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ARCHITETTURA URBANISTICA INGEGNERIA DELLE COSTRUZIONI
E INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE

SUSTAINABLE MANAGEMENT OF A UNIVERSITY CAMPUS

Case study: Politecnico di Milano, Campus Leonardo

TESI DI LAUREA MAGISTRALE IN
MANAGEMENT OF BUILT ENVIRONMENT

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Academic Year 2021-2022

Abstract

The following thesis examines the performance of Politecnico di Milano Campus Leonardo systems using climate change and pollution emissions as a starting point.

The first chapter includes a brief bibliography and literature that explains the environmental context as well as the European and global objectives that the projects should achieve.

The analysis will determine whether the trigeneration system, which provides electrical and heating energy, can serve all of the buildings on which it is dependent.

Following this first step, a second is carried out to determine whether the absorption chiller (which completes the HVAC primary system) is capable of providing cooling energy.

Following the analysis that shows that cooling energy is not being provided, a case study of a larger chiller installed in a part of campus that is currently serving the building will be examined.

Following the cutting-edge analysis, there is an explanation of how refrigerant fluids and associated CO2 emissions can be measured and evaluated.

The availability of new gases and machineries already developed to use the new gases are then investigated, allowing the project to achieve the goals set in the first chapter.

It is planned that in the conclusion, it will be explained how the project of removing the old chillers and replacing them with new ones that are more powerful

Keywords: sustainability, energy management, co2 emissions control

Abstract in lingua italiana

La presente tesi utilizza il cambiamento climatico e le emissioni inquinanti come punto di partenza per analizzare le prestazioni degli impianti installati al Politecnico di Milano, Campus Leonardo.

Il primo capitolo contiene una breve bibliografia e letteratura che spiega il contesto ambientale e gli obiettivi europei e globali che i progetti dovrebbero raggiungere.

L'analisi determinerà se il sistema di tri generazione, che fornisce energia elettrica e riscaldamento, può servire tutti gli edifici che dipendono da esso.
Dopo questa prima fase, viene eseguita una seconda analisi per determinare se il refrigeratore ad assorbimento (che completa il sistema primario HVAC) è sufficiente per fornire energia di raffreddamento.

In seguito ai risultati, verrà analizzato un caso di gruppo frigorifero più grande installato in una parte del campus che attualmente serve un gruppo di edifici simili e paragonabili al district Leonardo 32, focus del progetto.
Dopo un breve excursus sulle problematiche derivanti dalle emissioni di Co2 e dalla pericolosità dei gas refrigeranti, verrà presentato un nuovo gas ed un macchinario alimentato da esso.
Verrà sviluppato il progetto dell'installazione di tale macchinario e redatto un piano di manutenzione con attività di legge da eseguirsi successivamente all'installazione dello stesso.

In conclusione, verrà spiegato come il progetto possa raggiungere gli obiettivi discussi nel primo capitolo, migliorando l'efficienza del sistema e risparmiando energia.

Parole chiave: sostenibilità, gestione delle risorse energetiche, controllo delle emissioni Co2

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Introduction

Given climate change and the production of CO_2 in Milano and the metropolitan area, it is critical to find efficient solutions that help to reduce energy and resource waste.

The purpose of this thesis is to investigate and evaluate the state of the art of the Politecnico di Milano Campus Leonardo trigeneration system, to assess its sustainability and to find a possible solution, if needed.

The document begins with a review of sustainability literature, rules and goals, followed by a state-of-the-art study and data comparison to determine whether the current electricity and conditioning system is efficient.

After that it will be studied the current state of the art of Politecnico cooling systems to better understand the district system.

The analysis will be more focused on a case study: energy consumptions of the buildings before and after changing the number and power of refrigeration units; it will be possible to examine and determine whether it was more efficient, and to try to apply that change to the other buildings with a mixed solution.

If the analysis yields a positive result, a scenario case study will be created in which the cooling system is changed and how the efficiency results, produced co_2 amount, and so on may change.

The project will include machine solutions, a maintenance plan for the machine's life cycle and it will be show how the project can help to achieve the climate goals set in the first part.

1. Introduction literature - state of the art

The following chapter is based on literature that aids to understand environmental goals in the context of rules and goals.

1.1 Climate change and climate goals

The literature supporting the redaction of the state of the art of the current situation lays in regulation and goals settled during international conventions and agreements.
Here it follows a list of requirements and goals that will be the exploited during the rest of the elaborate.

It is involved the agenda 2030 and the Italian National Strategy for Sustainable Development - Strategia Nazionale per lo Sviluppo Sostenibile (SNSvS) as it involves the national strategy definition based on D.Lgs 152/2006 art. 4 which states that it must be defined and updated every three years.

Structure and contents of SNvS are now a reference for planning and evaluation processes.

Regions are asked to elaborate and adopt a sustainable development strategy that should define their contribution to achieve the national strategy goals.

(Which is currently happening to improve the Agenda 2030).

Current situation is that first SNvS review has been drawn and must be approved in CITE. SNSvS states 56 indicators that should grant territorial compatibility and integrated monitoring activities (art. 34 Dlgs 152/2006 e ss.mm.ii.)

SDGs are connected wih SNSvS (and agenda 2030) because they balance the three dimensions of sustainable development which are economic, social and environmental.

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1. Presentazione Riccio al webinar 16/06/2022 “La transizione delle città verso la sostenibilità”
2. Presentazione Cossu al webinar 16/06/2022 “la transizione delle città verso la sostenibilità”

1.1.1 PNIEC 2030 (Piano Nazionale Integrato per l'Energia e il Clima)

- Greenhouse gas effect reduction for 2030 that should be reduced by 33% compared to 2005.

- Primary energy consumption reduction should be reduced by 43% compared to 2007. The reduction should be achieved through buildings regeneration with an annual rate of 0,7% for residential buildings and 2,5% for commercial buildings.

-Gross annual consumptions will be covered by 30% by renewal energy sources covering 55% for electrical systems and 33,9% for thermal systems.

1.1.2 LTS 2050 (Strategia italiana di lungo termine sulla riduzione delle emissioni dei gas a effetto serra)

The main goal for LTS is the total reduction of greenhouse gas emissions.

Final energy consumptions will be reduced by 40% with respect to the current scenario and will be covered by 85-90% from renewal energy sources.

Electrification will exceed 50% thanks to the use of electric cars and heat pump systems in buildings.

Goals for 2030 that can be considered in this thesis (systems goals) are listed as it follows:

- Reduce energy requirements for heating, cooling, and hot water
- Reduce energy use for ventilation, lighting, appliances
- Increase the fraction of energy generated from renewable sources "on site" in buildings
- Reducing the impact of buildings in terms of greenhouse gas emissions
- Improving energy management at the level of individual buildings and districts
- Educating occupants to manage comfort and energy.

Guidelines to achieve the goals (related to systems) are:

- Diffusion of heat pump systems for thermal and cooling energy generation
- Use of distributed and centralized thermal storage technologies, including storage
- Development of networks for the transport of heat and cooling energy at district level, where the density of needs per sq.km allows this
- Energy flow and comfort monitoring systems (Digital Twin)
- Interplay between electricity and heat, balancing offer-demand, flexibility.

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3. White paper "Smart sustainable districts: un modello per progetti di rigenerazione urbana" -marzo 2022

Solutions stemming from goals and guidelines then can be exploited through different activities and scenarios, such as energy redevelopment, which will help reduce energy demand, leading to the progressive increase of renewable sources, such as environmental heat, waste heat, biomass, solar photovoltaic and thermal.

Heat pump generation plants, mainly electrically driven, but also thermally driven absorption systems, will be the main solution to achieve the previous goals fulfilling the guidelines.

At the same time, there will be a progressive reduction in the consumption of gas for thermal uses in buildings and an increase in electrical consumption for thermal and refrigerators, with the possible interactions between electrical and thermal sectors.

District heating and cooling networks allow the realization of energy efficiency on an urban scale, that help recovery of waste heat from neighboring processes and the integration of renewables that, in the size of the neighborhood, show a remarkable economy of scale.

Thanks to the flexibility that characterizes these energy infrastructures, it is possible to integrate a multiplicity of different waste heat sources of industrial processes, purifiers, groundwater or geothermal heat pumps, Solar thermal that, thanks to the support of heat accumulations, can be managed in their temporal variability.

The neighborhood-scale design compared to the single building allows a greater impact on decarbonization, involving different buildings in a single intervention.

- ISO 37100:2016 which will support the SDG 11: sustainable cities and communities through the vocabulary definition

- ISO 37104:2019 which aims to transform the cities according to the guidance for practical local implementation of ISO 37101

- ISO 37106:2021 which settles the guidance on establishing smart city operating models for sustainable communities

- ISO 37120:2019 which establishes indicators for city services and quality of life and the similar ISO 37122:2019 which is about the indicators of smart cities and ISO 37123 that states indicators for resilient cities

- ISO 37155-1:2020 Framework for integration and operation of smart community infrastructures – part 1: recommendations for considering opportunities and challenges from interactions in smart community infrastructures from relevant aspects through the life cycle

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4. White paper chapter G: Energia.1 "Soluzioni energy neutral" - M. Aprile (coordinatore), P. Caputo, A. Denarie, S. Mariani, M. Motta, L. Pagliano, C. Pulitano, R. Scoccia

- ISO 37160:2020 Smart community infrastructure – Electric power infrastructure – Measurement methods for the quality of thermal power infrastructure and requirements for plant operations and management

- ISO/DIS 37109 that should be considered in the second part of the thesis, as it is about recommendations and requirements for project developers – Meeting ISO 37101 framework principles

1.2 Sustainability

The second section discusses goals and already implemented solutions and plans that can serve as the framework for the analysis

1.2.1 Sustainable Development Goals (ONU)

The Sustainable Development Goals (SDGs) were established in 2015 to guide global development until 2030.

They outline a global strategy for all countries to end poverty, protect the environment, and ensure prosperity.

They are a set of 17 objectives that will be used to gauge progress.

The 17 goals are interconnected and are meant to be tackled as a group rather than individually.

Here are listed the goals to which this thesis can be related:

7 – Affordable and clean energy:

Goal targets:

- By 2030, ensure universal access to affordable, reliable, and modern energy services

- By 2030, increase the share of renewable energy in the global energy mix

- By 2030, double the global rate of improvement in energy efficiency

- By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology.

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5. https://www.undp.org/sustainable-development-goals

- By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, least developed countries, small island developing States, etc.

11 – Sustainable cities and communities

Cities currently house 4.2 billion people, with a population of 6.5 billion expected by 2050. Given that cities consume 60-80% of all energy and emit 70% of all carbon emissions, and that 90% of future urban growth is expected, goal targets (only the ones related to the present thesis) are listed as follows:

- Strengthen efforts to protect and safeguard the world’s cultural and natural heritage

- By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management

13 – Climate action

Climate-related disasters cause annual economic losses in hundreds of billions of dollars. Human toll of geophysical disasters, which are 91% climate-related and killed 1.3 million people and injured 4.4 billion between 1998 and 2017.

In 2017, it was estimated that each human was responsible for +1°C of global warming; to limit global warming, global CO_2 emissions should drop by 45% until 2030 and reach net zero by 2050.

Goal targets are:

- Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries

- Integrate climate change measures into national policies, strategies, and planning

1.2.2 Proposed mitigation plan and CO_2 emission reduction targets for Politecnico di Milano

Several Italian universities have a longstanding commitment to reducing CO2 emissions. Politecnico di Milano is coordinating the "cambiamenti climatici" working group of the Network of Universities for Sustainable Development (RUS).

This group enhanced "CO2 Polimi" project which is aimed to measuring, monitoring and reducing CO2 emissions and it is based on inventory of university CO2 emissions, including annual update (which have been realized just for 2014, 2015 and 2016 at the moment).

Activities (the ones concerning systems that will be treated in the present thesis) considered for the data collection are listed as it follows:

- electricity consumption
- gas consumption (excluding consumption for energy production electrical used outside)
- energy consumption from external district heating networks; and district cooling

Following the collection of those data, the related goals were established:

1) Trigenerator optimization for campus Leonardo
3) Lighting replacement and optimization.
4) Photovoltaic energy production
5) Replacement of refrigeration systems.
7) Systems regulation

6. https://www.undp.org/sustainable-development-goals#climate-action

7. Proposta di Piano di Mitigazione e di obiettivi di riduzione delle emissioni di CO2 del Politecnico di Milano - Stefano Caserini, D.I.C.A., Paola Baglione, Eleonora Perotto, A.D.I.G.E.N. - S.S.A, Con la collaborazione di Maurizio Delfanti, Ennio Macchi, Paolo Beria, Samuel Tolentino

1.3 Energy

The following chapter is about already taken action strictly connetted to energy management and consumption.

1.3.1 Energy storage and management

Storage systems and synergistic models for exchange is an actual matter as main energy variables in our country will be strongly influenced by the new European climate law (climate neutrality target in 2050, with a reduction of 55% compared to 1990 by 2030).
Renewable energy sources (RES) in many cases depend on atmospheric conditions and are therefore "not programmable" : balancing the production and consumption of energy becomes an essential condition for having a stable and reliable electricity network.

To address this problem, energy storage systems (SDA) can be introduced that decouple production and consumption; among these is the role that electric mobility can play, through appropriate interactions V2G (vehicle-2-grid) and G2V (grid-2-vehicles) through which vehicles can become active members of the electricity grid in a bidirectional way (acting at the same time as producers and consumers of electricity).

In Italy the ARERA has launched (Del. 300/2017) a series of pilot projects for the integration of new resources in the MSD (Market for the Dispatching Service): among these are the sda, with the UVAM and Fast Reserve projects (the latter allows a fast frequency adjustment service and will see the start of service delivery in 2023).

