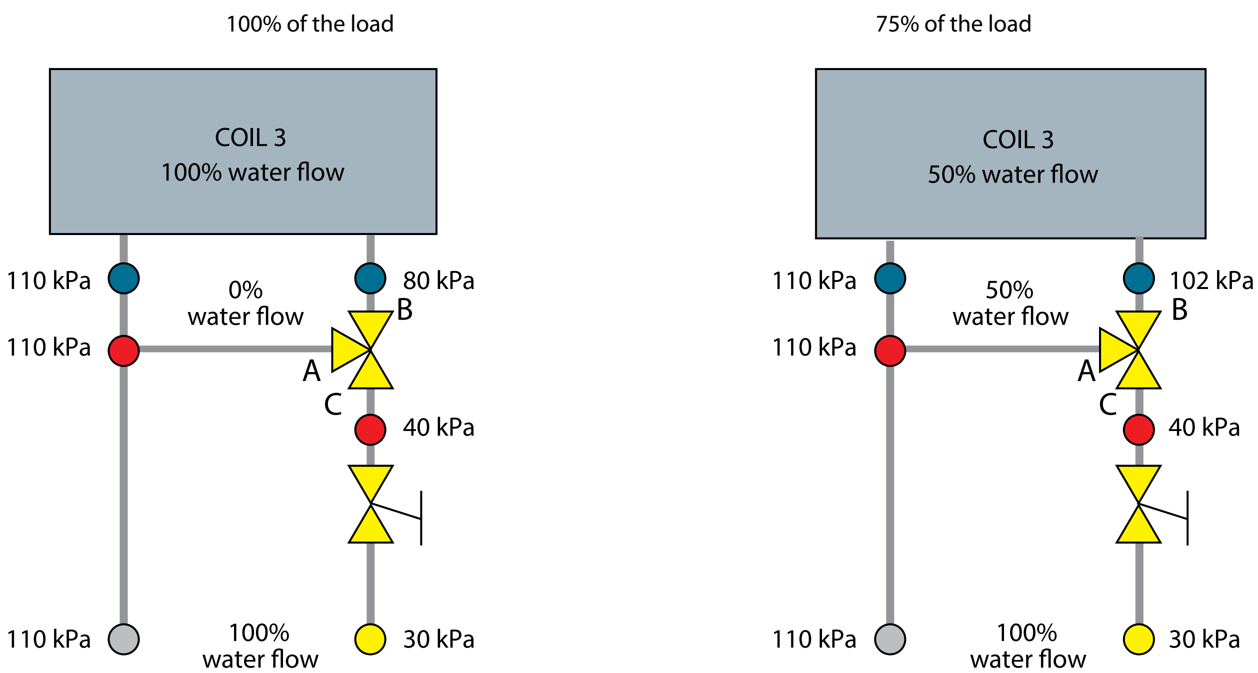


Figure 9-15: Circuit with 3-way valve and load variation

In the case of 2-way valves instead (Figure 9-16), the situation changes. First of all, the pressure difference at the terminal heads increases, since the flow in the common sectors drops and, moreover, the calibration is fixed, therefore, its loss falls from 10 to 2.5 kPa.

Secondly, since there is no longer the third way, the valve must work under pressure jumps, which are completely different from one another, 40 kPa at 100% of the load, 103 kPa at 75% of the load.

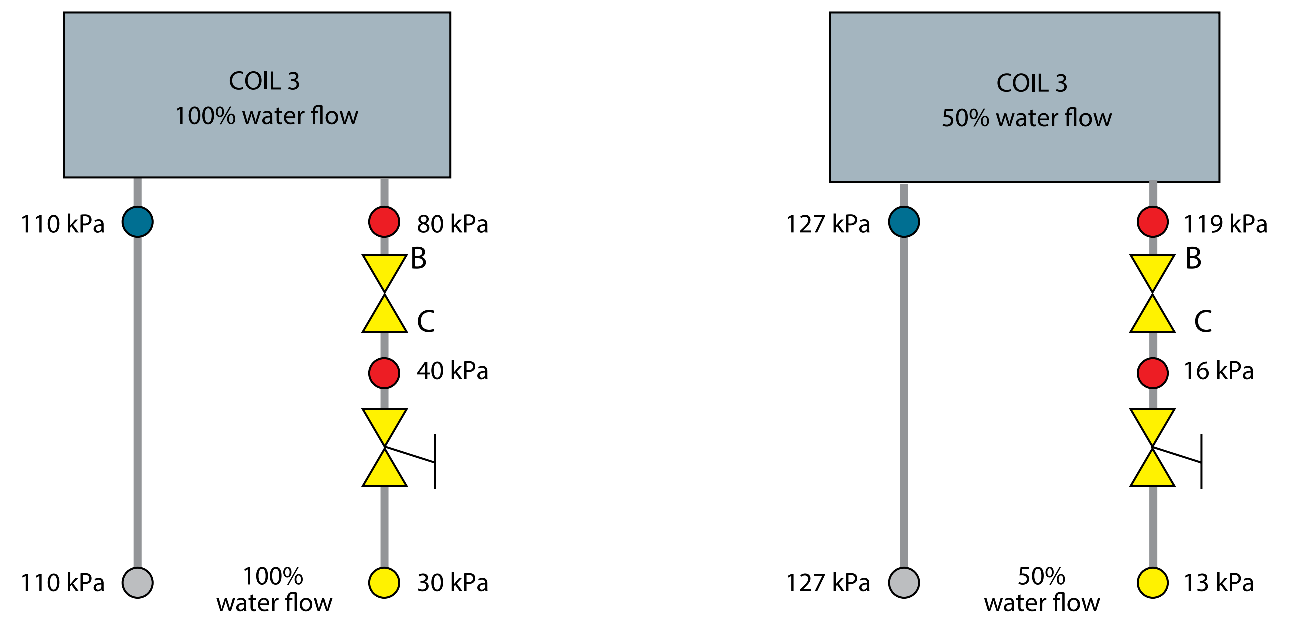


Figure 9-16: Circuit with 2-way valve and load variation

The following figure (Figure 9-17) shows how the pressure losses are distributed on the entire circuit when all the terminals work at 100%. It should be noted that the valves always lose nominal load (all open) equal to 40 kPa.

At full load, the load losses are absolutely equal, because the 3-way valves have the B-A way completely open and behave like 2-way valves. By analyzing in details the single losses, the blue histograms show the battery losses, the red ones those of the control valve and the yellow histograms the pressure drops of the calibration valves.

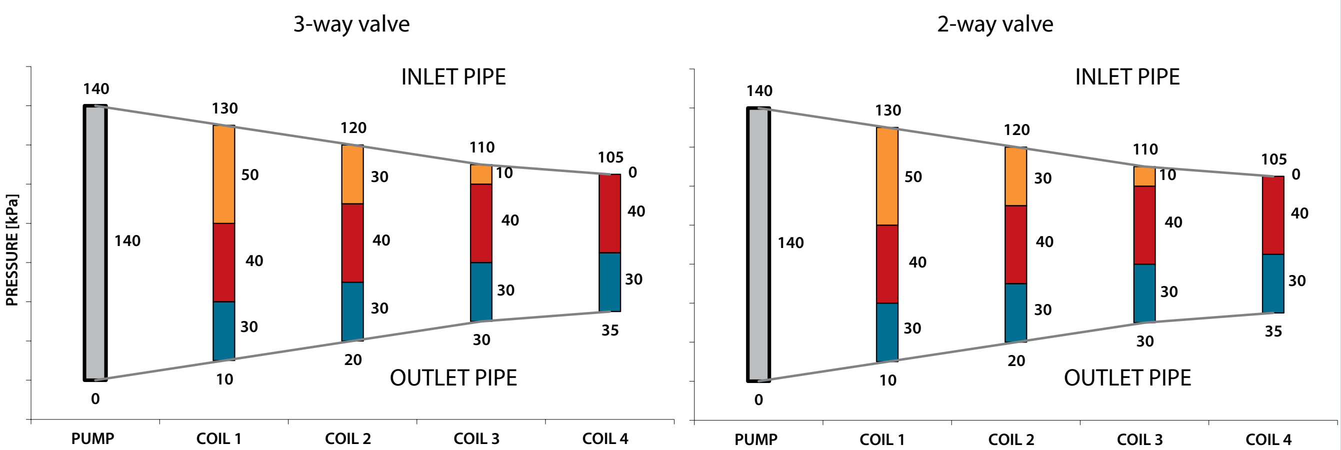


Figure 9-17: Pressure trend in the circuit with 3 and 2-way valves and uniform loads

The situation changes when pressure losses are different on each terminal, as shown in Figure 9-13, where the load at the terminals is as follows:

terminal 1 = 50%; terminal 2 = 63%; terminal 3 = 75%; terminal 4 = 100%

Also in this case obviously, the valves always have and identical loss of nominal load (all open) equal to 40 kPa.

With 3-way valves, the sum of the blue histograms (ΔP batteries), red (nominal ΔP valve) and green (compensation of the valve obturator on the bypass line) always gives 70 kPa. Calibration valves (yellow histograms) remain equal to the 100% case, because the flow that crosses them is always equal to the maximum. Furthermore, pressure losses of the common sectors remain constant, because the flow of water that crosses them is also constant.

With two-way valves, the pressure loss at the valve heads increases, compared to 40 kPa of the situation at 100% of the load: in fact, the flow of water in the battery decreases, and with it the pressure loss too. The circuit of every single terminal is no longer compensated by the third bypass way, as in the case of 3-way valves: also the calibration valves are crossed by the battery flow and no longer by the full flow.

There is also lesser water flow in the common sectors where load losses are lower. As a result, the 2-way valves have to compensate for this, by substantially narrowing their passage.

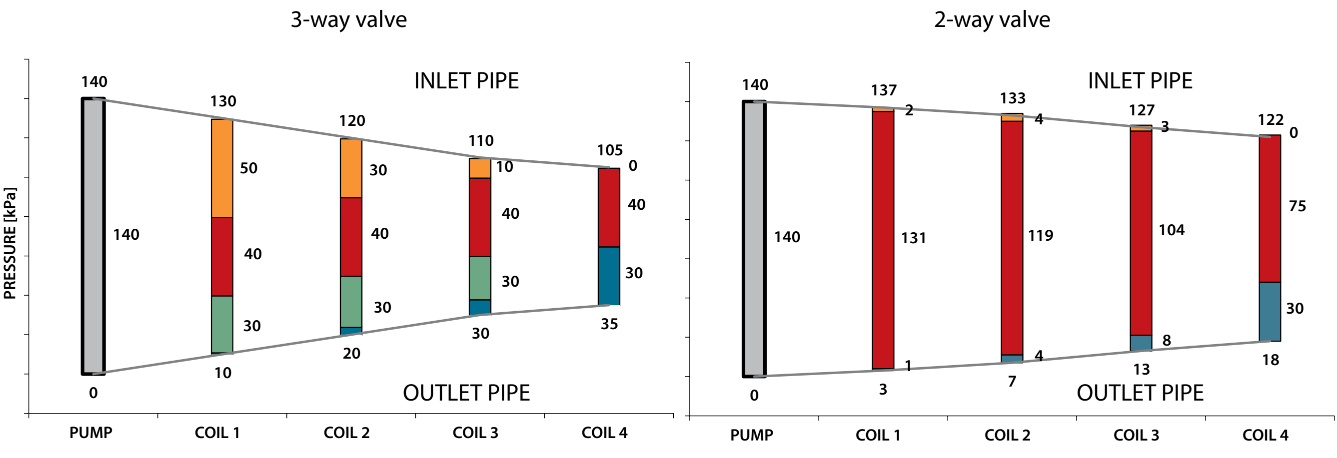


Figure 9-18: Pressure trend in the circuit with 3 and 2-way valves and differentiated loads

If the case of Figure 9-13 is reported on a power-pressure jump diagram, it is immediately clear that there is perfect correspondence between required power and valve opening, in the case of 3-ways, while the 2-way valves have to close a lot more, due to the increase of pressure at their heads, as shown above.

Even the valve of terminal 4 (red dot) must close, even if the required power is 100%.

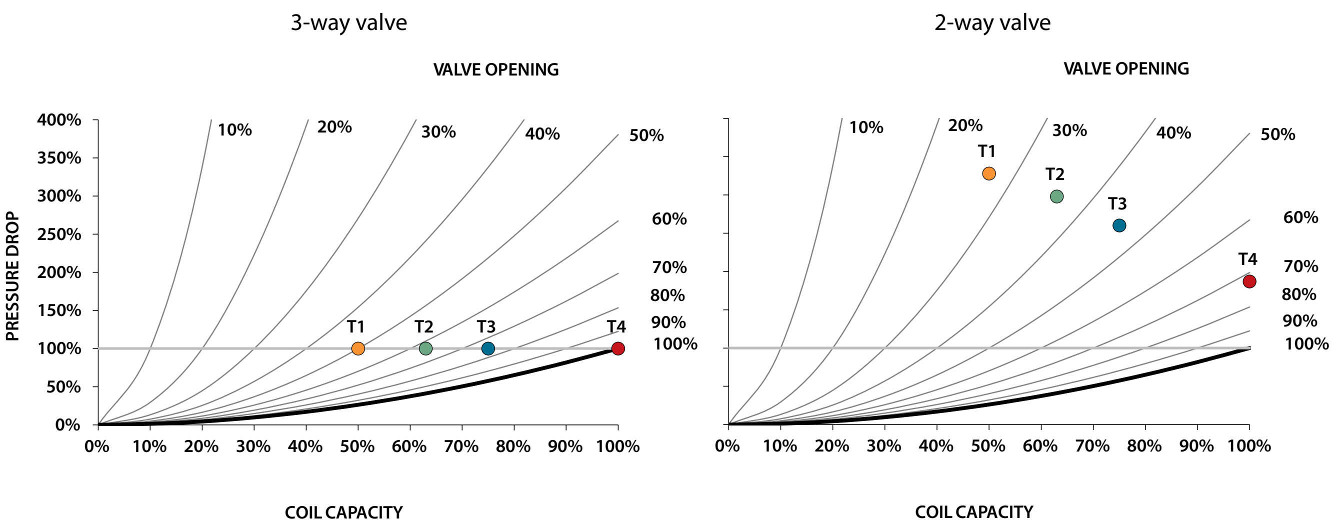


Figure 9-19: Power-pressure Jump diagram with 3 and 2-way valves

The phenomenon is even more evident if illustrated in a graph that shows the battery power output based on the opening of the valve.

Perfect linearity is achieved with 3-way valves, while 2-way valves are forced to close considerably more.

And this is where there is the risk of grafting a dangerous phenomenon of hunting due to poor control, because every valve struggles to adjust well below 10% -15% of opening.

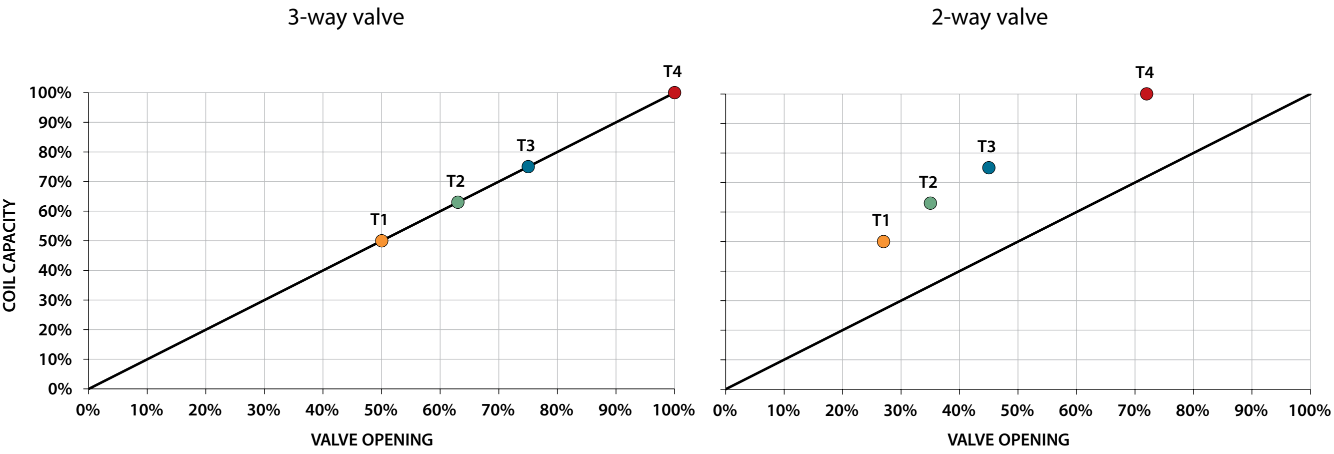


Figure 9-20: The battery power output based on the opening of the 3 and 2-way valve

The risk of hunting

Now suppose that there is a diametrically opposed situation in the circuit, where terminal 1 works at 100% of the load, while the others work at reduced load. Compared to 3-way valves, the power drops by 68%.

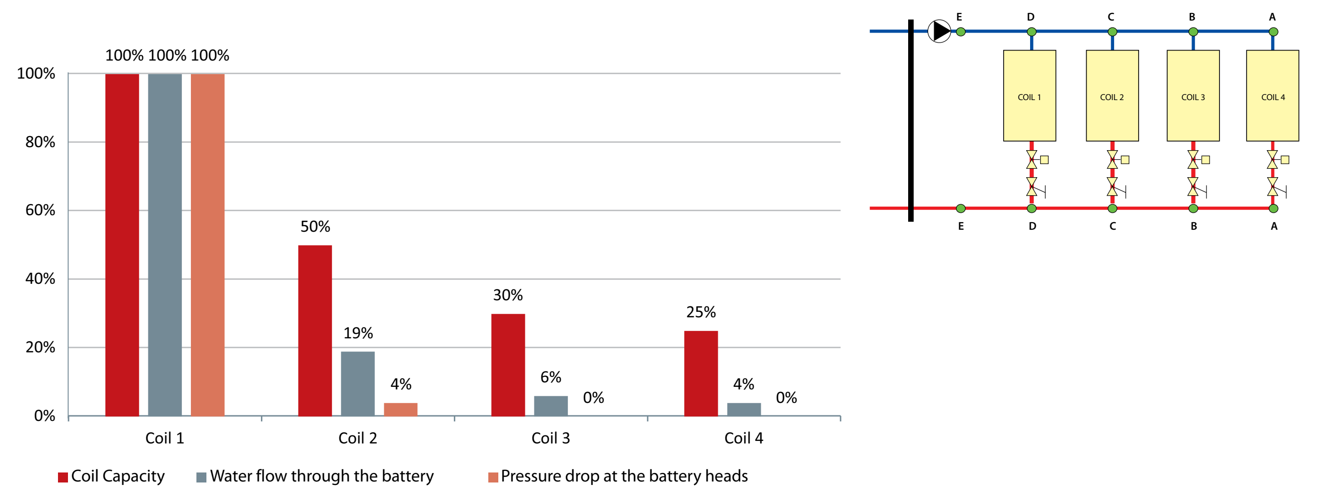


Figure 9-21: Speculated load variation in the hydraulic circuit with 4 identical terminals, from the first to the last the load decreases

The pressure drops of the common sectors are very low, due to the reduced flow. Therefore, it falls to the valves to close considerably more (red histograms) to compensate for excess pressure increase at the terminal heads. Those of terminals 3 and 4 work close to closure. The losses of the batteries (blue histograms), and of the calibration valves (yellow histograms), are almost zero because of the low flow.

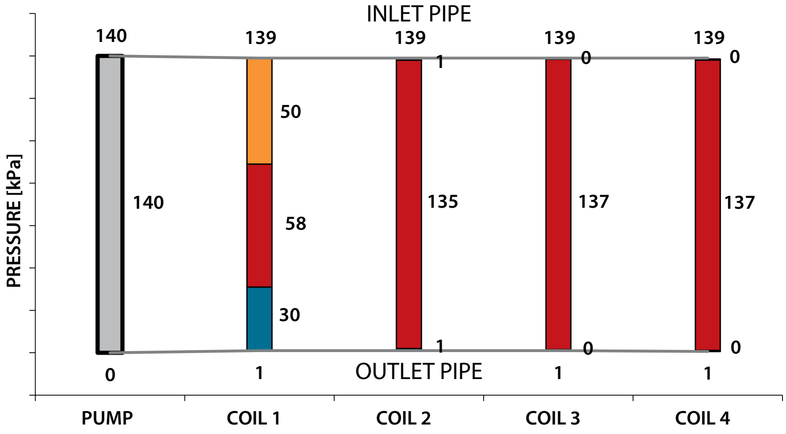


Figure 9-22: Pressure trend in the circuit along the decreasing loads

As can be seen from the two graphs, the valves have to close considerably more in comparison to the required power. Even terminal 3 works with the valve open at 16% (against a required power of 30%), at the limit of the hunting grafting, and terminal 4 with the valve open at 12% (against a required power of 25%), in full area of poor adjustment.

With 3-way valves, instead, the valves would work precisely in total linearity.

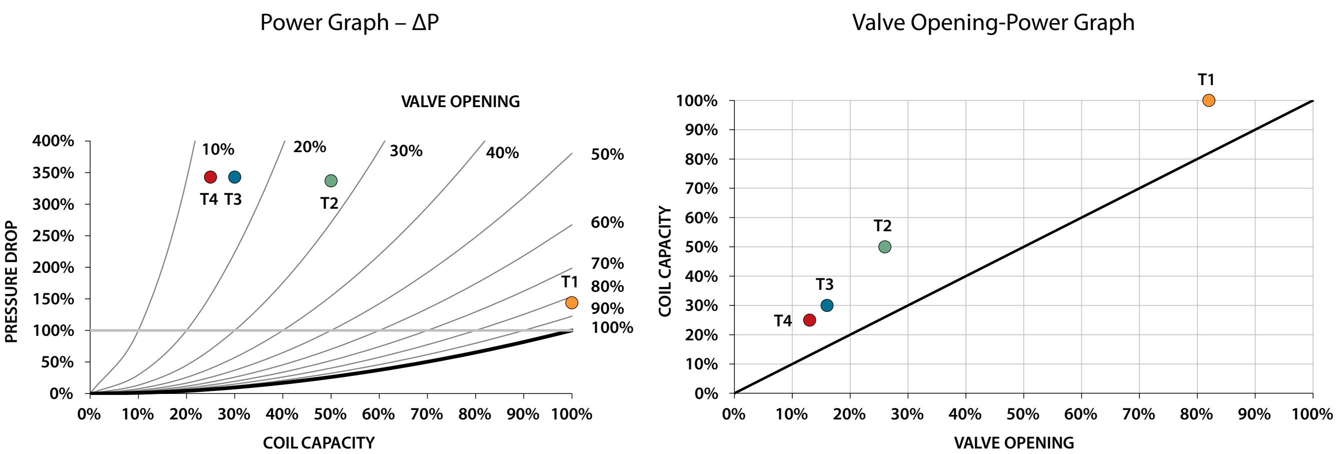


Figure 9-23: Characteristic Power-ΔP and Valve Opening-Power in the circuit with decreasing loads

The risk of starving

To improve the phenomenon of excess pressure at the heads of the valves and reduce pump consumption, the pressure could be adjusted by keeping it constant in the point A-A (the most distant), instead of E-E astride the pump, obtaining a significant power reduction (87% savings compared to the 3-way, against 68% of the control in EE). Unfortunately, however, this solution, in addition to not always being technically possible, can generate starving issues.

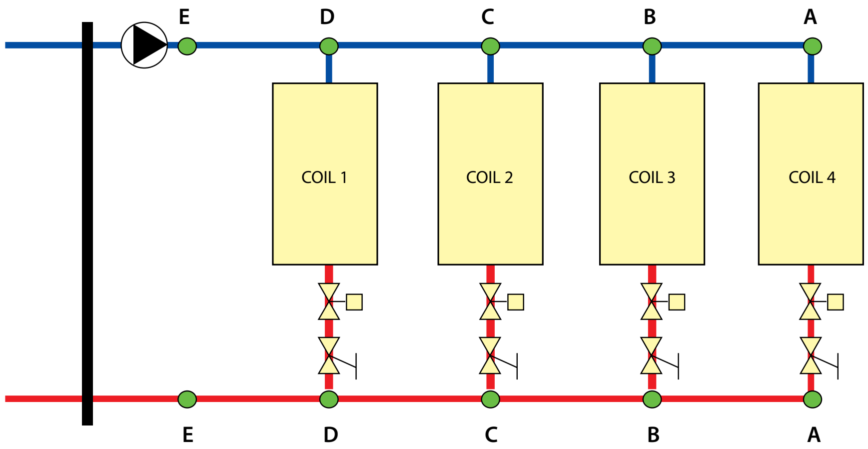


Figure 9-24: Hydraulic circuit with 4 identical terminals

As can be seen from the two graphs below, the total head provided by the pump is much smaller with the control in A-A, therefore, the valves must provide a lower load loss.

However, if we observe terminal 1, the load loss of the battery with control in E-E is equal to 30 kPa, while with control in A-A, it is equal to 8 kPa. It means that the battery is starving, because the pump isn't giving enough pressure for the load required.

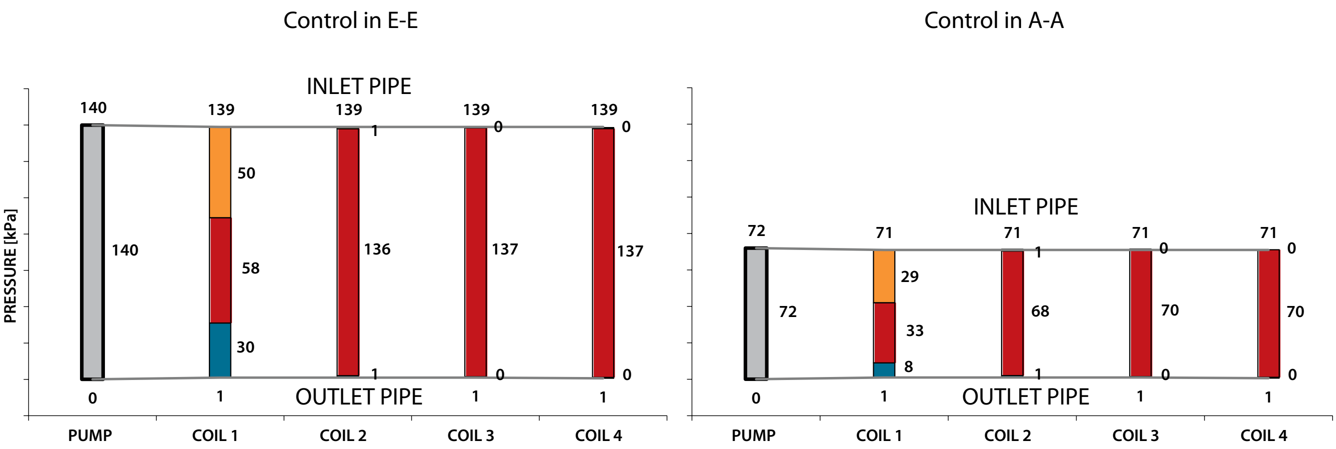


Figure 9-25: Pressure trend in the circuit with control in E-E and A-A

The phenomenon is better understood in the power-pressure difference diagram. The difference in pressure at the heads of terminal 1 (yellow dot) is too low, in the case of control in A-A. The valve remains completely open, but the power supplied is equal to 90% of the power required.

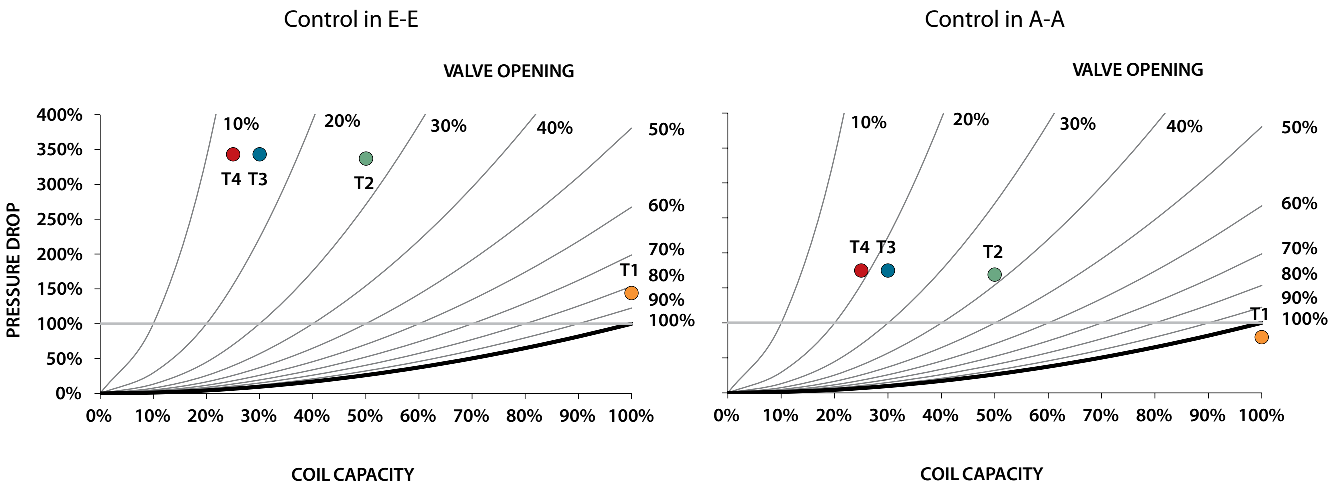


Figure 9-26: Characteristic Power-pressure Difference with control in E-E and A-A

It is even better noted in the valve opening-power diagram. Terminal 1 is under-powered because when the valve is opened at 100% it only provides 90% of the power required. The other terminals, however, work slightly better, because they provide equal power with larger valve opening.

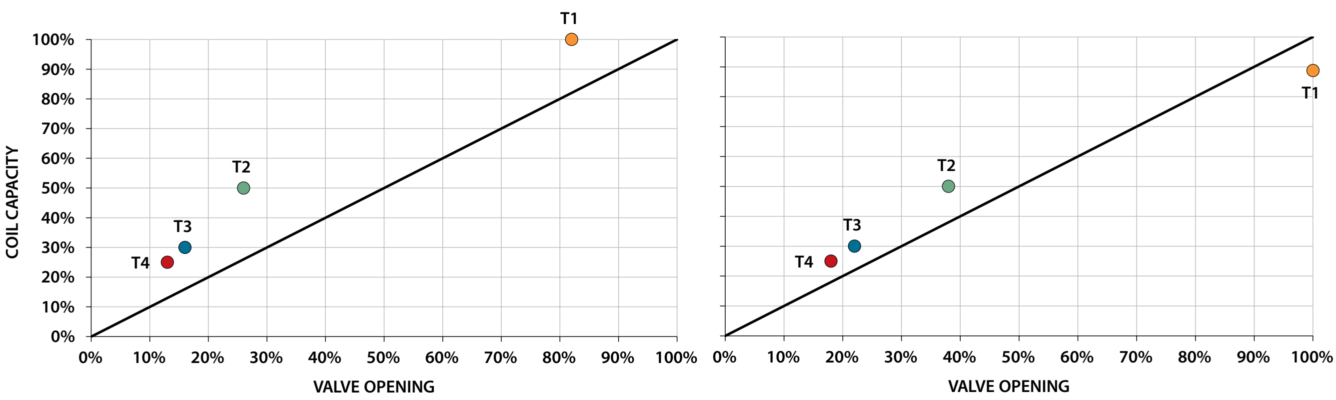


Figure 9-27: Valve Opening-Power with control in E-E and A-A

Conclusions

The correct way to obtain energy savings is to implement a variable flow system, which allows only the water needed to satisfy the power request of the terminals to circulate.

The use of traditional 2-way valves, however, causes serious adjustment problems with risk of both hunting, where the terminals require a minimum opening of the valve that operates in full area of poor adjustment, or with risk of starving on those terminals in which the pressure losses are greater than the pressure supplied by the pump.

The heat exchange battery of an AHU or of a fan coil does not have a linear trend between water flow and power output; therefore, the water flow must be reduced considerably more than the output is, but this approach poses an adjustment problem, as the valve stem needs to receive a linear signal. To overcome the problem, the valve obturators are built so as to compensate for the flow-power of the valve curve.

The best way is to intervene on the obturator curve on the basis of the input signal, so as to compensate for the flow-power curve and obtain linearity between signal and flow. The final result will therefore be a linear characteristic between the valve opening signal and the power output: when 50% of the power is needed, the signal will be of 5 V (half of the maximum value).

Chapter 10: Advantages of pressure-independent valves Danfoss AB-QM

The implementation of traditional 2-way valves to obtain a variable flow system reduces consumption, but introduces the problems due to control and balancing of the system.

It is possible to overcome these problems with the use of pressure-independent 2-way valves. Pressure-independent control and balancing valves, Danfoss AB-QM are PIBCBV type valves (pressure independent balancing and control valve) that, unlike the classic 2-way valves, are able to combine the typical advantages of 2-way valves with the accuracy of adjustment typical of 3-way valves. They are pressure-independent flow dynamic balancing valves.

How the pressure-independent valve Danfoss AB-QM works

Danfoss AB-QM valves substantially consist of two valves merged together: the 2-way control one and the calibration one. Compared to the traditional calibration valves, however, those mounted in Danfoss AB-QM valves are dynamic.

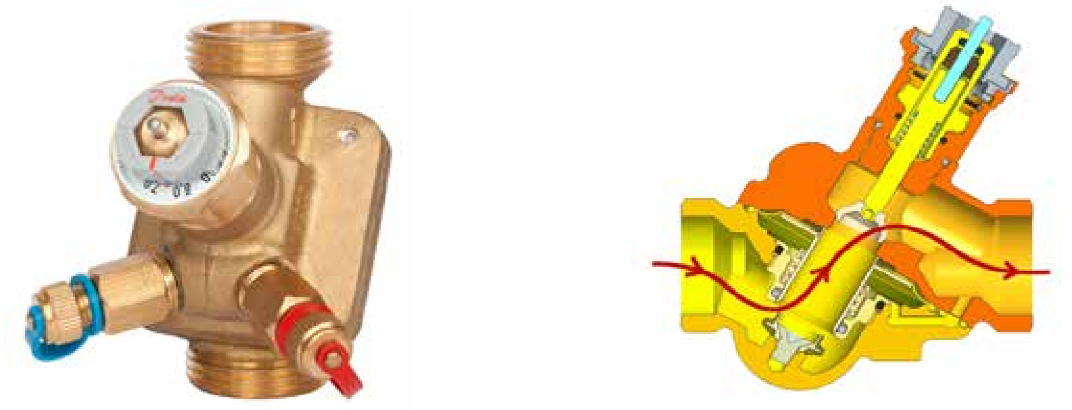


Figure 10-1: Danfoss AB-QM valves consist of two valves merged together: a two-way control one and a calibration one

The upper part of the valve is the true control valve that makes it possible to limit the maximum capacity. As better described in the following paragraphs, one of the main advantages offered by these valves is the possibility of varying the equipercentile profile to improve the adjustment.

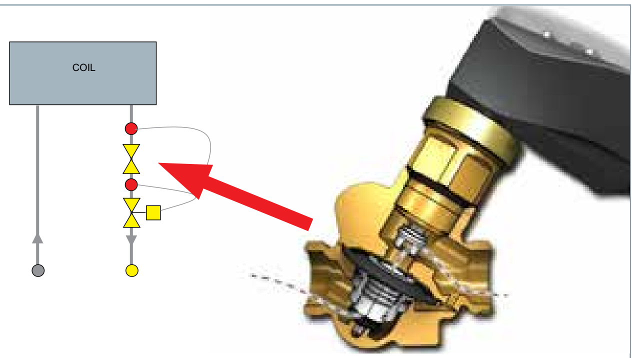


Figure 10-2: Task of the calibration valve integrated into the Danfoss AB-QM valve

The lower part of the AB-QM valve contains a dynamic differential pressure controller, which works to keep the pressure constant between points 1 and 2 of the control valve.

