MASTER THESIS: COOLING SYSTEM OF THE POLITO'S ENERGY CENTER.

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1. INTRODUCTION.

This Thesis is based on Thermal and Energetic acquired concepts throughout the completion of a university degree and master. It will be carried out with the PoliTo (Politecnico di Torino) university, working from the so-called Energy Center[1].

There is a heat pump used for the hot water production and air conditioning of the whole building. We are going to expose the objectives, deepen in the explanation of the Energy Center itself, describe the thermal plant inside it, show the improvements that were carried out once it was a reality and make a functional analysis of it.

Once all of this is exposed, the experimental data given by the sensor will be used. We are going to take the data of a whole year and we are going to separate it by months, calculating the average value for each month for each of the four values (in and out temperatures of the hot and cold streams). After that, the total average will be calculated.

The next step will be to analyse these calculations through the Coolpack simulation system to, finally, compare them with the theoretical ones expected when the project was launched.

All the schemes used will be shown in the annex and the support needed to fulfil this project in the Bibliography.

[1] Better explained ahead.

2. OBJECTIVES.

The main objective of this thesis is to analyse the correct functioning of the heat pump in charge of the Energy Center building air conditioning system. This will be carried out by comparing the theoretical results given by the different reports published from 2013 to 2016 with the experimental ones directly obtained from the whole refrigeration installation and then calculated using the simulator Coolpack.

The heat pump used is the Climaveneta Integra machine, from Mitsubishi[2]. The unit consists of a machine capable of satisfying, depending on the operating mode, the heating and cooling demand thanks to the combined production of hot and cold water. A sensor installed in it gives the temperatures in and out of the hot and cold streams. This streams are the ones that enter and go out from the condenser and evaporator respectively. With these values, we are going to calculate with the previously mentioned program the COP of the installation and we will compare it to the initially expected COP.

[2] We will give more information about it in the Description of the plant (point 4).

3. ENERGY CENTER.

The Energy Center Initiative (ECI) was launched in 2016 by *Politecnico di Torino* to support and stimulate projects that advise local, national and transnational authorities in terms of energy policies and technology. Its main objective is to develop new entrepreneurial activities in the energy sector, through the opportunities given by academic research, innovation and partnership.

It can be divided into two different parts, the Energy Center House (EC-H) and the Energy Center Lab (EC-L). The Energy Center House is a new building on the Politecnico di Torino campus that will host companies, start-ups, public administrations and others active in R&D, management, policy and decision-making in the energy field. On the other hand, the Energy Center Lab is the Interdepartmental Center for Energy, which brings together a multidisciplinary group of Politecnico researchers and lecturers dedicated to the study of technologies and integrated systems for the transition to a more sustainable society in terms of energy use and the environment.

It is located between via Nino Bixio e via Borsellino, right behind the university.

Figure 1. Energy Center from the outside.

Figure 2. Location of the Energy Center.

4. DESCRIPTION OF THE PLANT.

Inside the Energy Center we can find the thermo-mechanical/hydro plant whose objective is to provide an optimal air conditioning system and to produce domestic hot water (DHW). The project was launched in March 2013 and, nowadays, it is a reality.

SYSTEMS WITHIN THE PLANT.

The service given by the plan is about heating and production of hot water and this will be possible by using water as the heat transfer fluid. The type of generator is district heating working with water, with a nominal power of 211,97kW:

- Generation system: district heating and integration system through a multipurpose heat pump powered by groundwater.
- Thermoregulation system: temperature control in every environment of the building.
- Thermal energy accounting system: accounting of the thermal and refrigeration production in the plant: water withdrawal, district heating withdrawal, multipurpose group production, absorber production, DHW production, solar production…
- Thermal vector distribution: properly insulated pipes and air channels.
- Forced ventilation: external air system for the auditorium, restaurant and atrium, and primary air system for the offices.
- Thermal accumulation systems:
    - DHW production: 2500 litres.
    - Hot water production: 4000 litres.
    - Cold water production: 4000 litres.
- Production and distribution of the DHW: a 1500 litre boiler fed, via a coil, by the thermal power plant; and a 1000 litre kettle powered, via a coil, by solar panels positioned on the roof of the building.
- Thermal energy delivery terminals:
    - Radiant ceiling panels (offices).
    - Radiant floor panels (hall).

    - Air inlets.
    - Radiators (toilets).
- Water treatment system: softening and osmosis treatment system for humidification.
- Solar thermal system: 30 m^2 of solar panels.
- Photovoltaic system: production of 46,1 kW of electricity.

POLYVALENT UNIT.

HEAT PUMP.

As we all already know, a heat pump is a device used to warm up and sometimes also cool buildings by transferring thermal energy from a cooler space to a warmer space using the refrigeration cycle, being the opposite direction in which heat transfer would take place without the application of external power. Moreover, heat pumps have a smaller carbon footprint than heating systems burning fossil fuels such as natural gas.

The efficiency of a heat pump is expressed as a coefficient of performance (COP)[3]. The higher the number, the more efficient it is and the less energy it consumes. When used for space heating these devices are typically much more energy-efficient than simple electrical resistance heaters.

In the following table, we can see the variation of the COP with the output temperature and the pump type and source. In the case we are working on, we would be in the square marked in the table in yellow. This will be demonstrated by the theoretical and experimental analysis of the plant.

[3] The COP of our installation will be calculated through Coolpack.

COP variation with output temperature

Pump type and source	Typical use	35 °C (e.g. heated screed floor)	45 °C (e.g. heated screed floor)	55 °C (e.g. heated timber floor)	65 °C (e.g. radiator or DHW)	75 °C (e.g. radiator and DHW)	85 °C (e.g. radiator and DHW)
High-efficiency air source heat pump (ASHP), air at −20 °C[21]		2.2	2.0	-	-	-	-
Two-stage ASHP, air at −20 °C[22]	Low source temperature	*2.4*	2.2	1.9	-	-	-
High efficiency ASHP, air at 0 °C[21]	Low output temperature	*3.8*	2.8	2.2	2.0	-	-
Prototype transcritical CO_2 (R744) heat pump with tripartite gas cooler, source at 0 °C[23]	High output temperature	3.3	-	-	*4.2*	-	3.0
Ground source heat pump (GSHP), water at 0 °C[21]		5.0	3.7	2.9	2.4	-	-
GSHP, ground at 10 °C[21]	Low output temperature	*7.2*	5.0	3.7	2.9	2.4	-
Theoretical Carnot cycle limit, source −20 °C		5.6	4.9	4.4	4.0	3.7	3.4
Theoretical Carnot cycle limit, source 0 °C		8.8	7.1	6.0	5.2	4.6	4.2
Theoretical Lorentzen cycle limit (CO_2 pump), return fluid 25 °C, source 0 °C[23]		10.1	8.8	7.9	7.1	6.5	6.1
Theoretical Carnot cycle limit, source 10 °C		12.3	9.1	7.3	6.1	5.4	4.8

Figure 3. Variation of the COP caused by different factors. Source: Wikipedia.

In other terms, the heat pump is based on 4 different devices, as seen in Figure 6: an evaporator, a condenser, a compressor and a valve. The streams on the left and the right, blue and red respectively, correspond to the streams in Figure 3 of the same colour.

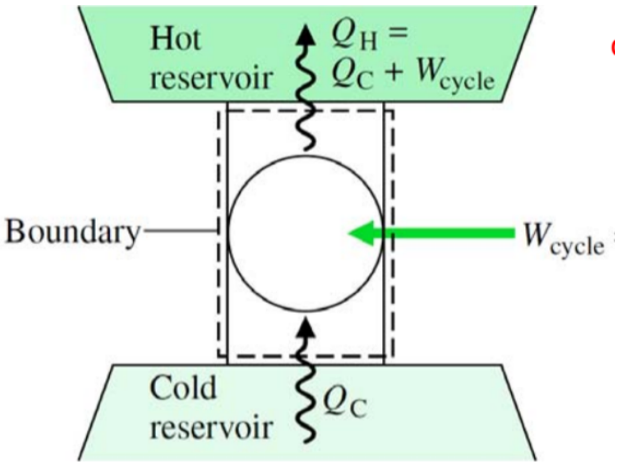


Figure 4. Functioning of a heat pump.

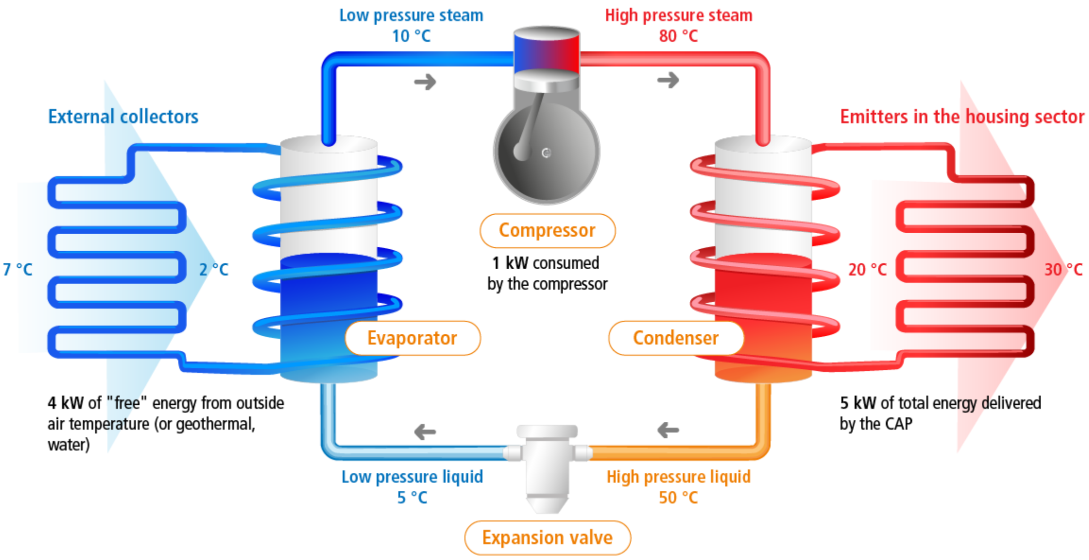


Figure 5. Devices that compose the heat pump.