The final goal of SSD must be to develop an efficient and secure integrated system for energy IES (Integrated Energy System) consisting of networks with production plants from different sources, renewable and not, connected: Such networks must be equipped with properly dimensioned sda to ensure a reliable, flexible and economical production, transmission and distribution of energy, minimizing the environmental impact in favor of sustainability.

The guidelines that will be used and developed through the case study that this thesis will care about and follow are:

1) Power generation systems mapping

2) Identification of facilities that can be combined with storage systems

3) Identification of elements to exploit stored energy such as district heating, agricultural uses (greenhouse heating) or industrial processes

Storing electricity might result expensive and based on technologies (batteries or re-molding) that have important environmental implications during production and disposal.

"Energy storage" means taking electricity from the grid, converting it into another form (e.g., chemical in the case of batteries, gravitational potential for repumping), moving it to storage, converting it into electricity before reinserting it into the grid.

This process can be very expensive (both environmentally and economically) if you must store the energy needed for a neighborhood or city.

Storing energy at an appropriate point in the transformation chain from primary energy to electricity is the key concept of "Generation Integrated Energy Storage (GIES)" systems.

The proposed solutions for the integration of the accumulations in intelligent districts can be about integration on supply of multiple services and an innovative logic of control tied to the market: An innovative strategy adds to self-consumption the simultaneous provision of network services on the MSD: the battery powered by renewable energy contributes to the proper functioning of the system.

To widespread the energy saving in residential contexts it is important to strengthen support mechanisms for the installation of small batteries based on the indications of the European Commission that at the beginning of 2020 has included these technologies in the pilot project for the creation of self-consumption groups of renewable energy or renewable energy communities.

In these integration schemes there are incentives for the energy produced on site and shared among the members of the configuration, and the installation of sda is allowed to increase the share of energy made available to the community.

Another driving force behind the spread of residential sda is the Super bonus (Law 17 July 2020, n. 77) which allows access to tax deductions of 110% also for the construction of photovoltaic systems and any sda integrated with them; the measure will be valid until December 2023.

With reference to the role of electric vehicles, the 2030 projections of the International Energy Agency indicate that the charging of such vehicles will take place for over 70% by private charging, with the remaining 30% covered by slow public charging systems (22 kW) and fast (150 kW).

To enable this, the systems should be designed to allow for the necessary charging points, including bi-directional network connection schemes.

In the case of Energy Community there is the possibility of increasing the production of shared energy (energy produced by one of the participants and used by the others), with economic incentive.

Innovative aspects of the showed applications are related to the modeling of the technologies and the logic of control of assets already diffused to commercial level: The modeling of the sda (of generous size) and its operation within the electricity market requires accurate models, but at the same time of limited computational burden.

The relevance of the sda real-time management software and of the algorithms of planning and optimization of the operation gets evident: for this reason, the battery controller that implements the advanced control logic in multiservice logic and the Energy Management System of the community (district or aggregate of resources) are important for the optimization of the various assets.

The actors involved include users or participants of the Energy Community, interested in environmental issues and the economic return of investments subject to various incentives and bonuses.

For the provision of services to the network, the aggregator is the interface with the electricity market: the main Italian aggregators have been looking for a long time for active domestic electrical users, with accumulations to be included in their portfolio for participation in pilot projects.

Finally, the technology provider can represent the added value: therefore, the creation of a national supply chain for the production and integration of the battery system is a goal to be pursued (also) with the tools put in place by Europe.

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8. Chapter G: Energia: "Sistemi di stoccaggio e modelli sinergici per lo scambio" -E. Zio (coordinatore), F. Bordignon, F. Bovera, F. Capella, A. Di Lieto, F. Di Maio, G. Locatelli, M. Merlo, G. Pontoglio, G. Rancilio

2. Case study: Politecnico di Milano campus Leonardo

The purpose of this chapter is to present a state-of-the-art situation that can be considered based on visual inspections, data collection and verification from system reports, energy balances, and so on.

2.1 Case study framework: Politecnico Campus Leonardo – Città Studi

Politecnico Leonardo is made of 30 buildings each of those are used in a different way that may include classrooms, offices, restaurants, labs, gym, locker rooms, etc.

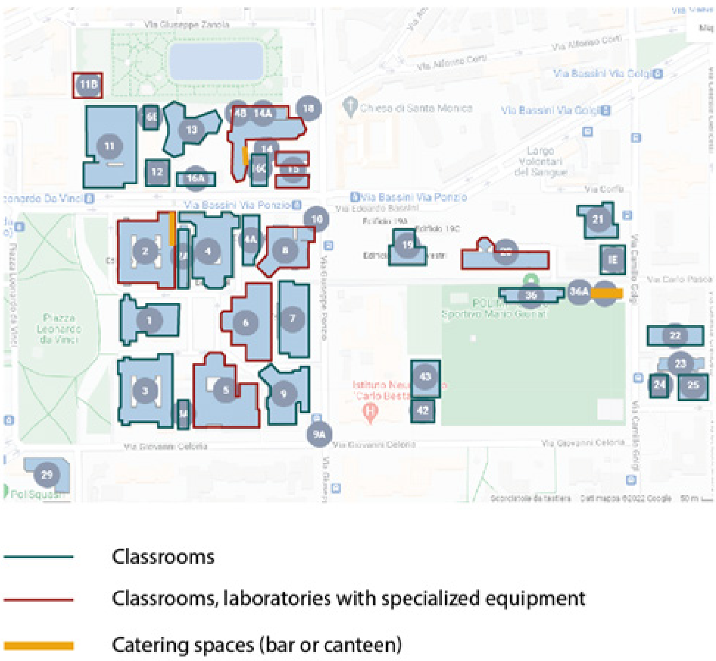


Figure 1 Use of the buildings in Polimi district

The energy requirements and consumptions of buildings are primarily divided into four macro categories:

A. Classrooms, which should have an average temperature of 24-27°C during the summer and 18-22°C during the winter season, according to D.Lgs 81/2008. (more or less 1 degree is tolerated)

B. Bars and canteens that, according to ATS rules, should have a temperature of 22-26°C during the summer and 20-22°C during the winter season.

C. Laboratories that are located inside the majority of the buildings and may request special accommodations based on the tools and equipment they require (for example, in DFIS, Building 8, there is a wind tunnel, etc.)

D. Other spaces such as storages, warehouses, vestrooms, bathrooms, porches, custode houses, and terzi spaces (as it will be possible to see in the following chapter in which the different buildings will be analysed).

The larger district can be divided into smaller districts; this is the analysis that will be developed in the following chapters.

2.2 Energy studies: state of the art

In the following paragraph, an analysis of the systems delivering electricity and thermal energy to buildings will be performed.

It is first explained how energy is provided at the primary level, and then at the secondary level, which is about the delivery of energy to buildings.

2.2.1 District energy production and supply

A trigeneration unit in the central power generation station provides electrical power, heating, and cooling.

While the heating system serves all buildings, the cooling system only serves the buildings closest to the central generation station.

To serve the buildings there is a private electric network, a district heating (tele-riscaldamento), a technological power station and a trigeneration unit.
The technological power station is made of:

- 3 water heaters (caldaie). Only two of which are working since one was powered off

Figure 2-4: Primary system station boilers

• 1 absorption chiller that exploits the heating energy coming from the co-generator and transforms it in refrigerated energy instead of wasting it

Figures 5-6: Primary system Absorption chiller

• 1 Water softening system that serves the trigenerator and heaters water circulation up to the subcentral stations, preventing water damage to the machines and subcentral machines receiving water.
Other softening systems will be installed in the subcentral to ensure that the water circulating inside the building is soft enough not to damage internal plumbing and machineries such as fan coils, radiators, taps, and so on.

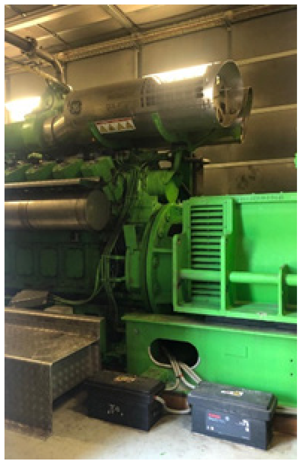
Figure 7-9 Primary system Softening system

• In the basement there’ s a pumping station (renewed in 2015) that is made of pumps and separators. Each of those pumps are implemented by inverters.

To complete the system, two expansion vases and two tanks. During summer inspection, just the electric pump serving the absorption chiller and the part of the system used as district cooling (tele-raffreddamento) were working.

Figures 10-11: Primary system pumping station and heating exchangers

• The trigeneration unit is made of an engine powered by natural gas and it’ s been observed to have an electrical performance of 43% and a thermal performance of 33-34%.



Figures 12-14: Primary system Trigeneration system

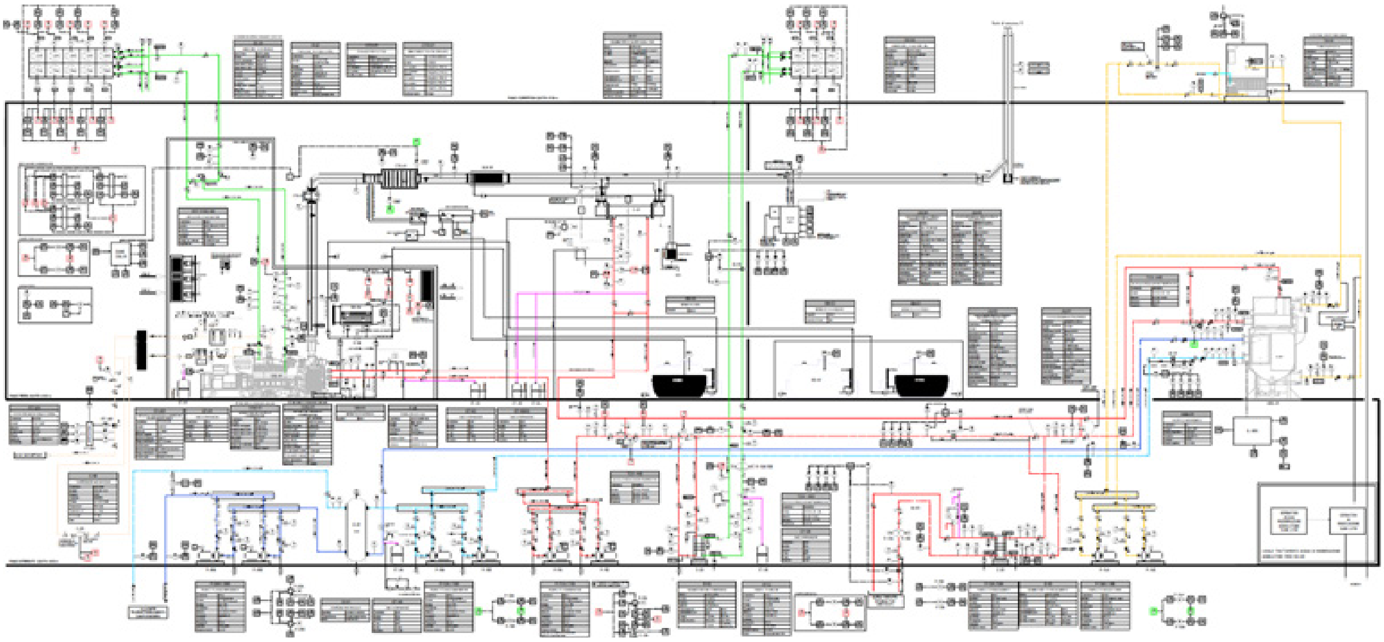


Figure 15: functional diagram of the primary network

2.2.2 Secondary system - substations

Every building is served by a sub-station.

The dimensions of substations beneath buildings vary depending on the buildings they serve. Regardless of size, they have the same structure. Substations are made of the following:

• A supply and return ducts line from the central power generation system (trigenerator)
• Various spilling points from the supply part allow water supply to the building above the subcentral station (secondary system). The collectors are supposed to serve a different system that might be an air handling unit, radiators, fancoils, etc. depending on the building they are underneath

• There is a returning ring which allows the water to also get back into the generation system (primary system)

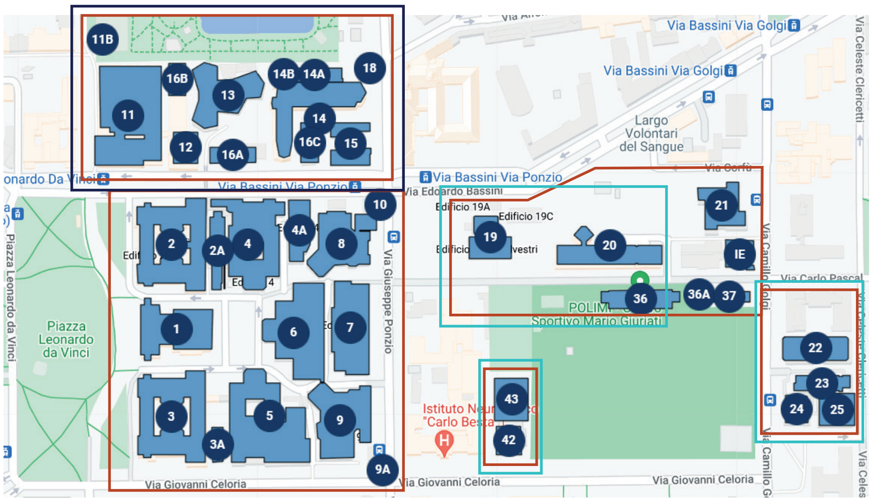
• There is a circuit breaker tank and a changer and measuring system moduled by two-ways valves

• Softening system for the water that need to be pumped into the building



Figure 16-18: Subcentral stations examples

Some buildings, for instance building 3 and 11 are served by 2 changers instead of just one.