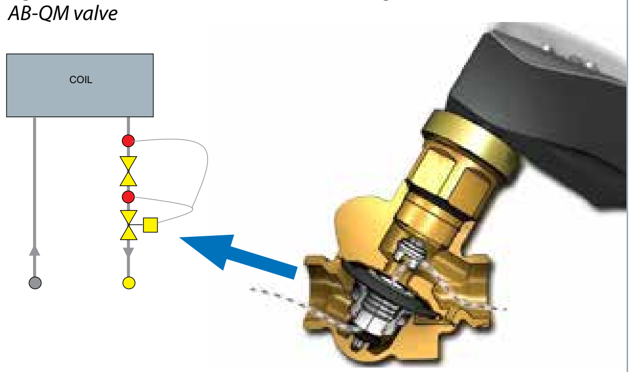


Figure 10-3: Task of the control valve integrated into the Danfoss AB-QM valve

Resolution of the over-pressure issue on the control valve thanks to the use of Danfoss AB-QM valves

Suppose there is a hydraulic installation like the one shown in Figure 10-4, with four identical terminals (for example 4 AHUs).

At 100% of the load, the flow is at its maximum in each common sector of the circuit, thus the ΔP pressure drops at the heads of each terminal are different. To make them equal, in the case of traditional 2-way valves, it is necessary to insert calibration valves downstream of the control valves. In the case of Danfoss AB-QM valves, both control and calibration valves are unnecessary, as balancing is automatic and dynamic.

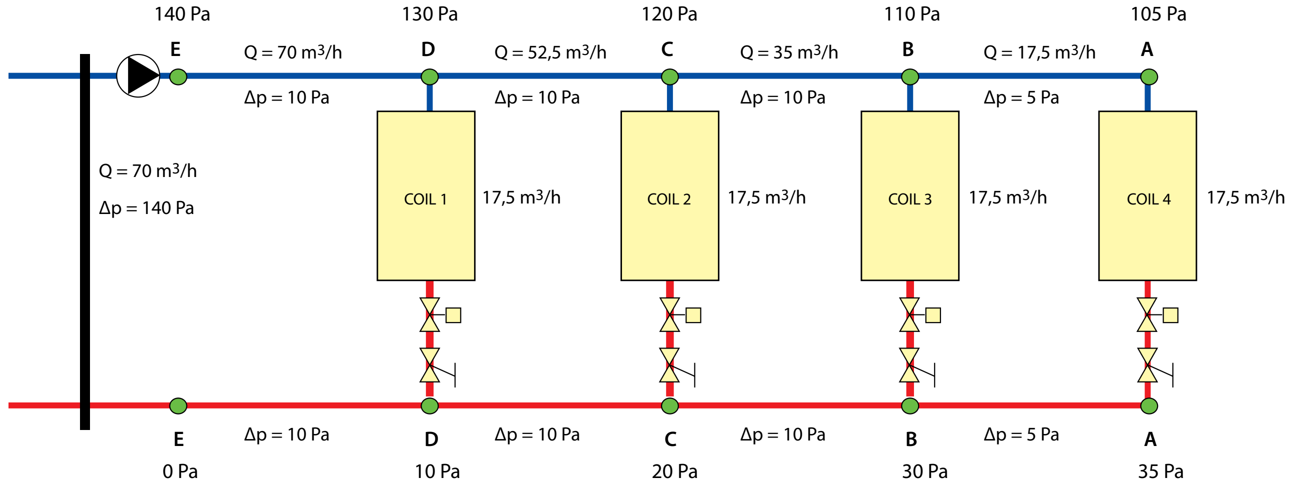


Figure 10-4: Hydraulic circuits with four identical terminals

Assume there is a variation in load in the circuit as shown in Figure 10-5. The flow of water in the batteries of the terminals drops and even more so, the loss of load (it varies approximately with the square of the water flow).

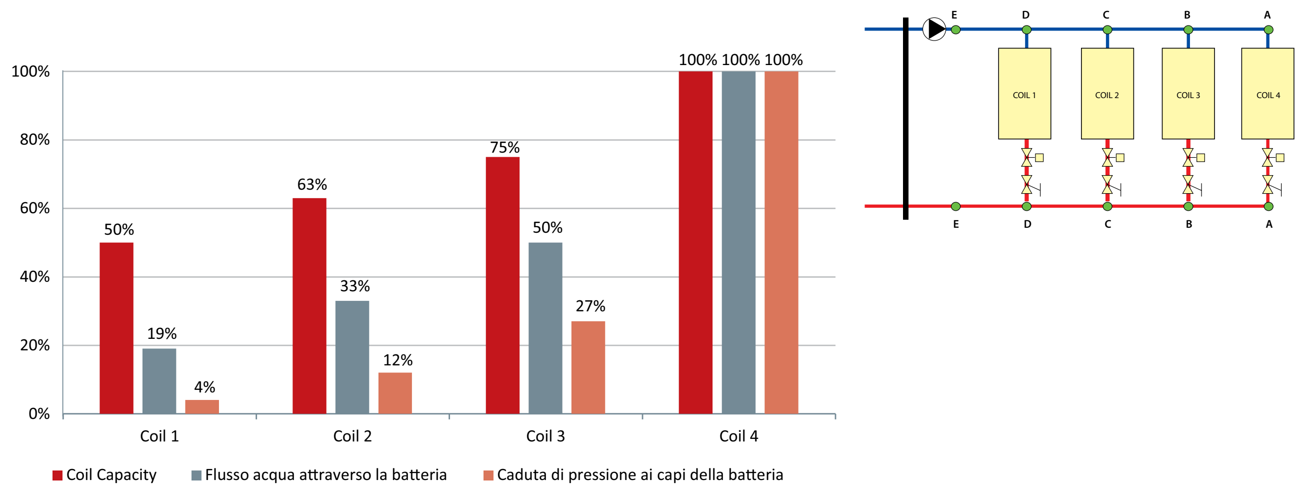


Figure 10-5: Speculated load variation in the hydraulic circuit with 4 identical terminals, from the first to the last the load increases

Compare the different pressure trend in the forward and return pipes when all terminals are at 100% of the load, and of the case in question, keeping the pressure difference constant at the heads of the pump in E-E.

The flow drops in the common sectors between the various terminals, and so do the pressure losses. For example, at the heads of Terminal 3, there is a Δp = of 80 kPa with all terminals at 100%, against 114 kPa of the valves of the case under consideration.

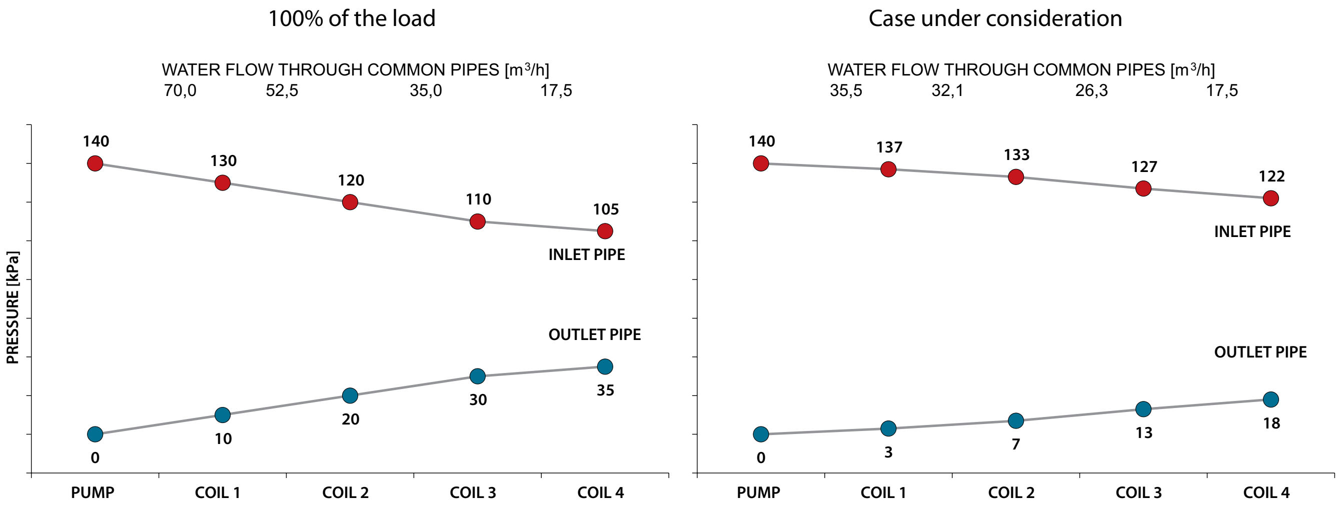


Figure 10-6: Pressure trend in the forward and return pipes when all terminals are at 100% of the load and of the case under consideration

Figure 10-7 shows what happens in terminal 3, where 50% of the nominal flow is required.
Battery load losses are similar in the two cases, but while in the case of a traditional 2-way valve, the calibration valve is fixed, therefore its losses of load decrease, with the Danfoss AB-QM valve, however, the calibration valve is dynamic and always maintains a constant pressure difference on the control valve.

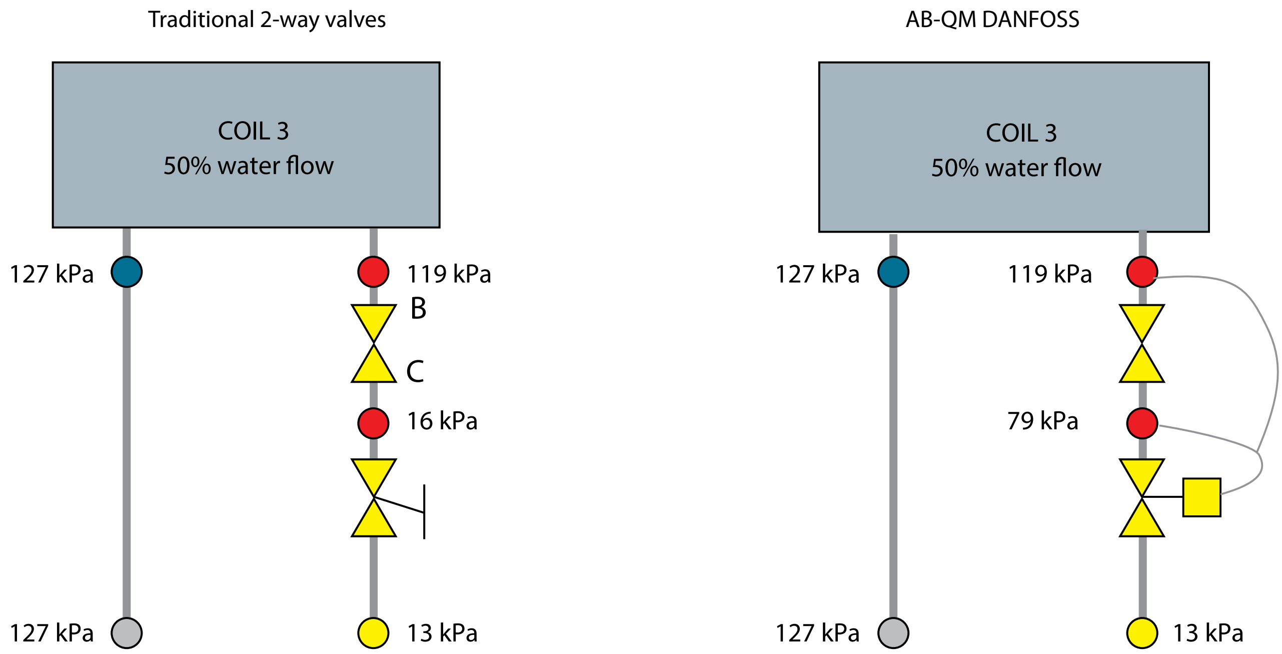


Figure 10-7: Terminal 3 circuit with traditional 3-way valve and Danfoss AB-QM valve

With traditional valves, all the control load is at the head of the obturators (red histograms), because the calibration valves (yellow histograms) are fixed, and load losses vary with the flow rate, as well as the battery load losses (blue histograms).

With Danfoss AB-QM valves instead, the calibration is dynamic and intervenes to keep the load loss on the obturator of the control valve constant.

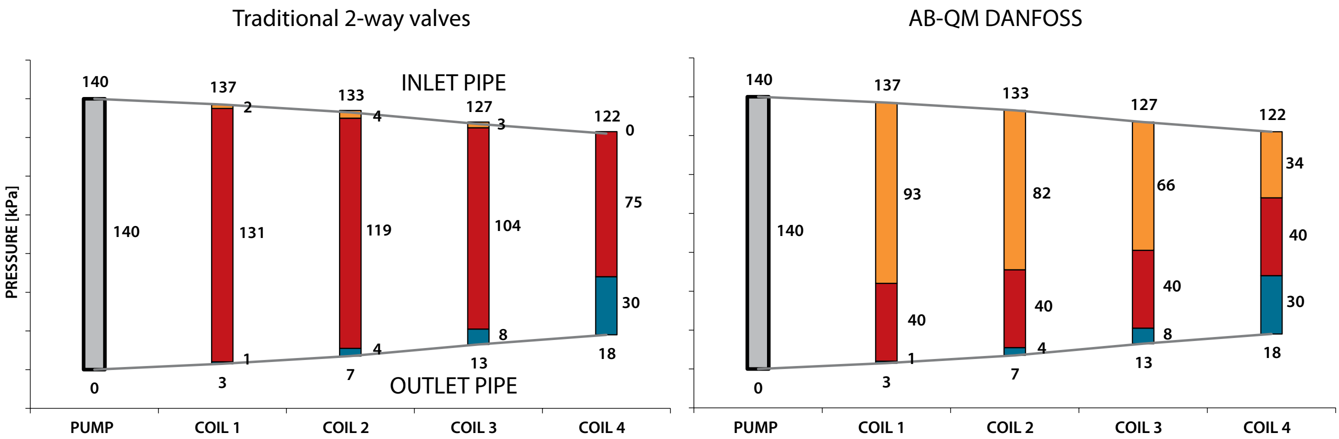


Figure 10-8: Pressure trend in the circuit with traditional 2-way valve and Danfoss AB-QM valve

If the case of Figure 10-5 is reported on a power-pressure jump diagram, it is immediately clear that, when using Danfoss AB-QM valves, a perfect match between required power and opening of the valves is obtained, because a constant pressure loss is kept at their heads, while traditional 2-way valves must close considerably more, due to the increase in pressure at their heads, as shown previously.

Even the valve of terminal 4 (red dot) must close, even if the required power is 100%.

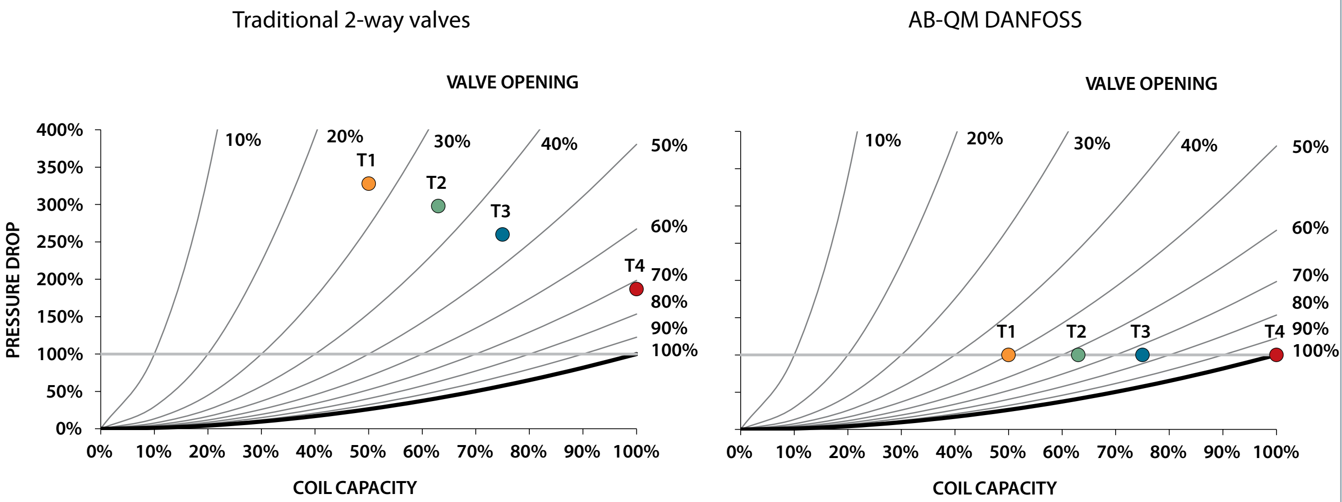


Figure 10-9: Power-pressure Jump diagram with traditional 2-way valves and Danfoss AB-QM valves

The phenomenon is even more evident if illustrated in a graph that shows the battery power output based on the opening of the valve.

With Danfoss AB-QM valves, perfect linearity is achieved, while traditional 2-way valves are forced to close considerably more, and this is where there is the risk of grafting a dangerous phenomenon of hunting due to poor control, because every valve struggles to adjust well below 10%-15% of opening.

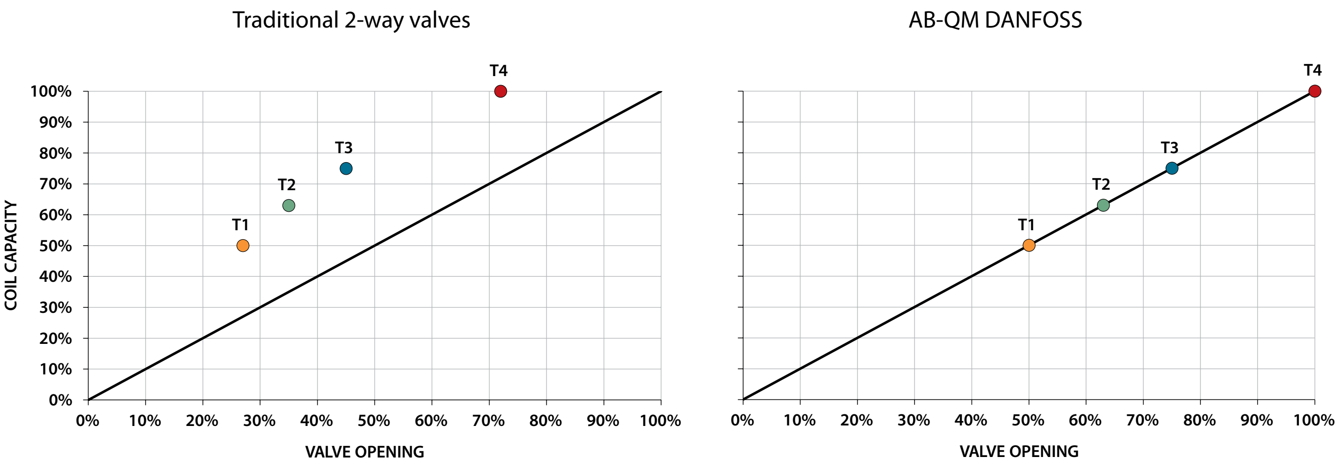


Figure 10-10: Battery power output according to the opening of the traditional 2-way valve and Danfoss AB-QM valve

Resolution of the risk of hunting issue thanks to the use of Danfoss AB-QM valves

Now suppose we have to analyze a diametrically opposed situation to the one shown above, where terminal 1 works at 100% of the load, while the others work at reduced load. Compared to the use of 3-way valves, the power is reduced by 68%.

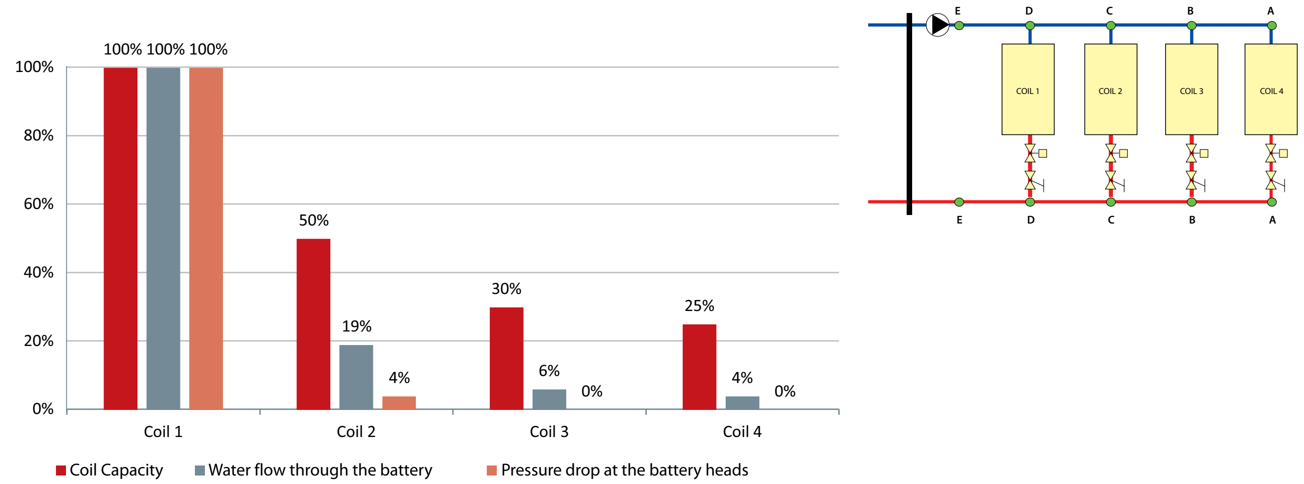


Figure 10-11: Speculated load variation in the hydraulic circuit with 4 identical terminals, from the first to the last the load decreases

The pressure drops of the common sectors are very low, due to reduced flow. Therefore, the traditional 2-way valves are the ones that have to close a lot (red histograms) to compensate for the excess of pressure increase at the terminal heads. Battery losses (blue histograms) and calibration valves (yellow histograms) are almost zero, due to the low flow.

By using Danfoss AB-QM valves, on the other hand, it is again the dynamic calibration that compensates for the increased pressure at the terminal heads.

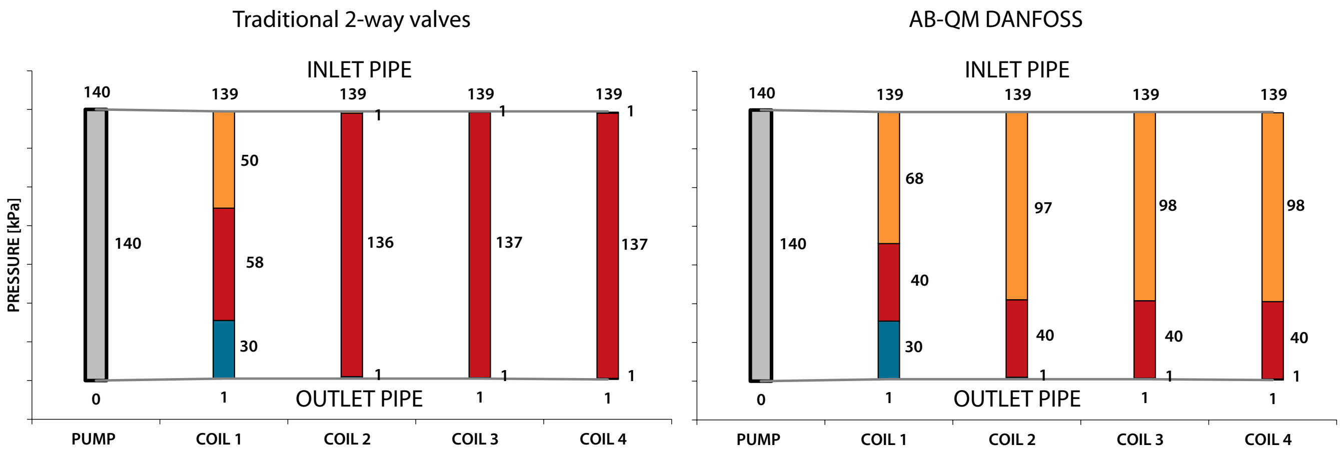


Figure 10-12: Pressure trend in the circuit along the loads that decrease with traditional 2-way valves and Danfoss AB-QM valves

As can be seen from the two graphs below, the traditional 2-way valves must close much more in comparison to the power required.

Even terminal 3 works with the valve open at 16% (against a required power of 30%), at the limit of the hunting grafting, while terminal 4 works with the valve open at 12% (against a required power at 25%), in full area of poor control. This happens because the pressure jump on the valve is inconstant.

Danfoss AB-QM valves instead, work in total linearity since the pressure jump is kept constant by the dynamic control.

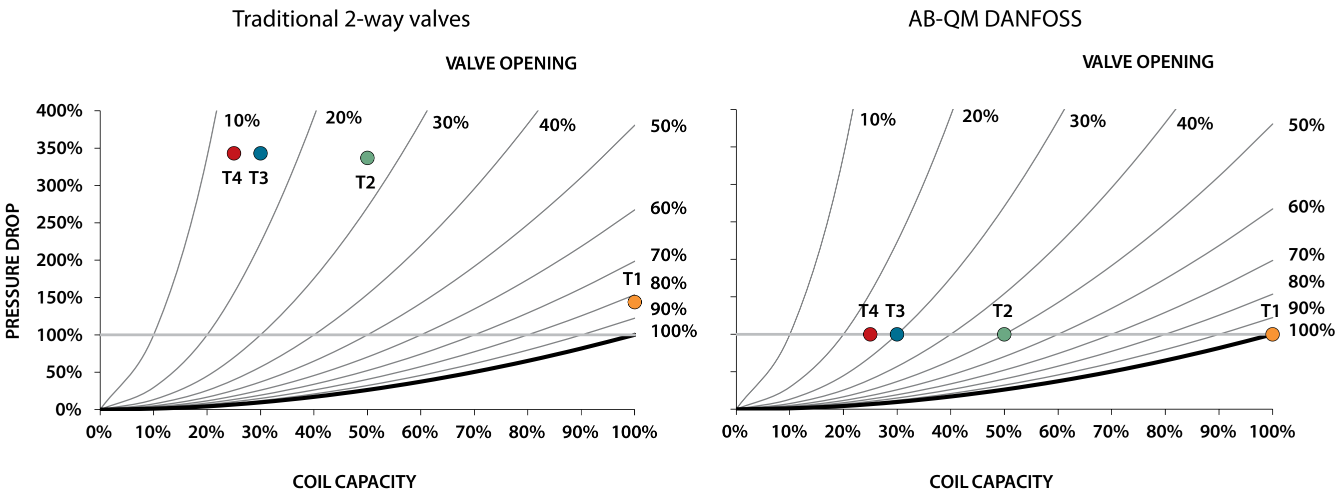


Figure 10-13: Characteristic power-ΔP and valve opening-power in the circuit with decreasing loads and with traditional 2-way valves and Danfoss AB-QM valves

The phenomenon is even more evident if shown in a diagram Opening-power.

The traditional 2-way valve of terminal 1 must close, even if the battery requires 100% of the power due to over-pressure at the valve heads.

With Danfoss AB-QM valves instead, there is always perfect linearity between valve opening and required power.

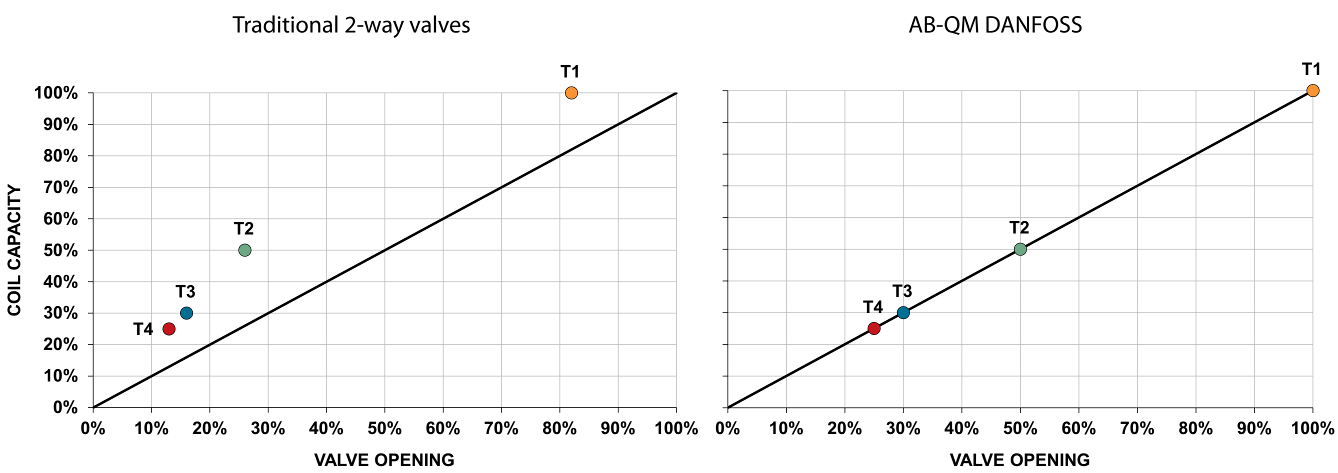


Figure 10-14: Characteristic Valve Opening-Power with traditional 2-way valves and Danfoss AB-QM valves

Resolution of the starving issue thanks to the use of Danfoss AB-QM valves

To improve the phenomenon of excess pressure at the heads of the valves, and reduce pump consumption, the pressure could be adjusted by keeping it constant in A-A (the most distant), instead of E-E astride the pump.

The power would be more than halved (87% savings compared to the 3-way, against 68% of the control in E-E). However, it is difficult to place the probes with traditional 2-way valves, while with Danfoss AB-QM valves it is sufficient to check the opening of the stems, always linear to the required power.

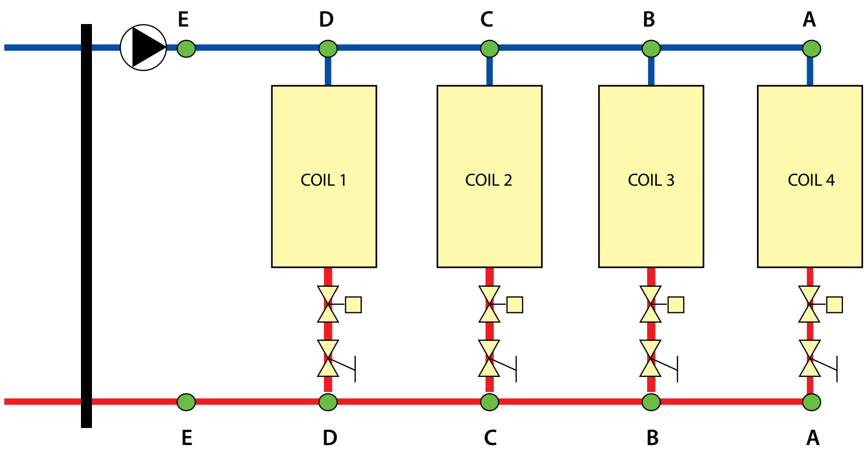


Figure 10-15: Hydraulic circuit with 4 identical terminals

As can be seen from the two graphs, the total head provided by the pump is much smaller with the control in A-A, therefore the valves must provide a lower load loss.

However, if we observe terminal 1, the load loss of the battery with traditional 2-way valves is equal to 8 kPa (blue histogram), against the required 30 kPa. It means that the battery is starving, because the pump isn't giving enough pressure for the load required.

This happens because the calibration valve is fixed and is unable to open (yellow histogram). By using Danfoss AB-QM valves, however, the problem is solved thanks to the dynamic calibration.

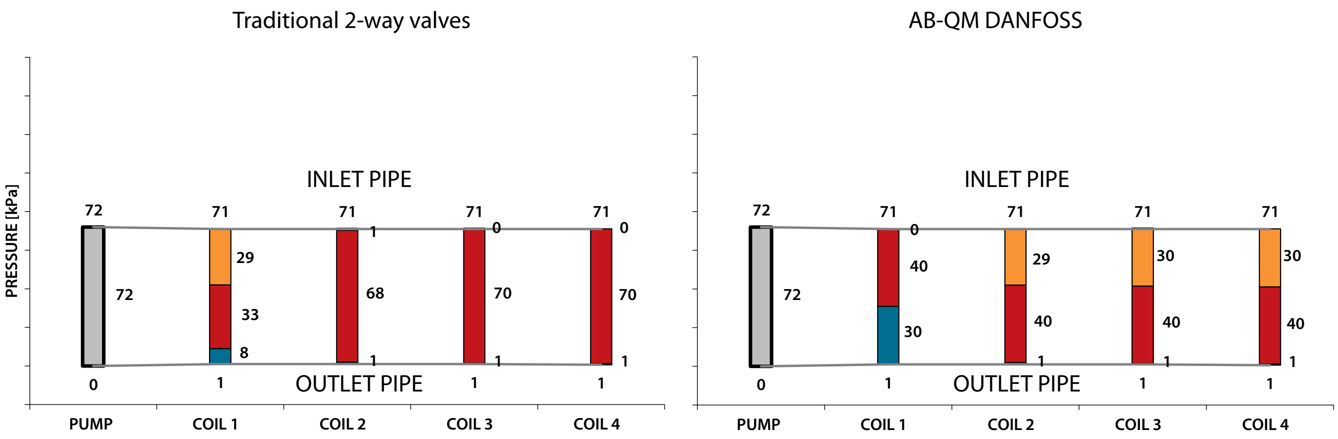


Figure 10-16: Pressure trend in the circuit with traditional 2-way valves and Danfoss AB-QM valves

The phenomenon is better understood in the power-pressure difference diagram. The difference in pressure at the heads of terminal 1 (yellow dot) is too low, in the case of traditional 2-way valves. The valve stays completely open, but the power supplied is equal to 90% of the required power. By using Danfoss AB-QM valves, instead, there is always perfect linearity.

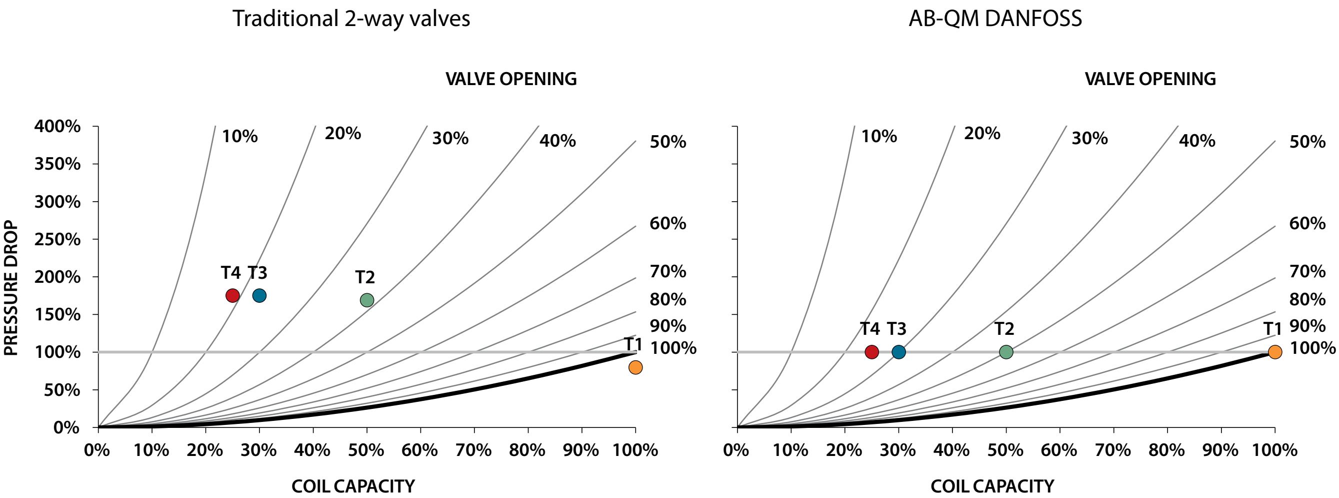


Figure 10-17: Characteristic Power-ΔP with traditional 2-way valves and Danfoss AB-QM valves

It is even clearer in the valve opening-power diagram. Terminal 1 is starving because when the traditional 2-way valve opens at 100%, it only provides 90% of the power required.