ABSORPTION REFRIGERATION UNIT.

Absorption refrigeration systems use as equipment to produce cold an absorption machine, which is a device that allows obtaining low temperatures, for all types of applications, but using hot water or heat as power supply, compared to a conventional system that uses electricity. This allows to obtain an efficient solution and can put in value waste heat or generated heat with renewable energy, among other options.

An absorption machine uses an absorption refrigeration cycle, instead of a compression one. A thermodynamic absorption refrigeration cycle, in the same way that happens in a compression one, is based on the fluid used as a refrigerant obtains heat from the liquid to be cooled, passing from the liquid state to the vapor state by reducing the pressure to which it is subjected.

In this refrigeration cycle, the fluid in the liquid state is at a higher pressure in the condenser and passes through the evaporator at a low pressure where it absorbs the heat needed to evaporate, this heat coming from the focus to be cooled. The refrigerant in vapor state advances the cycle, with high pressure, until it reaches the condenser, which is another heat exchanger where it gives up the heat it has obtained returning to the liquid state and returning to perform the cycle again. Using this type of cycle, it is possible to extract heat from a space, where the evaporator is located, cooling it, to dissipate it in another, where the condenser is located.

The difference between this cycle and a compression one[4] is that, in a compression cycle, the circulation of the fluid and required increase in pressure is obtained using a mechanical compressor, in the absorption cycle this is achieved by providing heat to the generator where the refrigerant is mixed with another fluid called absorbent whose function is to absorb the vapor in the low-pressure zone to be able to return it in liquid form to the generator.

Using absorption refrigeration equipment reduces, first of all, the primary energy that would have been needed to produce the electricity required to operate the conventional compression equipment it replaces, and if the heat used by the absorption machine is of free or waste origin, there is a saving of 100% of the primary energy required in the case of using a compression system. This additional advantage is maximized if waste heat, which was going to be discarded, or energy generated with renewable sources such as solar thermal energy is used, since this way a significant economic saving is also achieved.

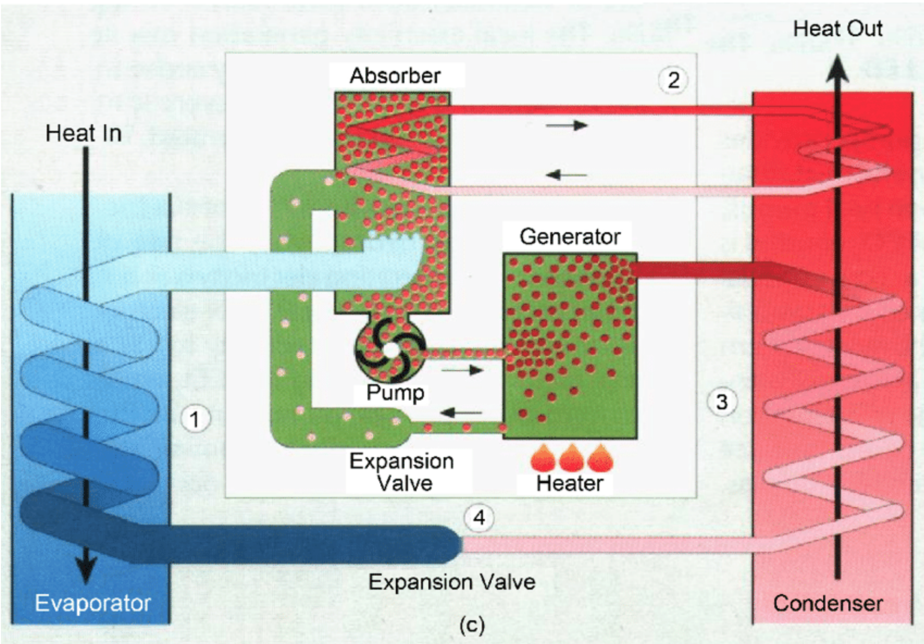


Figure 6. Functioning and devices of the absorption refrigeration system.

[4] This will affect to the Coolpack simulation in the following section.

ACTUAL MACHINE: CLIMAVENETA ERACS2-WQ/S 1702.

Once we have seen the general functioning of a heat pump and a refrigeration unit, we can now proceed to know in-depth which is the actual machine working inside the Energy Center. This is the CLIMAVENETA ERACS2-WQ/S 1702, a device made by Mitsubishi Electric Hydronics & IT cooling systems S.p.A. These are, as the company says, “units for 4-pipe systems, with scroll, screw and inverter screw compressors, from 33 to 1125 kW” with the following characteristics:

Figure 7. Characteristics of the Climaveneta ERACS2-WQ/S 1702. Source: Climaveneta Integra Booklet.

Mitsubishi sells “maximum comfort, simultaneous hot and cold-water production, unbeatable energy and system efficiency. The advantages of the INTEGRA all-in-one units installed in a 4-pipe system are limitless.” Between those advantages we can highlight the following:

Figure 8. Advantages of the Climaveneta ERACS2-WQ/S 1702. Source: Climaveneta Integra Booklet.

The unit consists of a machine capable of satisfying, depending on the operating mode, the heating and cooling demand thanks to the combined production of hot and cold water. Even though it works by absorption, the thermodynamic principle is the vapour compression refrigeration cycle with heat recovery. The internal configuration of the machine is characterised by two independent refrigeration circuits with respective screw-type compressors.

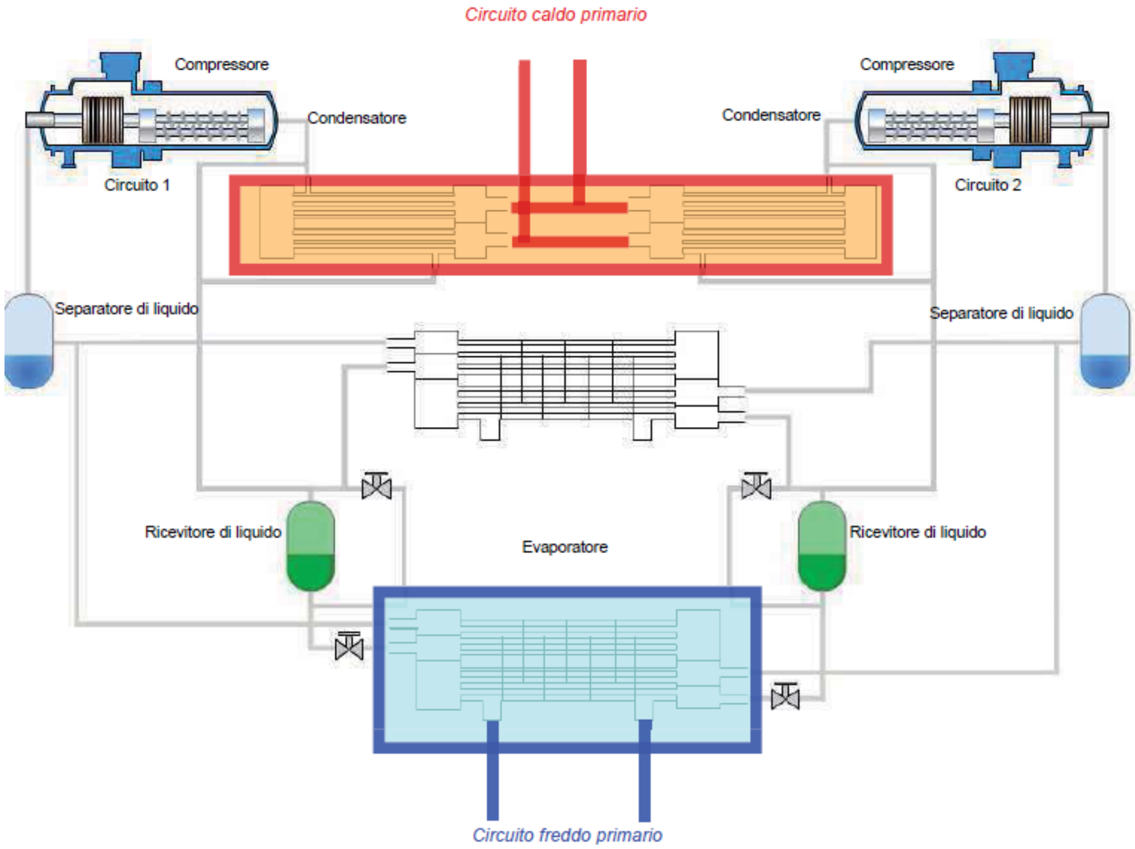


Figure 9. Actual system of the Energy Center. CLIMAVENETA ERACS2-WQ/S 1702. Source: Climaveneta Integra Booklet.

There are three operating modes depending on the thermal requirements of the system:

- Production of hot water only: The unit operates as a heat pump using the auxiliary exchanger as evaporator, removing thermal energy from the groundwater, and releasing this energy to the condenser on the hot water side, in this case the evaporator on the cold-water side is not used.
- Production of cold water only: The unit operates as a chiller using the auxiliary heat exchanger as a condenser, releasing thermal energy to the groundwater, and removing this energy from the evaporator on the cold side, in this case the condenser on the hot side is not used.
- Simultaneous production of hot and cold water: The unit uses the evaporator to remove thermal energy from the cold primary circuit where chilled water is produced and uses the condenser to release thermal energy to the hot primary circuit for the production of hot water, in this operating mode the auxiliary heat exchanger is not used.