District heating network provided by the trigenerator in the main thermal power central station

District cooling provided by two 1.5MkW refrigeration units

District cooling network provided by the absorber system in the thermal power central station

Figure 19 – District energy distribution systems

Some refrigeration units are used in the cooling system of larger buildings. Refrigeration system units’ range in size from 50kW in the smallest to 1.5MkW in the largest.

Two 1,5MkW refrigeration units installed in 2021 serve a portion of the district. Separate refrigeration units serve the rest of the district, which mostly consists of square buildings numbered 1 through 9. (at least 1 unit for building).

2.2.3 Analysis and methodology

The energy efficiency analysis will be conducted at several levels:

2.2.3.1 First level: Heat exchanger analysis to detect any energy loss in the circuit

The first level of analysis will examine all available data from the Etna platform regarding heat exchanger performance results.

Previous data are gathered for each building that is powered by the primary network (coming from the thermal central station).

To gather data, each average heat exchanger performance will be evaluated from 2020 to 2021, and it will be determined whether each building receives the same amount of energy.

The buildings will then be divided to determine which buildings are receiving more/less power and where they are, to determine whether it is a distance problem from the thermal central or a district problem, and so on.

2.2.3.2 Second level: analysis of refrigeration units' energy consumptions

It will be assessed based on the average energy consumed vs. the power of the refrigeration unit to better understand if they consume too much due to their age and conditions.

Based on this parameter, it will be determined which machine is the most efficient. Furthermore, the energy requirements of the building will be assessed and demonstrated if they are met.

In this case, the period considered will be from 2020 to 2021.

2.2.3.3 Third level: analysis of buildings 11–16 to determine consumption before and after 2021.

In 2021, two large refrigeration units were installed in place of the smaller refrigeration units that were previously supplying energy to the entire district.

An analysis will be performed to determine whether the energy requirements of each of these smaller district buildings were met before and after 2021, and whether they improved.

If there is a positive improvement, the needing of all the buildings showing a lack of power from the first level analysis and all the buildings showing they are not receiving the right amount of thermal energy from their small refrigeration units will be checked, and the case study of the two larger refrigeration units will be applied, if possible, as possible problem solutions.

2.3 Assessment of the primary system's energy production and distribution

The data presented below were downloaded by the system monitoring information system.

They have been organized based on the necessary information, using the previously described methodology.

Only the heat and electrical power will be assessed in this paragraph to report the system's state of the art, while the system's weaknesses will be discussed in the following chapter.

The time under consideration will run from January 2020, when the BEA department informed the system that it would not be shut down during the COVID-19 emergency, to end of 2021.

2.3.1 Heaters (caldaie)

In the following tabs and graphs, the season will be colored with light blue for winter, orange for midseason because the heaters may still be on (as in October-November or March-April), and red for summer because they should be turned off

2020	Average performance (kWh)							
Thermal season	Heater 1	Heater 2	Heater 3	Total perfomances	Gas Heater 1	Gas Heater 2	Gas Heater 3	Tot gas performances
Winter season	198,89	363,06	456,74	1018,7	22,24	39,77	48,91	110,92
Summer season	0	0	0	0	0	0	0	0
Midseasons	0	0	0	0	0	0	0	0

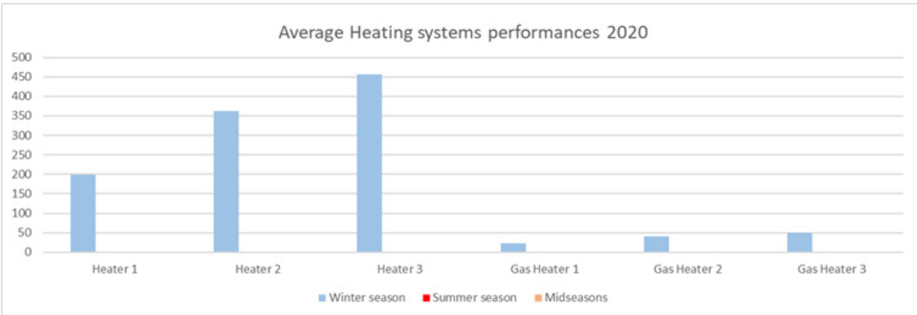


Table 1 Average heater performances in 2020

9. ETNA https://planetlab1.elet.polimi.it/searchexport/ with the courtesy and credentials of the energy monitoring department of Polimi

2021	Average performance (kWh)							
thermal season	Heater 1	Heater 2	Heater 3	Total perfomances	Gas Heater 1	Gas Heater 2	Gas Heater 3	Tot gas performances
Winter season	4,56	770,14	875,93	1650,64	0	84,76	94,22	178,98
Summer season	0,46	0,19	0,22	0,88	0	0	0	0
Midseasons	0,79	8,31	50,88	59,99	0	1	5	6

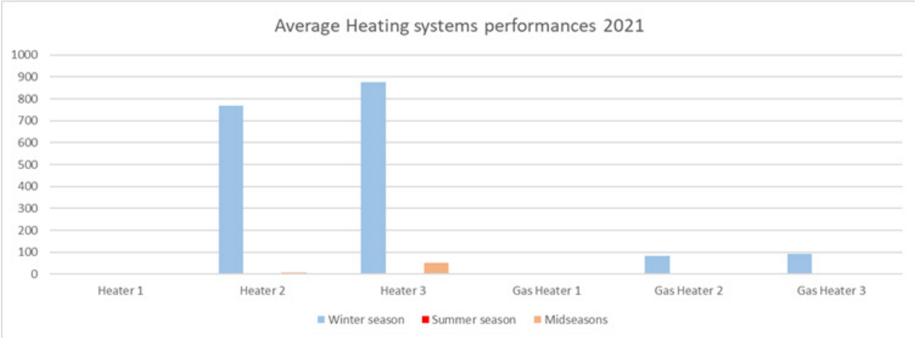


Table 2 Average heater performances in 2021

The data presented shows that the power generated by the heaters was sufficient for the served buildings and that they were constantly working and providing enough energy in the building.

During the mid-seasons in 2021, one heater was also operational.

For the following data on CO2 consumption, production, and savings, 2019 is included to show how results improved over time.

Year	Thermal systems		Electrical systems	Tot avoided
	Produced Co2 (tons)	Avoided Co2 (tons)	Avoided Co2 (tons)	Co2 (tons)
2019	11326,23	2537,94	13815,45	5027,16
2020	17511,03	2659,67	13832,81	5041,45
2021	13535,4	2923,9	16327,55	57156
Tot	42372,66	8121,51	43975,81	67224,61

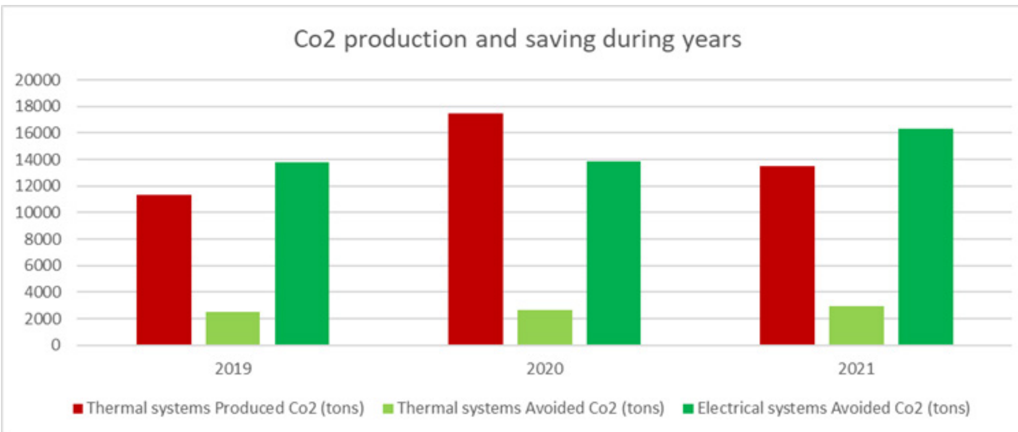


Table 3 Produced and avoided Co2 over the years

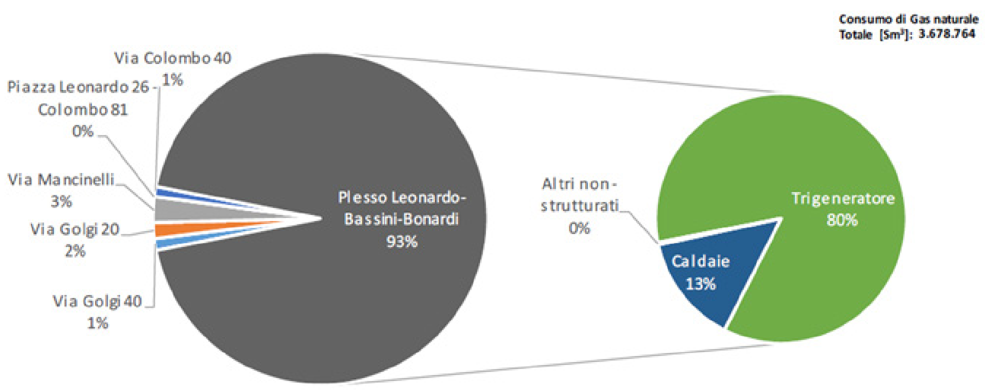


Figura 21. Consumo gas naturale, Sede Milano Città Studi

Figure 20 - Natural gas consumption, district level - BEA

3. Evaluation of system performance

In the following paragraph the systems performances are evaluated on the basis of the data collected from Etna system , a management software that allows to track the performances of the various systems.

A special and devoted acknowledgement goes to Lorenzo Redolfi, Filippo Bovera and Paola Baglione

for the data providing.

3.1 Weaknesses of the current state of the art – cooling system

The plate heat exchanger is a surface heat exchanger in which two fluid currents at different temperatures exchange thermal content via relief surfaces arranged next to each other, where the fluids alternate with countercurrent flow.

The plate heat exchanger is made up of a series of corrugated plates that are separated from each other by a rubber seal or other material that ensures the hydraulic seal to the outside and around the passage holes (to increase the exchange surface and turbulence and prevent them from bending).

Depending on the position of the plates, each pair delimits a passage chamber for the hot fluid or for the cold fluid; in fact, each plate is in contact on one side with the hot fluid and on the other side with the cold fluid, alternately (so in the first plate the cold fluid is on the right side and the hot fluid on the left side, in the next the hot fluid is on the right side and the cold fluid on the left side, and so on).

Each plate has four holes at the corners (two feed holes and two drain holes).

In a plate heat exchanger, the heat passes through the surface that separates the hot fluid from the cold one. This allows heat or cool liquids/gases with minimal energy levels. The temperature difference is the “driving energy” of the exchanger and this is the reason why the exchangers have been used as a proxy to understand how the systems are working.

The tabs below display the registered data from the Etna system that are assessing the current state of the heating energy originating from the primary and secondary systems.

The data was analyzed by comparing the supply and return temperatures of the primary and secondary systems during the winter, summer, and midseason.
Both the 2020 and 2021 time periods have been examined.

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10. B.E.A. Bilancio Energetico di Ateneo - Report 2020

SCT2	Building 2 Average °C exchanged			
	Primary system		Secondary system	
2020	Supply (°C)	Return (°C)	Supply (°C)	Return (°C)
Winter season	49,37	34,08	36,14	35,45
Summer season	23,70	23,10	23,62	23,19
Midseasons	25,55	22,58	24,08	23,75
2021	Supply (°C)	Return (°C)	Supply (°C)	Return (°C)
Winter season	56,52	37,82	38,82	37,82
Summer season	23,52	22,86	23,55	23,01
Midseasons	42,28	32,68	34,16	33,14

Table 4 - Data from SCT 2 corresponding to building 2

SCT3	Building 2 Average °C exchanged			
	Primary system		Secondary system	
2020	Supply (°C)	Return (°C)	Supply (°C)	Return (°C)
Winter season	61,12	40,92	40,28	38,73
Summer season	11,36	11,21	11,07	10,93
Midseasons	39,08	29,91	29,37	28,40
2021	Supply (°C)	Return (°C)	Supply (°C)	Return (°C)
Winter season	59,3	45,06	43,93	41,80
Summer season	24,70	24,42	24,19	23,65
Midseasons	48,04	35,25	35,62	33,54

Table 5 - Data from SCT 3 corresponding to building 3

SCT4	Building 2 Average °C exchanged			
	Primary system		Secondary system	
2020	Supply (°C)	Return (°C)	Supply (°C)	Return (°C)
Winter season	61,91	38,56	38,98	36,17
Summer season	11,42	10,79	10,59	10,64
Midseasons	38,24	28,82	29,52	28,60
2021	Supply (°C)	Return (°C)	Supply (°C)	Return (°C)
Winter season	58,94	44,60	44,13	41,92
Summer season	25,01	24,61	24,80	24,59
Midseasons	47,82	32,69	34,16	31,47

Table 6 - Data from SCT 4 corresponding to building 4

SCT5	Building 2 Average °C exchanged			
	Primary system		Secondary system	
2020	Supply (°C)	Return (°C)	Supply (°C)	Return (°C)
Winter season	60,71	39,81	38,59	37,57
Summer season	22,11	21,72	21,75	21,40
Midseasons	37,98	30,09	29,52	28,94
2021	Supply (°C)	Return (°C)	Supply (°C)	Return (°C)
Winter season	59,47	45,81	43,9	42,55
Summer season	2,77	2,48	2,24	2,36
Midseasons	46,11	33,81	33,04	32,12

Table 7 - Data from SCT 5 corresponding to building 5

In red it is possible to see a lack of data that may be caused by a temporary failure of the system.