By using Danfoss AB-QM valves, instead, the problem is averted and the adjustment always takes place in the best way.

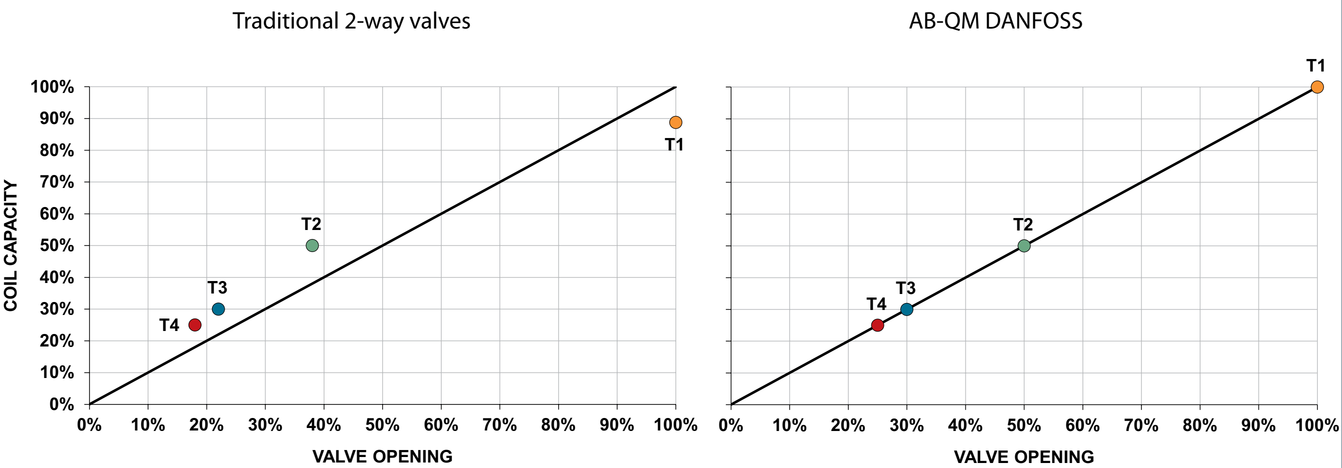


Figure 10-18: Characteristic Valve Opening-Power with traditional 2-way valves and Danfoss AB-QM valves

Simplification of the installation and reduction of installation and commissioning times

The use of AB-QM pressure-independent Danfoss valves offers important advantages also in terms of simplification of the installation, sizing of the valves themselves, installation and commissioning and greater comfort for guests. Furthermore, the use of Danfoss valves makes it possible to reduce the energy used by the whole system.

The sizing of Danfoss AB-QM valves is based exclusively on the required flow, it is not necessary therefore to make any calculation of the Kv coefficient and any calculation dedicated to the search for the right authority. Once the more critical circuit is identified, it will only be necessary to calculate the pump's total head (without valve), to consider the minimum working pressure of the Danfoss AB-QM valve and add the minimum pressure of the valve itself to the calculated total head of the pump.

As the Danfoss AB-QM valve is a control and automatic dynamic balancing valve, it is possible to simplify the hydraulic circuit by eliminating a series of shut-off and manual balancing valves, which are normally used, thus reducing costs and installation times.

For example, consider a typical case as illustrated in the diagram of Figure 10-19. On average, installation times are approximately €120 for a DN80 valve; €80 for a DN40 valve and €70 for a DN15 valve and approximately €30 per valve for balancing and calibration, for a total of €360. It can easily be deduced that in a complex plant, many thousands of euros can easily be saved in installation and commissioning activities alone.

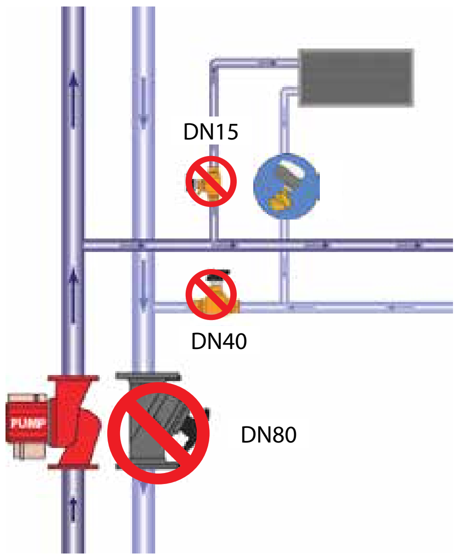


Figure 10-19: Diagram of a typical plant cutaway

Furthermore, not to be forgotten are the significant energy savings that are made on the refrigerating units, particularly sensitive to temperature hunting and flow on the circuit to which they are connected, thanks to a better and more precise balance of the system, which are mainly due to improved comfort in the rooms, which limits the continuous change of the temperature set point and the lower pumping of the refrigerating unit due to the splitting and decrease of working ΔT.

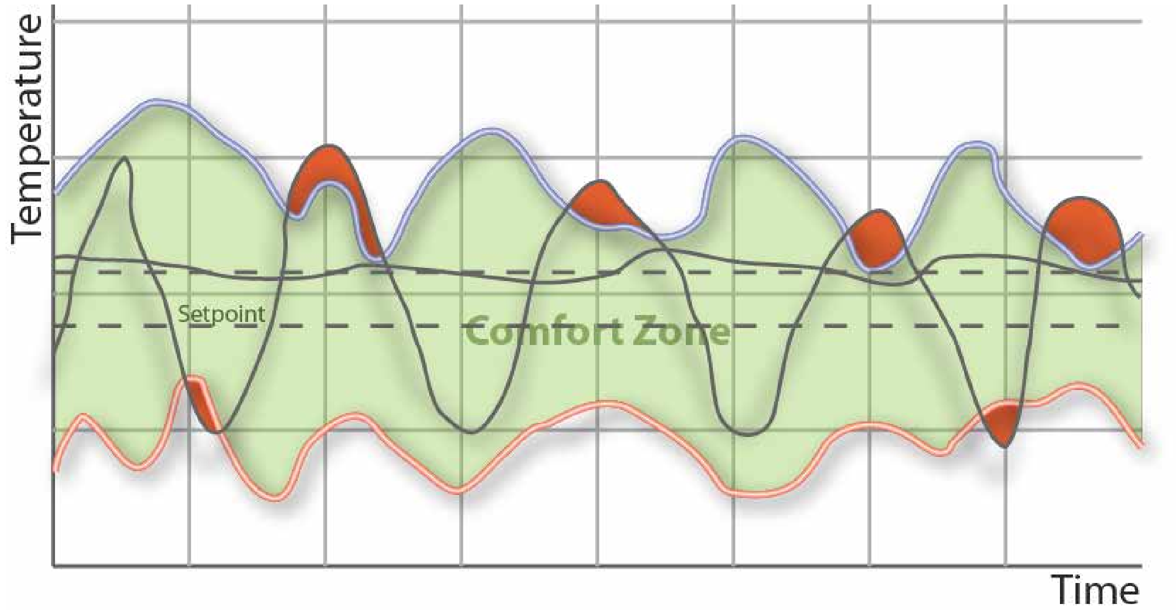


Figure 10-20: Hunting effects

Traditional 2-way valves involve greater hunting of the valves, with consequent variation of the temperature of the ambient air. Basically, the valves don't modulate all the time, but they act like on-off valves. This enlarges the field of ambient air temperature, with undesired peaks, especially in summer.

Load requests vary continuously over time but, thanks to the correct balance guaranteed by Danfoss valves and to control stabilization, even the temperature set-point can be optimized. The increase of 1 degree of the set point temperature saves between 10 and 16% of energy (cooling).

Another very interesting solution is the combination of the pressure-independent valve (and relative actuator) and the 6-way valve Danfoss ChangeOver6. This last solution is designed to facilitate installations (retrofit and new) in cases where a 4-pipe plant is present, such as a ceiling radiant panel with a 4-pipe system or a fan coil unit with a single 2-pipe battery and 4-pipe system.

The ChangeOver is a 6-way motorized ball valve that switches the flow of water between the heating and cooling circuits in the systems with 4-pipe installations, eliminating the possibility of crossing flows.

In addition to the advantages of balancing illustrated above, the fluids are also perfectly mixed for better temperature maintenance in the room throughout the year, and design and installation are made easier, as the terminals are always reached only with two pipes.

Figure 10-21: on the right ChangeOver6 valve with AB-QM and NovoCon® S actuators - on the left AB-QM valve with NovoCon® S actuator

Conclusions

The balancing problems of variable flow systems with traditional 2-way valves are solved thanks to the implementation of 2-way balancing valves of the pressure-independent type.

Danfoss AB-QM valves are valves of the PIBCV type (pressure independent balancing and control valve) that, unlike the classic 2-way valves, are able to combine the advantages of 2-way valves with the control accuracy of 3-way valves.

They are pressure-independent flow dynamic balancing valves.

Danfoss AB-QM valves substantially consist of a control valve merged to a dynamic differential pressure controller.

These are valves with authority equal to 1 that guarantee stability of the flow in any operating condition.

Their peculiar characteristics make it possible to eliminate the classic problems of low ΔT of the chiller and pumping problems, as well as ensuring precise control of the temperature set point, which translates into a better comfort for the hotel guests with the possibility of keeping the set point temperature higher.

Chapter 11: Advantages of variable air flow in hotel rooms

In hotels, it is possible to greatly reduce electrical energy consumption for the ventilation of the rooms if systems with variable air flow are implemented, thanks to the solutions based on the use of Danfoss inverters specifically dedicated to HVAC applications.

The hypothesis is to introduce air at 18°C throughout the year, with specific humidity of 4.8 g/kg in winter and 9.9 g/kg in summer.

The air flow rate is 80 m^3/h per room + 1,600 m^3/h in the hall and in the common areas, for an inlet air flow of 12,800 m^3/h and 9,800 m^3/h of extracted air.

In the rooms, the air flow starts only when people are inside (badge connected) and remains in operation for one hour from their exit. The closing takes place by means of a suitably inserted damper in the room supply channel.

Variation of air flow during the day

In the central hours of the day the flow rate is lowered in the rooms, as, in general, the rooms are empty. In this way, on the one hand, the energy consumed by the fans is reduced, and on the other hand, so is that used by the air handling, even if the reduction of the air expelled up to 0 leads to a reduction in the efficiency of the regenerator.

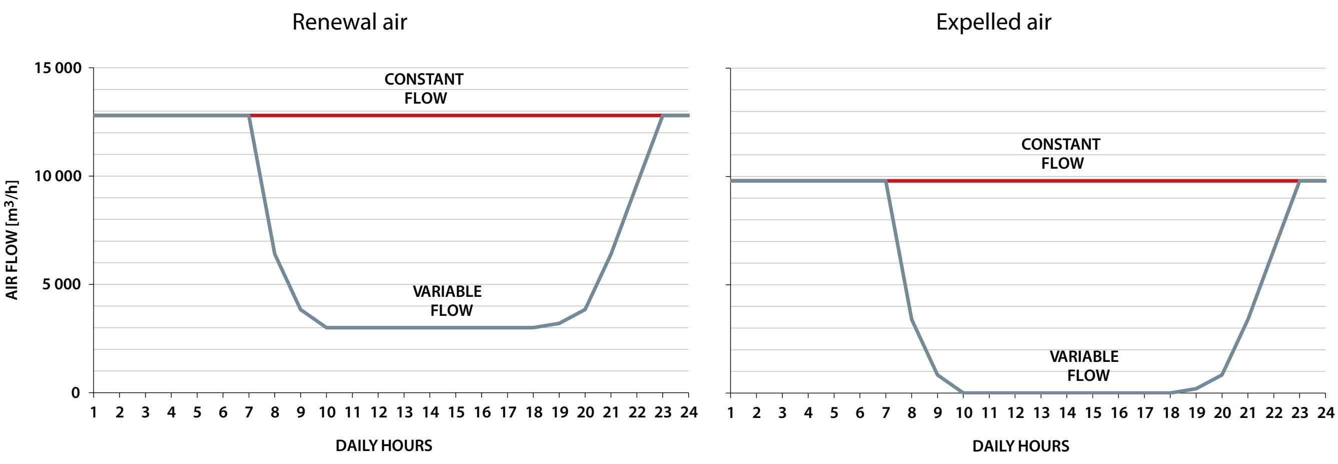


Figure 11-1: Time evolution of the renewal air flow and of the expelled air

As can be seen in the graph of Figure 11-2, the efficiency of the regenerator drops quickly, until it reaches 0 in correspondence of the hours when the expulsion air flow is cancelled. As a consequence, the energy required for the renewal air power drops less than the flow does.

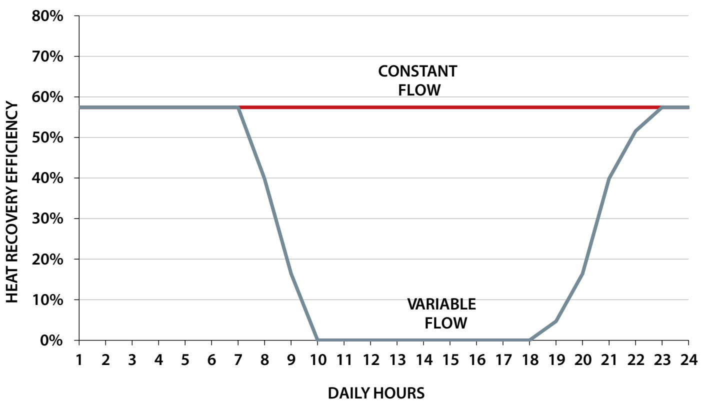


Figure 11-2: Hourly performance of the regenerator's efficiency

Effects of the air flow on the energy required to the generators

The reduction of the power required hourly to the generators for ventilation is considerable, especially in cooling over the summer months. However, there are some hours in the year in which the variable flow system consumes more.

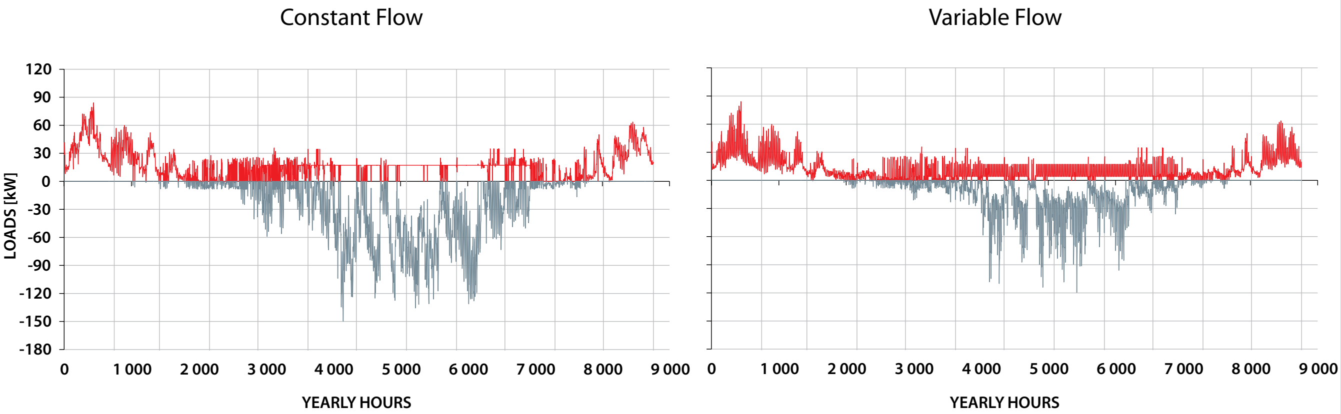


Figure 11-3: Trend of the required power for ventilation with constant flow and variable flow

Constant flow systems always require more power compared to systems with variable air flow, except for some special circumstances in some short periods of the year.

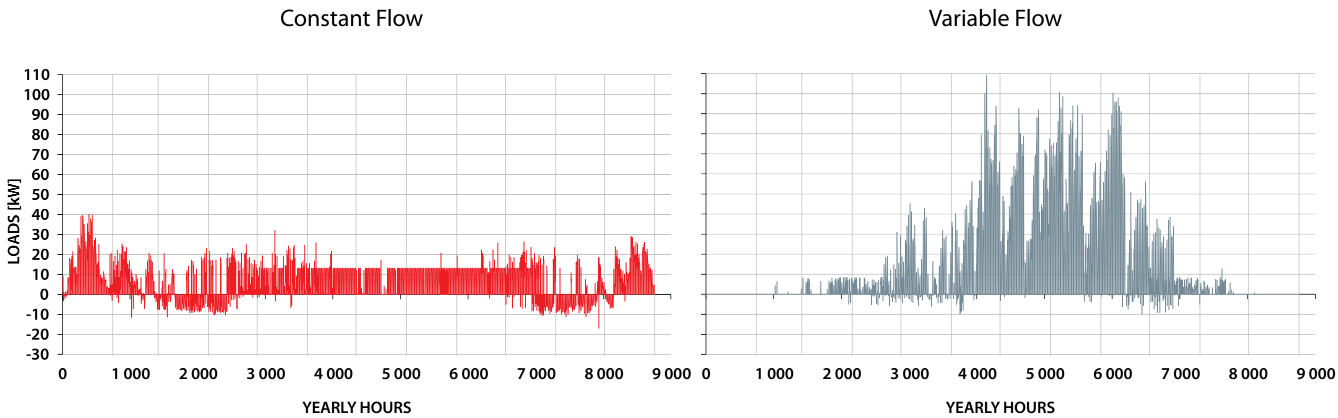


Figure 11-4: Trend of the difference of power required for ventilation with constant flow and variable flow

Variable flow systems require less energy from the generators and, in this way, lower the installation's annual costs. In the case under consideration, the variable flow rate leads to a reduction of over 27% in heating and about 16% in cooling.

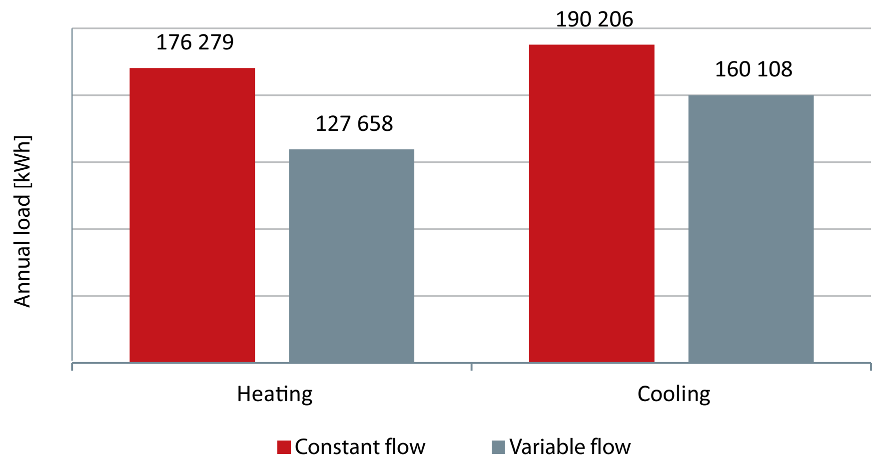


Figure 11-5: Annual energy required with constant flow and variable flow

Energy Consumed by AHU fans

Obviously, as can also be seen from the graphs in Figure 11-6, with a variable air flow system, the greater the savings, the greater the power required by full-load AHUs.

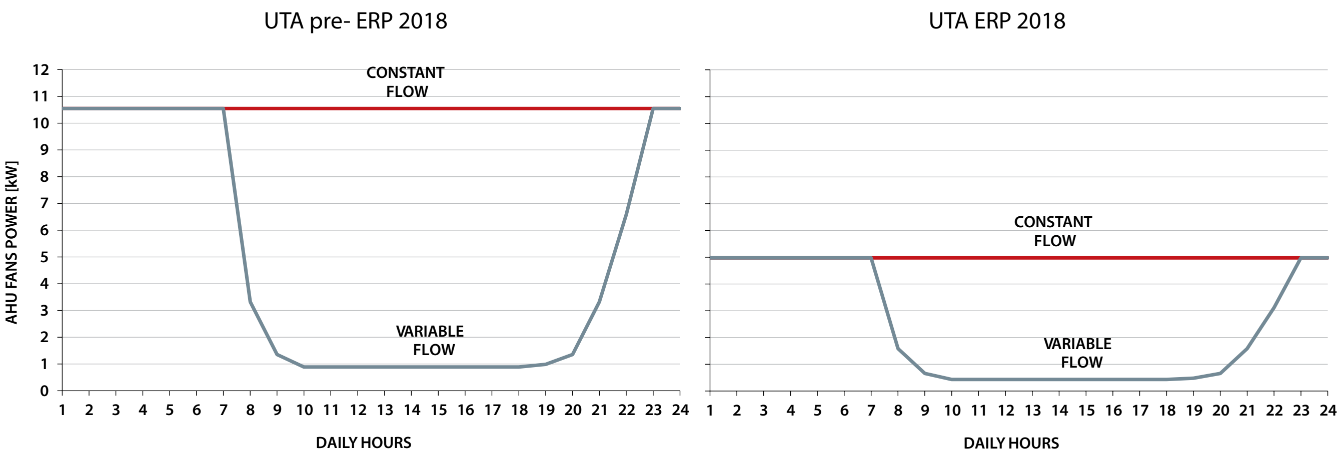


Figure 11-6: Power required by the fans of pre-ErP 2018 and compliant with the ErP 2018 Directive AHUs

The inverter is a component that plays a key role when ventilation systems with variable air flow are implemented. It is important to correctly choose this component to obtain a more reliable and efficient plant, and therefore reduce energy consumption and management costs.

Thanks to the variable fan torque characteristic, a small reduction in speed and flow corresponds to a remarkable decrease in the absorption of the electric motor and, therefore, of consumption.

In systems with pumps and fans, significant energy savings are due to the difference in efficiency between the two flow variation solutions.

Danfoss VLT® FC102 inverter is a frequency converter dedicated to HVAC applications for installation on fans with specific functions to ensure, in addition to an extremely precise and accurate control of the motor, also extreme ease of installation and commissioning. It has specific functions for HVAC applications, thanks to which it is able to manage an AHU in an evolved and completely self-sufficient way.

All Danfoss inverters, besides having the possibility of being combined with any type of electric motor, have an overall efficiency, thus including RFI and EMC filters, of over 98%, which means that a lower electrical consumption can be achieved in comparison to most similar products of the competition, and full efficiency in Class IE2 and Class IES2, according to the EN50598-2 standard.

Adjustment of fan motors via an inverter, for example of AHUs, offers a whole series of advantages, such as reduction of breakaway starting currents when the fan is started, less mechanical deterioration of the machine, less thermal and electrical stress on the motor, more stable operation of the system and reduced noise, in particular when triggered. Finally, the importance of the filters should not be underestimated, in order to limit problems due to radio frequency interferences and to harmonic disturbances on the electrical network. For this reason, all Danfoss inverters are equipped with RFI filters in Class C1/C2, according to the standards 61800-3, and with anti-harmonic inductances to meet the system standards related to the harmonic distortion.

Among the various specific functions that this type of inverter can offer, there is the automatic compensation of load losses, the fire function to ensure unconditional operation of the fans in case of necessity, the autocapture of the motor to start the inverter without the motor stopping, or the function broken belt to give an alarm in case the torque is lower than the programmed threshold, just to name a few. To meet the needs of connection with BMS systems (building management system) on the market, the interfaces for connection to the most common fieldbuses, such as Modbus, Bacnet, Lonworks, Profinet and Devicenet, are available.

Thanks to a display with integrated wireless communication, it is possible to access the control functions of the VLT® FC102 inverter also remotely, making configuration, monitoring and maintenance even easier and faster.

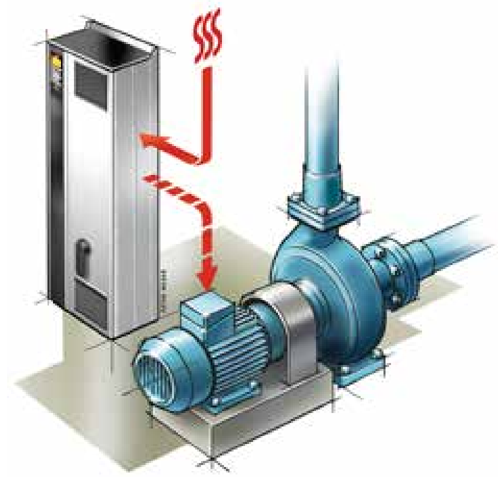


Figure 11-7: Danfoss products for HVAC applications

Conclusions

Since the rooms are not always occupied, it has been seen that the best solution is to introduce air only when people are inside, leaving it in operation for up to an hour after they have left.

Closing takes place by means of a suitably inserted damper in the room supply channel.

Generally, the rooms are empty in the middle of the day and this considerably reduces the consumption related to fans and air handling, compared to the constant flow solution during the whole day.

Reducing the expelled air flow to zero, however, reduces the efficiency of the regenerator and, therefore, the power of the renewal air drops less than the flow does.

However, the reduction in hourly power required to the air is still considerable, especially in cooling in the summer months. The systems with constant flow always require more power than the installations with variable air flow, except for some special circumstances in some short periods of the year.

Overall, the implementation of variable air flow requires less energy to the generators, significantly reducing annual costs of the plant with results, for the present case, of a reduction of over 27% in heating and about 16% in cooling.

Obviously, in a system with variable air flow, where AHUs work at reduced load most of the time, the greater the savings, the greater the power required by full-load machines.

Among the important elements to consider when choosing the inverter, especially in applications of this type, there are certainly the efficiency itself of the frequency converter, and the equipment and filter performance against radio frequency and harmonic interferences on the network. These aspects are essential to reduce to a minimum electricity consumption, as well as the potential inconveniences due to interferences with other devices, which could compromise the building's correct management.

All Danfoss inverters, besides having the possibility of being used with any type of electric motor, have an overall efficiency, thus including RFI and EMC filters, of over 98%, which means that a lower electrical consumption can be achieved in comparison to most similar products of the competition, and full efficiency in Class IE2 and IES2, according to the EN50598-2 standard.

Consider that each percentage point less of efficiency of the inverter corresponds to one percentage point more of energy consumption of the machine itself.

Chapter 12: Reduction of energy consumption and management costs with variable flow Danfoss solutions in installations with boiler and refrigerating unit

The aim of this chapter is to show the effect on the annual energy consumption, and on energy cost reduction, when Danfoss solutions are used as an alternative to other solutions, both in the renovation of existing buildings and in the construction of new buildings.

The analysis illustrated in the following paragraphs refers to buildings for hotel use with north-south orientation, where only the areas intended for the rooms and common areas have been taken into consideration. Areas intended for restaurants, meeting rooms and spas have not been taken into consideration in this first analysis.

The results related to the case of a building with east-west orientation have not been reported, as it was verified that they are very similar to the case of the building with a north-south orientation.

The following cases were each examined separately:

- Retrofit of building with year 2005 thermal insulation type
- Retrofit of building with year 2010 thermal insulation type
- Design of building with year 2021 thermal insulation type

For each of these cases, different technical implementation solutions were considered

Retrofit of building with year 2005 thermal insulation type

In this case, as it is a relatively outdated building, it is assumed that in the basic starting solution, low energy efficiency refrigerating machines could still be present, such as for example Class D Eurovent refrigerating units, and AHU at high pressure drops, with regenerator efficiency $\varepsilon = 50\%$ and fan efficiency $\eta = 50\%$. The following solutions were therefore considered to increase the plant performance:

Two solutions with measures to improve the efficiency of the equipment installed

- Class A Eurovent refrigerating unit installation
- Installation of AHU with energy efficiency ErP 2018

Two solutions with thermal insulation improvement measures, with equal system

- Intervention to bring the building to the year 2010 thermal insulation type
- Intervention to bring the building to the year 2021 thermal insulation type

Three Danfoss solutions for variable water and air flow systems

- • Variable water flow only, by using the Danfoss inverter VLT® FC102 and pressure-independent valves Danfoss AB-QB
- Variable air flow only, by using the Danfoss inverter VLT® FC102 and shutters per room
- Solution with variable flow rate of both water and air, by combining the two solutions mentioned above

Efficiency improvement of installed equipment

By performing only the replacement of the refrigerating unit with one of higher energy class, without intervening on balancing and efficiency improvement of the plant, an improvement limited to the consumption of the refrigerating unit only is obtained, due to its greater efficiency. The boiler increases consumption in an absolutely marginal way, while all other consumption remains unaffected.

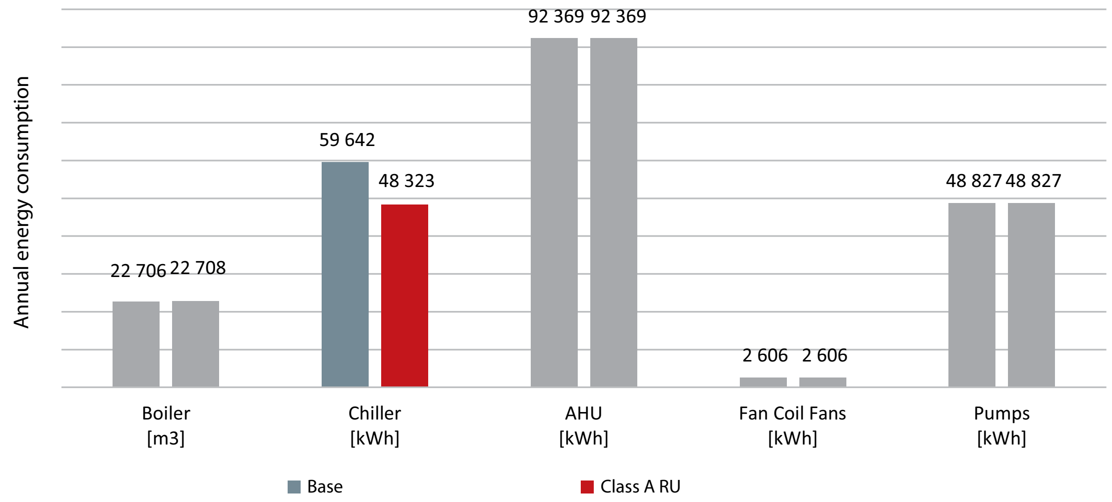


Figure 12-1: Benefits on energy consumption obtained by replacing the old refrigerating unit with one in Class A Eurovent

Assuming instead that only the air handling units are replaced (by keeping the refrigerating unit and the rest of the system unchanged), the item that changes the most is the consumption of the AHU fans, due to lower pressure drops and fan efficiency improvement.

The regenerator's efficiency improvement also lowers methane consumption and, marginally, the refrigerating unit's consumption.

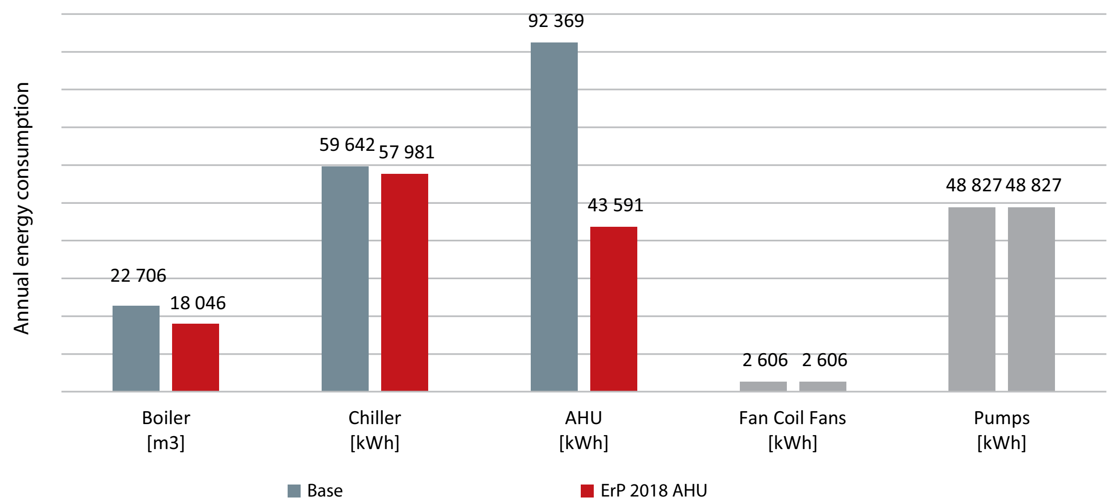


Figure 12-2: Benefits on energy consumption obtained with the replacement of old AHUs with new ErP 2018 certified units

Improvement of thermal insulation

By intervening on thermal insulation, improving it up to the construction typology typical of the year 2010, and leaving instead the plant unaltered, quite poor results are obtained, as only the methane consumption of the boiler decreases and, in marginal way, that of the electric energy absorbed by the refrigerating unit.

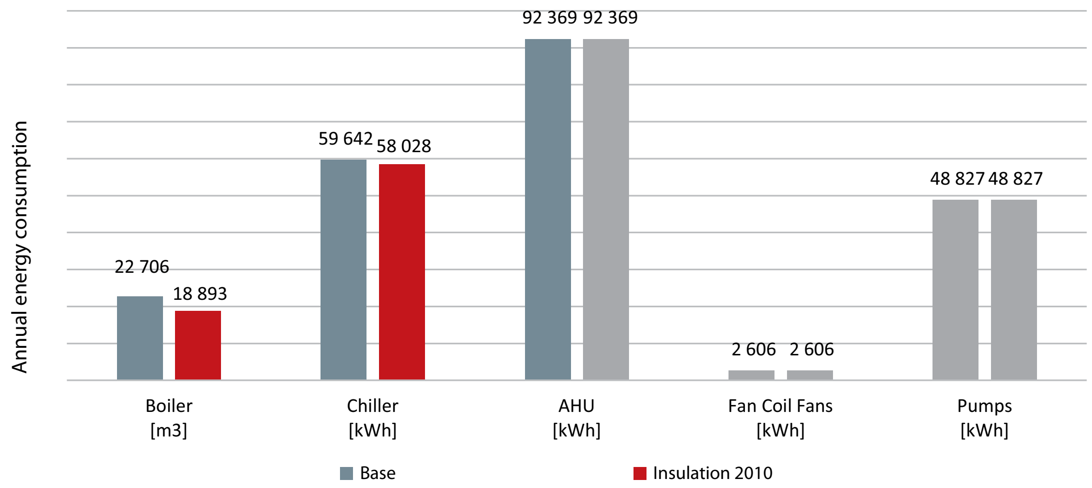


Figure 12-3: Benefits on energy consumption obtained with the improvement of thermal insulation (from year 2005 to 2010)

By improving the thermal insulation up to the construction typology typical of the year 2021, leaving instead the plant unaltered, quite poor results are also obtained. The methane consumption of the boiler decreases even more and, in an always marginal way, that of the electric energy absorbed by the refrigerating unit, but overall, the economic impact continues to be modest.