The change between the different operation modes takes place automatically, through a microprocessor on the unit, trying to optimise the energy spent according to the thermal load requirements of the user.

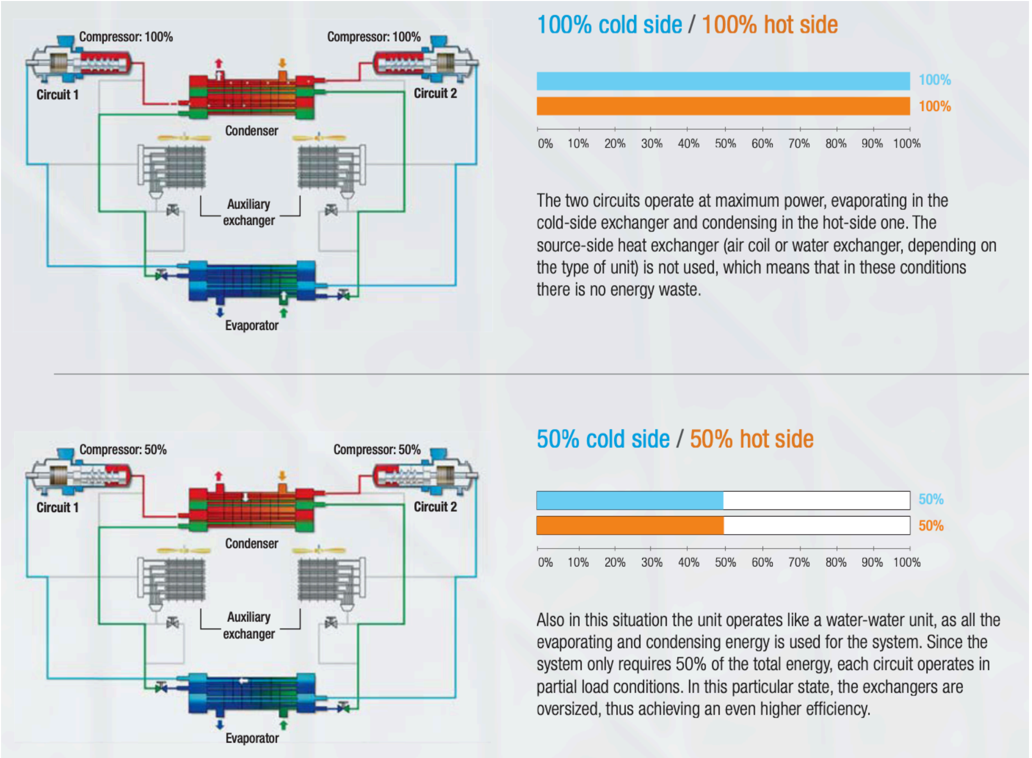


Figure 10. Type of functioning of CLIMAVENTA. Source: Climaveneta Integra Booklet. (I).

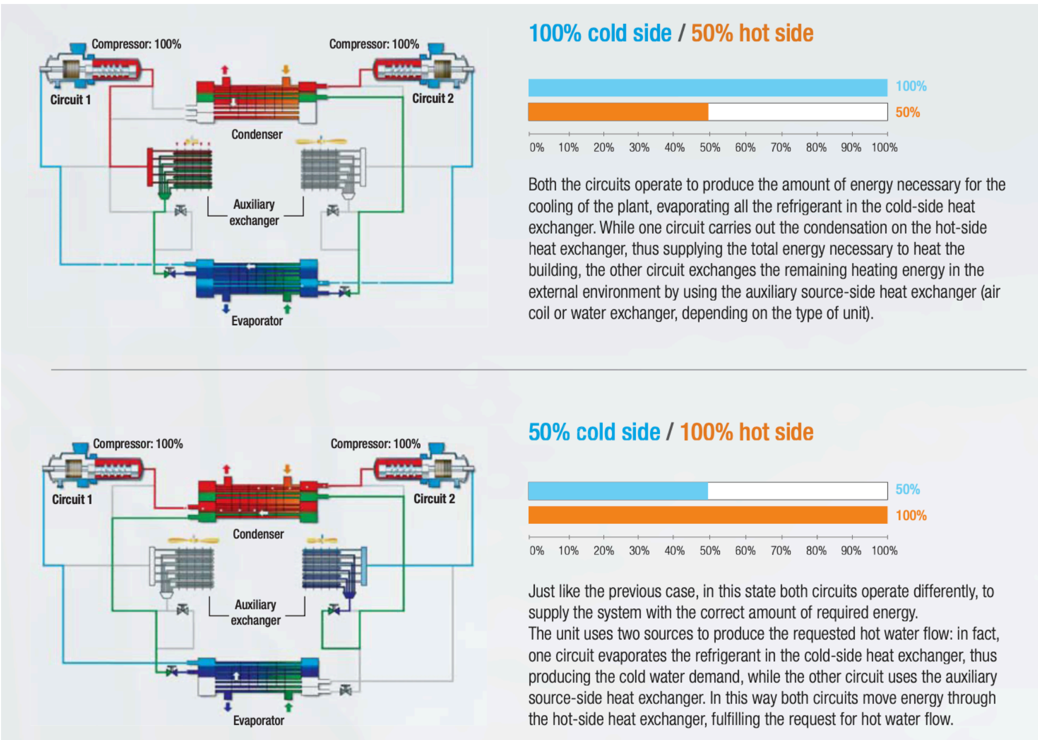


Figure 11. Type of functioning of CLIMAVENTA. Source: Climaveneta Integra Booklet. (II).

The type of regulation for the machine is characterised by a proportional step logic, as described in the product description provided by CLIMAVENETA. The proportionally required cooling capacity takes place using of a slide valve which, depending on the position assumed, determines a step reduction of the compression chamber; each compressor can therefore deliver between a 50% and a 100% of its capacity.

Thermoregulation takes place on the two hydraulic circuits, according to the return temperature of the water. This allows simultaneous satisfaction of the different heating and cooling requirements, according to the set mode.

DESIRED THERMOHYGROMETRIC CONDITIONS.

The thermal conditions considered acceptable for the rooms treated with air are the following:

- WINTER: + 20 ± 2ºC
- SUMMER: + 26 ± 2ºC
- Humidity: 50% ± 5%

In terms of the refrigeration system, the in and out temperatures of the primary fluid are the following:

	IN	**OUT**
Refrigerated water of the polyvalent heat pump	7ºC	12ºC
Hot water of the polyvalent heat pump	50ºC	45ºC

CHARACTERISTICS FORESEEN FOR THE REFRIGERATOR/HEAT PUMP.

The following tables and data are taken from the final report of the Energy Center[5]. Two pairs of pumps EP1 and EP2 (one pair for each well) with the following characteristics are planned for withdrawal:

HEAT PUMPS EP1 AND EP2 (WITH INVERTER)	
Flow rate (m3/h)	83
Prevalence (m)	50
DATA	
Specific mass H2O (kg/m3)	1000
Flow rate (m3/h)	83
Flow rate (m3/s)	0,0231
Flow rate (kg/s)	23,06
Prevalence (m)	50
Power of the pump (kW)	11,31
Efficiency of the pump (%)	0,85
Efficiency because of mechanic losses (%)	0,9
cos(fi)	0,8
Active Power absorbed (kW)	14,78
Active Power of the project (kW) + 20%	17,74
Reactive Power absorbed (kVAR)	11,09
Apparent Power absorbed (kVA)	18,48
Apparent Power of the project (kVA)	22,17

Figure 12. Characteristics of the refrigerator/heat pump (1).

[5] The report is from the March 2013 under the name "Progetto Definitivo impianti termomeccanici e idrici". This is the definitive report although after that there were more with improvements.

REFRIGERATION WITH RECOVERY		
Refrigeration power	kW	322
Total power absorbed	kW	110
Thermal power in the recuperator	kW	426
TER-(Pf+Pr)/Pi		6,8
REFRIGERATION		
Refrigeration power	kW	411
Total power absorbed	kW	73
EER		5,64
HEATING		
Thermal power in the condenser	kW	403
Total power absorbed	kW	109
COP		3,71

Figure 13. Characteristics of the refrigerator/heat pump (2).

The characteristics are:	Functioning:	
	REFRIGERATION	HEAT PUMP
Cold power (system side) (kW)	411	
Cold power (source side) (kW)		294
Electric absorption (kW)	73	109
Condenser thermal capacity (source side) (kW)	484	
Condenser thermal capacity (system side) (kW)		403
EER/COP	5,64	3,71
EVAPORATOR	**system side**	**source side**
in temperature	12	10
out temperature	7	5
delta T	5	5 to 7
CONDENSER	**source side**	**system side**
in temperature	15	45
out temperature	28 to 30	50
delta T	12 to 15	5

Figure 14. Characteristics of the refrigerator/heat pump (3).

5. IMPROVEMENTS.

The project was launched in March 2013, but by November 2014, some improvements were proposed to obtain an optimal functioning of the plant. The following is a summary of the proposals to improve the quality and performance of the mechanical systems included in the final design for the tender.

SOLAR INSTALLATION[6].

This project aims to install 15m^2 of solar panels, of vacuum type, for the production of hot domestic water (HDW). The objective is to save energy and money and to increase production from renewable sources. It is proposed to upgrade the plant to 30m^2 of panels of the same type in order to produce more power.

The power of this installation is calculated by $P = q * S$, where:

- P = thermal power (kW).
- q = specific power (kW/m2).
- S = surface (m).