In order to avoid starnge results, the lack of data is not being considered in further calculations.

SCT6	Building 2 Average °C exchanged			
	Primary system		Secondary system	
2020	Supply (°C)	Return (°C)	Supply (°C)	Return (°C)
Winter season	66,34	43,27	43,15	40,46
Summer season	24,81	24,37	24,61	24,24
Midseasons	42,51	33,4	33,26	32,19
2021	Supply (°C)	Return (°C)	Supply (°C)	Return (°C)
Winter season	62,01	45,53	46,16	42,07
Summer season	24,35	23,89	24,02	23,68
Midseasons	47,95	35,06	36,79	32,65

Table 8 - Data from SCT 6 corresponding to building 6

SCT7	Building 2 Average °C exchanged			
	Primary system		Secondary system	
2020	Supply (°C)	Return (°C)	Supply (°C)	Return (°C)
Winter season	58,93	39	40,36	39,4
Summer season	24,42	23,99	24,16	23,77
Midseasons	38,39	30,61	33,31	32,59
2021	Supply (°C)	Return (°C)	Supply (°C)	Return (°C)
Winter season	57,04	46,56	49,85	42,08
Summer season	24,04	23,65	23,78	23,43
Midseasons	43,58	34,89	38,13	33,11

Table 9 - Data from SCT 7 corresponding to building 7

SCT8	Building 2 Average °C exchanged			
	Primary system		Secondary system	
2020	Supply (°C)	Return (°C)	Supply (°C)	Return (°C)
Winter season	64,28	40,13	41	38,88
Summer season	23,48	23,09	23,84	22,9
Midseasons	42,66	30,83	31,47	30,11
2021	Supply (°C)	Return (°C)	Supply (°C)	Return (°C)
Winter season	62,35	46,55	47,12	44
Summer season	22,98	23	23,5	22,79
Midseasons	49,42	34,62	35,7	33,84

Table 10 - Data from SCT 8 corresponding to building 8

SCT9	Building 2 Average °C exchanged			
	Primary system		Secondary system	
2020	Supply (°C)	Return (°C)	Supply (°C)	Return (°C)
Winter season	65,66	43,17	45,02	42,67
Summer season	26,27	25,92	26,12	25,76
Midseasons	48,87	33,78	34,92	33,46
2021	Supply (°C)	Return (°C)	Supply (°C)	Return (°C)
Winter season	62,46	47,32	49,17	46,06
Summer season	25,98	25,37	25,95	25,54
Midseasons	48,59	36,16	37,72	35,57

Table 11 - Data from SCT 9 corresponding to building 9

Following the extraction of data from the Etna system, some differences between:

- Degrees obtained through primary system delivery and return
- Secondary system delivery and return degrees
- Primary and secondary system delivery degrees

A delta has been calculated to examine temperature variations (measured in Celsius degrees) and determine if the heating exchangers are working properly, given that they must exchange heating and cooling energy with the environment and that if the difference isn't large enough, dirt or clogging may occur.

Furthermore, some differences in temperature setting between 2020 and 2021 were discovered:

In the middle of the season (which includes both spring and autumn) in 2021:

With few exceptions, the primary system delivery temperatures (as well as the return) were all raised, as was the delta between those two.

- all secondary system delivery temperatures were raised, as was the delta between delivery and return - the delta between primary and secondary system delivery was increased

In winter 2021:

- the primary system delivery temperature decreased (except for SCT2) while the return temperature decreased, reducing the delta, which may lead to the conclusion that the leak of heating power was partially reduced, even though it is still more than 10 degrees per building.

- The secondary system delivery temperature, as well as the return and delta, were raised. - Of course, by decreasing the primary system temperature and increasing the secondary system temperature, the delta was reduced.

	2020 Midseasons								2021 Mideseasons							
;e Temperature (°C)	SCT2	SCT3	SCT4	SCT5	SCT6	SCT7	SCT8	SCT9	SCT2	SCT3	SCT4	SCT5	SCT6	SCT7	SCT8	SCT9
Tprimary system delivery	25,55	39,08	38,24	37,98	42,51	38,39	42,66	48,87	42,28	48,04	47,82	46,11	47,95	43,58	49,42	48,59
Tprimary system return	22,58	29,91	28,82	30,09	33,40	30,61	30,83	33,78	32,68	35,25	32,69	33,81	35,06	34,89	46,55	36,16
DELTA	2,97	9,17	9,42	7,89	9,11	7,78	11,83	15,09	9,60	12,79	15,13	12,30	12,89	8,69	2,87	12,43
Tsecondary system delivery	24,08	29,37	29,52	29,52	33,26	33,31	31,47	34,92	34,16	35,62	34,16	33,04	36,79	38,13	35,70	37,72
Tsecondary system return	23,75	28,40	28,60	28,94	32,19	32,59	30,11	33,46	33,14	33,54	31,47	32,12	32,65	33,11	33,84	35,57
DELTA	0,33	0,97	0,92	0,58	1,07	0,72	1,36	1,46	1,02	2,08	2,69	0,92	4,14	5,02	1,86	2,15
Tprimary system delivery	25,55	39,08	38,24	37,98	42,51	38,39	42,66	48,87	42,28	48,04	47,82	46,11	47,95	43,58	49,42	48,59
Tsecondary system delivery	24,08	29,37	29,52	29,52	33,26	33,31	31,47	34,92	34,16	35,62	34,16	33,04	36,79	38,13	35,70	37,72
DELTA	1,47	9,71	8,72	8,46	9,25	5,08	11,19	13,95	8,12	12,42	13,66	13,07	11,16	5,45	13,72	10,87
	2020 Winter								2021 Winter							
;e Temperature (°C)	SCT2	SCT3	SCT4	SCT5	SCT6	SCT7	SCT8	SCT9	SCT2	SCT3	SCT4	SCT5	SCT6	SCT7	SCT8	SCT9
Tprimary system delivery	49,37	61,12	61,91	60,71	66,34	58,93	64,28	65,66	56,52	59,30	58,94	59,74	62,01	57,04	62,35	62,46
Tprimary system return	34,08	40,92	38,56	39,81	43,27	39,00	40,13	43,17	37,82	45,06	44,60	45,81	45,53	46,56	46,55	47,32
DELTA	15,29	20,20	23,35	20,90	23,07	19,93	24,15	22,49	18,70	14,24	14,34	13,93	16,48	10,48	15,80	15,14
Tsecondary system delivery	36,14	40,28	38,98	38,59	43,15	40,36	41,00	45,02	38,82	43,93	44,14	43,90	46,16	49,85	47,12	49,17
Tsecondary system return	35,45	38,73	36,17	37,57	40,46	39,40	38,88	42,67	37,82	41,80	41,92	42,55	42,07	42,08	44,00	46,06
DELTA	0,69	1,55	2,81	1,02	2,69	0,96	2,12	2,35	1,00	2,13	2,22	1,35	4,09	7,77	3,12	3,11
Tprimary system delivery	49,37	61,12	61,91	60,71	66,34	58,93	64,28	65,66	56,52	59,30	58,94	59,74	62,01	57,04	62,35	62,46
Tsecondary system delivery	36,14	40,28	38,98	38,59	43,15	40,36	41,00	45,02	38,82	43,93	44,14	43,90	46,16	49,85	47,12	49,17
DELTA	13,23	20,84	22,93	22,12	23,19	18,57	23,28	20,64	17,70	15,37	14,80	15,84	15,85	7,19	15,23	13,29

Table 12 - Data from all the heating exchangers resume

The table shows how the temperature varies and the delta caused by the different heating machineries settings.

The delta changes in two averages that are also shown in the tables below:

• The average delta of increasing temperature (calculated only on positive values) indicating the number of degrees the temperature was raised in 2021 compared to 2020, showing how temperatures in 2021 mostly increased. The average amount of raised temperature is 5,12°C.

• The average delta of decreasing temperature (calculated only on negative values), which shows energy savings as the primary and secondary system temperatures are reduced. The average amount of energy saved is 1,36°C.

	2020 Midseasons								2021 Midseasons								DELTA 2020 vs 2021								Average delta of increasing temperature (Calculated only on positive values) - energy wasting	Average delta of decreasing temperature (Calculated only on negative values) - energy saving
Average Temperature (°C)	SCT2	SCT3	SCT4	SCT5	SCT6	SCT7	SCT8	SCT9	SCT2	SCT3	SCT4	SCT5	SCT6	SCT7	SCT8	SCT9	SCT2	SCT3	SCT4	SCT5	SCT6	SCT7	SCT8	SCT9	All heating exchangers (Midseason)	All heating exchangers (Midseason)
T primary system delivery	25,55	39,08	38,24	37,98	42,51	38,39	42,66	48,87	42,28	48,04	47,82	46,11	47,95	43,58	49,42	48,59	16,73	8,96	9,58	8,13	5,44	5,19	6,76	-0,28	8,68	-0,28
T primary system return	22,58	29,91	28,82	30,09	33,40	30,61	30,83	33,78	32,68	35,25	32,69	33,81	35,06	34,89	46,55	36,16	10,10	5,34	3,87	3,72	1,66	4,28	15,72	2,38	5,88	
DELTA	2,97	9,17	9,42	7,89	9,11	7,78	11,83	15,09	9,60	12,79	15,13	12,30	12,89	8,69	2,87	12,43	6,63	3,62	5,71	4,41	3,78	0,91	-8,96	-2,66	4,18	-5,81
T secondary system delivery	24,08	29,37	29,52	29,52	33,26	33,31	31,47	34,92	34,16	35,62	34,16	33,04	36,79	38,13	35,70	37,72	10,08	6,25	4,64	3,52	3,53	4,82	4,23	2,80	4,98	
T secondary system return	23,75	28,40	28,60	28,94	32,19	32,59	30,11	33,46	33,14	33,54	31,47	32,12	32,65	33,11	33,84	35,57	9,39	5,14	2,87	3,18	0,46	0,52	3,73	2,11	3,43	
DELTA	0,33	0,97	0,92	0,58	1,07	0,72	1,36	1,46	1,02	2,08	2,69	0,92	4,14	5,02	1,86	2,15	0,69	1,11	1,77	0,34	3,07	4,30	0,50	0,69	1,56	
T primary system delivery	25,55	39,08	38,24	37,98	42,51	38,39	42,66	48,87	42,28	48,04	47,82	46,11	47,95	43,58	49,42	48,59	16,73	8,96	9,58	8,13	5,44	5,19	6,76	-0,28	8,68	-0,28
T secondary system delivery	24,08	29,37	29,52	29,52	33,26	33,31	31,47	34,92	34,16	35,62	34,16	33,04	36,79	38,13	35,70	37,72	10,08	6,25	4,64	3,52	3,53	4,82	4,23	2,80	5,30	
DELTA	1,47	9,71	8,72	8,46	9,25	5,08	11,19	13,95	8,12	12,42	13,66	13,07	11,16	5,45	13,72	10,87	6,65	2,71	4,94	4,61	1,91	0,37	2,53	-3,08	3,19	-3,08
	2020 Winter								2021 Winter								DELTA 2020 vs 2021									
Average Temperature (°C)	SCT2	SCT3	SCT4	SCT5	SCT6	SCT7	SCT8	SCT9	SCT2	SCT3	SCT4	SCT5	SCT6	SCT7	SCT8	SCT9	SCT2	SCT3	SCT4	SCT5	SCT6	SCT7	SCT8	SCT9	All heating exchangers (Winter)	All heating exchangers (Winter)
T primary system delivery	49,37	61,12	61,91	60,71	66,34	58,93	64,28	65,66	56,52	59,30	58,94	59,74	62,01	57,04	62,35	62,46	7,15	-1,82	-2,97	-0,97	-4,33	-1,89	-1,93	-3,20	7,15	-2,44
T primary system return	34,08	40,92	38,56	39,81	43,27	39,00	40,13	43,17	37,82	45,06	44,60	45,81	45,53	46,56	46,55	47,32	3,74	4,14	6,04	6,00	2,26	7,56	6,42	4,15	5,04	
DELTA	15,29	20,20	23,35	20,90	23,07	19,93	24,15	22,49	18,70	14,24	14,34	13,93	16,48	10,48	15,80	15,14	3,41	-5,96	-9,01	-6,97	-6,59	-9,45	-8,35	-7,35	3,41	-7,67
T secondary system delivery	36,14	40,28	38,98	38,59	43,15	40,36	41,00	45,02	38,82	43,93	44,14	43,90	46,16	49,85	47,12	49,17	2,68	3,65	5,16	5,31	3,01	9,49	6,12	4,15	4,95	
T secondary system return	35,45	38,73	36,17	37,57	40,46	39,40	38,88	42,67	37,82	41,80	41,92	42,55	42,07	42,08	44,00	46,06	2,37	3,07	5,75	4,98	1,61	2,68	5,12	3,39	3,62	
DELTA	0,69	1,55	2,81	1,02	2,69	0,96	2,12	2,35	1,00	2,13	2,22	1,35	4,09	7,77	3,12	3,11	0,31	0,58	-0,59	0,33	1,40	6,81	1,00	0,76	1,60	-0,59
T primary system delivery	49,37	61,12	61,91	60,71	66,34	58,93	64,28	65,66	56,52	59,30	58,94	59,74	62,01	57,04	62,35	62,46	7,15	-1,82	-2,97	-0,97	-4,33	-1,89	-1,93	-3,20	7,15	-2,44
T secondary system delivery	36,14	40,28	38,98	38,59	43,15	40,36	41,00	45,02	38,82	43,93	44,14	43,90	46,16	49,85	47,12	49,17	2,68	3,65	5,16	5,31	3,01	9,49	6,12	4,15	4,95	
DELTA	13,23	20,84	22,93	22,12	23,19	18,57	23,28	20,64	17,70	15,37	14,80	15,84	15,85	7,19	15,23	13,29	4,47	-5,47	-8,13	-6,28	-7,34	-11,38	-8,05	-7,35	4,47	-7,71

Table 13 - Average delta of increasing temperatures

The rising temperature could be due to different machine settings, and thus lowering the set temperature could be beneficial. Especially if we consider the previous year the provided temperature and energy was less

The data from the summer period analysis show that the temperature difference isn't relevant because the heating system is turned off, and as a result, the temperature difference isn't as large as when the machines are running.