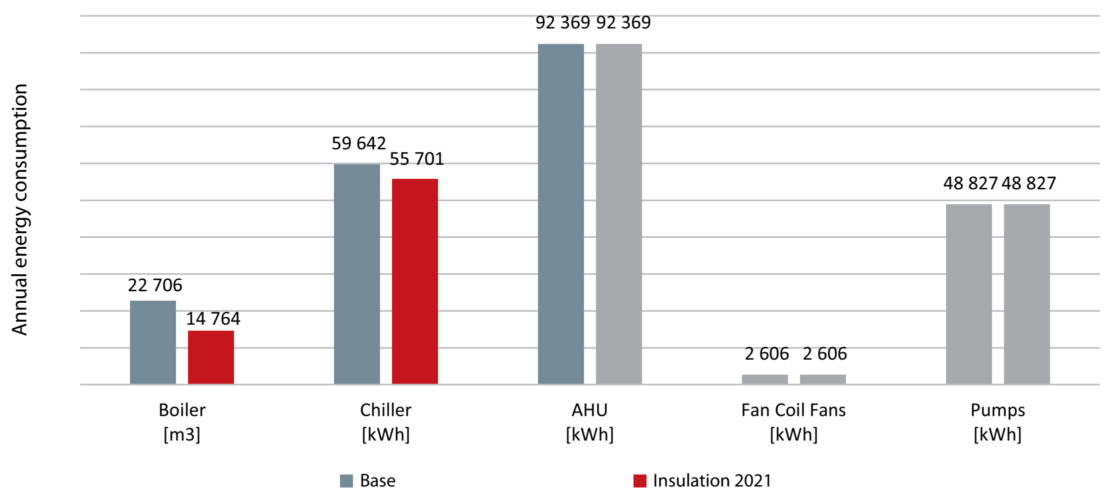


Figure 12-4: Benefits on energy consumption obtained with the improvement of thermal insulation (from year 2005 to 2021)

Use of Danfoss solutions for variable flow installations

Starting from the implementation of the variable flow of water only, a very stable and well-balanced plant is obtained, as already shown in Chapter 10, and it is immediately clear that the impact on consumption is definitely significant. The consumption of the pumps comes down from almost 49,000 kWh at just over 11,300 kWh, over 76% savings.

The considerable reduction in pump absorption impacts positively on the total electric consumption of about 18%. The savings obtained with this solution are over three times higher than that obtainable by replacing only the refrigerating unit from class D to Class A Eurovent.

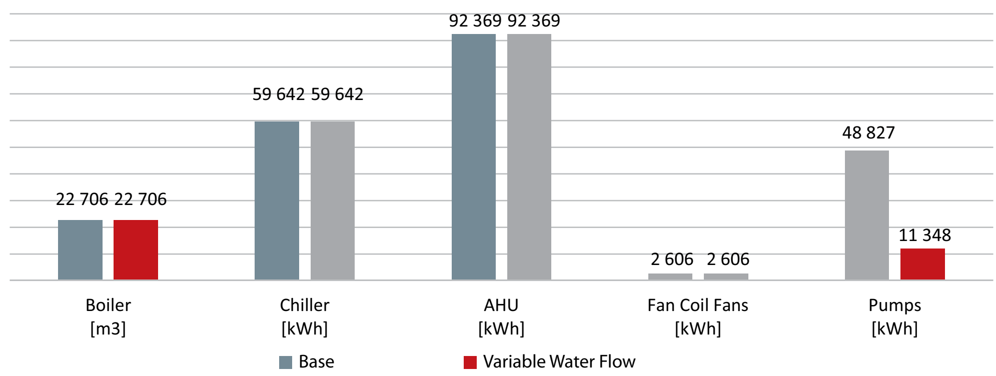


Figure 12-5: Benefits on energy consumption obtained with Danfoss variable water flow solutions (building 2005)

By intervening instead on the variable air flow only, the air flow reduction obtained with the use of Danfoss inverters brings down both the electric consumption of AHU fans and methane consumption and the electric consumption of the refrigerating unit. All of this is obtained with the sole addition of an inverter on the AHU fan and of shutters in the rooms.

The results are remarkable, as they reduce gas consumption by about 28%, and the total electricity consumption of the refrigerating unit and AHU by 30%.

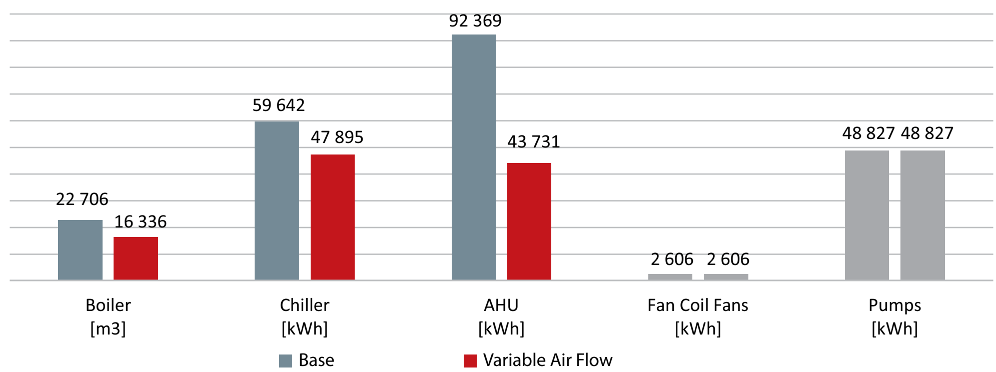


Figure 12-6: Benefits on energy consumption obtained with Danfoss variable air flow solutions

By combining the two types of intervention, and by implementing a plant solution with variable flow rate of both air and water, the best possible solution is obtained, as all the plant's consumption is reduced with very high percentages of reduction.

The total flow rate almost halves total energy expenditure, reducing the consumption of gas by 28% and the electric consumption by 48%. Assuming an average cost of gas of €0.60/m^3 and of electricity of €0.20/kWh, the reduction of consumption enables money savings on the bill for over 40%.

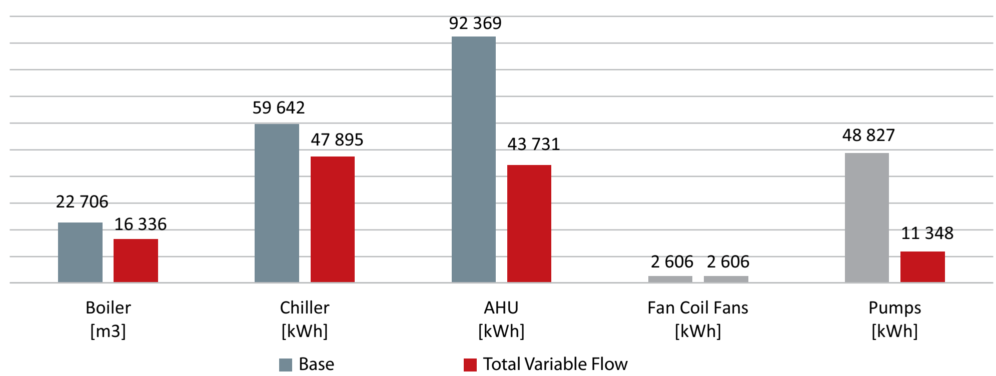


Figure 12-7: Benefits on energy consumption obtained with Danfoss variable water and air flow solutions

However, it is of the utmost importance to choose an appropriate design to obtain a reduction in energy consumption that is not limited only to reducing operating costs, but extends to the optimisation of the whole building's design.

In fact, think about the energy efficiency objectives in force starting from 2021 relating to the buildings' energy requirements, and the use of renewable energy sources to cover part of the request.

A building that consumes less energy is easier to design and build. If we consider, for example, solar energy as a renewable source (because it is the only renewable energy source available everywhere), we must find a suitable surface for the installation of solar panels (that can become quite large, and that it is not always available), especially in urban centres with purely vertical constructions.

So let us analyse, in the case of the retrofit just considered, what are the savings on the surface of photovoltaic panels necessary to obtain an annual energy balance of zero: i.e. a building which is able to produce independently all the energy that it consumes.

The following graphs show, respectively, the surface of equivalent photovoltaics necessary to bring the annual balances of the plant to zero and the savings obtainable with the individual solutions.

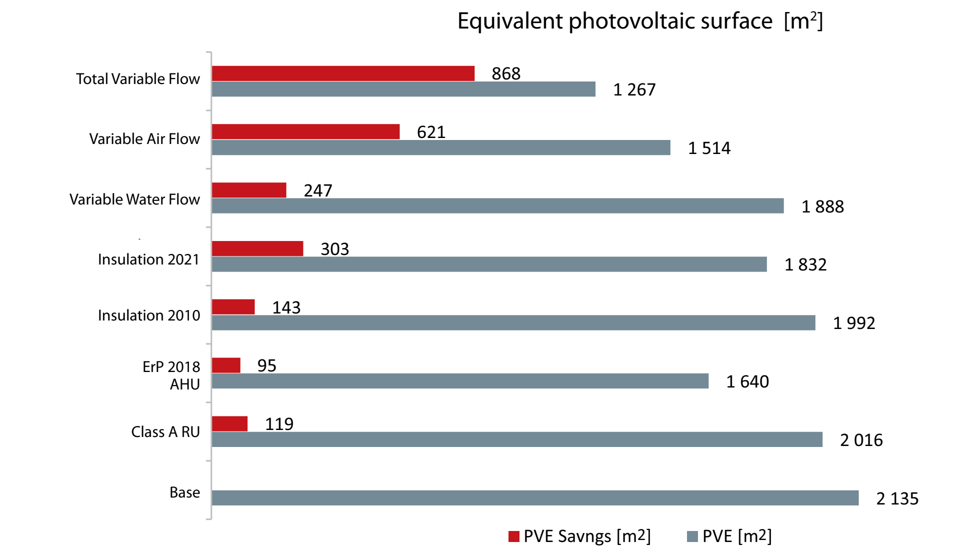


Figure 12-8: Equivalent photovoltaic surface obtained with Danfoss variable flow solutions

Similarly, the result can be reported in terms of the power of the equivalent photovoltaic plant.

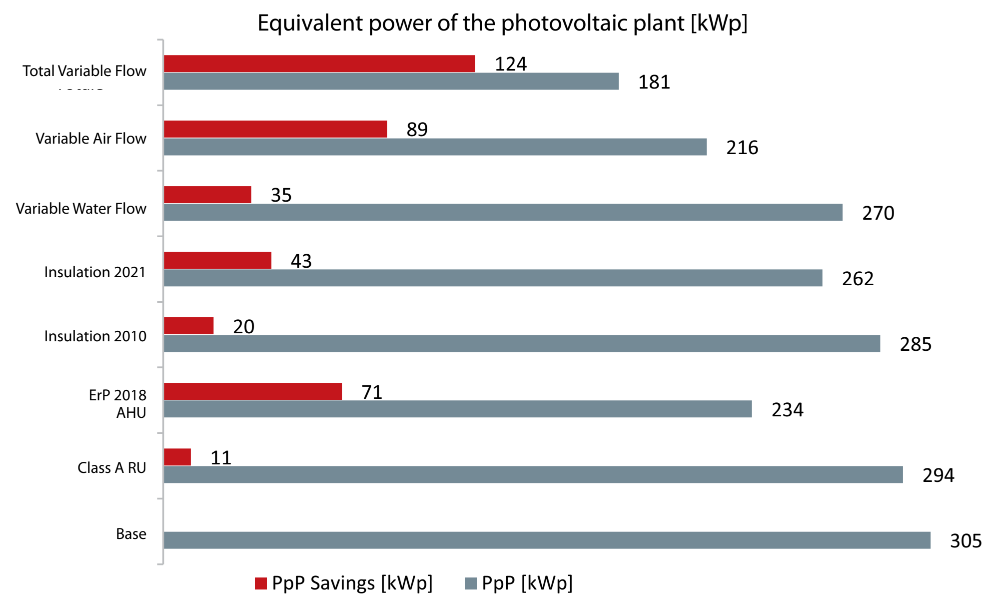


Figure 12-9: Equivalent photovoltaic power obtained with Danfoss variable flow solutions

Also, from an eco-sustainability point of view (a topic that many big hotel chains are focused on), the benefits of variable flow lead to important results, and with Danfoss solutions, tens of tons of CO_2 per year can be saved.

For reference, 1,000 kg of emissions are equivalent to those of a medium-powered car that travels 6,000 km.

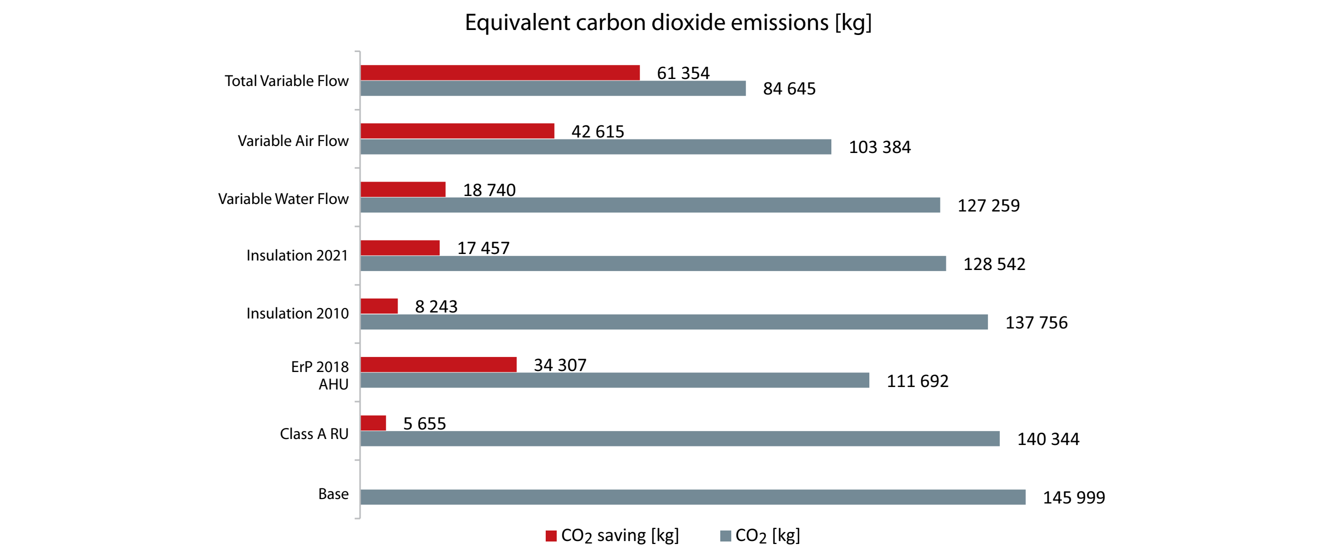


Figure 12-10: Equivalent carbon dioxide emissions obtained with Danfoss variable flow solutions

Before analysing the economic consequences of the interventions implemented in detail, let us evaluate what the benefits obtained with the variable flow rate are, both in the case of building retrofit with year 2010 thermal insulation type, and in case of a new building construction with year 2021 thermal insulation type.

Buildings with high thermal insulation have the advantage of significantly reducing heating consumption but, as seen in previous chapters, since cooling needs are increased, their impact on refrigerating units is lower.

It should also be considered that even the refrigeration equipment will have different efficiency.

In the case of buildings with year 2010 thermal insulation type, which are not too recent and therefore could potentially have already benefited from modernisation interventions, let us assume that poor energy efficient refrigeration equipment is installed, such as for example the refrigerating units in Class B Eurovent, and high load losses AHUs (regenerator efficiency $\varepsilon = 50\%$; fan performance $\eta = 50\%$), while in buildings with year 2021 thermal insulation type, we can obviously assumed that all the refrigerating units are in Class A Eurovent, and the AHUs have energy efficiency ErP 2018 (regenerator efficiency $\varepsilon = 75\%$; fan performance $\eta = 70\%$).

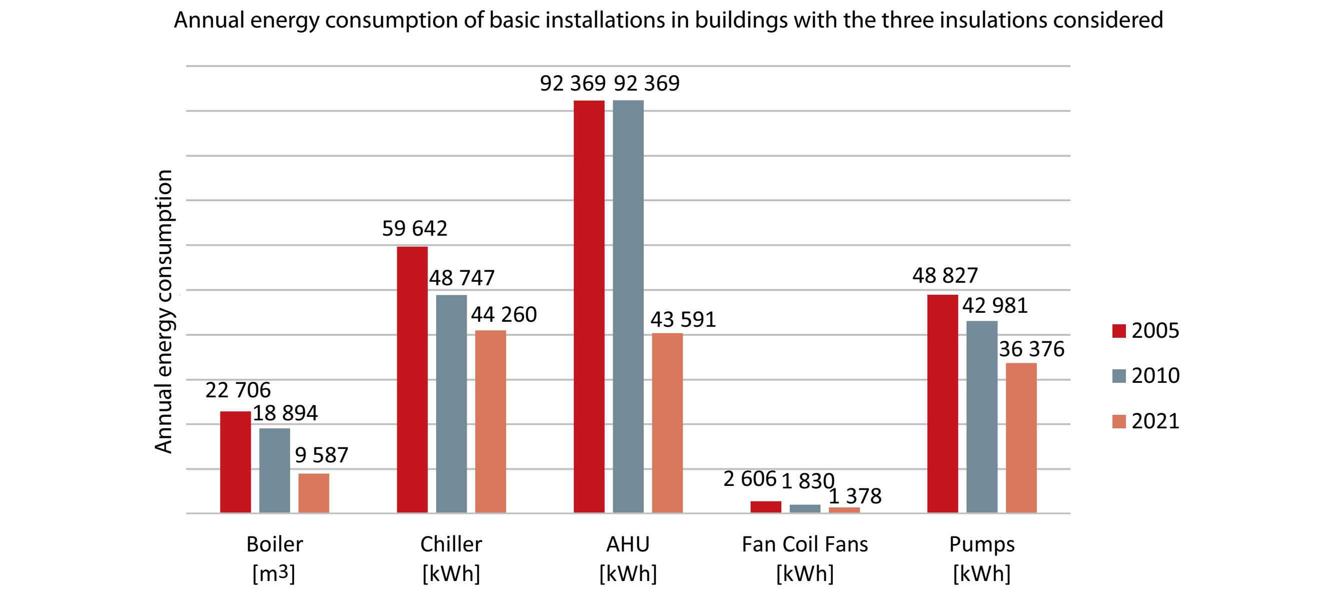


Figure 12-11: Annual energy consumption of basic installations based on the three types of thermal insulation considered

Since the approach adopted in the analysis is the same as that reported in the previous paragraphs, we can first evaluate the differences in basic solutions and then analyse the results directly.

As seen from the graph in Figure 12-11, by increasing the insulation, the gas consumption drops by almost 18% with the year 2010 insulation type, and by almost 60% in buildings with year 2021 insulation type, while the electricity consumption of the refrigerating unit decreases by 18% and 26% respectively in the case of year 2010 and year 2021 insulation types, in which, however, we must bear in mind that the equipment is in class B and A respectively, while in the case of year 2005 insulation type, the existence of class D equipment had been assumed.

Pump consumption is aligned, dropping by 12% in the case of year 2010 insulation type, and by 25% in the case of year 2021 insulation type. Likewise, AHU consumptions are visibly reduced thanks to the high energy efficiency ErP2018 in the case of year 2021 insulation type (about 53%).

Starting from these assumptions, it is possible to analyse, as in the previous case, the benefits that can be expected from the various modernisation interventions.

Retrofit of building with year 2010 thermal insulation type

The interventions considered in this case to increase the performance of the plants are:

Two solutions with measures to improve the efficiency of the equipment Installed

- Class A Eurovent refrigerating unit installation
- Installation of AHU with energy efficiency ErP 2018

One solution with thermal insulation improvement measures, with equal system

- Intervention to bring the building to the year 2021 thermal insulation type

Three Danfoss solutions for variable water and air flow systems

- Variable water flow only by using the Danfoss inverter VLT® FC102 and pressure-independent valves Danfoss AB-QM
- Variable air flow only by using the Danfoss inverter VLT® FC102 and shutters per room
- Solution with variable flow rate of both water and air by combining the two solutions mentioned above.

Efficiency improvement of installed equipment

Starting from the implementation of the variable flow of water only, a very stable and well-balanced plant is obtained, as already shown in Chapter 10, and it is immediately clear that the impact on consumption is definitely significant. The consumption of the pumps comes down from almost 49,000 kWh at just over 11,300 kWh, over 76% savings.

The considerable reduction in pump absorption impacts positively on the total electric consumption of about 18%. The savings obtained with this solution are over three times higher than that obtainable by replacing only the refrigerating unit from class D to Class A Eurovent.

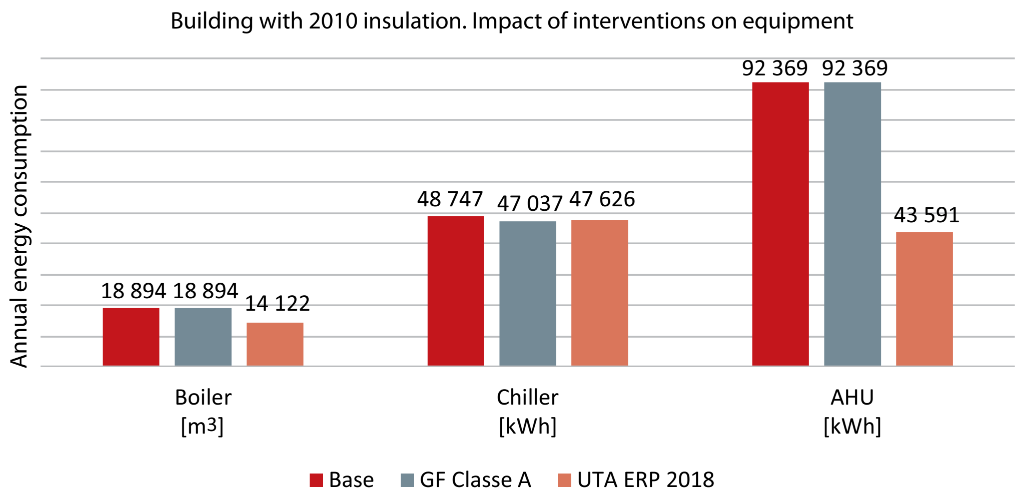


Figure 12-12: Benefits on energy consumption obtained by the replacement of the refrigerating unit and AHU with more efficient models

As in the previous case, the replacement of the refrigerating unit only, without intervening on the balancing and efficiency improvement of the system, has a negligible impact on electrical energy and gas consumption, due exclusively to its enhanced energy class.

On the other hand, the intervention on the AHU improves gas consumption by about 25% and electricity consumption by about 35%. Here also, the improvements are due to the greater efficiency of the regenerator, and the highest fan efficiency. On the contrary, in both cases there is absolutely no effect on the fan coils and pumps.

This does not mean that it is not an intervention to be considered. On the contrary, the increasingly restrictive regulations on environmental sustainability that discourage the use of refrigerants with high GWP, and encourage the use of high energy efficiency equipment, will make it almost mandatory to modernise older refrigerating units. Finally, we must consider that the optimisation of the plants through balancing and variable flow, and the modernisation of the refrigerating units, together represent the maximum of the efficiency improvement of the whole air conditioning system.

Improvement of thermal insulation

By intervening only on thermal insulation, as expected, gas consumption only will be reduced, equal to about 22% in this case.

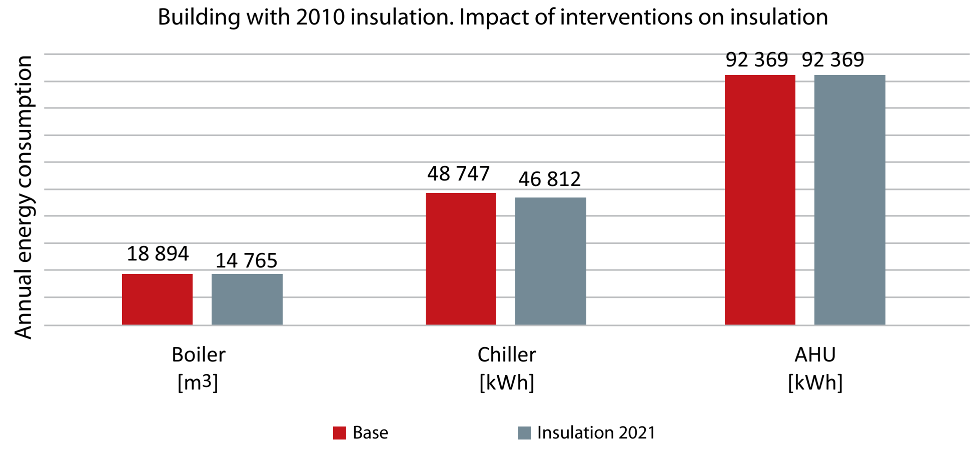


Figure 12-13: Benefits on energy consumption obtained with the improvement of thermal insulation (from year 2010 to 2021)

Use of Danfoss solutions for variable flow installations

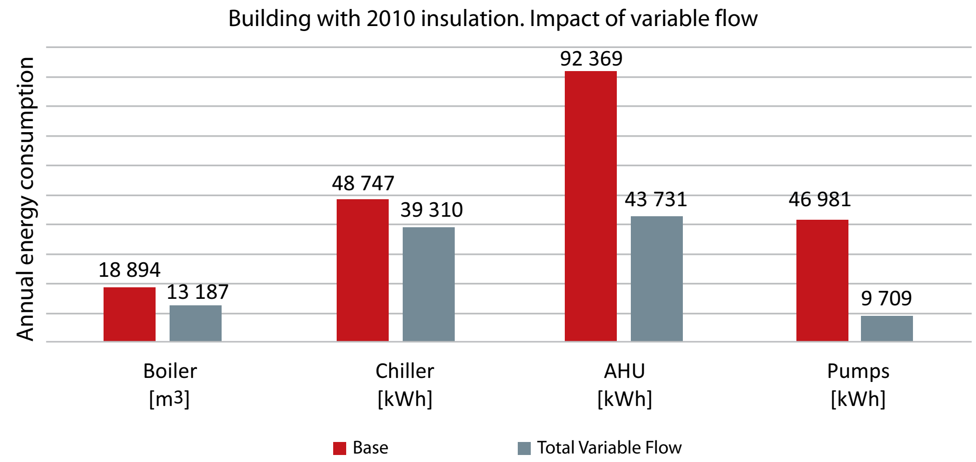


Figure 12-14: Benefits on energy consumption obtained with Danfoss variable water flow solutions (building 2010)

By intervening on the pumps, from just under 43,000 kWh it decreases to about 9,700 kWh, with a reduction in consumption of over 77%. By intervening on the variable air flow, savings of over 40% can be achieved on AHU and refrigerating unit energy consumption, and of 30% on gas consumption.

Overall, these interventions make it possible to reduce total electricity consumption by about 50%, and gas consumption by 30%.

The results obtained with the passage to the variable flow are far superior to any other type of intervention previously analyzed, and on average imply very low intervention costs and very slow return-on-investment.

If we better want to see what this means, keeping in mind the concept of equivalent photovoltaic surface defined in Chapter 1, which quantifies the surface of photovoltaic panels necessary to obtain an annual energy balance of zero, the implementation of the variable flow technology means being able to save the equivalent of 800 m^2 of photovoltaic panels and 115 kWp.

In terms of environmental impact, the variable flow rate leads to savings of around 44% of CO_2 emitted into the atmosphere (around 57 tonnes less).

Building design with year 2021 thermal insulation type

In this case, obviously all the equipment is supposed to have high efficiency. The purpose of this analysis is, however, to evaluate the benefits of a variable flow system, even in the case of new systems and high thermal insulation, by considering also, as shown above, that maximising the efficiency of the plants and reducing consumption will be a key element to design, according to the new directives concerning the use of renewable energy sources.

Regarding the characteristics of the equipment, let's consider Class A Eurovent refrigerating units, and AHUs compliant with the ErP 2018 Directive, with regenerator efficiency ε = 75% and fan performance η = 70%.

The solutions analyzed are the following:

Three Danfoss solutions for variable water and air flow systems

- Variable water flow only by using the inverter VLT® FC102 and pressure-independent valves Danfoss AB-QM combined with six-way valves ChangOver6 with electronic actuator NovoCon® S
- Variable air flow only by using the Danfoss inverter VLT® FC102 and shutters per room
- Solution with variable flow rate of both water and air by combining the two solutions mentioned above

Use of Danfoss solutions for variable flow installations

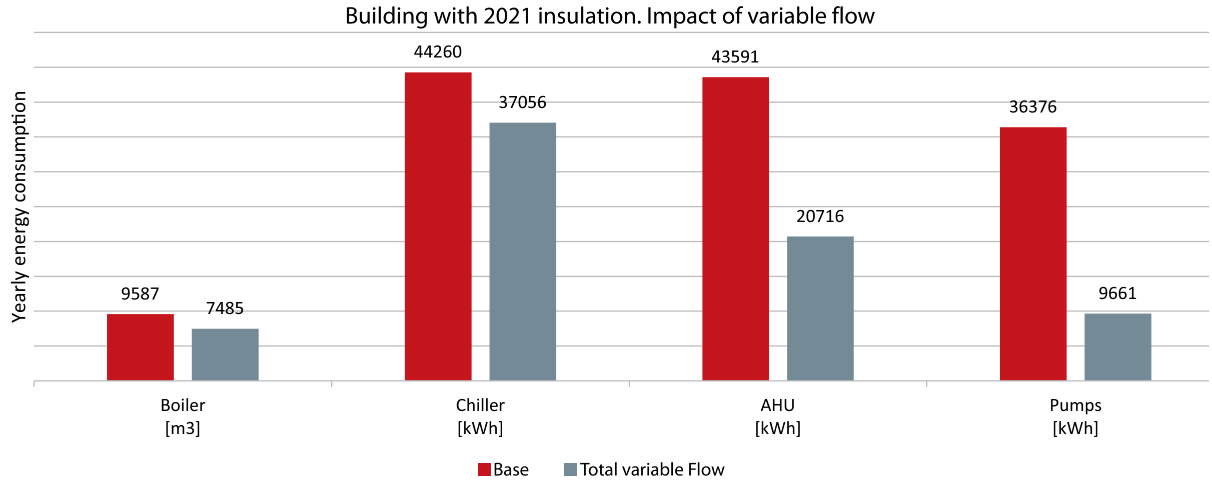


Figure 12-15: Benefits on energy consumption obtained with Danfoss variable flow solutions (building 2021)

By implementing the variable flow of water only the consumption of the pumps obviously changes, which breaks down from over 36,000 kWh to little more than 9,600 kWh (over 73%), while with variable air flow, benefits can be expected on AHU, refrigerating units and boiler electric consumptions (34%).

Overall, even in a building with high thermal insulation and with high efficiency equipment, designing the systems by implementing variable flow is always very advantageous, because significant additional energy savings are obtained anyway, albeit in a plant which already has high efficiency equipment. In fact, as can be deduced from the graphs shown in Figure 12-15, a further reduction of about 46% on electricity consumption of a high efficiency plant and a further 22% reduction on gas consumption are obtained.

Reporting the results in terms of equivalent photovoltaic surface, as defined in Chapter 1, and of emissions of carbon dioxide, the equivalent of almost 500 m^2 of solar panels and 64 kWp can be saved, with a reduction in emissions of approximately 32.5 tons of CO_2, i.e. about 40% less.

Economic grounds

The analysis highlighted the impacts in terms of energy of the various possible interventions on buildings, by showing how the implementation of the variable flow is the one allowing for greater reductions in consumption.

The following paragraphs demonstrate how the solution based on variable flow is also the best in economic terms, because not only is it the one that reduces costs the most, but it is also the one that guarantees the shortest return-on-investment.

As a hypothesis to carry out the calculations, an average cost of €0.60/m^3 for natural gas and of €0.20/kWh for electricity has been considered.

By keeping in mind that the variable flow solution provides for the implementation of pressure-independent valves, Danfoss AB-QM, with relative actuator and inverter, Danfoss series VLT® FC102 on pumps and fans, in a hotel with the characteristics considered, the investments to implement variable flow rates are generally lower, or comparable at the most, to the purchase of new machines, as well as by far lower than those for carrying out structural interventions suitable for improving the thermal insulation of the building, it follows that payback times can vary on average from 18 to 24 months, as appropriate.

Furthermore, it should always be remembered that interventions of this type offer the great advantage of being able to be performed by limiting to the minimum the inconveniences for the comfort of the guests, as they can be carried out by only partially isolating the building, for example, just a floor or part of it at a time.

Economic savings on retrofit of building with year 2005 insulation type

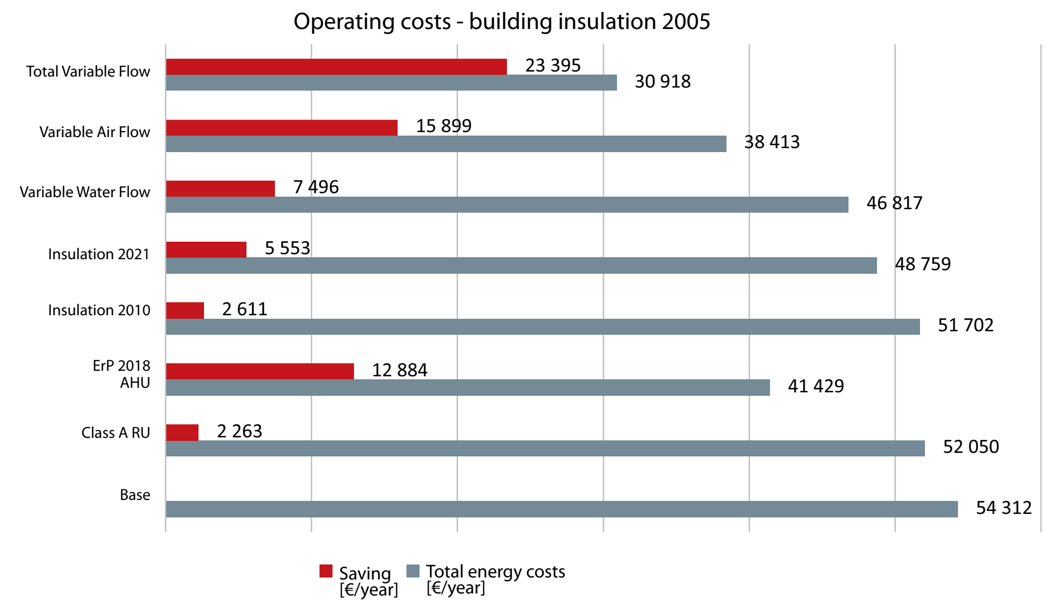


Figure 12-16: Building operating costs with year 2005 insulation type

The plant design with variable flow, which drastically breaks down energy consumption, is definitely the most advantageous, both from an economic point of view and from an investment point of view, with payback times that can be estimated at around 18 months.

By also intervening only on the variable air or water flow, savings already superior to any other type of intervention are achieved. Implementing a solution with total variable flow (air and water) almost halves energy management spending.