The expected values are:

Specific power (kW/m2)	0,47
Reduction factor	0,7
Actual surface (m2)	15
THERMAL POWER OF THE SOLAR PANELS (kW)	**4,94**

Figure 15. Thermal power of the solar panels.

CENTRAL REFRIGERATION PLANT.

The following design solutions were adopted to maximize the efficiency of the installation:

[6] Further information in section 6.Functional analysis of the plant.

- Installation of a polyvalent group with screw compressor, increase of the coefficients of performance, exchanger with stainless steel tubes and R134a refrigerant fluid.
- Installation of an absorption refrigeration unit with an increase in the coefficient of performance.
- Expansion if the use of underwater also directly in the air handling unit (AHU) for free precooling.
- Complementary antifreeze hot water circuit exclusively for AHU.
- Hydronic cooling system for data centres and UPS to complement the split system already planned.

AHU (AIR HANDLING UNIT).

The following design solutions were proposed to improve the quality and performance of the air handling units:

- Installation of a recuperation system with regenerative enthalpy exchanger with efficiency in temperature of 95% and the humidity of 75%.
- Spray humidification (misting) instead of using the electric vapour producers.
- Adoption of plug-in fans with IE3 motors (instead of traditional centrifugal fans).
- Installation of precooling section fed directly to groundwater (not foreseen in the basic project).
- Installation of antifreeze section with a coil with finned tubes.
- Other improvements compared to the basic solutions, in terms of durability and maintainability such as, example, increasing the thickness of the sheet metal of the panels and inserting inspection doors between the profiles.

THERMOHYGROMETRIC WELL-BEING.

To increase environmental comfort (particularly in the workplace such as offices), the following design solutions were proposed:

- Installation of radiant suspended ceilings made of special metal instead of suspended ceilings in plasterboard (first and second floor) and standard metal suspended ceilings (third floor).
- Linear diffusers in combination with the radiant suspended ceiling.

AIR DISTRIBUTION.

For the qualitative and performance improvement of air distribution systems, the following design solutions were proposed:

- Use of pre-insulated antimicrobial and self-cleaning channels instead of pre-insulated antimicrobial channels and galvanized sheet channels.
- Installation of flow regulators in all air diffusion terminals in the room.
- Installation of linear diffusers in combination with the radiant false ceiling.

HEAT TRANSFER FLUID DISTRIBUTION.

The improvement proposals for the distribution of heat transfer fluids were the following:

- Adoption of multilayer pipes in terminal layouts.
- Installation of filtration systems in the well water line and the hot and cold circuits of the polyvalent group.
- Use of electric pumps with very high-efficiency motors (IE4 classification).

WATER AND SEWAGE SYSTEMS.

The improvement proposals in the field of water and sanitation systems are the following:

- Adoption of timed taps.

- Adoption of stainless-steel snap-fit tubes in the main distributions.
- Adoption of light cast iron pipes with elastomer collars and gaskets fixing for both the columns and the collectors up to the exit of the building.

SUPERVISION.

The proposed supervision system allows the maintenance of the plants with special attention to savings in management and the guarantee of project forecasts both in terms of performance and efficiency of the plant.

6. FUNCTIONAL ANALYSIS OF THE PLANT.

Below, a functional analysis of the installation will be carried out. The installation is divided into 3 different functional schemes called by the following names: M02.001, M02.003 and M02.011. All of them will be attached in full page in the annex, to allow a better global look and understanding of the plant[7].

We are going to explain the operation of the plant through the different devices more exhaustively, analysing the devices themselves and the inlet and outlet streams that pass through them.

In the following picture, taken from M02.001 [8], we can see the heart of the refrigeration system, the heat pump and the absorption refrigeration unit[9]. Both of these devices represent the CLIMAVENETA INTEGRA system. The heat pump is represented in a box in

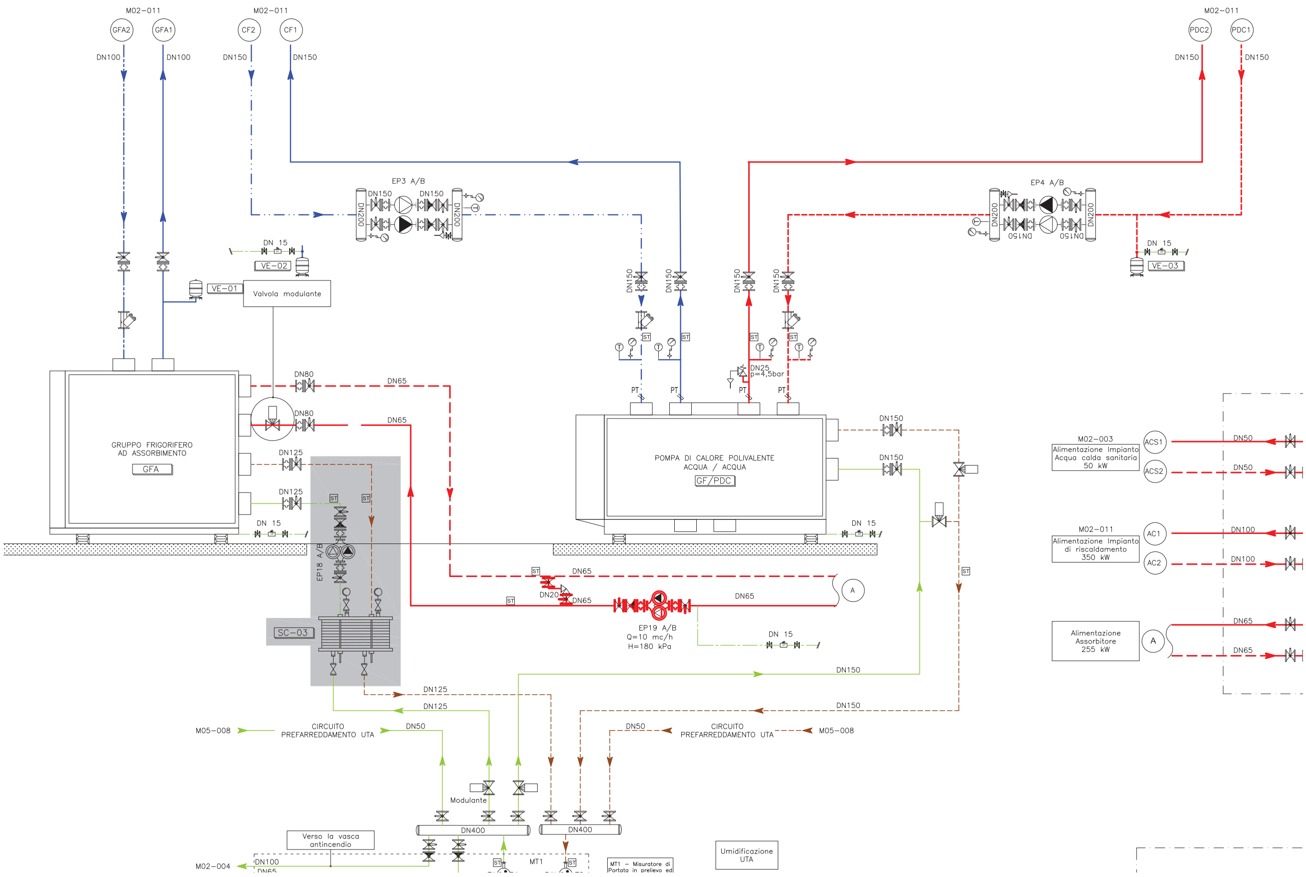


Figure 16. Zoom of the heart of the installation.

[7] There are other schemes related but we are not taking them into account because they are not important for the heat pump analysis.

[8] See Annex 1.

[9] Both have adopted the improvements previously mentioned.

the centre of Figure 10. It is connected through different streams to the rest of the devices inside the installation. The red arrows are hot water, and the blue ones are cold. As we have seen in the data given in the description of the plant, the hot water enters the heat pump at 50ºC and goes out at 45ºC, while the cold one enters at 7ºC and goes out at 12ºC. On the left of the heat pump, we can see two other streams, a green one and a dotted brown one. These two streams are the connections of the groundwater.

In terms of the absorption refrigeration unit, the scheme works the same way. It has two blue streams representing the cold water and another two representing the hot water that is red. The green and brown ones are also present, and they meet the ones coming from the heat pump below, in the precooling system.

The cold arrows of both and the hot ones of the heat pump, go to the scheme M02.011, but the hot ones of the refrigeration system are marked with an A. This means the connection follows in the next picture (Figure 11):

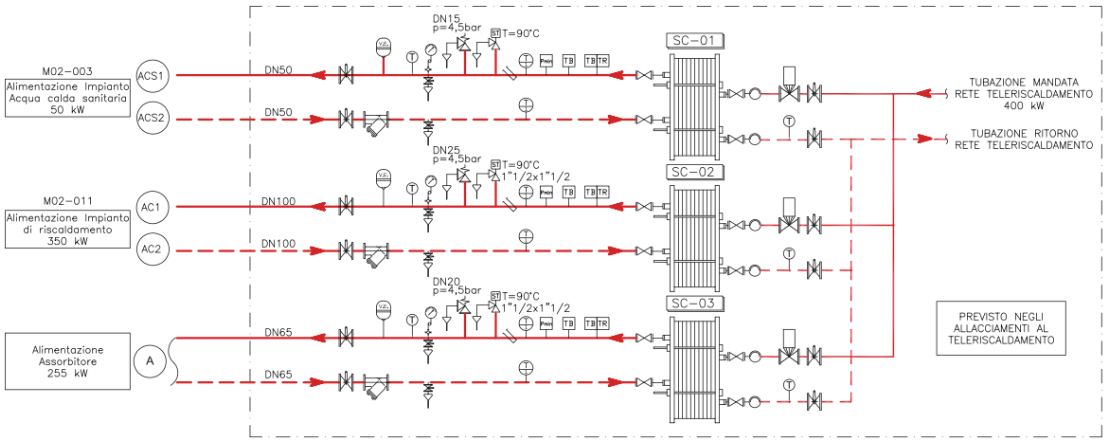


Figure 17. Connections of the streams.