	2020 Summer								2021 Summer								DELTA							
Average Temperature (°C)	SCT2	SCT3	SCT4	SCT5	SCT6	SCT7	SCT8	SCT9	SCT2	SCT3	SCT4	SCT5	SCT6	SCT7	SCT8	SCT9	SCT2	SCT3	SCT4	SCT5	SCT6	SCT7	SCT8	SCT9
Tprimary system delivery	23,70	11,36	11,42	22,11	24,81	24,42	23,48	26,27	23,52	24,70	25,08	2,77	24,35	24,04	22,98	25,98	0,18	-13,34	-13,59	19,34	0,46	0,38	0,50	0,29
Tprimary system return	23,10	11,21	10,79	21,72	24,37	23,99	23,09	25,92	22,86	24,42	24,68	2,48	23,89	23,65	23,00	25,37	0,24	-13,21	-13,82	19,24	0,48	0,34	0,09	0,55
DELTA	0,60	0,15	0,63	0,39	0,44	0,43	0,39	0,35	0,66	0,28	0,40	0,29	0,46	0,39	-0,02	0,61	-0,06	-0,13	0,23	0,10	-0,02	0,04	0,41	-0,26
Tsecondary system delivery	23,62	11,07	10,59	21,75	24,61	24,16	23,84	25,95	23,55	24,19	24,80	2,24	24,02	23,78	23,50	25,95	0,07	-13,12	-14,21	19,51	0,59	0,38	0,34	0,00
Tsecondary system return	23,19	10,93	10,64	21,40	24,24	23,77	22,90	25,54	23,08	23,65	24,59	2,36	23,68	23,43	22,79	25,54	0,18	-12,72	-13,95	19,04	0,56	0,34	0,11	0,00
DELTA	0,43	0,14	-0,05	0,35	0,37	0,39	0,94	0,41	0,54	0,54	0,21	-0,12	0,34	0,35	0,71	0,41	-0,11	-0,40	-0,26	0,47	0,08	0,04	0,23	0,00
Tprimary system delivery	23,70	11,36	11,42	22,11	24,81	24,42	23,48	26,27	23,52	24,70	25,08	2,77	24,35	24,04	22,98	25,98	0,18	-13,34	-13,59	19,34	0,46	0,38	0,50	0,29
Tsecondary system delivery	23,62	11,07	10,59	21,75	24,61	24,16	23,84	25,95	23,55	24,19	24,80	2,24	24,02	23,78	23,50	25,95	0,07	-13,12	-14,21	19,51	0,59	0,38	0,34	0,00
DELTA	0,08	0,29	0,83	0,36	0,20	0,26	-0,36	0,32	-0,08	0,51	0,21	0,53	0,33	0,26	-0,52	0,08	0,11	-0,22	0,62	-0,17	-0,13	0,00	0,16	0,29

Table 14 - DELTA

The paragraph above is just an assessment of the heating system that seems to provide all the needed energy to the buildings.

The heating energy is produced from the primary system, composed by the trigenerator and spread through other heaters and district heating systems, providing the district a good amount of heating energy.

The registered temperatures on the heat exchangers show that there is a fair amount of degrees that differ from the primary and secondary system deliveries.

In midseasons the data are different from years, there is a raising of all the temperatures between 2020 and 2021 even if the campus has not been shut down but has always being active and functioning.

The setting temperatures of the machines could have been changed and then maybe even kept the same and higher temperatures might have been recorded because of the amount of people getting back to the university in 2021, while during 2020 less people were occupying the rooms.
Unfortunately, this is just an assumption, the data to check it weren’t available during the thesis writing process.

3.2 Cooling energy supply and demand of the district

BEA (Bilancio Energetico di Ateneo - University Energy Report) is a tool for collecting energy data from university systems.

Every year, it is derived from system data or energy bills. The information gathered is gathered at several levels, including the site, campus, and building.
All data is collected in the ETNA database and processed using Energy Commission-developed IT tools.

The conversion from carriers, whether direct or indirect, to energy requirements is then carried out at the building level, using a model borrowed from the standards UNI TS 11300 and UNI EN 16247. Some requirements are also differentiated at the level of a single building based on the final destination of use.

The University consumes 46 GWh of electricity per year. The annual consumption of natural gas is approximately 4 MSmc, which is influenced by the presence of a tri-generation system (PoliGrid) serving Plesso Leonardo-Bonardi-Bassini.

Despite having a higher energy requirement, the Città Studi Headquarters has a lower primary energy consumption due to the presence of the cogeneration engine.

From the 2020 BEA (published in 2022) the following tabs were showing the needed energy amounts:

Tabella 22. Valore aggregato dei fabbisogni energetici, Sede Città Studi

Sede Città Studi	Fabbisogno Energia Elettrica [kWh_{el}]	Fabbisogno Energia Termica [kWh_{th}]	Fabbisogno Energia Frigorifera [kWh_{fr}]
Campus Leonardo 32	4.636.419	4.500.235	2.520.834
Campus Bonardi	1.751.736	1.738.357	1.104.571
Campus Bassini	2.092.679	1.369.577	833.670
Campus Golgi 40	815.157	698.546	149.094
Campus Golgi 20	295.685	444.166	63.672
Campus Mancinelli	1.736.466	714.863	244.398
Campus Leonardo 26	140.489	4.593	50.574
Campus Colombo 81	754.477	6.369	305.133
Campus Colombo 40	263.580	272.556	91.623
Totale Sede	12.486.689	9.749.262	5.363.568
Superfici di riferimento [m^2]	200.681	160.858	-
Totale Fabb. per metri quadri per anno	**62,22**	**60,61**	-

Table 15 - Energetic requirements

11 https://www.commissionenergia.polimi.it/

The cooling energy required by the final uses was obtained from the tele-cooling network as well as directly from the electricity consumption of the refrigeration units located in the consumption area and serving the final uses.

The consumption of natural gas is following:

Tabella 21. Prelievo di gas naturale, totale annuale, Sede Città Studi

Milano Città Studi				
Campus/Plesso	Totale Annuo [sm^3]	Totale per metri quadri [sm^3/m^2]	Totale Annuo [kWh]	Totale per metri quadri [kWh/m^2]
Plesso Leonardo, Via Bonardi e Via Bassini	3.452.789	22,89	33.146.776	219,72
Via Golgi 40	41.862	2,97	401.875	28,51
Via Golgi 20	57.056	6,05	547.738	58,10
Via Mancinelli	91.256	5,99	876.058	57,49
Piazza Leonardo 26 - Colombo 81	822,0	0,12	7.891	1,12
Via Colombo 40	34.979	8,11	335.798	77,81
Totale / Media	3.678.764	18,30	35.316.136	198,22

Table 16 - Natural gas taken

According to the data collected by the Etna system, the district's absorption chiller is operating as it follows:

2020	Average performance (kW/h)
Thermal season	Absorption chiller (TRG)
Winter season	0
Summer season	227,21
Midseasons	55,85

2021	Average performance (kW/h)
Thermal season	Absorption chiller (TRG)
Winter season	0
Summer season	231,13
Midseasons	42,54

Table 17 - Average performance 2020

The tables show how the absorption chiller is insufficiently powerful to provide cooling energy for the entire district.

Other chillers were installed over the years to get more power, particularly close to some buildings and districts that may require a load of energy.

We can take as an example the Bonardi district, which, according to BEA, includes buildings: 11-12-13-13A-14-14A-14B-15-16-18 in which in 2021 was installed a couple of 1,5MW chillers that started to work in the summer.

The chiller was switched on from 12th of may until 20th of September.

The new data were added to the previous ones, resulting as follow:

2021: summer season				
Chiller average Power (KVA)	Average performance absorption chiller (W)	Total refrigerating energy produced (W)	Energy requirements of the building (BEA) (W)	Energy missing to fulfill the requirements
155.765,30	231.130	386.895,30	1.104.571.000	1.104.184.105
124612,24	231,13	124843,37	1.104.571	979.728

Table 17bis - Average performance 2021

The average power of the chiller was calculated by adding active (kW) and reactive (VAR) power, yielding (KVA) as follows:

Active power= 71747,63 kW

Reactive power= 6135,02 (Var)

Number of chillers=2

(71747,63+6135,02) = 77882,65 kVA*2= 155765,3 kVA

Converting the kVA in kW by dividing the result by 0,8 = 124.614,24 kW

As the results show, the new chillers produce more energy than the absorption chiller, but it is also entirely dedicated to the smaller district Bonardi, whereas the absorption chiller can only provide refrigerating energy to the buildings adjacent to it.

When compared to the cooling energy required by the Bonardi district, the two chillers produce 11,3% of the required energy, which is more than the absorption chiller can provide for the entire district.

3.3 COP Calculation

COP is the Coefficient of Performance, and it is usually calculated on heating/cooling machines.

The energy performance of heat pumps, specifically the COP, is determined by three factors. The energy performance of heat pumps, specifically the COP, is determined by three major factors:

• the temperature of the cold source

• the temperature of the hot well; and

• the machine's load factor.

The technical specification UNI/TS 11300-4 takes all three of these factors into account, as follow:

• Determining the COP at full load first, using interpolation or extrapolation between the COP at full load data declared by the suppliers. These data are determined at pairs of predefined cold source and hot well temperatures depending on the specific application

• Then applying a full load COP correction factor, which is considered fixed and independent of the cold source and hot well temperatures.

According to UNI EN 14825, determining the load factor of the machine allows to refer to the performance of the same at the steps closest to the load conditions required.

• In particular, the power supplied by the machine (DC = Declared Capacity) and its COP at the nearest modulation step with respect to the required load must be determined using the following criteria:

• This power value and the corresponding COP may be used if the power provided by the machine at the modulation step closest to the required load is between 10% of the required load.

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12 Nota interpretativa sul calcolo delle prestazioni energetiche delle pompe di calore aria-acqua - CTI – Commissione Tecnica 251 "Impianti di riscaldamento - Progettazione, fabbisogni di energia e sicurezza (UNI/TS 11300-2 e 11300-4) - CTI - Comitato Termotecnico Italiano Energia e Ambiente

• If the power provided by the machine at the modulation step closest to the required load is not within 10% of the required load, the thermal and electric powers, as well as the COP, are calculated in correspondence of the two modulation steps on horseback of the demanded load, the greater and smaller, and the same magnitudes are calculated for linear interpolation.

• If the power provided by the machine at the minimum modulation step is greater than 10% greater than the required load, the formula for on/off machines applies (formula 29 of UNI EN 14825 for air-water heat pumps).
It should be noted that the formula (29), which requires the CR referred to the power at full load, refers to machines on/off. If the formula is applied to step or modulating machines, a value of Capacity Ratio CR referring to the minimum power provided by the machine, rather than the one related to full load power, must be used to calculate the correct COP in the operating conditions between OFF and Minimum Power.

The machine's efficiency is inversely proportional to the temperature differences at which thermal exchanges occur, that is, between the condensation T and the evaporation T. This means that in the case of winter air conditioning (T2>T1):

• COP is reduced by lowering the external T of the source, just as it is in the case of summer air conditioning (T2T1)

• the EER decreases as the external air T increases

e nel caso estivo:

$$EER_h = \frac{Q_s}{L_{el}} = \frac{T_1}{T_2 - T_1} = \frac{T_{evapor}}{\Delta T}$$

T1> T2

dove L_{el} è il lavoro elettrico fornito alla macchina

dove Q_s è l'energia termica fornita all'ambiente climatizzato

13 Misura delle prestazioni in campo di una pompa di calore di grande taglia - G. Centi, D. Iatauro, C. Romeo, P. Signoretti, L. Terrinoni - Report RdS/PAR2016/270

4. Campus Leonardo 32, state of the art

The following chapter is aimed to present the Politecnico Campus 32 asset and current state of the art, which will be the framework of the project setting.

4.1. Campus Leonardo, district Leonardo 32 framing and buildings details

The perimeter of the area to be studied, as well as the buildings within it, are depicted in the images below. It starts with a general overview and then builds detail tables to collect data and assess the district's current state of the art.

The first image depicts the district's size; the following tables depict the district's energy requirements; and the same data has been collected at the building scale.

Figura 90. Campus Piazza Leonardo da Vinci 32 e gli edifici componente

Per l'intero Campus, i parametri geometrici e le caratteristiche degli edifici sono riassunti nelle seguenti tabelle.

Tabella 95. Parametri geometrici e caratteristiche Campus Piazza Leonardo da Vinci 32

Volumetria netta [m^3]	258.544,11
Superficie netta [m^2]	79.719,68
Superficie netta riscaldata [m^2]	62.745,76
Superficie netta raffrescata [m^2]	-
Coefficiente di forma S/V	-
Superficie disperdente [m^2]	17.957,52

Tabella 96. suddivisione dell'area di Campus Piazza Leonardo da Vinci 32 in base alla destinazione d'uso principale

Aule	Ufficio	Laboratori	Diversi*
23%	34%	24%	19%

Archivio, biblioteca, ascensore, portineria, appartamento custode, locale tecnico, sala riunioni, locale tecnico, ecc.