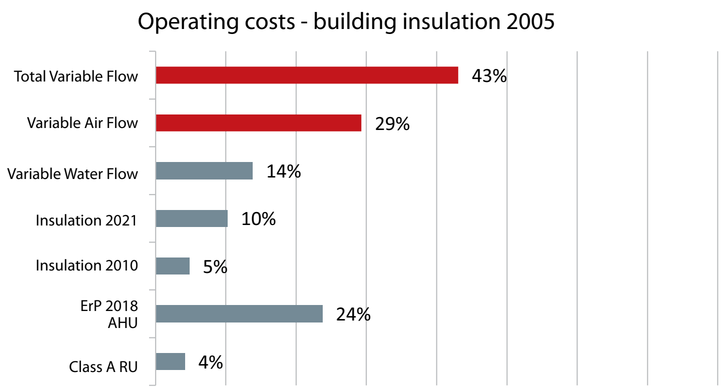


Figure 12-17: Savings on building operating costs with year 2005 insulation type

Economic savings on retrofit of building with year 2010 insulation type

In this case also, the economic advantages of variable flow plants are remarkable. In percentage terms, the savings are comparable to the previous case, reducing costs by up to 45% in comparison to the constant flow plant solution.

Savings on operating costs - building insulation 2010

In this case too, the economic advantages of variable flow systems are considerable.

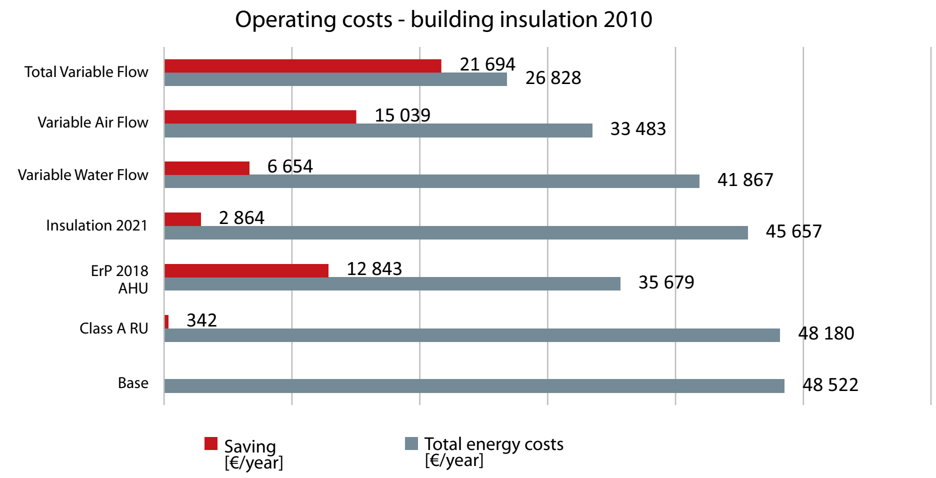


Figure 12-18: Building operating costs with year 2010 insulation type

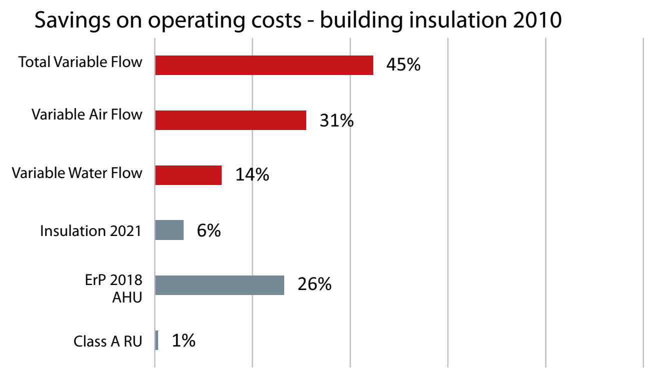


Figure 12-19: Savings on building operating costs with year 2010 insulation type

Economic savings on retrofit of building with year 2021 insulation type

In this case, although starting from a situation already in itself very efficient, it is evident how it is always important to design systems with variable flow rates, still having the possibility to save an additional 40% on energy costs.

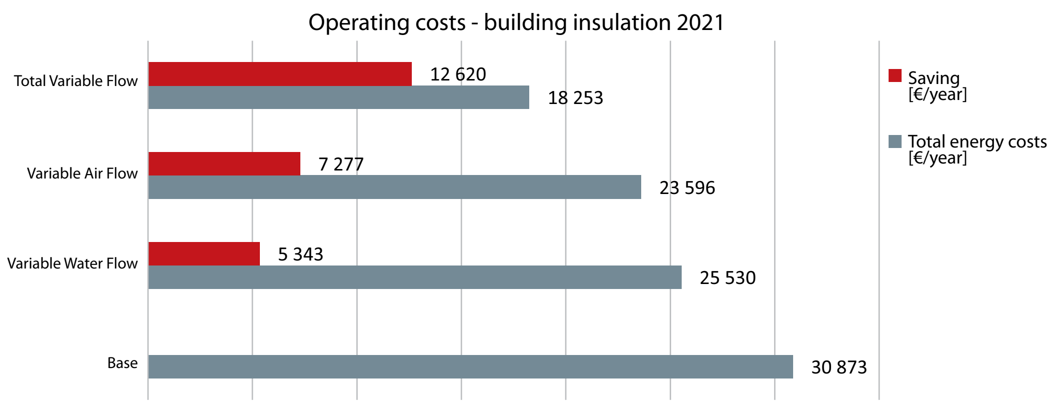


Figure 12-20: Building operating costs with year 2021 insulation type

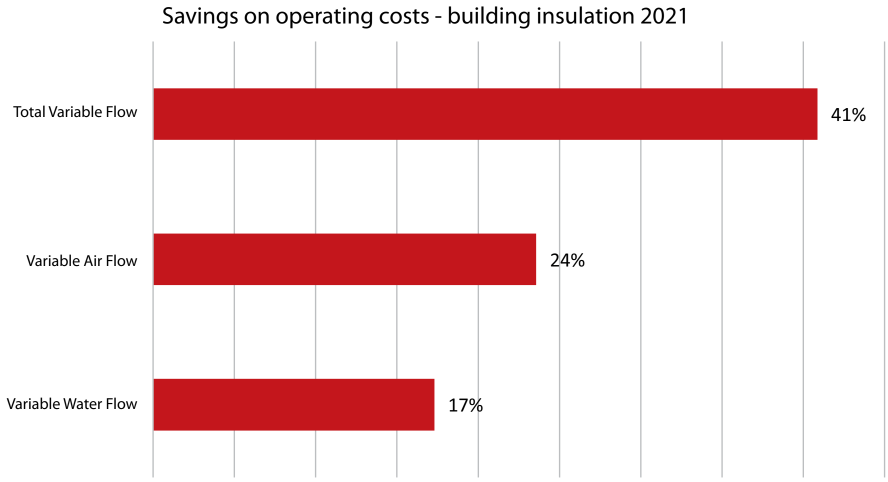


Figure 12-21: Savings on building operating costs with year 2021 insulation type

Conclusions

The economic implications of energy savings that are obtained with a well-balanced variable flow system are considerable.

Intervening by modernising existing systems, by means of pressure-independent dynamic balancing valves, and with inverter on pumps and fans, is the best solution and offers several advantages, compared, for example, only to the replacement of equipment or to structural interventions on the building's insulation.

First of all, it is generally possible to perform these works without totally interrupting the service for hotel guests, as it is possible, for example, to intervene on single floors or rooms, in parallel with also other maintenance or modernisation interventions. This means being able to limit discomfort for people.

Secondly, the annual energy savings on gas consumption and heating and cooling electricity are by far superior to those obtainable with other solutions, reducing electric energy consumption up to 45%, and gas consumption by 30%.

Considering also that the necessary investments are generally lower than those required by alternative approaches, a plant with variable flow, built using Danfoss solutions, represents the more advantageous solution, both economically and technically, with return-on-investment that can be between 18 and 24 months.

Chapter 13: Advantages of Danfoss solutions in other hotel areas

The analysis carried out in the previous chapters hypothesised the implementation of a well-balanced plant with variable flow, to evaluate its impact in energetic and economical terms, considering only the rooms and common areas and excluding any conference rooms, spas or dining rooms.

However, these areas, though not always existent, are quite common in hotels, especially in superior class facilities and, as will be shown in the following paragraphs, may be very energy intensive.

The advantages of using variable air flow with the Danfoss inverter for HVAC applications and balancing valves Danfoss AB-QM have been analyzed.

Restaurant and spa premises

By keeping in mind the characteristics of the building used for the simulation and the energy analysis defined in Chapter 2, it has been assumed that both the restaurant and spa areas have a maximum capacity of 150 people and two types of functioning are hypothesised, that of the weekdays (254 days), and that of weekends and holidays (110 days).

Two types of plants are also hypothesised, one with new high efficiency AHUs, and total fan power of 3.5 kW; the other with older air handling units, with total fan power of 8 kW.

From the graphs shown in Figure 13-1 and Figure 13-4, it is clear that with fixed speed plant designs, the flow remains constant in all opening hours, regardless of the influx of people, while with the inverter solution the flow rate varies with the number of people, with an average value slightly lower than that necessary for maximum capacity.

Dining area and breakfast room

The greatest influx occurs most likely on weekdays, approximately three hours during breakfast time, and dinner between 6 pm and 11 pm.

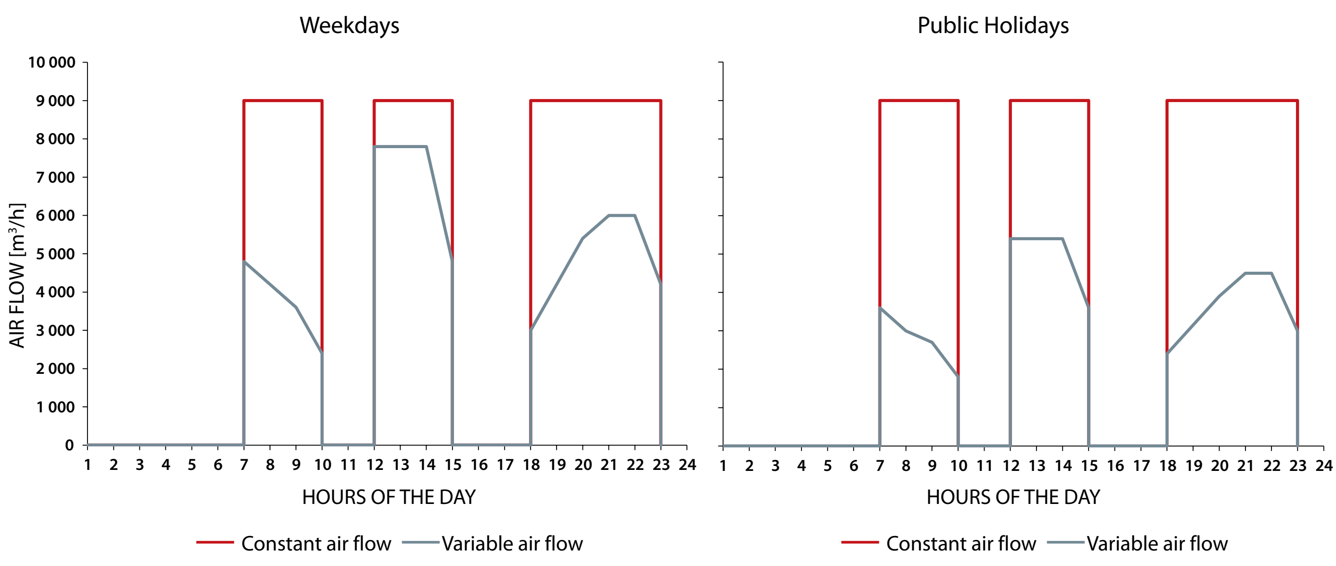


Figure 13-1: Required air flow in the Dining and Breakfast Room

Naturally, the energy saving, in absolute terms, is greater in the case of older AHUs, because with their fan's low performance and load losses, their consumption with constant flow is greater.

Considering also the use of a balancing valve Danfoss AB-QM on the water circuit, further energy advantages can be realised, related to the strong reduction in flow rate in the batteries and in the AHU pipes.

Overall, by implementing the Danfoss variable flow solution, up to almost 70% less energy is consumed, equivalent to over €5k per year saved on electricity expenditure.

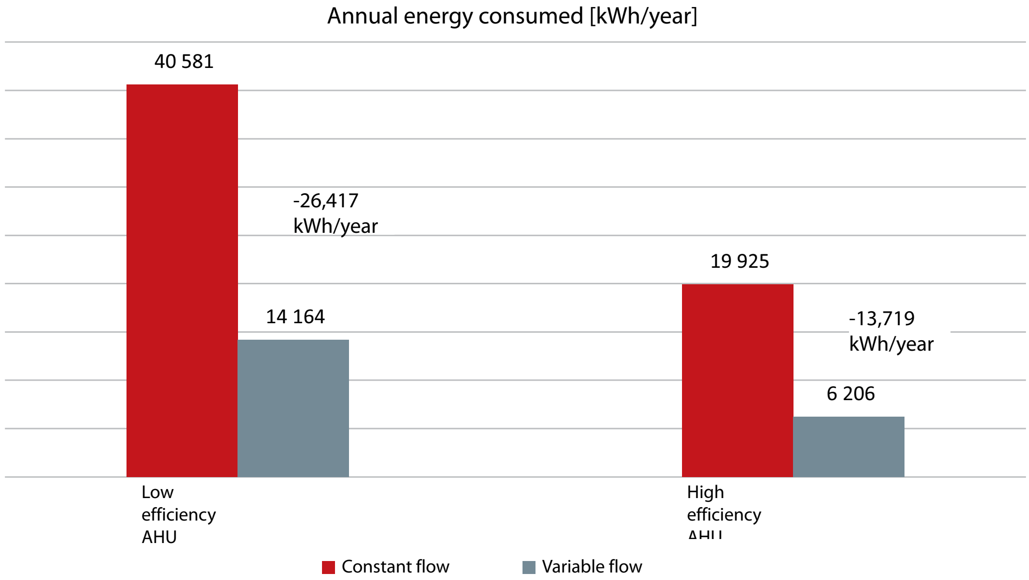


Figure 13-2: Annual energy consumed in the Dining and Breakfast Room

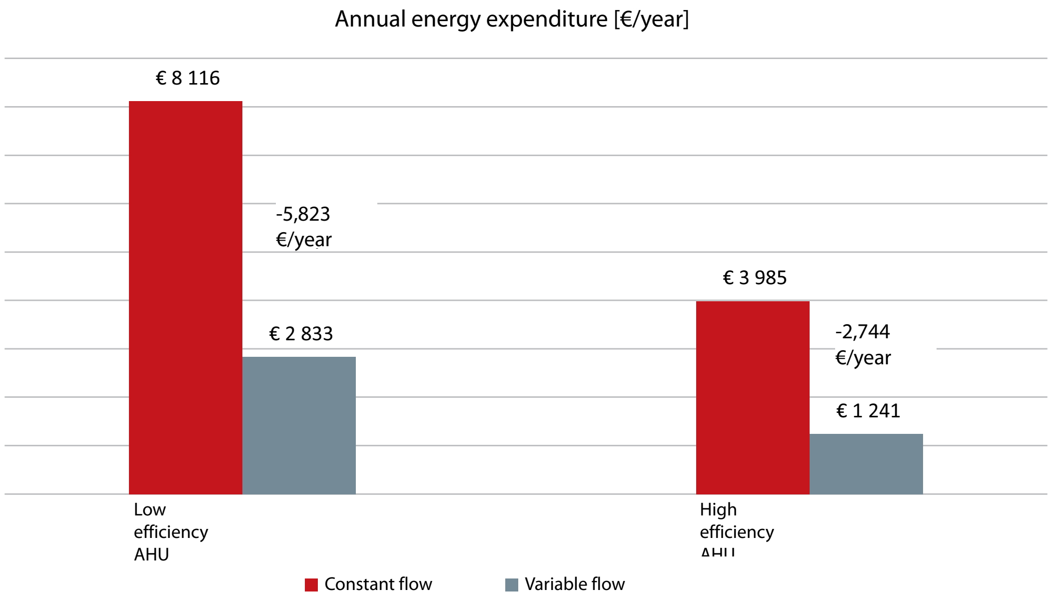


Figure 13-3: Annual expenditure on energy consumed in the Dining and Breakfast Room

Spa premises

In the spa premises, the influx is more prolonged than in the restaurant, and requires a greater flow of air; therefore, the benefits resulting from the use of the inverter are even more evident.

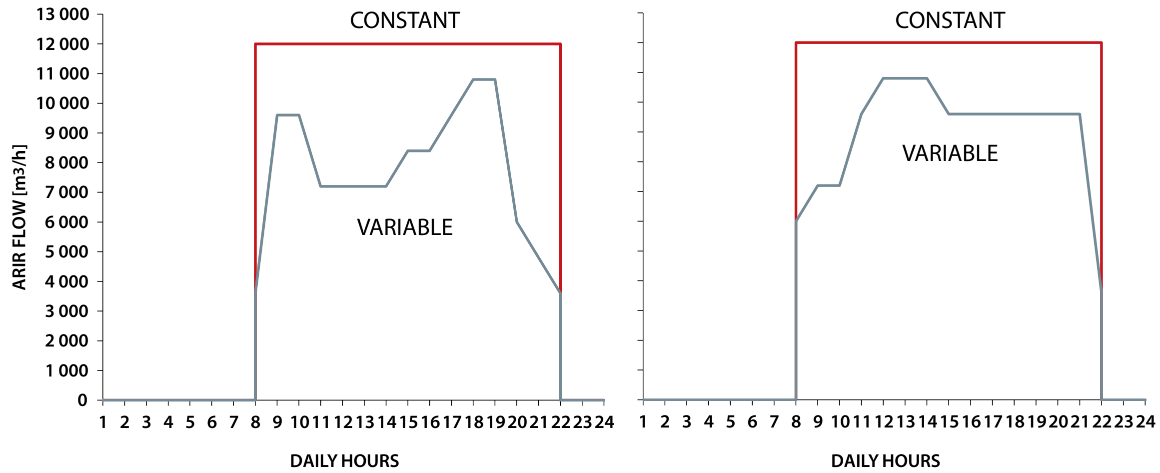


Figure 13-4: Required air flow in the Spa premises

Overall, the advantages brought about by the use of the inverters, and of the Danfoss balancing valves, are around 30,000 kWh/year, corresponding to just under €6k less on the bill, i.e. over 55% savings compared to a constant flow system.

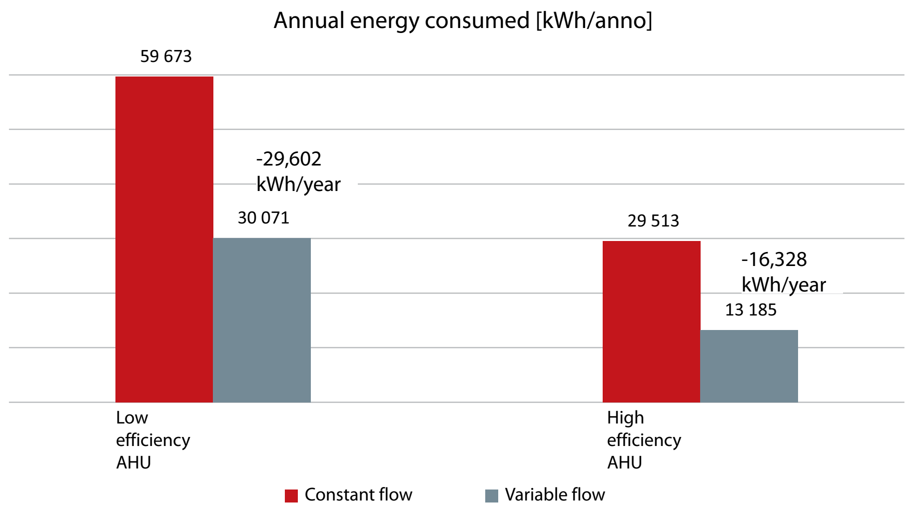


Figure 13-5: Annual energy consumed in the Spa premises

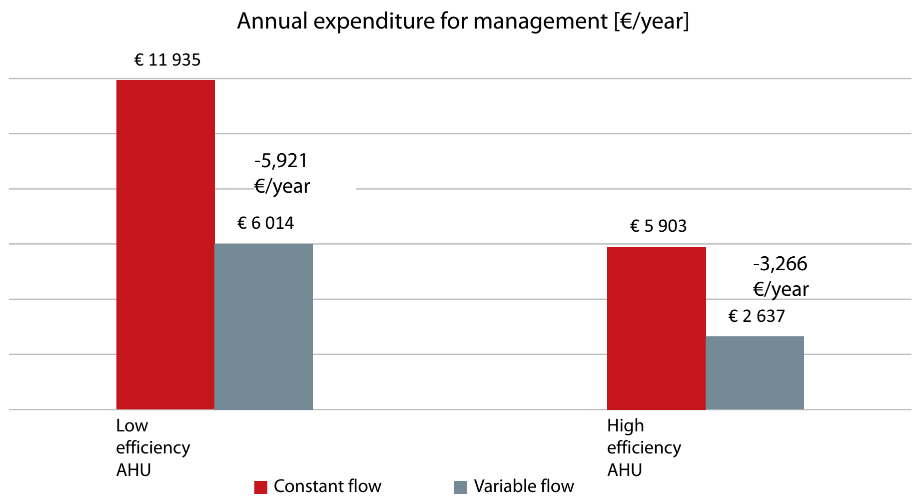


Figure 13-6: Annual expenditure on energy consumed in the Spa premises

Conference room

Based on the characteristics of the analyzed hotel, it was hypothesised that the conference room has a maximum capacity of 200 people, and two types of operation: one with a fully occupied room for 80 days; and the other with the room occupied for half of its capacity for 100 days a year.

Two types of plants were also hypothesised: one with new high efficiency AHUs, and total fan power of 3kW; the other with older air handling units, with total fan power of 7 kW.

It can be seen from the graphs that with the fixed speed plant designs, the flow remains constant in all hours of opening, regardless of the influx of people, while with the inverter solution, the flow varies with the number of people, always slightly less than that necessary for maximum capacity.

Since the use of these areas is normally prolonged for several hours a day, the variable flow system with the use of inverters and Danfoss balancing valves offer significant advantages.

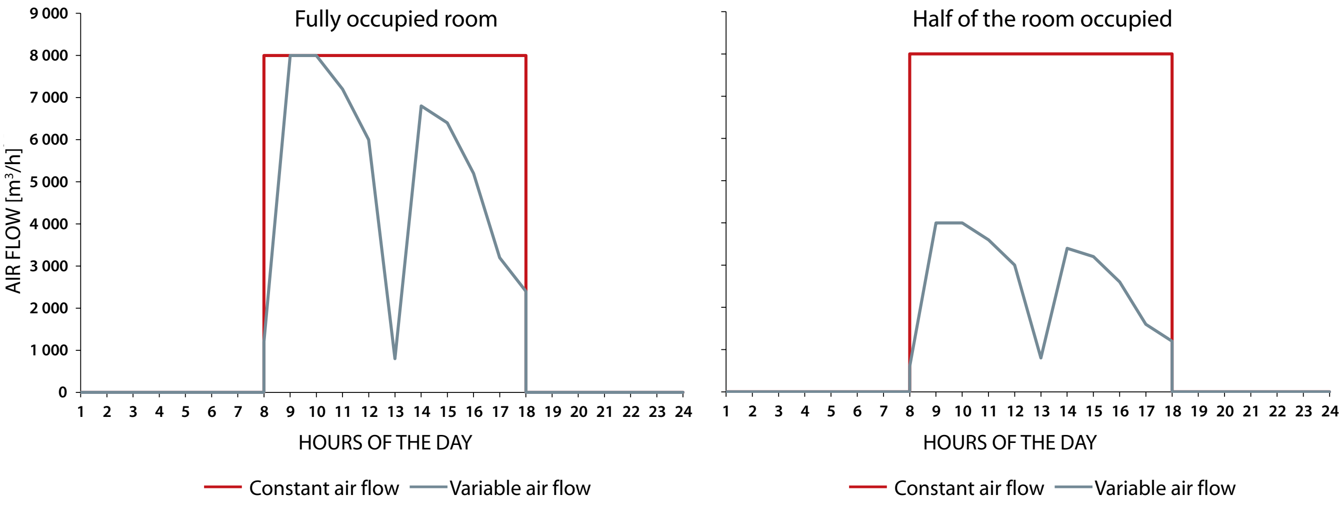


Figure 13-7: Required air flow in the Conference Room

Overall, the advantages of using Danfoss solutions can reach about 10,000 kWh/year, corresponding to just under €2k less on the bill, i.e. slightly less than 70% of savings, compared to a constant flow system.

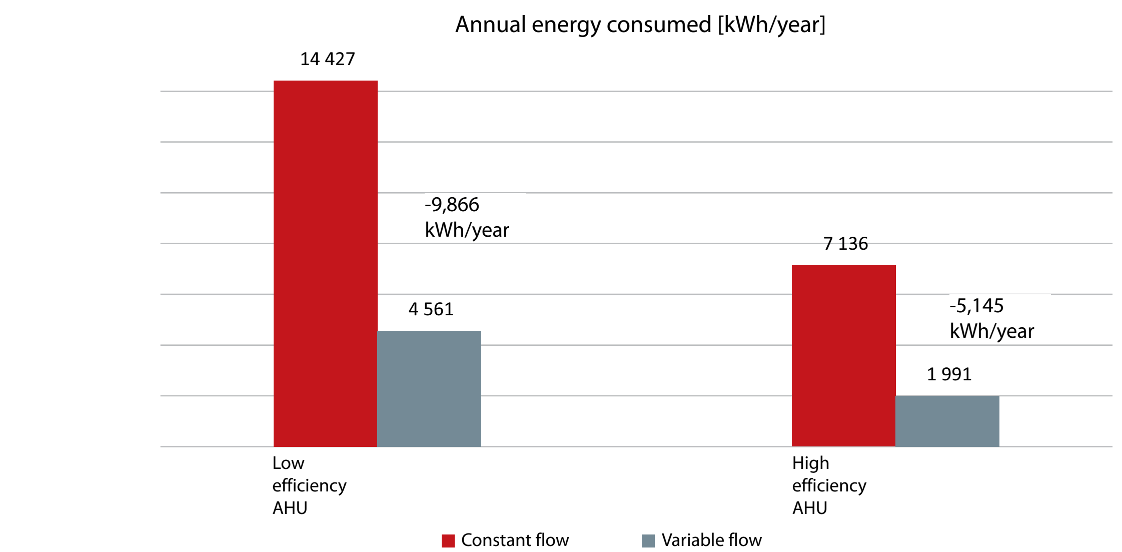


Figure 13-8: Annual energy consumed in the Conference Room

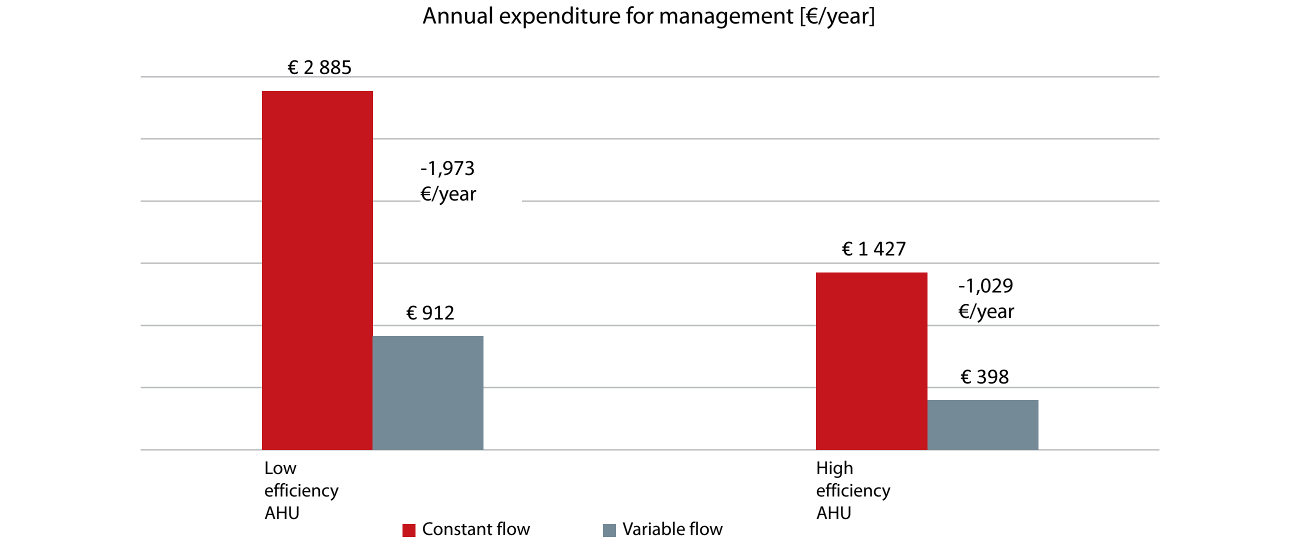


Figure 13-9: Annual expenditure on energy consumed in the Conference Room

Savings obtainable by taking into account bedrooms, common areas and additional rooms

In the previous paragraphs, the benefits offered by variable flow systems, comparing them with other types of efficiency improvement interventions, were analyzed separately by taking into account only the rooms and common areas or only the areas intended for restaurants, spas and conference rooms, for the three types of building considered.

It is possible to quantify what the overall achievable benefits are, considering instead the whole building with all its main areas, so that the overall potentials of energy efficiency improvement and of savings obtainable on expenditure for the energy related to heating and cooling systems can be identified.

The same conditions already used in the previous paragraphs have been assumed regarding the plants and the parameters for the simulation. The comparison was made with respect to the basic solution with constant flow, Class B refrigerating units and low efficiency AHUs.

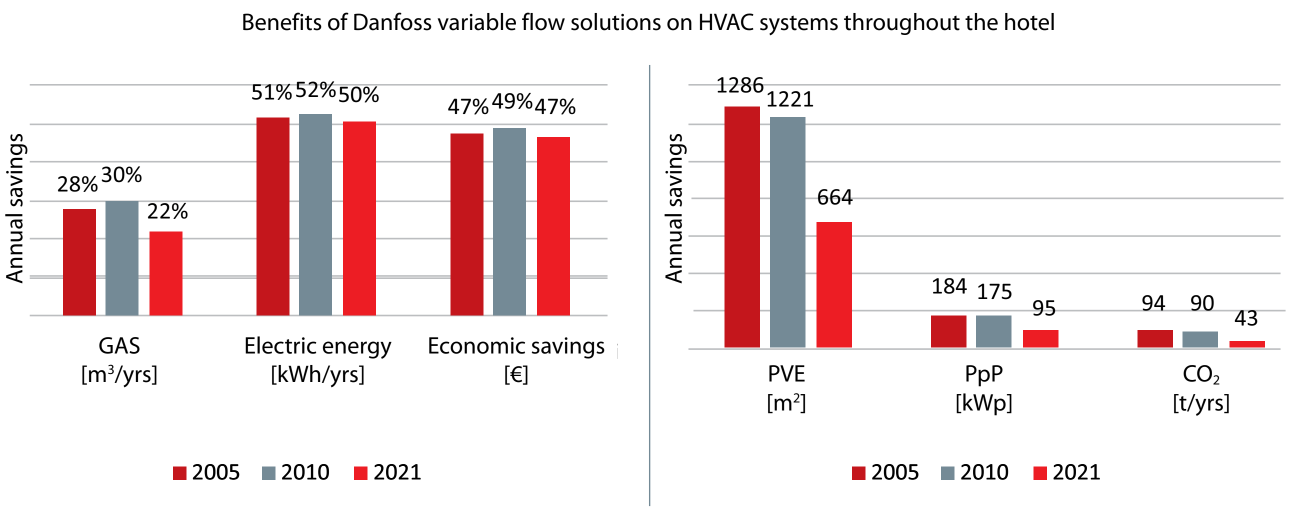


Figure 13-10: Benefits obtainable with Danfoss variable flow solutions applied to all hotel areas

The timing of the return-on-investment of this type of intervention of energy efficiency improvement is among the lowest, and therefore among the most affordable.

As can be seen, there is an overall reduction of about 50% of electricity and 30% of gas, managing to reduce the total energy expenditure by almost half.

Obviously in renovation, much depends on the initial situation and on the type of technology to be installed. For example, a mechanical actuator has a lower cost than an electronic one, but if one wanted, for example, to integrate the components inside a Building Management System (BMS), the most advanced technological choice would be certainly the most desirable.

For the cases in question, the return-on-investment has been estimated, on average, between 18 and 24 months.

Chapter 14: Danfoss MTCV multifunctional thermostatic circulation valves

The MTCV is a family of multifunctional thermostatic balancing valves used in domestic hot water systems with recirculation.

These are valves that guarantee thermal balancing in domestic hot water systems by maintaining a constant supply temperature and by limiting at the minimum necessary level the flow in the recirculation pipes.

The re-circulation ring

The recirculation ring is used to ensure the immediate power supply of all the requirements of domestic hot water services in every section of the plant.
Basically, the recirculation ring is composed of a return pipe (blue piping), which connects all the bathrooms to the accumulation of domestic hot water, and of a circulation pump, which allows the water to transit. It is called ring because it closes the circuit of distribution of domestic hot water in a ring (red piping).

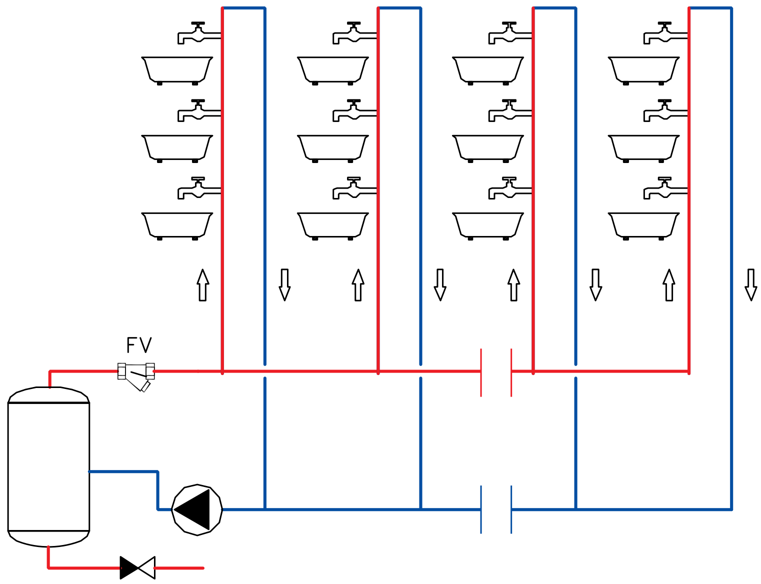


Figure 14-1: The recirculation ring

If the circuit were open, the water flow rate inside the piping would vary according to the number of open taps. In extreme cases, in certain hours of the day, the flow could become void, if all utilities did not require hot water. The water inside the pipes would cool and the user who needed domestic hot water would need to wait some time for hot water to be able to arrive from the tank. It is a phenomenon that generally occurs in apartments with single hot water production: sometimes it is necessary to wait a few tens of seconds.

In a very large centralised system, as in the case of condominiums and hotels, times would be much longer and therefore unacceptable.

The recirculation ring cannot be constructed as shown in the previous figure, because if this were so, balance between the various ascension pipes would not be achievable. Therefore, it is correct to install some static calibration valves.

Difference between static balancing valves and Danfoss thermostatic valves

The static balancing valves balance the flow rate between the various ascension pipes, in view of correct installation operations, which take time. However, once balanced, the flow will always be constant for 8,760 hours per year, with consequent energy consumption of the circulation pump.