It is shown that these connections arrive to the three heat exchangers (SC-01, SC-02 and SC-03) each with a different purpose. SC-01, with a power of 50kW, works for the district heating system and is connected with the scheme M02.003[10]. SC-02, with a power of 350kW, works for the production of domestic hot water (DHW) and is connected with

[10] See Annex 2.

the scheme M02.011[11]. Finally, SC-03, with a power of 360kW, is the one connected with the hot streams of the absorption refrigeration unit.

As above mentioned, production of domestic hot water (DHW) is carried out in our installation. This is achieved through solar panels. By doing a zoom of the scheme M02.003, we can optimally see the functioning.

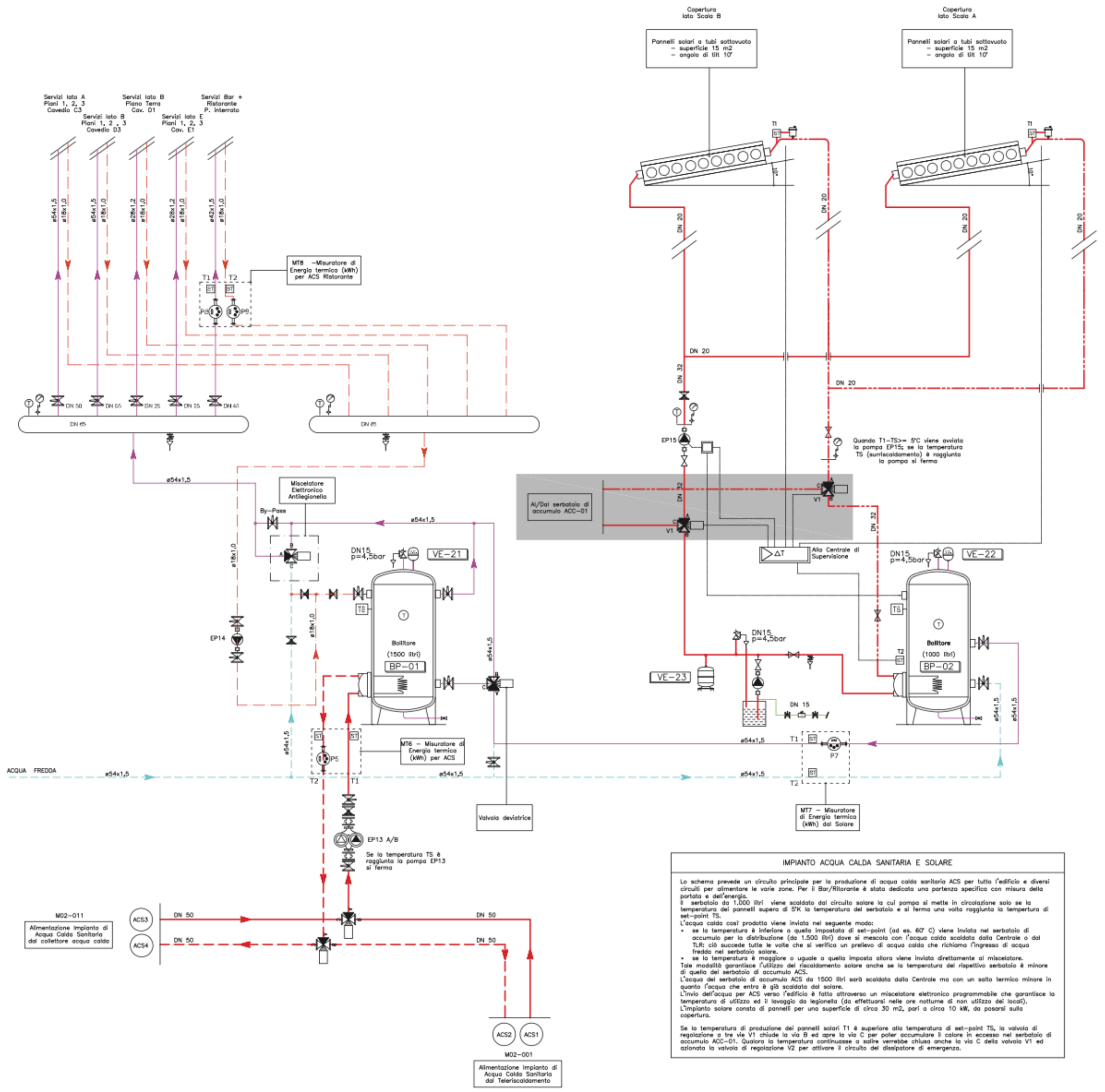


Figure 18. Zoom of the DHW production system.

[11] See Annex 3.

The solar panels are of the type of vacuum tubes[12]. They are tilted 10º and have a surface of 15 m^2. The 1000-litre tank is heated by the solar circuit whose pump is put into circulation only if the temperature of the panels exceeds the tank temperature by 5ºK and stops once the setpoint SP temperature is reached. The produced hot water is sent in the following way: if the temperature is less than the SP temperature, it is sent to the reservoir (1500 L) of accumulation for the distribution, where it is mixed with the hot water heated in the Central. If the temperature is bigger or equal to the SP temperature, it is directly sent to the mixer. This functioning guarantees the use of solar heating even if the temperature of the respective tank is lower than that of the DHW storage tank.

As seen in all of the previous schemes, every connection goes directly to scheme M02.011[13], where almost every stream meets with the reservoirs.

[12] Improvement set in November 2014 shown in the part 5. Improvements above.
[13] See Annex 3.

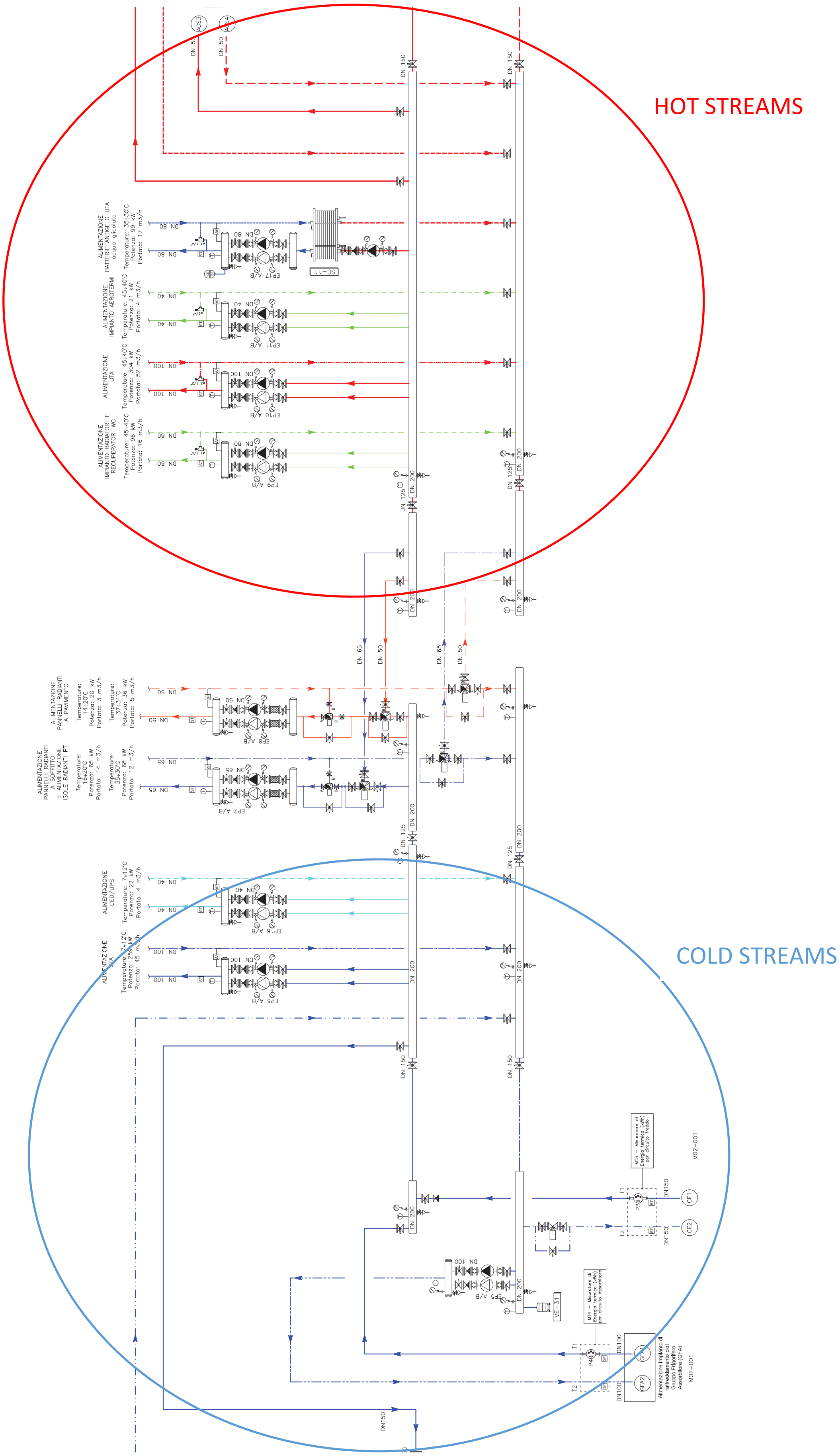


Figure 19. Last connection of every stream.