Figure 21 - Campus Leonardo 32

Aggregato del Campus

La tabella che segue mostra i valori aggregati del fabbisogno energetico del Campus.

Tabella 136. Valore aggregati dei fabbisogni, Campus Piazza Leonardo da Vinci 32

Campus Leonardo 32	Fabbisogno Energia Elettrica [kWh_{el}]	Fabbisogno Energia Termica [kWh_{th}]	Fabbisogno Energia Frigorifera [kWh_{fr}]
Totale Campus	4.636.419	4.500.235	2.520.834
Superfici di riferimento [m^2]	79.720	62.746	-
Totale Fabb. per metri quadri per anno	**58,16**	**71,72**	**-**

Table 18 - Campus Leonardo 32 energy requirements

After the overview on the Leonardo 32 district, the data have been found and colected at building level as it follows below.

The buildings can be matched with the SCT data presented in the previous tables, if the data were available.

Furthermore, considering BEA is related only to 2020 only this year data are comparable.

Tabella 137. fabbisogni energetici, edificio 1

Edificio 01	Quantità complessiva [kWh]		Fabbisogno Energia Elettrica [kWh_{el}]	Fabbisogno Energia Termica [kWh_{th}]	Fabbisogno Energia Frigorifera [kWh_{fr}]
Energia Elettrica	471.890	*Ripartizione:*	87%	0%	13%
		Eff. Conv:	98%	0%	350%
		Quantità:	402.057,94	-	215.695,07
Gas Naturale	-	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	0%	0%
		Quantità:	-	-	-
Energia Termica da Fluido Caldo	427.886	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	98%	0%
		Quantità:	-	419.327,82	-
Energia Frigorifera da Fluido Freddo	-	*Ripartizione:*	0%	0%	0%
		Eff. Conv:	0%	0%	98%
		Quantità:	-	-	-
Totale Fabbisogno			402.058	419.328	215.695
Superfici di riferimento [m^2]			7.118	4.445	-
Totale Fabb. per metri quadri per anno			**56,48**	**94,35**	**-**

Table 19 - Building 01 energy requirement

Tabella 138. fabbisogni energetici, edificio 2

Edificio 02	Quantità complessiva [kWh]		Fabbisogno Energia Elettrica [kWh_{el}]	Fabbisogno Energia Termica [kWh_{th}]	Fabbisogno Energia Frigorifera [kWh_{fr}]
Energia Elettrica	485.345	*Ripartizione:*	79%	0%	21%
		Eff. Conv:	98%	0%	350%
		Quantità:	374.415,17	-	361.509,56
Gas Naturale	-	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	0%	0%
		Quantità:	-	-	-
Energia Termica da Fluido Caldo	611.538	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	98%	0%
		Quantità:	-	599.307,22	-
Energia Frigorifera da Fluido Freddo	-	*Ripartizione:*	0%	0%	0%
		Eff. Conv:	0%	0%	98%
		Quantità:	-	-	-
Totale Fabbisogno			374.415	599.307	361.510
Superfici di riferimento [m^2]			11.903	7.848	-
Totale Fabb. per metri quadri per anno			31,46	76,37	-

Table 20 - Building 02 energy requirement

Tabella 139. fabbisogni energetici, edificio 2A

Edificio 2A	Quantità complessiva [kWh]		Fabbisogno Energia Elettrica [kWh_{el}]	Fabbisogno Energia Termica [kWh_{th}]	Fabbisogno Energia Frigorifera [kWh_{fr}]
Energia Elettrica	79.624	*Ripartizione:*	100%	0%	0%
		Eff. Conv:	98%	0%	0%
		Quantità:	78.031,43	-	-
Gas Naturale	-	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	0%	0%
		Quantità:	-	-	-
Energia Termica da Fluido Caldo	75.400	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	98%	0%
		Quantità:	-	73.891,86	-
Energia Frigorifera da Fluido Freddo	6.724	*Ripartizione:*	0%	0%	100%
		Eff. Conv:	0%	0%	98%
		Quantità:	-	-	6.589,70
Totale Fabbisogno			78.031	73.892	6.590
Superfici di riferimento [m^2]			2.000	644	-
Totale Fabb. per metri quadri per anno			39,02	114,82	-

Table 21 - Building 02A energy requirement

Tabella 140. fabbisogni energetici, edificio 3

Edificio 03	Quantità complessiva [kWh]		Fabbisogno Energia Elettrica [kWh_{el}]	Fabbisogno Energia Termica [kWh_{th}]	Fabbisogno Energia Frigorifera [kWh_{fr}]
Energia Elettrica	936.900	*Ripartizione:*	79%	0%	21%
		Eff. Conv:	98%	0%	290%
		Quantità:	725.817,57	-	570.132,68
Gas Naturale	-	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	0%	0%
		Quantità:	-	-	-
Energia Termica da Fluido Caldo	590.732	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	98%	0%
		Quantità:	-	578.916,89	-
Energia Frigorifera da Fluido Freddo	-	*Ripartizione:*	0%	0%	0%
		Eff. Conv:	0%	0%	98%
		Quantità:	-	-	-
Totale Fabbisogno			725.818	578.917	570.133
Superfici di riferimento [m^2]			10.488	8.828	-
Totale Fabb. per metri quadri per anno			69,21	65,58	-

Table 22 - Building 03 energy requirement

Tabella 141. fabbisogni energetici, edificio 4

Edificio 04	Quantità complessiva [kWh]		Fabbisogno Energia Elettrica [kWh_{el}]	Fabbisogno Energia Termica [kWh_{th}]	Fabbisogno Energia Frigorifera [kWh_{fr}]
Energia Elettrica	294.608	*Ripartizione:*	92%	0%	8%
		Eff. Conv:	98%	0%	383%
		Quantità:	265.705,09	-	89.827,39
Gas Naturale	-	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	0%	0%
		Quantità:	-	-	-
Energia Termica da Fluido Caldo	388.118	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	98%	0%
		Quantità:	-	380.356,10	-
Energia Frigorifera da Fluido Freddo	60.156	*Ripartizione:*	0%	0%	100%
		Eff. Conv:	0%	0%	98%
		Quantità:	-	-	58.952,86
Totale Fabbisogno			265.705	380.356	148.780
Superfici di riferimento [m^2]			9.142	5.757	-
Totale Fabb. per metri quadri per anno			29,07	66,06	-

Table 23 - Building 04 energy requirement

Tabella 142. fabbisogni energetici, edificio 4A

Edificio 4A	Quantità complessiva [kWh]		Fabbisogno Energia Elettrica [kWh_{el}]	Fabbisogno Energia Termica [kWh_{th}]	Fabbisogno Energia Frigorifera [kWh_{fr}]
Energia Elettrica	109.981	*Ripartizione:*	100%	0%	0%
		Eff. Conv:	98%	0%	0%
		Quantità:	107.781,78	-	-
Gas Naturale	-	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	0%	0%
		Quantità:	-	-	-
Energia Termica da Fluido Caldo	214.597	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	98%	0%
		Quantità:	-	210.305,18	-
Energia Frigorifera da Fluido Freddo	-	*Ripartizione:*	0%	0%	0%
		Eff. Conv:	0%	0%	98%
		Quantità:	-	-	-
Totale Fabbisogno			107.782	210.305	-
Superfici di riferimento [m^2]			2.723	2.650	-
Totale Fabb. per metri quadri per anno			39,58	79,36	-

Table 24 - Building 04A energy requirement

Tabella 143. fabbisogni energetici, edificio 5

Edificio 05	Quantità complessiva [kWh]		Fabbisogno Energia Elettrica [kWh_{el}]	Fabbisogno Energia Termica [kWh_{th}]	Fabbisogno Energia Frigorifera [kWh_{fr}]
Energia Elettrica	1.030.198	*Ripartizione:*	90%	0%	10%
		Eff. Conv:	98%	0%	235%
		Quantità:	905.668,29	-	249.209,23
Gas Naturale	-	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	0%	0%
		Quantità:	-	-	-
Energia Termica da Fluido Caldo	603.333	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	98%	0%
		Quantità:	-	591.266,81	-
Energia Frigorifera da Fluido Freddo	-	*Ripartizione:*	0%	0%	0%
		Eff. Conv:	0%	0%	98%
		Quantità:	-	-	-
Totale Fabbisogno			905.668	591.267	249.209
Superfici di riferimento [m^2]			9.887	9.624	-
Totale Fabb. per metri quadri per anno			91,61	61,43	-

Table 25 - Building 05 energy requirement

Tabella 144. fabbisogni energetici, edificio 6

Edificio 06	Quantità complessiva [kWh]		Fabbisogno Energia Elettrica $[kWh_{el}]$	Fabbisogno Energia Termica $[kWh_{th}]$	Fabbisogno Energia Frigorifera $[kWh_{fr}]$
Energia Elettrica	760.678	*Ripartizione:*	83%	0%	17%
		Eff. Conv:	98%	0%	235%
		Quantità:	616.052,90	-	310.324,69
Gas Naturale	-	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	0%	0%
		Quantità:	-	-	-
Energia Termica da Fluido Caldo	682.580	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	98%	0%
		Quantità:	-	668.928,37	-
Energia Frigorifera da Fluido Freddo	-	*Ripartizione:*	0%	0%	0%
		Eff. Conv:	0%	0%	98%
		Quantità:	-	-	-
Totale Fabbisogno			616.053	668.928	310.325
Superfici di riferimento $[m^2]$			9.481	8.329	-
Totale Fabb. per metri quadri per anno			64,98	80,31	-

Table 26 - Building 06 energy requirement

Tabella 145. fabbisogni energetici, edificio 7

Edificio 07	Quantità complessiva [kWh]		Fabbisogno Energia Elettrica $[kWh_{el}]$	Fabbisogno Energia Termica $[kWh_{th}]$	Fabbisogno Energia Frigorifera $[kWh_{fr}]$
Energia Elettrica	642.397	*Ripartizione:*	80%	0%	20%
		Eff. Conv:	98%	336%	235%
		Quantità:	503.277,00	-	302.795,90
Gas Naturale	-	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	0%	0%
		Quantità:	-	-	-
Energia Termica da Fluido Caldo	234.780	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	98%	0%
		Quantità:	-	230.084,05	-
Energia Frigorifera da Fluido Freddo	-	*Ripartizione:*	0%	0%	0%
		Eff. Conv:	0%	0%	98%
		Quantità:	-	-	-
Totale Fabbisogno			503.277	230.084	302.796
Superfici di riferimento $[m^2]$			5.223	4.147	-
Totale Fabb. per metri quadri per anno			96,36	55,49	-

Table 27 - Building 07 energy requirement

Edificio 08	Quantità complessiva [kWh]		Fabbisogno Energia Elettrica $[kWh_{el}]$	Fabbisogno Energia Termica $[kWh_{th}]$	Fabbisogno Energia Frigorifera $[kWh_{fr}]$
Energia Elettrica	465.409	*Ripartizione:*	80%	0%	20%
		Eff. Conv:	98%	0%	235%
		Quantità:	366.108,04	-	215.797,92
Gas Naturale	-	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	0%	0%
		Quantità:	-	-	-
Energia Termica da Fluido Caldo	382.850	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	98%	0%
		Quantità:	-	375.192,92	-
Energia Frigorifera da Fluido Freddo	-	*Ripartizione:*	0%	0%	0%
		Eff. Conv:	0%	0%	98%
		Quantità:	-	-	-
Totale Fabbisogno			366.108	375.193	215.798
Superfici di riferimento $[m^2]$			5.380	5.002	-
Totale Fabb. per metri quadri per anno			68,05	75,00	-

Table 28 - Building 08 energy requirement

Tabella 147. fabbisogni energetici, edificio 9

Edificio 09	Quantità complessiva [kWh]		Fabbisogno Energia Elettrica [kWh_{el}]	Fabbisogno Energia Termica [kWh_{th}]	Fabbisogno Energia Frigorifera [kWh_{fr}]
Energia Elettrica	344.263	*Ripartizione:*	83%	0%	17%
		Eff. Conv:	98%	0%	235%
		Quantità:	279.870,68	-	137.899,89
Gas Naturale	-	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	0%	0%
		Quantità:	-	-	-
Energia Termica da Fluido Caldo	380.263	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	98%	0%
		Quantità:	-	372.657,56	-
Energia Frigorifera da Fluido Freddo	-	*Ripartizione:*	0%	0%	0%
		Eff. Conv:	0%	0%	98%
		Quantità:	-	-	-
Totale Fabbisogno			279.871	372.658	137.900
Superfici di riferimento [m^2]			**6.197**	**5.327**	**-**
Totale Fabb. per metri quadri per anno			**45,16**	**69,96**	**-**

Table 29 - Building 09 energy requirement

Tabella 148. fabbisogni energetici, edificio 9°

Edificio 9A	Quantità complessiva [kWh]		Fabbisogno Energia Elettrica [kWh_{el}]	Fabbisogno Energia Termica [kWh_{th}]	Fabbisogno Energia Frigorifera [kWh_{fr}]
Energia Elettrica	5.956	*Ripartizione:*	85%	0%	15%
		Eff. Conv:	98%	0%	235%
		Quantità:	4.961,01	-	2.099,48
Gas Naturale	-	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	0%	0%
		Quantità:	-	-	-
Energia Termica da Fluido Caldo	-	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	98%	0%
		Quantità:	-	-	-
Energia Frigorifera da Fluido Freddo	-	*Ripartizione:*	0%	0%	0%
		Eff. Conv:	0%	0%	98%
		Quantità:	-	-	-
Totale Fabbisogno			4.961	-	2.099
Superfici di riferimento [m^2]			**105**	**85**	**-**
Totale Fabb. per metri quadri per anno			**47,36**	**0,00**	**-**

Table 30 - Building 09A energy requirement

Tabella 149. fabbisogni energetici, edificio 10

Edificio 10	Quantità complessiva [kWh]		Fabbisogno Energia Elettrica [kWh_{el}]	Fabbisogno Energia Termica [kWh_{th}]	Fabbisogno Energia Frigorifera [kWh_{fr}]
Energia Elettrica	6.809	*Ripartizione:*	100%	0%	0%
		Eff. Conv:	98%	0%	0%
		Quantità:	6.672,53	-	-
Gas Naturale	-	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	0%	0%
		Quantità:	-	-	-
Energia Termica da Fluido Caldo	-	*Ripartizione:*	0%	100%	0%
		Eff. Conv:	0%	98%	0%
		Quantità:	-	-	-
Energia Frigorifera da Fluido Freddo	-	*Ripartizione:*	0%	0%	0%
		Eff. Conv:	0%	0%	98%
		Quantità:	-	-	-
Totale Fabbisogno			6.673	-	-
Superfici di riferimento [m^2]			**74**	**60**	**-**
Totale Fabb. per metri quadri per anno			**89,91**	**0,00**	**-**

Table 31 - Building 10 energy requirement

As a recap of the BEA data presented, here is a table that shows the electrical energy and cold fluid required by all of the buildings currently laying in the district.