In doing so, however, a great deal of water is wasted, because in some cases there is absolutely no need for the pump to guarantee hot water everywhere. For example, in the hours of greater consumption, when even the most distant taps of each ascension pipe require hot water, automatically all the other taps are certainly fed, in theory without the need for the pump: it is the hydrostatic pressure that moves the water up to the highest floors and the flow is guaranteed by the opening of the most distant taps.

On the other hand, at certain times of the day, the flow of the recirculation ring could also prove to be poor in some branches, if the plant were not correctly balanced.

Danfoss multi-function thermostatic balancing valves work by relying on the thermal balance of the system, maintaining a constant temperature in the plant itself, and limiting the flow rate in the recirculation pipes to the minimum required level, to ensure the lowest possible consumption on the one hand and the best plant performance on the other.

The versions of the Danfoss MTCV valves

The Danfoss MTCV valve family consists of three distinct versions, all in lead-free brass, to comply with the new regulations introduced by the Directive on the quality of drinking water, entered in force in December 2013.

The MTCV valve family consists of three versions:

- Basic version
- Version with automatic disinfection module (self-operated) – thermo-element
- Version with electronic regulator with TWA thermal actuator and PT1000 thermal sensors

Figure 14-2: the MTCV valve family. On the left version B with automatic disinfection module. In the centre the basic version A. On the right version C with electronic controller

Basic Version

The MTCV valve in the basic version is a proportional self-operated thermostatic valve. The valves are inserted at the bottom of pipe on the return line of the recirculation ring, as shown in Figure 14-3.

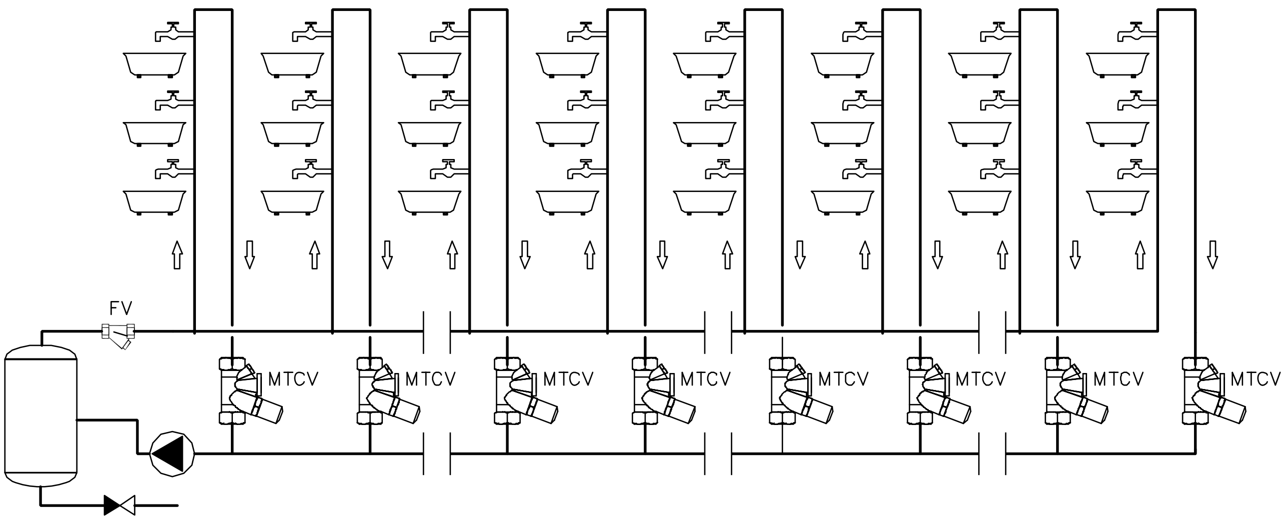
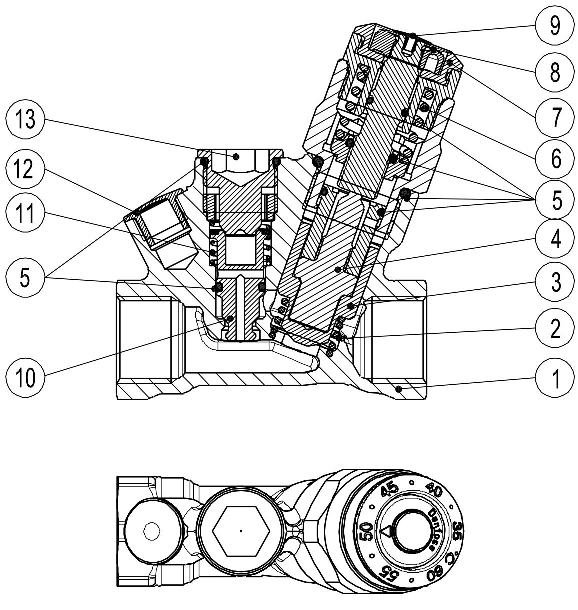


Figure 14-3: Diagram of the return ring with Danfoss MTCV valves inserted at the bottom of the pipes

The main element of the valve is the thermo-element (item 4), which is sensitive to changes in the water temperature of the sanitary equipment.

1. Valve body
2. Spring
3. Cone
4. Thermo-element
5. O-ring
6. Safety spring
7. Adjusting ring
8. Adjustment knob
9. Adjustment cover cap
10. Cone disinfection module
11. Safety spring
12. Thermometer cap
13. Disinfection module socket



Basic version - A

Figure 14-4: Danfoss MTCV valve structure - Basic version - A

A special seal on the thermoelement protects it from direct contact with water, prolonging its life and ensuring an accurate setting at the same time.

A safety spring (6) protects the thermoelement from possible damage when the water temperature exceeds the valve's default value.

If the water temperature exceeds the default value, the thermoelement expands and the cone moves towards the seat of the valve, limiting the circulation flow. If the water temperature drops below the default value, the thermoelement opens the valve, increasing the flow rate in the circulation pipe. The valve is in equilibrium (nominal flow = calculated flow) when the water temperature has reached the default value set for the valve.

If the temperature is 5°C beyond the default value, the flow through the valve stops.

This operation, shown in the next figure, explains the advantages of MTCV valves compared to the static balancing ones. If the water temperature is very low, it means that the plant requires more water than assumed in the project, because suddenly many taps are opened. On the contrary, when the water temperature is high, it means that the taps are already open and the required water flow required by the recirculation ring is low.

The yellow dot corresponds approximately to the project flow in case fixed calibration valves were used. The value is high because it is necessary to ensure sufficient flow in any operating condition.

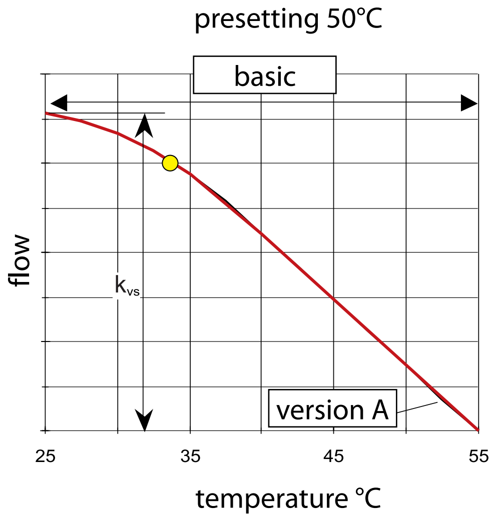


Figure 14-5: Control characteristic of the Danfoss MTCV valve - Basic version – A

Figure 14-6 shows the typical percentage flow of the recirculation ring of a hotel in a non-touristic city, where the occupation is maximum in the days from Tuesday to Friday morning, and drops over the weekend.

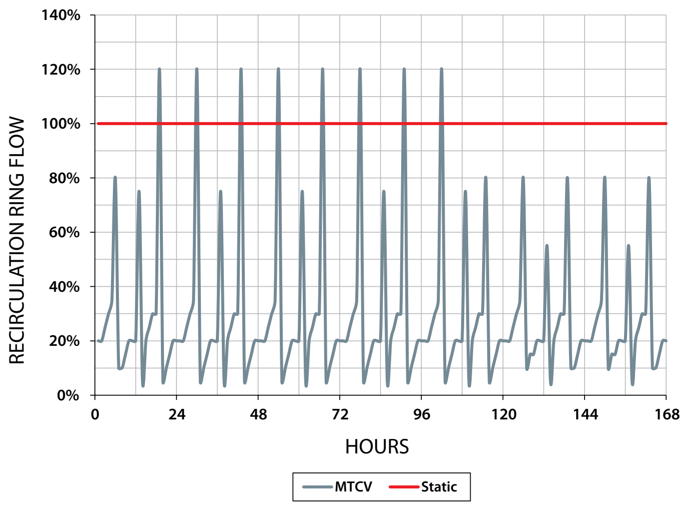


Figure 14-6: Typical percentage flow of a hotel's recirculation ring

As can be seen from the graph, the flow rate has a peak at about 6am in the morning, when the first showers start, and then lowers quickly, with the peak of consumption. The effect is repeated around 7pm, when people come back to the hotel.

In the space of a week, the average flow rate is equal to 30% of the water flow that would be achieved with static calibration valves.

Version with automatic disinfection module (self-operated) - thermoelement

The standard version of the Danfoss MTCV valve - A can be easily and quickly equipped with the thermal disinfection function against Legionella bacteria that could be present in domestic hot water systems.

Simply remove the cap from the disinfection hole, operation that is feasible even when the system is full, and install the disinfection module (17).

14. Bypass for disinfection
15. Thermometer
16. Cu Gasket
17. Disinfection module

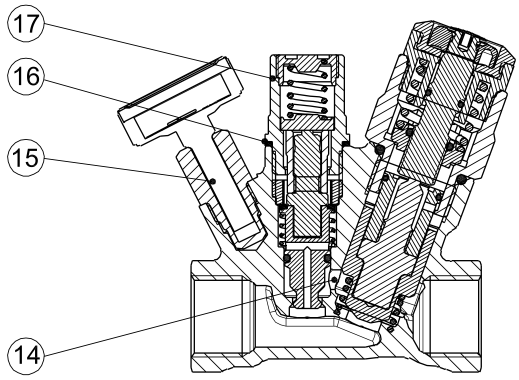


Figure 14-7: Self-operated version of the Danfoss MTCV valve with automatic disinfection module - B

The disinfection module automatically opens a bypass of Kv min. = 0.15 m^3/h, which is able to ensure the flow of hot water, at a temperature above 60°C, necessary for the continuous disinfection of the plant.

In the basic version of the Danfoss MTCV valve, this bypass is always closed to prevent the accumulation of dirt and limestone.

Therefore, the Danfoss MTCV valve can be equipped with the disinfection module even after a long period of operation in the basic version without the risk of blocking the bypass.

The temperature range of the adjustment module in the basic version A is 35-60°C. With the version with the disinfection module, when the temperature of the hot water exceeds 65°C to begin the anti-legionella process, the flow through the main seat of the MTCV valve stops and the bypass opens for the 'disinfection delivery'.

The disinfection process is performed until 70°C are reached, useful for completely destroying Legionella. If the temperature of the hot water increases further, the flow through the disinfection bypass is reduced (the process of thermal balancing of the plant during disinfection) and it stops when it reaches 75°C. This operating logic serves to protect the hot water system against corrosion and limestone deposits, in addition to minimising the risk of burns.

The adjustment logic is shown in Figure 14-8.

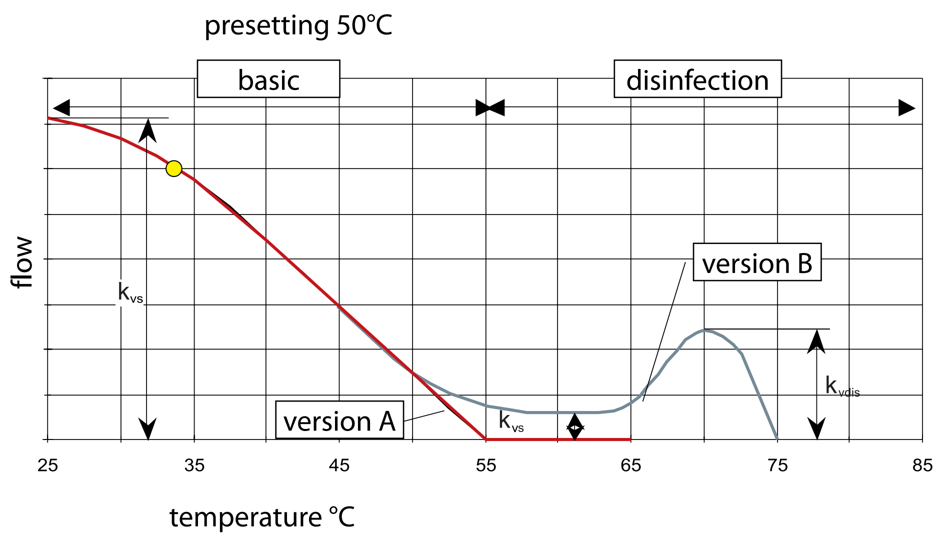


Figure 14-8: Control characteristic of the Danfoss MTCV valve - Self-operated version - B

A thermometer can be mounted as an option both on the basic version, and on the version with module, to measure and control the temperature of the circulation hot water.

Version with electronic controller with TWA thermal actuator and PT1000 thermal sensors

The “A” and “B” versions of the MTCV can be equipped with an electronically controlled disinfection process (version C).

Figure 14 9: On the left Danfoss MTCV Valve version C equipped with electronic controller - On the right electronic CCR2 for the optimization of disinfection processes

Instead of the mechanical actuator, it is possible to mount the adapter (21) and then the TWA thermal actuator with electronic control.

18. Bypass (closed position)
19. PT 1000 thermal sensor
20. Cu Gasket
21. Adapter for the assembly of the TWA thermal actuator

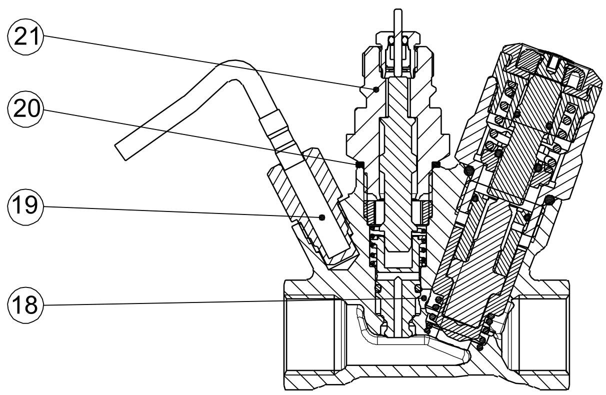


Figure 14-10: Version with electronic controller of the Danfoss MTCV valve - C

A PT 1000 thermal sensor must be mounted in the head of the thermometer (19).

The thermal actuator and the sensor are connected to the electronic controller CCR-2, which makes it possible to control an efficient and effective disinfection process in each circulation ascension pipe.

The temperature range of the main control module is 35-60°C. When the disinfection/water thermal treatment process starts, the CCR-2 controller controls the flow through the MTCV valve and the TWA thermal actuators.

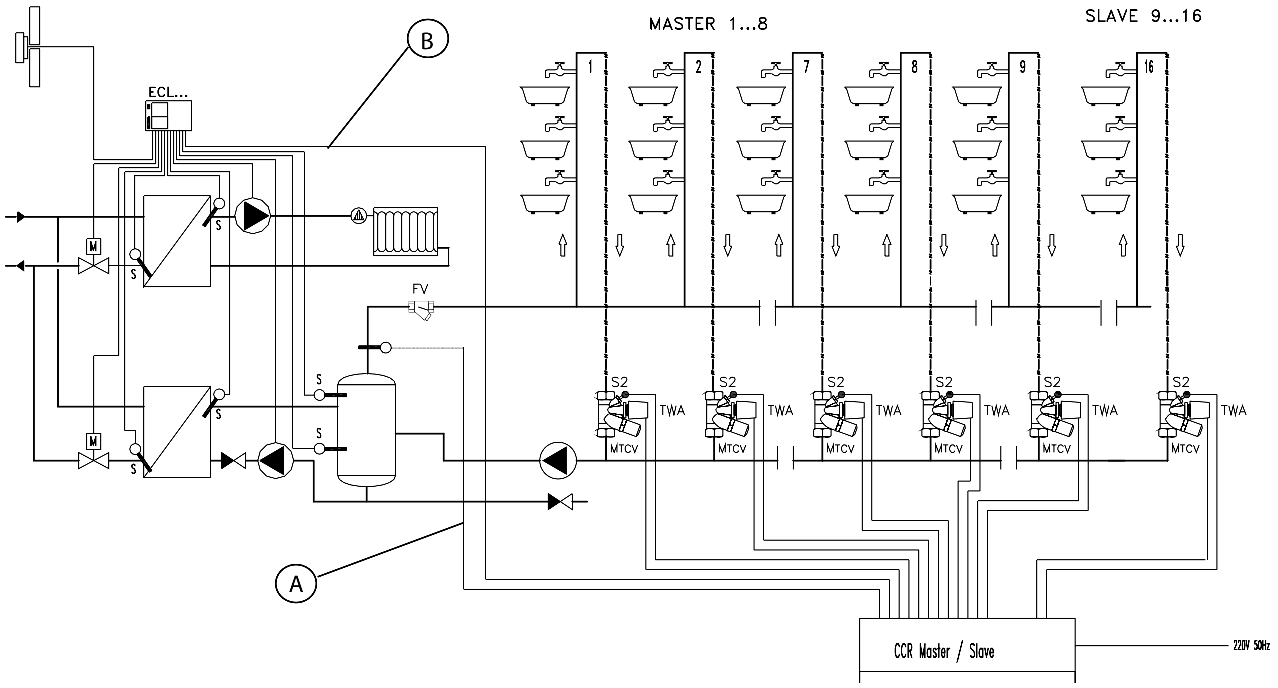


Figure 14-11: Diagram of a system controlled by the electronic controller CCR-2

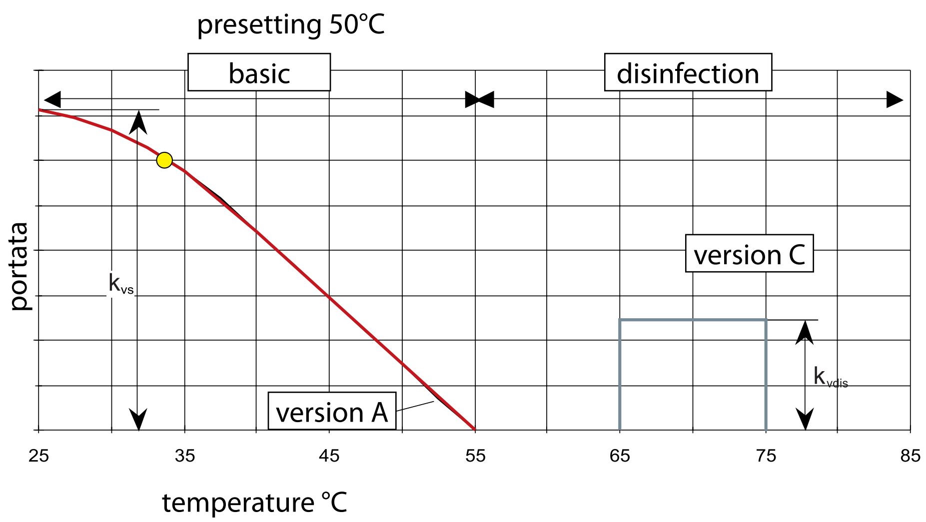


Figure 14-12: Control characteristic of the Danfoss MTCV valve - Version with electronic controller - C

The advantages offered by a disinfection process controlled electronically with the CCR-2 include:

- Total control of the disinfection process in each circulation ascension pipe.
- Optimization of total disinfection time.
- Optional temperature selection for disinfection.
- Optional duration selection for disinfection.
- Online measurement and monitoring of water temperature in each ascension pipe.
- Possibility to connect the controller to the heating substation or the boiler room (e.g., Danfoss ECL) or to a BMS (RS 485).

Calculation of the water flow for the balancing valves MTCV

In the 70s and 80s, the system used to be measured considering the flow required in the recirculating ring, which was calculated considering the loss of heat through the piping starting from the most distant element, so that in this point the preset temperature was always guaranteed.

The disadvantage of this sizing method is that the flow circulating in each pipe is proportional to the nominal consumption of water of all the services in the same pipe. This nominal consumption is the same in both the nearest pipe and the one farthest from the heat exchanger, if the number of related services are the same for each pipe, as often happens in hotels.

It is obvious that heat losses are greater in the furthest ascension pipe, and the water will have a lower temperature in it. The traditional sizing methods do not take this aspect into account and, consequently, the temperature of the water will be different in the different pipes.

The sizing method currently used, however, compensates for heat losses through the pipes.

Heat losses are calculated by taking into account the thermal insulation of the pipes and the difference between the temperature of the rooms crossed by the pipes. Due to heat losses, it is assumed that the temperature drop is within the range of 5 and 10 K, according to the nominal temperature of the hot water.

This method makes it possible to obtain the same water temperature in all the pipes. Furthermore, there is the advantage of managing to reduce the water flow, as illustrated above.

The calculation formulas are shown in Danfoss' technical documentation, along with some very interesting practical examples.

Estimates of obtainable saving

It is not possible to standardise the obtainable energy savings for pumping, because the variables to be considered are many. However, it is possible to indicate credible estimates.

For example, with the water consumption of a hotel like the one taken into consideration in this study, it is possible to obtain a reliable idea of potential savings, assuming that the power of the recirculating pump is equal to 200 W per pipe in the case of a 10-storey building (for different values, a proportion must be made).

The estimated savings are shown according to the number of floors and pipes of the building.

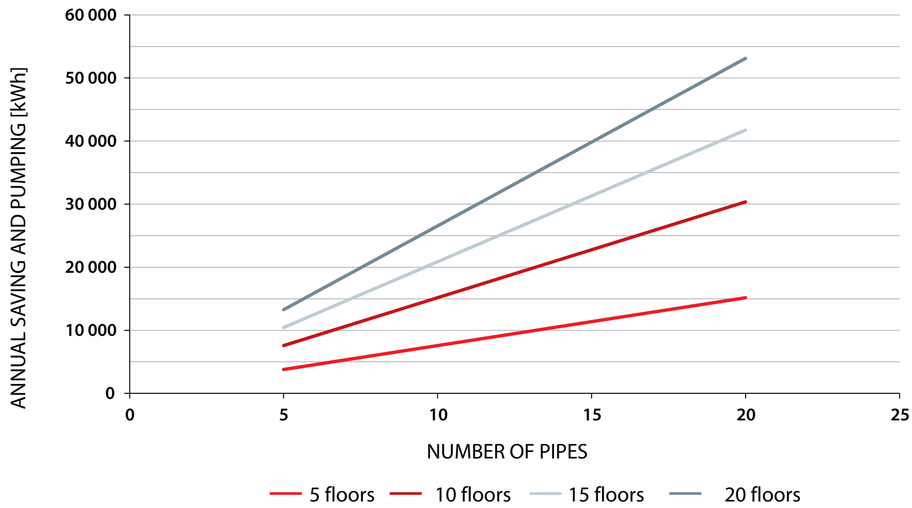


Figure 14-13: Estimated annual energy savings for pumping

It is even more difficult to estimate the saving of methane burned by boilers (or of electricity for heat pumps), because much depends on the climate, the water content of the plant, and the thermal insulation.

The next figure gives an approximate estimate of possible savings in the case of a methane boiler.

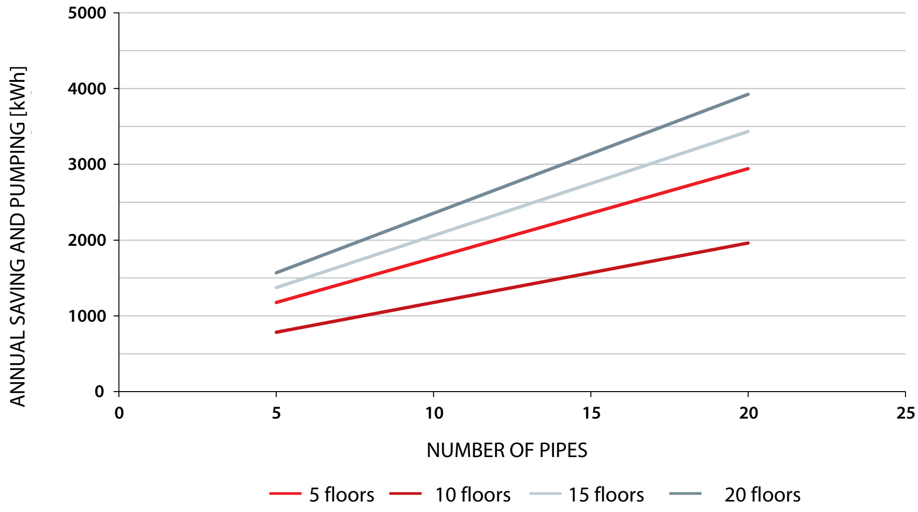


Figure 14-14: Estimate of the annual energy savings consumed by the boiler

Assuming we analyse a 9-storey building with 10 pipes (5 per side), as shown in the graphs in Figure 14-13 and Figure 14-14, the savings that can be obtained are decidedly interesting, equal to about 14,000 kWh/year of electricity and about 1,700m^3/year of methane gas. This is equivalent to obtaining an economic saving of over 3,800 €/year, with costs of return-on-investment of 4-6 months.

Conclusions

In recent years, interesting developments have emerged in the field of recirculation systems of domestic hot water, which have been stimulated by some new needs and trends, including:

- Increase in the cost of producing domestic hot water
- Increase in the cost of water
- High level of reliability required for the supply of domestic hot water
- Quality and hygiene of the water, for example to prevent legionellosis

Danfoss has developed complete solutions for the control of recirculation systems that offer the following advantages:

- Reduction of production costs of domestic hot water.
- Reduction of water consumption due to the time waiting for current water to reach the required temperature
- Equal hot water temperature in all the system's sections
- Possibility of heat thermal disinfection
- Automated anti-Legionella system
- Reduction of the risk of burns during the anti-Legionella disinfection process
- Possibility of monitoring and controlling the hot water temperature during the anti-Legionella disinfection process

The implementation of this new type of valves, in addition to increasing the comfort and quality of the service offered to the guests, has an extremely contained cost and can guarantee important economic savings with a return-on-investment period within on average six months.

Figure 14-15: MTCV balancing valves with CCR2 electronic control unit and TVM thermostatic mixing valve

Chapter 15: Use of new Danfoss compressors

Danfoss has a facility dedicated to the construction of compressors, both for refrigeration and for air conditioning.
For the air conditioning sector, in particular, it offers extremely innovative products, like the scroll compressor, with intrinsic variable volume, and the centrifugal compressor, with magnetic levitation Turbocor.

Volumetric compressors and centrifugal compressors

To better understand the technological innovations proposed by Danfoss, a brief summary is required between the various types of compressors used for both air conditioning and refrigeration.

The compressors are divided into two basic categories, depending on their working principle: volumetric and turbochargers (or dynamic compressors).

The volumetric compressors work according to the Pascal principle of fluidostatic: the variation of pressure occurs because the volume of the compression chamber varies during compression, increasing the refrigerant pressure contained in it.

Centrifugal compressors work according to the principle of conservation of energy: the increase in pressure occurs thanks to 3a change in the momentum of the fluid, exactly like in pumps and fans.

Volumetric compressors differ in turn in two distinct categories: reciprocating compressors and rotary compressors.

This last category includes screw compressors and orbital scroll compressors.

Limits of traditional scroll compressors

The principle of operation of the orbital scroll compressor has been known for over a century, but only in the last thirty years has technical progress allowed to effectively build the components that constitute it with the very small tolerances required by the system.

Figure 15-1 shows how the scroll compressor works. The compression chamber is formed by the space obtained between the profiles of two spirals, one below in eccentric motion, and one above which is fixed.

During a phase of the motion a certain amount of fluid at the pressure of the suction line from the evaporator remains trapped in the volume Va that is formed between two points of contact of the profile of the spirals (blue area in the 1^ orbit). From this point on, compression proceeds through the progressive decrease in volume and the trapped fluid is pushed from the periphery to the centre of the spiral (purple area, fuchsia area), up to volume Vm in correspondence of the outlet in contact with the line of the delivery to the condenser (red area in the centre), after a rotation of 360° of the eccentric element.

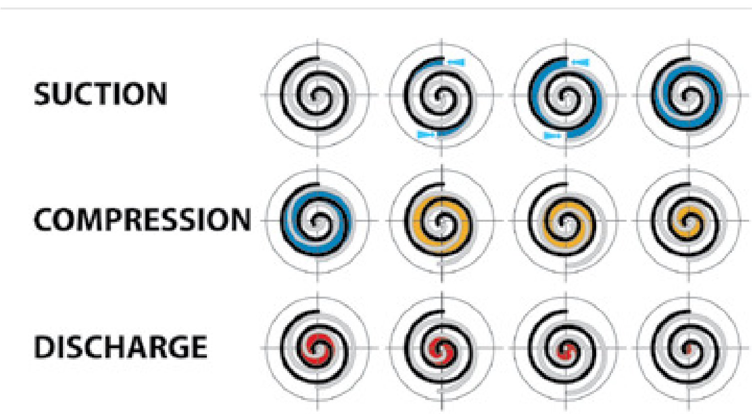


Figure 15-1: Operating principle of the orbital scroll compressor

As you can guess, the system requires minimal machining tolerances, as the two spirals must always remain in contact between each other, to ensure the seal between the different pressure zones, and avoid harmful impacts between their surfaces.

The problem of the seal is solved by the connection system of the rotating spiral to the crankshaft, which allows for a certain backlash: the contact between the two surfaces is maintained by centrifugal force exerted by the mass of the orbiting spiral, designed on purpose to win the maximum compression pressure expected.

The main problem of rotary compressors, both screw and scroll, is not being able to adapt to variations in the compression ratio, that is the ratio between the condensation pressure and the pressure of evaporation shown in Figure 15-2. Indeed, rotary compressors are also referred to as "with fixed compression ratio", to distinguish them from traditional reciprocating compressors "with variable compression ratio".

$$RC = \frac{condensation\ pressure}{evaporation\ pressure} = \frac{pC}{pE}$$

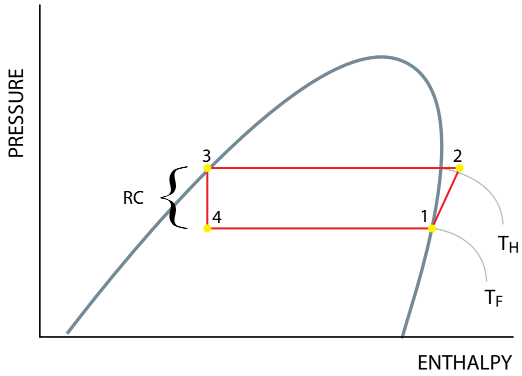


Figure 15-2: Pressure-Enthalpy of the refrigeration cycle diagram

The variation of the compression ratio occurs for climate changes (outdoor air temperature among all), for the temperature of the water produced, and for the functioning in splitting, in the case of several parallel compressors on the same refrigerating circuit: the lower the percentage of thermal load, the lower the compression ratio.

The rotary compressors, both scroll and screw, have an optimised design for a certain compression ratio: this is obtained by sizing adequately the Vm and Va volumes of the compression chamber.

The Intrinsic Volume V_i is defined as the ratio between the volumes V_m and V_a:

$$V_i = \frac{V_m}{V_a}$$

As a consequence, the ratio of the compressor varies with the variation of the compression ratio, based on the optimisation obtained in the project phase. Figure 15-3 shows what happens to three types of different compressors as the compression ratio varies.

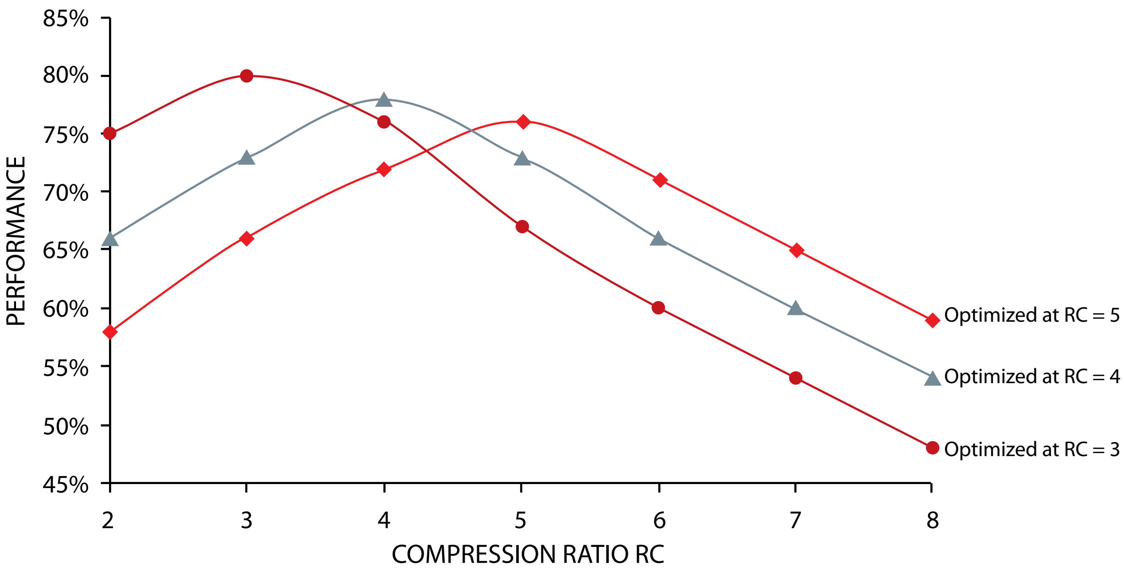


Figure 15-3: Performance of the compressors according to the compression ratio

As you can see, performance is maximum in correspondence of the compression ratio for which they were designed, while it goes down in all other cases.

To better understand the meaning of the diagram, the typical compression ratio of a heat pump in winter ranges from 4.5 in the milder days in splitting to more than 6 in freezing temperatures, while in summer it goes from 4 in the hottest days to 2 in the coolest ones. Therefore, it is impossible to mount a compressor which is ideal in all conditions.

Figure 15-4 shows the reason for performance losses when varying the compression ratio from the design conditions.

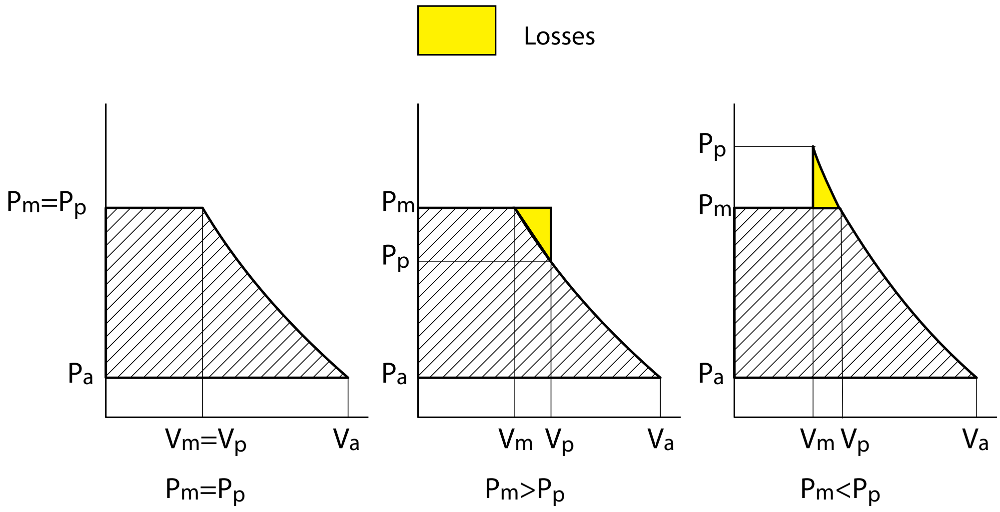


Figure 15-4: Pressure-Volume diagram and compressor losses

Figure 15-4 shows the compression phase in a diagram volume-pressure. In the left diagram, the discharge pressure corresponds to the design pressure, thus the volume change requested corresponds to the intrinsic volume. Compression is ideal without any loss.