7. EXPERIMENTAL DATA.

Every 15 minutes, a sensor installed in the heat pump, gives the real value of the different temperatures at every point. The data we have is comprised between May 14th 2019 at 15:30 and May 14th 2020 at 15:15. Therefore, we have a data bank of almost 35000 figures.

We are not showing all the data here because it would take so much space, but a summary of the average values of each month for the different parameters. This will help us to get an idea of the experimental values that, later, will be compared with the theoretical ones obtained from the program.

What we have done with the data is, first of all, delete all the null values that would distort the real solution. Then, the average of each of the four values (the in and out temperatures of the hot and cold streams) has been calculated for each month and, finally, the total average for each stream.

MONTH	HOT		COLD	
	OUT	IN	OUT	IN
may-19	42,61	44,04	12,70	13,49
jun-19	43,05	44,66	15,10	15,41
jul-19	45,76	46,64	12,90	13,10
ago-19	41,60	42,70	16,50	16,08
sept-19	44,40	45,68	12,94	12,90
oct-19	35,39	36,17	15,93	15,83
nov-19	27,31	47,30	20,37	18,95
dic-19	26,14	52,61	20,30	18,29
ene-20	24,30	55,10	18,99	17,20
feb-20	25,40	53,20	20,49	18,18
mar-20	25,86	52,38	20,96	18,58
abr-20	31,35	49,55	22,00	19,84
may-20	28,54	28,98	22,30	22,10
AVERAGE	34,00	46,88	17,74	16,78

Figure 20. In and out T of the heat pump.

The next step has been to plot the previous results to make it easier to analyse. As we can see, the difference between the in and out streams for both cases is very low from May to November and from April on to the next May. In those periods, it only differs more or less 2 degrees, while in the months between November and April the hot streams have a difference of between 10 and 30 degrees. Let's see what the reason for this could be.

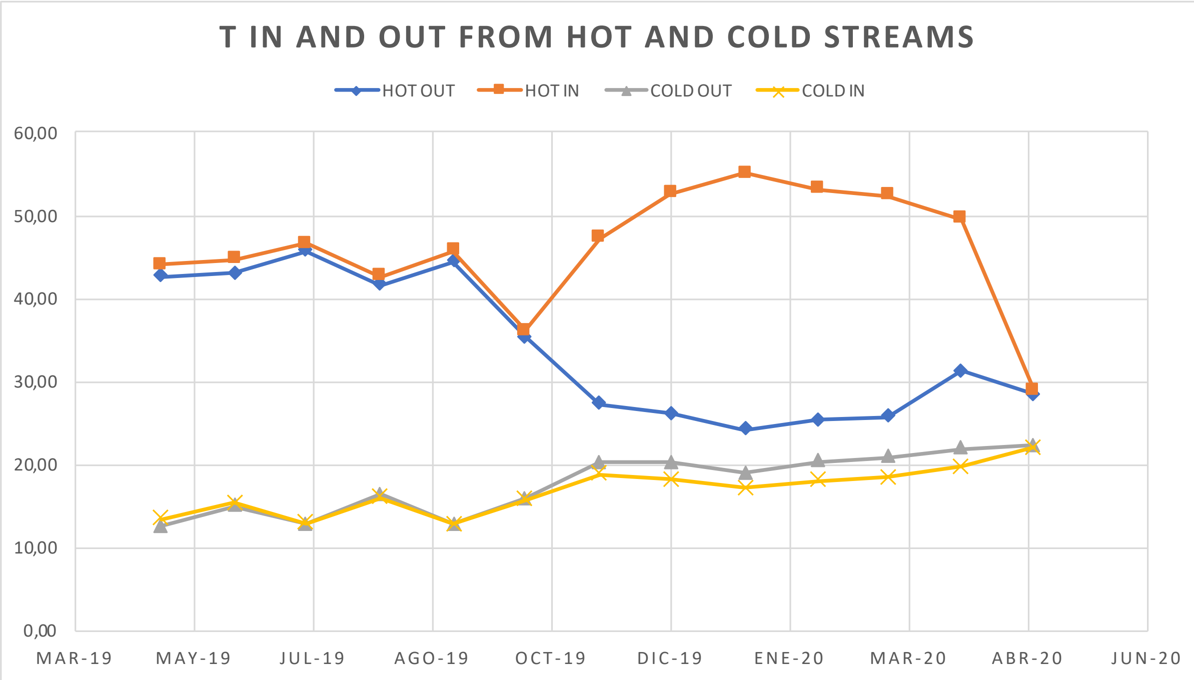


Figure 21. T in and out for the hot and cold streams.

In the following chart, the temperature in the outside of the system is shown. It is the maximum and minimum average temperature for each month in the city of Turin for a whole year. It is also plotted for a better understanding. As we can see, from November to April the outside temperature is colder[14] than the rest of the year.

[14] Highlited in yellow on the graph.

Month	High / Low (°C)
January	8° / 3°
February	9° / 4°
March	14° / 7°
April	17° / 10°
May	21° / 14°
June	25° / 18°
July	28° / 20°
August	27° / 20°
September	23° / 17°
October	17° / 12°
November	12° / 7°
December	9° / 4°

Figure 22. Monthly temperature along a year in Turin.

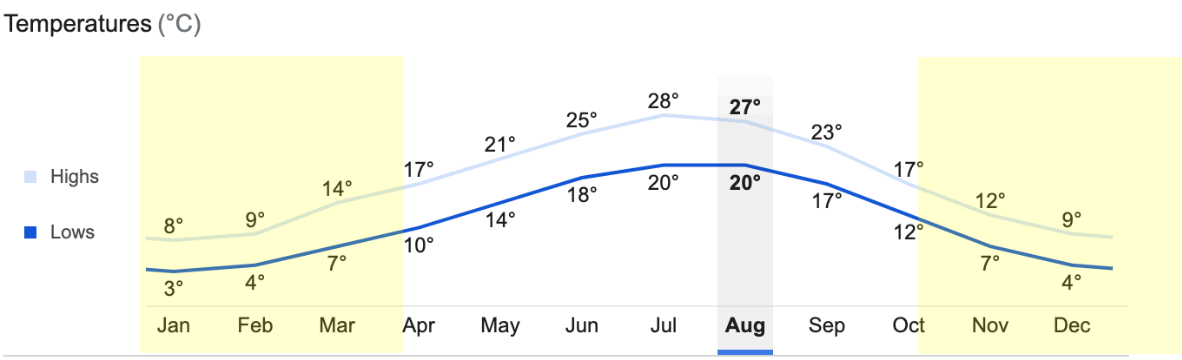


Figure 23. Graph of the monthly temperature along a year in Turin.

In view of the data, we can conclude that when the outside temperature is colder, the difference between the in stream and the out stream in the hot part varies so much more than when the outside temperature is higher. In figure 17, we can see that the cold streams vary a little more than in the hot months because of the direct contact with the huge difference in the hot ones. However, this difference is not important because the temperature is similar to the outside temperature, so it does not affect the cold streams.

Now, the next thing we need to do is to obtain the COP of the experimental situation to compare it with the data we had in the plant report. We are going to do so in the next point with the help of the Coolpack program.

8. THE PROGRAM: COOLPACK.

As already mentioned before, the program we are going to use to obtain the values, that we are going to compare with the theoretical ones from the report, of the functioning of the cooling system of the Energy Center is Coolpack. The objective of this program is to develop simulation models to be used for energy optimization of refrigeration systems. The idea behind the development of Coolpack is different from the usual ones. Instead of creating a large, general and comprehensive simulation program, they have created a collection of small, easy to use and numerically robust simulation programs.

The typical simulation program in Coolpack deals with only one type of refrigeration system and has a specific investigation purpose. It therefore only requires the user inputs/selections necessary to describe operating conditions etc. and not any inputs for describing the system design or for specifying the input/output structure associated with the simulation purpose.

The aim of the use of this program in this Thesis (as previously mentioned) is to calculate the COP of the experimental data obtained from the installation by using the simulator. This way, we will be able to compare it with the expected ones in first place. As the program is simple, the option it gives us is to use a one-stage system with constant compressor capacity. In the following two pictures, we can see how we have added the data to the program.