Building	Electrical energy (kWh)	Cold fluid	Total
Building 01	215.695,07		215695,07
Building 02	361.509,56		361509,56
Building 02a		6.589,70	6589,7
Building 03	570.132,68		570132,68
Building 04	89.827,39	58.952,86	148780,25
Building 04a	no data		0
Building 05	249.209,23		249209,23
Building 06	310.324,69		310324,69
Building 07	302.795,90		302795,9
Building 08	215.797,92		215.797,92
Building 09	137899,89		137899,89
Building 9a	2.099,48		2099,48
Building 10	no data		0
Total required energy	2455291,81	65542,56	2520834,37

Table 32 - Leonardo 32 electrical and cooling energy requirement

According to BEA data, the district is served by approximately 22 chillers and a few split systems. Each chiller has a different brand, power, and is powered by a different refrigerant gas (kind and weight) which may be toxic to the environment.

Building	Electrical energy (kWh)	Cold fluid	Total	Supplying machines
Building 01	215.695,07		215695,07	1 chiller Carrier 1 chiller Climaveneta
Building 02	361.509,56		361509,56	1 chiller carrier 1 chiller Mitsubishi split system
Building 02a		6.589,70	6589,7	1 chiller Thermocold
Building 03	570.132,68		570132,68	1 chiller MTA 1 chiller Bicold 1 chiller Clivet
Building 04	89.827,39	58.952,86	148780,25	1 chiler Aermec 1 chiller Climaveneta
Building 04a	no data		0	no data
Building 05	249.209,23		249209,23	1 chiller MTA 1 chiller RC Group
Building 06	310.324,69		310324,69	1 chiller Bluebox
Building 07	302.795,90		302795,9	1 chiller Aermec 1 chiller Climavet 1 chiller Mc Quay
Building 08	215.797,92		215.797,92	1 chiller Aermec 1 chiller Bluebox
Building 09	137899,89		137899,89	2 chiller Sveso 1 chiller Clivet 1 chiller Galletti
Building 9a	2.099,48		2099,48	1 heat pump Clivet CAEN31
Building 10	no data		0	no data
Total required energy	2455291,81	65542,56	2520834,37	Tot chillers = 22

Table 33 - Leonardo 32 machineries

According to the data, some buildings share a district heating or cooling system.

For some buildings, the different brands are similar, possibly because they were installed at the same time.

Another piece of information that has not been gathered is the year the machines were installed. Different years of installation and different types of refrigerant fluid make it difficult to collect data on the machines' environmental impact.

5. Refrigerant fluids: environmental impact state of the art

The following chapter is about the refrigerant fluids that are already existing and the latest discovered that can be introduced in the machineries as an alternative to R410a (most common refrigerant gas).

5.1 Refrigerant fluids: research, development and new elements

The ozone depletion potential (ODP) is a normalized indicator of the ability of refrigerants (and other chemicals) to destroy stratospheric ozone molecules, based on a value of one for R-11.

As the following table shows, the most used refrigerant gas may be dangerous as they have a ODP (which is the measure for assessing the destructive effect of the refrigerant).

The global warming potential (GWP) is a normalized measure of a substance's ability to warm the planet by acting as a greenhouse gas.

GWP is calculated for any integration period, also known as the integration time horizon (ITH).

As shown in the table, the majority of the most commonly used refrigerant fluids have a high ODP, and it may be time to look for other gases with very low or no ODP.

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14 Calm JM, Hourahan GC, 2007. Refrigerant Data Update. HPAC Engineering, 79(1)50-64
15 https://www.total-environmental.co.uk

TABLE 1 (continued). Physical, safety, and environmental data for refrigerants (sorted by ASHRAE Standard 34 designations).																
Refrigerant		Physical data							Safety data					Environmental data		
Number	Chemical formula or blend composition, common name	Molecular mass	NBP (°C)	NBP (°F)	T_c (°C)	T_c (°F)	P_c (MPa)	P_c (psia)	OEL (PPMv)	LFL (%)	HOC (MJ/kg)	HOC (Btu/lb)	ASHRAE 34 safety group	Atmospheric life, τ_{atm} (yr)	ODP	GWP 100 yr
400 >>	R-12/114 (50.0/50.0), R-400 (50/50)	141.63	-20.8	-5.4	129.1	264.4	3.94	571	1000	none			A1		1.000	10000
400 >>	R-12/114 (60.0/40.0), R-400 (60/40)	136.94	-23.2	-9.8	125.6	258.1	4.01	582	1000	none			A1		1.000	11000
401A	R-22/152a/124 (53.0/13.0/34.0), MP39	94.44	-32.9	-27.2	107.3	225.1	4.61	669	1000	none			A1		0.033	1200
401B	R-22/152a/124 (61.0/11.0/28.0), MP66	92.84	-34.5	-30.1	105.6	222.1	4.69	680	1000	none	-2.7	-1161	A1		0.036	1300
401C	R-22/152a/124 (33.0/15.0/52.0), MP52	101.03	-28.3	-18.9	111.7	233.1	4.37	634		none			A1		0.027	930
402A	R-125/290/22 (60.0/2.0/38.0), HP80	101.55	-48.9	-56.0	75.9	168.6	4.22	612	1000	none	-1.4	-602	A1		0.019	2800
402B	R-125/290/22 (38.0/2.0/60.0), HP81	94.71	-47.0	-52.6	82.9	181.2	4.52	656	1000	none	-1.6	-688	A1		0.030	2400
403A	R-290/22/218 (5.0/75.0/20.0), 69-S	91.99	-47.7	-53.9	87.0	188.6	4.70	682	1000	13.0			A1		0.038	3100
403B	R-290/22/218 (5.0/56.0/39.0), 69-L	103.26	-49.2	-56.6	79.6	175.3	4.33	628	1000	none			A1		0.028	4500
404A	R-125/143a/134a (44.0/52.0/4.0), HP62 and FX-70	97.60	-46.2	-51.2	72.0	161.6	3.72	540	1000	none	-6.6	-2837	A1		0	3900
405A	R-22/152a/142b/C318 (45.0/7.0/5.5/42.5), G2015	111.91	-32.6	-26.7	106.1	223.0	4.28	621	1000	none			d		0.026	5300
406A	R-22/600a/142b (55.0/4.0/41.0), Autofrost-X3	89.86	-32.5	-26.5	116.9	242.4	4.86	705	1000	8.2			A2		0.056	1900
407A	R-32/125/134a (20.0/40.0/40.0), Klea 60	90.11	-45.0	-49.0	81.8	179.2	4.47	648	1000	none	-3.6	-1548	A1		0	2100
407B	R-32/125/134a (10.0/70.0/20.0), Klea 61	102.94	-46.5	-51.7	74.3	165.7	4.07	590	1000	none	-1.8	-774	A1		0	2800
407C	R-32/125/134a (23.0/25.0/52.0), Klea 66 and Suva 9000	86.20	-43.6	-46.5	85.8	186.4	4.60	667	1000	none	-4.9	-2107	A1		0	1800
407D	R-32/125/134a (15.0/15.0/70.0)	90.96	-39.2	-38.6	91.2	196.2	4.45	645	1000	none	-4.3	-1849	A1		0	1600
407E	R-32/125/134a (25.0/15.0/60.0)	83.78	-42.7	-44.9	88.3	190.9	4.69	680	1000	none	-4.8	-2064	A1		0	1600
408A	R-125/143a/22 (7.0/46.0/47.0), FX-10	87.01	-44.6	-48.3	83.1	181.6	4.29	622	1000	none	5.7	2451	A1		0.024	3200
409A	R-22/124/142b (60.0/25.0/15.0), FX-56	97.43	-34.4	-29.9	109.3	228.7	4.70	682	1000	none	3.0	1290	A1		0.046	1600
409B	R-22/124/142b (65.0/25.0/10.0), FX-57	96.67	-35.6	-32.1	106.9	224.4	4.73	686		none			A1		0.045	1600
410A	R-32/125 (50.0/50.0), Suva 9100 and AZ-20	72.58	-51.4	-60.5	70.5	158.9	4.81	698	1000	none	-4.4	-1892	A1		0	2100
410B	R-32/125 (45.0/55.0)	75.57	-51.3	-60.3	69.7	157.5	4.71	683		none			A1		0	2200

Table 34 - Physical, safety and environmental data for refrigerant gas

5.1.1 Other indicators

5.1.1.1 SEER: Seasonal Energy Efficiency Ratio

After years of development, the seasonal energy efficiency ratio (SEER) was first used for central air conditioners in 1979 and has since been modified several times, most recently in 1994.

SEER is a national metric that does not take regional differences in summer climate into account. The SEER rating downplays high-temperature performance (EER95). performance at 28°C, designs can (and frequently are) optimized for moderate temperatures. High-temperature performance is given very little weight even in modulating equipment.

Indeed, because the test for single-speed equipment is entirely based on
5.1.1.2 EER: Energy Efficiency Ratio

The EER is the ratio between the output energy and the electricity consumed;

The higher the air conditioner is efficient (low consumption).

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16 "Climatic Impacts on Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER) for Air-Source Heat Pumps" - Fairey, Philip; Parker, Danny S; Wilcox, Bruce; Lombardi, Matthew. ASHRAE Transactions; Atlanta Vol. 110, (2004): 178-188

The ratio includes the following values:

A (best) EER >3,20

B 3,20 = EER > 3,00

C 3,00 = EER > 2,80

D 2,80 = EER > 2,60

E 2,60 = EER > 2,40

F 2,40 = EER > 2,20

G (worst) 2,20 = EER

5.1.2 Analysis of the most used fluids and new options

In the following paragraph it will be assessed how much the most known and used refrigerant fluids are polluting and dangerous for the environment and will be show the new alternatives produced and sold on the market.

Following the previous chapter's assessment of the state of the art of the environmental impact of already present and sold fluids, the following lines discuss some new elements that entered the market following the implementation of laws and measures to combat climate change.

As previously stated, the recent EU 517/2014 Regulation and Kigali's amendment to the Montreal Protocol have imposed increasingly stringent limits on the use of high-GWP refrigerants, forcing the air conditioning and refrigeration industry to use new low-GWP refrigerants.

A group of Politecnico di Milano students and professors investigated the substitution of R410a gas with some alternatives. According to the results of the analysis, the new alternatives may be good or better substitutes that can help reduce COP and GWP.

The analyzed alternatives were:

- R1234yf,
- R1234ze(E),
- R450A
- R513A

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17 Experimental analysis of the substitution of R134a with R1234yf, R1234ze(E), R450A and R513A in a small capacity water-to-water heat pump - Luigi Pietro Maria Colombo, Andrea Lucchini(, Luca Molinaroli – corresponding author: Prof. Luca Molinaroli

As previously stated, each of the gases was a better solution than R410a, but one aspect that required further investigation was the rotation frequency of the compressor shaft required to achieve the same heat output as R410a and the COP.

In fact, more significant increases are required for R1234ze(E).

Nonetheless, the increased rotation frequency of the compressor shaft causes a decrease in the heat pump's COP due to the increased mass flow and heat output to be exchanged, which causes evaporation and condensation temperatures to separate.

The COP is reduced more significantly when R1234ze(E) and R450A are used, especially at low water temperatures at the condenser outlet, where the COP is in the 84% ÷ 86% range.

The results of the mentioned research show that any of the low GWP alternative refrigerants produce a lower thermal power, within the range 77% ÷ 99% depending on refrigerant and cooling conditions tested, and operate with a slightly lower COP, within the range 93% ÷ 100%.

This increase varies depending on the refrigerant fluid and the test conditions within the range of 2%÷50%, but generally results in a further reduction of the heat pump COP in the range of 82%÷98%.

5.2 Proposal: installation of machineries fuelled by different refrigerant gas

The following paragraph is about the machineries that use the gas found in the previous one's research.

Based on the previously presented research, a machinery fueled by HFO R1234ze was discovered; it is manufactured by Clivet (a brand already used and installed at Politecnico Leonardo, as seen in previous chapters), and the model's name is SCREWLine4-I WDAT-iZ4 - 580.2.

Clivet appears to have come from a study involving the substitution of R410a with R1234ze as the Polimi research group, as shown in the image below.