In the diagram at the centre, the discharge pressure required is higher compared to that of the project. The refrigerant is compressed up to the volume which is in correspondence with the outlet, at a pressure which is lower than the one in the delivery line. Therefore, there is a return of refrigerant from the delivery towards the chamber of compression: this reflux in practice reduces the volume of the chamber and keeps the compression going until the two pressures are equal. The greater the reflux flow, the greater the difference in flow: in practice, the compressor recompresses twice part of the fluid increasing its work, with a loss equal to that highlighted in yellow.

In the diagram on the right, the discharge pressure required is lower than the design one: the compressor however compresses the fluid up to the opening of the pressure port, doing a greater job (yellow area). The fluid then re-expands inside the delivery conduit.

Scroll compressor IDV with Intrinsic Variable Volume

The scroll technology with IDV (Intermediate Discharge Valves) provides for the implementation of mechanical discharge valves in different points of the compression chamber, so as to vary the Intrinsic Volume and increase the efficiency of the compressor.

The improvement in performance is visible in Figure 15-5: the curve becomes a straight line that unites all the maximum points of the various compressor optimisations.

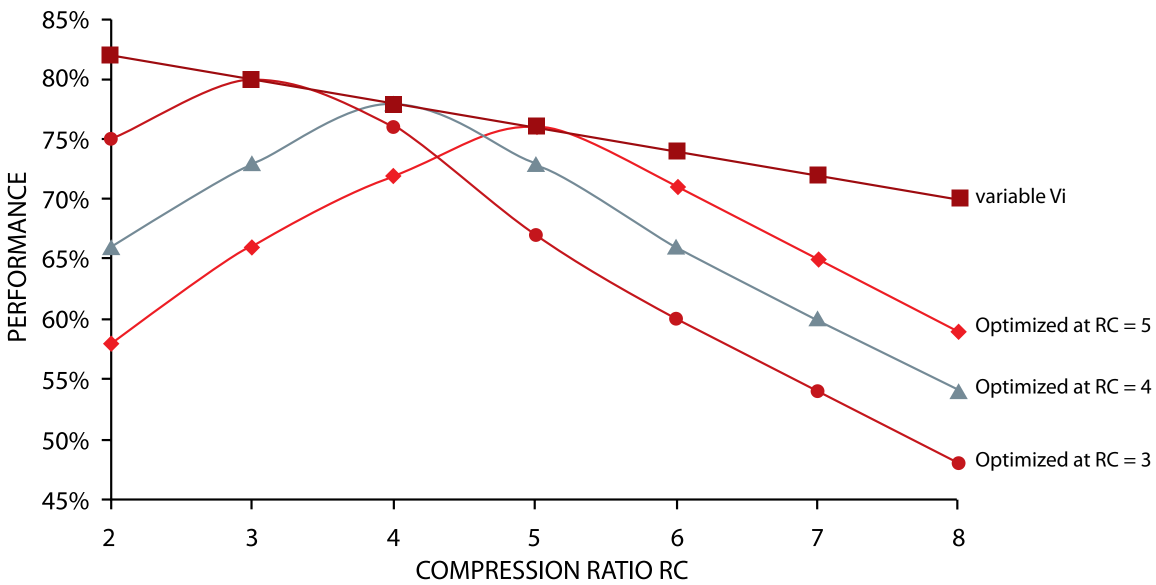


Figure 15-5:Efficiency of the variable intrinsic volume compressor according to the compression ratio

This system basically reduces the compression work when the application does not require all the nominal load, thus adapting, for example, the refrigeration power demand according to the occupation of the rooms and the temperature of external air. In this way, the efficiency of the refrigerating unit is further increased, as refrigeration capacity requirements are met by doing less compression work.

In the following paragraphs, the same conditions used for the simulation related to the building with year 2021 thermal insulation type, dealt with in the previous chapters, have been assumed.

Assuming that a chiller equipped with a scroll compressor IDV is used, it is possible to reduce by a further 7% the electrical consumption of the fridge unit (already supposed in energy class A), which impacts for about 3.6% on energy consumption, reducing by a further

2.7% the relative costs for energy compared to the solution already optimised with variable flow with Danfoss inverter and balancing valves.

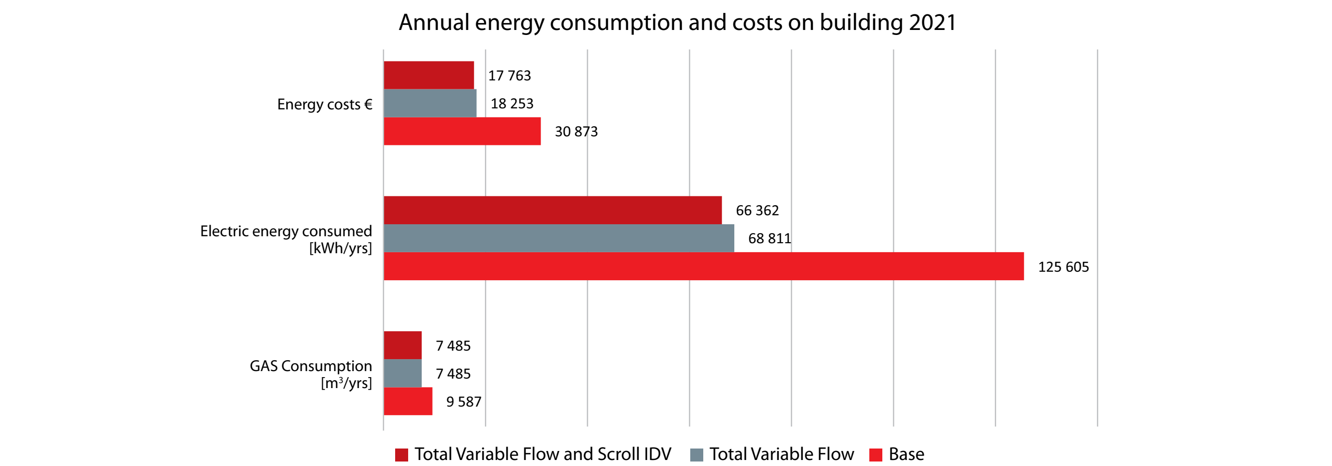


Figure 15-6: Comparison of consumption and energy costs with scroll compressors IDV

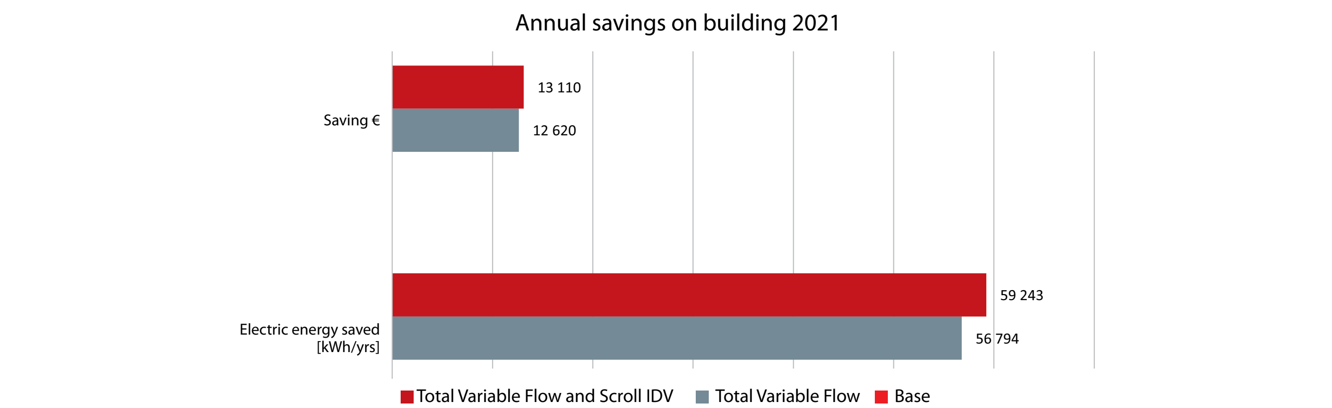


Figure 15-7: Annual savings in building with year 2021 insulation with scroll compressors IDV

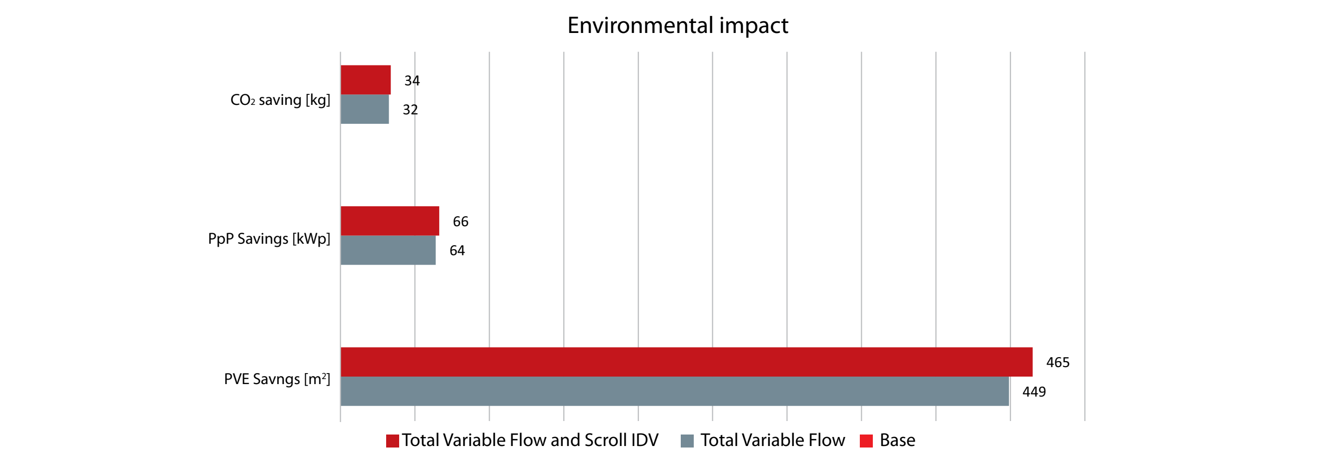


Figure 15-8: Reduction of environmental impact with scroll compressors IDV

The energy and cost savings, as well as the improvement of the environmental impact, derive from the performance of the energy efficiency index (EER) throughout the period of seasonal operation, as shown in Figure 15-9.

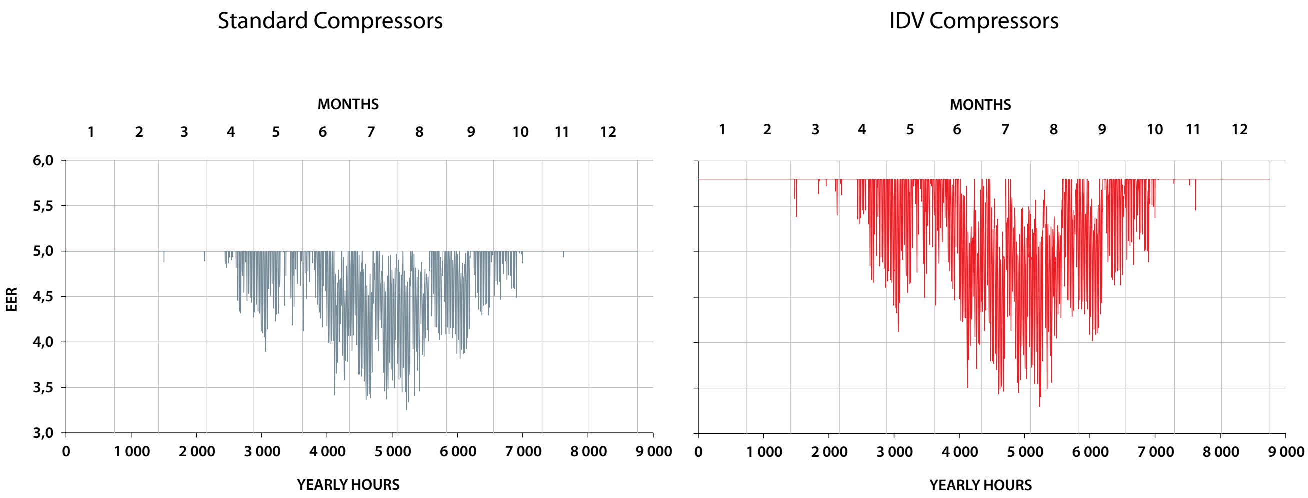


Figure 15-9: Performance of the energy efficiency index (EER) in standard and IDV compressors

As you can see from the graphs, the efficiency of the IDV compressor is always better than that of a traditional scroll compressor.

Greater benefits could even be obtained if the compressors were used in a heat pump, as shows the progress of the coefficient of performance (COP) in Figure 15-10.

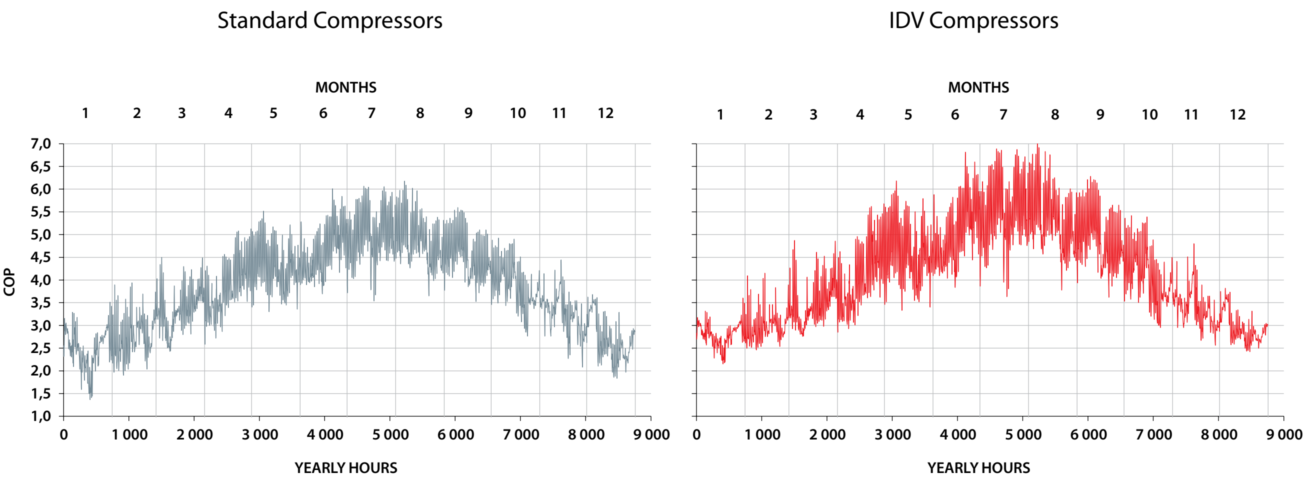


Figure 15-10: Performance coefficient (COP) trend in standard and IDV compressors

Centrifugal turbochargers

Centrifugal turbochargers are dynamic machines whose operating principle is very similar to that of a common fan, and is based on the law of conservation of energy. The distinction between the two categories, fans and centrifugal compressors, is substantially formal, even if some problems increase with the compressors, because of the pressure jumps which are clearly higher.

Figure 15-11 here below shows the rotor of a turbomachine. The speed of the fluid entering and leaving the rotor vane, named by the letter c, consists of two distinct components, a peripheral speed u and a tangential speed w. The peripheral speed u is function of the speed of rotation of the rotor and of the radius thereof, according to:

$$u = \omega r \tag{1}$$

with:

ω - rotation speed
r - radius

The peripheral speed u increases as the radius increases: so it is higher at the exit of the rotor rather than at the entrance.

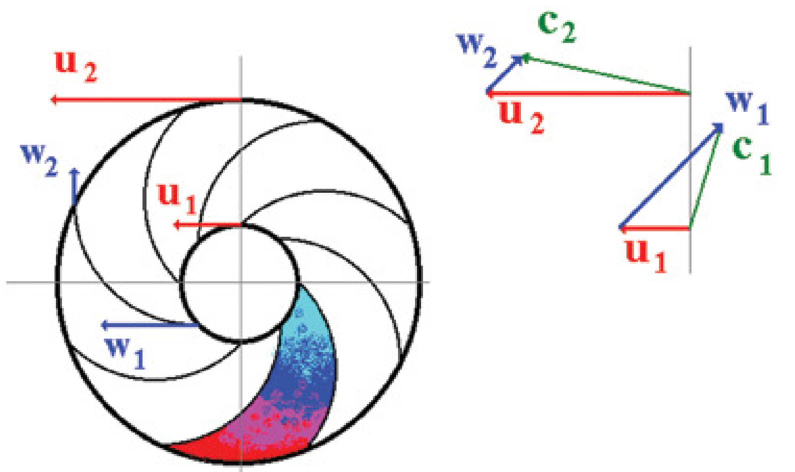


Figure 15-11: Rotor of a turbomachine and velocity vectors

The relative velocity w depends on the flow rate of the fluid and the section of the conduit between the two vanes: since the flow is constant, the speed decreases from the entrance to the outlet of the duct, because the section increases.

Applying the Bernoulli theorem, also considering the effect of centrifugal forces, the pressure jump p obtained between the section of entry and of exit of the rotor is given by:

$$\frac{p_2 - p_1}{\rho} = \frac{u_2^2 - u_1^2}{2g} + \frac{w_1^2 - w_2^2}{2g} = \frac{c_2^2 - c_1^2}{2g} \tag{2}$$

with:

p - fluid pressure

c - fluid velocity

u - peripheral velocity of the fluid

w - relative velocity of the fluid

ρ - fluid density

g - gravity acceleration

1 - conditions at the rotor's entry

2 - conditions at the rotor's exit

Therefore, with centrifugal compressors, to get high flow and/or high pressure jump, either the diameter is increased, or the number of revolutions is increased.

While in volumetric machines, the pressure variation is the result of a decrease in the volume of the chamber of compression, in turbomachines, the pressure increase is given by the variation of the kinetic energy of the fluid current.

Centrifugal turbochargers have an operating curve which is absolutely similar to that of fans.

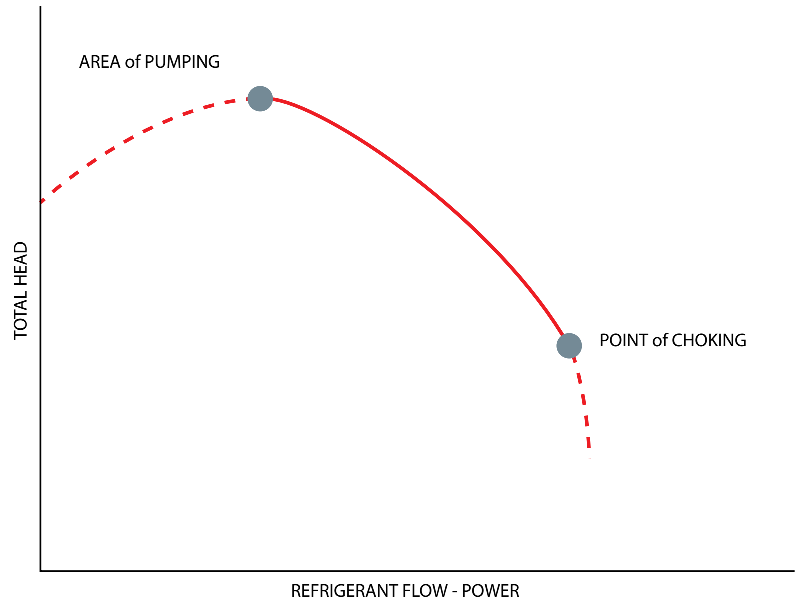


Figure 15-12: Characteristic curve of centrifugal turbochargers

In the part of the continuous line curve, the operation is stable: when the condensation pressure decreases, thus when the required pressure jump drops, the flow rate of the fluid increases. As a consequence, its output speed also increases. If the speed equals that of sound (Mach number = 1), the mass flow rate stabilises, and does not increase anymore, even if the pressure decreases further. The point of the curve where these critical conditions occur is called chocking point: the part of the curve to the right of this point (higher flow rates) is, in fact, unreachable.

Like every other condition, the more the chocking point is moved towards higher flows, the greater the speed of the sound of the fluid. As an indication, for evaporation pressures commonly used in air conditioning, sound speed in the R134a refrigerant is about 45 m/s [4].

At low flow rates, there is a second zone of functional instability, probably the most important, called surge. As seen in Figure 15-12, the pressure generated increases as the flow rate decreases, to a maximum point, and then decreases. There is, therefore, an area where an identical pressure of operation corresponds to two different flow rates (dots on the right and left of the maximum).

Assume that the work point is on the area to the left of the maximum: if the pressure decreases, the dot should move to the left, by reducing the flow. Instead, it can happen that the condensation pressure, due to the compressibility of the fluid, or to other reasons, decreases less quickly than the pressure generated by the machine does: a reflux towards the compressor is thus induced, with consequent cancellation of flow. In these conditions, the condensation pressure decreases, and the flow becomes positive again; at this point, however, the condensation pressure increases again, and the cycle repeats itself. Pumping, therefore, forces to limit the operation of the compressors to the stable area only.

Adjustment of power at constant rpm

At constant revolutions, the adjustment of centrifugal turbochargers occurs by changing the angle of incidence of the incoming refrigerant, by means of pre-rotation vanes placed at the entrance of the rotor.

At full opening, these vanes have the task of conveying the refrigerant in order for it to be tangent to the rotor blades, so as to minimise load losses for incidence.

The wording "pre-rotation" comes from this task.

For the same inclination of the pre-rotation vanes, the condition of tangency between the fluid particles and the vanes only remains for a functioning condition, generally the nominal one.

The vanes' action changes the velocity triangles by changing the refrigerant flow rate, thus the power supplied.

Figure 15-13 shows the curves of a traditional centrifugal turbocharger when the angle of inclination of the vanes varies (in red), and the respective equidistant efficiency curves (in blue). As you can see, the splitting system is energetically penalising. The modification of the incidence angle leads to a decrease of the compressor performance, the more pronounced, the lower the required power with the same total head.

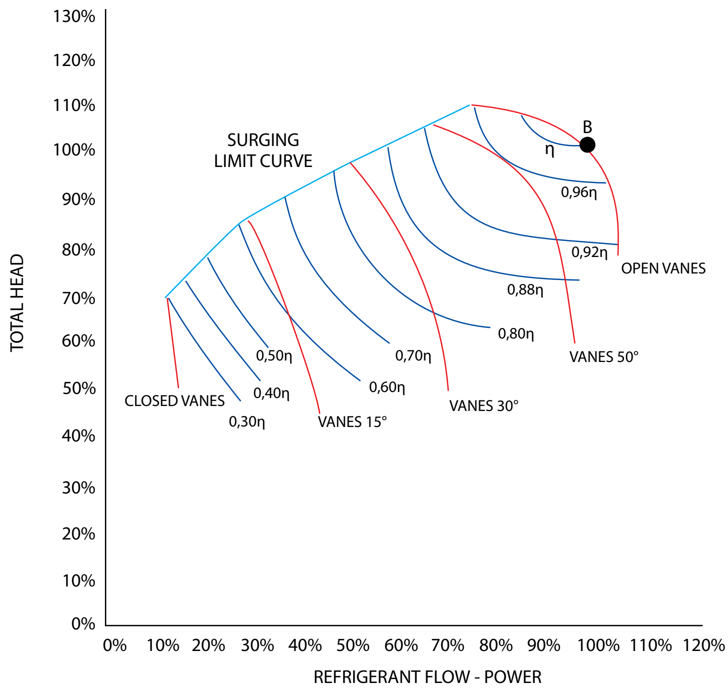


Figure 15-13: Characteristic curves of a traditional centrifugal turbocharger when the angle of inclination of the vanes varies

The control system with pre-rotation vanes does not eliminate the surging phenomenon. For equal total head, the adjustment of the cooling power supplied can take place up to a certain percentage, beyond which the surging phenomenon is grafted anyway. For even lower powers, for equal total head, other splitting systems must intervene, such as the On-Off of the compressor or, better, with a refrigerant bypass between delivery and suction, as generally required by centrifugal compressor manufacturers.

Centrifugal turbochargers: performance when revolutions vary

As for all other turbomachines (also for centrifugal compressors), the flow (therefore the power supplied) and the total head are directly proportional to the number of revolutions respectively, and to the square of the number of revolutions N, according to the known laws of engineering similitude:

$$Q = f(N) \qquad H = f(N^2)$$

As the speed of rotation decreases, the curves of the centrifugal compressors flatten, as shown in Figure 15-14. High total heads can be obtained only by increasing the rotation speed, limiting the power attainable.

The curve at 110% of the revolutions reaches the zone of chocking from about 108% of the refrigerant flow, as evidenced by the almost vertical curve section.

The surging limit curve delimits the stable operating zone. Surging starts with refrigerant flows that are even lower, as the total head required lowers and, consequently, the number of N revolutions of the compressor. In the example in Figure 15-14, surging starts at about 75% of the flow with N = 100% and at 18% of the flow for N = 70%.

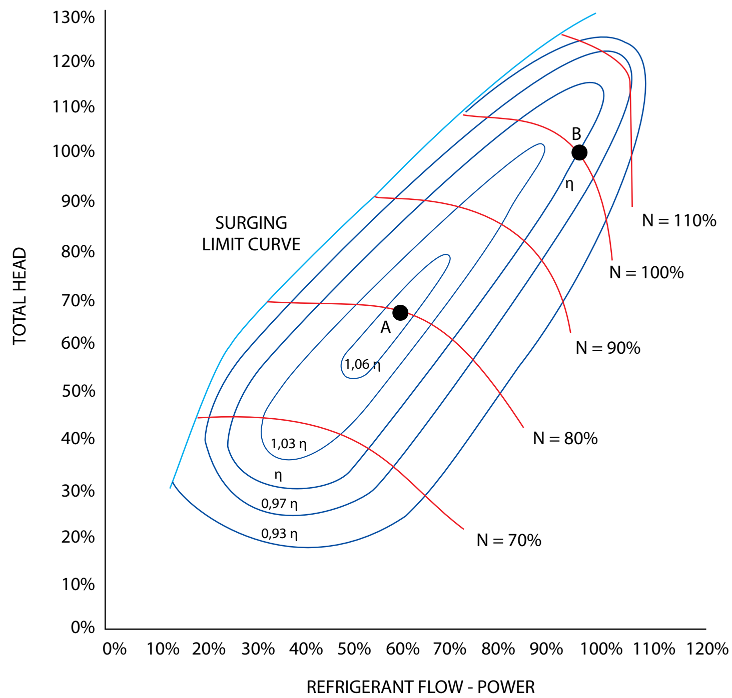


Figure 15-14: Characteristic curves of centrifugal compressors

Figure 15-14 also shows the equidistant efficiency curves. Energy losses in a turbomachine are to be attributed to the following factors:

1. continuous friction losses along the stator ducts and in the scroll: they vary with the square of the flow
2. incidence losses in the scroll and at the mouth of the rotor: they depend on the velocity triangles and are void with the design nominal flow of the pump
3. reverse flow through sealing clearance: decrease as the total head decreases
4. ventilation losses: decrease with the cube of rpm.

In addition to these factors, the efficiency of the electric motor and of the inverter's performance must be taken into account.

Incidence losses represent the largest share and increase as we move away from the nominal project flow rate, while all other losses decrease as the number of revolutions decreases. When the number of revolutions decreases, the efficiency improves the more the points with loss for null incidence are approached.

Point A, where performance is maximum, does not reach on the curve 100% of the number of revolutions, but at lower rotation speed and for an operating point far from the nominal project one B.

In Figure 15-14, point A is obtained with flow rate Q = 60% and total head H = 68% compared to the project values (point B with Q = H =100%).

The highest performance points are found in the central sectors of the curves, just where incidence losses decrease. Therefore, the performance of a centrifugal turbocharger does not only vary with the refrigerant flow rate, therefore with the power supplied, and with total head, but also according to the position of the point of operation along the curve.

When the operating point is on the surging limit curve, the power adjustment by varying the number of revolutions of the compressor can no longer take place. Therefore, control with pre-rotation vanes intervenes, in sequence.

The intervention of the pre-rotation vanes changes substantially the curves and moves the starting area of surging towards lower powers (to the left), without completely eliminating it. The area in which there is an adjustment with fixed revolutions with intervention of the pre-rotation vanes is highlighted in grey in Figure 15-15.

For even lower powers, for equal total head, other splitting systems must intervene, like the On-Off of the compressor or, better, with a refrigerant bypass between delivery and suction, as generally required by centrifugal compressor manufacturers (green area of Figure 15-15).

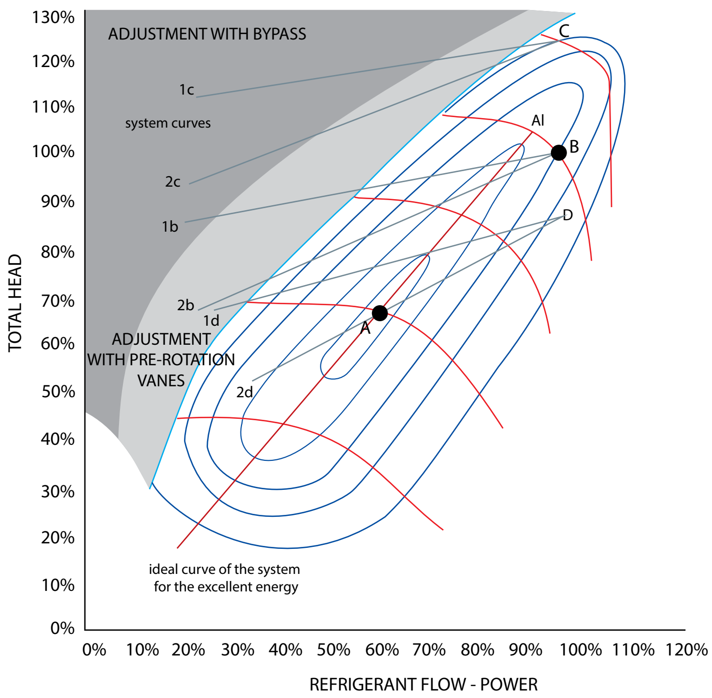


Figure 15-15: Type of power regulation according to the system's curves

Optimum operation of a centrifugal turbocharger with inverter

From the foregoing in the previous paragraphs, the ideal condition of operation of a centrifugal compressor would be obtained if the operating curve of the refrigerating unit system plant were the ideal one (fuchsia curve in Figure 15-15). This curve touches all points of maximum performance, i.e. the points of operation where incidence losses are minimal.

On the contrary, a refrigerating unit system plant whose curve lay almost completely in the grey and green areas, i.e. those with low efficiency for the splitting system with fixed revolutions used, would be extremely inefficient.

Summing up in a simple and concise way, a centrifugal compressor, continuously adjusted on the number of revolutions by means of an inverter, works well if the required power variation matches also a variation of total head, such as to maintain the curve of the system to the right of the grey area, possibly keeping it in the areas with higher performance.

The condensation temperature depends on (all other conditions being equal):

- Environmental climate conditions: the lower the condensation temperature, the lower the temperature of the thermal source, air or water, and the humidity of the outside air (only in the case of evaporative condensation)
- Type of heat exchange: if water is used as a vector fluid of the exchange, or even air via an evaporative condenser, lower condensation temperatures are obtained compared to the use of air alone in a sensible condenser only
- Condenser geometry: greater exchange surfaces result in lower condensation temperatures
- Refrigerant flow in the condenser: when flow rates decrease, the condensation temperature is lowered.

Therefore, the condensation temperature decreases linearly as the required power decreases.

The condensation temperature depends then exclusively on the conditions of the refrigerating unit system plant (power required) and on weather conditions. It is not possible in any way to intervene to modify the curves of the refrigerating unit system plant.

In the power-total head scheme of Figure 15-14, the system curves draw, starting from every point, an infinite bundle of lines from various angles.

Savings obtainable by using the inverter

Figure 15-16 briefly summarises an indication of savings obtainable by using an inverter. The greater savings the lesser power and total head.

The reduction of power always involves a reduction of total head, because the refrigerant flow is reduced and, therefore, the temperature and condensation pressure. However, the reduction depends considerably on the temperature of the thermal source (air or water). If the splitting takes place at the almost constant temperature of the source, the advantage of using the inverter is limited.

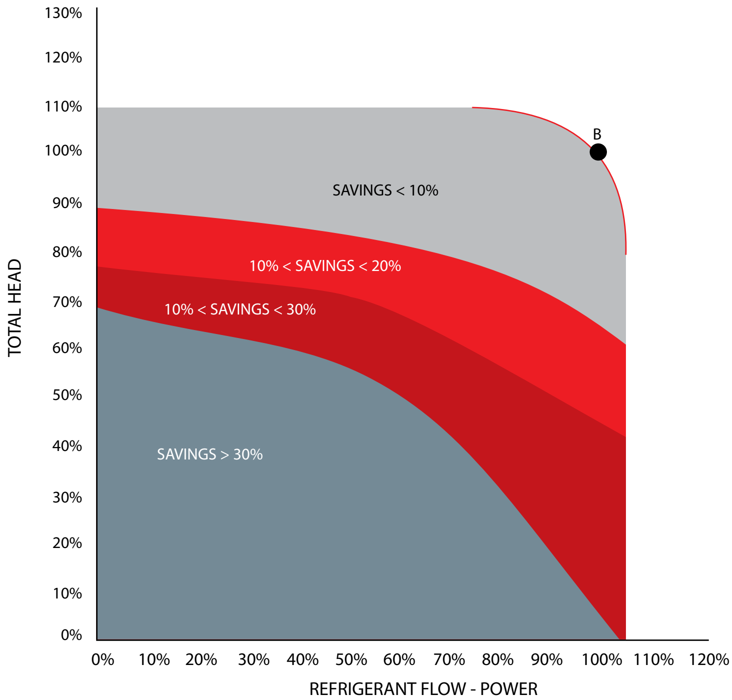


Figure 15-16: Savings obtainable with the inverter according to the required power and total head

The Turbocor® compressor

The Danfoss Turbocor® compressor is the main technological innovation introduced in the compressor sector of the last 15 years.

Figure 15-17 shows a cutaway of the compressor.