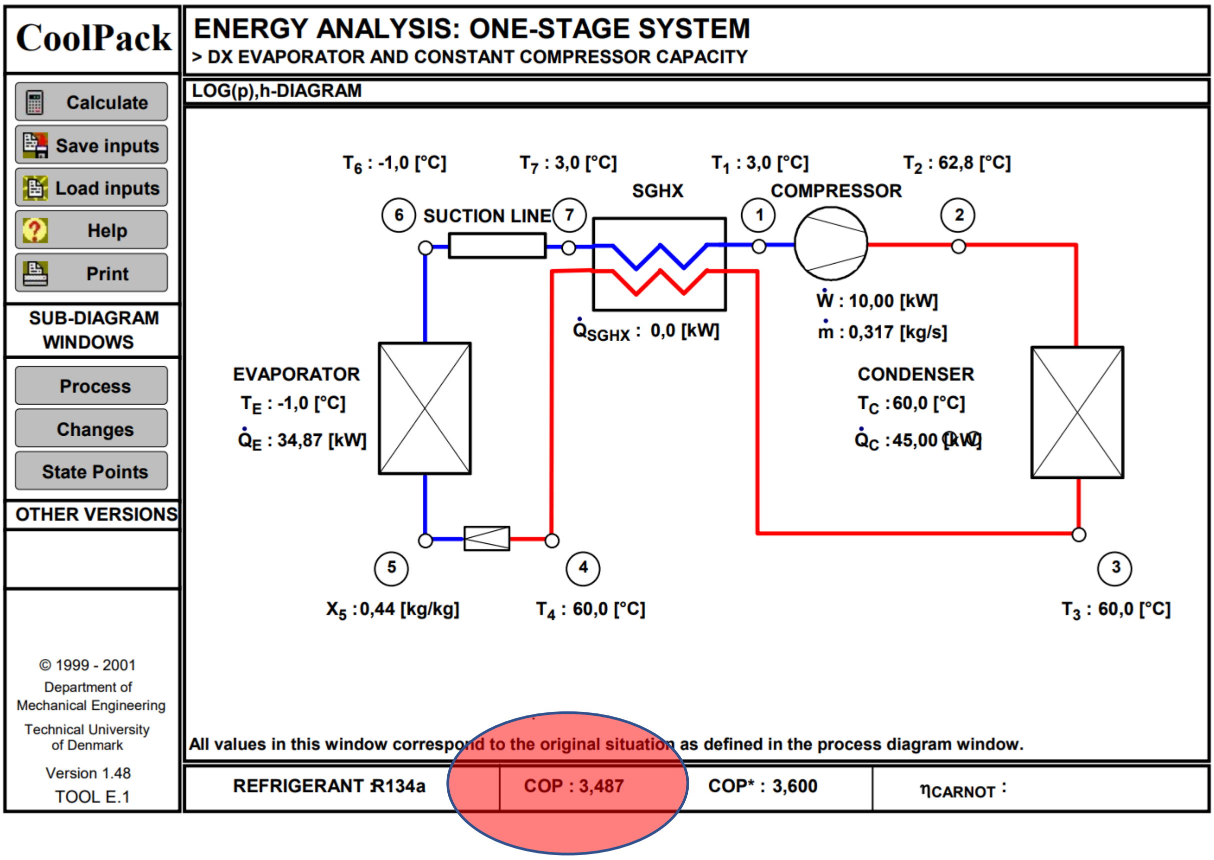
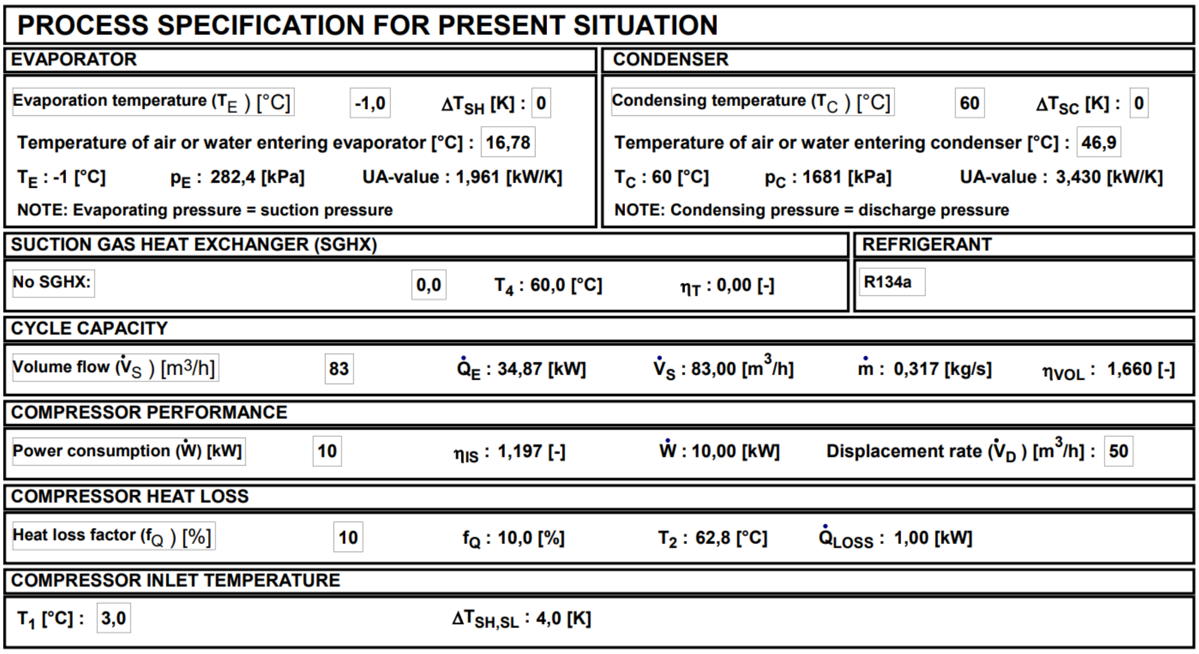


Figure 24. Coolpack program (I).

In this first picture of the program, we can see that it is of the type of one-stage system with constant compressor capacity as we have already mentioned before and the different states of the circuit and their characteristics. This has been done by introducing the experimental data directly obtain from the machine into the following picture (Figure 24). As the program is quite simple, we could only change some of the values. These values are the temperature of water entering the evaporator and the condenser. We have used the average in values from the table (the ones highlighted in yellow).

AVERAGE	34,00	46,88	17,74	16,78

Figure 25. Average experimental data.



PROCESS SPECIFICATION FOR PRESENT SITUATION

EVAPORATOR

Evaporation temperature (T_E) [°C] -1,0 ΔT_{SH} [K] : 0

Temperature of air or water entering evaporator [°C] : 16,78

T_E : -1 [°C] p_E : 282,4 [kPa] UA-value : 1,961 [kW/K]

NOTE: Evaporating pressure = suction pressure

CONDENSER

Condensing temperature (T_C) [°C] 60 ΔT_{SC} [K] : 0

Temperature of air or water entering condenser [°C] : 46,9

T_C : 60 [°C] p_C : 1681 [kPa] UA-value : 3,430 [kW/K]

NOTE: Condensing pressure = discharge pressure

SUCTION GAS HEAT EXCHANGER (SGHX)

No SGHX: 0,0 T_4 : 60,0 [°C] η_T : 0,00 [-]

REFRIGERANT

R134a

CYCLE CAPACITY

Volume flow ($\dot{V}_S$) [m3/h] 83 $\dot{Q}_E$: 34,87 [kW] $\dot{V}_S$: 83,00 [m^3/h] $\dot{m}$: 0,317 [kg/s] η_{VOL} : 1,660 [-]

COMPRESSOR PERFORMANCE

Power consumption ($\dot{W}$) [kW] 10 η_{IS} : 1,197 [-] $\dot{W}$: 10,00 [kW] Displacement rate ($\dot{V}_D$) [m^3/h] : 50

COMPRESSOR HEAT LOSS

Heat loss factor (f_Q) [%] 10 f_Q : 10,0 [%] T_2 : 62,8 [°C] $\dot{Q}_{LOSS}$: 1,00 [kW]

COMPRESSOR INLET TEMPERATURE

T_1 [°C] : 3,0 $\Delta T_{SH,SL}$: 4,0 [K]

Figure 26. Coolpack program (II).

This way, we have obtained the experimental COP from our installation[15]. In the following and last point, we are going to discuss the relation between this experimental value and the theoretical one given in the report.

[15] Highlighted in red in the Figure 23.

9. COMPARISON BETWEEN THEORETICAL AND EXPERIMENTAL DATA.

In this step we are going to carry out the comparison between the experimental data and the theoretical one expected at the beginning of the Energy Center project. Here we show the two different COPs.

Figure 27. Comparison between the experimental and theoretical COPs respectively.

As we can see, they do not differ too much. That little variation is due to the difference in the expected temperatures and the real ones. As shown in the Figure 20, the temperatures we have experimentally obtained:

AVERAGE	34,00	46,88	17,74	16,78

Figure 28. Experimental temperatures taken from Figure 20.

are not exactly the expected ones shown in the following picture (from Figure 14):

EVAPORATOR	**system side**	**source side**
in temperature	12	10
out temperature	7	5
delta T	5	5 to 7
CONDENSER	**source side**	**system side**
in temperature	15	45
out temperature	28 to 30	50
delta T	12 to 15	5

Figure 29. Expected temperatures taken from Figure 14.

The only thing that is left to do are the conclusion we can take from all the work done. It is going to take place in the following and last step.

10. CONCLUSIONS.

Once we have done all the previous work, now we are able to make conclusions. We can see that the expected temperature and the experimental one differs a little bit. This is due to the effect of the changes in the external temperature and the heat losses inside the machine, however, it is not significant.

The main objective of the Thesis was to analyze the experimental COP to decide if the operation of the installation is optimal. The bigger the COP is the better for the installation. In the previous step we have seen that the theoretical one is of 3,71. On the other hand, the experimental one is of 3,487. This little variation is due to the temperature difference but it is so small that we could despise it.

All in all, we can say that the machine of the Energy Center is working properly and giving the correct expected results.

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12. ANNEX.

ANNEX 1. M02.001.