18 SCREWLine4-i WDAT-iZ4 120.1 – 580.2 Presentazione prodotto

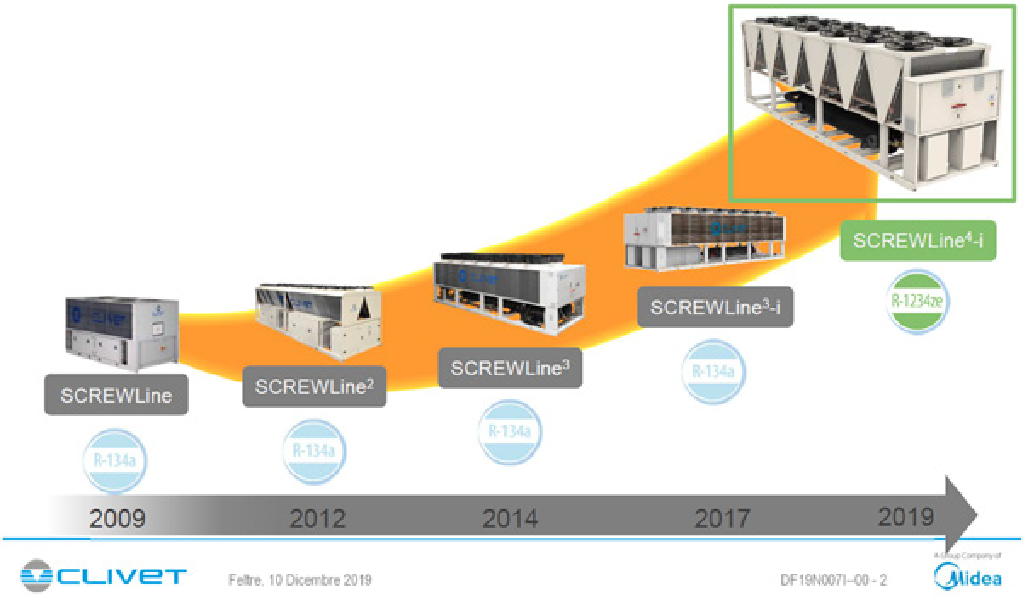
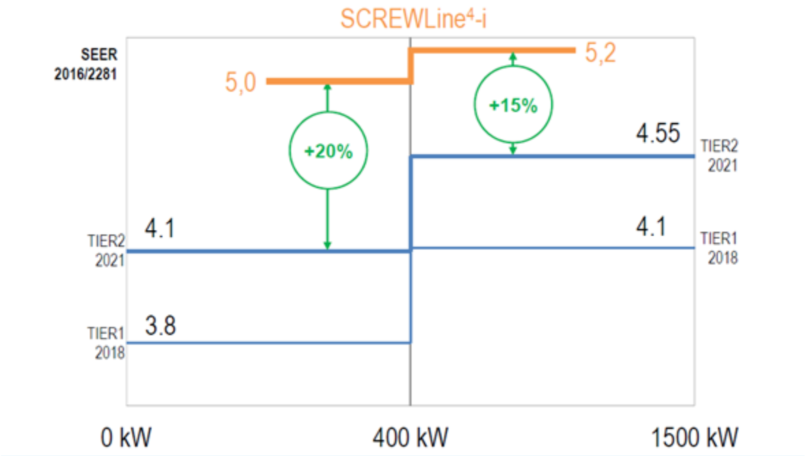


Figure 22 - Clivet SCREWLine4-i WDAT-iZ4 120.1 – 580.2 Chiller

Technical data about the proposed machines and the preferability of using a refrigerant fluid such as R1234ze instead of R410a are presented in the following tables:

Refrigerante	R-1234ze	R-134a
Tipo di refrigerante	HFO	HFC
GWP	< 1	1430
Dispersione in atmosfera	16 giorni	14 anni
Classificazione ASHRAE 34, ISO 817	A2L	A1

Cooling power	1055 kW
EER	3,03
SEER	5,24
N. compressors	2
N. refrigerant circuits	2



Figures 23-25 Technical info and data about the chiller

The proposed machinery allows to:

- Provide only the necessary energy to the plant under all operating conditions.
- Follow the load even when there is a strong bias;
- Ensure high efficiency values, thus lowering operating costs;
- Reduce the sound level at partial load;
- Ensure no current is absorbed at the cue.
- The unit can modulate up to 15% of its nominal load thanks to the two inverter compressors, allowing precise capacity control and easy switching from low to high capacities.

The water content of the system can be significantly reduced thanks to this modulation capacity, avoiding the use of large inertial tanks to ensure reliable and accurate operation.

Because of the high efficiency of condensation heat recovery
- Partial recovery equals approximately 12% of available heat. Allows for the free production of hot water for:
- post-heating batteries
- domestic hot water

The on-board pumping unit allows for cost savings:
- Set-up times and costs
- Pumping unit area and relative clearance

The proposed option is the on with double circuits and double pumps.

The option to install this chiller considering the needing it operates on more than one building include ECOSHARE functionality : automatic management of a group of operating units on the same hydraulic circuit via a CLIVET premises communication network.

The unit designated as MASTER oversees the group.

The local network can be expanded to include up to 7 units (1 Master and 6 Slave).
- Maximum dependability Failure does not bring the entire system to a halt. Distribution Logic:
- Vertical saturation occurs when the previous unit is fully loaded.
- Horizontal saturation occurs when resources are activated in response to the group's maximum efficiency.
- Pumping Unit: For both distribution logic, the pumping unit can be always active or only when at least one Unit compressor (chiller, heat pump, multifunction, etc.) is active.
The machinery can also be controlled remotely and fit into the already present monitoring system.

5.3 Fitting the machineries in Polimi Leonardo 32 District

Considering the Politecnico di Milano district Leonardo 32 (as previously presented), installing at least 3 Clivet SCREWLine4-I WDAT-iZ4 - 580.2 would be beneficial in allowing the campus to receive more thermal energy.
The three chillers could replace all of the smaller ones, the older machines, those that use R410a refrigerant fluid, and even the most dangerous ones.

Figure 26 - Proposal of display of the 3 chillers

The three new chillers are sized to provide enough power and refrigerant energy for the following smaller districts:

• Chiller n. 1:
serves buildings 1-3-5 that require energy, excluding technical rooms (that will have their own smaller split not removable since the temperature must be at a mandatory level) deposit, storage, etc.

• Chiller n. 2:
will serve the buildings 2-2a-4-4a that require energy, excluding technical rooms, porches, storages, deposits and third-party areas (that will provide cooling energy in another way or that can be included at any time if the chance happen).

• Chiller n. 3:
serving buildings 6-7-8-9-9a-10 with exception of terraces, deposits, storages, etc.

The installation of the three chillers can provided the required energy working as a reinforcement of the already present network and creating a whole new one, collecting the buildings and the needings.

Given that the new refrigerant fluid R1234ze(E) was only recently discovered and used, it is possible that the ecological district will be the first to test the new gas.

Monitoring emissions could be a good investment to see if changing all of the other machines would be better for the environment.

It could be a long-term investment if, for example, a smaller district changed machineries every 5-10 years, resulting in new machineries and an eco-friendlier system network that can fully support trigeneration, saving more CO2.

5.4 Maintenance plan and activities

As a consequence of the installation of the new three chillers, a maintenance plan will be useful to determine activities and frequences.

For the maintenance of the machineries to be installed, a plan of activities with the frequencies required for mandatory and preventive maintenance is following.

Machines, of course, have a life cycle and may require corrective maintenance.

Maintenance on the three new chillers should not require any more effort than is currently expected on smaller chillers, especially since they will be removed to make room for the three new ones.

The only difference may occur with F-GAS if the refrigerant gas weight is greater than that contained in smaller chillers, but in most cases, 3 F-GAS will be used instead of more documents in the case of more gas kilos contained in more machines.

Air Conditioners and Heat Pumps
Monthly performance
Activity description
Visual check of the operating state of the equipment and the possible presence of alarms or malfunctions.
Annual performance
Activity description
EU - Cleaning and sanitizing of filters
Every 2 Years
Activity description
Energy Efficiency Ratio - TYPE 2 - P>100 kW - refrigerating or steam-compression machines with electric or direct flame absorption.
Recording and archiving of maintenance activities
Quarterly performance
Activity description
Intervention of a specialized technician with execution of all the operations previewed from the book of use and maintenance and/or however of all the operations necessary to the good operation of the apparatuses in compliance with the enforced norm.
FGAS: control of refrigerant gas leaks. t CO2>500.
UI - General external cleaning of equipment
UI - Cleaning of air filters and possible replacement.
UI - Control of the operation of the condensate drainage system with complete cleaning of the condensate collection basin
UI - Electric fan absorption control.
UI - Clamping of terminals, connections and electrical connections.
UI - Noise control.
EU - General visual inspection of equipment and verification of its integrity.
EU - State control of coolant connection pipes and their insulation.
UE - Control of the electric absorption of the fan and the compressor.
EU - Sealing of the refrigeration circuit.
Recording and archiving of maintenance activities
Every 4 Years
Activity description
Energy Efficiency Control - TYPE 2 - 12<=P<=100 kW - electric or direct flame powered steam compression machines or pdc.
Energy Efficiency Control - TYPE 2 - P>=12 kW - pdc with steam compression driven by endothermic engine.

Table 35 - Maintenance activities and frequences

6. Conclusions

The following chapter is about achieving the goals set at the beginning of the present thesis through the presented project of chiller installation.

6.1 PNIEC 2030 (Piano Nazionale Integrato per l'Energia e il Clima)

• Greenhouse gas effect reduction for 2030 that should be reduced by 33% compared to 2005.

At the very least, the goal is met by removing all the old machinery and replacing it with one that uses a better refrigerant fluid. To compare emissions in 2030 versus 2005, only time will tell if it works, but it is possible that it will be less than half, because old gases stay in the air for years, whereas R1234ze is only present for a few days.

• Primary energy consumption reduction should be reduced by 43% compared to 2007. The reduction should be achieved through buildings regeneration with an annual rate of 0,7% for residential buildings and 2,5% for commercial buildings.

This goal has already been met in part by the installation of a trigenerator that generates electricity from natural gas. If the three new chillers are installed, they will use the trigenerator's electrical energy to become an independent system capable of providing electrical, heating, and cooling energy on its own.

• Gross annual consumptions will be covered by 30% by renewal energy sources covering 55% for electrical systems and 33,9% for thermal systems.

This goal has also been partially met due to the installation of a trigenerator in terms of electricity, while the three chillers could be met as the R1234ze gas will not be present in the air for years and the old ones will be decommissioned.

6.2 LTS 2050 (Strategia italiana di lungo termine sulla riduzione delle emissioni dei gas a effetto serra)

• Reduce energy requirements for heating, cooling, and hot water

The installation of a trigenerator and a chiller network, which require less electrical energy and provide more cooling energy than smaller machineries, achieves the goal because the relationship reverses: one machine provides energy for more buildings rather than multiple machines producing energy for one building.

• Increase the fraction of energy generated from renewable sources "on site" in buildings

The goal was met by installing the trigen, which used natural gas energy to power all of the machines. Chillers cannot use natural resources, but a gas with a life cycle of a few days is the closest machinery that can be installed.

• Reducing the impact of buildings in terms of greenhouse gas emissions

The installation of chillers achieves this goal because it is possible to remove the old ones using older gases that are more polluting than R1234ze, and because the chillers can work as heating pumps combined with district heating, etc., resulting in a low emissions network.

• Improving energy management at the level of individual buildings and districts

The network formed by the three chillers is essentially how the small district will be managed, in addition to trigen, which manages energy for the entire larger district. In any case, creating a district cooling system already fulfills the goal and is an improvement over the previous situation.
Guidelines to achieve the goals (related to systems) that have been followed are:

• Diffusion of heat pump systems for thermal and cooling energy generation

Which is the reason the chiller/heating pumps were chosen: pump systems can implement and develop any present system.

• Use of distributed and centralized thermal storage technologies, including storage

This is aided by the installation of trigen, which not only produces enough energy to power the entire university district, but is also reused and sold, so powering the chillers will not be a problem.

• Development of networks for the transport of heat and cooling energy at district level, where the density of needs per sq.km allows this

Tthree chillers provide energy to more than 10 buildings.

• Interplay between electricity and heat, balancing offer-demand, flexibility

6.3 Sustainable Development Goals (ONU)

The Sustainable Development Goals (SDGs) that will be achieved through the project are:

7 – Affordable and clean energy:

- By 2030, increase the share of renewable energy in the global energy mix that is achieved by using the energy stemming from the trigen primary system, deriving from natural gas. The natural gas is used to provide electricity and heating energy to the whole district and provides energy also to the chillers, creating an energetic community.

- By 2030, double the global rate of improvement in energy efficiency

11 – Sustainable cities and communities:

- By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management

Milano, as is well known, is probably the most polluted city in northern Italy. Universities and larger buildings are the most polluting, which is why it is critical to develop systems that reduce co2 production in these structures. Politecnico campus Leonardo could be considered a whole city itself, reducing its ecological impact can help Milano to reduce the whole city’s impact. Also, considering this project a model, it can be repeated in different universities creating a bigger network. It can also be installed at district level for residential activities.

13 – Climate action

- Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries

There hasn’t been a properly climatic hazard in Milano, but some episodes of ”orange sky” or other strange colors are common. Reducing the impact may also help to reduce those incidents (also before they become more serious issues).

- Integrate climate change measures into national policies, strategies, and planning

Policy changes should be made at the municipal/regional/state levels, but this type of project could be included in city plans to combat climate change. As previously stated, district systems may be included in the resilience plan.

5.4 Proposed mitigation plan and CO_2 emission reduction targets for Politecnico di Milano

- electricity consumption that is self produced by trigen

- gas consumption (excluding consumption for energy production electrical used outside)

Natural gas for electricity production and the lightest R1234ze gas for cooling system (which also is a heating pump)

- energy consumption from external district heating networks; and district cooling

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