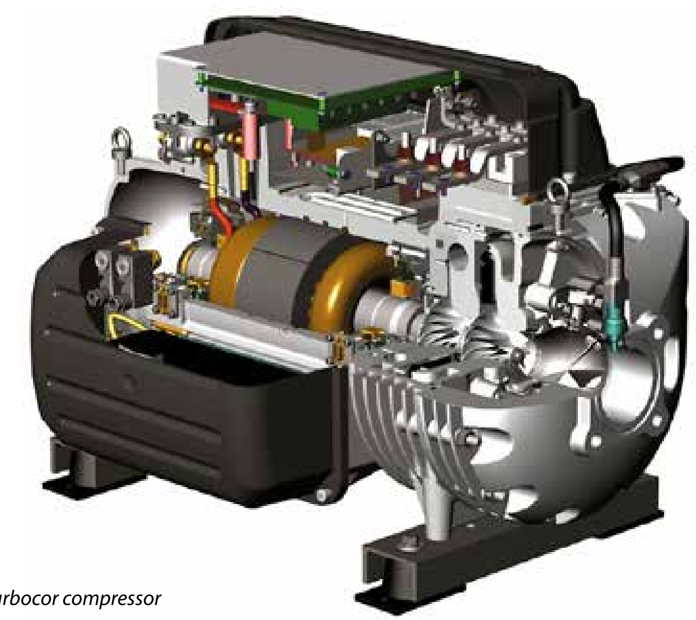
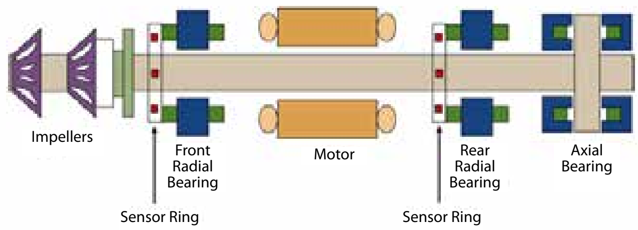


Figure 15-17: Cutaway of the Turbocor compressor



The support system, with magnetic suspension bearings, makes it possible to work at high rpm (over 40,000 revolutions/minute), in order to consistently reduce the dimensions of the rotor, and of the whole compressor. The weight and the size are very limited compared to traditional screw or centrifugal compressors of equal power.

The system makes it possible to work oil free.

This allows two important results to be obtained from the point of view of energy efficiency.

On the one hand, the efficiency losses of the exchangers due to the presence of oil are reduced by about 9%, as shown in Figure 15-18.

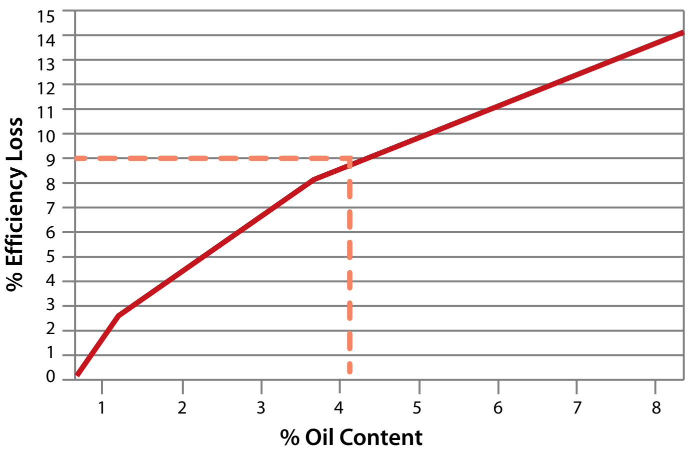


Figure 1: Percent efficiency loss

Figure 15-18: Loss of efficiency of the exchangers according to the amount of oil

On the other hand, the compressor can work with any jump of pressure, unlike traditional compressors, scroll, screw and alternatives, which need a minimum of pressure jump between condensation and evaporation to guarantee lubrication.

Therefore, the efficiency of the system greatly improves, above all at partial loads, as shown in the following figure.

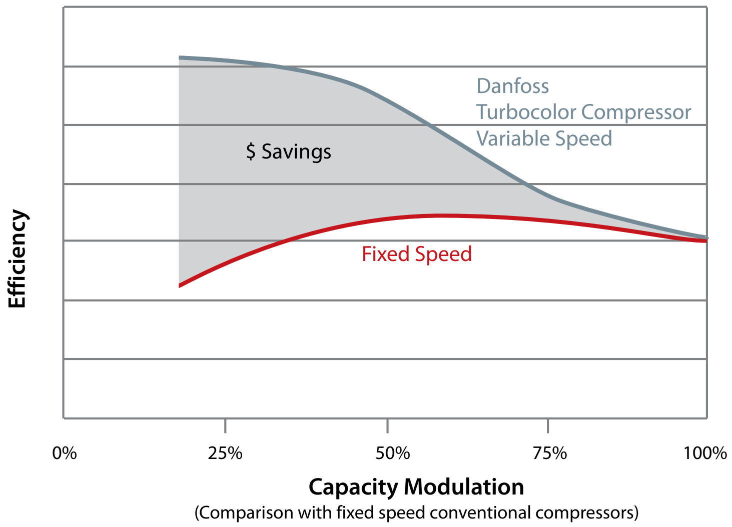
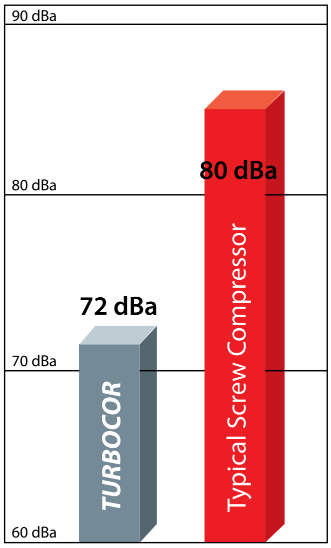


Figure 3: Frictionless design is more efficient over entire range

Furthermore, the Danfoss Turbocor compressor is very silent.



Take the simulation for example related to the building with thermal insulation 2021 dealt with in the previous chapters. Assuming a chiller equipped with Turbocor compressor is used, it is possible to reduce electricity consumption of the refrigerating unit by a further 20% (already assumed in energy class A), which impacts more than approximately 10% on energy consumption, reducing by a further 8% the related costs for energy, compared to the already optimised solution with variable flow rate with inverter and Danfoss balancing valves.

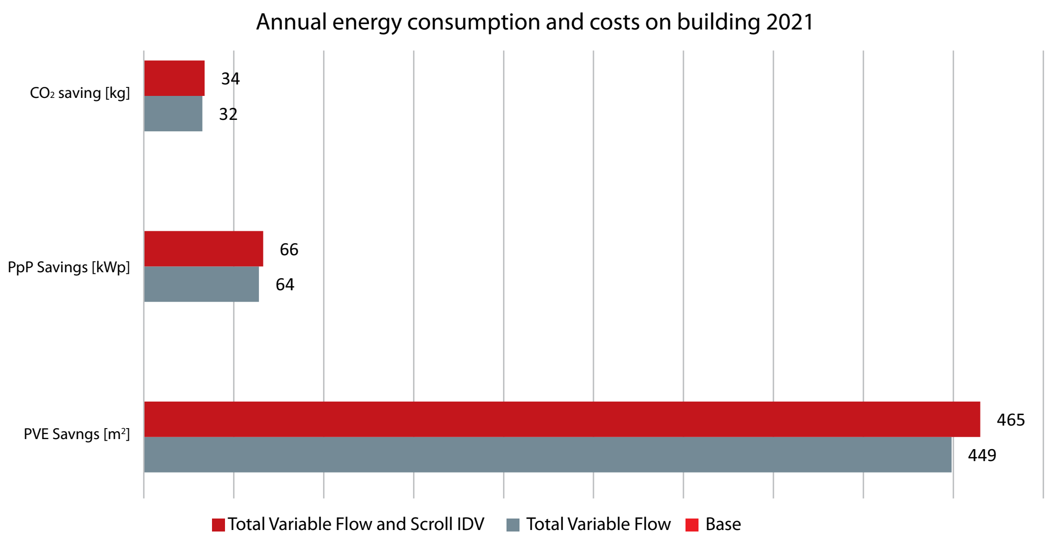


Figure 15-19: Comparison between consumption and energy costs with Turbocor compressors

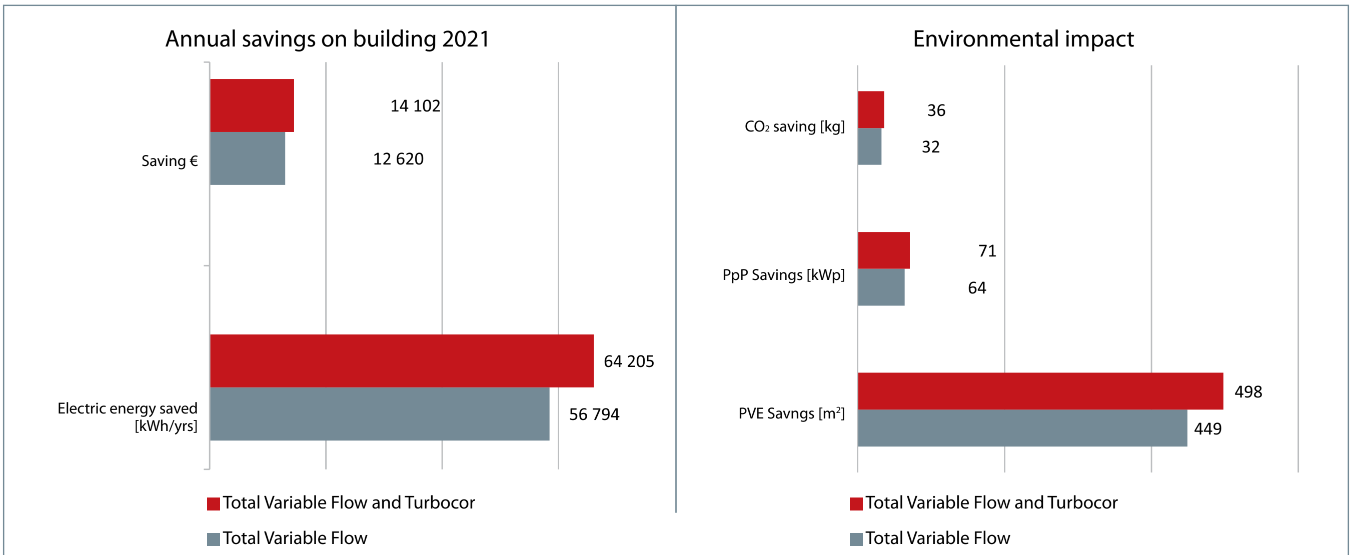


Figure 15-20: Annual savings and environmental impact reduction in building with year 2021 insulation with Turbocor compressors

The improvement of energy saving and environmental impact happens because the efficiency of the Turbocor compressor is far superior to that of a traditional scroll or screw compressor, as shown in the following figure.

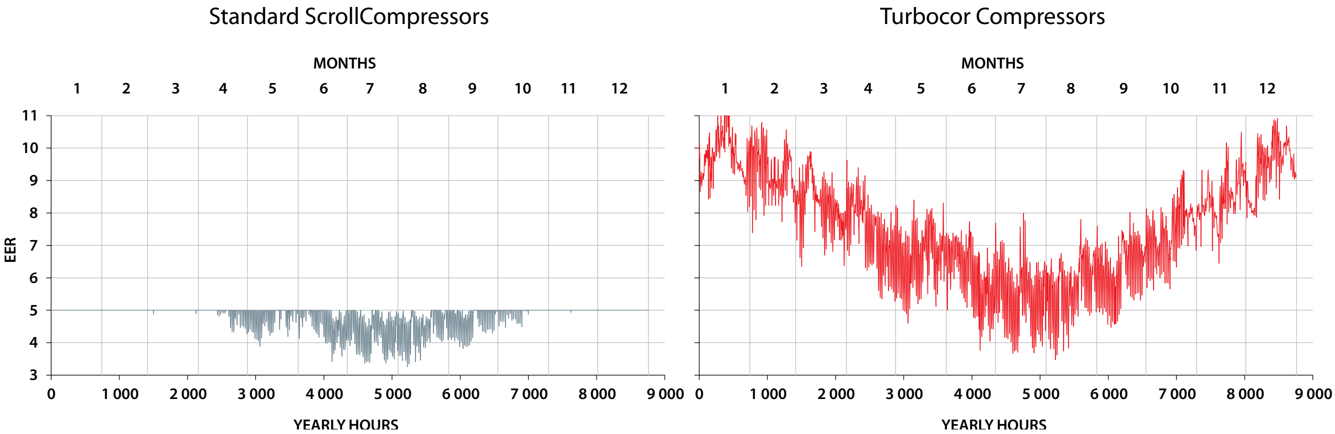


Figure 15-21: Performance of the energy efficiency index (EER) in standard scroll and Turbocor compressors

Conclusions

Modernising equipment, such as the refrigerating unit, even if it is not an intervention that brings more savings on energy consumption, may however still be a correct choice. This is both because an old machine can result in high maintenance costs, and because the regulations on the subject of environmental impact are becoming more and more restrictive. Tax breaks on the purchase of high-efficiency machines with low GWP refrigerants incentivise the purchase of new high-efficiency machines, with new low environmental impact refrigerants.

In this case, it is important to consider which technology is present inside the fridge group. For the same energy class, some machines may still be more efficient than others.

One of the most important components of the refrigerating unit is without a doubt the compressor. In the case considered, the use of centrifugal compressors Danfoss Turbocor® or Danfoss Scroll IDV compressors can further reduce the total energy consumption of the HVAC plant by about 8% and 3% respectively, compared to a machine of the same energy class, but with traditional scroll compressors.

Chapter 16: Efficiency improvement of cold food management installations

The zone of the kitchens impacts for, on average, at least 10-11% on total energy costs. Storage and food conservation are included in this context.

The latter, although not the most critical from the energy consumption point of view, is still important to consider, both because it is still possible to intervene to make systems more efficient, and because proper food storage is important for the quality and satisfaction of the service offered to the guests, a factor that has a very strong impact on the image and reputation of the hotel.

It should also be considered that poor cold food management has also a negative impact on operating costs, for example it causes food waste.

Danfoss has historical experience in the management of the cold food chain, proposing technologically advanced solutions for conservation, management and real-time monitoring of food, including reporting regarding HACCP regulations.

Given the size of the hotel and restaurant considered in this analysis, we assumed a total volume for cold rooms equal to 108m^3, assuming 2 m^2 for low temperature (for example, two cells of 12m^2 each) and 30m^2 for medium temperature (for example 3 cells of 10m^2 each) for 3.6m height.

The hypotheses considered in the simulation are the following:

	MBT	LBT
Cell size	5x2x3,6 m^3	6x2x3,6 m^3
Type of products frozen	Mix	Mix congelati
Outdoor air temperature	26 °C	26 °C
Daily occupancy/exchange	65%/40%	60%20%
Cell relative humidity	80%	80%
External air relative humidity	55%	55%
Daily operation	17,3 h	17,1 h
Door opening	regular	regular
People presence	2 h/day	2 h/day
Defrost	Electric 3 times/day x 30’	Electric 3 times/day x 30’
Tot additional loads (lights, fans, defrost, people)	973,6 W	1.554 W
Single cell refrigeration power	3.121 kW	1.946 kW

The total cooling power required by the cells is therefore equal to 10.26 kW.

Danfoss can offer a complete and technologically superior solution that includes expansion valves, cell control and detectors, condensing units and monitoring.

Precise overheating control gives the opportunity to make the most of the evaporator, maximizing the thermal exchange surface. It is possible to work with 4-5K of SH less than the average, which alone mean 12-15% of energy savings.

The condensing units comply with the EcoDesign 2018 directives and are ASERCOM certified and have a high SEPR coefficient (3.84 with R407F) which significantly reduces power consumption. The microchannel condenser technology minimizes refrigerant gas use and the technology with inverter compressor minimizes consumption, always working according to the required load and thereby reducing the electrical consumption of the compressor.

The intelligent algorithms of the thermostats manage defrosting based on real needs, monitoring the temperature variation of the evaporator.

Through a continuous and correct monitoring of temperatures and of alarms, correct management of cold food is obtained, which translates into a guarantee of high-quality food and less waste.

Even the safety of people is guaranteed thanks to the electric cables to prevent the formation of ice.

The high quality and reliability of Danfoss reduces maintenance costs to a minimum.

Using a condensing Danfoss OptymaPlus™ Inverter, compared to a machine with SEPR average market performance equal to 2.5, about 169 €/year can be saved for each kW of cooling capacity, which in the case in question results in around 1.7 k€/ year, a value equal to approximately 5-7% of energy costs related to the kitchen/restaurant area.

Chapter 17: Conclusions

In the hospitality industry, reaching targets of high energy efficiency is not only an obligation imposed by regulations (under the EU's Energy Performance of Buildings Directive, all new buildings must be nZEB [Nearly Zero Energy Building] from 2021), but also a genuine commercial opportunity to stand out as an environmentally friendly facility in front of its customers. And energy efficiency represents an even greater opportunity to reduce one's own operating costs, with an investment that has very short return times, provided you know how to choose the most effective lines of intervention, based on the features of your hotel.

The technical systems dedicated to air conditioning, ventilation, production of domestic hot water and refrigeration represent a real and substantial hidden opportunity, to be discovered and exploited to your advantage, both in the construction of new buildings, and in the restructuring of existing facilities.

Technical installations that absorb less energy with equal comfort mean they can drastically reduce the demand for energy to be generated in-situ, or to be acquired from other sources. To facilitate the comparison between the various opportunities of energy efficiency improvement, it is very useful to resort to a simple parameter understandable by anyone (which has been identified in the 'equivalent photovoltaic surface'). In substance, every 1,000 kWh/year saved on consumption of technical installations is equivalent to about 7m^2 of solar panels to install on the hotel to be equally eco-friendly.

In the case of purely vertical building developments, typical case of hotels located in art heritage cities, or restructuring of buildings in the historical centres, finding suitable spaces for the installations of the solar panels often becomes impossible. Therefore, the investment in highly efficient technical systems become the only viable solution, at competitive costs, to achieve the goals of energy self-sufficiency of the hotel structure.

To improve the energy efficiency of a hotel, you can basically follow three lines of intervention: make the equipment of the technical installations already installed more efficient; improve the thermal insulation of the building; and use technologically more advanced solutions in technical installations.

All three lines of intervention can potentially bring benefits, but they are quantitatively different according to the starting conditions of the structure, the type of existing building and the age of the existing equipment.

However, the detailed study reported in the previous chapters has unequivocally proved that the line of intervention which is more advantageous in economic terms, and which offers faster return-on-investment, is in any case that of using technologically advanced solutions in technical installations.

The most profitable choice is to move to variable flow plants for the circulation of hot water for heating and of air for cooling. Intuitively, it is easy to understand how guest comfort does not depend on how much air or water circulates for 24 hours a day in pipes and ducts. On the contrary, to satisfy the guest, it is sufficient that the water and the air circulate in the right quantity and, above all, at the right time, both in the rooms, and in the common areas, based on the relative occupancy rate.

By choosing technical installations with variable flow rates you can guarantee that guests experience increased levels of comfort, thanks to the greater possibility of personalised adjustment at the rooms, and that the manager of the structure benefits from improved profitability, thanks to the possibility of optimising energy consumption, based on the status of occupancy of the premises.

The choice of exploiting technologically advanced solutions with variable flow proved equally effective also for the domestic hot water system, which has a significant impact on the total energy consumption of a hotel.

From a technical and economic point of view, taking action to modernise existing systems, by means of pressure-independent dynamic balancing valves, and with inverters on pumps and fans, is the best solution, and offers several advantages, compared to, for example, replacing equipment, or structural interventions on the insulation of the building.

Annual energy savings on gas and electric energy consumption for heating and cooling by renewing the plants with technologically advanced solutions are much higher than those obtainable with traditional solutions, reducing electricity consumption by up to 50%, and gas consumption by up to 30%.

Furthermore, in the case of renovations of existing structures, it is generally possible to carry out renovation works of the plants without total service interruptions for hotel guests, as the work can be undertaken on single floors or rooms, in conjunction with other planned maintenance or modernisation interventions.

However, the components available on the market to achieve technical installations are not all the same. The choice of a technologically advanced balancing valve, of a very high efficiency inverter, or of a refrigerating unit compressor with optimised performance, has considerable influence both on the economic result achievable in terms of return-on-investment, and on the degree of long-term reliability of the plants.

Equally important is the design approach, which must be able to take into account the specificities of each individual structure, of its position on the territory, its orientation, the state of structural insulation, and any mandatory technical and regulatory constraints which must be respected.

A company such as Danfoss, with proven decades of expertise in both the design and construction of technologically advanced components for technical installations, and in joint planning with customers of plant solutions with fast economic returns, is an ideal candidate to guide you to discover the opportunities hidden in your hotel.

Index of figures

Figure 3-1: Trends in heating and cooling requirements for north and south facades 10
Figure 3-2: Annual heating and cooling requirements for north and south facades without endogenous loads....10
Figure 3-3: Annual heating and cooling requirements for north and south facades with endogenous loads....11
Figure 3-4: Trends in heating and cooling requirements for the north facade without and with endogenous loads....11
Figure 3-5: Trends in heating and cooling requirements for the south facade without and with endogenous loads....12
Figure 4-1: Trend of solar gains with north-south and east-west orientation....13
Figure 4-2: Energy requirements based on orientation 13
Figure 4-3: Energy requirement trend based on orientation 14
Figure 4-4: Requirement difference between north-south and east-west orientations 14
Figure 5-1: Annual energy requirement based on the type of insulation and orientation 15
Figure 5-2: Energy requirement trend with north-south orientation and years 2010 and 2005 insulation types....16
Figure 5-3: Energy requirement trend with north-south orientation and years 2010 and 2021 insulation types....16
Figure 5-4: Energy requirement trend with east-west orientation and years 2010 and 2005 insulation types....17
Figure 5-5: Energy requirement trend with east-west orientation and years 2010 and 2021 insulation types....17
Figure 6-1: Power required by the air handling with regenerator....18
Figure 6-2: Influence of the regenerator on energy consumption....18
Figure 6-3: Power required to terminals based on the temperature of the air supplied....19
Figure 6-4: Total power required to the generators....19
Figure 7-1: Temperature trend in the north and south-facing rooms....21
Figure 7-2: Temperature trend in the east and west-facing rooms 21
Figure 7-3: Total building requirement based on the required room temperature 22
Figure 7-4: Increased power and energy required to maintain 23° in the room all year long....22
Figure 8-1: Load on the air handling unit batteries 24
Figure 8-2: Trend of fan-coil load in heating....24
Figure 8-3: Trend of fan-coil load in cooling 25
Figure 8-4: Performance of the power to be supplied to the hot and cold circuits 25
Figure 8-5: Characteristic Power-Flow curve 26
Figure 8-6: Characteristic Power-Flow curves for different inlet water temperatures....26
Figure 8-7: Circulation in the coil with a 3-way valve and a 2-way valve 27
Figure 8-8: Flow rate trend in hot and cold circuits 27
Figure 9-1: Circuit and characteristic curve without adjusters 29
Figure 9-2: Circuit and characteristic curve in the presence of a 2-way valve....30
Figure 9-3: The efficiency of the constant pressure pump remains at very similar values in the three operating points 30
Figure 9-4: If the total head decreased along the grey line, the power required by the pump would decrease....31
Figure 9-5: Power required by the pump with constant total head and variable total head 31
Figure 9-6: Characteristic water Flow-Power output of a fan coil....32
Figure 9-7: Flow-Power of the valve curve (left) and Flow-Signal of the obturator curve (right)....32
Figure 9-8: Linear characteristic between the valve opening signal and the power output....32
Figure 9-9: Power output-load Loss diagram 33
Figure 9-10: Difference in constant pressure and flow with a three-way valve, difference in pressure which varies with the flow with a two-way valve.....33
Figure 9-11: Hydraulic circuit with 4 identical terminals....34
Figure 9-12: Pressure trend in the circuit with 4 identical terminals and calibration valves....34
Figure 9-13: Speculated load variation in the hydraulic circuit with 4 identical terminals, from the first to the last the load increases 34
Figure 9-14: Pressure in the hydraulic circuit with 4 identical terminals with 2 and 3-way valves 35
Figure 9-15: Circuit with 3-way valve and load variation....35
Figure 9-16: Circuit with 2-way valve and load variation....36
Figure 9-17: Pressure trend in the circuit with 3 and 2-way valves and uniform loads....36
Figure 9-18: Pressure trend in the circuit with 3 and 2-way valves and differentiated loads 37
Figure 9-19: Power-pressure Jump diagram with 3 and 2-way valves....37
Figure 9-20: The battery power output based on the opening of the 3 and 2-way valve 38
Figure 9-21: Speculated load variation in the hydraulic circuit with 4 identical terminals, from the first to the last the load decreases 38
Figure 9-22: Pressure trend in the circuit along the decreasing loads....39
Figure 9-23: Characteristic Power-ΔP and Valve Opening-Power in the circuit with decreasing loads....39
Figure 9-24: Hydraulic circuit with 4 identical terminals....40
Figure 9-25: Pressure trend in the circuit with control in E-E and A-A 40
Figure 9-26: Characteristic Power-pressure Difference with control in E-E and A-A....41
Figure 9-27: Valve Opening-Power with control in E-E and A-A....41
Figure 10-1: Danfoss AB-QM valves consist of two valves merged together: a two-way control one and a calibration one....42
Figure 10-2: Task of the calibration valve integrated into the Danfoss AB-QM valve....42
Figure 10-3: Task of the control valve integrated into the Danfoss AB-QM valve....43
Figure 10-4: Hydraulic circuits with four identical terminals....43
Figure 10-5: Speculated load variation in the hydraulic circuit with 4 identical terminals, from the first to the last the load increases 43
Figure 10-6: Pressure trend in the forward and return pipes when all terminals are at 100% of the load and of the case under consideration 44
Figure 10-7: Terminal 3 circuit with traditional 3-way valve and Danfoss AB-QM valve....44
Figure 10 8: Pressure trend in the circuit with traditional 2-way valve and Danfoss AB-QM valve 45
Figure 10 9: Power-pressure Jump diagram with traditional 2-way valves and Danfoss AB-QM valves....45
Figure 10-10: Battery power output according to the opening of the traditional 2-way valve and Danfoss AB-QM valve 46
Figure 10-11: Speculated load variation in the hydraulic circuit with 4 identical terminals, from the first to the last the load decreases....46
Figure 10-12: Pressure trend in the circuit along the loads that decrease with traditional 2-way valves and Danfoss AB-QM valves 47
Figure 10-13: Characteristic Power-ΔP and V Opening-Power in the circuit with decreasing loads and with traditional 2-way valves 47
Figure 10-14: Characteristic Valve Opening-Power with traditional 2-way valves and Danfoss AB-QM valves....48
Figure 10-15: Hydraulic circuit with 4 identical terminals 48
Figure 10-16: Pressure trend in the circuit with traditional 2-way valves and Danfoss AB-QM valves....49
Figure 10-17: Characteristic Power-ΔP with traditional 2-way valves and Danfoss AB-QM valves 49
Figure 10-18: Characteristic Valve Opening-Power with traditional 2-way valves and Danfoss AB-QM valves....50

Figure 10-19: Diagram of a typical plant cutaway ... 50
Figure 10-20: Hunting effects ... 51
Figure 10-21: on the right ChangeOver6 valve with AB-QM and NovoCon® S actuators - on the left AB-QM valve with NovoCon® S actuator ... 51
Figure 11-1: Time evolution of the renewal air flow and of the expelled air ... 53
Figure 11-2: Hourly performance of the regenerator's efficiency ... 53
Figure 11-3: Trend of the required power for ventilation with constant flow and variable flow ... 54
Figure 11-4: Trend of the difference of power required for ventilation with constant flow and variable flow ... 54
Figure 11-5: Annual energy required with constant flow and variable flow ... 55
Figure 11-6: Power required by the fans of pre-ErP 2018 and compliant with the ErP 2018 Directive AHUs ... 55
Figure 11-7: Danfoss products for HVAC applications ... 56
Figure 12-1: Benefits on energy consumption obtained by replacing the old refrigerating unit with one in Class A Eurovent ... 59
Figure 12-2: Benefits on energy consumption obtained with the replacement of old AHUs with new ErP 2018 certified units ... 59
Figure 12-3: Benefits on energy consumption obtained with the improvement of thermal insulation (from year 2005 to 2010) ... 60
Figure 12-4: Benefits on energy consumption obtained with the improvement of thermal insulation (from year 2005 to 2021) ... 60
Figure 12-5: Benefits on energy consumption obtained with Danfoss variable water flow solutions (building 2005) ... 61
Figure 12-6: Benefits on energy consumption obtained with Danfoss variable air flow solutions ... 61
Figure 12-7: Benefits on energy consumption obtained with Danfoss variable water and air flow solutions ... 61
Figure 12-8: Equivalent photovoltaic surface obtained with Danfoss variable flow solutions ... 62
Figure 12-9: Equivalent photovoltaic power obtained with Danfoss variable flow solutions ... 62
Figure 12-10: Equivalent carbon dioxide emissions obtained with Danfoss variable flow solutions ... 63
Figure 12-11: Annual energy consumption of basic installations based on the three types of thermal insulation considered ... 63
Figure 12-12: Benefits on energy consumption obtained by the replacement of the refrigerating unit and AHU with more efficient models ... 64
Figure 12-13: Benefits on energy consumption obtained with the improvement of thermal insulation (from year 2010 to 2021) ... 65
Figure 12-14: Benefits on energy consumption obtained with Danfoss variable water flow solutions (building 2010) ... 65
Figure 12-15: Benefits on energy consumption obtained with Danfoss variable water flow solutions (building 2021) ... 66
Figure 12-16: Building operating costs with year 2005 insulation type ... 67
Figure 12-17: Savings on building operating costs with year 2005 insulation type ... 67
Figure 12-18: Building operating costs with year 2010 insulation type ... 68
Figure 12-19: Savings on building operating costs with year 2010 insulation type ... 68
Figure 12-20: Building operating costs with year 2021 insulation type ... 68
Figure 12-21: Savings on building operating costs with year 2021 insulation type ... 69
Figure 13-1: Required air flow in the Dining and Breakfast Room ... 70
Figure 13-2: Annual energy consumed in the Dining and Breakfast Room ... 71
Figure 13-3: Annual expenditure on energy consumed in the Dining and Breakfast Room ... 71
Figure 13-4: Required air flow in the Spa premises ... 72
Figure 13-5: Annual energy consumed in the Spa premises ... 72
Figure 13-6: Annual expenditure on energy consumed in the Spa premises ... 72
Figure 13-7: Required air flow in the Conference Room ... 73
Figure 13-8: Annual energy consumed in the Conference Room ... 73
Figure 13-9: Annual expenditure on energy consumed in the Conference Room ... 74
Figure 13-10: Benefits obtainable with Danfoss variable flow solutions applied to all hotel areas ... 74
Figure 14-1: The recirculation ring ... 75
Figure 14-2: the MTCV valve family. On the left version B with automatic disinfection module. In the centre the basic version A. On the right version C with electronic controller ... 76
Figure 14-3: Diagram of the return ring with Danfoss MTCV valves inserted at the bottom of the pipes ... 77
Figure 14-4: Danfoss MTCV valve structure - Basic version - A ... 77
Figure 14-5: Control characteristic of the Danfoss MTCV valve - Basic version – A ... 78
Figure 14-6: Typical percentage flow of a hotel's recirculation ring ... 78
Figure 14-7: Self-operated version of the Danfoss MTCV valve with automatic disinfection module - B ... 79
Figure 14-8: Control characteristic of the Danfoss MTCV valve - Self-operated version - B ... 79
Figure 14-9: On the left Danfoss MTCV Valve version C equipped with electronic controller - On the right electronic CCR2 for the optimization of disinfection processes ... 80
Figure 14-10: Version with electronic controller of the Danfoss MTCV valve - C ... 80
Figure 14-11: Diagram of a system controlled by the electronic controller CCR-2 ... 81
Figure 14-12: Control characteristic of the Danfoss MTCV valve - Version with electronic controller - C ... 81
Figure 14-13: Estimated annual energy savings for pumping ... 82
Figure 14-14: Estimate of the annual energy savings consumed by the boiler ... 83
Figure 14-15: MTCV balancing valves with CCR2 electronic control unit and TVM thermostatic mixing valve ... 83
Figure 15-1: Operating principle of the orbital scroll compressor ... 84
Figure 15-2: Pressure-Enthalpy of the refrigeration cycle diagram ... 85
Figure 15-3: Performance of the compressors according to the compression ratio ... 85
Figure 15-4: Pressure-Volume diagram and compressor losses ... 86
Figure 15-5: Efficiency of the variable intrinsic volume compressor according to the compression ratio ... 86
Figure 15-6: Comparison of consumption and energy costs with scroll compressors IDV ... 87
Figure 15-7: Annual savings in building with year 2021 insulation with scroll compressors IDV ... 87
Figure 15-8: Reduction of environmental impact with scroll compressors IDV ... 87
Figure 15-9: Performance of the energy efficiency index (EER) in standard and IDV compressors ... 88
Figure 15-10: Performance coefficient (COP) trend in standard and IDV compressors ... 88
Figure 15-11: Rotor of a turbomachine and velocity vectors ... 89
Figure 15-12: Characteristic curve of centrifugal turbochargers ... 90
Figure 15-13: Characteristic curves of a traditional centrifugal turbocharger when the angle of inclination of the vanes varies ... 91
Figure 15-14: Characteristic curves of centrifugal compressors ... 92
Figure 15-15: Type of power regulation according to the system's curves ... 93
Figure 15-16: Savings obtainable with the inverter according to the required power and total head ... 94
Figure 15-17: Cutaway of the Turbocor compressor ... 94
Figure 15-18: Loss of efficiency of the exchangers according to the amount of oil ... 95
Figure 15-19: Comparison between consumption and energy costs with Turbocor compressors ... 96
Figure 15-20 Annual savings and environmental impact reduction in building with year 2021 insulation with Turbocor compressors ... 97
Figure 15-21: Performance of the energy efficiency index (EER) in standard scroll and Turbocor compressors ... 97

Notes

Whether it's a new project or a restructuring, **Danfoss** can help you save money on your building's **energy consumption**

25%

Energy bills savings for hotels with Danfoss technologies and solutions

HVAC

By using Danfoss solutions it is possible to reduce up to 45% of climatization systems energy consumption while ensuring the best comfort for guests. This is also building your hotel's green credentials.

Domestic hot sanitary water

Saving 15% (as minimum) of cost for hot water. Reduced water waste, reach temperature quickly.

Refrigeration systems

Our market-leading expertise in building sustainable and efficient cold rooms with accurate temperature control, meeting HACCP regulations, reduces the energy consumption by up to 30% with better food preservation.

Fire fighting systems

With our solutions, water consumption can be reduced by up to 80% compared to traditional sprinklers.

Elevators and lifting

High reliability and high efficiency drives guarantee more then 50% energy savings when modernizing a hydraulic elevator

Fresh water

Deliver high-quality service at lower costs with up to 65% less energy consumption.

ENGINEERING
TOMORROW

Danfoss
Your Hotel Sector Partner

We deliver our hotel expertise through the most advanced and efficient technologies to support smarter use of electricity and water, reduce running costs, improve environmental impact and deliver superior guest comfort.

HVAC

Domestic hot sanitary water

Refrigeration systems

Fire fighting systems

Elevators and lifting

Fresh water

Danfoss Iberia main offices:

Danfoss S.A.
Caléndula 93, El Soto de la Moraleja
Edificio I Miniparc III, 28109 Alcobendas
España
Tel: +34916586688

Danfoss SA, Branch office
Solsones 2, esc B, local C2 08820 Barcelona
Spain
Tel. +34916586688

Danfoss Italy main offices:

Corso E. Tazzoli 221,
10137 Torino
Italy
Tel: +390113000511

Via Energy Park 22
20871 - Vimercate (MB), Milano
Italy
Tel. +390113000511
(centralino sede Torino)

Danfoss France main offices:

Danfoss Commercial Compressors
B.P. 331
Z.I. de Reyrieux
01603 Trévoux Cédex, France
Tel: +33474002829

Danfoss Elancourt
1 bis avenue Jean d'Alembert
78996 ELANCOURT Cedex
France
Tel. + 33(0)130625000