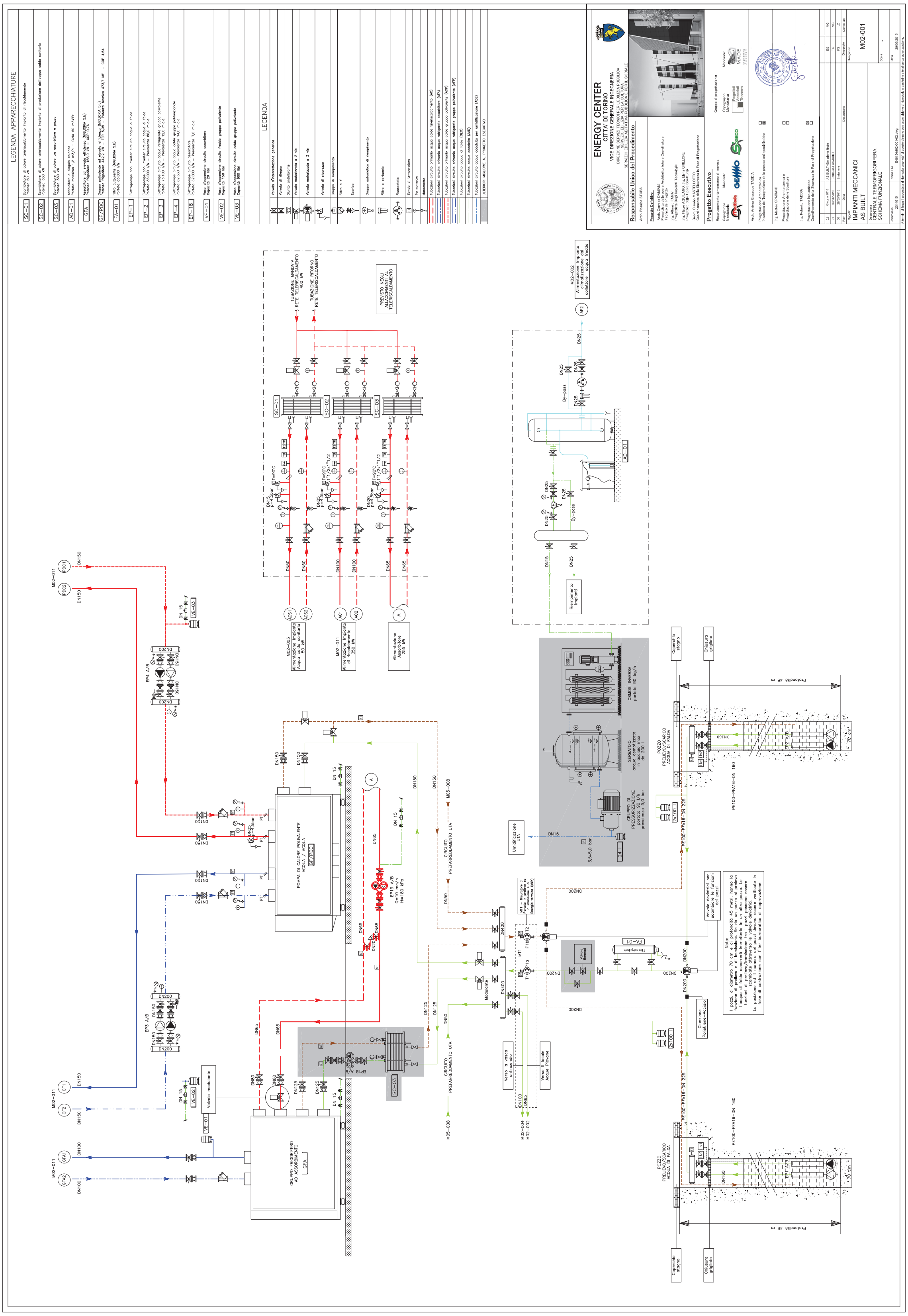

Figure 30. M02.001.

ANNEX 2. M02.003.

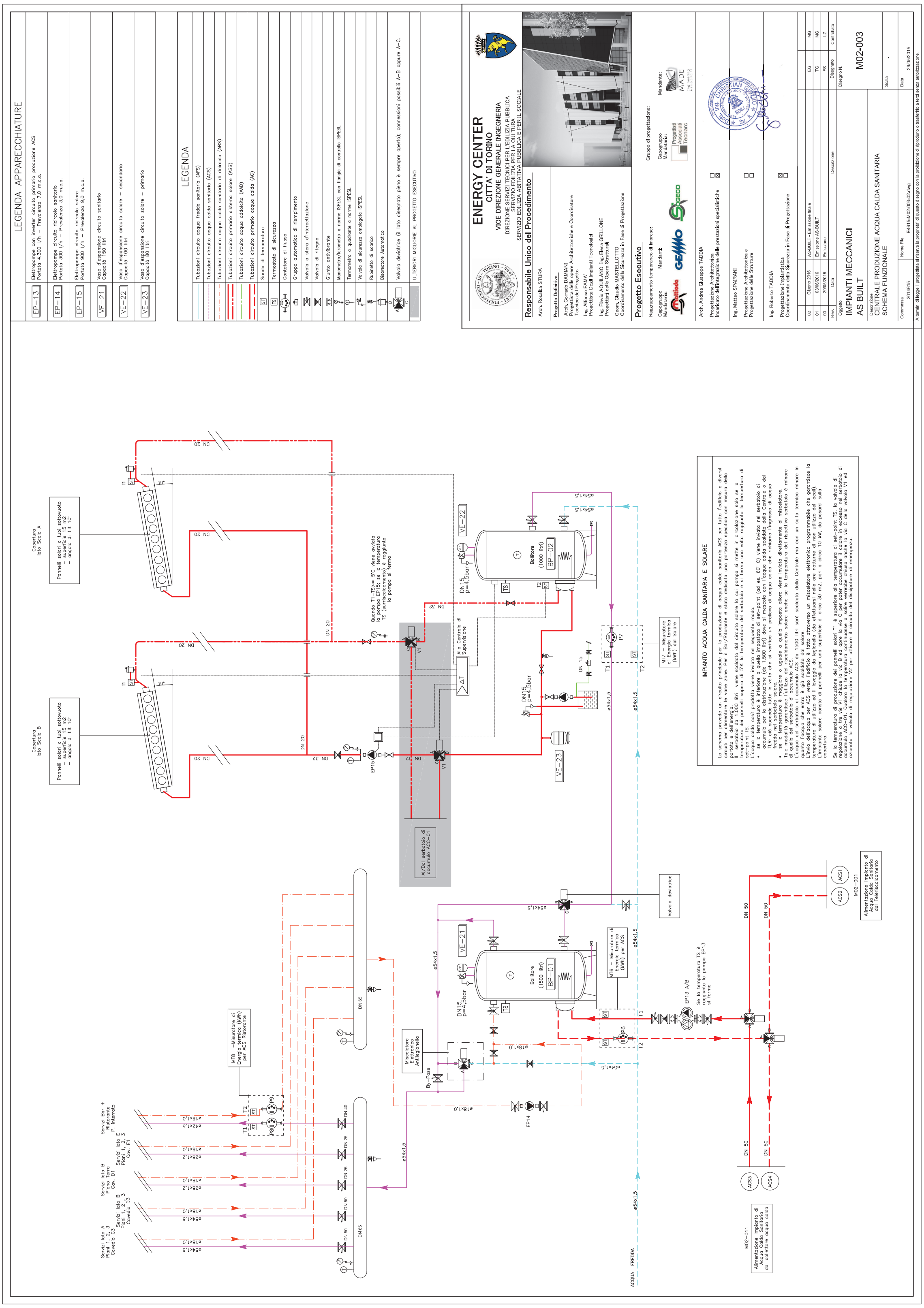

Figure 31. M02.003.

ANNEX 3. M02.011.

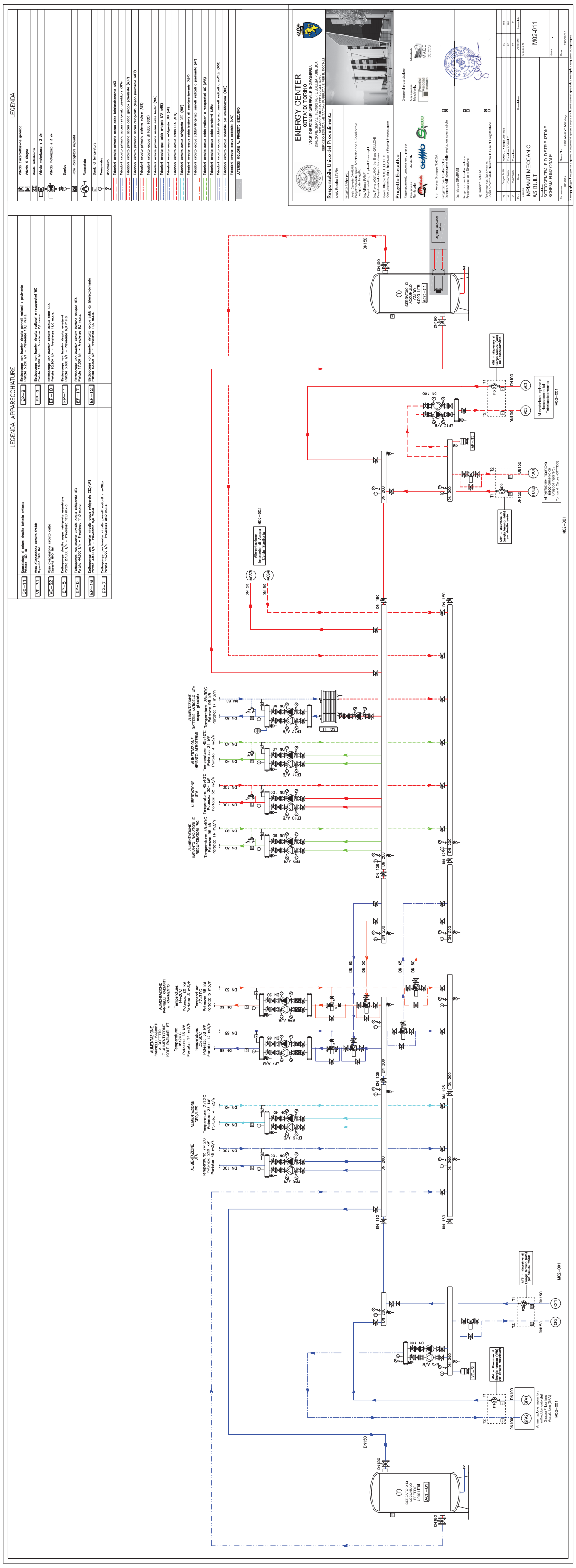

Figure 32. M02.011.